Deutsche Physikalische Gesellschaft DPG

DPG-Frühjahrstagung 2023

(DPG Spring Meeting 2023)

of the Atomic, Molecular, Quantum Optics and Photonics Section (SAMOP)

together with the division

Physics Education

as well as the working groups

Equal Opportunities, Young DPG

Welfenschloss Hannover
Foto: Matthias Schlenk, LUH

5 – 10 March 2023

Leibniz Universität Hannover

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Verantwortlich für den Inhalt: Dr. Bernhard Nunner, DPG e. V., Hauptstraße 5, 53604 Bad Honnef
Telefon: +49 (0)2224 9232-0, Telefax: +49 (0)2224 9232-50

Content

Deutsche Physikalische Gesellschaft DPG

62. Wochenendseminar „Physiker:innen im Beruf“

Der Übergang von der Hochschule in die **berufliche Karriere** fällt vielen nicht leicht: Die Möglichkeiten und Aufgabengebiete sind vielfältig - und wer kennt schon nach Studium oder Promotion die verschiedenen Anforderungen und Arbeitsabläufe?

Das Seminar bietet durch **Erfahrungsberichte** etablierter Physiker:innen sowie junger Berufsanfänger:innen Orientierung. Die 15 Vortragenden repräsentieren ganz verschiedene Arbeitsgebiete und zeigen damit das breite **Einsatzspektrum** von Physikerinnen und Physikern.

Neben den Vorträgen bietet der gemütliche Lichtenbergkeller des Physikzentrums Bad Honnef ein ideales Forum, mit den Vortragenden am Abend **in kleiner Runde offen** zu **diskutieren** und Erfahrungen zu sammeln.

Zielgruppe:
Physikstudierende ab Bachelor bis zur Promotion. Max. 80 Personen.

5. bis 7. Mai 2023

Physikzentrum Bad Honnef

Weitere Infos und Anmeldung: www.pib.dpg-physik.de

Dear Participants,

Welcome to the DPG-Frühjahrstagung (DPG Spring Meeting) of the Atomic, Molecular, Quantum Optics and Photonics Section (SAMOP) with the participating divisions and working groups involved on the campus of the Leibniz University of Hannover.

I am very pleased that with our DPG-Frühjahrstagungen (DPG Spring Meetings), even more so in presence, we can once again set a widely visible and public sign for the outstanding importance of basic research for scientific and societal progress. Basic research is indispensable for tackling the major societal challenges. Above all a sustainable energy supply with regard to climate change with its dramatic consequences for all life on our planet. On the other hand, the spring conferences are probably the most important instrument of the DPG to enable as many scientists as possible, especially young scientists, to participate in a cross-border, international and peaceful scientific exchange.

The last year has shown us with full force how important and by no means self-evident such a necessary and international exchange is, how vulnerable our world order is and how quickly a change can take place that even threatens the existence of countries. Therefore, it is the special responsibility of the DPG – guided by the values in our DPG Statutes, our compass – to stand up for freedom, tolerance, truthfulness and dignity in science and to act in awareness that we are particularly responsible for shaping the whole of human life: especially and particularly in troubled times!

The DPG conference in Hannover plays an outstanding role for peaceful international scientific exchange and discourse as well as for the perception and appreciation of the work of the DPG. I would therefore like to thank all those involved for their great commitment to the success of this conference. My special thanks go to the University of Hannover for its hospitality and support. I would like to sincerely thank the Wilhelm and Else Heraeus Foundation for once again generously supporting all DPG spring conferences. My great appreciation goes to the participating divisions and working groups for a great programme. I would especially like to thank the Local Organising Committee, Prof. Silke Ospelkaus, University of Hannover, and her entire team. For the support of all DPG-Frühjahrstagungen (DPG Spring Meetings), my special thanks go to the DPG Head Office.

Prof. Dr. Joachim Ullrich
President
Deutsche Physikalische Gesellschaft e. V.

Organisation

Organiser
Deutsche Physikalische Gesellschaft e. V.
Hauptstraße 5, 53604 Bad Honnef
Phone +49 (0) 2224 9232-0
Fax +49 (0) 2224 9232-50
Email dpg@dpg-physik.de
Homepage www.dpg-physik.de

Local Organiser
Prof. Dr. Silke Ospelkaus
Leibniz Universität Hannover
Institut für Quantenoptik
Welfengarten 1, 30167 Hannover
Phone +49 (0) 511-762 2589
Email kaisik@iqo.uni-hannover.de

Scientific Organisation

Chair of the AMOP Section (SAMOP)
Prof. Dr. Gereon Niedner-Schatteburg
FB Chemie - Physikalische Chemie
Technische Universität Kaiserslautern
Erwin-Schrödinger-Str., Geb. 52, R 535
67663 Kaiserslautern
Phone +49 (0) 0631 205-4697
Email gns@chemie.uni-kl.de

Chairs of the Participating Divisions

(A)	Atomic Physics	–	Prof. Dr. Thomas Fennel (thomas.fennel@uni-rostock.de)
(DD)	Physics Education	–	Prof. Dr. Susanne Heinicke (susanne.heinicke@uni-muenster.de)
(MO)	Molecular Physics	–	Prof. Dr. Jochen Küpper (jochen.kuepper@cfel.de)
(MS)	Mass Spectrometry	–	Prof. Dr. Yuri A. Litvinov (y.litvinov@gsi.de)
(QI)	Quantum Information	–	Prof. Dr. Otfried Gühne (otfried.guehne@uni-siegen.de)
(Q)	Quantum Optics and Photonics	–	Prof. Dr. Christiane Koch (christiane.koch@fu-berlin.de)

Chairs of the Participating Working Groups

(AKC)	Equal Opportunities	–	OStR Agnes Sandner (akc@dpg-physik.de)
(AKjDPG)	Young DPG	–	Vivienne Leidel (leidel@jdpg.de)

Symposia

SYAD	–	SAMOP Dissertation Prize 2023
SYAS	–	Awards Symposium
SYCC	–	From Molecular Spectroscopy to Collision Control at the Quantum Limit
SYHC	–	Precision Physics with Highly Charged Ions
SYHD	–	Molecules in Helium Droplets
SYML	–	Machine Learning in Atomic and Molecular Physics
SYPD	–	PhD Symposium – Many-body Physics in Ultracold Quantum Systems
SYQR	–	Quantum Optics and Quantum Information with Rigid Rotors

Organisation of the Exhibition of Scientific Instruments and Literature
DPG-Kongress-, Ausstellungs- und Verwaltungsgesellschaft mbH
Hauptstraße 5, 53604 Bad Honnef
Phone +49 (0) 2224 9232-0
Fax +49 (0) 2224 9232-50
Email dpg@dpg-physik.de
Homepage www.dpg-gmbh.de

Programme
The scientific programme consists of **1.533** contributions:

10	Plenary talks
1	Evening talk
8	Prize talks
88	Invited talks
819	Talks
603	Posters
4	Tutorials

The programme stated in this document corresponds to the status of the programme publication January 24, 2023 and will not be updated!

Information for Participants

The conference will be held March 5 – 10, 2023.

Conference Information

Conference Venue
Leibniz Universität Hannover
Welfengarten 1
30167 Hannover

Most of the activities will take place in the main building of the university (Welfengarten 1). Sessions of the Division Physics Education (Didaktik der Physik) will take place in the Verfügungsgebäude (Schneiderberg 50) and the Kalihörsaal (Historic building Chemistry, Callinstraße 9). For a detailed map of the campus and the buildings please see "Maps" at the end of this document.

Conference Office / Information Desk
The conference office and the information desk are located in room C 109 on the right side of the „Lichthof" in the main building of the Leibniz Universität Hannover. The opening hours are the following:

		Registration	Information Desk
Sunday	March 5	15:00 – 19:30	16:00 – 22:00
Monday	March 6	08:00 – 17:00	08:00 – 19:00
Tuesday	March 7	08:00 – 17:00	08:30 – 19:00
Wednesday	March 8	08:00 – 17:00	08:30 – 21:00
Thursday	March 9	08:00 – 17:00	08:30 – 19:00
Friday	March 10	08:00 – 12:00	08:30 – 17:00

You will receive your name tag, a receipt for your conference fee, a conference ticket for public transport (GVH, 2nd class, zone ABC, valid March 5 — 10, 2023), and the Login-Password for using WLAN (WiFi) at the registration. The name tag must be worn visibly during the entire conference.

The organisers, staff of the conference desk, and the student assistants will be identifiable by coloured name tags or Φ-T-shirts. Please contact them if you have any questions. Do not hesitate to inquire about all necessary information concerning the conference, orientation in Hannover, accommodation, restaurants, going out, and cultural events at the information desk.

With the DPG-App through the DPG Meeting!
The updated DPG-App is ready-to-use and contains additional functions/features: In addition to the option of target groups, the electronical programme booklets for DPG Conferences (E-Verhandlungen) are ac-

cessible and it is possible to compile a „favorite list" regarding events one wants to attend. Just download the DPG-App for Android or iOS now and utilize the supplemental offerings. You will find more information under *https://www.dpg-physik.de/service/dpg-app.html*.

Presentation

Scientific presentations will be held either orally or by poster and will be given in English or German.

All lecture halls are equipped with projectors (16:9). Speakers are requested to connect their own laptops. The connection standard is HDMI – please bring your own adapters for your device. A limited number of laptops and HDMI adapters will be available for loan. If you would like to take advantage of this offer, please inform the information desk no later than the day before your presentation. In this case, please bring your presentation file on a USB stick to the presentation. An upload system is not provided.

Speakers are requested to be in the lecture hall at least 15 minutes prior to the start of the session, reporting to the chairperson of the session as well as the technical staff to ensure the laptops handshake with the projectors ("beamers") and to receive a brief introduction to the equipment in the lecture hall. If you need other presentation facilities please ask for availability at the information desk as soon as you arrive at the conference or better in advance via E-Mail *dpgtagung@iqo.uni-hannover.de*.

Usually, presentations will have the following durations. For exact information, please refer to your division.

- Contributed talks are 15 minutes including discussion and speaker change
  (12 min talk + 3 min discussion/speaker change)
- Invited talks are 30 minutes including discussion and speaker change
  (25 min talk + 5 min discussion/speaker change)
- Plenary presentations are 45 minutes

Poster Presentation (Monday — Thursday)

The poster sessions will take place in the Gallery of the Lichthof (main building) from Monday to Thursday 16:30 to 19:00. The poster boards will be marked with the number according to the scientific programme. Authors are asked to mount their poster before their session. Each poster should display the number according to the scientific programme. Each poster should not be larger than 85 cm x 120 cm (DIN A0).

For the mounting of the poster please use the provided mounting material at the poster frame or contact the student staff available at the poster area. The presenting authors should be at hand for discussion at their poster during at least half of the poster session and should note this time at the poster. The posters have to be removed after the session. Any posters remaining on poster boards will be removed early in the next morning and disposed without requesting your permission. The conference management accepts no liability for the posters.

Broadcast of Plenary Lectures

All plenary lectures will be presented in the Audimax (E415) and broadcasted live in the lecture hall E214 (next to the Audimax).

Wilhelm and Else Heraeus Communication Programme

Important notes for participants who apply for a grant of the Wilhelm and Else Heraeus Foundation:
At the beginning of the conference you will receive an identification form at the conference office. The participation in the conference must be certified by the conference desk. You have the possibility to leave this certificate with the staff members of the DPG (preferably at the conference office) or submit it to the DPG head office (DPG-Geschäftsstelle, Hauptstr. 5, 53604 Bad Honnef, Germany) by **April 14, 2023 at the latest.** For more detailed information refer to *http://samop23.dpg-tagungen.de*.
The Deutsche Physikalische Gesellschaft thanks the Wilhelm and Else Heraeus Foundation for the generous financial support of young academic talents. We hope that young physicists will continue to seize the offered opportunity for active scientific communication at scientific conferences. A total of about 37,800 young academics were supported by this programme so far.

Communication / Internet Access
To use the WLAN network on the campus of Leibniz Universität Hannover with your own notebooks, access data, login and password will be issued with the registration documents.
Leibniz Universität Hannover is a member of the Eduroam Union. If your university is also part of the Eduroam Union, you can also use the Leibniz Universität Hannover WLAN in all buildings via your own Eduroam access.

Catering
Coffee and tea will be available all day in the Lichthof and in the East Entrance Foyer/Audimax. Additional coffee stands are located near the lecture halls for breaks between lectures.
Lunch will be available at the Mensa on the corner of Schneiderberg/Callinstraße (opening hours: 08:00 – 14:30 / meal times: 11:30 – 14:00) and at the "Contine" on the Conti-Campus, Königsworther Str. 1 (opening hours: 08:00 – 16:00 / meal times: 11:00 – 16:00). Snacks are also available in the Sprengelstube cafeteria in the basement of the main university building, Welfengarten 1 (08:00 – 16:00).
There are various offers for snacks as well as restaurants in the immediate vicinity of the university (a list is available at the information desk).

Cloakroom
Participants are asked to look carefully after their wardrobe, valuables, laptops, and other belongings. The organisers decline any liability. In room F335 of Leibniz Universität Hannover you will find a cloakroom managed by student assistants. The opening hours are as follows:

Sunday	March 5	16:45 – 22:15
Monday	March 6	08:45 – 19:15
Tuesday	March 7	08:45 – 19:15
Wednesday	March 8	08:45 – 21:30
Thursday	March 9	08:45 – 19:15
Friday	March 10	08:45 – 16:45

Notice Board
All changes to the conference programme (i.e. cancellation of presentations, change of rooms, etc.) are also transferred directly to the online version of the programme which will be updated continuously and is available in different formats (sorted by publication date, filterable by conference parts and as an rss-feed). Please use the form *https://samop23.dpg-tagungen.de/programm/notice-board-form* to notify changes or cancellations.

Room of Silence
The Room of Silence is located next to the Sprengelstube on the ground floor of the main building and has the room number F031. This room offers space to relax, pray and meditate. It is not dedicated to a specific religious tradition, all religious communities are welcome.

Lost Property
You can hand in lost property at the information desk. You can also collect your lost property there.

Liability Exclusion
Participants are asked to look carefully after their wardrobe, valuables, laptops and other belongings. There can be no liability assumed.

SAY CHEESE!
The DPG Spring Meetings are basically public to the press. Please note: On behalf of DPG, photos and videos will be recorded during the Spring Meetings. In the context of public relations, these recordings (as the case may be) will be published on our website, in social media or within prints of the DPG for example.

CO_2 compensation for the DPG conferences
By decision of the Executive Board, the DPG will compensate for fossil CO_2 emissions resulting from mobility for DPG conferences and committee meetings.

Acknowledgement
The Deutsche Physikalische Gesellschaft (DPG) and the local organisers want to thank the following institutions for supporting the conference:

- Wilhelm and Else Heraeus Foundation, Hanau
- Leibniz Universität Hannover
- all industrial sponsors (see below)
- and all staff, who make the success of the conference possible.

Sponsors of the DPG Spring Meeting Hannover 2023

Main Sponsors:

MenloSystems

Schäfter+Kirchhoff

TOPTICA

Sponsors:

CAENels Gear For Science

PFEIFFER VACUUM

THORLABS

Social Events

Tutorials
On Sunday, March 5, tutorials on current scientific topics will take place from 17:00 to 19:00 in B305 and B302. The tutorials are primarily aimed at students and young scientists. The tutorials are open to all conference participants.

Welcome Evening
Sunday, March 5, 19:30 – 22:00
On Sunday, the Welcome Evening will be held in the atrium (Lichthof) of the main building of Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover to which all registered participants are kindly invited. Snacks and drinks will be served. Do not miss the opportunity to meet people in an informal atmosphere. Please wear your name tag which you received at the registration. Access to the welcome evening is only available to registered participants. Registration office will be open on Sunday from 15:00 to 19:30.

Opening of the Conference
A short opening address will be given by the chair of the AMOP Section (SAMOP) on Monday, March 6 from 08:55 until 09:00 in the Audimax (E415).

Awarding of the DPG-Teacher‘s Award („DPG-Lehrerpreis“)
Dienstag, 7. März, 14:30 Uhr, DD HS 2.202 (in german language)
Der DPG-Lehrerpreis wird für herausragende Leistungen in der Gestaltung und Weiterentwicklung des Faches Physik an Schulen vergeben, beispielsweise für Leistungen, die in besonderem Maße geeignet sind, Schülerinnen und Schüler für das Fach Physik zu motivieren, die Bedeutung der Physik für das Leben und Zusammenleben der Menschen aufzuzeigen sowie Talente für die Physik zu erschließen. Weitere Informationen unter *https://www.dpg-physik.de/auszeichnungen/dpg-preise/dpg-lehrerpreis*

Awarding of the SAMOP-Dissertationprize 2023
Tuesday, March 7, 14:30, Audimax (E415)
Talks by the four finalists will be given at the symposium (SYAD) on Monday. The award will be presented on Tuesday immediately before the Awards Symposium (SYAS) at 14:30 in the Audimax (E415).

Public Evening Talk
Wednesday, March 8, 20:00 – 21:00, Audimax (E415)
Prof. Dr. Reinhard Werner, Leibniz Universität Hannover will speak about
„Das Ende der klassischen Welt – Der Physik-Nobelpreis 2022“

The Public Evening Talk is open for the interested public and all conference participants. It will be held in German. The entrance is free.

Members‘ Assemblies of the Divisions and Working Groups
During the DPG Spring Meeting, Members‘ Assemblies of the divisions and working groups take place. Please refer to the scientific programme for the time and place of the meetings.

Job Market
During the conference various companies and organisations will present their working fields and career opportunities to all interested participants. The presentations will take place from Tuesday to Thursday, in F435 (4th floor). The presentations will last for about 30 minutes plus discussion.

Programme: **Tuesday, March 7**

11:30 – 12:30	Eisenführ Speiser Patentanwälte Rechtsanwälte PartGmbB *„Physik trifft Recht – eine Karriere als Patentanwalt“*
13:30 – 14:30	ZEISS *„Working opportunities and career options at ZEISS“*

Wednesday, March 8

11:30 – 12:30	Trumpf Lasersystems for Semiconductor Manufacturing GmbH *„TRUMPF Lasersystems for EUV Lithography – Enabler für das digitale Zeitalter gesucht"*
13:30 – 14:30	Basycon Unternehmensberatung GmbH *„Aus der Wissenschaft in die Beratung"*

Thursday, March 9

11:30 – 12:30	BearingPoint GmbH *„Quantentechnologien und Beratung"*
13:30 – 14:30	d-fine GmbH *„Verwendung von Finanzderivaten in Industrieunternehmen"*

Exhibition of Scientific Instruments and Literature
From Tuesday, March 7, to Thursday, March 9, there will be an exhibition of scientific instruments and literature in the Lichthof. Several companies (see list of exhibitors at the end of this booklet) will present their products. Opening hours are from 10:30 to 19:00. All conference participants are welcome to attend the exhibition. The entrance is free.

DPG Tower building contest – Hoch hinaus!
The time has come to show how well the knowledge of mechanics still is and teams can work together. The jDPG challenges you to a tower building contest! Who builds the highest tower with given materials – wins. It's simple as that… or isn't it?

The "jDPG Tower building contest" will start on Tuesday, March 7, 10:30 – right after the plenary talks – and will take place in the Audimax (E415). All interested conference participants are welcome.

jDPG Pub Crawl
Tuesday, March 7, 20:00
Meeting Point: Main Entrance of the University
In case you need some time to take a rest in the middle of the conference and you are looking for conversations beyond physics, the local group of the Young DPG cordially invites you to a pub crawl through the nightlife in Hannover. With subsequent visit of the plenary talks on Wednesday ;-)

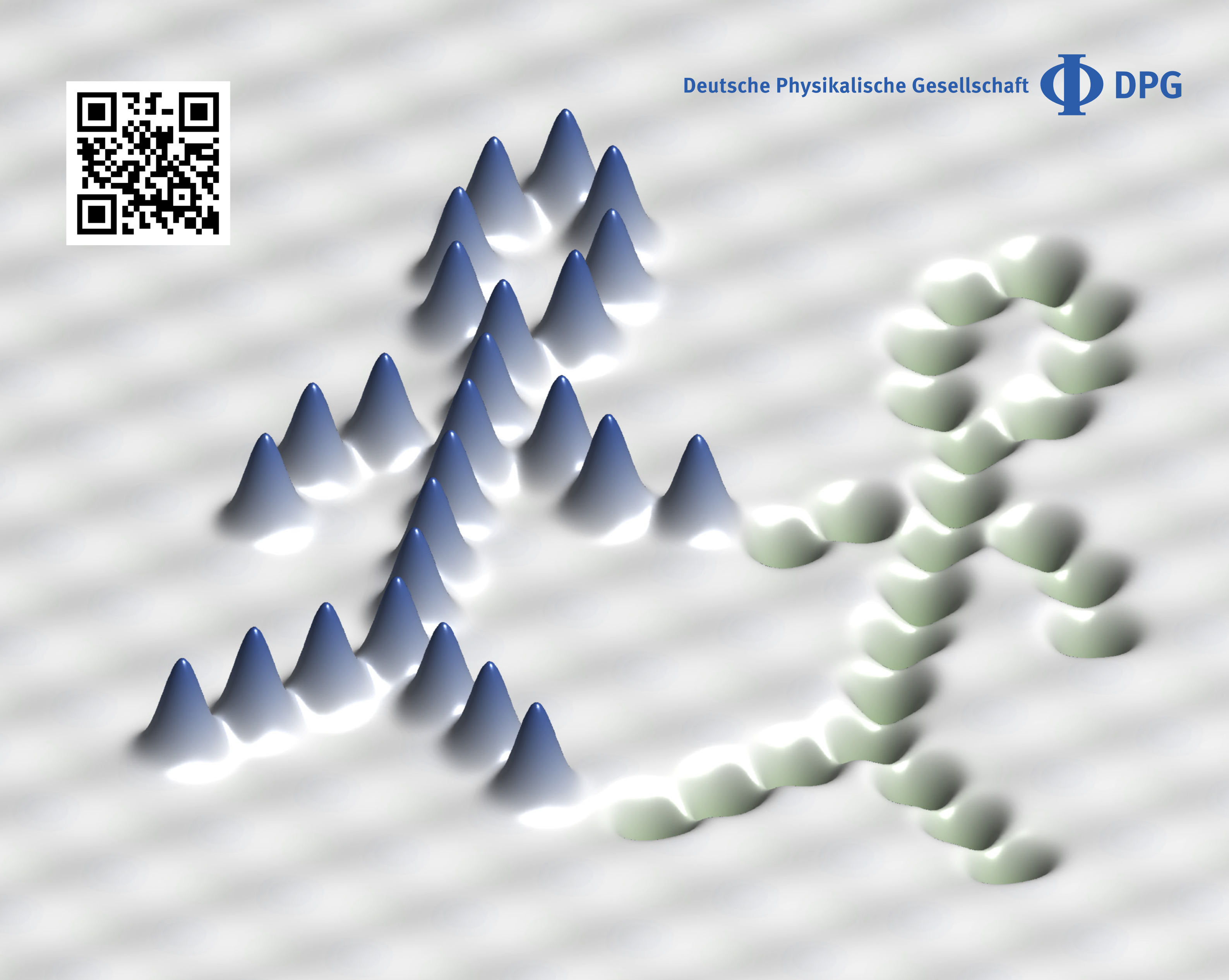
Labtours
There will be laboratory visits to local institutes, see the announcement on the board near the conference desk.

Laboratory tour at the PTB in Braunschweig
On Wednesday afternoon, March 8, there will be a trip to Braunschweig to visit laboratories at the Physikalisch-Technische Bundesanstalt (PTB). Participation is free of charge.

<u>Schedule:</u>

14:00	Departure by bus from the main entrance of the University.
15:00 – 18:00	Laboratory visit at the PTB
18:10	Departure for the return journey to Hannover,
19:10	Arrival at the university

Registration at the information desk is required for all laboratory tours.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Synopsis of the Daily Programme

Sunday, March 5, 2023

AKjDPG

Tutorials

17:00	B305	AKjDPG 1.1	A Tutorial on Quantum Simulation •Christian Groß
17:45	B305	AKjDPG 1.2	Developing utility scale quantum computers with trapped ions •Winfried Hensinger
17:00	B302	AKjDPG 2.1	New perspectives in the investigation of ultrafast molecular dynamics •Andrea Trabattoni
17:45	B302	AKjDPG 2.2	Femtosecond spectroscopy in the condensed and gas phase •Lukas Bruder

Sessions

17:00	B305	AKjDPG 1	Tutorial Quantum Simulation and Computing
17:00	B302	AKjDPG 2	Tutorial Molecular Spectroscopy

19:30	Lichthof		**Welcome Evening** (for registered participants)

Monday, March 6, 2023

08:55	E415		**Opening of the Conference**

Plenary Talks

09:00	E415	PV I	Probing the quantum nature of gravity in table-top experiments •Markus Aspelmeyer
09:45	E415	PV II	Quantum Chemistry on Quantum Computers: Challenges and New Directions •Sabrina Maniscalco

SYAD

Invited Talks

14:30	E415	SYAD 1.1	Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems •Luca Asteria
15:00	E415	SYAD 1.2	From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers •Patrick Rupprecht
15:30	E415	SYAD 1.3	Particle Delocalization in Many-Body Localized Phases •Maximilian Kiefer-Emmanouilidis
16:00	E415	SYAD 1.4	Feshbach resonances in a hybrid atom-ion system •Pascal Weckesser

Session

14:30	E415	SYAD 1	SAMOP Dissertation Prize Symposium (SYAD)

Monday, March 6, 2023

SYHC

			Invited Talks
11:00	E415	SYHC 1.1	First experiments at CRYRING@ESR •Esther Babette Menz
11:30	E415	SYHC 1.2	Testing quantum electrodynamics in the simplest and heaviest multi-electronic atoms •Martino Trassinelli
12:00	E415	SYHC 1.3	Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings •Beatriz Jurado
12:30	E415	SYHC 1.4	Laboratory X-ray Astropohysics with Trapped Highly Charged Ions at Synchrotron Light Sources •Sonja Bernitt
17:00	E415	SYHC 2.1	Observation of metastable electronic states in highly charged ions by Penning-trap mass spectrometry •Kathrin Kromer
17:30	E415	SYHC 2.2	Towards extreme-ultraviolet optical clocks •José R. Crespo López-Urrutia
18:00	E415	SYHC 2.3	Coupling atomic and nuclear degrees of freedom in highly charged ions •Adriana Pálffy
18:30	E415	SYHC 2.4	Laser Spectroscopy at the Storage Rings of GSI/FAIR •Wilfried Nörtershäuser
			Sessions
11:00	E415	SYHC 1	Highly Charged Ions for Atomic, Nuclear and Astrophysics
17:00	E415	SYHC 2	Intersection of the Electron-Shell and Nuclear Degrees of Freedom

A

			Invited Talks
11:00	F303	A 3.1	Time-resolved Kapitza-Dirac effect •Kang Lin
17:00	F107	A 6.1	Nonperturbative dynamics in heavy-ion-atom collisions •Pierre-Michel Hillenbrand
17:00	F303	A 7.1	Multi-frequency optical lattice for dynamic lattice-geometry control •Luca Asteria
			Sessions
11:00	A320	A 1	Quantum Technologies
11:00	F107	A 2	Collisions, Scattering and Correlation Phenomena
11:00	F303	A 3	Interaction with Strong or Short Laser Pulses I
11:00	F442	A 4	Quantum Effects (QED)
13:15	F303	A 5	Members' Assembly
17:00	F107	A 6	Precision Spectroscopy of Atoms and Ions I
17:00	F303	A 7	Ultra-cold Atoms, Ions and BEC I
17:00	F342	A 8	Quantum Technologies: Color Centers

MO

			Sessions
11:00	F102	MO 1	Cold Molecules
11:00	F142	MO 2	Photochemistry
11:00	F303	MO 3	Interaction with Strong or Short Laser Pulses I

Monday, March 6, 2023

Q

			Invited Talks
11:00	E001	Q 2.1	Interferometry with Bose-Einstein Condensates for inertial sensing •Sven Abend
17:00	A320	Q 9.1	Compressibility and the equation of state of an optical quantum gas in a box •Julian Schmitt
17:00	E001	Q 10.1	Maiman's ruby laser reborn as diode pumped cw laser •Walter Luhs

			Sessions
11:00	A320	Q 1	Quantum Technologies
11:00	E001	Q 2	Matter Wave Optics
11:00	E214	Q 3	Quantum Computing and Simulation
11:00	F102	Q 4	Cold Molecules
11:00	F342	Q 5	Quantum Optics: Open Quantum Systems
11:00	F442	Q 6	Quantum Effects (QED)
16:30	Empore Lichthof	Q 7	Poster I
16:30	Empore Lichthof	Q 8	QI Poster I
17:00	A320	Q 9	Quantum Gases: Bosons I
17:00	E001	Q 10	Photonics I
17:00	E214	Q 11	Precision Measurements: Gravity I
17:00	F107	Q 12	Precision Spectroscopy of Atoms and Ions I
17:00	F303	Q 13	Ultra-cold Atoms, Ions and BEC I
17:00	F342	Q 14	Quantum Technologies: Color Centers I
17:00	F442	Q 15	Quantum Communication

QI

			Invited Talks
11:00	B305	QI 3.1	Characterising quantum device variability with machine learning •Natalia Ares
11:00	F428	QI 5.1	Building Superconducting Quantum Hardware towards Error-Corrected Quantum Computing •Christopher Eichler

			Sessions
11:00	A320	QI 1	Quantum Technologies I
11:00	B302	QI 2	Quantum Foundations
11:00	B305	QI 3	Quantum Machine Learning
11:00	E214	QI 4	Quantum Computing and Simulation
11:00	F428	QI 5	Superconducting Qubits and Hybrid Systems
16:30	Empore Lichthof	QI 6	Poster I
17:00	F342	QI 7	Quantum Technologies: Color Centers I
17:00	F442	QI 8	Quantum Communication I

DD

			Invited Talk
11:00	DD HS 2.202	DD 1.1	Welchen Beitrag kann die Hochschul-Fachdidaktik zur Lehre der Physik als Haupt- und Nebenfach leisten? •Christian Kautz

			Sessions
11:00	DD HS 2.202	DD 1	Eröffnung und Hauptvortrag 1: Kautz
12:00	DD 108	DD 2	Inklusion
12:00	DD 110	DD 3	Digitale Medien I
12:00	DD 111	DD 4	Quantenphysik I
12:00	DD 405	DD 5	Hochschuldidaktik I

Monday, March 6, 2023

DD

12:00	DD 407	DD 6	Interesse und Persönlichkeit I
14:30	DD 108	DD 7	Lehr-Lernforschung I
14:30	DD 110	DD 8	Digitale Medien II
14:30	DD 111	DD 9	Quantenphysik II
14:30	DD 405	DD 10	Workshop Lehramtsstudie KFP/DPG
14:30	DD 407	DD 11	Nature of Science, Geschichte
16:00	DD 108	DD 12	Lehr-Lernforschung II
16:00	DD 110	DD 13	Digitale Medien III
16:00	DD 111	DD 14	Quantenphysik III
16:00	DD 405	DD 15	Hochschuldidaktik II
16:00	DD 407	DD 16	Lehreraus- und -fortbildung I
17:00	Empore Lichthof	DD 17	Poster – Außerschulisches Lernen
17:00	Empore Lichthof	DD 18	Poster – Bildung für nachhaltige Entwicklung
17:00	Empore Lichthof	DD 19	Poster – Physikunterricht: Inklusion, Sprache, Anregungen
17:00	Empore Lichthof	DD 20	Poster – Quantenphysik
17:00	Empore Lichthof	DD 21	Poster – Lehr-Lernforschung
17:00	Empore Lichthof	DD 22	Poster – Neue / digitale Medien
17:00	Empore Lichthof	DD 23	Poster – Lehreraus- und -fortbildung
17:00	Empore Lichthof	DD 24	Poster – Neue Konzepte
17:00	Empore Lichthof	DD 25	Poster – Praktika und Experimente
17:00	Empore Lichthof	DD 26	Poster – Astronomie
17:00	Empore Lichthof	DD 27	Poster – Hochschuldidaktik
17:00	Empore Lichthof	DD 28	Poster – Weitere fachdidaktische Forschung
17:00	Empore Lichthof	DD 29	Poster – Arbeitsgruppen Physikdidaktik Quo vadis

AKC

			Invited Talks
14:30	F128	AKC 1.1	Vordenkerinnen in Physik und Philosophie •Betti Hartmann, •Carla Schriever
15:15	F128	AKC 1.2	Physik-Projekt-Tage – Ein Workshop für Schülerinnen der Oberstufe •Anna Benecke
			Sessions
14:30	F128	AKC 1	AKC 1
17:00	Empore Lichthof	AKC 2	AKC 2

Tuesday, March 7, 2023

			Plenary Talks
09:00	E415	PV III	Educational Transformation at a Critical Time: The essential roles and promise of physicists •Noah Finkelstein
09:45	E415	PV IV	New Lightwave Science with Photonic Crystal Fibres •Philip Russell

SYAS

14:30	E415		**Awarding of the SAMOP Dissertation Prize 2023**
			Prize Talks
14:35	E415	SYAS 1.1	The Reaction Microscope: A Bubble Chamber for AMOP •Joachim Ullrich (Laureate of the Stern-Gerlach-Medal 2021)
15:05	E415	SYAS 1.2	Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions •Rainer Blatt (Laureate of the Herbert-Walther-Prize 2023)
15:35	E415	SYAS 1.3	Amplitude, Phase and Entanglement in Strong Field Ionization •Sebastian Eckart (Laureate of the Gustav-Hertz-Prize 2023)
16:05	E415	SYAS 1.4	All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers •Marvin Edelmann (Laureate of the Georg-Simon-Ohm-Prize 2023)
			Session
14:30	E415	SYAS 1	Award Symposium

SYML

			Invited Talks
11:00	E415	SYML 1.1	Imaging a complex molecular structure with laser-induced electron diffraction and machine learning •Katharina Chirvi
11:30	E415	SYML 1.2	Physics-inspired learning algorithms for optimal shaping of atoms with light •Maximilian Prüfer
12:00	E415	SYML 1.3	Machine-Learning assisted quantum computing and interferometry •Ludwig Mathey
12:30	E415	SYML 1.4	Efficient quantum state tomography with convolutional neural networks •Moritz Reh
			Session
11:00	E415	SYML 1	Machine Learning in Atomic and Molecular Physics

A

			Invited Talk
11:00	F107	A 10.1	Interaction of twisted light with a trapped atom: Interplay of electronic and motional degrees of freedom •Anton Peshkov
			Sessions
11:00	F102	A 9	Ultrafast Dynamics I
11:00	F107	A 10	Atomic Systems in External Fields
11:00	F303	A 11	Precision Spectroscopy of Atoms and Ions II
16:30	Empore Lichthof	A 12	Poster I

MO

			Invited Talk
11:00	F102	MO 4.1	Revealing chiral charge migration in UV-excited molecules •Vincent Wanie

Tuesday, March 7, 2023

MO

			Sessions
11:00	F102	MO 4	Ultrafast Dynamics I
11:00	F142	MO 5	Electronic Spectroscopy
16:30	Empore Lichthof	MO 6	Poster I

MS

			Invited Talk
11:00	F128	MS 1.1	Lasers against barium – Detection of ^{135}Cs in the environment by AMS •Alexander Wieser
			Session
11:00	F128	MS 1	Accelerator Mass Spectrometry I

Q

			Invited Talks
11:00	E001	Q 17.1	Thin-film lithium niobate waveguides for integrated quantum photonic technologies •Francesco Lenzini
11:00	E214	Q 18.1	Atoms coupled to nanofibers: from topological phases to correlated photon emission •Beatriz Olmos
			Sessions
11:00	A320	Q 16	Photonic Quantum Technologies
11:00	E001	Q 17	Integrated Photonics I
11:00	E214	Q 18	Quantum Optics: Cavity and Waveguide QED I
11:00	F303	Q 19	Precision Spectroscopy of Atoms and Ions II
11:00	F342	Q 20	Quantum Gases: Bosons II
11:00	F442	Q 21	Quantum Technologies: Color Centers II
16:30	Empore Lichthof	Q 22	Poster II

QI

			Invited Talks
11:00	B302	QI 10.1	Quantum information in minimal quantum thermal machines •Géraldine Haack
11:00	B305	QI 11.1	Characterisation of multipartite entanglement beyond the single-copy paradigm •Nicolai Friis
			Sessions
11:00	A320	QI 9	Photonic Quantum Technologies
11:00	B302	QI 10	Quantum Thermodynamics and Open Quantum Systems I
11:00	B305	QI 11	Quantum Entanglement I
11:00	E001	QI 12	Integrated Photonics I
11:00	F428	QI 13	Quantum Simulation
11:00	F442	QI 14	Quantum Technologies: Color Centers II
13:15	B305	QI 15	Members' Assembly

DD

			Prize Talks, Invited Talk
12:15	DD 108	DD 35.1	Durchführung eines MINT-Berufsinformationstags für die Mittelstufe in Form eines Digitalkongresses •Sebastian Bauer (Träger des DPG-Lehrerpreises 2021)

12:35	DD 108	DD 35.2	... mehr als nur Physik in the lænd •Pirmin Gohn, •Hermann Klein (Träger des DPG-Lehrerpreises 2022)
14:30	DD HS 2.202		**Verleihung des DPG-Lehrerpreises 2022**
14:40	DD HS 2.202	DD 39.1	Die Welt der Smartphone-Experimente mit phyphox •Sebastian Staacks, •Christoph Stampfer (Träger des Georg-Kerschenstei-ner-Preises 2023)
15:20	DD HS 2.202	DD 39.2	Entwicklung und Beforschung von Unterrichtskonzeptionen •Thomas Wilhelm (Träger des Robert-Wichard-Pohl-Preises 2023)
16:30	DD HS 2.202	DD 40.1	Zwischen Corona und KI: Wo steht die Hochschullehre und wie geht sie weiter? •Peter Salden

Sessions

11:00	DD 108	DD 30	Lehr-Lernforschung III
11:00	DD 110	DD 31	Praktika und neue Praktikumsversuche
11:00	DD 111	DD 32	Quantenphysik IV
11:00	DD 405	DD 33	Interesse und Persönlichkeit II
11:00	DD 407	DD 34	Lehreraus- und -fortbildung II
12:15	DD 108	DD 35	Impulse aus der Unterrichtspraxis – Vorträge Lehrerpreis
12:15	DD 110	DD 36	Digitale Medien IV
12:15	DD 405	DD 37	Hochschuldidaktik III
12:15	DD 407	DD 38	Bildung für nachhaltige Entwicklung I
14:30	DD HS 2.202	DD 39	Preisträgersymposium Didaktik
16:30	DD HS 2.202	DD 40	Hauptvortrag 2: Salden
18:00	DD HS 2.202	DD 41	Mitgliederversammlung FV DD

10:30	Lichthof	**Exhibition of Scientific Instruments and Literature** (free entrance)

10:30	e415	**jDPG Tower Building Contest**

Job Market

11:30	F435	Eisenführ Speiser Patentanwälte Rechtsanwälte PartGmbB: *„Physik trifft Recht - eine Karriere als Patentanwalt“*
13:30	F435	ZEISS: *„Working opportunities and career options at ZEISS“*

20:00	Main Entrance University	**jDPG Pub Crawl**

Wednesday, March 8, 2023

Plenary Talks

09:00	E415	PV V	The device-independent scenario: quantum information information processing based on Bell Theorem •Antonio Acin
09:45	E415	PV VI	Cavity-enhanced light-induced processes in aerosol droplets •Ruth Signorell

SYHD

Invited Talks

11:00	E415	SYHD 1.1	Structure and field-induced dynamics of small helium clusters •Maksim Kunitski
11:30	E415	SYHD 1.2	Coherent Diffraction Imaging of isolated helium nanodroplets and their ultrafast dynamics •Daniela Rupp
12:00	E415	SYHD 1.3	Clustering dynamics in superfluid helium nanodroplets: A theoretical study •Nadine Halberstadt
12:30	E415	SYHD 1.4	Messenger spectroscopy of molecular ions – Development of a new experimental setup •Elisabeth Gruber

Session

11:00	E415	SYHD 1	Molecules in Helium Droplets

A

Invited Talks

11:00	F107	A 13.1	Stability and Melting Dynamics of Mixed Species Coulomb Crystals with Highly Charged Ions •Luca Rüffert
11:00	F303	A 14.1	Realization of the Periodic Quantum Rabi Model in the Deep Strong Coupling Regime with Ultracold Rubidium Atoms •Stefanie Moll
14:30	F107	A 17.1	Adiabatic properties of the bicircular attoclock •Paul Winter

Sessions

11:00	F107	A 13	Highly Charged Ions and their Applications I
11:00	F303	A 14	Ultra-cold Atoms, Ions and BEC II
11:00	F102	A 15	Precision Measurements: Atom Interferometry I
14:30	F102	A 16	Molecules in Intense Fields and Quantum Control
14:30	F107	A 17	Interaction with Strong or Short Laser Pulses II
14:30	F303	A 18	Ultra-cold Plasmas and Rydberg Systems I
14:30	F428	A 19	Ultra-cold Atoms, Ions and BEC III
16:30	Empore Lichthof	A 20	Poster II

MO

Invited Talks

11:00	F142	MO 7.1	Augmenting basis with normalizing flows for solving Schrödinger equations: theoretical analysis •Yahya Saleh
14:30	F102	MO 9.1	Full Angle-Resolved Mapping of Electron Rescattering Probabilities in the Molecular Frame •Jochen Mikosch

Wednesday, March 8, 2023

MO

11:00	F142	MO 7	Machine Learning and Computational and Theoretical Molecular Physics
13:15	F142	MO 8	Members' Assembly
14:30	F102	MO 9	Molecules in Intense Fields and Quantum Control
14:30	F142	MO 10	Collisions
14:30	E214	MO 11	Quantum Technologies
14:30	F107	MO 12	Interaction with Strong or Short Laser Pulses II
16:30	Empore Lichthof	MO 13	Poster II

MS

Invited Talk

14:30	F128	MS 3.1	Durable, low-temperature and highly-selective catalysis in NO reduction and CO oxidation driven by uni-sized Pt clusters supported on Si and SiC substrates •Hisato Yasumatsu

Sessions

11:00	F128	MS 2	Multi-Reflection Time-of-Flight Spectrometers
14:30	F128	MS 3	Mass Spectrometry Applications

Q

Invited Talks

14:30	E214	Q 36.1	BMBF-Förderprogramm: Wissenschaftliche Vorprojekte •Bernhard Ihrig

Sessions

11:00	A320	Q 23	Optomechanics I & Optovibronics
11:00	B305	Q 24	Quantum Networks I
11:00	E001	Q 25	Solid State Quantum Optics
11:00	E214	Q 26	Quantum Gases: Bosons III
11:00	F303	Q 27	Ultra-cold Atoms, Ions and BEC II
11:00	F342	Q 28	Quantum Technologies: Trapped Ions
11:00	F428	Q 29	Implementations: Ions and Atoms
11:00	F442	Q 30	Nano-optics
11:00	F102	Q 31	Precision Measurements: Atom Interferometry I
13:00	F342	Q 32	Members' Assembly
14:30	A320	Q 33	Quantum Gases: Bosons IV
14:30	B305	Q 34	Quantum Communication
14:30	E001	Q 35	Quantum Optics: Cavity and Waveguide QED II
14:30	E214	Q 36	Quantum Technologies
14:30	F142	Q 37	Collisions (with Q)
14:30	F303	Q 38	Ultra-cold Plasmas and Rydberg Systems I
14:30	F342	Q 39	Quantum Optics & Nano-Optics
14:30	F442	Q 40	Photonics II
14:30	F428	Q 41	Ultra-cold Atoms, Ions and BEC III
16:30	Empore Lichthof	Q 42	Poster III
16:30	Empore Lichthof	Q 43	QI Poster II
17:00	A320	Q 44	Integrated Photonics II

QI

Invited Talks

11:00	B305	QI 17.1	Self-testing with dishonest parties and entanglement certification in quantum networks •Gláucia Murta
11:00	F428	QI 19.1	Experimental quantum error correction with trapped ions •Philipp Schindler

Wednesday, March 8, 2023

QI

14:30	B305	QI 21.1	Qube and Qube-II – Towards Quantum Key Distribution with Small Satellites •Lukas Knips

Sessions

11:00	B302	QI 16	Concepts and Methods I
11:00	B305	QI 17	Quantum Networks I
11:00	F342	QI 18	Quantum Technologies: Trapped Ions
11:00	F428	QI 19	Implementations: Ions and Atoms
14:30	B302	QI 20	Concepts and Methods II
14:30	B305	QI 21	Quantum Communication II
14:30	E214	QI 22	Quantum Technologies II
16:30	Empore Lichthof	QI 23	Poster II
17:00	A320	QI 24	Integrated Photonics II

DD

Invited Talk

12:10	DD HS 2.202	DD 47.1	Reflexivität zu Sprache und Physiklernen durch Fallverstehen? Eine kasuistische Begleitveranstaltung zu Schulpraktika im Lehramtsstudium •Thorid Rabe

Sessions

11:00	DD 108	DD 42	Lehr-Lernforschung IV
11:00	DD 110	DD 43	Experimente I
11:00	DD 111	DD 44	Quantenphysik V
11:00	DD 405	DD 45	Hochschuldidaktik IV
11:00	DD 407	DD 46	Bildung für nachhaltige Entwicklung II
12:10	DD HS 2.202	DD 47	Hauptvortrag 3: Rabe & Helzel
14:30	DD 108	DD 48	Lehr-Lernforschung V
14:30	DD 110	DD 49	Experimente II
14:30	DD 111	DD 50	Quantenphysik VI
14:30	DD 405	DD 51	Hochschuldidaktik V
14:30	DD 407	DD 52	außerschulisch/Hochschule
16:00	DD 108	DD 53	Workshop Studienreformforum

10:30 Lichthof — **Exhibition of Scientific Instruments and Literature** *(free entrance)*

Job Market

11:30	F435	Trumpf Lasersystems for Semiconductor Manufacturing GmbH: *„TRUMPF Lasersystems for EUV Lithography – Enabler für das digitale Zeitalter gesucht“*
13:30	F435	Basycon Unternehmensberatung GmbH: *„Aus der Wissenschaft in die Beratung“*

Evening Talk *(free entrance)*

20:00	E415	PV VII	Das Ende der klassischen Welt – Der Physik-Nobelpreis 2022 •Reinhard Werner

Thursday, March 9, 2023

			Plenary Talks
09:00	E415	PV VIII	Highly charged helium droplets •Paul Scheier
09:45	E415	PV IX	Exploring fundamental interactions and constants with trapped ions •Sven Sturm

SYCC

			Invited Talks
11:00	E415	SYCC 1.1	The unity of physics: the beauty and power of spectroscopy •Paul Julienne
11:30	E415	SYCC 1.2	Using high-resolution molecular spectroscopy to explore how chemical reactions work •Johannes Hecker Denschlag
12:00	E415	SYCC 1.3	Monitoring ultracold collisions with laser light •Olivier Dulieu
12:30	E415	SYCC 1.4	The birth of a degenerate Fermi gas of molecules •Jun Ye
			Session
11:00	E415	SYCC 1	From Molecular Spectroscopy to Collision Control at the Quantum Limit

SYPD

			Invited Talks
14:30	E415	SYPD 1.1	Entanglement and quantum metrology with microcavities •Jakob Reichel
15:00	E415	SYPD 1.2	Many-body physics in dipolar quantum gases •Francesca Ferlaino
15:30	E415	SYPD 1.3	Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets •Markus Greiner
16:00	E415	SYPD 1.4	Quantum gas in a box •Zoran Hadzibabic
			Session
14:30	E415	SYPD 1	Many-body Physics in Ultracold Quantum Systems

A

			Invited Talks
11:00	F107	A 22.1	Efficient and accurate simulation of wide-angle single-shot scattering •Paul Tuemmler
11:00	F303	A 23.1	Trapping Ions and Ion Coulomb Crystals in a 1D Optical Lattice •Daniel Hoenig
14:30	F107	A 24.1	Intra-cavity photoelectron tomography with an intra-cavity velocity-map imaging spectrometer at 100 MHz repetition rate •Jan-Hendrik Oelmann
14:30	F303	A 26.1	Laser spectroscopy of the heaviest elements with the RADRIS technique •Tom Kieck
			Sessions
11:00	F102	A 21	Ultrafast Dynamics II
11:00	F107	A 22	Atomic Clusters
11:00	F303	A 23	Ultra-cold Atoms, Ions and BEC IV
14:30	F107	A 24	Interaction with Strong or Short Laser Pulses III
14:30	F142	A 25	Cluster and Experimental Techniques

Thursday, March 9, 2023

A

14:30	F303	A 26	Precision Spectroscopy of Atoms and Ions III
16:30	Empore Lichthof	A 27	Poster III

MO

Invited Talk

11:00	F142	MO 15.1	Excited state dipole moments from rotationally resolved Stark spectroscopy •Michael Schmitt

Sessions

11:00	F102	MO 14	Ultrafast Dynamics II
11:00	F142	MO 15	Rotational- and Vibrational-resolution Spectroscopy
11:00	F107	MO 16	Atomic Clusters
14:30	F102	MO 17	Quantum Optics and Quantum Information with Rigid Rotors
14:30	F142	MO 18	Cluster and Experimental Techniques
14:30	F107	MO 19	Interaction with Strong or Short Laser Pulses III
16:30	Empore Lichthof	MO 20	Poster III

MS

Invited Talks

11:00	F128	MS 4.1	Observation of the radiative decay of the thorium-229 nuclear clock isomer •Sandro Kraemer
11:30	F128	MS 4.2	Mass measurements of heavy and superheavy nuclides and isomers with SHIPTRAP •Manuel J. Gutiérrez

Sessions

11:00	F128	MS 4	Heavy and Superheavy Elements
13:00	F128	MS 5	Members' Assembly
14:30	F128	MS 6	Accelerator Mass Spectrometry II
16:30	Empore Lichthof	MS 7	Poster

Q

Invited Talks

11:00	E001	Q 47.1	Quantum metrology with non-classical states of light •Michèle Heurs
11:00	E214	Q 48.1	Using optomechanical systems to test gravitational theory – possibilities and limitations •Dennis Rätzel
14:30	E001	Q 52.1	Nonperturbative Floquet engineering and Floquet-dissipative state preparation •Francesco Petiziol
14:30	E214	Q 53.1	Quantum information with atomic quantum metasurfaces and integrated nanophotonics •Rivka Bekenstein

Sessions

11:00	A320	Q 45	Photonics III
11:00	B305	Q 46	Quantum Control
11:00	E001	Q 47	Precision Measurements with Optical Clocks
11:00	E214	Q 48	Optomechanics II
11:00	F303	Q 49	Ultra-cold Atoms, Ions and BEC IV
11:00	F342	Q 50	Quantum Gases: Fermions I
14:30	A320	Q 51	Precision Measurements
14:30	E001	Q 52	Floquet Engineering and Topology
14:30	E214	Q 53	Single Quantum Emitters

Thursday, March 9, 2023

Q

14:30	F102	Q 54	Quantum Optics and Quantum Information with Rigid Rotors
14:30	F303	Q 55	Precision Spectroscopy of Atoms and Ions III
14:30	F342	Q 56	Quantum Gases: Fermions II
14:30	F428	Q 57	Quantum Networks II
14:30	F442	Q 58	Quantum Optics with Photons I
16:30	Empore Lichthof	Q 59	Poster IV

QI

Invited Talks

11:00	B305	QI 26.1	Quantum firmware: optimal control for quantum simulators •Tommaso Calarco
11:00	F428	QI 28.1	Conveyor-mode single-electron shuttling in Si/SiGe for a scalable quantum computing architecture •Inga Seidler
14:30	B305	QI 30.1	Adaptive constant-depth circuits for manipulating non-abelian anyons •Robert König

Sessions

11:00	B302	QI 25	Quantum Entanglement II
11:00	B305	QI 26	Quantum Control
11:00	E001	QI 27	Precision Measurements with Optical Clocks
11:00	F428	QI 28	Spin Qubits
14:30	B302	QI 29	Quantum Thermodynamics and Open Quantum Systems II
14:30	B305	QI 30	Quantum Algorithms
14:30	E214	QI 31	Single Quantum Emitters
14:30	F102	QI 32	Quantum Optics and Quantum Information with Rigid Rotors
14:30	F428	QI 33	Quantum Networks II

10:30 Lichthof **Exhibition of Scientific Instruments and Literature** *(free entrance)*

Job Market

11:30	F435	BearingPoint GmbH: *„Quantentechnologien und Beratung“*
13:30	F435	d-fine GmbH: *„Verwendung von Finanzderivaten in Industrieunternehmen“*

Friday, March 10, 2023

			Plenary Talks
09:00	E415	PV X	Lightwave electronics in trivial, topological, and strongly correlated solids •Misha Ivanov
09:45	E415	PV XI	Quantum Simulation using Ultracold Atoms and Molecules •Immanuel Bloch

SYQR

			Invited Talks
11:00	E415	SYQR 1.1	Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets •Henrik Stapelfeldt
11:30	E415	SYQR 1.2	Quantum toolbox for molecular state spaces •Victor V. Albert
12:00	E415	SYQR 1.3	Coherent rotational state control of chiral molecules •Sandra Eibenberger-Arias
12:30	E415	SYQR 1.4	Optically levitated rotors: potential control and optimal measurement •Martin Frimmer
14:30	E415	SYQR 2.1	Rotational optomechanics with levitated nanodumbbells •Tongcang Li
15:00	E415	SYQR 2.2	Quantum rotations of nanoparticles •Benjamin A. Stickler
15:30	E415	SYQR 2.3	Quantum control of trapped molecular ions •Stefan Willitsch
16:00	E415	SYQR 2.4	Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables •Monika Leibscher
			Sessions
11:00	E415	SYQR 1	Quantum Optics and Quantum Information with Rigid Rotors 1
14:30	E415	SYQR 2	Quantum Optics and Quantum Information with Rigid Rotors 2

A

			Invited Talks
11:00	F107	A 28.1	Coherent multidimensional spectroscopy of an ultracold gas •Friedemann Landmesser
11:00	F303	A 29.1	An elementary network of entangled optical atomic clocks •Raghavendra Srinivas
14:30	F107	A 30.1	Investigation of Molecular Ions as Sensitive Probes for Fundamental Physics •Carsten Zuelch
14:30	F303	A 31.1	Observation of vibrational dynamics in an ion-Rydberg molecule by a high-resolution ion microscope •Moritz Berngruber
			Sessions
11:00	F107	A 28	Ultra-cold Plasmas and Rydberg Systems II
11:00	F303	A 29	Precision Spectroscopy of Atoms and Ions IV
14:30	F107	A 30	Highly Charged Ions and their Applications II
14:30	F303	A 31	Ultra-cold Atoms, Ions and BEC V
14:30	F342	A 32	Precision Measurements: Atom Interferometry II
14:30	B302	A 33	Precision Spectroscopy of Atoms and Ions V
14:30	F102	A 34	Ultrafast Dynamics III

Friday, March 10, 2023

MO

			Invited Talk
11:00	F142	MO 22.1	A QED Theory of Mediated RET Between a Pair of Chiral Molecules •Akbar Salam
			Sessions
11:00	F102	MO 21	Molecular Physics with X-rays
11:00	F142	MO 22	Theoretical and Computational Molecular Physics
11:00	F102	MO 23	Ultrafast Dynamics III

MS

			Invited Talks
11:00	F128	MS 8.1	Two color resonant laser SNMS for isotope micro imaging of nuclear fuel debris •Tetsuo Sakamoto
14:30	F128	MS 9.1	Developments to improve antiproton and other mass measurements •Christian Smorra on behalf of the BASE collaboration
			Sessions
11:00	F128	MS 8	Accelerator Mass Spectrometry III
14:30	F128	MS 9	Penning traps, highest precision, neutrino physics, storage rings, new facilities and approaches

Q

			Invited Talk
11:00	E001	Q 61.1	Quantum Imaging With Nonlinear Interferometers •Markus Gräfe
			Sessions
11:00	A320	Q 60	Photonics IV
11:00	E001	Q 61	Quantum Optics with Photons II
11:00	E214	Q 62	Precision Measurements: Gravity II
11:00	F107	Q 63	Ultra-cold Plasmas and Rydberg Systems II
11:00	F303	Q 64	Precision Spectroscopy of Atoms and Ions IV
11:00	F342	Q 65	Many-body Physics
11:00	F428	Q 66	Quantum Metrology
11:00	F442	Q 67	Optomechanics III
14:30	B305	Q 68	Quantum Gases: Bosons V
14:30	F303	Q 69	Ultra-cold Atoms, Ions and BEC V
14:30	F342	Q 70	Precision Measurements: Atom Interferometry II
14:30	F442	Q 71	Quantum Optics: Cavity and Waveguide QED III
14:30	B302	Q 72	Precision Spectroscopy of Atoms and Ions V

QI

			Sessions
11:00	B302	QI 34	Concepts and Methods III
11:00	B305	QI 35	Quantum Computers: Algorithms and Benchmarking
11:00	F428	QI 36	Quantum Metrology
14:30	F428	QI 37	Quantum Many Body Systems

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Bewerbung möglich vom 1. bis 31. März 2023
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Plenary and Evening Talks

Plenary Talk PV I Mon 9:00 E415

Probing the quantum nature of gravity in table-top experiments — •Markus Aspelmeyer — University of Vienna, Faculty of Physics, Vienna, Austria — Austrian Academy of Sciences, IQOQI, Vienna, Austria

No experiment today provides evidence that gravity requires a quantum description. The growing ability to achieve quantum optical control over massive solid-state objects may change that situation – by enabling experiments that directly probe the phenomenology of quantum states of gravitational source masses. This can lead to experimental outcomes that are inconsistent with the predictions of a purely classical field theory of gravity. Such 'Quantum Cavendish' experiments will rely on delocalized motional quantum states of sufficiently massive objects and gravity experiments on the micrometer scale. I review the current status in the lab and the challenges to be overcome for future experiments.

Plenary Talk PV II Mon 9:45 E415

Quantum Chemistry on Quantum Computers: Challenges and New Directions — •Sabrina Maniscalco — Algorithmiq Ltd, Kanavakatu 3C, 00160 Helsinki, Finland — QTF Centre of Excellence, Department of Physics, Faculty of Science, University of Helsinki, Finland

Simulating electronic structure problems is one of the most attractive applications of quantum computers. Current devices, however, are limited: they are still operating with small number of qubits and high level of noise. Moreover, they are affected by a large number of both technical and fundamental problems. In my talk I will focus on one of the most studied applications of quantum computers, namely quantum chemistry simulations, and I will highlight both the current major roadblocks and a new framework to overcome them. As an example I will focus on three key steps, namely how to map optimally fermionic systems to qubits [1], how to initialise the quantum computers [3], and how to measure them in the most efficient manner [4,5].

References: [1] A. Miller, Z. Zimborás, S. Knecht, S. Maniscalco, G. García-Pérez, arXiv:2212.09731. [2] A. Nykänen, M. A. C. Rossi, E. Borrelli, S. Maniscalco, G. García-Pérez, arXiv:2212.09719. [3] A. Fitzpatrick, A. Nykänen, N. Talarico, A. Lunghi, S. Maniscalco, G. García-Pérez, S. Knecht, arXiv:2212.11405. [4] G. García-Pérez, M.A. C. Rossi, B. Sokolov, F. Tacchino, P. Kl. Barkoutsos, G. Mazzola, I. Tavernelli, S. Maniscalco, PRX Quantum 2, 040342 (2021). [5] A. Glos, A. Nykänen, E. Borrelli, S. Maniscalco, M. A. C. Rossi, Z. Zimborás, G. García-Pérez, arXiv:2208.07817.

Plenary Talk PV III Tue 9:00 E415

Educational Transformation at a Critical Time: The essential roles and promise of physicists — •Noah Finkelstein — University of Colorado, Boulder USA

Significant, perhaps unprecedented, attention is being paid to the needs for transformation within the fields of science, technology, engineering, and mathematics (STEM) education at the undergraduate level. This talk examines how higher education STEM disciplines, and physicists and physics departments in particular, are positioned to contribute to these discussions and address our challenges. I will review our own efforts in physics education transformation and the growth of work in physics education research (PER). Building from theory on student learning and educational environments, this talk will review examples of physicists' support of learning at the individual, course, and departmental scales. Examples will consider: how we can build on understanding of student reasoning to study and transform our introductory through upper division courses, studies of how our environments do and do not support identity formation in physics, and models for engaging in sustainable and scalable transformation.

Plenary Talk PV IV Tue 9:45 E415

New Lightwave Science with Photonic Crystal Fibres — •Philip Russell — MPI Science of Light, Erlangen, Germany

Photonic crystal fibres (PCFs), thin strands of glass with an array of hollow channels running along their length, offer light guidance in both hollow and solid glass cores. They permit unprecedented control over dispersion, birefringence and nonlinearity, and over the last three decades have ushered in a new era of linear and nonlinear fibre optics. Gas-filled hollow-core PCF provides low-loss diffraction-free transmission of light in a single transverse mode, and through pressure-adjustable dispersion provides a simple means of compressing pulses to single-cycle durations, as well reducing the threshold power for nonlinear effects by orders of magnitude. Operating on opposite sides of the gas-pressure-tuneable zero dispersion point permits a novel form of holography based on Raman coherence, which has been used for highly efficient state-preserving frequency up-conversion of single photons by 125 THz in hydrogen (doi.org//10.1126/science.abn1434). Chiral PCF, formed by spinning the preform during fibre drawing, provides circular and vortex birefringence, as well as permitting localization of light in core-less (i.e., defect-free) 2D lattices of chiral coupled cores (doi.org//10.1002/lpor.202200570). After a brief introduction, a number of recent developments will be covered in the talk.

Plenary Talk PV V Wed 9:00 E415

The device-independent scenario: quantum information information processing based on Bell Theorem — •Antonio Acin — ICFO - The Institute of Photonic Sciences

Bell theorem implies the existence of quantum correlations that cannot be explained by classical physics, this phenomenon often known as Bell non-locality. Despite its fundamental importance, the role of Bell non-locality in standard quantum information theory is, perhaps surprisingly, marginal. Bell non-locality is however the fundamental resource for device-independent quantum information processing, in which devices are seen as quantum black boxes processing classical information. The talk introduces the main concepts and tools of the device-independent scenario and its relevance for the certification of quantum systems and technologies.

Plenary Talk PV VI Wed 9:45 E415

Cavity-enhanced light-induced processes in aerosol droplets — •Ruth Signorell — Department of Chemistry and Applied Biosciences, ETH Zurich, CH-8093 Zurich, Switzerland

When light interacts with an aerosol particle, the light intensity can be greatly amplified inside the particle as the latter acts as a light-amplifying cavity. This optical phenomenon can be viewed as a dielectric analogue of plasmon resonances in metallic nanoparticles. The role these optical confinement effects play in aerosols are diverse. We report their influence in three different areas: (1) Photochemical processes have been identified as the main causes of degradation and oxidation of matter in atmospheric aerosol particles. Photochemistry in aerosol particles is accelerated by optical confinement effects compared with reactions in bulk condensed matter. We have studied and quantified the acceleration of in-particle photochemistry using photoacoustic spectroscopy and X-ray spectro-microscopic imaging of single aerosol particles. (2) Low-energy electron scattering in liquid water plays a crucial role in a variety of physical, chemical, and biological processes. However, the quantitative description of electron scattering has been hampered by the lack of scattering cross-sections for liquid water. By exploiting optical confinement effects in photoemission images of water droplets, we have contributed to solving this problem. (3) Optical confinement also affects ultrafast, laser-driven plasma formation from aerosol particles by structuring the internal light intensity. We report recent coherent diffraction imaging experiments during nanoplasma expansion of core-shell aerosol particles.

Evening Talk PV VII Wed 20:00 E415

Das Ende der klassischen Welt – Der Physik-Nobelpreis 2022 — •Reinhard Werner — Leibniz Universität Hannover

Der Physik-Nobelpreis 2022 ging an John Clauser, Alain Aspect und Anton Zeilinger „für Experimente mit verschränkten Photonen, den Nachweis der Verletzung der Bellschen Ungleichungen und Pionierarbeiten der Quanteninformationswissenschaft". Dies ist nicht weniger als der experimentelle Nachweis für das Versagen aller klassischen Beschreibungen und Bilder in der Mikrophysik. Der Vortrag zeichnet die Ideengeschichte dieses Durchbruchs nach und geht auf häufige Missverständnisse ein, oft verbunden mit dem Ausdruck „spukhafte Fernwirkung". Bemerkenswert ist, dass die Preisträger, ebenso wie Einstein (in Bezug auf Quantentheorie), Bell und die Theoretiker, die die Quanteninformationswissenschaft begannen, deutlich abseits des Mainstreams standen. Mehrfach sehen wir hier Entwicklungen, die von einer Handvoll Exoten begonnen wurden und Jahrzehnte später zum festen Bestandteil der Physik wurden. Der Vortrag endet mit ein paar Betrachtungen was gerade diese Exoten ausgezeichnet hat, und wie wir die Chancen verbessern können, dass ihre modernen unkonventionellen Kollegen Gehör finden.

Plenary Talk PV VIII Thu 9:00 E415

Highly charged helium droplets — •Paul Scheier — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria

Helium nanodroplets provide an inert matrix, free of walls with outstanding properties to grow complexes and clusters at sub-Kelvin temperatures. However, like for almost every existing method of cluster and nanoparticle formation pickup into neutral helium droplets leads to a wide distribution of dopant cluster sizes. Recently, we discovered that large helium droplets can become highly-charged. Micrometer sized droplets can reach charge states up to several 100. The charge centers self-organize as two-dimensional Wigner crystals at the surface of the droplets and act as seeds for the growth of dopant clusters. Cluster ions of a specific size and composition can be formed by this technique with unprecedented efficiency. Soft-landing of dopant clusters formed in highly-charged helium droplets can be achieved via collisions with a surface set on a retarding potential. Due to the fact that several hundred nanoparticles are formed simultaneously in one helium droplet and the suppression of splashing, the deposition time compared to neutral helium droplets can be reduced by more than two orders of magnitude.

Plenary Talk PV IX Thu 9:45 E415

Exploring fundamental interactions and constants with trapped ions — •Sven Sturm — Max Planck Institute for Nuclear Physics (MPIK), Heidelberg

Single ions in cryogenic Penning traps are almost ideal tools for exploring the validity of quantum electrodynamics (QED) as well as for determining the values of fundamental constants - the links that allow us to compare theories to actual measurements. We utilise the extraordinary control over the motion of the trapped ions, which are decoupled from any disturbing environment, to determine their mass, magnetic moment (g-factor) and transition spectrum with highest precision. This way, we have measured the masses of electron, proton, deuteron and helium. Furthermore, with highly charged ions we can explore the strongest electromagnetic fields and perform stringent tests of strong-field QED. Novel techniques have lately enabled a leap in precision, so that the comparison of experiment and theory allows searching for new physics beyond the Standard Model. Finally, the Penning-trap toolbox enables laser spectroscopy of otherwise difficult-to-access species, such as the molecular hydrogen ion. I will present the techniques as well as our previous and future campaigns.

Plenary Talk PV X Fri 9:00 E415

Lightwave electronics in trivial, topological, and strongly correlated solids — •Misha Ivanov — Max Born Institute, Berlin, Germany

Modern light generation technology has evolved to the point where a theorist may reasonably expect an experimentalist to generate light pulses where individual oscillations of the electric field are shaped almost at will. Control of the carrier-envelope phase of few-cycle pulses is now almost routine. One can also reliably generate complex polarization states in two and three dimensions, sculpting the Lissajous figures drawn by the electric field vector during a single optical cycle. As these fields can be made strong enough to compete with the internal electric fields in a medium, coherent electronic motion can be excited and shaped almost at will, at the time-scale of a single light oscillation. How can we use such opportunities? What happens to a crystal exposed to such light? Do we change its effective band structure and density of states? Can these changes be controlled?

I will address these questions by considering several examples, ranging from trivial to topological to correlated solids, showing how our ability to control light on the sub-cycle time-scale leads to interesting and often unexpected results.

Plenary Talk PV XI Fri 9:45 E415

Quantum Simulation using Ultracold Atoms and Molecules — •Immanuel Bloch — Max Planck Institute of Quantum Optics — LMU Munich

40 years ago, Richard Feynman outlined his vision of a quantum simulator for carrying out complex calculations of physical problems. Today, his dream has become a reality and a highly active field of resarch across different platforms. In my talk, I will delineate how ultracold atoms in optical lattices started this vibrant and interdisciplinary research field 20 years ago and now allow probing quantum phases in- and out-of-equilibrium with fundamentally new tools and single particle resolution. Ultracold polar molecules allow to significantly extend the simulation capabilities due to their more complex internal structure and strong dipolar interactions. So far, however, efficient and general techniques to cool them to quantum degeneracy have remained out of reach. In the talk, I will discuss how microwave shielding provides an efficient general solution that allows to cool three-dimensional bulk samples of polar molecules to deep quantum degeneracy as well as to provide a handle on controlling their scattering properties using novel 'field-linked' resonances. Realizing such full control over polar molecules promises to harness their full potential for quantum simulations.

Symposium SAMOP Dissertation Prize 2023 (SYAD)

jointly organized by all divisions of the section AMOP

Gereon Niedner-Schatteburg
Fachbereich Chemie
Technische Universität Kaiserslautern
Erwin-Schrödinger-Straße
67663 Kaiserslautern
gns@chemie.uni-kl.de

The divisions of the section AMOP award a PhD prize 2023. The prize acknowledges outstanding research from a PhD work and its excellent written and oral presentation. Eligible for nomination were outstanding PhD theses from the research fields of AMOP completed in 2021 or 2022. Based on the nominations, a jury formed by representatives of the AMOP research areas selected four finalists for the award. The finalists are invited to present their research in this dissertation prize symposium. Right after the symposium, the awardee will be selected by the prize committee.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Sessions

SYAD 1.1–1.4	Mon	14:30–16:30	E415	**SAMOP Dissertation Prize Symposium (SYAD)**

Sessions

– Invited Talks –

SYAD 1: SAMOP Dissertation Prize Symposium (SYAD)

Time: Monday 14:30–16:30 Location: E415

Invited Talk SYAD 1.1 Mon 14:30 E415

Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems — •Luca Asteria — Institut für Laserphysik, Hamburg University, Hamburg — The Hamburg Centre for Ultrafast Imaging, Hamburg

Ultracold atoms in optical lattices are promising platforms for studies of fundamental physics and quantum simulation of many body physics. An in-situ detection of the atomic density distribution within the lattice however is challenging due to diffraction limits within the optical detection.

Here we demonstrate a new detection technique, based on a magnification of the pure density distribution prior to the optical detection which allows large scale images of the lattice system with sub-lattice spacing resolution. The protocol is based on a T/4 evolution in a harmonic trap and subsequent time of flight which magnifies the initial atomic density distribution up to a factor of 90. We get thus an effective resolution as small as 80μm, which even allows the observation of the motion of the atoms within the lattice sites, a promising step towards the real-space study of systems with orbital degrees of freedom.

Furthermore, we demonstrate how similar matter wave protocols could be used to access spatial coherence properties at the microscopic range level. This paves the way for quantum simulations of new types of materials and various applications in quantum technologies.

Invited Talk SYAD 1.2 Mon 15:00 E415

From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers — •Patrick Rupprecht — Max-Planck-Institut für Kernphysik

Core-level absorption spectroscopy has proven to be a powerful tool to gain a deeper understanding of ultrafast quantum dynamics in atoms, molecules, and solid-state materials. Especially the capability of x-ray transient absorption spectroscopy (XTAS) to elucidate dynamics in neutral molecules on the atto- and femtosecond time scales stands out.

In my talk, I will present a novel source for few-cycle, center-wavelength-tunable ($\lambda_c = 1 - 2\ \mu m$) laser pulses in combination with a flexible transient absorption setup at the *Max Planck Institute for Nuclear Physics*. These experimental capabilities are utilized to control the quantum-mechanical part of the electron–electron interaction, the exchange energy, for the first time by perturbing gaseous SF_6 molecules with infrared pulses of variable intensity of up to 2×10^{14} W/cm^2. In a second experiment, time-resolved x-ray absorption spectroscopy is used to elucidate vibrational molecular dynamics in the perturbative limit with an unprecedented spatial precision of 14 fm. These XTAS studies pave the way for new ultrafast chemical control schemes as well as precision metrology on molecular bonds.

Invited Talk SYAD 1.3 Mon 15:30 E415

Particle Delocalization in Many-Body Localized Phases — •Maximilian Kiefer-Emmanouilidis — Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Kaiserslautern, Germany — Deutsches Forschungszentrum für Künstliche Intelligenz, Kaiserslautern, Germany — University of Manitoba, Winnipeg, Canada

Can a generic isolated quantum many-body system avoid thermalization? Textbook thermodynamics say no, at least for any generic interacting system. In 2006 Basko et al. argued to the contrary and described the phenomenon known today as many-body localization (MBL), where in highly disordered materials interacting electrons may localize in space, thus withstanding thermalization. In this talk I present evidence gathered during my dissertation which fundamentally questions the current picture of the MBL phase. I show that even in the paradigmatic model of MBL, where the von Neumann entanglement entropy grows $S \sim \ln t$ particles can spread subdiffusively. In my dissertation I studied the contribution to a systems entanglement entropy which stems from particle-number fluctuations. This quantity known as the number entropy S_N describes the entanglement generated by particles moving between partitioning cuts and is easily accessible in setups of ultracold atoms utilizing a quantum gas microscope. In a system that exhibits MBL, particles should travel only short distances, and thus S_N should be bounded after a quench. I have shown numerically that the number entropy grows proportional to the entanglement entropy, $S_N \sim \ln S \sim \ln\ln t$, and is therefore unbounded if S is unbounded. This questions the existence of the MBL phase.

Invited Talk SYAD 1.4 Mon 16:00 E415

Feshbach resonances in a hybrid atom-ion system — •Pascal Weckesser — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany

In the past decade, hybrid atom-ion systems have emerged as a new platform featuring long-range interactions. Cooling the system close to the quantum limit allows the investigation of novel quantum phenomena, such as charged mesoscopic molecules, as well as the study of quantum chemistry and quantum simulation. Reaching the ultracold regime, however, is a challenging task, as intrinsic heating effects of conventional radiofrequency (rf) traps limit most experiments to the millikelvin regime, where atom-ion interactions remain classical.

In my talk, I will discuss two pathways to overcome this limitation and present the first observation of Feshbach resonances between atoms and ions. We minimize the intrinsic heating rates by choosing a system with large mass imbalance - ^{6}Li atoms and ^{138}Ba$^+$ ions. Additionally, we can optically trap the ions allowing us to operate in complete absence of detrimental rf fields. As a result, we cool the system to the s- and p-wave scattering regime and find 11 resonances by magnetic-field dependent ion loss spectroscopy. We further demonstrate the tunability of the resonances by controlling the ion's sympathetic cooling rate. These results pave the way towards studying complex many-body systems, such as charged polarons in the strong coupling regime or the coherent formation of molecular ions.

Awards Symposium (SYAS)

jointly organized by all divisions of the section AMOP

Gereon Niedner-Schatteburg
Fachbereich Chemie
Technische Universität Kaiserslautern
Erwin-Schrödinger-Straße
67663 Kaiserslautern
gns@chemie.uni-kl.de

The German Physical Society DPG grants a series of highly regarded prizes, and these are handed out in the course of the "DPG Jahrestagung" which is held in 2023 at Dresden. Part of the recognition of the awardees is an invitation to hold a prize talk at one of the annual spring meetings, such that their award winning topics are presented to an expert audience and in order to attract high attention. In 2022 there is a group of four awardees who will present their prize talks in the course of the SAMOP spring meeting, and it is this symposium which serves as platform to do so:

Prof. Joachium Ullrich is the award winner of the Stern-Gerlach-Medal 2021, and due to the pandemic constraints of the last two years it is only now that he can present the according prize talk.

Prof. Rainer Blatt is the award winner of the Herbert-Walther-Prize 2023.

Dr. Sebastian Eckart is the award winner of the Gustav-Hertz-Prize 2023.

M.Sc. Marvin Edelmann is the award winner of the Georg-Simon-Ohm-Prize 2023.

At the beginning of the SYAS session there will be the SAMOP Dissertation Prize 2023 awarding ceremony.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Prize Talks

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich
SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt
SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Sessions

SYAS 1.1–1.4	Tue	14:30–16:35	E415	**Award Symposium**

Sessions

– Prize Talks –

SYAS 1: Award Symposium

Time: Tuesday 14:30–16:35 Location: E415

SAMOP Dissertation Prize 2023 awarding ceremony

Prize Talk SYAS 1.1 Tue 14:35 E415

The Reaction Microscope: A Bubble Chamber for AMOP — •Joachim Ullrich — 69256 Mauer, Germany — Laureate of the Stern-Gerlach-Medal 2021

Reactions Microscopes developed in 1994 revolutionised the experimental study of atomic and molecular break-up reactions and provided unprecedented insights into many-particle quantum dynamics. They enabled for the first time the coincident detection of the momentum vectors of several electrons and ions after (multiple) ionisation of atoms or molecules with high resolution and coverage of a large part of the final-state many-body momentum space. The talk will highlight the technology and its development, illustrate benchmark experiments and focus on the rich future potential of the method.

Prize Talk SYAS 1.2 Tue 15:05 E415

Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions — •Rainer Blatt — Inst. f. Experimentalphysik, Univ. Innsbruck, Austria — Inst. f. Quantenoptik u. Quanteninformation Innsbruck, ÖAW, Innsbruck, Austria — Laureate of the Herbert-Walther-Prize 2023

The state-of-the-art of the Innsbruck trapped-ion quantum computer [1] is briefly reviewed. We present an overview on the available quantum toolbox and discuss the scalability of the approach. With up to 50 fully controlled ion qubits we perform quantum simulations investigating quantum transport [2] and emerging hydrodynamics features [3]. Employing the quantum toolbox for entanglement-enhanced Ramsey interferometry, we find optimal parameters for quantum metrology [4]. Quantum computers can be protected from noise by encoding the logical quantum information redundantly into multiple qubits using error-correcting codes. Manipulating logical quantum states by imperfect operations requires that all operations on the quantum register obey a fault-tolerant circuit design to avoid spreading uncontrolled errors. We demonstrate a fault-tolerant universal set of gates on two logical qubits in the trapped-ion quantum computer [5].

[1] I. Pogorelov et al., PRX Quantum 2, 020343 (2021) [2] C. Maier et al., Phys. Rev. Lett. 122, 050501 (2019) [3] M. K. Joshi et al., Science 376, 720 (2022) [4] C. D. Marciniak et al., Nature 603, 604 (2022) [5] L. Postler et al., Nature 605, 675 (2022)

Prize Talk SYAS 1.3 Tue 15:35 E415

Amplitude, Phase and Entanglement in Strong Field Ionization — •Sebastian Eckart — Institut für Kernphysik, Max-von-Laue-Str. 1, 60438 Frankfurt am Main — Laureate of the Gustav-Hertz-Prize 2023

We report on experiments with highly intense femtosecond laser pulses with tailored polarization. The electric field of the laser bends the atomic potential and leads to tunnel ionization of single atoms and molecules. The momenta of the liberated electrons and the ions are measured in coincidence using cold-target recoil-ion momentum spectroscopy (COLTRIMS) reaction microscopes.

We explore properties of the amplitude [1] and the phase [2] of the wave function of the liberated electron. For example, this allows us to measure the Wigner time delay of the electron which is liberated from molecular hydrogen as a function of the electron's emission direction with respect to the molecular axis. Moreover, we prepare two spatially separated atoms from a single oxygen molecule. We probe this pair of atoms on femtosecond time scales and show that the valence electrons of the two atoms are entangled [5].

References:
[1] S. Eckart et al. Nat. Phys. 14, 701 (2018)
[2] S. Eckart et al. Phys. Rev. Lett. 121, 163202 (2018)
[3] S. Eckart, Phys. Rev. Research 2, 033248 (2020)
[4] D. Trabert et al. Nat. Commun. 12, 1697 (2021)
[5] S. Eckart et al. arXiv:2108.10426

Prize Talk SYAS 1.4 Tue 16:05 E415

All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers — •Marvin Edelmann — Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany — Department of Physics, Universität Hamburg, Jungiusstr. 9, 20355 Hamburg, Germany — Laureate of the Georg-Simon-Ohm-Prize 2023

Optical pulse trains with ultra-low intensity noise are highly desirable for a variety of cutting-edge scientific and industrial applications including nonlinear microscopy, frequency-metrology, and photonic microwave generation.

In this work, new investigations regarding all-optical noise suppressing mechanisms in state-of-the-art Kerr-type fiber oscillators and amplifiers are presented. The highly efficient noise-transfer dynamics resulting from the nonlinear interaction of input intensity fluctuations with artificial transmission-functions enable the construction of versatile ultrafast laser systems with quantum-limited noise performance and ultra-stable laser working points.

The underlaying mechanism is further generalized to show that self-amplitude modulation with saturable absorbers, the physical effect fundamentally enabling the generation of ultrashort laser pulses via mode-locked steady-states, inevitably results in strong intra-pulse intensity noise shaping. Resulting intra-pulse noise distributions of an ultrafast laser system are utilized to demonstrate shot-noise limited intensity noise suppression via tailored optical filtering.

Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit (SYCC)
A symposium in honour of Prof. Dr. Eberhard Tiemann.

jointly organised by
the Quantum Optics and Photonics Divisions (Q),
the Atomic Physics Division (A),
the Mass Spectrometry Division (MS),
the Molecular Physics Division (MO), and
the Quantum Information Division (QI)

Silke Ospelkaus
Leibniz Universität Hannover
silke.ospelkaus@iqo.uni-hannover.de

In this symposium, we would like to honor Professor Eberhard Tiemann's scientific work. Professor Tiemann has dedicated almost his entire scientific career to precision molecular spectroscopy of small molecules which extended to the dissociation threshold. This has laid the foundations for precision control of ultracold atomic collisions and atomic interactions and has been the key for numerous exciting experiments with ultracold atomic quantum gases ranging from precision control of atomic interactions for the realization of precise atomic clocks to the observation of novel many-body phases. Furthermore, it has opened the route for the preparation of ultracold gases of diatomic molecules with a vast field of new applications in chemistry and physics.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Sessions

SYCC 1.1–1.4	Thu	11:00–13:00	E415	**From Molecular Spectroscopy to Collision Control at the Quantum Limit**

Sessions

– Invited Talks –

SYCC 1: From Molecular Spectroscopy to Collision Control at the Quantum Limit

Time: Thursday 11:00–13:00 Location: E415

Invited Talk SYCC 1.1 Thu 11:00 E415

The unity of physics: the beauty and power of spectroscopy — •Paul Julienne — Joint Quantum Institute, NIST and the University of Maryland, College Park, Maryland, USA

Physics exhibits a deep unity across all its disciplines. This is nowhere so evident as in the power of spectroscopy, the highly specific frequency-dependent interaction of light with matter, to inform us about a wide range of phenomena. We rightly honor Professor Eberhard Tiemann for his beautiful applications of molecular spectroscopy to essential science needed for ultracold matter studies that have come to span many areas of physics. His work on molecular potentials has enabled highly predictive models to be developed for the interactions of many magnetically and optically controllable ultracold atoms. Precise knowledge of these interactions has been a key to the success of the multidisciplinary reach of experiments involving cold atoms and molecules. I will illustrate this for two cases related to ultracold chemistry: the production of cold ground state molecules and the understanding of product distributions in three-body recombination of cold atoms.

Invited Talk SYCC 1.2 Thu 11:30 E415

Using high-resolution molecular spectroscopy to explore how chemical reactions work — •Johannes Hecker Denschlag — Institut für Quantenmaterie, Universität Ulm

Understanding in detail chemical reactions which involve three or more atoms is still a major challenge. Our group has developed experimental and theoretical methods which allow for gaining novel insights in ultracold few-body reactions. These methods are based on a state-to-state chemistry approach and rely heavily on high-resolution molecular spectroscopy. In my talk I will give an overview of our research on three-body recombination of ultracold Rb atoms. This will include recent results where we have found a propensity rule for spin conservation and a universal scaling law for the molecular production rate.

Invited Talk SYCC 1.3 Thu 12:00 E415

Monitoring ultracold collisions with laser light — •Olivier Dulieu — Laboratoire Aime Cotton, CNRS, Paris-Saclay University, Orsay, France

Quantum gases of ultracold molecules are considered as an attractive platform for future developments in quantum information and quantum simulation. A full control of the molecules is a prerequisite for such applications, which is presently hindered in the ongoing experiments by loss processes assigned to the so-called sticky collisions. Happily, laser light offers opportunities for an exquisite monitoring of the interactions between molecules, to prevent them from colliding with each other. Based on the accurate knowledge of their spectrocopy, I will report on a novel proposal for a two-photon scheme which induces an effective optical shielding of interactions at large distances, while avoiding the heating of the molecular quantum gas by off-resonant photon scattering. I will argue about the advantages of this proposal with respect to previously proposed approaches like microwave shielding. This work is performed in collaboration with M. Meyer, L. Karpa, S. Ospelkaus at LHU, C. Karam, R. Vexiau, N. Bouloufa in Orsay, and M. Lepers (Dijon, F).

Invited Talk SYCC 1.4 Thu 12:30 E415

The birth of a degenerate Fermi gas of molecules — •Jun Ye — JILA, NIST and Univ Colorado, Boulder, Colorado, USA

It is an honor to help celebrate the scientific legacy of Prof. Eberhard Tiemann. Prof. Tiemann played an important role during the early stages of the first experiment in producing a high phase-space density gas of polar molecules in the absolute ground state. The experiment was jointly performed with my late colleague Prof. Deborah Jin in 2008.

In 2018 we finally produced the first degenerate Fermi gas of polar molecules, with 30,000 KRb molecules and T/T_F of 0.3. A precisely controlled electric field is applied to tune the elastic dipolar interaction by orders of magnitude while suppressing reactive losses. Efficient dipolar evaporation leads to the onset of quantum degeneracy in two-dimensional optical traps. The electric field tuning of the rotational energy also produces sharp collision resonances, giving rise to three orders-of-magnitude modulation of the chemical reaction rate, and permitting dipolar evaporative cooling in 3D. The precise control of electric field has also allowed us to prepare and address isolated, individual two-dimensional layers of molecules with arbitrary choices of rotational state. We study exchanges of rotational angular momenta between molecules of neighboring layers through long-range dipolar interactions, demonstrating quantum-state engineered stereo chemical reaction. Meanwhile, these interacting molecules in 2D were used to realize a tunable spin Hamiltonian for quantum magnetism.

Symposium Precision Physics with highly Charged Ions (SYHC)

jointly organised by
the Mass Spectrometry Division (MS),
the Atomic Physics Division (A), and
the Molecular Physics Division (MO)

Klaus Blaum
Max-Planck-Institut für Kernphysik
Saupfercheckweg 1
69117 Heidelberg
klaus.blaum@mpi-hd.mpg.de

Yury A Litvinov
GSI Helmholtzzentrum für
Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt
y.litvinov@gsi.de

Thomas Stöhlker
Helmholtz-Institut Jena
Fröbelstieg 3
07743 Jena
t.stoehlker@hi-jena.gsi.de

Precision studies with highly charged ions are in the focus of several research fields as they provide conditions inaccessible in neutral atoms. For example, enormous electromagnetic field strengths, which a bound electron experiences in a heavy ion, allow for precision tests of quantum electrodynamics. In the absence of bound electrons, nuclear decay modes can significantly differ from the ones known in neutral atoms. In astrophysical plasmas, atoms are as a rule highly ionized. This symposium aims at discussing the most recent advances in experimental and theoretical investigations with highly charged ions in the realm of the atomic physics, nuclear structure, astrophysics and applications.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYHC 1.1	Mon	11:00–11:30	E415	**First experiments at CRYRING@ESR** — •Esther Babette Menz, Michael Lestinsky, Håkan Danared, Claude Krantz, Zoran Andelkovic, Carsten Brandau, Angela Bräuning-Demian, Svetlana Fedotova, Wolfgang Geithner, Frank Herfurth, Anton Kalinin, Ingrid Kraus, Uwe Spillmann, Gleb Vorobyev, Thomas Stöhlker
SYHC 1.2	Mon	11:30–12:00	E415	**Testing quantum electrodynamics in the simplest and heaviest multi-electronic atoms** — •Martino Trassinelli
SYHC 1.3	Mon	12:00–12:30	E415	**Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings** — •Beatriz Jurado
SYHC 1.4	Mon	12:30–13:00	E415	**Laboratory X-ray Astropohysics with Trapped Highly Charged Ions at Synchrotron Light Sources** — •Sonja Bernitt
SYHC 2.1	Mon	17:00–17:30	E415	**Observation of metastable electronic states in highly charged ions by Penning-trap mass spectrometry** — •Kathrin Kromer, Menno Door, Pavel Filianin, Zoltán Harman, Jost Herkenhoff, Paul Indelicato, Christoph H. Keitel, Daniel Lange, Chunhai Lyu, Yuri N. Novikov, Christoph Schweiger, Sergey Eliseev, Klaus Blaum
SYHC 2.2	Mon	17:30–18:00	E415	**Towards extreme-ultraviolet optical clocks** — •José R. Crespo López-Urrutia
SYHC 2.3	Mon	18:00–18:30	E415	**Coupling atomic and nuclear degrees of freedom in highly charged ions** — •Adriana Pálffy
SYHC 2.4	Mon	18:30–19:00	E415	**Laser Spectroscopy at the Storage Rings of GSI/FAIR** — •Wilfried Nörtershäuser

Sessions

SYHC 1.1–1.4	Mon	11:00–13:00	E415	**Highly Charged Ions for Atomic, Nuclear and Astrophysics**
SYHC 2.1–2.4	Mon	17:00–19:00	E415	**Intersection of the Electron-Shell and Nuclear Degrees of Freedom**

Sessions

– Invited Talks –

SYHC 1: Highly Charged Ions for Atomic, Nuclear and Astrophysics

Time: Monday 11:00–13:00 Location: E415

Invited Talk SYHC 1.1 Mon 11:00 E415

First experiments at CRYRING@ESR — •Esther Babette Menz[1,2,3], Michael Lestinsky[1], Håkan Danared[4], Claude Krantz[1], Zoran Andelkovic[1], Carsten Brandau[1,5], Angela Bräuning-Demian[1], Svetlana Fedotova[1], Wolfgang Geithner[1], Frank Herfurth[1], Anton Kalinin[1], Ingrid Kraus[1], Uwe Spillmann[1], Gleb Vorobyev[1], and Thomas Stöhlker[1,2,3] for the SPARC-Collaboration — [1]GSI, Darmstadt — [2]Helmholtz-Institut Jena — [3]IOQ, Friedrich-Schiller-Universität Jena — [4]European Spallation Source, Lund — [5]I. Phys. Institut, Justus-Liebig-Universität Giessen

After its move from Stockholm and successull commissioning at its new site at GSI, CRYRING@ESR is now in operation and able to accept previously inaccessible ion species available from the accelerator complex as well as a smaller selection from a local injector. As a user facility is serves experiments on nuclear and atomic physics proposed through the SPARC collaboration as well as material science experiments at the newly installed extraction beamline. In the last few years a number of new experimental setups have been installed, tested and used for first experiments. These include a dielectronic recombination setup as well as a microcalorimeter-based X-ray spectroscopy setup that make use of the ultracold electron cooler to perform merged-beam experiments and a gas jet target for atomic collisions in the experimental section. We will give an overview of the setup and the progress in recent years, present data from the first experiments and take a look at the plans for upcoming beamtime periods.

Invited Talk SYHC 1.2 Mon 11:30 E415

Testing quantum electrodynamics in the simplest and heaviest multi-electronic atoms — •Martino Trassinelli for the SPARC-Collaboration — CNRS, Institut des NanoSciences de Paris, Paris, France

Transition energy measurements in heavy, few-electron atoms allow to test bound-state QED in extremely high Coulomb fields, which enhance the impact of the quantum vacuum fluctuations on the atomic energies. Up to now, experiments have been unable to achieve sensitivity to higher-order QED effects in extremely strong fields. Here we present a novel multi-reference method based on Doppler-tuned x-ray emission from stored Uranium ions with different charge states. By performing high-accuracy x-ray spectroscopy of two, three, and four electron uranium ions in the same measurement campaign, we could obtain the absolute energy of the $1s_{1/2}2p_{3/2} \rightarrow 1s_{1/2}2s_{1/2}$ transition with an accuracy of 0.17 eV, a factor of six improvement over previous measurement. This allows to be sensitive to two-loop quantum electrodynamics effects in heavy highly charged ions. Furthermore, by comparing the transition energy in helium-like uranium transition to similar transitions in lithium-like and beryllium-like uranium, the contribution of electron-electron interaction, i.e. two-electron QED, in heavy bound systems could be disentangled from the one-electron QED contributions and from the uncertainty related to the nuclear radius. This result excludes a number of the most-accurate state-of-the-art theoretical predictions and represents a new paradigm for precision tests of bound-state QED.

Invited Talk SYHC 1.3 Mon 12:00 E415

Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings — •Beatriz Jurado — LP2i, Bordeaux, France

Obtaining reliable cross sections for neutron-induced reactions on unstable nuclei nuclei is crucial to our understanding of the stellar nucleosynthesis of heavy elements and for applications in nuclear technology. However, the measurement of these cross sections is very complicated, or even impossible, due to the radioactivity of the targets involved. The NECTAR (Nuclear rEaCTions At storage Rings) project aims to circumvent this problem by using the surrogate-reaction method in inverse kinematics at heavy-ion storage rings, which offer unique and largely unexplored possibilities for the study of nuclear reactions. In this talk, I will present the setup and the new methodology, which we are developing within NECTAR to perform high-precision surrogate-reaction experiments at the heavy-ion storage rings of the GSI/FAIR facility. In particular, I will present the first results of the proof of principle experiment, which we successfully conducted in June 2022 at the ESR storage ring of GSI/FAIR.

Acknowledgement: This work is supported by the European Research Council (ERC) under the European Union Horizon 2020 research and innovation program (ERC-Advanced grant NECTAR, grant agreement No 884715).

Invited Talk SYHC 1.4 Mon 12:30 E415

Laboratory X-ray Astropohysics with Trapped Highly Charged Ions at Synchrotron Light Sources — •Sonja Bernitt — Helmholtz-Institut Jena, Germany — GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

The newest generation of high-resolution UV and X-ray spectroscopic instruments onboard current and future satellite observatories has the potential to uncover previously inaccessible details of processes in astrophysical plasmas, such as the ones found in galaxy clusters and in the proximity of active galactic nuclei. This is essential for advancing our understanding of extreme environments and the evolution of the universe.

However, what can be reconstructed from spectra is currently limited by the availability and quality of atomic data, which are the basis for plasma models. That is especially the case for highly charged ions (HCI), ubiquitous in hot astrophysical environments. Laboratory measurements are necessary to provide atomic data, like transition energies, as well as rates of excitation and ionization processes.

Here, work with electron beam ion traps (EBITs) is presented, in which radiation from ultrabrilliant UV and X-ray synchrotron light sources is used to resonantly excite electronic transitions in trapped HCI. Subsequent fluorescence and changes in ion charge state are detected, allowing to gather spectroscopic data, reaching unprecedented resolving powers and signal-to-noise ratios. This has led to a variety of new insights into questions related to astrophysics.

SYHC 2: Intersection of the Electron-Shell and Nuclear Degrees of Freedom

Time: Monday 17:00–19:00 Location: E415

Invited Talk SYHC 2.1 Mon 17:00 E415

Observation of metastable electronic states in highly charged ions by Penning-trap mass spectrometry — •Kathrin Kromer[1], Menno Door[1], Pavel Filianin[1], Zoltán Harman[1], Jost Herkenhoff[1], Paul Indelicato[2], Christoph H. Keitel[1], Daniel Lange[1], Chunhai Lyu[1], Yuri N. Novikov[1], Christoph Schweiger[1], Sergey Eliseev[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, — [2]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, Paris, France

The vast landscape of transitions in highly charged ions including transitions in the optical and the extreme ultraviolet (XUV) regime offer up the opportunity for next generation clock research. Thanks to the rapid advances in the development of frequency combs, the XUV spectral range has become accessible for spectroscopy. However, the search for suitable clock transitions, e.g. involving long-lived metastable electronic states, usually relies heavily on complicated atomic structure calculations. With the mass spectrometer Pentatrap, we have found a new way to measure metastable state energies without actively driving the transition and therefore being independent of theoretical predictions. We use the metastable states populated during the ion production inside an electron beam ion trap (EBIT) and measure their mass difference to the ground state in a Penning-trap mass spectrometer. With this method we have detected a metastable state in lead and measured its energy as a mass difference of just 30.X(0.6) eV on top of the mass of the lead nuclei of ≈194 GeV, making it the most precise mass determination to date with a relative uncertainty of 3×10^{-12}.

Invited Talk SYHC 2.2 Mon 17:30 E415

Towards extreme-ultraviolet optical clocks — •José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik

Frequency metrology with optical clocks has become a key tool for novel fundamental physics studies using atomic systems. Its outstanding resolution, reproducibility and accuracy makes it in principle capable of sensing effects of all Standard Model interactions on the frequency of electronic transitions, such as, e. g., a variation of the fine-structure constant. Disentangling the different sources of the underlying modifications of the electronic wave function is thereby crucial. For this, it is necessary to change the neutron number as well as the overlap of the electronic wave function with that of the nucleus in a well-defined way, as in the generalized King-plot method [1]. Isoelectronic and isonuclear sequences of highly charged ions (HCI) offer a plethora of possibilities in this regard [2], since they possess many different types of exceptionally long-lived metastable states up to x-ray energies. The development of an optical clock based on HCI [3] show the promise from an extension of frequency metrology beyond the optical range. For this purpose, we are preparing an experiment combining an extreme-ultraviolet frequency comb based on high-harmonic-generation [4] with a superconducting radio-frequency trap [5].

[1] Berengut, J. C., et al., Rev. Res. 2, 043444 (2020)
[2] Kozlov, M. G., et al., Rev. Mod. Phys. 90, 045005 (2018)
[3] King, S.A., et al., Nature 611, 43 (2022)
[4] Nauta, J., et al., Opt. Express 29, 2624 (2021)
[5] Stark J., et al., Rev. Sci. Instrum. 92, 083203 (2021)

Invited Talk SYHC 2.3 Mon 18:00 E415

Coupling atomic and nuclear degrees of freedom in highly charged ions — •Adriana Pálffy — Institut für Theoretische Physik und Astrophysik, Universität Würzburg

Nuclear transitions of low energy can couple efficiently to the atomic shell in a variety of processes such as internal conversion, its inverse process nuclear excitation by electron capture or electronic bridge. The talk will illustrate two such examples involving highly charged ions.

First, the talk will follow theoretical developments on employing electronic bridge processes for the driving the nuclear clock transition in ^{229}Th [1]. This nucleus possesses the lowest known nuclear transition energy and promises a novel and unprecedently precise nuclear clock. The nuclear excited level is a metastable state with energy of 8.19(12) eV, allowing driving with vacuum-ultraviolet lasers. Second, we will discuss recent results for nuclear excitation by electron capture employing electron vortex beams whose wave function has been especially designed and reshaped on demand [2]. On the example of ^{93m}Mo, we show theoretically that the use of tailored electron vortex beams increases the depletion by 4 orders of magnitude compared to the spontaneous nuclear decay of the isomer.

[1] P. V. Bilous *et al.*, Phys. Rev. Lett. 124, 192502 (2020).
[2] Y. Wu *et al.*, Phys. Rev. Lett. 126, 162501 (2022).

Invited Talk SYHC 2.4 Mon 18:30 E415

Laser Spectroscopy at the Storage Rings of GSI/FAIR — •Wilfried Nörtershäuser — TU Darmstadt, Institut für Kernphysik, Schlossgartenstr. 9, 64289 Darmstadt — Helmholtz-Forschungsakademie Hessen für FAIR (HFHF), Campus Darmstadt, Schlossgartenstr. 9, 64289 Darmstadt

The availability of highly charged ions and the large Doppler shifts of relativistic beams make laser spectroscopy at storage rings an attractive tool to test strong-field QED as well as electron-electron correlations in few-body calculations. Laser light can also be used to address and analyze internal and external degrees of motion of the stored ions. An overview on recent results and activities in these fields at the GSI/FAIR storage rings ESR and CRYRING@ESR will be presented.

Symposium Molecules in Helium Droplets (SYHD)

jointly organised by
the Molecular Physics Division (MO) and
the Atomic Physics Division (A)

Alkwin Slenczka
Universität Regensburg
alkwin.slenczka@chemie.uni-regensburg.de

With four invited talks, SYHD reports on helium considering dimers up to nano-sized droplets, the latter empty, singly doped with molecules, with clusters via multiple particle doping, and ionized droplets, addressing quantum features such as vortices, quantum halos and Efimov states. Thereby, techniques such as coulomb explosion imaging, coherent diffractive imaging with X-FEL pulses, messenger spectroscopy of ions, and mass selected ion spectroscopy are applied as well as time dependent helium density functional theory.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYHD 1.1	Wed	11:00–11:30	E415	**Structure and field-induced dynamics of small helium clusters** — •Maksim Kunitski, Jan Kruse, Qingze Guan, Dörte Blume, Reinhard Dörner
SYHD 1.2	Wed	11:30–12:00	E415	**Coherent Diffraction Imaging of isolated helium nanodroplets and their ultrafast dynamics** — •Daniela Rupp
SYHD 1.3	Wed	12:00–12:30	E415	**Clustering dynamics in superfluid helium nanodroplets: A theoretical study** — •Nadine Halberstadt, Ernesto García Alfonso, Martí Pi, Manuel Barranco
SYHD 1.4	Wed	12:30–13:00	E415	**Messenger spectroscopy of molecular ions – Development of a new experimental setup** — •Elisabeth Gruber

Sessions

SYHD 1.1–1.4	Wed	11:00–13:00	E415	**Molecules in Helium Droplets**

Sessions

– Invited Talks –

SYHD 1: Molecules in Helium Droplets

Time: Wednesday 11:00–13:00 Location: E415

Invited Talk SYHD 1.1 Wed 11:00 E415

Structure and field-induced dynamics of small helium clusters — •Maksim Kunitski[1], Jan Kruse[1], Qingze Guan[2], Dörte Blume[2], and Reinhard Dörner[1] — [1]Institut für Kernphysik, Goethe-Universität Frankfurt am Main, Max-von-Laue-Straße 1, 60438 Frankfurt am Main, Germany — [2]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, 440 W. Brooks St., Norman, OK 73019, USA

Small helium clusters are peculiar few body quantum systems. The helium dimer has a single weakly bound state of a huge spatial extent. About 80% of its probability distribution resides in the classically forbidden tunnelling region. This is why such objects are termed “quantum halos”. The helium trimer has two bound states, one of which is of Efimov nature. We utilize laser-triggered Coulomb explosion imaging for measuring spatial probability distributions of these quantum objects. Application of an additional laser pulse in a pump-probe manner allows us to observe the structural response dynamics of small helium clusters to a strong laser field on a picosecond time scale.

The results of our experimental approach on He_2, He_3 and He_4 will be discussed.

Invited Talk SYHD 1.2 Wed 11:30 E415

Coherent Diffraction Imaging of isolated helium nanodroplets and their ultrafast dynamics — •Daniela Rupp — ETH Zurich

Isolated helium nanodroplets are used as ideal model systems for exploring light-matter interaction and provide fascinating possibilities to embed dopant atoms or molecules and study their arrangement and properties at ultracold temperatures. Via single-pulse single-particle coherent diffractive imaging (CDI) with the intense femtosecond pulses from short-wavelength free electron lasers (X-FELs) and high-harmonic generation (HHG) sources, it is possible to study single specimen in free flight. The elastically scattered photons form an interference pattern, encoding the particle's structure and the light-induced dynamics during and after pulsed laser excitation. In this presentation, an overview on the young and thriving field of helium nanodroplets in intense short-wavelength pulses will be given and recent results on their ultrafast changes in the electronic and geometric structure will be discussed.

Invited Talk SYHD 1.3 Wed 12:00 E415

Clustering dynamics in superfluid helium nanodroplets: A theoretical study — •Nadine Halberstadt[1], Ernesto García Alfonso[1], Martí Pi[2,3], and Manuel Barranco[2,3] — [1]LCAR, CNRS and Université Toulouse 3, F-31062 Toulouse, France — [2]Departament FQA, Facultat de Física, Universitat de Barcelona, Barcelona, Spain — [3]Institute of Nanoscience and Nanotechnology (IN[2]UB), Universitat de Barcelona, Barcelona, Spain

In this work we study the collision of heliophilic atoms with a superfluid helium droplet, followed by their solvation and clustering. We use time-dependent Helium density functional theory (^{4}He-TDDFT), which has proven to be the best compromise between accuracy and feasibility to study the stability and real time dynamics of doped helium droplets with a size comparable to experiments.

We also investigate the effect of the presence of a quantum vortex on the pickup and clustering process, in relation with the pioneering experiment by Vilesov's group which used atom doping to visualize quantum vortices.

Our simulations reveal rather surprising final cluster configurations, very different from the gas phase ones. This is due to the fast cooling property associated to superfluidity, which quenches metastable configurations, and to the high density shell building around each dopant atom which can prevent dopant-dopant bond formation.

They also reproduce the attractivity of dopant atoms to the vortex lines, with a cluster building along them but in a final configuration very different from the gas phase one.

Invited Talk SYHD 1.4 Wed 12:30 E415

Messenger spectroscopy of molecular ions – Development of a new experimental setup — •Elisabeth Gruber — Institute of Ion Physics and Applied Physics, Universität Innsbruck, A-6020 Innsbruck, Austria

Helium nanodroplets (HNDs) provide an inert matrix with outstanding properties to isolate diverse molecular ions, to grow complexes and clusters at sub-Kelvin temperature and to study the latter spectroscopically. Here, we present a newly developed experimental setup, which allows the formation of mass-selected and helium-tagged molecular ions, perfectly suitable for messenger-spectroscopy, by using HNDs instead of the commonly used RF-multipole trap technique. The setup combines an in-house-assembled helium nanocluster source with a commercially available quadrupole time-of-flight mass spectrometer. In the first step, HNDs are highly ionized by electron impact and afterwards doped with the molecules of interest. A gentle shrinking of the helium matrix of the doped HNDs by collisions with helium gas delivers helium-tagged molecular ions, detached from the helium droplets due to Coulomb repulsion. A subsequent quadrupole mass filter allows the selection of a specific dopant-helium-complex, which is then analysed spectroscopically. In contrast to previous studies, where the absorption spectra are predominantly obtained from the precursor ion depletion, the new setup enables the detection of the photoproduct from virtually zero background signal. This enables high quality spectra even for weak absorption lines at reduced data acquisition times. Recent results obtained with the new setup will be presented.

Symposium Machine Learning in Atomic and Molecular Physics (SYML)

jointly organised by
the Molecular Physics Division (MO) and
the Atomic Physics Division (A)

Andrej Yachmenev
Center for Free-Electron Laser Science
Deutsches Elektronen-Synchrotron DESY
Hamburg
andrey.yachmenev@cfel.de

Christof Weitenberg
Department of Physics
Universität Hamburg
cweitenb@physnet.uni-hamburg.de

Machine-learning tools are increasingly employed to assist challenging problems in natural sciences. In atomic and molecular physics this notably includes the solution of the electronic Schrödinger equation, efficient quantum state tomography, problems in quantum computing and quantum simulation, optimal control of atomic systems, and inverse problems in x-ray-diffraction imaging and spectroscopy. This symposium gathers experts from experiments and theory and aims to provide an overview of this rapidly growing topic.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYML 1.1	Tue	11:00–11:30	E415	**Imaging a complex molecular structure with laser-induced electron diffraction and machine learning** — •Katharina Chirvi, Xinyao Liu, Kasra Amini, Aurelien Sanchez, Blanca Belsa, Tobias Steinle, Jens Biegert
SYML 1.2	Tue	11:30–12:00	E415	**Physics-inspired learning algorithms for optimal shaping of atoms with light** — •Maximilian Prüfer
SYML 1.3	Tue	12:00–12:30	E415	**Machine-Learning assisted quantum computing and interferometry** — •Ludwig Mathey, Lukas Broers, Nicolas Heimann
SYML 1.4	Tue	12:30–13:00	E415	**Efficient quantum state tomography with convolutional neural networks** — •Moritz Reh, Tobias Schmale, Martin Gärttner

Sessions

SYML 1.1–1.4	Tue	11:00–13:00	E415	**Machine Learning in Atomic and Molecular Physics**

Sessions

– Invited Talks –

SYML 1: Machine Learning in Atomic and Molecular Physics

Time: Tuesday 11:00–13:00 Location: E415

Invited Talk SYML 1.1 Tue 11:00 E415

Imaging a complex molecular structure with laser-induced electron diffraction and machine learning — •Katharina Chirvi[1], Xinyao Liu[1], Kasra Amini[1], Aurelien Sanchez[1], Blanca Belsa[1], Tobias Steinle[1], and Jens Biegert[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]ICREA, Pg. Lluis Companys 23, 08010 Barcelona, Spain

Imaging a molecular structure with electron or X-ray diffraction relies on finding a global extremum in a multi-dimensional solution space. Laser-induced electron diffraction (LIED) is a powerful laser-based method that image the structure of a single gas-phase molecule with combined sub-atomic picometre and atto-to-femtosecond spatio-temporal resolution. In LIED, the structural information of the molecule is extracted from the coherently scattered electron wave packet, driven by an intense laser field after photoionization. However, retrieving the molecular geometry from a diffraction pattern becomes progressively difficult with increasing molecular structure and is a general challenge for any diffraction-based imaging technique. A machine learning (ML)-based approach is tailored to overcome this limitation since it achieves pattern matching in a complex solution space with high precision. We demonstrate the accurate retrieval of the three-dimensional structure of the chiral molecule Fenchone ($C_{10}H_{16}O$) by implementing LIED in combination with an ML algorithm. Our results show that ML-LIED provides new opportunities to determine the structure of large and complex molecules.

Invited Talk SYML 1.2 Tue 11:30 E415

Physics-inspired learning algorithms for optimal shaping of atoms with light — •Maximilian Prüfer — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Nowadays the high degree of control over optical potentials is key to many quantum simulations performed with ultracold atomic systems. In this talk I will show how arbitrary optical potentials can be created using, e.g., digital micromirror devices. Experimentally it is advantageous to optimize the desired potentials 'offline', that is not using the actual experiment but a digital twin trained using machine learning methods. In our new approach we use a physics-inspired model with few parameters combined with an iterative algorithm based on Iterative Learning Control. These methods allow for model-based 'offline' optimization as well as experimental feedback-based 'online' optimization which leads to an order of magnitude faster optimization compared to heuristic methods.

Invited Talk SYML 1.3 Tue 12:00 E415

Machine-Learning assisted quantum computing and interferometry — •Ludwig Mathey[1,2], Lukas Broers[1], and Nicolas Heimann[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

In this talk I will discuss our recent work on developing machine-learning based algorithms to control the complexity of technologies such as quantum computing and high-precision interferometry.

In the context of quantum machine learning, I will first discuss our work on mitigating barren plateaus. Barren plateaus present a challenge to efficient quantum machine learning which derives from vanishing gradients of the objective function. We point out that parametrizations that are non-local in time, such as a Fourier mode representation of the parameter space, can noticeably improve the performance. As a second objective in the context of quantum machine learning, I will discuss algorithmic implementations directly aimed at concrete experimental platforms, towards optimal quantum algorithm realizations.

In context of machine-learning assisted interferometry, I will present our work that demonstrates improved interferometer operation aimed towards gravitational wave detection. Here, a key challenge is the reduction of noise of the interferometer mirrors, in particular in-situ. I will discuss our demonstration of in-situ seismic noise reduction, and our way forward.

Invited Talk SYML 1.4 Tue 12:30 E415

Efficient quantum state tomography with convolutional neural networks — •Moritz Reh[1], Tobias Schmale[2], and Martin Gärttner[1,3,4] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Hannover, Welfengarten 1, 30167 Hannover — [3]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [4]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Capturing the properties of quantum many-body systems poses a major challenge from a theoretical standpoint, as both the task of numerical simulation as well as the characterization of an experiment from sparse data are suffering from the curse of dimensionality. Variational approaches based on neural networks have therefore become popular, mitigating the curse of dimensionality by searching for a solution in an artificially reduced space. We will motivate and introduce a particular class of such a scheme that allows to describe mixed states in spin systems, before showing its application to quantum state tomography (QST). We show an excellent representability of prototypical ground- and steady states with this ansatz using a number of variational parameters that scales polynomially in system size. This compressed representation allows us to reconstruct states with high classical fidelities outperforming standard methods such as maximum likelihood estimation of the full density matrix.

PhD-Symposium – Many-body Physics in Ultracold Quantum Systems (SYPD)

jointly organised by the Working Group "Young DPG" (AKjDPG)
supported by all divisions of the section AMOP

Mareike Hetzel
Institut für Quantenoptik
Leibniz Universität Hannover
Welfengarten 1
30167 Hannover
hetzel@iqo.uni-hannover.de

Bernd Meyer-Hoppe
Institut für Quantenoptik
Leibniz Universität Hannover
Welfengarten 1
30167 Hannover
b.meyer@iqo.uni-hannover.de

Exploring the fascinating properties of many-body quantum systems demands a well-controlled experimental platform. Because of their low temperature and good isolation from the environment, ultracold neutral atom systems excellently fulfill these requirements. In this session, we will explore a wide range of intriguing effects in these systems. We will look into supersolidity caused by long-range dipolar interactions and non-equilibrium phenomena. We will learn about quantum entanglement and how it can be employed for quantum simulation, where atoms can be used to model complex systems and simulate their behavior. Furthermore, we will discuss applications of ultracold quantum systems where atoms are collectively manipulated to measure real-world properties.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Sessions

SYPD 1.1–1.4	Thu	14:30–16:30	E415	**Many-body Physics in Ultracold Quantum Systems**

Sessions

– Invited Talks –

SYPD 1: Many-body Physics in Ultracold Quantum Systems

Time: Thursday 14:30–16:30 Location: E415

Invited Talk SYPD 1.1 Thu 14:30 E415

Entanglement and quantum metrology with microcavities — •Jakob Reichel — Laboratoire Kastler Brossel (ENS-PSL, SU, CRNS, CdF) Paris

Entanglement is at the heart of quantum science and technology, and is a key resource for quantum-enhanced precision measurement. In cold-atom systems, photon-mediated interactions in optical cavities are a particularly attractive platform for generating high-fidelity entangled states in a scalable way. This relatively new approach is rapidly gaining importance, with important advances being achieved in the last few years. I will try to give an overview of the different ways in which cavities can be used to create and detect entanglement, and discuss some recent advances, showing where we are on the way to entanglement-enhanced metrology-grade clocks and sensors. One of the factors driving the progress in this field is the advancement of optical cavity technology, and I will also highlight the progress of the fiber Fabry-Perot microcavities used in the work in our group.

Invited Talk SYPD 1.2 Thu 15:00 E415

Many-body physics in dipolar quantum gases — •Francesca Ferlaino — Institute for Experimental Physics, University of Innsbruck, Austria — Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Innsbruck, Austria

Brought to quantum degeneracy, ultracold gases enable the study of many-body quantum phenomena, in which the interaction between atoms can be so carefully mastered as to determine the very state of matter. Typically, this interaction has a short-range and isotropic nature, the latter meaning that the atoms globally attract or repel each other. However, there is another possibility that naturally emerges for some specific atomic species, such as erbium and dysprosium, featuring an extraordinarily large magnetic dipole moment. Magnetic properties give rise to dipolar many-body interactions, qualitatively very different from others in that they are long-range and anisotropic, thus adding connectivity and directionality at the quantum level.

In the present talk, we will retrace the fundamental steps in the study of dipolar gases, with emphasis on the Innsbruck results, from their creation to the new phenomena unveiled such as the emergence of rotonic excitations, so named by Landau, to the observation of a new and paradoxical state of matter with multiple spontaneous symmetry breaking, known as supersolid.

Invited Talk SYPD 1.3 Thu 15:30 E415

Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets — •Markus Greiner — Harvard University, Cambridge, Massachusetts, USA

Ultracold atoms in our quantum gas microscope offer a fascinating view of the quantum world. With quantum simulations we can experimentally realize and study quantum-mechanical model systems that are otherwise extremely difficult to compute on classical computers, but relevant to understanding real world quantum materials. I will present recent work on frustrated quantum magnets, fractional quantum Hall physics, and on dipolar physics.

Invited Talk SYPD 1.4 Thu 16:00 E415

Quantum gas in a box — •Zoran Hadzibabic — University of Cambridge

Ultracold atomic gases are used with great success to study fundamental many-body phenomena. While traditionally they were produced in harmonic traps and had inhomogeneous densities, one can now also create homogeneous samples using optical box traps [1,2]. This simplifies the interpretation of experiments, provides more direct connections with theory, and sometimes allows qualitatively new studies [2]. I will give an overview of our recent experiments with box-trapped Bose gases, focusing on non-equilibrium phenomena such as turbulence and evolution of far-from-equilibrium closed quantum systems [3-5].

[1] Bose-Einstein condensation of atoms in a uniform potential, A. L. Gaunt et al., Phys. Rev. Lett. 110, 200406 (2013).

[2] Review: Quantum gases in optical boxes, N. Navon, R. P. Smith, and Z. Hadzibabic, Nat. Phys. 17, 1334 (2021).

[3] Emergence of a turbulent cascade in a quantum gas, N. Navon, A. L. Gaunt, R. P. Smith, and Z. Hadzibabic, Nature 539, 72 (2016).

[4] Bidirectional dynamic scaling in an isolated Bose gas far from equilibrium, J. A. P. Glidden et al., Nat. Phys. 17, 457 (2021).

[5] Universal equation of state for wave turbulence in a quantum gas, L. H. Dogra et al., arXiv:2212.08652.

Symposium Quantum Optics and Quantum Information with Rigid Rotors (SYQR)

jointly organised by
the Quantum Information Division (QI),
the Quantum Optics and Photonics Division (Q), and
the Molecular Physics Division (MO)

Klaus Hornberger
Universität Duisburg-Essen

Melanie Schnell
Deutsches Elektronen-Synchrotron DESY
Hamburg

This symposium aims at highlighting the potential offered by the intrinsic anharmonicity and non-commutativity of quantum rigid rotor dynamics for future technologies. Note that the associated session MO18/Q52/QI33 takes place already on Thursday, 14:30–16:30, in F102.

Overview of Invited Talks and Sessions

(Lecture hall E415)

Invited Talks

SYQR 1.1	Fri	11:00–11:30	E415	**Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets** — •Henrik Stapelfeldt
SYQR 1.2	Fri	11:30–12:00	E415	**Quantum toolbox for molecular state spaces** — Eric Kubischta, Shubham Jain, Ian Teixeira, Eric R. Hudson, Wesley C. Campbell, Mikhail Lemeshko, •Victor V. Albert
SYQR 1.3	Fri	12:00–12:30	E415	**Coherent rotational state control of chiral molecules** — •Sandra Eibenberger-Arias
SYQR 1.4	Fri	12:30–13:00	E415	**Optically levitated rotors: potential control and optimal measurement** — •Martin Frimmer
SYQR 2.1	Fri	14:30–15:00	E415	**Rotational optomechanics with levitated nanodumbbells** — •Tongcang Li
SYQR 2.2	Fri	15:00–15:30	E415	**Quantum rotations of nanoparticles** — •Benjamin A. Stickler
SYQR 2.3	Fri	15:30–16:00	E415	**Quantum control of trapped molecular ions** — •Stefan Willitsch
SYQR 2.4	Fri	16:00–16:30	E415	**Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables** — •Monika Leibscher

Sessions

SYQR 1.1–1.4	Fri	11:00–13:00	E415	**Quantum Optics and Quantum Information with Rigid Rotors 1**
SYQR 2.1–2.4	Fri	14:30–16:30	E415	**Quantum Optics and Quantum Information with Rigid Rotors 2**

Sessions

– Invited Talks –

SYQR 1: Quantum Optics and Quantum Information with Rigid Rotors 1

Time: Friday 11:00–13:00 Location: E415

Invited Talk SYQR 1.1 Fri 11:00 E415

Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets — •Henrik Stapelfeldt — Aarhus University, Aarhus, Denmark

Dimers of sodium or potassium, residing on the surface of helium nanodroplets, are set into rotation and vibration, through the dynamic Stark effect, by a moderately intense femtosecond pump pulse. Coulomb explosion of the dimers, induced by an intense, delayed femtosecond probe pulse, is used to record the time-dependent nuclear motion.

Concerning rotation, the measured alignment traces show a distinct, periodic structure that differs qualitatively from the well-known alignment dynamics of linear molecules in either the gas phase or dissolved in liquid helium. Instead, the observed alignment dynamics of Na2 and of K2 agree with that obtained from a 2D rigid rotor model, strongly indicating that the rotation of each dimer occurs in a plane, defined by the He droplet surface.

Concerning vibration, the Coulomb explosion probe method enables us to measure the distribution of internuclear distances as a function of time. For K2, we observe a distinct oscillatory pattern caused by a two-state vibrational wave packet in the initial electronic state of the dimer. The wave packet is imaged for more than 250 vibrational periods with a precision better than 0.1 Å on its central position and a resolution < 1 Å of its shape. Unlike the rotational motion, the vibration of the dimer is essentially unaffected by the presence of the He droplet.

Invited Talk SYQR 1.2 Fri 11:30 E415

Quantum toolbox for molecular state spaces — Eric Kubischta[1], Shubham Jain[1], Ian Teixeira[1], Eric R. Hudson[2], Wesley C. Campbell[2], Mikhail Lemeshko[3], and •Victor V. Albert[1] — [1]Joint Center for Quantum Information and Computer Science, NIST and University of Maryland, College Park, MD, USA — [2]UCLA Center for Quantum Science and Engineering & Department of Physics and Astronomy, Los Angeles, California, USA — [3]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Rotational states of symmetric- and asymmetric-top trapped molecules, modeled by infinite-dimensional Hilbert spaces of various quantized rigid bodies, present new opportunities for both the development of basic science and for the storage and processing of quantum information.

This work adapts basic quantum tools from established discrete- and continuous-variable systems to symmetric rigid bodies, developing a set of "position-state" labels for molecular orientations and a Pauli-type group of unitary operations. Our approach builds on the conjugate relationship between states of fixed angular momentum and fixed orientation and can be extended to incorporate nuclear spin.

We also study different types of noise present in molecular systems. We show that some noise can be highly non-local in the molecule's orientation-momentum "phase" space, characterizing instances where conventional (i.e., exact) error-correction can fail. We comment on the different strategies that can circumvent this no-go result.

Invited Talk SYQR 1.3 Fri 12:00 E415

Coherent rotational state control of chiral molecules — •Sandra Eibenberger-Arias — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany

Chiral molecules are ubiquitous in nature and they are of great importance in many biological and chemical processes. They are also at the center of some interesting fundamental physics questions, for example whether there is parity violation in chiral molecules, which has been long predicted but never experimentally observed.

I will present important recent experimental developments targeted at the understanding and the control of cold, chiral molecules in the gas phase. I will discuss enantiomer-specific state transfer (ESST) [1], an all-coherent method to populate a chosen rotational state preferentially with one enantiomer, providing a way of quantum-controlled chiral separation. In recent experiments [2,3], we realize increased control of chiral molecules. We employ a quantitative comparison between experiment and theory for the transfer efficiency of ESST. Straightforward extensions to our scheme will allow to create a molecular beam with an enantiomer-pure rotational level, holding great prospects for future spectroscopic and scattering studies.

[1] S. Eibenberger, J. Doyle, D. Patterson, Phys. Rev. Lett. 118, 123002 (2017) [2] A. O. Hernandez-Castillo, J. Bischoff, J. H. Lee, J. Langenhan, M. Karra, G. Meijer, and S. Eibenberger-Arias, Phys. Chem. Chem. Phys. 23, 7048-7056 (2021) [3] J. H. Lee, J. Bischoff, A. O. Hernandez-Castillo, B. Sartakov, G. Meijer, and S. Eibenberger-Arias, Phys. Rev. Lett. 128, 173001 (2022)

Invited Talk SYQR 1.4 Fri 12:30 E415

Optically levitated rotors: potential control and optimal measurement — •Martin Frimmer — Photonics Laboratory, ETH Zürich, Switzerland

Optically levitated nanoparticles have attracted significant attention recently and especially their rotational degrees of freedom offer exciting opportunities for sensing and quantum physics. The quantum control recently achieved for the center-of-mass motion of a levitated scatterer is to be extended to the orientational degrees of freedom of anisotropic scatterers. In this talk, we address the problem of optimally detecting the librational degrees of freedom of an anisotropic dielectric scatterer. Furthermore, we discuss a method to tune the conservative potential governing the librational degrees of freedom in an optical focus while keeping the center-of-mass motion trapped.

SYQR 2: Quantum Optics and Quantum Information with Rigid Rotors 2

Time: Friday 14:30–16:30 Location: E415

Invited Talk SYQR 2.1 Fri 14:30 E415

Rotational optomechanics with levitated nanodumbbells — •Tongcang Li — Purdue University, West Lafayette, USA

Thanks to its geometry, an optically levitated nanodumbbell is ideal for studying rotational optomechanics. We have synthesized and optically levitated silica nanodumbbells in a high vacuum. With a linearly polarized laser, we observed the torsional vibration (liberation) of a levitated nanodumbbell. With a circularly polarized laser, we drove a nanodumbbell to rotate beyond 1 GHz. We show an optically levitated nanodumbbell is an ultrasensitive torque detector. Recently, we levitated a nanodumbbell near a surface to study surface interactions.

Invited Talk SYQR 2.2 Fri 15:00 E415

Quantum rotations of nanoparticles — •Benjamin A. Stickler — University of Duisburg-Essen, Duisburg, Germany

Rotations of rigid bodies exhibit pronounced quantum phenomena that do not exist for their center-of-mass motion. By levitating nanoparticles in ultra-high vacuum, researchers are developing a promising platform for observing and exploiting these quantum effects in an unexplored mass and size regime [1]. This talk will discuss the prospects of observing orientational quantum revivals [2], quantum tennis racket flips [3], and spin-controlled interference [4] with nanoscale particles. I will review how rotational cooling into the quantum regime can be achieved [5] and how environmental decoherence impacts quantum experiments with nanoscale rotors [6].

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589 (2021) [2] Stickler, Papendell, Kuhn, Millen, Arndt, and Hornberger, New J. Phys. 20, 122001 (2018). [3] Ma, Khosla, Stickler, and Kim, Phys. Rev. Lett. 125, 053604 (2020). [4] Rusconi, Perdriat, Hétet, Romero-Isart, and Stickler, Phys. Rev. Lett. 129, 093605 (2022). [5] Schäfer, Rudolph, Hornberger, and Stickler, Phys. Rev. Lett. 126, 163603 (2021). [6] Stickler, Papendell, and Hornberger, Phys. Rev. A 94, 033828 (2016).

Invited Talk SYQR 2.3 Fri 15:30 E415

Quantum control of trapped molecular ions — •Stefan Willitsch — University of Basel, Department of Chemistry, Klingelbergstrasse 80, 4056 Basel, Switzerland

Molecules are quantum systems of prime significance in a variety of contexts ranging from physics over chemistry to biology. In spite of their importance, the development of quantum technologies for molecules has remained a long-standing challenge due to their complex energy-level structures. Trapped molecular ions are particular attractive in this context as it is possible to observe, manipulate and control single isolated molecules under precisely controlled conditions. In the talk, we will highlight new experimental methods for the detection, preparation and manipulation of the quantum states of single trapped molecular ions and discuss applications of these techniques in the realms of precision molecular spectroscopy, quantum science and chemistry.

Invited Talk SYQR 2.4 Fri 16:00 E415

Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables — •Monika Leibscher — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Berlin, Germany

Full quantum control over randomly oriented molecules requires complete breaking of the rotational symmetry by external fields. We present a graphical method to analyze the controllability of quantum asymmetric tops and determine the number, polarization and frequencies of the external fields which are required to fully control the rotational dynamics [1,2]. The results of the controllability analysis allow us to design pulse sequences which drive the molecules to the desired target states. We apply this strategy to observe and control chiral properties in randomly rotating molecules [1]. As an example, we discuss the creation of chiral wavepackets in achiral molecules. Planar molecules can become temporarily chiral upon coherent excitation of the out-of-plane vibration [3]. With the help of controllability analysis, we identify different excitation schemes that result in a net chiral signal and simulate the resulting ro-vibrational dynamics.

[1] M. Leibscher, E. Pozzoli, C. Pérez, M. Schnell, M. Sigalotti, U. Boscain, C. P. Koch, Commun. Phys. 5, 110 (2022). [2] E. Pozzoli, M. Leibscher, M. Sigalotti, U. Boscain and C. P. Koch, J. Phys. A: Math. Theor. 55, 215301 (2022). [3] D. S. Tikhonov, A. Blech, M. Leibscher, L. Greeman, M. Schnell, and C. P. Koch, Science Advances in press (2022).

Atomic Physics Division
Fachverband Atomphysik (A)

Thomas Fennel
Institut für Physik
Universität Rostock
Albert-Einstein-Straße 23
18059 Rostock
thomas.fennel@uni-rostock.de

Overview of Invited Talks and Sessions

(Lecture halls F107 and F303; Poster Empore Lichthof)

Invited Talks

A 3.1	Mon	11:00–11:30	F303	**Time-resolved Kapitza-Dirac effect** — •Kang Lin, Maksim Kunitski, Sebastian Eckart, Alexander Hartung, Qinying Ji, Lothar Schmidt, Markus Schöffler, Till Jahnke, Reinhard Dörner
A 6.1	Mon	17:00–17:30	F107	**Nonperturbative dynamics in heavy-ion-atom collisions** — •Pierre-Michel Hillenbrand, Siegbert Hagmann, Alexandre Gumberidze, Yury Litvinov, Thomas Stöhlker
A 7.1	Mon	17:00–17:30	F303	**Multi-frequency optical lattice for dynamic lattice-geometry control** — Marcel Kosch, •Luca Asteria, Henrik Zahn, Klaus Sengstock, Christof Weitenberg
A 10.1	Tue	11:00–11:30	F107	**Interaction of twisted light with a trapped atom: Interplay of electronic and motional degrees of freedom** — •Anton Peshkov, Yuriy Bidasyuk, Richard Lange, Tanja Mehlstäubler, Nils Huntemann, Ekkehard Peik, Andrey Surzhykov
A 13.1	Wed	11:00–11:30	F107	**Stability and Melting Dynamics of Mixed Species Coulomb Crystals with Highly Charged Ions** — •Luca Rüffert, Elwin Dijck, Tanja Mehlstäubler, José Crespo
A 14.1	Wed	11:00–11:30	F303	**Realization of the Periodic Quantum Rabi Model in the Deep Strong Coupling Regime with Ultracold Rubidium Atoms** — •Stefanie Moll, Geram Hunanyan, Johannes Koch, Enrique Rico, Enrique Solano, Martin Weitz
A 17.1	Wed	14:30–15:00	F107	**Adiabatic properties of the bicircular attoclock** — •Paul Winter, Manfred Lein
A 22.1	Thu	11:00–11:30	F107	**Efficient and accurate simulation of wide-angle single-shot scattering** — •Paul Tuemmler, Björn Kruse, Christian Peltz, Thomas Fennel
A 23.1	Thu	11:00–11:30	F303	**Trapping Ions and Ion Coulomb Crystals in a 1D Optical Lattice** — •Daniel Hoenig, Fabian Thielemann, Joachim Welz, Wei Wu, Thomas Walker, Leon Karpa, Amir Mohammadi, Tobias Schaetz
A 24.1	Thu	14:30–15:00	F107	**Intra-cavity photoelectron tomography with an intra-cavity velocity-map imaging spectrometer at 100 MHz repetition rate** — •Jan-Hendrik Oelmann, Tobias Heldt, Lennart Guth, Janko Nauta, Nick Lackmann, Valentin Wössner, Stepan Kokh, Thomas Pfeifer, José R. Crespo López-Urrutia
A 26.1	Thu	14:30–15:00	F303	**Laser spectroscopy of the heaviest elements with the RADRIS technique** — •Tom Kieck
A 28.1	Fri	11:00–11:30	F107	**Coherent multidimensional spectroscopy of an ultracold gas** — •Friedemann Landmesser, Tobias Sixt, Katrin Dulitz, Lukas Bruder, Frank Stienkemeier
A 29.1	Fri	11:00–11:30	F303	**An elementary network of entangled optical atomic clocks** — •Raghavendra Srinivas, Bethan Nichol, David Nadlinger, Peter Drmota, Dougal Main, Gabriel Araneda, Chris Ballance, David Lucas
A 30.1	Fri	14:30–15:00	F107	**Investigation of Molecular Ions as Sensitive Probes for Fundamental Physics** — •Carsten Zuelch, Konstantin Gaul, Robert Berger
A 31.1	Fri	14:30–15:00	F303	**Observation of vibrational dynamics in an ion-Rydberg molecule by a high-resolution ion microscope** — •Moritz Berngruber, Viraatt Anasuri, Yiquan Zou, Nicolas Zuber, Óscar Andrey Herrera Sancho, Ruven Conrad, Florian Meinert, Robert Löw, Tilman Pfau

Invited Talks of the joint Symposium Precision Physics with Highly Charged Ions

See SYHC for the full program of the symposium.

SYHC 1.1	Mon	11:00–11:30	E415	**First experiments at CRYRING@ESR** — •Esther Babette Menz, Michael Lestinsky, Håkan Danared, Claude Krantz, Zoran Andelkovic, Carsten Brandau, Angela Bräuning-Demian, Svetlana Fedotova, Wolfgang Geithner, Frank Herfurth, Anton Kalinin, Ingrid Kraus, Uwe Spillmann, Gleb Vorobyev, Thomas Stöhlker
SYHC 1.2	Mon	11:30–12:00	E415	**Testing quantum electrodynamics in the simplest and heaviest multi-electronic atoms** — •Martino Trassinelli
SYHC 1.3	Mon	12:00–12:30	E415	**Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings** — •Beatriz Jurado
SYHC 1.4	Mon	12:30–13:00	E415	**Laboratory X-ray Astropohysics with Trapped Highly Charged Ions at Synchrotron Light Sources** — •Sonja Bernitt
SYHC 2.1	Mon	17:00–17:30	E415	**Observation of metastable electronic states in highly charged ions by Penning-trap mass spectrometry** — •Kathrin Kromer, Menno Door, Pavel Filianin, Zoltán Harman, Jost Herkenhoff, Paul Indelicato, Christoph H. Keitel, Daniel Lange, Chunhai Lyu, Yuri N. Novikov, Christoph Schweiger, Sergey Eliseev, Klaus Blaum
SYHC 2.2	Mon	17:30–18:00	E415	**Towards extreme-ultraviolet optical clocks** — •José R. Crespo López-Urrutia
SYHC 2.3	Mon	18:00–18:30	E415	**Coupling atomic and nuclear degrees of freedom in highly charged ions** — •Adriana Pálffy
SYHC 2.4	Mon	18:30–19:00	E415	**Laser Spectroscopy at the Storage Rings of GSI/FAIR** — •Wilfried Nörtershäuser

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2023

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Invited Talks of the joint Symposium Machine Learning in Atomic and Molecular Physics

See SYML for the full program of the symposium.

SYML 1.1	Tue	11:00–11:30	E415	**Imaging a complex molecular structure with laser-induced electron diffraction and machine learning** — •Katharina Chirvi, Xinyao Liu, Kasra Amini, Aurelien Sanchez, Blanca Belsa, Tobias Steinle, Jens Biegert
SYML 1.2	Tue	11:30–12:00	E415	**Physics-inspired learning algorithms for optimal shaping of atoms with light** — •Maximilian Prüfer
SYML 1.3	Tue	12:00–12:30	E415	**Machine-Learning assisted quantum computing and interferometry** — •Ludwig Mathey, Lukas Broers, Nicolas Heimann
SYML 1.4	Tue	12:30–13:00	E415	**Efficient quantum state tomography with convolutional neural networks** — •Moritz Reh, Tobias Schmale, Martin Gärttner

Prize Talks of the joint Awards Symposium

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich
SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt
SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Invited Talks of the joint Symposium Molecules in Helium Droplets

See SYHD for the full program of the symposium.

SYHD 1.1	Wed	11:00–11:30	E415	**Structure and field-induced dynamics of small helium clusters** — •Maksim Kunitski, Jan Kruse, Qingze Guan, Dörte Blume, Reinhard Dörner
SYHD 1.2	Wed	11:30–12:00	E415	**Coherent Diffraction Imaging of isolated helium nanodroplets and their ultrafast dynamics** — •Daniela Rupp
SYHD 1.3	Wed	12:00–12:30	E415	**Clustering dynamics in superfluid helium nanodroplets: A theoretical study** — •Nadine Halberstadt, Ernesto García Alfonso, Martí Pi, Manuel Barranco
SYHD 1.4	Wed	12:30–13:00	E415	**Messenger spectroscopy of molecular ions – Development of a new experimental setup** — •Elisabeth Gruber

Invited Talks of the joint Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit

See SYCC for the full program of the symposium.

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Sessions

A 1.1–1.8	Mon	11:00–13:00	A320	**Quantum Technologies (joint session Q/A/QI)**
A 2.1–2.8	Mon	11:00–13:00	F107	**Collisions, Scattering and Correlation Phenomena**
A 3.1–3.7	Mon	11:00–13:00	F303	**Interaction with Strong or Short Laser Pulses I (joint session A/MO)**
A 4.1–4.8	Mon	11:00–13:00	F442	**Quantum Effects (QED) (joint session Q/A)**
A 5	Mon	13:15–14:00	F303	**Members' Assembly**
A 6.1–6.6	Mon	17:00–18:45	F107	**Precision Spectroscopy of Atoms and Ions I (joint session A/Q)**
A 7.1–7.7	Mon	17:00–19:00	F303	**Ultra-cold Atoms, Ions and BEC I (joint session A/Q)**
A 8.1–8.8	Mon	17:00–19:00	F342	**Quantum Technologies: Color Centers (joint session Q/A/QI)**
A 9.1–9.7	Tue	11:00–13:00	F102	**Ultrafast Dynamics I (joint session MO/A)**
A 10.1–10.7	Tue	11:00–13:00	F107	**Atomic Systems in External Fields**
A 11.1–11.7	Tue	11:00–12:45	F303	**Precision Spectroscopy of Atoms and Ions II (joint session A/Q)**
A 12.1–12.41	Tue	16:30–19:00	Empore Lichthof	**Poster I**
A 13.1–13.7	Wed	11:00–13:00	F107	**Highly Charged Ions and their Applications I**
A 14.1–14.7	Wed	11:00–13:00	F303	**Ultra-cold Atoms, Ions and BEC II (joint session A/Q)**
A 15.1–15.8	Wed	11:00–13:00	F102	**Precision Measurements: Atom Interferometry I (joint session Q/A)**
A 16.1–16.7	Wed	14:30–16:30	F102	**Molecules in Intense Fields and Quantum Control (joint session MO/A)**
A 17.1–17.6	Wed	14:30–16:15	F107	**Interaction with Strong or Short Laser Pulses II (joint session A/MO)**
A 18.1–18.8	Wed	14:30–16:30	F303	**Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)**
A 19.1–19.6	Wed	14:30–16:00	F428	**Ultra-cold Atoms, Ions and BEC III (joint session A/Q)**
A 20.1–20.32	Wed	16:30–19:00	Empore Lichthof	**Poster II**
A 21.1–21.8	Thu	11:00–13:00	F102	**Ultrafast Dynamics II (joint session MO/A)**
A 22.1–22.7	Thu	11:00–13:00	F107	**Atomic Clusters (joint session A/MO)**
A 23.1–23.7	Thu	11:00–13:00	F303	**Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)**
A 24.1–24.5	Thu	14:30–16:00	F107	**Interaction with Strong or Short Laser Pulses III (joint session A/MO)**
A 25.1–25.8	Thu	14:30–16:30	F142	**Cluster and Experimental Techniques (joint session MO/A)**
A 26.1–26.7	Thu	14:30–16:30	F303	**Precision Spectroscopy of Atoms and Ions III (joint session A/Q)**

A 27.1–27.40	Thu	16:30–19:00	Empore Lichthof	**Poster III**
A 28.1–28.6	Fri	11:00–12:45	F107	**Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)**
A 29.1–29.6	Fri	11:00–12:45	F303	**Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)**
A 30.1–30.7	Fri	14:30–16:30	F107	**Highly Charged Ions and their Applications II**
A 31.1–31.7	Fri	14:30–16:30	F303	**Ultra-cold Atoms, Ions and BEC V (joint session A/Q)**
A 32.1–32.8	Fri	14:30–16:30	F342	**Precision Measurements: Atom Interferometry II (joint session Q/A)**
A 33.1–33.6	Fri	14:30–16:00	B302	**Precision Spectroscopy of Atoms and Ions V (joint session A/Q)**
A 34.1–34.8	Fri	14:30–16:30	F102	**Ultrafast Dynamics III (joint session MO/A)**

Members’ Assembly of the Atomic Physics Division

Monday 13:15–14:00 F303

Sessions

– Invited Talks, Contributed Talks, and Posters –

A 1: Quantum Technologies (joint session Q/A/QI)

Time: Monday 11:00–13:00 Location: A320

See Q 1 for details of this session.

A 2: Collisions, Scattering and Correlation Phenomena

Time: Monday 11:00–13:00 Location: F107

A 2.1 Mon 11:00 F107

Scattering of twisted electron wave packets by crystals — •Sophia Strnat[1,2], Dmitry Karlovets[3], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [2]Technische Universität Braunschweig, Braunschweig, Deutschland — [3]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland

The transmission electron microscopes (TEM) is one of the main tools in material studies. Nowadays TEMs provide beam sizes down to the sub-angström scale [1]. Further, electron beams carrying non-zero angular momentum with energies up to few hundred keV can be produced. These so-called twisted electron beams posses a magnetic moment which allows for additional probing of magnetic properties of materials. We describe the twisted electrons as spacially localized wave packets to take the finite beam size in TEMs into account. In particular, we investigate the elastic scattering of a Bessel-Gaussian electron mode by graphene in a generalized Born approximation (developed in [2, 3]). We study the scattering of a 80 keV electron wave packet with a size ranging from 0.5 Å to 5 Å and show that a non-zero orbital angular momentum projection significantly alters the scattering pattern.

[1] P. E. Batson *et al.*, *Nature* **418**,617-620 (2002)
[2] D. V. Karlovets *et al.*, *Phys. Rev.* **A** 92, 052703 (2015)
[3] D. V. Karlovets *et al.*, *Phys. Rev.* **A** 95, 032703 (2017)

A 2.2 Mon 11:15 F107

Radiation-field-driven ionization in laser-assisted slow atomic collisions — •Andreas Jacob, Carsten Müller, and Alexander Voitkiv — Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf

It is generally assumed that for ionization processes, which occur in slow atomic collisions, the coupling of the colliding system to the quantum radiation field is irrelevant. We show [1], however, that – contrary to expectations – such a coupling can strongly influence ionization of a beam of atomic species A slowly traversing a gas of atomic species B excited by a weak laser field. Our results imply furthermore that the Breit interaction can, in fact, dominate over the Coulomb interaction at very low energies.

[1] A. Jacob, C. Müller, and A. B. Voitkiv, arXiv:2208.09812 (2022).

A 2.3 Mon 11:30 F107

Entanglement created in collisions governed by the Coulomb interaction — •Yimeng Wang, Karl P. Horn, and Christiane P. Koch — Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

Entanglement or inseparability is central to quantum physics. However, the test for separability can be rather hard to implement with increasing Hilbert space dimension, especially for entanglement in motional degrees of freedom where the von Neumann entropy as well as other quantum entropies are divergent or ill-defined. The goal of this work is to quantify the entanglement of the scattering between an electron and a proton, by calculating the momentum uncertainty of either particle, extending earlier work [1,2] on entanglement in low-energy hydrogen bound states. We inspect both Rydberg states and scattering states and evaluate the behavior of entanglement versus energy near zero, to study the analytical properties of the "spectrum of entanglement" across the ionization threshold. The quantification of entanglement for scattering states will provide a new perspective on quantum scattering states, and demonstrate the difference between the weakly-bound states, a flat continuum, and shape resonances.

[1] Paolo Tommasini, Eddy Timmermans and A. F. R. de Toledo Piza, Am. J. Phys. 66 881 (1998).
[2] Sofia Qvarfort, Sougato Bose and Alessio Serafini, New J. Phys. 22 093062 (2020).

A 2.4 Mon 11:45 F107

Calculations of Delbrück scattering to all orders in αZ — •Jonas Sommerfeldt[1,2], Vladimir Yerokhin[3], and Andrey Surzhykov[1,2] — [1]Physikalisch Technische Bundesanstalt, D-38116 Braunschweig, Germany — [2]Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [3]Max-Planck Institut für Kernphysik, D-69117 Heidelberg, Germany

Delbrück scattering is the process in which photons are elastically scattered by the electric field of an atomic nucleus via the production of virtual electron-positron pairs. It is one of the few non-linear quantum electrodynamical processes that can be observed experimentally [1] and, hence, testing the respective theoretical predictions serves as an important test of QED in strong electromagnetic fields. Despite the strong motivation for the theoretical analysis of Delbrück scattering, most of the previous studies have been limited to some approximation regarding the coupling between the virtual electron positron pair and the nucleus leading to large disagreements between theory and experiment for certain parameter regimes [2]. In this contribution, therefore, we present an efficient approach to calculate amplitudes for Delbrück scattering that accounts for the interaction with nucleus to all orders including the Coulomb corrections [3].

[1] M. Schumacher, Radiat. Phys. Chem. 56 (1999) 101-111
[2] P. Rullhusen et al., Z Physik A 293 (1979) 287-292
[3] J. Sommerfeldt et al., Phys. Rev. A 105 (2022) 02280

A 2.5 Mon 12:00 F107

First Dielectronic Recombination Measurements with Low-Charged Heavy Ions at the Cryogenic Storage Ring — •Leonard W. Isberner[1,2], Manfred Grieser[2], Robert von Hahn[2], Zoltán Harman[2], Ábel Kálosi[3,2], Christoph H. Keitel[2], Claude Krantz[4], Daniel Paul[3,2], Daniel W. Savin[3], Suvam Singh[2], Andreas Wolf[2], Stefan Schippers[1], and Oldřich Novotný[2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Gießen, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Columbia Astrophysics Laboratory, Columbia University, New York, NY, USA — [4]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Accurate plasma modeling, e.g. for astrophysical environments, requires detailed information on fundamental processes such as the recombination of free electrons with atomic ions. Although electron-ion recombination has been investigated in magnetic heavy ion storage rings over the past three decades, those studies were restricted to ions with low to moderate mass-to-charge ratios due to the relatively high residual gas pressure in magnetic storage rings. The electrostatic Cryogenic Storage Ring (CSR), located at the Max-Planck-Institut für Kernphysik in Heidelberg, provides excellent vacuum conditions and thus offers a unique environment for recombination studies with high mass-to-charge ratio ions. Here we report on the first recombination measurements with atomic ions at CSR. Our observations of resonant recombination features for Ne^{2+} and Xe^{3+} demonstrate the feasibility of atomic recombination studies with low-charged heavy ions at CSR.

A 2.6 Mon 12:15 F107

Hyperfine-induced effect on angular and polarization behaviors of the $K\alpha_1$ line following electron-impact excitation of He-like Tl^{79+} ions — •Zhongwen Wu[1,2,3], Ziqiang Tian[1], Jun Jiang[1], Chenzhong Dong[1], and Stephan Fritzsche[2,3,4] — [1]Northwest Normal University, P. R. China — [2]Helmholtz-Institut Jena, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany — [4]Friedrich-Schiller-Universität Jena, Germany

For atoms or ions with nonzero nuclear spin, the hyperfine interaction of nuclear magnetic moment with those of bound electrons leads to splitting of their fine-structure levels and, thus, affects their excitation and decay properties. In this contribution, we studied angular and polarization behaviors of the $K\alpha_1$ line following electron-impact excitation of He-like spin-1/2 Tl^{79+} ions using the multi-configurational Dirac-Fock method and relativistic distorted-wave theory. Special attention was paid to the effect of the hyperfine interaction on the behaviors. It was found that the hyperfine-induced effect depends dominantly on impact electron energy. For low energies close to the excitation threshold, the hyperfine interaction contributes to making the $K\alpha_1$ line more anisotropic and polarized.

In contrast, such an effect diminishes quickly with increasing energy and even vanishes at medium and high energies, which is rather different from the case of radiative electron capture. The present study is accessible at both electron-beam ion traps and ion storage rings and thus accurate angular or polarization measurements of the $K\alpha_1$ line at low energies are expected to probe the hyperfine interaction in highly charged few-electron ions.

A 2.7 Mon 12:30 F107

Search for Exotic Molecules in Rydberg Positronium-Neutral Atom Mixtures — •Milena Simić and Matthew Eiles — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The interaction between a Rydberg atom and a distant ground-state atom can bind the two atoms together into a long-range Rydberg molecule. The mechanism behind this interaction is the scattering of the low-energy Rydberg electron off of the ground-state atom. By replacing the Rydberg atom with Rydberg positronium, an additional interaction plays a role. This interaction, between the positron and the neutral atom, is also determined by low-energy scattering phase shifts, but now of the positron off of the ground state atom. These phase shifts, like those of electrons, have been computed for a variety of atoms. In this talk, we discuss the prospects of forming exotic long-range Rydberg molecules composed of both matter and antimatter. Compared to normal long-range Rydberg molecules, the replacement of the heavy atomic core with a positron brings new physics into play: the molecular bond is now determined by two scattering processes instead of one, the reduced mass of the molecule is very light, and the decay channel opened by annihilation could be significant.

A 2.8 Mon 12:45 F107

Berechnung der Ruhemassen von Elementarteilchen durch Polynome mit der Basis π — •Helmut Schmidt — LMU München

Lösungen der Schrödingergleichungen können in ein Polynom mit der Basis 2π transformiert werden. Für jedes Objekt ergibt die Energie als Polynom $E = r(t)(2\pi)^d + xy(t)(2\pi)^{d-1} + z(t)(2\pi)^{d-2}$. Jeder Koeffizient führt zu einer archimedische Spirale. Besitzen 2 Objekte und eine Beobachter einen gemeinsamen Schwerpunkt, können die Energien durch ein einziges Polynom in Beziehung gesetzt und berechnet werden. Die ganzzahligen Quantenzahlen r, xy, z und d bewirken einen Zusammenhalt und führen zu den vier fundamentalen Wechselwirkungen. Davon ist unser Weltbild, mit 3 isotropen Dimensionen x, y und z und Rotationen mit 2π, zu unterscheiden. Die Polynome werden durch einfache Operatoren (Addition) für die Parität, Zeit und Ladung umgeformt. Zahlreiche Rechnungen zu Elementarteilchen werden angeführt.

$m_{neutron}/m_e = (2\pi)^4 + (2\pi)^3 + (2\pi)^2 - (2\pi)^1 - (2\pi)^0 - (2\pi)^{-1} + 2(2\pi)^{-2} + 2(2\pi)^{-4} - 2(2\pi)^{-6} + 6(2\pi)^{-8} = 1838.6836611$

Ladungsoperator für alle Teilchen:
$\widehat{C} = -\pi + 2\pi^{-1} - \pi^{-3} + 2\pi^{-5} - \pi^{-7} + \pi^{-9} - \pi^{-12}$.

Protonenmasse:
$m_{proton} = m_{neutron} + \widehat{C} m_e = 1836.15267363 m_e$

Feinstrukturkonstante:
$1/\alpha = \pi^4 + \pi^3 + \pi^2 - 1 - \pi^{-1} + \pi^{-2} - \pi^{-3} + \pi^{-7} - \pi^{-9} - 2\pi^{-10} - 2\pi^{-11} - 2\pi^{-12} = 137.035999037$

Gravitationskonstante: $hGc^5 s^8/m^{10} \sqrt{\pi^4 - \pi^2 - 1/\pi - 1/\pi^3} = 1.00000$

A 3: Interaction with Strong or Short Laser Pulses I (joint session A/MO)

Time: Monday 11:00–13:00 Location: F303

Invited Talk A 3.1 Mon 11:00 F303

Time-resolved Kapitza-Dirac effect — •Kang Lin, Maksim Kunitski, Sebastian Eckart, Alexander Hartung, Qinying Ji, Lothar Schmidt, Markus Schöffler, Till Jahnke, and Reinhard Dörner — Goethe University

The Kapitza-Dirac effect describes that that an electron beam can be diffracted when passing through a light standing wave. In analogy to optical diffraction, the incident electron beam behaves like a wave, while the light standing wave plays the role of the grating. The Kapitza-Dirac effect serves as an optical diagnosis of the electron property in frequency domain. However, with the advent of pulsed laser technique, the ultrafast time information is imprinted in both the electron wavepacket and the light standing wave. It is totally unclear how an electron wavepacket will be diffracted by an ultrafast light standing wave. Here, a principle new phenomenon, termed as time-resolved Kapitza-Dirac effect, is discovered. We track the spatiotemporal evolution of an electron wavepacket diffracted by an ultrafast femtosecond (10-15 seconds) light standing wave. By scanning the time delay between the electron wavepacket and the standing wave, we observe so far unseen quantum interference effects. We show that the momentum spacing between diffraction peaks decreases continuously with the time delay increasing, which can be fractions instead of multiply integers of 2-photon momenta. The time-resolved Kapitza-Dirac effect can directly measure the chirp of the electron wavepacket optically.

A 3.2 Mon 11:30 F303

Laser-Driven Acceleration of Gold Ions — •Laura Desiree Geulig, Erin Grace Fitzpatrick, Maximilian Weiser, Veronika Kratzer, Vitus Magin, Masoud Afshari, Jörg Schreiber, and Peter G. Thirolf — Ludwig-Maximilians-Universität München

The efficient acceleration of gold ions is a first step towards the 'fission-fusion' reaction mechanism, which aims at investigating the rapid neutron capture process in the vicinity of the N=126 waiting point [1]. In our recent measurement at the PHELIX laser with a pulse length of 500fs, for the first time, the laser-based acceleration of gold ions above 7 MeV/u was demonstrated. Additionally, individual gold charge states were resolved with unprecedent resolution [2]. This has allowed the investigation of the role of collisional ionization using a developmental branch of the particle-in-cell simulation code EPOCH [3], showing a much better agreement of the simulated charge state distributions with the experimentally measured ones than when only considering field ionization. This work is continued at the Centre for Advanced Laser Applications (CALA), using the ATLAS3000 laser (800nm central wavelength, 25 fs pulse length).

[1] D. Habs et al., Appl. Phys. B 103, 471-484 (2011)
[2] F.H. Lindner et al., Sci. Rep. 12, 4784 (2022)
[3] M. Afshari et al., Sci.Rep. 12, 18260 (2022)

A 3.3 Mon 11:45 F303

Transfer learning and visualization of a convolutional neural network for recognition of the internuclear distance in a molecule from electron momentum distributions — •Nikolay Shvetsov-Shilovski and Manfred Lein — Leibniz Universität Hannover

We use a convolutional neural network (CNN) to retrieve the internuclear distance in the two-dimensional H_2^+ molecule ionized by an intense few-cycle laser pulse from the photoelectron momentum distributions [1]. We study the effect of the carrier-envelope phase on the retrieval of the internuclear distance with a CNN [2]. By using the transfer learning technique, we make our CNN applicable to momentum distributions obtained at the parameters it was not explicitly trained for. We compare the CNN with alternative approaches that are shown to have very limited transferability. Finally, we use the occlusion sensitivity technique to extract features of the momentum distributions that allow a CNN to predict the internuclear distance.

[1] N. I. Shvetsov-Shilovski and M. Lein, Phys. Rev. A, 105, L021102 (2022).
[2] N. I. Shvetsov-Shilovski and M. Lein, submitted to Phys. Rev. A, arXiv:2211.01210.

A 3.4 Mon 12:00 F303

Holographic Single-Shot Imaging and Reconstruction of ultrafast laser-driven dynamics in thin films — •Richard Altenkirch, Franziska Fennel, Christian Peltz, Thomas Fennel, and Stefan Lochbrunner — Institute of Physics, Universität Rostock, Germany

Well controlled laser material processing with a spatial resolution on the scale of the laser wavelength is significant to a large variety of both research and industrial applications. A full characterization of the spatial and temporal evolution of the ultrafast laser-induced plasma dynamics will be key to future developments in the respective fields. So far, the established diagnostic methods are mostly sensitive to the target absorption and luminescence. Here, we present an experimental and numerical approach based on coherent diffractive imaging (CDI), a technique well known from free particle characterization at XFEL's [1], also providing access to the phase delay caused by the target. In a two-color pump-probe experiment, a thin film is excited by a short pump pulse and the resulting plasma dynamics are imaged by a frequency doubled probe pulse. The corresponding complex near field behind the target is reconstructed from the recorded scattering image via a phase retrieval approach [2]. We also present a thorough characterization of the method and a first successful application to experimental data.

[1] H. Chapman et al., Nature Physics **2** 839-843 (2006)
[2] J. Fienup, Appl. Opt. **21**, 2758-2769 (1982)

A 3.5 Mon 12:15 F303

Modeling controlled sub-wavelength plasma formation in dielectrics — •Jonas Apportin, Christian Peltz, Björn Kruse, Benjamin Liewehr, and Thomas Fennel — Institute for Physics, Rostock, Germany

Laser induced damage in dielectrics due to short pulse excitation plays a major role in a variety of scientific and industrial applications, such as the preparation of 3D structured evanescently coupled waveguides [1]. Here the irreversible modifications originate from higher order nonlinearities like strong field ionization and plasma formation. Improving user control over these material modifications, e.g. permanent refractive index modifications, therefore strongly relies on a better understanding of the underlying interaction dynamics, in particular the early phases of interaction. To this end we developed and utilized a numerical model, that combines a local description of the dynamics in terms of corresponding rate equations for ionization, collisions and heating with a fully electromagnetic field propagation via the Finite-Difference-Time-Domain method, adding self-consistent feedback effects like the sudden buildup of plasma mirrors. Here we present first numerical results regarding the creation and control of sub-wavelength gratings formed at the rear side of fused silica films.

[1] D. Blömer et al., Opt. Express 14, 2151-2157 (2006)

A 3.6 Mon 12:30 F303

Ultrafast two-electron correlations from metal needle tips — •Jonas Heimerl, Stefan Meier, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

When two electrons are emitted in a very confined space-time volume on the nanometer-femtosecond scale, strong Coulomb interaction is present. With the advent of multi-hit capable electron detectors, the field of ultrafast light matter interaction around metal needle tips is venturing into correlated multi-electron dynamics. Here we show the Coulomb-induced energy anti-correlation of two electrons emitted from nanometer-sized tungsten needle tips triggered by femtosecond laser pulses [1]. We extract two important key parameters: (1) the mean energy splitting of 3.3 eV and (2) the correlation decay time of 82 fs. Both parameters are essential for modern ultrafast electron microscopes, as shown in similar work from the Göttingen group [2]. We demonstrate that by filtering the electrons energetically, clear sub-Poissonian distributed electron beams can be achieved, highly relevant for beating the shot-noise limit in imaging applications. Furthermore, we show that in the strong field regime, where ponderomotive effects of the laser field become important, the anti-correlation gap is strongly influenced.

[1] S. Meier, J. Heimerl and P. Hommelhoff, arXiv:2209.11806 (2022)
[2] R. Haindl et al., arXiv:2209.12300 (2022)

A 3.7 Mon 12:45 F303

Testing Born's rule via photoionization of helium — •Peter Robert Förderer[1], David Busto[1,2], Anne L'Huillier[2], Andreas Buchleitner[1,3], and Christoph Dittel[1,3,4] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Department of Physics, Lund University, Box 118, 22100 Lund, Sweden — [3]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [4]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany

We propose a protocol to test Born's rule (a fundamental axiom of quantum mechanics) via the Sorkin test, applied to photoionization of helium, induced by the combination of an ultrashort extreme ultraviolet pulse with a trichromatic infrared laser pulse. We numerically simulate the outcome of the Sorkin test, the Sorkin parameter κ, for realistic parameters and randomly sampled, typical experimental imperfections. The latter do not only lead to a spread, but also to a systematic offset of κ from its ideal value $\kappa = 0$. A determination of κ with an achievable precision of the order $10^{-3} - 10^{-4}$ is predicted, which is comparable to the precision of 10^{-3} reached in the best optical experiments [Kauten, et. al., New J. Phys. 19, 033017 (2017)] in the quantum regime.

A 4: Quantum Effects (QED) (joint session Q/A)

Time: Monday 11:00–13:00 Location: F442

See Q 6 for details of this session.

A 5: Members' Assembly

Time: Monday 13:15–14:00 Location: F303

All members of the Atomic Physics Division are invited to participate.

A 6: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

Time: Monday 17:00–18:45 Location: F107

Invited Talk A 6.1 Mon 17:00 F107

Nonperturbative dynamics in heavy-ion-atom collisions — •Pierre-Michel Hillenbrand[1], Siegbert Hagmann[2], Alexandre Gumberidze[2], Yury Litvinov[2,3], and Thomas Stöhlker[2,4,5] — [1]Justus-Liebig-Univ., Giessen — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Ruprecht-Karls-Univ., Heidelberg — [4]Helmholtzinstitut Jena — [5]Friedrich-Schiller-Univ., Jena

Experimental data for atomic collisions of highly-charged ions are essential for benchmarking the theoretical description of dynamical processes in atomic physics. Of particular challenge is the accurate description of those processes that exceed the applicability of relativistic first-order perturbation theories. Recently, we have investigated two characteristic cases of such collision systems at the GSI heavy-ion accelerator. For collisions of U^{89+} projectiles with N_2 and Xe targets at 76 MeV/u, we studied the electron-loss-to-continuum cusp both experimentally and theoretically. We compared the continuum electron spectra of the two collision systems, which originate from the ionization of the projectile, and were able to identify a clear signature for the non-perturbative character of the collision systems [1]. Furthermore, we performed an x-ray spectroscopy experiment for slow collisions of Xe^{54+} and Xe^{53+} projectiles with a Xe target at 30 and 15 MeV/u. We analyzed the target $K\alpha$ satellite and hypersatellite lines to derive cross section ratios for double-to-single target K-shell vacancy production and compared the results to relativistic two-center calculations [2].

[1] Phys. Rev. A **104**, 012809 (2021)
[2] Phys. Rev. A **105**, 022810 (2022)

A 6.2 Mon 17:30 F107

High-precision hyperfine structure measurement of $^9Be^{3+}$ for tests of nuclear shielding theory — •Stefan Dickopf, Annabelle Kaiser, Marius Müller, Bastian Sikora, Zoltan Harman, Christoph Keitel, Stefan Ulmer, Andreas Mooser, and Klaus Blaum — Max-Planck Institute for Nuclear Physics, Heidelberg, Germany

Hyperfine structure (HFS) measurements on $^3He^{1+}$ in our Penning-trap setup have recently been used to determine the magnetic moment of its nucleus [1]. To use this value for high accuracy magnetic field measurements with ^{3}He-NMR-probes it has to be corrected for by a diamagnetic shielding due to the orbiting electrons. By measuring the HFS of $^9Be^{3+}$ and comparing it to measurements on $^9Be^{1+}$ we can test the theory of the diamagnetic shielding factor [2,3].

A determination of the g-factor of the nucleus with a precision of about 10^{-9} is planned, making a test of the diamagnetic shielding on the same level possible. Recent improvements to our setup and a high precision mass measurement carried out at the PENTATRAP experiment will further allow us to determine the bound electron g-factor of $^9Be^{3+}$ to a few parts in 10^{-11}, yielding an additional high-precision test of QED g-factor calculations [1].

[1] A. Schneider et al, Nature 606, 878-883 (2022)
[2] D. J. Wineland, J. J. Bollinger, and Wayne M. Itano, Phys. Rev. Lett. 50, 628-631 (1983)
[3] K. Pachucki and M. Puchalski, Optics Communication 283, 641-643 (2010)

A 6.3 Mon 17:45 F107

Hyperfine Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •C. M. König[1], F. Heisse[1], I. V. Kortunov[2], J. Morgner[1], T. Sailer[1], B. Tu[1,3], V. Vogt[2], K. Blaum[1], S. Schiller[2], and S. Sturm[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Institut für Experimentalphysik, Univ. Düsseldorf, 40225 Düsseldorf — [3]Institute of Modern Physics, Fudan University, Shanghai 200433

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. In the Penning-trap setup Alphatrap [1] we can perform high-precision spectroscopy on single MHI using non-destructive quantum state detection. Measurements on the hyperfine structure (HFS) of HD^+, allow us to extract the bound g factors of the constituent particles, as well as coefficients of the hyperfine hamiltonian. The latter can be compared with high-precision *ab-initio* theory and are important for a better understanding of rovibrational

spectroscopy performed on this ion, from which fundamental constants, such as m_p/m_e are determined to high precision [2].
We are currently extending our methods to single-ion rovibrational laser spectroscopy of MHI. The development of these techniques is one of the required steps towards spectroscopy of an antimatter $\overline{H_2^-}$ ion [3]. I will present an overview of our setup, measurement results of the HFS of HD^+ and first steps towards rovibrational laser spectroscopy.
[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] I. V. Kortunov, *et al.*, Nature Physics vol **17**, 569-573 (2021)
[3] E. Myers, Phys. Rev. A **98**, 010101(R) (2018)

A 6.4 Mon 18:00 F107

Probing a beyond standard model force via isotope shift spectroscopy in ultracold mercury — •Thorsten Groh, Felix Affeld, and Simon Stellmer — Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany

High precision spectroscopy of atomic isotope shifts could probe for a new beyond standard model (SM) force carrier that directly couples electrons and neutrons [Delaunay, PRD 96, 093001; Berengut, PRL 120, 091801], where signatures of such new particles would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

While latest spectroscopy of Ytterbium [Hur, PRL 128, 163201; Figueroa, PRL 128, 073001; Ono, PRX 12, 021033] down to the Hz-level already show strong deviations from linearity, it is hard to distinguish new physics from many SM effects like quadratic field shift and nuclear deformations.

Mercury is one of the heaviest laser-coolable elements with a core close to the lead nuclear shell closure, which suppresses nuclear deformations. It is an ideal platform for isotope spectroscopy possessing five naturally occurring bosonic isotopes, all of which we spectroscopically address in a magneto-optical trap. Our precision isotope shift spectroscopy in ultracold mercury on a total of five optical transitions combined with multidimensional King plot analysis show strong nonlinearities. We report on our latest improvements in the measurements and on new analysis of the nonlinearity origins.

A 6.5 Mon 18:15 F107

1s Hyperfine splitting in Muonic Hydrogen — •Siddharth Rajamohanan[1], Ahmed Ouf[1], and Randolf Pohl[2] — [1]QUANTUM, Institut für Physik & Exzellenzcluster PRISMA,Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany — [2]Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+, Johannes Gutenberg-Universität Mainz,55099 Mainz, Germany

Precision measurements on atoms and ions are a powerful tool for testing bound-state QED theory and the Standard Model [1]. Experiments done in the last decade by the CREMA collaboration on muonic Hydrogen and Helium have given a more accurate understanding of the lightest nuclei charge radius [2,3]. Our present experiment aims at a measurement of ground state Hyperfine Splitting in muonic hydrogen up to a relative accuracy of 1 ppm using pulsed laser spectroscopy. This allows us to determine the Zemach radius, which encodes the magnetic properties of the proton. A unique laser system, multi-pass cavity, and scintillation detection system are necessary for the experiment. We report the current status of our experiment and the recent developments.
[1] M. S. Safronova, D. Budker, D. DeMille, Derek F. Jackson Kimball, A. Derevianko, and Charles W. Clark, Rev. Mod. Phys. 90, 025008 (2018)
[2] R. Pohl et al., Nature 466, 213 (2010)
[3] A. Antognini, et al., Science, Vol. 339, 2013, pp. 417-420

A 6.6 Mon 18:30 F107

Ground-state hyperfine spectroscopy of $^3He^+$ in a Penning trap — •Marius Müller[1], Antonia Schneider[1], Bastian Sikora[1], Stefan Dickopf[1], Annabelle Kaiser[1], Natalia S. Oreshkina[1], Alexander Rischka[1], Igor A. Valuev[1], Stefan Ulmer[2], Jochen Walz[3,4], Zoltan Harman[1], Christoph H. Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Japan — [3]Helmholtz-Institut, Mainz, Germany — [4]Johannes Gutenberg Universität, Mainz, Germany

Hyperpolarized ^3He NMR magnetometers have intrinsically smaller systematic corrections than standard water NMR probes [1]. Therefore, they are an excellent candidate for high-precision absolute magnetometry in several experiments such as the muon g-2 experiments.

We measured the four ground-state hyperfine transition frequencies of a single $^3He^+$ ion, stored in the 5.7 T magnetic field of our cryogenic double Penning trap setup. From the spin-flip resonances the electronic and nuclear g-factors g_e and g_I, the zero-field hyperfine splitting E_{hfs}, as well as the Zemach radius r_Z were extracted with a relative precision of 220 ppt, 810 ppt, 30 ppt and 0.9 %, respectively [2]. This constitutes a direct calibration of ^3He NMR probes and an improvement of the precision by one order of magnitude compared to previous indirect measurements of the nuclear magnetic moment.
[1] Farooq et al., Phys. Rev. Lett. 124, 223001 (2020)
[2] Schneider et al., Nature 606, 878-883 (2022)

A 7: Ultra-cold Atoms, Ions and BEC I (joint session A/Q)

Time: Monday 17:00–19:00 Location: F303

Invited Talk A 7.1 Mon 17:00 F303

Multi-frequency optical lattice for dynamic lattice-geometry control — Marcel Kosch[1], •Luca Asteria[1,2], Henrik Zahn[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut für Laserphysik, Hamburg University — [2]The Hamburg Centre for Ultrafast Imaging — [3]Zentrum für Optische Quantentechnologien, Hamburg

Ultracold atoms in optical lattices are pristine model systems with a tunability and flexibility that goes beyond solid-state analogies. However, a fast change of the lattice geometry remains intrinsically difficult. Here we introduce a multi-frequency lattice for fast and flexible lattice-geometry control and demonstrate it for a three-beam lattice, realizing the full dynamical tunability between honeycomb lattice, boron-nitride lattice and triangular lattice on the microsecond scale, i.e., fast compared to the relevant energy scales. At the same time, the scheme ensures intrinsically high stability of the lattice geometry. We introduce the concept of a geometry phase as the parameter that fully controls the geometry and observe its signature as a staggered flux in a momentum space lattice. Tuning the geometry phase allows to dynamically control the sublattice offset in the boron-nitride lattice. We use a fast sweep of the offset to transfer atoms into higher Bloch bands, and perform a new type of Bloch band spectroscopy by modulating the sublattice offset. Finally, we generalize the geometry phase concept and the multi-frequency lattice to 3D optical lattices and quasi-periodic potentials. This scheme will allow novel Floquet and quench protocols to create and probe, e.g., topological properties.

A 7.2 Mon 17:30 F303

Sturdy and Compact Laser System for Cold Atom Experiments in BECCAL on the ISS — •Tim Kroh[1,2], Victoria Henderson[1,2], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hrudya Thaivalappil Sunilkumar[1], Hamish Beck[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jean Pierre Marburger[3], Faruk Alexander Sellami[3], Esther del Pino Rosendo[3], André Wenzlawski[3], Matthias Dammasch[2], Ahmad Bawamia[2], Andreas Wicht[2], Patrick Windpassinger[3], Achim Peters[1,2], and the BECCAL Team[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]DLR-SC — [5]DLR-SI — [6]DLR-QT — [7]IQ & IMS, LUH — [8]ILP, UHH — [9]ZARM, Bremen — [10]IQO, UULM

BECCAL (Bose-Einstein Condensate–Cold Atom Laboratory), a mul- ti-user facility designed for operation on the ISS, is a DLR and NASA collaboration built on the heritage of NASA's CAL, sounding rocket and drop tower experiments. Fundamental physics will be explored with Rb and K BECs and ultra-cold atoms in microgravity, at longer time- and ultra-low energy scales compared to those achieved on earth. The laser system design provides a reliable and robust combination of micro-integrated diode lasers (from FBH) and miniaturized free-space optics on Zerodur boards (from JGU), interconnected with fiber optics, to meet the unique challenge of matching the complexity of the required light fields to the stringent size, weight, and power limitations on the ISS. An update one the BECCAL laser system design will be given based on the requirements, concepts, and heritage which formed it. Funding by DLR / BMWK grant numbers 50 WP 2102, 2103, 2104.

A 7.3 Mon 17:45 F303

Observation of vortices and vortex stripes in a dipolar BEC of Dysprosium — •Lauritz Klaus[1,2], Thomas Bland[1,2], Elena Poli[2], Claudia Politi[1,2], Giacomo Lamporesi[3], Eva Casotti[1,2], Russell Bisset[2], Manfred Mark[1,2], and Francesca Ferlaino[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [2]Institut für Experimentalphysik, Universität Innsbruck, Austria — [3]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, Italy

Quantized vortices are a defining feature of superfluid systems under rotation and have been extensively investigated in ultracold atom experiments with isotropic contact interactions. However, they have never been observed in dipolar quantum gases. We here report on the creation of vortices in a strongly magnetic Bose-Einstein-Condensate (BEC) of ^{162}Dy atoms. We are imparting angular momentum to the BEC by the means of magnetostirring, a novel technique making use of the alignment of the dipolar atoms along the rotating magnetic field. We show that for a critical rotation frequency, the dipolar BEC starts to nucleate vortices and that the vortices arrange in stripes along the direction of the magnetic field during the rotations. The next key step will be extending the concept of magnetostirring to the recently observed supersolid states and study the vortex formation in this very exotic state of quantum matter.

A 7.4 Mon 18:00 F303

Optimizing optical potentials with physics-inspired learning algorithms — •Martino Calzavara[1,4], Yevhenii Kuriatnikov[2], Andreas Deutschmann-Olek[3], Felix Motzoi[1], Sebastian Erne[2], Andreas Kugi[3], Tommaso Calarco[1,4], Jörg Schmiedmayer[2], and Maximilian Prüfer[2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [3]Automation and Control Institute, TU Wien, Gußhausstraße 27-29, 1040 Vienna, Austria — [4]Institute for Theoretical Physics, Universität zu Köln, 50937 Cologne, Germany

We present our new experimental and theoretical framework which combines a broadband superluminescent diode (SLED/SLD) with fast learning algorithms to provide speed and accuracy improvements for the optimization of 1D optical dipole potentials, here generated with a Digital Micromirror Device (DMD). We employ Machine Learning (ML) tools to train a physics-inspired model acting as a digital twin of the optical system predicting the behavior of the optical apparatus including all its imperfections. Implementing an algorithm based on Iterative Learning Control (ILC), we optimize optical potentials an order of magnitude faster than heuristic optimization methods. We compare iterative model-based "offline" optimization and experimental feedback-based "online" optimization. Our methods provide a new route to fast optimization of optical potentials which is relevant for the dynamical manipulation of ultracold gases.

A 7.5 Mon 18:15 F303

A strontium quantum gas microscope with cavity-enhanced optical lattices — •Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Jan Trautmann[1,2], Sebastian Pucher[1,2], Felix Spriestersbach[1,2], Immanuel Bloch[1,3,2], and Sebastian Blatt[1,3,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Alkaline-earth atoms in optical lattices have emerged as a powerful platform for precision measurements, quantum simulation and quantum computation with neutral atoms. We present a setup combining techniques developed for optical atomic clocks and quantum gas microscopes, thus marrying high frequency resolution with microscopic spatial resolution. We demonstrate single-site and single-atom resolved fluorescence imaging of individual strontium atoms in a large and homogeneous cavity enhanced optical lattice. To prepare a two-dimensional system we optically address a single layer of the optical lattice on the ultra-narrow 1S0-3P2 transition. The required high spatial resolution is achieved by application of a magnetic field gradient and precise engineering of lattice light shifts. We perform high resolution fluorescence imaging of single atoms by employing a two color imaging scheme. Narrow-line sideband cooling suppresses heating and allows to maintain low temperatures during the imaging process.

A 7.6 Mon 18:30 F303

Quantum Simulation of Spin 1 Heisenberg Models with Dysprosium — •Katharina Brechtelsbauer and Hans-Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In this work, we propose Dysprosium atoms for the simulation of the one-dimensional spin-1 Heisenberg model, which is known to have a rich phase diagram including the famous Haldane phase [1]. For realizing the model, we make use of the strong dipolar exchange interactions that naturally occur in the ground state of Dysprosium due to its large total angular momentum of J=8. To implement spin-1 particles, we encode the spin degree of freedom into three Zeeman sub-levels which are energetically isolated by applying a magnetic field. Using the density-matrix renormalization group, we analyze the ground-state properties of the resulting effective model. We find that a chain of fermionic Dysprosium atoms in a suitable magnetic field can form a Haldane state with the characteristic spin-1/2 edge modes. Furthermore, we discuss the use of AC Stark shifts and Raman-type schemes to isolate effective spin-1 systems and to increase the tunability of the model parameters.

[1] W. Chen, K. Hida, and B. C. Sanctuary, Phys Rev B 67, 104401 (2003)

A 7.7 Mon 18:45 F303

Simulation of sympathetic cooling in a linear paul trap driven by alternative waveforms — •Paul Oskar Sund[1], Martin Kernbach[1,2], and Andreas W. Schell[1,2] — [1]Leibniz Universität, Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Linear quadrupole ion traps have been established as a versatile platform for quantum computing and atomic clocks, since they allow for an environment-isolated manipulation of multiple ions simultaneously combined with flexible optical access. However, the preparation of ion species by sympathetic cooling at room-temperature demands up to several minutes, while encountering rf-heating and scattering losses. In general, the particles dynamic is determined by the ponderomotive trap force resulting from the periodical oscillating electrical field, which is dependent on the applied waveform.

Therefore the ongoing cooling dynamics were investigated by numerically solving the Mathieu's differential equations of motion in a two-particle sympathetic cooling model under various driving waveforms and initial conditions. The simulation reveals differences in rf-heating, cooling speed and steady state energies at Coulomb-crystallization. Furthermore, shifted stability regions compared to the harmonic trap driving are found. Based on these results a further systematic investigation with alternative driving waveforms appears to be promising for improving the trapping stability and preparation times.

A 8: Quantum Technologies: Color Centers (joint session Q/A/QI)

Time: Monday 17:00–19:00 Location: F342

See Q 14 for details of this session.

A 9: Ultrafast Dynamics I (joint session MO/A)

Time: Tuesday 11:00–13:00 Location: F102

See MO 4 for details of this session.

A 10: Atomic Systems in External Fields

Time: Tuesday 11:00–13:00 Location: F107

Invited Talk A 10.1 Tue 11:00 F107

Interaction of twisted light with a trapped atom: Interplay of electronic and motional degrees of freedom — •Anton Peshkov[1,2], Yuriy Bidasyuk[1], Richard Lange[1], Tanja Mehlstäubler[1,3], Nils Huntemann[1], Ekkehard Peik[1], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig — [3]Leibniz Universität Hannover

Twisted light modes with orbital angular momentum (OAM) show great promise for applications in atomic clocks since excitation of a trapped atom in their low-intensity center can result in significant suppression of an undesirable light shift. In such experiments, however, an accurate description of induced Rabi oscillations is complicated by the transverse atomic motion within the strongly inhomogeneous optical field of twisted light. Here, we present a theoretical model to describe the time evolution of a single atom in a twisted Laguerre-Gaussian beam, taking into account vibrational states of the atom's center-of-mass motion in a harmonic potential created by a trap. Calculations have been performed for the $4s_{1/2} \rightarrow 3d_{5/2}$ electric quadrupole (E2) transition in Ca^+ ion. An analysis based on the density matrix formalism and the Liouville-von Neumann equation shows that the atom may undergo unconventional anharmonic Rabi oscillations that are attributed to the strong coupling between vibrational levels. This effect is accompanied by the angular momentum transfer from twisted light to the atomic center-of-mass motion and becomes most pronounced when the Rabi frequency is comparable to the trapping one.

A 10.2 Tue 11:30 F107

Mirrorless lasing in sodium vapor with buffer gas — •Sushree Subhadarshinee Sahoo[1,2], Emmanuel Klinger[1,2,3], Buddhika Hondamuni[1,2], Razmik Aramyan[1,2], Arne Wickenbrock[1,2], and Dmitry Budker[1,2,4] — [1]Johannes Gutenberg-Universität, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung, 55128 Mainz, Germany — [3]FEMTO-ST, UMR CNRS 6174, Université Bourgogne Franche-Comté, 25030 Besançon, France — [4]Department of Physics, University of California, Berkeley, California 94720, USA

The study of mirrorless lasing in sodium vapor has been of great interest in recent years because of its potential application in remote sensing of magnetic fields in the mesosphere. Mirrorless lasing is achieved by exciting the sodium atoms with resonant laser light at 589 and 569 nm by two-photon transition, which leads to the generation of directional infrared light. The use of this phenomenon on-sky measurements necessitates simulating the atmospheric conditions of the mesosphere in a laboratory. Hence, in this work, We investigate the effect of buffer gas on mirrorless lasing in sodium vapor. We observe that the generation amplitude of the mirrorless lasing increases with the increasing pressure of the buffer gas while there is a higher lasing threshold in the optical power as well as the number density of atoms. This study suggests that mirrorless lasing can indeed be generated in the upper atmosphere.

A 10.3 Tue 11:45 F107

Generating a focal field dominated by an arbitrary multipole component in 4Pi optical systems — •Yuxiong Duan[2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institute of Optics, Information and Photonics, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Selective multipole excitation is of great interest in laser spectroscopy of atoms and nano-particles [1,2]. In particular, tailored excitation fields have been utilized for addressing individual multipole resonances while suppressing others. However, almost without exception, the light fields that have been applied contain numerous multipole components [3]. In contrast, here we establish a theoretical framework for shaping a focal field which is dominated by only the target multipole. This is possible in 4Pi optical systems. We derive analytically the angular spectrum of pure multipoles. Taking an ideal parabolic mirror as an example, we demonstrate how to determine the matching incident beam through a mathematical relation to the angular spectrum of the target multipole. Moreover, geometric factors including the limited system size and the orientation of the quantization axis of the target multipole have been investigated. Our results indicate that the generated field can be applied for maximizing the selective multipole excitation strength and enriching laser spectroscopy with high controllability.

[1] C. T. Schmiegelow, et al, Nat. Commun. 7, 1-6 (2016).
[2] P. Woźniak, et al, Laser Photonics Rev. 9, 231-240 (2015).
[3] R. Maiwald, et al, Nat. Phys. 5, 551-554 (2009).

A 10.4 Tue 12:00 F107

Towards Driving Quantum Systems with the Non-Radiating Near-Field of a Modulated Electron Beam — •Thomas Weigner[1], Matthias Kolb[1], Thomas Spielauer[1], Johann Toyfl[1], Giovanni Boero[2], and Philipp Haslinger[1] — [1]VCQ, Technische Universität Wien, Atominstitut Stadionallee 2, Vienna, Austria — [2]EPFL, BM 3110 Station 17, Lausanne, Switzerland

Coherent manipulation of quantum systems generally relies on electromagnetic radiation as produced by lasers or microwave sources. In the experiment presented here we attempt a novel approach to drive quantum systems, as it was recently proposed (D. Rätzel, D. Hartley, O. Schwartz, P. Haslinger, A Quantum Klystron - Controlling Quantum Systems with Modulated Electron Beams. Phys. Rev. Research 3, 023247, 2021).

This method utilizes the non-radiating near-field of a modulated electron beam to coherently drive quantum systems, leading to new possibilities for controlling quantum states. For instance, one can locally address subsystems far below the diffraction limit of electromagnetic radiation or paint potentials at atomic scales.

In this proof of concept experiment, we want to couple the oscillating near-field of a spatially modulated electron beam to the unpaired spins of a solid, organic radical sample (BDPA) or the hyperfine levels of laser cooled Potassium atoms. The electron beam is generated with a cathodic ray tube from a fast analog oscilloscope.

A 10.5 Tue 12:15 F107

The Auger electron knows if the photoelectron met another atom — •Andreas Hans[1], Niklas Golchert[1], Emilia Heikura[1], Nils Kiefer[1], Lutz Marder[1], Catmarna Küstner-Wetekam[1], Johannes Viehmann[1], Jerome Palaudoux[2], Francis Penent[2], and Arno Ehresmann[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Sorbonné Universite, CNRS, Laboratoire de Chimie Physique-Matière et Rayonnement, LCPMR, F-75005 Paris Cedex 05, France

Auger spectroscopy is a powerful and omnipresent method in both fundamental research and applied science. Generally, in a two-step model the Auger process is regarded to be independent from the initial photoionization event. Only for very low excess energies of the photoelectron, the electrons need to be considered to be correlated through the so-called post collision interaction (PCI). Here we demonstrate that this picture fails if an atom is located in an environment the photoelectron can interact with. In particular, a Coulomb contribution needs to be subtracted from the Auger electron's kinetic energy if the photoelectron created charged atoms nearby by electron-impact ionization.

A 10.6 Tue 12:30 F107

Relativistic strong-field ionization of hydrogen-like atomic systems in constant crossed electromagnetic fields — •Alexandra Eckey[1], Michael Klaiber[2], Alexander B. Voitkiv[1], and Carsten Müller[1] — [1]Heinrich-Heine-Universität Düsseldorf, Germany — [2]Lochhofstraße 8, 78120 Furtwangen, Germany

We study relativistic strong-field ionization of hydrogen-like atoms or ions in a constant crossed electromagnetic field by formulating the transition amplitude within the strong-field approximation in the Goeppert-Mayer gauge, with initial and final electron states being described by the corresponding Dirac-Coulomb and Dirac-Volkov wave functions, respectively. By adapting an established method, Coulomb corrections to the electron motion during tunneling are included. We calculate total and energy-differential ionization rates in a wide range of atomic numbers and applied field strengths and compare them with predictions from other theories.

A 10.7 Tue 12:45 F107

Majorana Zero Modes in Fermionic Wires coupled by Aharonov-Bohm Cages — •Niklas Tausendpfund[1,2], Sebastian Diehl[2], and Matteo Rizzi[1,2] — [1]Peter Grünberg Institut 8, Forschungszentrum Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Germany

We devise a number-conserving scheme for the realization of Majorana Zero Modes in an interacting fermionic ladder coupled by Aharonov-Bohm cages. The latter provide an efficient mechanism to cancel single- particle hopping by destructive interference. The crucial parity symmetry in each wire is thus encoded in the geometry of the setup, in particular, its translation invariance. A generic nearest-neighbor inter- action generates the desired correlated hopping of pairs. We exhibit the presence of an extended topological region in parameter space, first in a simplified effective model via bosonization techniques, and subsequently in a larger parameter regime with matrix-product-states numerical simulations. We demonstrate the adiabatic connection to previous models, including exactly-solvable ones, and we briefly comment on possible experimental realizations in synthetic quantum platforms, like cold atomic samples.

A 11: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

Time: Tuesday 11:00–12:45 Location: F303

A 11.1 Tue 11:00 F303

Highly-sensitive photodetachment spectroscopy in an MR-ToF device — •Franziska Maria Maier[1,2] and Erich Leistenschneider[1] — [1]ISOLDE/CERN — [2]Universität Greifswald

For the MIRACLS and GANDALPH collaboration.

The electron affinity (EA) reflects the energy released when an electron is attached to a neutral atom. An experimental determination of this quantity serves as an important benchmark for atomic models describing electron-correlation effects [1]. However, the EA of several radioactive elements is still unknown and detailed information about isotope shifts or hyperfine splittings of EAs are only available for a handful of cases, mainly with modest precision.

Exploiting the low-energy version of the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) [2], we have initiated a high-precision measurement of the isotope shift in the electron affinity. By trapping ion bunches between the two electrostatic mirrors of MIRACLS multi-reflection time-of-flight (MR-ToF) device, the same ion bunch is probed by the spectroscopy laser repeatedly. Thus, the signal sensitivity is 3-4 orders of magnitude higher compared to conventional single-pass photodetachment experiments, see e.g. [1].

I will introduce the novel technique, present the first experimental results on Chlorine and discuss future possibilities of an MR-ToF device for highly sensitive and high-precision measurements of EAs for various radioactive samples.

[1] D. Leimbach et al., Nat Commun 11, 3824 (2020).
[2] S. Sels et al., Nucl. Instr. Meth. Phys. Res. B 463, 310 (2020).

A 11.2 Tue 11:15 F303

Nuclear polarization effects in atoms and ions — Victor V. Flambaum[1,2,3], Igor B. Samsonov[1], Hoang Bao Tran Tan[1,4], and •Anna V. Viatkina[2,3,5,6] — [1]School of Physics, University of New South Wales, Sydney 2052, Australia — [2]Helmholtz Institute Mainz, GSI Helmholtzzentrum für Schwerionenforschung, 55099 Mainz, Germany — [3]Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [4]Department of Physics, University of Nevada, Reno, Nevada 89557, USA — [5]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [6]Institute of Mathematical Physics, Technical University Braunschweig, 38106 Braunschweig, Germany

Precision isotope shift spectroscopy offers an opportunity to search for new physics by means of measuring King plot (KP) nonlinearities. However, KP nonlinearities might arise from standard-model effects as well, thus obscuring possible new-physics signal. One of such effects is the variation of nuclear polarizabilities between isotopes. Even though this effect is estimated to be relatively small and not the leading contribution to KP nonlinearity, it should not be overlooked in the interpretation of the data. In our work, we calculated energy-level shifts due to electric-dipole and -quadrupole nuclear polarization for 1s, 2s, $2p_{1/2}$ states in hydrogenlike ions, and for high-ns valence states in neutral atoms with $Z \geq 20$. We fit the results with elementary functions of nuclear parameters and derive a set of effective potentials which may be used to calculate polarization energy-level shifts in many-electron atoms and ions.

A 11.3 Tue 11:30 F303

Enhancing Atom-Photon Interaction with Novel Integrated Nano-photonic Resonators — •Benyamin Shnirman — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany

The marriage of thermal atomic vapor with nanophotonics provides a unique testbed for the manipulation of atom-atom and atom-photon interactions. While benefitting from strong miniaturisation, integration and scalability, this platform struggles with short atom-light interaction due to the thermal motion.

In order to overcome this dephasing mechanism, we need atom-light interaction to reach the strong coupling regime. A suitable candidate is a photonic crystal cavity (PhC), which combines a tight mode confinement with a high quality factor. In order to create an interface for atom-light interaction, we have developed a novel fabrication technique to suspend PhC's. This allows us to investigate cavity QED effects that are sensitive to single photons and single atoms. We present first characterization data of the fabricated PhC's and compare it to the simulation results.

Our other lines of research on nanophotonics and thermal atoms include the use of the Rydberg blockade effect on chip to generate single photons. In order to couple to the Rydberg states efficiently, the light field is locally enhanced by ultralow-loss micro-ring resonators.We also study topological edge states in arrays of ring resonators and how thermal atoms can be used to study the effect of optical nonlinearity on the bulk and edge modes.

A 11.4 Tue 11:45 F303

Minimizing entanglement of sources of P,T-violation with complementary low-energy experiments — •Konstantin Gaul and Robert Berger — Fachbereich Chemie, Philipps-Universität Marburg,Hans-Meerwein-Straße 4, 35032 Marburg, Germany

The detection of an atomic or molecular P,T-odd electric dipole moment (EDM) would be a direct evidence of physics beyond the Standard Model. Internal enhancement effects render atoms and molecules very promising candidates for a first direct detection of P,T-violation. The EDM of an atom or molecule stems from various fundamental sources of P,T-violation, such as P,T-odd currents or EDMs of elementary particles [1]. Therefore, interpretations and predictions of EDMs are difficult and several experiments are required for a global model-independent analysis of the results [2]. In this contribution all sources of the P,T-odd EDMs of atoms and molecules are studied within a simple qualitative electronic-structure model in terms of electronic and nuclear angular momenta and the nuclear charge number. For comparison accurate calculations of the electronic structure parameters [3] of most experimentally relevant atoms and molecules are performed and selection of good candidates for future experiments is discussed in the light of minimizing the coverage region in the global P,T-odd parameter space.

[1] Khriplovich, Lamoreaux, CP Violation without Strangeness (1997).
[2] Jung, JHEP 2013, 168 (2013); Engel *et al.*, PPNP 71, 21 (2013); Chupp, Ramsey-Musolf, PRC 91, 035502 (2015).
[3] Gaul *et al.*, PRA 99, 032509 (2019); JCP 152, 044101 (2020).

A 11.5 Tue 12:00 F303

Path integral formalism for radiative corrections in bound-state QED — •Sreya Banerjee and Zoltán Harman — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

A step-by-step theory of radiative corrections in bound-state quantum electrodynamics is developed using Feynman's path integral formalism. As a first step, we derive the free Dirac propagator in spherical coordinates. This is followed by the derivation of the Dirac-Coulomb Green's function (DCGF) in the Furry picture by reducing it in a basis such that the effective action becomes similar to that of the non-relativistic hydrogen atom. As such, the DCGF is obtained in closed form along with the energy spectrum of the bound states. In the final step, the lowest-order vacuum polarization correction and one-loop self-energy correction to the energy levels of bound electrons are calculated using perturbative path integral formalism. Starting from an interparticle classical action, we arrive directly at the propagators of quantum electrodynamics. The energy level shifts are then calculated from the perturbative shift of poles of the Green's functions obtained.

A 11.6 Tue 12:15 F303

Trapping and cooling Th ions with Ca ion crystal for quantum logic spectroscopy — •Azer Trimeche[1], Jonas Stricker[2,3], Can Patric Leichtweiss[1], Valerii Andriushkov[2], Dennis Renisch[2,3], Dmitry Budker[1,2], Christoph E. Düllmann[2,3,4], and Ferdinand Schmidt-Kaler[1] — [1]QUATUM, Institute of Physics, Johannes Gutenberg-Universität Mainz — [2]Helmholtz-Institut Mainz — [3]Department of Chemistry, Johannes Gutenberg-Universität Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Thorium isotopes became of high interest in the search for new physics, and fundamental physics tests, because of their unique nuclear and atomic properties. The Trapping And Cooling of Thorium Ions in Calcium crystals (*TACTICa*) project develops ion trapping and spectroscopic techniques for a precise determination of the nuclear moments, hyperfine intervals, and isotope shifts with different Th isotopes. For the production, we dispose of two different sources: an ion recoil source [1] and a laser ablation source [2]. Th ions are trapped in a Ca^+ crystal [3], tagged by fluorescence calorimetry technique [4], cooled down sympathetically by polarization gradient cooling of Ca^+ crystal [5], and investigated by quantum logic spectroscopy technique.

[1] R. Haas et al., Hyperfine interactions 241 (2020) 25.
[2] K. Groot-Berning et al., *PRA* 99 (2019) 023420.
[3] K. Groot-Berning et al., *PRL* 123 (2019) 106802.
[4] M. Gajewski et al. *PRA* 106 (2022) 033108.
[5] W. Li et al., *NJP* 24(4) (2022) 043028.

A 11.7 Tue 12:30 F303

Metallic magnetic calorimeters: Novel detectors for high-resolution X-ray spectroscopy — •D. Hengstler[1], A. Abeln[1], S. Allgeier[1], A. Brunold[1], L. Eisenmann[1], M. Friedrich[1], A. Gumberidze[2], M.-O. Herdrich[2,3,4], F. Kröger[2,3,4], P. Kuntz[1], A. Fleischmann[1], M. Lestinsky[2], E. Menz[2,3,4], A. Orlow[1], Ph. Pfäfflein[2,3,4], U. Spillmann[2], B. Zhu[4], G. Weber[2,3,4], Th. Stöhlker[2,3,4], and C. Enss[1] — [1]KIP, Heidelberg University — [2]GSI, Darmstadt — [3]IOQ, Jena University — [4]HI Jena

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. They are operated at mK temperatures and convert the energy of each incident photon into a temperature rise which is monitored by a paramagnetic sensor.

To probe QED, we developed the 2-dimensional detector array maXs-100. The detector features 8x8 pixels with an active detection area of 1 cm^2 and a stopping power of 40 % at 100 keV. An absolute energy calibration on eV-level as well as an energy resolution of 40 eV (FWHM) at 60 keV were demonstrated. We discuss the detector performance during the recent beam time at the ion storage ring CRYRING@FAIR (Darmstadt), where electron transitions within highly charged, He-like U^{90+} ions were studied and present ongoing detector improvements and possible future applications.

This work was conducted in the framework of the SPARC collaboration, exp. E138 of FAIR Phase-0 supported by GSI. We acknowledge substantial support by ErUM-FSP APPA (BMBF no 05P19VHFA1).

A 12: Poster I

Time: Tuesday 16:30–19:00 Location: Empore Lichthof

A 12.1 Tue 16:30 Empore Lichthof

Femtosecond-modulated attoscond dynamics in atomic resonant ionization — •Hao Liang[1], Meng Han[2], and Jan Micheal Rost[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Laboratorium für Physikalische Chemie, ETH Zürich, Zürich, Switzerland

Reconstruction of attosecond harmonic beating by interference of two-photon transition (RABBITT) techniques were recently used to measure the resonance transition among bound states of atomic and molecular systems. In those studies, changing the relative delay between infrared pulse and attosecond pulse train is solely regarded as the carrier envelope phase scanning. However, in the case that the relative delay is comparable to the pulse duration, the resonance ionization dynamics itself also dramatically alters, including both the ionization time and phase. In this work, by performing experimental measurement and time-dependent Schrödinger equation simulation, we investigate $1s^2$-$1s3p$ transition of Helium atom, and reveal the importance of ac-stark shift and population accumulation during resonant process.

A 12.2 Tue 16:30 Empore Lichthof

Study of Rydberg states in ultra cold ytterbium — •Alexander Miethke and Axel Görlitz — Institut für Experimentalphysik, Heinrich-Heine-Universität, Düsseldorf, Deutschland

In recent years Rydberg atoms with their special features, like dipole-dipole interaction or van-der-Waals blockade, have become more and more important for quantum optics. Particularly ultra cold Rydberg atoms are of great interest for the investigation of long range interaction.

A special feature of ytterbium is that due to its two valance electrons atoms in Rydberg states can be easily manipulated and imaged using optical fields. A first step towards studies of ultra cold ytterbium is to gain precise knowledge on the Rydberg states.

Here we present the study of the Rydberg states of ultra cold ytterbium. Using a Micro-Channel-Plate to detect the Rydberg atoms it is possible to measure lifetimes and hyperfine structures of several states. In addition we could measure the energy and polarizability of s, p and d states in the region of high principal quantum numbers n (n=70-90).

A 12.3 Tue 16:30 Empore Lichthof

Dynamical phase transition in an open quantum system — •Julian Fess[1], Ling-Na Wu[2], Jens Nettersheim[1], Alexander Schnell[2], Sabrina Burgardt[1], Silvia Hiebel[1], Daniel Adam[1], André Eckardt[2], and Artur Widera[1] — [1]Department of Physics and State Research Center OPTIMAS, RPTU Kaiserslautern, Kaiserslautern, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, Berlin, Germany

Phase transitions correspond to the singular behavior of physical systems in response to continuous control parameters. Recently, dynamical quantum phase transitions have been observed in the non-equilibrium dynamics of isolated quantum systems, with time as the control parameter. However, signatures of such dynamical phase transition in open systems, were so far elusive. Here, we demonstrate that dynamical phase transitions can also occur in open quantum systems. We measure the relaxation dynamics of the large atomic spin of individual Caesium atoms induced by the dissipative coupling via spin-exchange processes to an ultracold Bose gas of Rubidium atoms. For initial states far from equilibrium, the entropy of the spin state is found to peak in time, transiently approaching its maximum possible value, before eventually relaxing to its lower equilibrium value. Moreover, a finite-size scaling analysis shows that it corresponds to a dynamical phase transition. Our results show that dynamical phase transitions are not restricted to occur in isolated systems, but, surprisingly, are possible also during the dissipative evolution of open quantum systems.

A 12.4 Tue 16:30 Empore Lichthof

QRydDemo - A Rydberg atom quantum computer demonstrator — •jiachen zhao[1], ratnesh kumar gupta[1], philipp ilzhöfer[1], govind unnikrishnan[1], jennifer krauter[1], achim scholz[1], sebastian weber[2], hans peter büchler[2], simone montangero[3], jürgen stuhler[4], florian meinert[1], and tilman pfau[1] — [1]5th Institute of Physics, University of Stuttgart, Germany — [2]Institute for Theoretical Physics III, University of Stuttgart, Germany — [3]Department of Physics and Astronomy, University of Padova, Padova, Italy — [4]TOPTICA Photonics AG, Gräfelfing, Germany

Quantum computing is attracting great interest due to its potential for solving computationally hard problems. The QRydDemo project aims to build a quantum computer based on neutral strontium atoms individually trapped in an optical tweezer array. We will study a so far unexplored qubit encoded in the 3P0 and 3P2 fine-structure states of Strontium. This qubit provides "triple magic trapping" and the potential to improve the coherence time by a factor of 1000 from previous demonstrations of 10 microseconds to 10 milliseconds. We will combine this qubit with a novel tweezer architecture which allows for reshuffling of the qubits during the quantum computation. Such a dynamically adjustable qubit array allows for new algorithmic possibilities by effectively increasing the connectivity for deep quantum circuits to solve real-world problems. We plan to offer access to the hardware through a currently developed compiler software stack via our website www.thequantumlaend.de.

A 12.5 Tue 16:30 Empore Lichthof

Investigation of ultrashort FEL pulses utilizing the split-and-delay unit at FLASH2 — •Matthias Dreimann[1], Evgeny Schneidmiller[3], Dennis Eckermann[1], Frank Wahlert[2], Sebastian Roling[2], Michael Wöstmann[1], Victor Kärcher[1], Tobias Reiker[1], Marion Kuhlmann[3], Sven Toleikis[3], Rolf Treusch[3], Elke Plönjes-Palm[3], and Helmut Zacharias[1] — [1]Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster — [2]Physikalisches Institut, Westfälische Wilhelms-Universität Münster — [3]Deutsches Elektronen-Synchrotron DESY

A split-and-delay unit for the XUV and soft X-ray spectral range has been installed at beamlines FL23 and FL24 at the FLASH2 Free-Electron Laser at DESY. It enables time-resolved pump-probe experiments from 30 eV up to 1800 eV including the whole spectral range of FLASH2. Using wavefront beam splitting and grazing incidence mirrors a relative pulse delay of -5 ps < $\Delta\tau$ < +18 ps is achieved. With a measured timing jitter of tj = 121 as and a nominal time resolution of tr = 66 as a sub-fs resolution of this device enables time-resolved experiments with ultrashort FEL pulses. The development of ultrashort FEL pulses with few-fs and sub-fs pulses is a research field in the FEL community with promising applications. One of theses applications are pump/probe experiments with ultrashort FEL pulses, as the temporal dynamic of the system is a key to the fundamental understanding of its underlying physics. We present first results of the investigation of ultrashort FEL pulses which in future will allow sub-fs temporal resolution in experiments.

A 12.6 Tue 16:30 Empore Lichthof

Optimizing optical potentials with physics-inspired learning algorithms — •Martino Calzavara[1,4], Yevhenii Kuriatnikov[2], Andreas Deutschmann-Olek[3], Felix Motzoi[1], Sebastian Erne[2], Andreas Kugi[3], Tommaso Calarco[1,4], Jörg Schmiedmayer[2], and Maximilian Prüfer[2] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [3]Automation and Control Institute, TU Wien, Gußhausstraße 27-29, 1040 Vienna, Austria — [4]Institute for Theoretical Physics, Universität zu Köln, 50937 Cologne, Germany

We present our new experimental and theoretical framework which combines a broadband superluminescent diode (SLED/SLD) with fast learning algorithms to provide speed and accuracy improvements for the optimization of 1D optical dipole potentials, here generated with a Digital Micromirror Device (DMD). We employ Machine Learning (ML) tools to train a physics-inspired model acting as a digital twin of the optical system predicting the behavior of the optical apparatus including all its imperfections. Implementing an algorithm based on Iterative Learning Control (ILC), we optimize optical potentials an order of magnitude faster than heuristic optimization methods. We compare iterative model-based "offline" optimization and experimental feedback-based "online" optimization. Our methods provide a new route to fast optimization of optical potentials which is relevant for the dynamical manipulation of ultracold gases.

A 12.7 Tue 16:30 Empore Lichthof

Exploring time-, frequency- and phase-resolved measurement techniques with Mössbauer nuclei — •Lukas Wolff and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Mössbauer nuclei form a versatile platform for spectroscopy and quantum optics at hard x-ray energies owing to their extremely narrow line-widths and exceptional coherence properties. The development of novel x-ray sources and recent theoretical progress in x-ray cavity-QED can open a path towards a plethora of nonlinear and non-equilibrium phenomena. To characterize these phenomena in experiment and to compare with theoretical predictions, advanced measurement and data analysis techniques are required.

As one example, this poster reviews a data acquisition technique which uses single-line nuclear reference absorbers to record time- and frequency-resolved Nuclear Resonant Scattering spectra at accelerator-based x-ray sources. These spectra can be interpreted via a Fourier transform along the time axis thus providing direct access to the nuclear target spectrum, including phase information. This is of primary interest for the characterization of collective level schemes in thin-film x-ray cavities. Our findings are validated by evaluation of numerical data using the software package pynuss.

The poster further discusses a perturbative expansion of the nuclear density matrix that can be used to devise multi-pulse experiments with Mössbauer nuclei to access nonlinear and time-dependent phenomena. These multi-pulse schemes can build upon recent experimental work on coherent control of nuclei and x-ray pulse-shaping.

A 12.8 Tue 16:30 Empore Lichthof

Feshbach Resonances in a hybrid Atom-Ion System — •Joachim Siemund[1], Fabian Thielemann[1], Wei Wu[1], Thomas Walker[1], Pascal Weckesser[1,2], Daniel Hönig[1], Amir Mohammadi[1], and Tobias Schätz[1] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

We present the observation of Feshbach resonances between neutral atoms and ions [1,2]. These resonances - a quantum phenomenon only observable at ultracold temperatures - allow the 2-body and 3-body interaction rates between particles to be tuned with the possibility to even switch them off. This can be used to enhance sympathetic cooling. While Feshbach resonances are commonly utilized in neutral atom experiments, reaching the ultracold regime in hybrid rf-optical traps is challenging, as the driven motion of the ion by the rf trap limits the achievable collision energy [3]. Having reached the onset of the quantum regime even in hybrid traps paves the way for all-optical trapping of both species, circumventing the fundamental rf-heating, and for new applications, such as the coherent formation of molecular ions and simulations of quantum chemistry [4].

[1] WECKESSER, Pascal, et al. arXiv:2105.09382, 2021.
[2] SCHMIDT, J., et al. Phys.Rev.Lett. 2020, 124-5.
[3] CETINA, Marko et al. Phys.Rev.Lett. 2012, 109-25.
[4] BISSBORT, Ulf, et al. Phys.Rev.Lett. 2013, 111-8.

A 12.9 Tue 16:30 Empore Lichthof

Coherent and Dephasing Spectroscopy for Single-Impurity Probing of an Ultracold Bath — •Sabrina Burgardt[1], Daniel Adam[1], Quentin Bouton[2], Jens Nettersheim[1], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern-Landau, Kaiserslautern 67663, Germany — [2]Laboratoire de Physique des Lasers, CNRS, UMR 7538, Universite Sorbonne Paris Nord, F-93430 Villetaneuse, France

We report Ramsey spectroscopy on the clock states of individual Cs impurities immersed in an ultracold Rb bath. We record both the interaction-driven phase evolution and the decay of fringe contrast of the Ramsey interference signal to obtain information about bath density or temperature nondestructively. The Ramsey fringe is modified by a differential shift of the collisional energy when the two Cs states superposed interact with the Rb bath. This differential shift is directly affected by the mean gas density and the details of the Rb-Cs interspecies scattering length, affecting the phase evolution and the contrast of the Ramsey signal. Additionally, we enhance the temperature dependence of the phase shift preparing the system close to a low-magnetic-field Feshbach resonance where the s-wave scattering length is significantly affected by the collisional (kinetic) energy. Analyzing coherent phase evolution and decay of the Ramsey fringe contrast, we probe the Rb clouds density and temperature. Our results point at using individual impurity atoms as nondestructive quantum probes in complex quantum systems.

A 12.10 Tue 16:30 Empore Lichthof

Inner-Shell Ionization of Low-Charged Silicon and Iron Ions — •Stefan Schippers[1], Alfred Müller[1], Simon Reinwardt[2], Michael Martins[2], and Stephan Fritzsche[3,4,5] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen — [2]Institut für Experimentalphysik, Universität Hamburg — [3]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [4]Helmholtz-Institut Jena — [5]Institut für Theoretische Physik, Friedrich-Schiller-Universität Jena

We report on recent experimental and theoretical work on single and multiple L-shell photoionization of low-charged iron ions (Fe^{+}, Fe^{2+}, Fe^{3+}) [1-3] and on single and multiple K-shell photoionization of low-charged silicon ions (Si^{-}, Si^{+}, Si^{2+}, Si^{3+}) [4,5]. The experiments were carried out at the photon-ion end-station PIPE of beamline P04 of the PETRA III synchrotron light source. The results are particularly relevant for the determination of the elemental abundances in the interstellar medium. Our data are decisive for being able to answer the question how much of the interstellar iron and silicon is in the gas phase and how much is chemically bound in dust grains. [1] S. Schippers et al., Astrophys. J. 849, 5 (2017). [2] R. Beerwerth et al., Astrophys. J. 887, 189 (2019). [3] S. Schippers et al., Astrophys. J. 908, 52 (2021). [4] A. Perry-Sassmannshausen et al., Phys. Rev. A 104, 053107 (2021). [5] S. Schippers et al., Astrophys. J. 931, 100 (2022).

A 12.11 Tue 16:30 Empore Lichthof

K-shell Photodetachment of Carbon, Oxygen and Silicon Anions — Alexander Perry-Sassmannshausen[1], Alexander Borovik Jr.[1], Ticia Buhr[1], Angelika Hamann[1], Simon Reinwardt[2], Sebastian Stock[3,4], Florian Trinter[5,6], Michael Martins[2], Stephan Fritzsche[3,4,7], Alfred Müller[1], and •Stefan Schippers[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen — [2]Institut für Experimentalphysik, Universität Hamburg — [3]Helmholtz-Institut Jena — [4]Institut für Theoretische Physik, Friedrich-Schiller-Universität Jena — [5]Institut für Kernphysik, Goethe-Universität, Franfurt am Main — [6]Molecular Physics, Fritz-Haber-Institut der MPG, Berlin — [7]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt

Using the PIPE end-station at PETRA III, we have measured cross sections σ_m for multiple (m-fold) photodetachment of C^{-} [1], O^{-}[2], and Si^{-} [3] in the photon energy ranges 280–1000 eV, 525–1500 eV, and 1830–1900 eV, respectively. All cross sections exhibit near-threshold resonances. For C^{-} and O^{-}, the cross section σ_5 shows signatures of double-core hole formation, in addition. The measured threshold energies agree with results of atomic-structure calculations, which also treat the complex deexcitation cascades that set in after the initial creation of one or two inner-shell holes. [1] A. Perry-Sassmannshausen et al., Phys. Rev. Lett. 124, 083203 (2020). [2] S. Schippers et al., Phys. Rev. A 106, 013114 (2022). [3] A. Perry-Sassmannshausen et al., Phys. Rev. A 104, 053107 (2021).

A 12.12 Tue 16:30 Empore Lichthof

JAC – A platform for Just Atomic Computations — •Stephan Fritzsche — Helmholtz-Institut Jena, Germany – Friedrich-Schiller University Jena

Electronic structure calculations of atoms and ions have a long tradition in physics with applications in basic research and spectroscopy. With the Jena Atomic Calculator (JAC), I here present a modern implementation of a (relativistic) electronic structure code for the computation of atomic amplitudes, properties as well as a large number of excitation and decay processes for open-shell atoms and ions across the periodic table. JAC [1,2] is based on Julia, a new programming language for scientific computing, and provides an easy-to-use but powerful platform to extent atomic theory towards new applications.

[1] S. Fritzsche. A fresh computational approach to atomic structures, processes and cascades. Comp. Phys. Commun., 240, 1 (2019), DOI:10.1016/j.cpc.2019.01.012. [2] S. Fritzsche. JAC: User Guide, Compendium & Theoretical Background. https://github.com/OpenJAC/JAC.jl, unpublished (02.11.2022).

A 12.13 Tue 16:30 Empore Lichthof

Orientation Recovery of Single-shot Scattering Images of Molecules and 3-Dimensional Density Reconstruction using Machine Learning — •Siddhartha Poddar, Ulf Saalmann, and Jan Michael Rost — Nöthnitzer Str. 38, 01187, Dresden, Germany

As an orientation recovery technique of coherent diffractive images at X-ray free-electron lasers for a single molecule, we have applied a pairwise distance learning algorithm to pairs of scattering images with the help of a deep learning network called Siamese Neural Network (SNN) or popularly known as twin network. With this a priori orientation information in the knowledge, now it is possible to successfully reconstruct the 3D electronic density of the corresponding molecule using many tomographic techniques available. So, the implementation of our reconstruction procedure, from 2D images to 3D molecular structure, has two successive steps. First, we train the twin network with a dataset consisting of approximately 100000 scattering images of an asymmetric 4-atomic test molecule and predict the orientations of a new unseen set of images for the same molecule. Second, we align and arrange this small subset of oriented images to compute the overall structure of the molecule using tomography.

A 12.14 Tue 16:30 Empore Lichthof

A dipolar quantum gas microscope — •Paul Uerlings, Jens Hertkorn, Kevin Ng, Lucas Lavoine, Ralf Klemt, Tim Langen, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

We present the progress towards the construction of a dipolar quantum gas microscope using dysprosium atoms. This new apparatus combines the single-site resolution of a quantum gas microscope with the long-range and anisotropic interactions found in dipolar quantum gases. We will use fermionic and bosonic isotopes of dysprosium trapped in an ultraviolet optical lattice with a lattice spacing of 180 nm. Combined with the long-range dipole interaction, the short lattice spacing will significantly enhance nearest neighbor coupling to be on the order of 200 Hz (10 nK). We will combine this lattice setup with a single-particle, spin-, and energy resolved super-resolution imaging technique. This will allow us to experimentally study strongly correlated dipolar Bose- and Fermi-Hubbard physics, where even next-nearest-neighbor interactions could become visible. The strong and tunable dipolar interactions open up the possibility to explore a wide range of problems ranging from quantum magnetism and lattice spin models to topological matter.

A 12.15 Tue 16:30 Empore Lichthof

Identification of highly-forbidden optical transitions in highly charged ions — •Shuying Chen[1], Lukas J. Spiess[1], Steven A. King[1], Alexander Wilzewski[1], Malte Wehrheim[1], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Optical clocks are the most accurate measurement devices and have been used in many applications from metrology to fundamental physics. Highly charged ions (HCI) have advantages as references in optical clocks, being less sensitive to external fields perturbations [1]. Recently, our group has demonstrated the first HCI clock based on Ar^{13+} [2], using quantum logic spectroscopy (QLS) to to readout the internal state of the HCI. The statistical uncertainty was mostly limited by the excited state lifetime of 10 ms. An improved HCI clock is under consideration using a transition with an excited state lifetime >1s. The biggest challenge of the proposed HCI clock species is the large frequency uncertainty of their transitions, mostly obtained from ab initio atomic structure calculations with percent-level uncertainties corresponding to a few terahertz. Here we propose and assess various experimental search techniques, including an off-resonant optical dipole force [3], to find transitions for the next generation HCI clocks in a feasible time scale. [1] M. G. Kozlov, *et al.*, Rev. Mod. Phys. **90**, 045005 (2018) [2] S. A. King, L. J. Spieß, *et al.*, Nature **611**, 43-47 (2022). [3] F. Wolf, *et al.*, Nature **530**, 457-460 (2016).

A 12.16 Tue 16:30 Empore Lichthof

Ellipticity studies in high-order harmonic generation from endohedral fullerenes — •KM AKANKSHA DUBEY[1,2], OREN COHEN[3], and MARCELO F. CIAPPINA[1,2] — [1]Physics Program, Guangdong Technion - Israel Institute of Technology, Shantou 515063, Guangdong, China — [2]Technion - Israel Institute of Technology, Haifa 32000, Israel — [3]Solid State Institute and Physics Department, Technion - Israel Institute of Technology, Haifa 3200003, Israel

Endohedral fullerenes ($A@C_{60}$), fullerenes with an encaged atom/molecule (A), are capable of controlling resonant HHG, when driven by a strong laser pulse [1]. Being giant molecules, the multi-center nature of HHG arises naturally [2-3]. Thus, elliptical HHG could be generated even with a linearly polarized ultrafast laser pulse [4]. Elliptical HHG in fullerenes/carbon clusters are found to be very rich owing to the complex nature of these molecular targets [5]. Employing the molecular SFA, we aim at evaluating the ellipticity dependence of HHG from $A@C_{60}$ under linearly and elliptically polarized ultrafast laser pulses. Further, to account for electron correlations in the HHG spectrum [6], we perform TDDFT simulations. 1. P. V. Redkin, M. B. Danailov, and R. A. Ganeev, Phys. Rev. A *84*, 013407 (2011). 2. M. F. Ciappina, A. Becker, and A. Jaroń-Becker, Phys. Rev. A *76*, 063406 (2007). 3. M. F. Ciappina, A. Becker, and A. Jaroń-Becker, Phys. Rev. A *78*, 063405 (2008). 4. A. Etches, C. B. Madsen, and L. B. Madsen, Phys. Rev. A *81*, 013409 (2010). 5. F. Cajiao - Vélez, and A. Jaron, arXiv:2203.15933v1 [quant-ph]. 6. O. Neufeld, and O. Cohen, Phys. Rev. Res. *2*, 033037 (2020).

A 12.17 Tue 16:30 Empore Lichthof

Temperature Dependence of Atom-Ion Feshbach Resonances — •FABIAN THIELEMANN, JOACHIM SIEMUND, WEI WU, THOMAS WALKER, and TOBIAS SCHAETZ — Albert-Ludwigs Universität, Freiburg, Deutschland

We recently observed magnetic Feshbach resonances between atoms and ions using inelastic loss spectroscopy. In our experiment we immerse a single, Doppler-cooled $^{138}Ba^+$ ion into a cloud of ultracold, spin-polarized ^6Li atoms. Collisions lead to sympathetic cooling of the ion to temperatures that allow us to resolve individual Feshbach resonances. The final collision energy depends on many parameters, such as the excess micromotion of the ion in the rf trap, the atom-ion mass ratio and the temperature of the atomic cloud. In this poster, we present experimental results on how the properties of a Feshbach resonance change when the temperature of the atomic bath - and thus the atom-ion collision energy - is varied. This could aide in the partial wave assignment of the surprisingly large number of resonances.

A 12.18 Tue 16:30 Empore Lichthof

Quadrupole transitions with continuous dynamical decoupling — •VÍCTOR JOSÉ MARTÍNEZ LAHUERTA[1], LENNART PELZER[2], LUDWIG KRINNER[2], KAI DIETZE[2], PIET SCHMIDT[2], and KLEMENS HAMMERER[3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Schneiderberg 39 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt (PTB), Bunde- sallee 100, 38116 Braunschweig, Germany — [3]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover

We consider the mechanism of continuous dynamical decoupling, focusing on gaining insensitivity to magnetic field fluctuations and quadrupole shifts. This mechanism consists in the application of a radio-frequency magnetic field orthogonal to the quantization axis of a given spin manifold. We account for the approximations realized during the calculations perturbatively by using the so-called Magnus expansion, showing that they can be considered as an effective shift of the Zeeman splitting of the manifolds. We can apply our formalism to properly describe a quadrupole transition between two manifolds, where the particular case of a transition between $S = 1/2$ and $D = 5/2$ of $^{40}Ca^+$ is studied with a comparison with experimental data. We finish by considering the implementation of a Mölmer-Sörensen gate within the framework of continuous dynamical decoupling.

A 12.19 Tue 16:30 Empore Lichthof

Detecting the external magnetic field alignment using the vortex light atom interaction. — •SHREYAS RAMAKRISHNA[1,2,3], RIAAN P SCHMIDT[4,5], ANTON A PESHKOV[4,5], ANDREY SURZHYKOV[4,5,6], and STEPHAN FRITZSCHE[1,2,3] — [1]Helmholtz Institute Jena, Frobelstieg 3, D-07749 Jena, Germany — [2]GSI Helmholtzzentrum fur Schwerionenforschung GmbH, Planckstrasse 1, D-64291, Germany — [3]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universitat Jena, Max-Wien-Platz 1, D-07743 Jena, Germany — [4]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany — [5]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [6]Laboratory for Emerging Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig, Germany

We analyze photoexcitation of atoms by cylindrically polarized Bessel beams in the framework of density matrix theory based on the Liouville-von Neumann equation. In particular, we study the dependence of the population of excited atomic states on the direction of the external magnetic field for the case of the $(5s^2S_{1/2}(F=1) \rightarrow 5p^2P_{3/2}(F=0))$ electric dipole transition in ^{87}Rb. Moreover, we demonstrate that the steady-state excited-state population is very sensitive not only to the polarization and OAM of the incoming light field, but also to the position of the atom within the beam cross-section. The results of our calculations agree well with the experimental findings of F. Castellucci et.al [Phys. Rev. Lett. 127, 233202 (2021)] and can be useful to plan future measurements.

A 12.20 Tue 16:30 Empore Lichthof

Status of the ALPHATRAP *g*-factor experiment — •VALENTIN HAHN, FABIAN HEISSE, CHARLOTTE KÖNIG, JONATHAN MORGNER, FABIAN RAAB, SVEN STURM, and KLAUS BLAUM — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Quantum electrodynamics (QED) is considered to be the most successful quantum field theory in the Standard Model. Its most precise test is conducted via the comparison of QED calculations with the measurement of the free electron *g*-factor. However, this test is restricted to low electrical field strengths. Consequently, it is of utmost importance to perform similar tests at high field strengths.

The ALPHATRAP experiment is a dedicated cryogenic Penning-trap setup to measure the *g*-factor of bound electrons in highly charged ions beyond hydrogen-like lead [1]. There, an electric field strength on the order of 10^{16} V/cm acts on the electron, allowing to test bound state QED with highest precision.

Our latest measurements of the *g*-factor for different charge states of a single highly charged tin ion are presented. Furthermore, an outlook on upcoming studies and prospects will be given.

[1] S. Sturm et al., Eur. Phys. J. Spec. Top. 227, 14251491 (2019)

A 12.21 Tue 16:30 Empore Lichthof

A study of the Hanle effect with twisted light — •RIAAN PHILIPP SCHMIDT — Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany — Institute of Mathematical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

We analyze the depolarization of resonance fluorescence from atoms exposed to twisted (Bessel) radiation. Special attention has been paid to the dependence on the external magnetic field strength, known as the Hanle effect, which is investigated within the framework of the density-matrix theory based on the Liouville-von Neumann equation. While the derived expressions can be employed to study the Hanle effect for any atomic system, detailed calculations of the P_1 and P_3 Stokes parameters of the emitted radiation have been performed for the $6s^2\,{}^1S_0 - 6s6p\,{}^3P_1$ transition in mercury. Our results indicate how the fluorescence depolarization may be affected by the spatial structure and polarization of the incident light field, as well as by the applied magnetic field. This study contributes to a better understanding of the potential of twisted light in atomic spectroscopy.

A 12.22 Tue 16:30 Empore Lichthof

Interaction of twisted light with the ^{229}Th nuclear clock candidate — •TOBIAS KIRSCHBAUM and ADRIANA PÁLFFY — Julius-Maximilians-Universität Würzburg, Germany

Twisted light refers to light beams that carry orbital angular momentum. The interaction of twisted light with matter is a rapidly developing topic in optics and related fields thereof [1], in particular due to the modification of selection rules in atomic photo-excitation rendering dipole forbidden channels possible. In turn, these channels become attractive for next-generation atomic clocks.

A compelling alternative for these novel atomic clocks is the ^{229}Th nucleus which has its first excited state at ≈ 8 eV accessible by narrow-band VUV lasers. The transition from the ground to the excited state has a radiative lifetime of a few hours [2] and presents $M1/E2$ multipole mixing in which the $M1$ channel strongly dominates. Here, we present a theoretical approach to excite the ^{229}Th isomer with twisted light fields. Thereby, we investigate how the efficiency of the direct radiative excitation of the isomeric state can be increased and study the selective driving in targets with nuclear hyperfine splitting.

[1] A. Afanasev *et al.*, Phys. Rev. A **97**, 023422 (2018).
[2] E. Peik *et al.*, Quantum Sci. Technol. **6**, 034002 (2021).

A 12.23 Tue 16:30 Empore Lichthof

Non-Hermiticity and parity-time symmetry at x-ray wavelengths — •Fabian Richter and Adriana Pálffy — Julius- Maximilians-Universität Würzburg, Germany

A certain class of Hamiltonians which are non-Hermitian but obey parity-time (PT) symmetry exhibit real spectra thus mimicking Hermitian properties. This theoretical concept has recently found fertile ground in optics and photonics where non-Hermitian eigenstates can be created and superposed through optical gain and loss [1]. So far, these concepts have been mostly discussed in the optical regime. Similar control of x-rays is desirable due to their superior penetration power, high focusability and detection efficiency.

Here, we investigate theoretically non-Hermitian x-ray photonics based on PT symmetry in a thin-film cavity setup containing Mössbauer nuclei resonant to the x-ray radiation. These cavities present loss which is modelled by a Lindblad term in the master equation [2]. The presence of an external magnetic field introduces PT-symmetry breaking which could be used to control the properties of x-ray scattering.

[1] L. Feng *et al.*, Nature Photon. **11**, 752-762 (2017).
[2] X. Kong, D. Chang, A. Pálffy , Phys. Rev. A **102**, 033710 (2020).

A 12.24 Tue 16:30 Empore Lichthof

Enhancing atom-photon interaction with integrated nanophotonic resonators — •Xiaoyu Cheng — 5. Physikalisches Institut, Universität Stuttgart

We study hybrid devices consisting of thermal atomic vapor and nanophotonic structures for manipulating the interaction between atoms and photons.

We exploit cooperative effects to develop a compact, on-demand and highly efficient single-photon-source using the Rydberg blockade effect. In order to couple to the Rydberg states efficiently, the light field is locally enhanced by ultralow-loss micro-ring resonators. Due to the large spatial extent of Rydberg atoms, we carefully design the ring resonators to realize sufficient interactions between Rydberg atoms and the evanescent mode of the resonator. In order to create individual photons deterministically, we use the Four-Wave-Mixing (FWM) process in the Rydberg blockade regime to develop a single-photon-source at room temperature.

In parallel, we also explore the coherent atom-light interaction in the strong coupling regime with the help of the photonic crystal cavity (PhC). The strong field confinement and relatively high quality factor of PhCs overcome the dephasing during the short atom-light interaction period. This allows us to investigate cavity QED effects that are sensitive to single photons and single atoms. We also study topological edge states in arrays of ring resonators coupled to thermal atoms to study the effect of optical nonlinearity on the bulk and edge modes.

A 12.25 Tue 16:30 Empore Lichthof

Search for double core-hole states in Xe clusters — •Niklas Golchert[1], Nils Kiefer[1], Lutz Marder[1], Catmarna Küstner-Wetekam[1], Emilia Heikura[1], Johannes Viehmann[1], Francis Penent[2], Jérôme Palaudoux[2], Christophe Nicolas[3], Arno Ehresmann[1], and Andreas Hans[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Sorbonne Université, CNRS, Laboratoire de Chimie Physique-Matière et Rayonnement, LCPMR, F-75005 Paris Cedex 05, France — [3]Synchrotron SOLEIL, L'Orme des Merisiers, Saint-Aubin, BP 48, F-91192 Gif-sur-Yvette Cedex, France

Excited or ionized loosely bound atomic or molecular systems like clusters may undergo new interatomic and intermolecular relaxation processes being impossible in isolated systems. Noble-gas clusters are, due to their low chemical reactivity, well suited to investigate such fundamental relaxation processes. In the present work, the formation and decay of double core-holes (DCHs) in the 4d shell of xenon clusters upon photoionization is investigated. DCHs can enhance the chemical shift in molecules, which makes them important in ESCA (Electron Spectroscopy for chemical analysis). Two different paths were used to create the double core-holes, namely single-photon double ionization, and via $M_{4,5}N_{4,5}N_{4,5}$ Auger after single-photon 3d-electron photoionization. Measurements were performed with a multi-electron coincidence technique using a magnetic-bottle-type time-of-flight spectrometer and synchrotron radiation. Here, we present first results of the outlined processes.

A 12.26 Tue 16:30 Empore Lichthof

The Attoclock and its Interpretations, Theoretically and Experimentally — •Ossama Kullie — Institute for Physics, University of Kassel.

The measurement of the tunneling time in experiments with intense short laser pulse, termed attoclock, triggered a hot debate about the tunneling time and the separation into two regimes of ionization, the multiphoton and the tunneling. Theoretically, a crucial issue is the tunneling time, whether it is a real, which implies that time is an observable in QM, or an imaginary quantity, which implies that time is a parameter in QM. Another point is the statistical interpretation of the tunneling time. nevertheless, our real tunneling time is conform with the statistical point of view. Experimentally the issue is crucial since the result depends on the field strength calibration, and its consequence for the tunneling or multiphoton ionization regimes and hence the interpretation of the theoretical result. In our picture we illustrate these issues in the theory with comperision to experimental result. [1] O. Kullie. Phys. Rep. 2020,2, 233. [2] O. K. Phys. Rev. A. **92**, 052118 (2015), [3] O. K. Ann. of Phys. **389**, 333 (2018), [4] O. K. Mathematics **6**, 192 (2018). [5] O. K. J. Phys. B **49**, 095601, (2016).

A 12.27 Tue 16:30 Empore Lichthof

Sensitivity to new physics of forbidden optical transitions in highly charged ions — •Nils-Holger Rehbehn[1], Michael Karl Rosner[1], Julian C. Berengut[1,2], Piet O. Schmidt[3,4], and José R. Crespo López-Urrutia[1] — [1]Max-Planck Institut für Kernphysik, Heidelberg, Germany — [2]School of Physics, University of New South Wales, Sydney, Australia — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Leibniz Universität, Hannover, Germany

One potential dark matter candidate is a light boson coupling neutrons and electrons. Such a hypothetical fifth force could be detected through so-called King plots, where the isotope shifts of two optical transitions are plotted against each other for a series of isotopes. Deviations from the expected linearity could reveal such a fifth force. To extract non-linearity effects by higher-order SM, the generalized King plot can be used, which requires an extended number of transitions and isotopes. For this, we investigate in calcium and xenon forbidden transitions in highly charged states. We analyze theoretically their King plot sensitivity to a hypothetical fifth-force, for future high-precision coherent laser spectroscopy measurements.

A 12.28 Tue 16:30 Empore Lichthof

Coherent x-ray double-pulse generation — •Junhee Lee and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

A scheme for producing coherent x-ray double-pulses of nanosecond-scale duration and temporal separation is devised, based on the Mössbauer effect of ^{57}Fe operating at 14.4 keV. Our work is motivated by the recent demonstration of the coherent control of nuclear dynamics using double-pulses with tunable relative phase [1]. The temporal phase of the x-rays can be employed to shape their pulse spectra [2], similar to pulse-shape control at lower frequencies. Also the splitting of γ-ray photons into double-pulses or trains has been demonstrated [3]. However, further progress in the coherent manipulation of nuclear dynamics requires more versatile pulse control. Here, we propose a new method to control the time-dependent phase and temporal intensity. Our approach is based on the coherent scattering enabled by the Mössbauer effect, with additional phase control realized using mechanical displacements. By using multiple Mössbauer targets, interference between the different scattering channels can be enginered in such a way that the desired intensity modulation is achieved.

[1] K. P. Heeg et al., *Coherent x-ray-optical control of nuclear excitons*, Nature 590, 401 (2021).
[2] K. P. Heeg et al., *Spectral narrowing of x-ray pulses for precision spectroscopy with nuclear resonances*, Science 357, 375 (2017).
[3] F. Vagizov et al., *Coherent control of the waveforms of recoilless γ-ray photons*, Nature 508, 80 (2014).

A 12.29 Tue 16:30 Empore Lichthof

Polarons and bipolarons in a two-dimensional square lattice — •Gustavo Alexis Dominguez Castro — Institute for Theoretical Physics, Hannover university

Quantum simulation experiments with cold atoms have in recent years advanced our understanding of isolated quasiparticles, but so far they have provided limited information regarding their interactions and possible bound states. Here, we show how exploring mobile impurities immersed in a Bose-Einstein condensate in a two-dimensional lattice can address this problem. First, the spectral properties of individual impurities are examined, and in addition to the attractive and repulsive polarons known from continuum gases, we identify a new kind of quasiparticle stable for repulsive boson-impurity interactions. The spatial correlations between the impurity and the bosons are calculated showing that there is an increased density of bosons at the site of the impurity both for repulsive and attractive interactions. We then derive an effective Schrödinger equation describing two polarons interacting via the exchange of density oscillations in the BEC. Using this, we show that the attractive nature of the effective interaction between two polarons mediated by the BEC combined with the two-dimensionality of the lattice leads to the formation of bound states. Our results show that optical lattices are a promising platform to explore the spatial properties of polarons as well as to finally observe the elusive bipolarons.

A 12.30 Tue 16:30 Empore Lichthof

Towards a compound ^{27}Al - ^{40}Ca and multi-ion ^{40}Ca clock — •Lennart Pelzer[1], Johannes Kramer[1,2], Kai Dietze[1,2], Fabian Dawel[1,2], Marek Hild[1,2], Victor Martinez-Lahuerta[2], Klemens Hammerer[2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Optical atomic clocks based on a single aluminium ion reach a record fractional frequency systematic uncertainty below 10^{-18}. This outstanding precision allows for applications like relativistic geodesy on the cm-level and helps to tighten the bounds for physics beyond the standard model. But single ion clocks are impeded by their low signal-to-noise ratio and require therefore long averaging times. Even state-of-the-art laser stabilization is not sufficient to enable lifetime-limited interrogation of $^{27}Al^+$. Thus, pre-stabilization of the clock laser via a $^{40}Ca^+$ multi-ion reference could further improve the coherence time of the laser and thus increase the interrogation time on $^{27}Al^+$. Here we present the status of PTB's $^{27}Al^+$ clock and the implementation of a multi-ion Ca^+ reference based on dynamical decoupling. The estimated error budget of 1×10^{-18} of the $^{27}Al^+$ clock is based on measurements using a $^{40}Ca^+$ ion as a sensor. A continuous dynamic decoupling scheme is used to suppress inhomogeneous broadening from quadrupole and tensor ac Stark shifts in multi-ion $^{40}Ca^+$ crystals. Simultaneous suppression of first order Zeeman shifts allows interrogation of the crystal close to its natural lifetime limit.

A 12.31 Tue 16:30 Empore Lichthof

Numerical Description of Single-Cycle Electron Emission from Tungsten Nanotips — •Elisabeth Anne Herzig, Lennart Seiffert, and Thomas Fennel — University of Rostock, Institute of physics, Albert-Einstein-Straße 23, 18059 Rostock

Exposing nanostructures to strong fields enables the emission of energetic electrons via near-field driven elastic backscattering [1]. The availability of intense single cycle or sub-single cycle waveforms [2, 3] will enable to explore the formation and propagation of attosecond electron pulses in previously inaccessible regimes of the strong-field interaction. Here, the electron emission from tungsten nanotips under intense single-cycle pulses is inspected theoretically via one-dimensional TDSE simulations. The calculated carrier-envelope phase-dependent photoelectron energy spectra reveal prominent signatures with pronounced differences to previous studies performed with many-cycle pulses [4]. The physical origins behind the observed spectral features are disentangled by extending the famous Simple Man's Model of strong-field physics. Furthermore, collective effects can be unveiled within the one-dimensional time-dependent density functional theory. Here, first insights will be presented and discussed.

[1] M. F. Ciappina et al., Rep. Prog. Phys. 80, 054401 (2017)
[2] A. Wirth et al., Science 334, 195 (2011)
[3] M. T. Hassan et al., Nature 530, 66 (2016)
[4] L. Seiffert et al., J. Phys. B 51, 134001 (2018)

A 12.32 Tue 16:30 Empore Lichthof

Highly stable optical benches for the BECCAL ISS mission — •Jean Pierre Marburger[1], Faruk Alexander Sellami[1], Marc Kitzmann[3], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Tim Kroh[3], Victoria Henderson[3], Patrick Windpassinger[1], and the MAIUS and BECCAL team[1,3,4,5,6,7,8,9,10,11] — [1]Institut für Physik, JGU, Mainz — [2]ILP, UHH, Hamburg — [3]Institut für Physik, HU Berlin, Berlin — [4]FBH, Berlin — [5]IQ & IMS, LUH, Hannover — [6]ZARM, Bremen — [7]Institut für Quantenoptik, Universität Ulm, Ulm — [8]DLR-SC, Braunschweig — [9]DLR-SI, Hannover — [10]DLR-QT, Ulm — [11]OHB SE, Bremen

The NASA-DLR BECCAL mission is a multi-user experimental facility that will enable many quantum optical experiments aboard the ISS, using different isotopes of rubidium and potassium. For intensity control and distribution of the required light fields, we make use of our fiber-to-fiber coupled optical bench toolkit which has previously been and will be employed in sounding rocket missions such as KALEXUS, FOKUS, MAIUS-1/2/3. In contrast, the ISS imposes even harsher conditions, such as a further limited SWAP budget and a much longer mission duration, necessitating further improvements. The presented poster will cover technical demonstrators and tests we have performed to ascertain the suitability of these improvements. Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WP 1703 and 50 WP 2103.

A 12.33 Tue 16:30 Empore Lichthof

Setup of a calcium beam clock — •Lukas Möller, Anica Hamer, Lara Becker, and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn, Germany

The use of optical transitions as frequency standards for highly accurate and precise time keeping is well-established around the world. A calcium beam clock offers the high performance of an optical clock, inside a compact design. The goal of this project is to build a calcium beam clock, which will at first be used as a test setup for high precision isotope shift measurements. We plan to eventually make the setup available as an experiment as part of a masters-level laboratory course. On this poster I will report on the current progress of the setup.

A 12.34 Tue 16:30 Empore Lichthof

Exploring the Many-Body Dynamics Near a Conical Intersection with Trapped Rydberg Ions — •Abdessamad Belfakir[1], Filippo Gambetta[2], Chi Zhang[3], Markus Hennrich[3], Igor Lesanovsky[4], and Weibin Li[1] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [2]Phasecraft Ltd, Bristol, United Kingdom — [3]Department of Physics, Stockholm University, 10691 Stockholm, Sweden — [4]Institut für Theoretische Physik, University of Tübingen, 72076 Tübingen, Germany

We demonstrate that trapped Rydberg ions are a platform to engineer conical intersections and to simulate their ensuing dynamics on larger length scales and timescales of the order of nanometres and microseconds, respectively; all this in a highly controllable system. In this context, the shape of the potential energy surfaces and the position of the conical intersection can be tuned thanks to the interplay between the high polarizability and the strong dipolar exchange interactions of Rydberg ions. We study how the presence of a conical intersection affects both the nuclear and electronic dynamics demonstrating, in particular, how it results in the inhibition of the nuclear motion. These effects can be monitored in real time via a direct spectroscopic measurement of the electronic populations in a state-of-the-art experimental setup. We further explore topological dynamics of the spin-phonon coupled dynamics near the conical intersection.

A 12.35 Tue 16:30 Empore Lichthof

A calcium beam clock for high-precision isotope shift measurements — •Anica Hamer and Simon Stellmer — Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany

In the pursuit of finding new particles and new physics beyond the standard model (BSM), the isotope shift of optical transitions treasures a wealth of information on the interaction between the nucleus and the electrons. It can be an approach to find evidence for novel types of interactions between neutrons and electrons that might be mediated by new bosons as force carriers with masses in the 1 keV to 100 MeV mass range [Berengut, PRL 120, 091801].

Calcium is an excellent candidate for BSM searches via isotope shift spectroscopy possessing five stable bosonic isotopes. Where in heavier elements like Ytterbium BSM effects are hard to distinguish from SM effects like quadratic field shift and nuclear deformations [Hur, PRL 128, 163201], the latter are strongly suppressed in the Ca nucleus. We can also benefit from King plot comparisons to ionic Ca data, where latest precision isotope spectroscopy [Solaro, PRL 125, 123003; Gebert, PRL 115, 0530039] down to the Hz-level can already put a limit on BSM scenarios.

The goal of this project is a highly precise determination of the isotope shifts in Ca on the $^1S_0 \to {}^3P_1$ (657 nm, 370 Hz linewidth) and $^1S_0 \to {}^1D_2$ transitions (458 nm, < 1 kHz) with target uncertainties in the 10 mHz range. The concept is based on Ramsey-Bordé atomic clock setup where two isotopes are interrogated co-located and simultaneously to suppress systematic shifts.

A 12.36 Tue 16:30 Empore Lichthof

Lattice control of non-ergodicity in a polar lattice gas — •Henning Korbmacher — Leibniz Universität Hannover, Institut für theoretische Physik, Hannover, Germany

Inter-site interactions in polar lattice gases may result, due to Hilbert-space fragmentation, in a lack of ergodicity even in absence of disorder. We show that the inter-site interaction in a one-dimensional dipolar gas in an optical lattice departs from the usually considered 1/r^3 dependence, acquiring a universal form that depends on the transversal confinement and the lattice depth. Due to the crucial role played by the nearest- and next-to-nearest neighbors, the Hilbert-space fragmentation and particle dynamics are very similar to that of a power-law model 1/r^b, where b<3 is experimentally controllable by properly tailoring the transversal confinement. Our results are of direct relevance for experiments on dipolar gases in optical lattices and show that the particle dynamics may be remarkably different if the quasi-1D lattice model is realized in a strong 3D lattice or by means of a strong transversal harmonic confinement.

A 12.37 Tue 16:30 Empore Lichthof

Probing the spatio-temporal dynamics of Ion-Rydberg hybrid systems using a high-resolution ion microscope — •Viraatt S. V. Anasuri[1], Moritz Berngruber[1], Yi-Quan Zou[1], Óscar Andrey Herrera Sancho[1,2], Ruven Conrad[1], Nicolas Zuber[1], Florian Meinert[1], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Escuela de Física and Centro de Investigación en Ciencias Atómicas Nucleares y Moleculares, Universidad de Costa Rica, 2060 San Pedro, San José, Costa Rica

The long-range interaction between an ion and a highly excited Rydberg atom lead to fascinating dynamical phenomena with exaggerated spatial and temporal properties that are accessible using our high-resolution ion microscope. We study the vibrational dynamics of molecular bound states that are formed in the potential wells located at the avoided crossings between the Rb nP Rydberg state and the hydrogenic manifold. We observe oscillations of the wavepacket within the molecular potential with a frequency, orders of magnitude slower than that observed in conventional molecules. To investigate the fermionic correlations in a Fermi gas, we are upgrading our apparatus to produce an ultracold gas of Lithium atoms. To this end, we are currently planning a dual species atomic source for Rb and Li, which in combination with our currently being used dual species Zeeman slower will aid us in our goal to extend our current studies to a multi-species hybrid system.

A 12.38 Tue 16:30 Empore Lichthof

Addressing Rydberg s- and p-states in optical tweezers — •Roxana Wedowski, Ludwig Müller, Lea-Marina Steinert, Philip Osterholz, Arno Trautmann, and Christian Gross — Eberhard Karls Universität, Tübingen, Germany

Rydberg atom-based quantum simulators offer unique capabilities to implement strongly correlated many-body phenomena. An experimental system with single potassium-39 atoms placed in 2D arrays of optical tweezers allows us to study renowned models in spin physics, such as XYZ-type spin interactions. So far, this has been realized by off-resonant coupling via a single photon transition to Rydberg states. Here, we present an upgrade to the UV Laser system for the one photon excitation by elimination of limiting factors like phase noise. Additionally, a two-photon excitation scheme is implemented offering increased tunability. The flexible design of the simulated Hamiltonian, combined with the geometrical versatility of the system, is expected to reveal exciting prospects for the implementation of quantum magnets and nonlinear enhanced detection.

A 12.39 Tue 16:30 Empore Lichthof

Direct Frequency Comb Spectroscopy of the 1S-3S Transition in Hydrogen — •Derya Taray[1], Alexey Grinin[1], Vitaly Wirthl[1], Omer Amit[1], Arthur Matveev[1], Dylan Yost[3], Randolf Pohl[4], Thomas Udem[1,2], and Theodor W. Hänsch[1,2] — [1]Department for Laser Spectroscopy, Max Planck Institute of Quantum Optics, 85748 Garching, Germany — [2]Ludwig Maximilian University, 80539 Munich, Germany — [3]Department of Physics, Colorado State University, Fort Collins, CO, USA — [4]Institute of Physics, QUANTUM and Cluster of Excellence PRISMA+, Johannes Gutenberg University, 55128 Mainz, Germany

The energy levels of the hydrogen atom can be both calculated and measured very precisely. Precision spectroscopy on these transitions therefore, allows the determination of fundamental constants and testing the theory of QED for completeness.

Here we present the latest measurement of the 1S-3S transition, using two photon direct frequency comb spectroscopy. Its implications for the purposes mentioned above are shown together with additional measurements in hydrogen. Also we give an outlook on the next anticipated measurements, current problems and improvements of the experiment.

A 12.40 Tue 16:30 Empore Lichthof

Experimental quantification of Interatomic Coulombic Decay in rare gas clusters after inner-shell ionization — Catmarna Küstner-Wetekam, Lutz Marder, Dana Bloss, Nils Kiefer, •Isabel Ludwig, Arno Ehresmann, and Andreas Hans — Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Non-local decay mechanisms like Interatomic Coulombic Decay (ICD) are of great interest to understand radiation damage in biologically relevant samples. Weakly bound rare gas clusters can be used as a prototype system to study these processes in a less complex sample. In order to measure comparatively weak processes such as ICD after inner-shell ionization, it is neccessary to use multi-coincidence spectroscopy, particularly electron-electron and electron-electron-photon coincidences. Here, we present a method to quantify the branching ratio of the core-level ICD to competing local Auger decays in pure argon and krypton clusters.

A 12.41 Tue 16:30 Empore Lichthof

Theoretical study of radio-frequency induced Floquet Feshbach resonances in ultracold Lithium-6 gases — •Alexander Guthmann and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Feshbach resonances are an indispensable tool in the research of ultracold atoms. The position of magnetic Feshbach resonances is determined by the magnetic field value where the energy of a dimer bound state crosses the asymptotic atomic threshold. By applying an oscillating magnetic field in the radio frequency regime, the colliding atom pair can be coupled to the dimer state, and new Feshbach resonances at different magnetic field values can be produced. Using techniques of Floquet theory, we convert the time-dependent problem into an equivalent time-independent problem, and derive a Hamiltonian which can be used for coupled-channel calculations. We use the example of Lithium-6 featuring an unusually broad s-wave resonance at 832G caused by a weakly bound halo state. Results from coupled-channel calculations show that this halo state allows the creation of RF-induced resonances with large widths and tunability at technically achievable modulation strengths. These theoretical investigations will be presented, and the possibilities of experimental observation and associated technical challenges will be discussed.

A 13: Highly Charged Ions and their Applications I

Time: Wednesday 11:00–13:00 Location: F107

Invited Talk A 13.1 Wed 11:00 F107

Stability and Melting Dynamics of Mixed Species Coulomb Crystals with Highly Charged Ions — •Luca Rüffert[1], Elwin Dijck[2], Tanja Mehlstäubler[1], and José Crespo[2] — [1]Bundesallee 100, 38116 Braunschweig — [2]Saupfercheckweg 1, 69117 Heidelberg

Coulomb Crystals of various ionic species confined by a Paul trap are being used in a variety of different applications spanning from high precision spectroscopy to quantum information processing. In particular, multi-ion atomic clocks could offer increased precision and mixed crystals with highly charged ions enable the use of quantum logic operations. Pick up of electric field noise and insufficient cooling can cause those crystals to heat up and affect the systems stability in a negative way to the point of angular or radial melting. Investigating the melting dynamics of mixed species crystals aids in finding robust operating parameters to mitigate heating effects.

In collaboration between PTB Braunschweig and MPIK we are using highly charged ions implanted in Be+ ion crystals of various sizes to analyze the effects of those highly charged ions (HiCIs) on the structural stability of ion coulomb crystals (ICCs). By running Monte Carlo simulations and directly compare them to the experiment, our goal is to show how the inclusion of HiCIs inside an ICC can enhance the stability and therefore increase the melting temperature of those systems. In addition varying the charge state of the highly charged ion allows to investigate the effect of differing charge-to-mass ratios. I will present the current state of our research and discuss the different criterions for the melting of ICCs.

A 13.2 Wed 11:30 F107

Scaling relations for hydrogen-like ions in intense laser fields in the quasi-static regime — •Anvar Khujakulov and Alejandro Saenz — Newtonstraße 15, 12489 Berlin

With the availability of light sources with extreme intensities, the understanding of the behaviour of matter exposed to such light fields is of great interest. The full solution of the time-dependent Dirac equation is, however, even for the simlest system, hydrogen-like ions exposed to such light sources, prohibitively difficult. On the other hand, for highly charged ions even when exposed to intense x-rays, ionization usually occurs in the so-called quasi-static regime where the initially bound electron follows adiabatically the time variation of the electric-field component. Therefore, a systematic investigation of the ionization behaviour in the static limit was performed. Approximate scaling relations were found that allow for the prediction of the ionization rate of a highly charged ion exposed to an intense field based on the results of a lighter ion exposed to a weak field. Most importanly, a scaling relation is found that allows for obtaining results in very good agreement with the Dirac equation from the solution of a scaled Schröodinger-equation. The results should be useful for plasma simulations, the design of experiments, the isolation of relativistic effects, or the calibration of light sources with extreme peak intensities.

A 13.3 Wed 11:45 F107

Highly Efficient Dynamic Capture of Ion Bunches into a Penning Trap for high-intensity Laser Experiments — •Markus Kiffer[1], Stefan Ringleb[1], Sugam Kumar[3], Manuel Vogel[2], Gerhard Paulus[1], Wolfgang Quint[2,5], and Thomas Stöhlker[1,2,4] — [1]Friedrich-Schiller-Universität, Jena — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Inter-University Accelerator Centre, New Delhi — [4]Helmholtz-Institut Jena, Jena — [5]Ruprecht Karls-Universität Heidelberg, Heidelberg

Highly-charged ions are an ideal candidate to investigate matter-light interactions. In particular, hydrogen-like systems provide a single active electron in a well-defined 1s state. For ions, such as O^{7+} or Ne^{9+}, the mean electric field intensity of the nucleus is on the order of 10^{20} W/cm^2, which is in the range of high-intensity laser systems. This presents the opportunity to measure relativistic tunnel ionisation or HHG generation in highly charged ions.

We present the status of the HILITE (High-Intensity Laser Ion-Trap Experiment) Penning trap experiment. HILTE provides a well-defined ion target for experiments at external laser facilities. The setup includes an ion source that creates bunches of various ions species. These bunches are transported by a beamline and captured dynamically into a Penning trap. We will show results of highly efficient ion bunch capture as well as ion cloud manipulation techniques to provide a high-density ion target. We will also introduce the scientific case of our next planned beamtime at the JETI200 laser facility in Jena.

A 13.4 Wed 12:00 F107

Laser cooling of bunched relativistic ion beams at the FAIR SIS100 — •Sebastian Klammes[1], Michael Bussmann[2,3], Jens Gumm[4], Volker Hannen[5], Thomas Kühl[1,6], Benedikt Langfeld[4], Ulrich Schramm[2,7], Mathias Siebold[2], Peter Spiller[1], Thomas Stöhlker[1,6,8], Ken Ueberholz[5], Thomas Walther[4,9], and Danyal Winters[1] — [1]GSI Darmstadt — [2]HZDR Dresden — [3]CASUS Görlitz — [4]TU-Darmstadt — [5]Uni Münster — [6]HI-Jena — [7]TU-Dresden — [8]Uni-Jena — [9]HFHF Frankfurt am Main

The heavy-ion synchrotron SIS100 is the core machine of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. It is capable of accelerating a large range of ions, which will be produced by the upgraded GSI facility, up to highly relativistic velocities and extracting them for unique experiments, e.g. APPA/SPARC. In order to cool such intense beams of heavy highly charged ions, laser cooling of bunched ion beams was preferred. Therefore, laser beams from three complementary laser systems (cw and pulsed) will be superimposed in time, space and frequency to interact simultaneously with a very broad ion velocity range to maximize the cooling efficiency at the SIS100. With the construction of the synchrotron, the laser cooling pilot facility at SIS100, being also the only in-ring experiment, is currently being realized. We will present this project, give an update of its current status and also give an overview of the laser and detector systems that will be used.

A 13.5 Wed 12:15 F107

Broadband laser cooling of stored relativistic bunched ion beams at the ESR — •Danyal Winters[1], Lars Bozyk[1], Michael Bussmann[2,3], Noah Eizenhöfer[4], Volker Hannen[5], Max Horst[4,9], Daniel Kiefer[4], Nils Kiefer[6], Sebastian Klammes[1], Thomas Kühl[1,7], Benedikt Langfeld[4,9], Xinwen Ma[8], Wilfried Nörtershäuser[4,9], Rodolfo Sánchez[1], Ulrich Schramm[2,10], Mathias Siebold[2], Peter Spiller[1], Markus Steck[1], Thomas Stöhlker[1,7,11], Ken Ueberholz[5], Thomas Walther[4,9], Hanbing Wang[8], Weiqiang Wen[8], and Daniel Winzen[5] — [1]GSI Darmstadt — [2]HZDR Dresden — [3]CASUS Görlitz — [4]TU Darmstadt — [5]Uni Münster — [6]Uni Kassel — [7]HI Jena — [8]IMP Lanzhou — [9]HFHF Darmstadt — [10]TU Dresden — [11]Uni-Jena

High-precision experiments at heavy-ion storage rings strongly benefit from cold ion beams, *i.e.* beams with a small longitudinal momentum spread and a small emittance. Especially for the higher ion intensities and Lorentz factors (γ) at FAIR (SIS100), laser cooling will be a powerful tool for cooling of relativistic bunched ion beams. The principle is based on resonant photon absorption (momentum & energy) in the longitudinal direction and subsequent spontaneous fluorescence (ion recoil) by the ions, combined with a moderate bunching of the ion beam. We will report on results from a 2021 laser cooling beamtime at the ESR. We could demonstrate - for the first time - broadband laser cooling of stored relativistic bunched ion beams, using a new pulsed UV laser system with a very high repetition rate (MHz), tunable pulse length, and high power.

A 13.6 Wed 12:30 F107

Towards electron cooling in the HITRAP cooling trap — •Simon Rausch[1,2], Max Horst[1,2], Zoran Andelkovic[3], Svetlana Fedotova[3], Wolfgang Geithner[3], Frank Herfurth[3], Dennis Neidherr[3], Wilfried Nörtershäuser[1,2], Nils Stallkamp[3,4], and Gleb Vorobyev[3] — [1]Institut für Kernphysik, TU Darmstadt, Schloßgartenstr. 9, Darmstadt — [2]Helmholtz Akademie Hessen für FAIR HFHF, Campus Darmstadt, Darmstadt — [3]GSI Helmholtzzentrum, Planckstr. 1, Darmstadt — [4]Institut für Kernphysik, JWGU Frankfurt, Max-von-Laue-Str. 9, Frankfurt a. M.

The HITRAP project at the GSI Helmholtzzentrum für Schwerionenforschung is designed to decelerate and cool heavy, highly charged ions. After deceleration to 6 keV/nucleon, the ion cloud can be captured within a Penning-Malmberg trap and cooled using electron cooling. For this, electrons and ions are stored simultaneously in a nested-trap configuration to enable energy transfer between them.

We present the current status of the HITRAP cooling trap and the next steps towards achieving electron cooling. We were able to capture several 10^5 highly charged Ar-ions, delivered by an EBIT at 4 keV/q. Simultaneously, about 10^9 electrons can be stored in the trap. Although the ions visibly effect the electron plasma, no cooling was observed so far. It was possible to detect ion motions, dependencies of ion properties on the storage time and to observe the space charge induced by the electron cloud. The next steps will include implementing additional detection methods in order to demonstrate electron cooling.

Funding by BMBF under contract 05P21RDFA1 is acknowledged.

A 13.7 Wed 12:45 F107

Cryogenic fast-opening valve at the ARTEMIS experiment at GSI in Darmstadt — •Bianca Reich[1,2], Khwaish Anjum[1,3], Patrick Baus[4], Gerhard Birkl[4], Manasa Chambath[1,5], Jan Hellmann[1,6], Kanika Kanika[1,2], Jeffrey Klimes[1,2], Arya Krishnan[1,4], Wolfgang Quint[1,2], Wolfgang Schott[1,7], and Manuel Vogel[1] — [1]GSI Helmholtz Center for Heavy Ion Research, Germany — [2]University of Heidelberg, Germany — [3]University of Jena, Germany — [4]Technical University of Darmstadt, Germany — [5]NITTE University, India — [6]University of Giessen, Germany — [7]Technical University of Munich, Germany

The ARTEMIS experiment at the HITRAP facility at GSI in Darmstadt aims to measure the g-factor of an electron bound to a highly charged ion by performing laser-microwave double-resonance spectroscopy. To separate the Penning trap at liquid-helium temperature to a room-temperature low-energy beamline for dynamic capture of externally produced ions a cryogenic fast-opening valve was conceived, built and implemented. The main advantage of the valve is the remote-controlled operation within sub-second times without disturbing the magnetic field of the trap. It keeps the ambient conditions inside the trap stable by effectively shielding heat radiation and separating the beamline vacuum with several 10^{-10} mbar from the cryogenic vacuum of the Penning trap with better than 10^{-16} mbar in a completely sealed state and better than 10^{-14} mbar when the valve is operated. Whereby the pressure inside the trap is estimated from the lifetime of the captures ions. The design and measurements will be presented.

A 14: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: F303

Invited Talk A 14.1 Wed 11:00 F303

Realization of the Periodic Quantum Rabi Model in the Deep Strong Coupling Regime with Ultracold Rubidium Atoms — •Stefanie Moll[1], Geram Hunanyan[1], Johannes Koch[1], Enrique Rico[2,3], Enrique Solano[2,3], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain

At moderate coupling strengths, the interaction of light and matter is well described in terms of the Jaynes-Cummings model. However, when the coupling strength approaches the optical resonance frequency, the system enters the deep strong coupling regime, where the full quantum Rabi Hamiltonian applies, leading to non-intuitive dynamics.

In our experiment we realize the quantum Rabi model using ultracold Rubidium atoms in an optical lattice potential, creating an effective two-level system, here encoded in different Bloch bands. The bosonic mode is represented by the oscillation of atoms in a superimposed optical dipole trapping potential.

We observe atomic dynamics in the deep strong coupling regime with the cold atoms system. At long interaction times we observe collapse and revival of the initial state, as can be described within the so-called periodic quantum Rabi model.

A 14.2 Wed 11:30 F303

Metastable phases in spinor Bose-Einstein condensates at finite temperatures — •Eduardo Serrano-Ensástiga[1,2] and Francisco Mireles[1] — [1]Departamento de Física, Centro de Nanociencias y Nanotecnología, Universidad Nacional Autónoma de México, Ensenada, Baja California, México — [2]Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, Liège, Belgium

Spinor Bose-Einstein condensates (BEC) with the spin as a degree of freedom have been studied intensively since its first experimental realization in 1998. A field with current scientific interest is the presence of metastable phases and their role in a variety of phenomena, such as domain formation, quench dynamics, or quantum dynamical phase transitions, among others. In this talk, we present the metastable spin-phase diagrams of a spinor BEC at finite temperatures for spin 1 and 2. The resulting phase diagrams offer further insights of the different quench dynamics observed in experiments, and they allow us to infer similar quench processes due to a sudden change in the temperature or other external fields. Our approach starts with the Hartree-Fock (HF) approximation but takes advantage of the common symmetries between the Hamiltonian and the order parameter. [1] E. Serrano-Ensástiga and F. Mireles, Phys. Rev. A 104, 063308 (2021). [2] E. Serrano-Ensástiga and F. Mireles, arXiv:2211.16428 (2022).

A 14.3 Wed 11:45 F303

Ultradilute quantum liquid of dipolar atoms in a bilayer — •Grecia Guijarro[1,2], Grigory Astrakharchik[1], and Jordi Boronat[1] — [1]Theoretische Physik, Saarland University, Campus E2.6, 66123 Saarbrücken, Germany — [2]Departament de Física, Universitat Politècnica de Catalunya, Campus Nord B4-B5, 08034 Barcelona, Spain

We show that ultradilute quantum liquids can be formed with ultracold bosonic dipolar atoms in a bilayer geometry. Contrary to previous realizations of ultradilute liquids, there is no need of stabilizing the system with an additional repulsive short-range potential. The advantage of the proposed system is that dipolar interactions on their own are sufficient for creation of a self-bound state and no additional short-range potential is needed for the stabilization. We perform quantum Monte Carlo simulations and find a rich ground state phase diagram that contains quantum phase transitions between liquid, solid, atomic gas, and molecular gas phases. The stabilization mechanism of the liquid phase is consistent with the microscopic scenario in which the effective dimer-dimer attraction is balanced by an effective three-dimer repulsion. The equilibrium density of the liquid, which is extremely small, can be controlled by the interlayer distance. From the equation of state, we extract the spinodal density, below which the homogeneous system breaks into droplets. Our results offer a new example of a two-dimensional interacting dipolar liquid in a clean and highly controllable setup.

A 14.4 Wed 12:00 F303

strongly-interacting bosons at 2D-1D dimensional crossover — •Hepeng Yao, Lorenzo Pizzino, and Thierry Giamarchi — DQMP, University of Geneva, 24 Quai Ernest-Ansermet, CH-1211 Geneva, Switzerland

Quantum gases at dimensional crossover exhibit fruitful physics which reflects fascinating properties of non-integer dimensions. While various fascinating researches have been carried out in the tight-binding limit [1,2], the smooth dimensional crossover for strongly-interacting ultracold bosons in continuous lattice, which is strongly adapted to current generation of experiments, is rarely studied. In this talk, I will present our study about strongly-interacting bosons under continuous potential at 2D-1D dimensional crossover [3]. Using quantum Monte Carlo calculations, we investigate this dimensional crossover by computing longitudinal and transverse superfluid fractions as well as the superfluid correlation as a function of temperature, interactions and potential. Especially, we find the correlation function evolves from a Berezinskii-Kosterlitz-Thouless (BKT) to Tomonaga-Luttinger liquid (TLL) type, with the coexistence of 2D and 1D behaviors appearing at the dimensional crossover. In the end, I will discuss the consequences of these findings for cold atomic experiments

[1]. M. Cazalilla, A. Ho, and T. Giamarchi, New Journal of Physics 8(8), 158 (2006)

[2]. G. Bollmark, N. Laflorencie, and A. Kantian, Phys. Rev. B 102, 195145 (2020)

[3]. H. Yao, L. Pizzino, T. Giamarchi, arXiv:2204.02240(2022)

A 14.5 Wed 12:15 F303

Making statistics work: a quantum engine in the BEC-BCS crossover — •Jennifer Koch[1], Keerthy Menon[2], Eloisa Cuestas[2], Sian Barbosa[1], Eric Lutz[3], Thomás Fogarty[2], Thomas Busch[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]OIST Graduate University, Onna, Okinawa, Japan — [3]Institute for Theoretical Physics I, University of Stuttgart, Germany

Heat engines convert thermal energy into mechanical work both in the classical and quantum regimes. However, quantum theory offers genuine nonclassical forms of energy, different from heat, which so far have not been exploited in cyclic engines to produce useful work. In this talk, we present the experimental realization of a novel quantum many-body engine fuelled by the energy difference between fermionic and bosonic ensembles of ultracold particles that follows from the Pauli exclusion principle. We employ a harmonically trapped superfluid gas of ^{6}Li atoms close to a magnetic Feshbach resonance which allows us to effectively change the quantum statistics from Bose-Einstein to Fermi-Dirac. We replace the traditional heating and cooling strokes of a quantum Otto cycle by tuning the gas between a Bose-Einstein condensate and a unitary Fermi gas (and back) through a magnetic field. In the talk, we will focus on the quantum nature of such a Pauli engine, which is revealed by contrasting it to a classical thermal engine and to a purely interaction-driven device. Our findings establish quantum statistics as a useful thermodynamic resource for work production.

[1] Koch, J. et al. arXiv: 2209.14202 (2022)

A 14.6 Wed 12:30 F303

Induced interaction between ionic polarons in condensates — •Luis Ardila — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

In this talk, we will discuss ionic polarons and their induced interaction created as a result of charged particles interacting with a Bose-Einstein condensate. Here we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state. Using quantum Monte Carlo simulations, we unravel its vastly different polaronic properties compared to neutral quantum impurities. Moreover, we identify a transition between the regime amenable to conventional perturbative treatment in the limit of weak atom-ion interactions and a many-body bound state with vanishing quasi-particle residue composed of hundreds of atoms. Contrary to the case of neutral impurities, ionic polarons can bound many excitations and bosons from the condensate, forming many-body bound-states and changing the ground-state properties of the polaron radically. Also, transport properties are accessible by using external electric fields. Finally, we investigate the specific case of two ions that mediate interactions via the bosonic bath. This interaction can be sizable with respect to the Coulomb interaction, giving rise to notable effects which may have direct consequences in the platform employed for future quantum technologies.

A 14.7 Wed 12:45 F303

Observation of Universal Hall Response in Strongly Interacting Fermions — •Tianwei Zhou[1], Giacomo Cappellini[2,3], Daniele Tusi[2], Lorenzo Franchi[1], Jacopo Parravicini[1,2,3], Massimo Inguscio[2,3], Jacopo Catani[2,3], and Leonardo Fallani[1,2,3] — [1]Department of Physics and Astronomy, University of Florence, 50019 Sesto Fiorentino, Italy — [2]LENS, 50019 Sesto Fiorentino, Italy — [3]CNR-INO, 50019 Sesto Fiorentino, Italy

I will present the recent experiment performed at University of Florence with ultracold 173Yb Fermi gases in optical lattices, in the presence of momentum-dependent Raman coupling between different internal states [1] and strong atom-atom interactions.

Specifically, I will report on the first quantum simulation of the Hall effect for strongly interacting fermions [2]. By performing direct measurements of current and charge polarization in an ultracold-atom simulator, we trace the buildup of the Hall response [3] in a synthetic ladder pierced by a magnetic flux, going beyond stationary Hall voltage measurements in solid-state systems. We witness the onset of a clear interaction-dependent behavior, where the Hall response deviates significantly from that expected for a non-interacting electron gas, approaching a universal value. Our system, able to reach hard to compute regimes also demonstrates the power of quantum simulation for strongly correlated topological states of matter.

References [1] M. Mancini et al., Science 349, 1510 (2015). [2] T.-W. Zhou et al., arXiv:2205.13567 (2022). [3] S. Greschner et al., Phys. Rev. Lett. 122, 083402 (2019).

A 15: Precision Measurements: Atom Interferometry I (joint session Q/A)

Time: Wednesday 11:00–13:00 Location: F102

See Q 31 for details of this session.

A 16: Molecules in Intense Fields and Quantum Control (joint session MO/A)

Time: Wednesday 14:30–16:30 Location: F102

See MO 9 for details of this session.

A 17: Interaction with Strong or Short Laser Pulses II (joint session A/MO)

Time: Wednesday 14:30–16:15 Location: F107

Invited Talk A 17.1 Wed 14:30 F107

Adiabatic properties of the bicircular attoclock — •Paul Winter and Manfred Lein — Leibniz University Hannover

If the right field-strength ratio between a circularly polarized laser pulse and its counter-rotating second harmonic is chosen, one can create a quasilinear electric field in the temporal vicinity of the maximal field. In contrast to conventional linear polarization, rescattering is avoided and a detailed study of direct ionization in strong fields is possible.

The well-defined direction of the field at the ionization time enables us to investigate orientation dependencies in the ionization of molecules in a controlled manner. As our main observables, the ionization yield and the orientation-dependent attoclock shift (i.e. the potential-induced shift of the peak of the electron momentum distribution) are obtained by solving the two-dimensional time-dependent Schrödinger equation for HeH^+ and H_2.

In the regime of small Keldysh parameter $\gamma = \sqrt{2I_p}\frac{\omega}{E} \ll 1$, ionization can be described by two-step models, in which the electron travels classically after tunneling out. A crucial factor in these adiabatic models (and hence for the predicted attoshift) is the location of the exit point, which is sensitive to molecular properties such as the dipole moment and the polarizability of the ionized orbital.

A 17.2 Wed 15:00 F107

Towards strong-field XUV coherent control — •F. Richter[1], C. Manzoni[2], A. Ngai[1], M. Michelbach[1], D. Uhl[1], F. Landmesser[1], N. Rendler[1], S. D. Ganeshamandiram[1], C. Callegari[3], M. Di Fraia[3], N. Pal[3], O. Plekan[3], G. Sansone[1], K. Prince[3], T. Laarmann[4], M. Mudrich[5], P. Rebernik[3], R. Feifel[6], R. Squibb[6], M. Wollenhaupt[7], S. Hartweg[1], G. Cerullo[2], F. Stienkemeier[1], and L. Bruder[1] — [1]Institute of Physics, University of Freiburg — [2]Dipartimento di Fisica, Politecnico di Milano — [3]Elettra - Sincrotrone Trieste S.C.p.A. — [4]Department of Physics, University of Hamburg — [5]Department of Physics and Astronomy, Aarhus University — [6]Department of Physics, University of Gothenburg — [7]Institute of Physics, University of Oldenburg

Within the NIR and VIS wavelength regime there are various coherent control schemes. However, for coherent control in the XUV regime two major challenges arise: (i) The technical challenge to manipulate the pulses. (ii) XUV radiation induces typically extremely fast relaxation dynamics, which compete with the coherent control scheme. Ultrafast control schemes are, hence, paramount which can be achieved by using intense pulses beyond the weak field regime. Intense optical fields are known to induce Rabi oscillations leading to Autler-Townes level splittings. We investigate the population control of the respective sub-levels as shown in the NIR [1]. We will present simulations of the expected Autler-Townes splitting as well as preliminary results from our beamtime at the free electron laser FERMI.

[1] M. Wollenhaupt et al., Phys. Rev. A 68, 015401 (2003).

A 17.3 Wed 15:15 F107

The N-shaped partition method: A novel parallel implementation of the Crank Nicolson algorithm — •Francisco Navarrete and Dieter Bauer — Institute of Physics, University of Rostock

We develop an algorithm to solve tridiagonal systems of linear equations, which appear in implicit finite-difference schemes of partial differential equations (PDEs), being the time-dependent Schrödinger equation (TDSE) an ideal candidate to benefit from it. Our N-shaped partition method optimizes the implementation of the numerical calculation on parallel architectures, without memory size constraints. Specifically, we discuss the realization of our method on graphics processing units (GPUs) and the Message Passing Interface (MPI). In GPU implementations, our scheme is particularly advantageous for systems whose size exceeds the global memory of a single processor. Moreover, because of its lack of memory constraints and the generality of the algorithm, it is well-suited for mixed architectures, typically available in large high performance computing (HPC) centres. We also provide an analytical estimation of the optimal parameters to implement our algorithm, and test numerically the suitability of our formula in a GPU implementation. Our method will be helpful to tackle problems which require large spatial grids for which ab-initio studies might be otherwise prohibitive both because of large shared-memory requirements and computation times.

A 17.4 Wed 15:30 F107

Dephasing effects in high-order harmonic generation from finite Su-Schrieffer-Heeger chains — •Christoph Jürss and Dieter Bauer — Insitute of Physics, University of Rostock, Germany

The Su-Schrieffer-Heeger (SSH) model describes a linear, one-dimensional chain that displays topological effects. Due to its simplicity, the SSH-model has been used to study numerous effects in topological insulators. The most interesting feature of topologically non-trivial insulators are their topologically protected edge states. It was shown in previous studies that the generation of high-order harmonics can be influenced by the topological nature of the solid and even by just the edge states themselves. In order to obtain more realistic simulated harmonic spectra, relaxation and dephasing effects should be taken into account. This is usually done for the bulk, i.e., with no edge states present. In this work, we implement dephasing for the finite SSH-model and compare the results to those from the respective bulk.

A 17.5 Wed 15:45 F107

Delay time and Non-Adiabatic Calibration of the Attoclock. *Multiphoton process versus tunneling in strong field interaction* — •Ossama Kullie[1] and Igor Ivanov[2] — [1]Institute for Physics, University of Kassel — [2]nstitute for Basic Science (IBS), Gwangju 61005, Republic of Korea

Recent measurement of the tunneling time in attosecond experiments (termed attoclock), triggered a hot debate about the tunneling time, the role of time in quantum mechanics and the separation of the interaction with the laser pulse into two regimes of a different character, the multiphoton and the tunneling (field-) ionization. In the adiabatic field calibration, we showed in earlier works (see e.g. [1]) that our real tunneling time model fits well to the experimental data. In the present work [2], we investigate the nonadiabatic case (see [3]) and combine it with a new result of a numerical integration of the TDSE (see [4]). Our model explains the experimental of Hofmann et al [3] with an excellent agreement. Our model is appealing because it offers a clear picture of the multiphoton and tunneling. In the nonadiabatic case, the barrier itself is mainly driven by multiphoton absorption and the number of the absorbed photons depends on the δ-value of the barrier height. Surprisingly, for a filed strength $F < F_a$ (the atomic field strength) the model always indicates a time delay with respect to the lower quantum limit at $F = F_a$. Its saturation at the adiabatic limit explains the well-known Hartman effect or Hartman paradox. [1] O. kulllie. PRA **92** 052118 (2015). [2] O. kulllie and I. Ivanov arxiv.2005.09938v4. [3] J. of Mod. Opt. **66**, 1052, 2019. [4] Phys. Rev. A **89**, 021402, 2014.

A 17.6 Wed 16:00 F107

Writing waveguides in polymers with femtosecond laser. — •Dmitrii Perevoznik[1,2] and Uwe Morgner[1,2,3] — [1]Institut für Quantenoptik, Welfengarten 1, 30167, Hannover — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering -Innovation AcrossDisciplines), Hannover, Germany — [3]Laser Zentrum Hannover e.V ., Hollerithalle 8, D-30419 Hannover, Germany

Writing waveguides with femtosecond laser is a very promising technique and has already proven its performance in glasses and crystals. Nevertheless, writing waveguides in polymers is a just developing field and polymer material can offer the potential to create low-cost and complex structures inside the volume of the material. Singlemode waveguides with propagation losses of 0.6 *m were achieved by putting modifications, done by femtosecond laser, around waveguide core forming different geometries. Also shown are various optical elements embedded in waveguides, such as waveguide splitters or Bragg gratings.

A 18: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Wednesday 14:30–16:30 Location: F303

A 18.1 Wed 14:30 F303

Topological phases of Rydberg spin excitations in a honeycomb lattice induced by density-dependent Peierls phases — •Simon Ohler[1], Maximilian Kiefer-Emmanouilidis[1,2], and Michael Fleischhauer[1] — [1]University of Kaiserslautern-Landau, D-67663 Kaiserslautern, Germany — [2]German Research Centre for Artificial Intelligence, D-67663 Kaiserslautern, Germany

We show that the nonlinear transport of bosonic excitations in a honeycomb lattice of spin-orbit coupled Rydberg atoms gives rise to disordered quantum phases which are topological and candidates for spin liquids. As demonstrated in [Lienhard *et al.* Phys. Rev. X, **10**, 021031 (2020)] the spin-orbit coupling breaks time-reversal and chiral symmetries and leads to a density-dependent complex hopping of the hard-core bosons or equivalently to complex XY spin interactions. Using exact diagonalization (ED) we investigate the phase diagram resulting from the competition between density-dependent and direct transport.

In mean-field there is a transition from a quasi-condensate to a 120°-phase when the complex hopping exceeds the direct one. In the full model a new phase with a finite spin gap emerges close to the mean-field critical point due to quantum fluctuations induced by the density-dependence of the hopping. We show that this phase is a genuine disordered one. It has a large spin chirality and a many-body Chern number $C = 1$, which is robust to disorder. ED simulations of small lattices point to a non-degenerate ground state and thus to a bosonic integer-quantum Hall (BIQH) phase, protected by $U(1)$ symmetry.

A 18.2 Wed 14:45 F303

Self-Organized Criticality and Griffith's Effects — •Daniel Brady and Michael Fleischhauer — University of Kaiserslautern - Landau, Kaiserslautern, Germany

Rydberg atoms interact strongly over very large distances leading to effects such as blockade and facilitation. Using Monte-Carlo simulations of an optically driven Rydberg many body gas in the facilitation regime, we analyse the effects of disorder on the facilitation dynamics of the system. In the absence of disorder, realised e.g. by the thermal motion of the atoms, the system exhibits a phase transition between an active and an absorbing phase. The presence of an additional slow decay results in self-organized criticality.

In the low temperature limit, dynamics in the gas are entirely determined on a local scale giving rise to a heterogeneous, disordered Griffiths phase. Here, the facilitation dynamics are constrained to clusters where inter-atom distances equal the facilitation distance. The structure of these clusters can be mapped to an Erdos-Renyi graph. We numerically investigate the dynamics and improve an existing Langevin equation to this regime.

Furthermore, since the network structure changes slower than the internal facilitation dynamics in this regime, spatial correlations appear between atoms. We investigate these utilizing a two atom toy model.

A 18.3 Wed 15:00 F303

Deexcitation of Rydberg atoms in the neutrino mass experiment KATRIN using THz radiation* — •Shivani Ramachandran — Bergische Universität Wuppertal (BUW)

The key requirement for the KArlsruhe TRItium Neutrino experiment (KATRIN) in measuring the effective electron anti-neutrino mass with a sensitivity of 200 meV at 90% (C.L.)is, minimal background. In order to achieve that and eliminate some known contributors, several background suppression methods have already been implemented. Presently the most prominent contribution to the background in the measured signal is electrons produced by the thermal ionization of Rydberg atoms. They originate due to the sputtering of ^{210}Pb from inherent radioactivity from the walls of the KATRIN main spectrometer. A plausible method is using THz and microwave radiation (method developed by ASACUSA CERN) which can lead to a reduced lifetime of Rydberg atoms and allow for dedicated stimulated de-excitation. The influence of THz light source in the main spectrometer along with the state and spatial evolution of the Rydberg atoms is presented via simulations. Different species of atoms are sputtered which can lead to two-electron excited states, ultralong-range Rydberg atoms, etc, such possibilities are discussed. The influence of magnetic fields on the emission of ionization electrons is also investigated to understand the background model better.

*Gefördert durch die BMBF-Verbundforschung Astroteilchenphysik

A 18.4 Wed 15:15 F303

A linear response protocol to probe aging in a disordered Rydberg quantum spin system — •Moritz Hornung, Eduard Braun, Dillen Lee, Titus Franz, Sebastian Geier, Gerhard Zürn, and Matthias Weidemüller — Physikalisches Institut, Heidelberg University, Germany

In spite of many years of research, the question of whether or not the spin glass transition in disordered Heisenberg spin systems is a true phase transition is still open for debate. Of late, emerging platforms for quantum simulation greatly increase the accessibility of these systems and thus provide further insight into the topic. Already, anomalously slow dynamics that are characteristic for spin glasses have been observed on a platform consisting of Rydberg atoms, where the spin degree of freedom is encoded within highly excited electronic states.

To extend on these findings, we propose an experimental sequence based on slow ramps of the external field. This allows for the initialization of low energy states, which correspond to the low effective temperatures needed in order to observe a spin glass transition. We then introduce a small perturbation of the external field to measure the linear response depending on the speed of the initialization ramp. Finally, the platform is used to probe whether aging, rejuvenation and memory effects as observed in open spin glasses exist in a similar fashion for isolated quantum spin systems. The experimental results are complemented with numerical simulations based on exact diagonalization of a small system.

A 18.5 Wed 15:30 F303

Analysing crosstalk with the digital twin of a Rydberg atom QPU — •Alice Pagano[1,2,3], Daniel Jaschke[1,2,3], Sebastian Weber[4], and Simone Montangero[1,2,3] — [1]Institute for Complex Quantum Systems, Ulm University — [2]Dipartimento di Fisica e Astronomia "G. Galilei" & Padua Quantum Technologies Research Center, Università degli Studi di Padova — [3]INFN, Sezione di Padova — [4]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, Stuttgart University

Decoherence and crosstalk are two adversaries when aiming to parallelize a quantum algorithm: on the one hand, the execution of gates in parallel reduces decoherence due to a shorter runtime, but on the other hand, parallel gates in close proximity are vulnerable to crosstalk. This challenge is visible in Rydberg atom quantum computers where atoms experience strong van der Waals interactions decaying with distance. We demonstrate how the preparation of a 64-qubit GHZ state is affected by crosstalk in the closed system with the help of a tensor network digital twin of a Rydberg atom QPU. Then, we compare the error from crosstalk to the decoherence effects proving the necessity to parallelize algorithms.

A 18.6 Wed 15:45 F303

Probing the presence of phase transitions in disordered quantum spin systems — •Eduard Jürgen Braun, Moritz Hornung, Titus Franz, Dillen Lee, Sebastian Geier, Gerhard Zürn, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Closed many-body quantum systems out of equilibrium can show interesting behaviour without classical counterpart, where many-body localization and discrete time crystals are among the most prominent examples. Some theories also predict a spin-glass to paramagnet quantum phase transition within a many-body localized phase. Inspired by these predictions, in this talk we are going to present our latest results to probe a possible quantum phase transition in a disordered spin system.

To experimentally study the existence of a phase transition we will use our quantum simulation platform based on a frozen Rydberg gas in order to probe nonequilibrium properties of Heisenberg XXZ spin models. By choice of an appropriate combination of Rydberg states, different symmetry classes, like the Heisenberg XX, XXZ and Ising models can be realized. For these interacting systems, we have found glassy dynamics and a non-thermalizing regime hinting towards the presence of a localized phase.

A 18.7 Wed 16:00 F303

Spatially and temporally resolved wavepacket dynamics of an ion-Rydberg system by means of a high-resolution ion microscope — •Herrera-Sancho OA, Berngruber Moritz, Anasuri Viraatt SV, Conrad R, Yi-Quan Zou, Zuber Nicolas, Meinert Florian, Löw Robert, and Pfau Tilman — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, Germany

The superb control along with the manipulation of ultracold temperature species have permitted access to explore interactions in ensembles of neutral atoms. When these complex systems are excited to Rydberg states, and are very close, consequently induces a blockade effect. The latter has opened the door in order to address many questions and give rise to explore, for example, trimers with multiple correlated systems, ultracold ionic impurities, individual ion-atom collisions and to probe quantum macroscopicity. In this direction, we focus on the direct spatially and temporally resolved S-state wavepacket dynamics of an ion-Rydberg system using our advanced high-resolution ion microscope. By employing a single cold Rb+ ion which facilitates the excitation of a Rydberg atom over thirty micrometers distances, the experimental findings provide evidence to indicate the shape of the wavepacket dynamics in the polarization C4 potential of the ion-Rydberg interaction. These results are compared with the theoretical predictions where it is examined the effect of the adiabatic transition from the S-states with no bound states into the steep section corresponding to non-adiabatic of the high-l states.

A 18.8 Wed 16:15 F303

Chiral Rydberg States of Laser Cooled Atoms — •Stefan Aull[1], Steffen Giesen[2], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Experimentalphysik 1, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]Fb. 15 - Chemie, Hans-Meerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

We propose a protocol for the preparation of chiral Rydberg states. It has been shown theoretically that using a suitable superposition of hydrogen wavefunctions, it is possible to construct an electron density and probability current distribution that has chiral nature [1]. Following a well established procedure for circular Rydberg state generation and subsequent manipulation with taylored radio frequency pulses under the influence of electric and magnetic fields, the necessary superposition of hydrogen-like states with correspondingly adjusted phases can be prepared. Enantio-sensitive detection using photo-ionization with circularly polarized light is under theoretical and experimental development. The results are aimed to be used for chiral discrimination [2] of molecules.

[1] A. F. Ordonez and O. Smirnova, Propensity rules in photoelectron circular dichroism in chiral molecules. I. Chiral hydrogen, Phys. Rev. A, vol. 99, no. 4, p. 43416

[2] S. Y. Buhmann et al., Quantum sensing protocol for motionally chiral Rydberg atoms, New Journal of Physics, vol. 23, no. 8, Art. no. 8, Aug. 2021

A 19: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

Time: Wednesday 14:30–16:00 Location: F428

A 19.1 Wed 14:30 F428

Dynamics of a single trapped ion in a high-density medium: A stochastic approach — Mateo Londoño[1], •Javier Madroñero[1], and Jesús Pérez-Ríos[2] — [1]Centre for Bioinformatics and Photonics (CIBioFi), Universidad del Valle, Cali, Colombia — [2]Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794, USA

Based on the Langevin equation, a stochastic formulation is implemented to describe the dynamics of a trapped ion in a bath of ultracold atoms, including an excess of micromotion. The ion dynamics is described following a hybrid analytical-numerical approach in which the ion is treated as a classical impurity in a thermal bath. As a result, the ion energy*s time evolution and distribution are derived from studying the sympathetic cooling process. Furthermore, the ion dynamics under different stochastic noise terms is also considered to gain information on the bath properties* role in the system*s energy transfer processes. Finally, the results obtained from this formulation are contrasted with those obtained with a more traditional Monte Carlo approach [1].

[1] Londoño M., Madroñero J., and Pérez-Ríos J., Phys. Rev A 106, 022803 (2022)

A 19.2 Wed 14:45 F428

Competing non-superradiant Fermi-surface instabilities induced by cavity-mediated interactions — Bernhard Frank[1], •Michele Pini[2], and Francesco Piazza[2] — [1]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187, Dresden, Germany

The experimental realization of ultracold Fermi gases in optical resonators provides an interesting new platform to study unconventional quantum phases of matter induced by long-range cavity-mediated interactions. So far, mostly superradiant instabilities accompanied by charge density waves of the fermions have been studied in these systems. Here, we report instead on pair condensation instabilities, solving the competition problem within a controlled perturbative approach by exploiting the long-range nature of the cavity-mediated interaction. We show that a spin-polarized Fermi gas undergoes a phase transition to either a Cooper or a pair density wave superfluid at a common T_c. Below T_c, however, these phases turn out to be mutually exclusive, with one of them always dominating above the other. Moreover, these pairing instabilities occur both for attractive or repulsive interactions. This allows to observe them in the latter regime, where the superradiant instability is absent. In addition, the value of T_c is also found to be well within reach of the parameters of current experimental realizations, which is very promising for an experimental observation of these non-superradiant instabilities in the near future.

A 19.3 Wed 15:00 F428

Proposal for a long-lived quantum memory using matter-wave optics with Bose-Einstein condensates in microgravity — •Elisa Da Ros[1], Simon Kanthak[1], Erhan Sağlamyürek[2,3], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]University of Calgary, Calgary, Canada — [3]University of Alberta, Edmonton, Canada — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Bose-Einstein condensates (BECs) are a promising platform for implementing optical quantum memories [1]. Most of the decoherence mechanisms that affect the lifetime of BEC-based memories can be compensated through conventional methods, but, ultimately, the density-dependent interatomic collisions set the upper limit on the lifetime to around 100~ms timescales. Here [2] we propose a new protocol that utilizes matter-wave optics techniques to minimize such density-dependent effects. Optical atom lenses first collimate and then refocus an initially expanding BEC. This allows performing the memory write-in and read-out operations at high density while decreasing the collision rate during the storage period. We show an expected memory lifetime in a microgravity environment of up to 100 s, which is ultimately limited by the background vacuum quality.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWK) under grant number No. 50WM2055.

[1] E. Sağlamyürek, et al., Nat. Photon. 12, 774-782 (2018).

[2] E. Da Ros, et al., arXiv:2210.13859 (2022).

A 19.4 Wed 15:15 F428

Einstein-Elevator — •Alexander Heidt — HITec, Hannover, Niedersachsen

More and more people are striving to explore space and to colonize it as well as to use its advantages for basic research in physics. To be able to accomplish this, technologies are necessary that operate in special gravity conditions. With the motivation to develop and investigate such technologies, the Einstein-Elevator was built, which, in addition to simulating weightlessness, is able to simulate other gravity conditions. The advantages of the Einstein-Elevator are the high repetition rate of up to one hundred flights per day in combination with a weight of the payload of up to 1,000 kg for the experiment setup, which can have a diameter of up to 1.70 m and a height of 2 m. The duration of the gravity condition is four seconds and these can be adjusted between Lunar and Martian gravity down to microgravity. Currently, several projects are underway in various research fields, including the core research areas mechanical engineering and fundamental physics: In the area of fundamental physics research based on atom interferometry is carried out. Projects currently in progress include INTENTAS to measure the entanglement of atoms in microgravity with a compact sensor, with special requirements for stabilizing a magnetic field, and DESIRE to measure dark energy, where the motion, especially the rotation, of the Einstein elevator must be stabilized. In addition, the team is continuously developing the facility, opening up gravitational conditions that could not previously be simulated on Earth.

A 19.5 Wed 15:30 F428

Statistically Suppressed Coherence in the Anyon-Hubbard Dimer — •Martin Bonkhoff, Imke Schneider, Axel Pelster, and Sebastian Eggert — Physics Departement and Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

The impact of statistical transmutation on superfluid tendencies is investigated for the Anyon-Hubbard dimer, a two-site restriction of the lattice generalization of Kundu anyons [1], experimentally accessible via the creation of density-dependent gauge phases and additional strong confinement [2]. We find a duality relation between the anyonic and the Bose-Hubbard dimer, which allows us to construct the corresponding, exact, algebraic Bethe-Ansatz solution. For large particle numbers and weak on-site interactions, the coherence properties are found to be strongly suppressed by statistical transmutation, with underlying mechanisms and applications analogous to one-axis spin-squeezing and entangled coherent states in quantum optics [3,4].

References:

[1] Bonkhoff, M. and Jägering, K. and Eggert, S. and Pelster, A. and Thorwart, M. and Posske, T., Phys. Rev. Lett. 126, 163201 (2021)

[2] Frölian, A., Chisholm, C.S., Neri, E. et al., Nature 608, 293-297 (2022)

[3] Kitagawa, M. and Ueda, M., Phys. Rev. A 47, 5138-5143 (1993)

[4] Rice, D. A., Jaeger, G. and Sanders, B. C., Phys. Rev. A 62, 012101 (2000)

A 19.6 Wed 15:45 F428

Light-induced correlations in cold dysprosium atoms — •Marvin Proske[1], Ishan Varma[1], Nivedith Anil[1], Dimitra Cristea[1], Nico Bassler[2], Claudiu Genes[2,3], Kai Philipp Schmidt[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU Mainz — [2]Department of Physics, FAU Erlangen-Nuremberg — [3]MPI for the Science of Light, Erlangen

When the average atomic distance in a cloud of ultracold atoms, is below the wavelength of the scattering light, a direct matter-matter coupling is introduced by electric and magnetic interactions. This alters the spectral and temporal response of the sample, where the atoms cannot be treated as individual emitters anymore. We intend to experimentally study light-matter interactions in dense dipolar media with large magnetic moments to explore the impact of magnetic dipole-dipole interactions onto the cooperative response of the sample. With the largest ground-state magnetic moment in the periodic table (10 Bohrmagneton), dysprosium is the perfect choice for these experiments.

This talk reports on the progess made in generating extremely dense cold dysprosium clouds. We discuss the measures taken to optically transport the atoms into a home-built science cell, which serves as a highly accessible platform to manipulate the atomic cloud. The small dimensions of the cell allow for extremely tight dipole trapping, enabled by a self-designed high NA objective. Further, we give a perspective on future measurements exploring collective effects in the generated atom cloud.

A 20: Poster II

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

A 20.1 Wed 16:30 Empore Lichthof

Towards high-resolution imaging of RbSr molecules in an optical lattice — •Simon Lepleux, Noah Wach, Premjith Thekkeppatt, Digvijay Digvijay, Junyu He, Klaasjan van Druten, and Florian Schreck — Van der Waals-Zeeman Institute, University of Amsterdam

Polar, open-shell molecules in their rovibrational ground state exhibit a rich structure along with long range electric dipole interactions and a magnetic dipole moment. Polar molecules in an optical lattice impart long range interactions between lattice sites, which gives rise to exotic phases and extended Hubbard models. Utilizing a high-resolution microscope with single molecule addressing and manipulation techniques in an optical lattice will enable us to study spin lattice models.

We present the design and characterization of a custom microscope objective for an alkali - alkaline earth optical lattice experimental setup that offers us single-site resolution. Our infinity corrected microscope objective is constructed with commercially available lenses. It has a numerical aperture of 0.4 and a long working distance of 42.6 mm. The performance of the microscope is diffraction limited from 461 nm to 795 nm.

A 20.2 Wed 16:30 Empore Lichthof

Towards high-resolution spectroscopy and direct laser excitation of thorium-229 — •Gregor Zitzer[1], Johannes Tiedau[1], Maksim Okhapkin[1], Johannes Thielking[1], Ke Zhang[1], Christoph Mokry[2,3], Jörg Runke[2,4], Christoph E. Düllmann[2,3,4], and Ekkehard Peik[1] — [1]Physikalisch-Technische Bundesanstalt — [2]Department of Chemistry - TRIGA Site, Johannes Gutenberg University Mainz — [3]Helmholtz Institute Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

Exciting the electronic levels of an atom with laser light is a well-established workhorse in atomic physics. Likewise, exciting the nuclear core of an atom with electromagnetic radiation is possible, although typical energies are in the keV to MeV range. Here, thorium-229, with a first excited state at only 8 eV excitation energy, is the only known exception that will allow excitation by coherent laser radiation. This unique feature promises advantages for optical clocks and for measurements to uncover physics beyond the standard model.

In our setup, thorium-229 ions are produced as recoil ions from the alpha decay of uranium-233, featuring a 2 % branching to the isomer. The recoil ions are slowed down in helium buffer gas, filtered, and transferred to a linear Paul trap, where they are cotrapped with strontium-88 ions for sympathetic cooling.

In addition, we show our latest progress on direct laser excitation with vacuum-ultraviolet light produced via four-wave-mixing in xenon, producing up to 40 μJ per pulse. As a proof of concept, we investigate atomic transitions of ^{232}Th$^+$ at 148 nm.

A 20.3 Wed 16:30 Empore Lichthof

Blue-detuned painted optical potentials for microgravity applications — •Kai Frye-Arndt[1,2], Holger Ahlers[2], Waldemar Herr[2], Christian Schubert[2], Ernst Rasel[1], and the BECCAL Team[1,2,3,4,5,6,7,8,9,10] — [1]Leibniz Universität Hannover — [2]DLR-SI, Hannover — [3]Universität Ulm — [4]FBH Berlin — [5]HU, Berlin — [6]JGU, Mainz — [7]ZARM, Universität Bremen — [8]DLR-QT, Ulm — [9]DLR-SC, Braunschweig — [10]Universität Hamburg

Steering a far-off-resonance laser beam to create arbitrarily shaped optical potentials can provide great flexibility for manipulating ultracold atoms. However, experiments are often disturbed by gravity induced dynamics or by levitation techniques, which introduce residual electromagnetic fields, limit the trapping volumes or restricting the choice of species. The Bose-Einstein and Cold Atom Laboratory (BECCAL) will enable the exiting possibility to study ultracold atoms in extended microgravity, lifting these constraints.

Here, we present a design of a compact and robust setup to paint optical potentials using a 2D acousto optic deflector. We show various characterization measurements and simulations investigating the dynamics of the moving light beam and the atoms.

We acknowledge support by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50 WP 1431 and 1700. Supported and funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC-2123 QuantumFrontiers 390837967.

A 20.4 Wed 16:30 Empore Lichthof

Towards studying the collective effects in laser-driven heavy ion acceleration — •Erin G. Fitzpatrick, Laura D. Geulig, Maximilian J. Weiser, Veronika Kratzer, Vitus Magin, Florian H. Lindner, and Peter G. Thirolf — Ludwig-Maximilians-Universität München

The ultra-high ion bunch density offered from laser-driven ion acceleration may affect the stopping behavior in matter via collective effects and ultimately enable to establish new nuclear reaction schemes like the 'fission-fusion' mechanism, aiming to generate extremely neutron-rich isotopes near N=126 [1]. One prerequisite needed for the realization of this mechanism is laser driven heavy ions with extremely high bunch densities. Experimental campaigns at different PW class lasers resulted in the acceleration of gold ions with bunch densities of about 10^{13} cm^{-3} (10^{16} cm^{-3}) at 1mm (100 μm) from the target [2]. At the Center for Advanced Laser Applications (CALA) we are working towards measuring collective effects in laser-driven ion bunches, like a potential reduction in stopping power. Focusing on ion bunch energy deposition in CR-39 detectors downstream (approx. 0.1mm) from the ion source, we must consider shot-to-shot fluctuations of the ion bunch properties that require an experimental design that quantifies particle stopping while also providing a shot specific reference spectrum. An overview of the current results and developing experimental design is given.

[1] D. Habs et al., Appl. Phys. B 103, 471-484 (2011)
[2] F.H. Lindner et al., Sci. Rep. 12, 4784 (2022)

A 20.5 Wed 16:30 Empore Lichthof

Towards building and loading a Ioffe trap using a 2D MOT — •Benedikt Tscharn, Lukas Schumacher, Marcel Willig, Gregor Schwendler, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Exzellenzcluster PRISMA+, Mainz, Germany

Unique information about atomic and nuclear structure of light atoms can be determined by precision laser spectroscopy and provide information about fundamental constants, interactions and properties [1]. We plan to build an apparatus for high-precision laser spectroscopy of ultracold ^{6}Li at 670 nm in a magnetic Ioffe trap.

Only very slow atoms can be captured inside the Ioffe trap. Therefore, a 2D magneto-optical trap using permanent magnets was built that is used to precool hot lithium vapour which is subsequently transported into the Ioffe trap using a push laser beam [2].

In this contribution we provide an overview about the setup of the 2D MOT, the lasers and the cold lithium loading beam and give an outlook to the magnetic trap.

[1] S. Schmidt et al., J. Phys. Conf. Ser. accepted (2018), arXiv 1808.07240
[2] H. Schumacher, Johannes Gutenberg-Universität Mainz, Master Thesis (2022)

A 20.6 Wed 16:30 Empore Lichthof

High-resolution dielectronic recombination spectroscopy with slow cooled Be-like Pb^{78+} ions at CRYRING@ESR — S. Fuchs[1,2], C. Brandau[1,3], E. B. Menz[3,4,5], M. Lestinsky[3], A. Borovik Jr.[1], Y. N. Zhang[6], Z. Andelkovic[3], F. Herfurth[2], C. Kozhuharov[3], C. Krantz[3], U. Spillmann[3], M. Steck[3], G. Vorobyev[3], R. Hess[3], V. Hannen[7], D. Banaś[8], M. Fogle[9], S. Fritzsche[4,5], E. Lindroth[10], X. Ma[11], A. Müller[1], R. Schuch[10], A. Surzhykov[12,13], M. Trassinelli[14], Th. Stöhlker[3,4,5], Z. Harman[15], and •S. Schippers[1,2] — [1]JLU Gießen — [2]HFHF Campus Gießen — [3]GSI — [4]HI Jena — [5]FSU Jena — [6]Xi'an Jiaotong University — [7]WWU Münster — [8]JKU Kielce — [9]Auburn University — [10]Stockholm University — [11]IMPCAS Lanzhou — [12]TU Braunschweig — [13]PTB — [14]INSP Paris — [15]MPIK

Dielectronic recombination (DR) spectroscopy is a very successful and widely used technique to study the properties of highly charged ions. Its high precision and versatility make it an important spectroscopic tool in the physics program of the SPARC collaboration. The heavy-ion storage ring CRYRING@ESR of the international FAIR facility in Darmstadt is a very attractive machine for performing DR spectroscopy because of its electron cooler that is equipped with an ultra-cold electron beam promising highest experimental resolving power and because of the extreme versatility of the storage ring ESR as its injector. Here, we report on the first DR experiment with highly charged ions at this new facility. The comparison between experiment and theory shows that the resolving power is according to the expectations.

A 20.7 Wed 16:30 Empore Lichthof

Optogalvanic Spectroscopy of Atomic Hydrogen — •Hendrik Schürg, Merten Heppener, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, Institut für Physik/QUANTUM & Exzellenzcluster PRISMA$^+$, Mainz, Germany

Laser spectroscopy on atoms has proven to be a successful path to high-precision results for the root-mean-square charge radii of the lightest nuclei. Similar to studies on deuterium in a cyrogenic atomic beam [1,2], we propose to determine the triton charge radius by measuring the hydrogen-tritium 1S-2S isotope shift on thermal atoms in a sealed discharge cell – providing encapsulation of the radioactive tritium gas. The resonant excitation to the 2S state is intended to be monitored via the optogalvanic effect, corresponding to a laser-induced change of the plasma's impedance. Optogalvanic spectroscopy at the hydrogen Balmer-β dipole transitions in a low-pressure microwave discharge is demonstrated as a pre-stage to two-photon 1S-2S spectroscopy. We present studies on systematic effects and control parameters of the plasma as well as an evaluation of optogalvanic detection methods.

[1] C. G. Parthey et al. Phys. Rev. Lett. 104, 233001 (2010)
[2] U. D. Jentschura et al. Phys. Rev. A 83, 042505 (2011)

A 20.8 Wed 16:30 Empore Lichthof

Towards a strontium quantum gas microscope — •Jonatan Höschele[1], Sandra Buob[1], Antonio Rubio[1], Vasiliy Makhalov[1], and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain

Ultracold atoms in optical lattices represent an outstanding tool to create and study quantum many-body systems. Combining these lattice systems with the properties of alkaline-earth atoms like strontium gives rise to exciting phenomena such as cooperative effects in atom-photon scattering and exotic magnetic phases of the Fermi-Hubbard model.

To study these systems experimentally, we aim at the realization of a strontium quantum-gas microscope. We routinely generate Bose-Einstein condensates of strontium atoms, which we plan to load into an optical lattice, operating at a magic wavelength. An imaging setup involving a high-NA objective will allow us to image with single-atom and single-site resolution, enabling the detection of density as well as spin correlations in the prepared many-body states.

A 20.9 Wed 16:30 Empore Lichthof

Trapping and Cooling Thorium Ions with ^{40}Ca^{+} — •Can Patric Leichtweiss[1], Valerii Andriushkov[2], Azer Trimeche[1], Jonas Stricker[2,3], Dennis Renisch[2,3], Leonard Fendel[3], Dmitry Budker[1,2], Christoph E. Düllmann[2,3,4], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institute of Physics, Johannes Gutenberg-Universität Mainz, Germany — [2]Helmholtz-Institut Mainz, Germany — [3]Department Chemie - Standort TRIGA, Johannes Gutenberg-Universität Mainz, Germany — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

We are aiming for quantum logic spectroscopy (QLS) with thorium ions. We employ the **t**rapping **a**nd **c**ooling of **t**horium **i**ons [1] in **ca**lcium crystals (*TACTICa*) to investigate different isotopes for the purpose of high-precision spectroscopy. After sympathetical polarization gradient cooling [2] QLS on the Th |6d7s^2, J=3/2>→|6d7s7p, J=5/2> transition at 402 nm will be carried out. QLS is based on the excitation of axial common modes in the Th$^+$-Ca$^+$ crystal, using an optical lattice generated by a pair of counterpropagating Gaussian beams or a vortex beam.

[1] K. Groot-Berning et al., *Phys. Rev. A* 99, (2019) 023420
[2] W. Li et al., *New J. Phys.* 24 (2022) 043028.

A 20.10 Wed 16:30 Empore Lichthof

Fragmentation of CH4 in shaped laser fields — •Weiyu Zhang, David Chicharro Vacas, Thomas Pfeifer, and Robert Moshammer — Saupfercheckweg 1, 69117 Heidelberg

Ultrashort laser pulses are widely used to probe the dynamics of atoms and molecules. An intuitive and accessible way to control the laser pulses is always wanted. Limited by the electronic speed, temporal pulse shaping cannot be applied directly. Here, with the spatial liquid modulator, we exhibit one flexible and reliable way to compress and shape pulse. In this talk, the spectral Fourier setup will be introduced. Within the freedom to give and change pulse through amplitude, phase, and polarization, it is possible to better resolve dynamics. Here, we combine the pulse shaper with the Reaction Microscope (REMI) to carry out the real-time pump-probe measurement for methane. Spatially, the methane molecule is a regular tetrahedron structure, which can be distorted by the external laser field and to is dissociated. Different ionization and dissociation channels are compared and analyzed.

A 20.11 Wed 16:30 Empore Lichthof

Towards topological x-ray quantum control — •Jonathan Sturm[1], Petar Andrejić[2], and Adriana Pálffy[1] — [1]Julius-Maximilians Universität Würzburg — [2]Friedrich-Alexander Universität Erlangen-Nürnberg

Thin film cavities with embedded Mössbauer nuclei such as ^{57}Fe have proven themselves as powerful platforms for resonant x-ray control. Arriving at grazing incidence, incoming x-rays form a standing wave inside the cavity that interacts with the resonant layer, allowing for well-controlled nucleus-field coupling. Alternatively, forward incidence enables excitation of multiple field modes, rendering the nanostructure a multi-mode waveguide. Both principles can be well described using a recently developed Green's function formalism for the cavity field [1,2].

We investigate theoretically a multi-mode waveguide with several embedded Mössbauer domains implementing tight-binding models known from molecular and solid-state physics. In particular, we arrange the individual Mössbauer domains such that weak and strong inter-domain couplings alternate, facilitating an x-ray photonic implementation of the topological Su-Schrieffer-Heeger model in order to study the behaviour of the waveguide field in presence of a topological boundary mode.

[1] X. Kong *et al.*, Phys. Rev. A **102**, 033710 (2020).
[2] P. Andrejić and A. Pálffy, Phys. Rev. A **104**, 033702 (2021).

A 20.12 Wed 16:30 Empore Lichthof

Dynamically-controllable resonant x-ray optics via mechanically-induced refractive-index control — •Miriam Gerharz[1], Dominik Lentrodt[1,2,3], Lars Bocklage[4], Kai Schlage[4], Kai Schulze[5,6], Christian Ott[1], Lukas Wolff[1], René Steinbrügge[4], Olaf Leupold[4], Ilya Sergeev[4], Gerhard Paulus[5,6], Christoph H. Keitel[1], Ralf Röhlsberger[4,5,6], Thomas Pfeifer[1], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisches Institut, Freiburg, Germany — [3]EUCOR Centre for Quantum Science and Quantum Computing, Freiburg, Germany — [4]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [5]Helmholtz-Institut Jena, Jena, Germany — [6]Institut für Optik und Quantenelektronik, Jena, Germany

In this project we introduce a concept for dynamically-controllable resonant x-ray optics. Using piezo-control methods, we can displace a solid-state target much faster than the lifetime of its resonances. This creates a mechanically-induced phase shift, which can be associated with a frequency-dependent effective refractive index $n(\omega)$ of the moving target. Hence, we can achieve polarization control by mechanically-induced birefringence. We theoretically and experimentally demonstrate the approach with a x-ray polarization interferometer, in which the interference is controlled by the mechanically-induced refractive-index control. This setup can be used for temporal gating and provides a sensitive tool for a noise background analysis on sub-Ångstrom level.

A 20.13 Wed 16:30 Empore Lichthof

Producing large and stable magnetic fields for Feshbach resonance experiments in a ^{6}Li - ^{138}Ba^{+} hybrid system. — •Wei Wu, Fabian Thielemann, Joachim Siemund, Thomas Walker, and Tobias Schaetz — Physikalisches Institut Albert-Ludwigs-Universität Freiburg Hermann-Herder-Str. 3 79104 Freiburg

For many ultra-cold physics experiments, such as those involving Feshbach resonances, both a high magnetic field strength (> 100 G) and low noise (< 100 mG) are needed. Further, the coils should be compact enough to fit with the experiment. Here we present our Bitter electromagnet configuration for the Feshbach resonances experiments in the atom-ion hybrid system[1,2], and characterize its performance. Meanwhile, we investigate the field's short- and long-term stability with Ramsey spectroscopy of ^{6}Li, discuss plans for improvements to the system.

[1] Weckesser P, Thielemann F, Wiater D, et al. Observation of Fes- hbach resonances between a single ion and ultracold atoms[J]. Nature, 2021, 600(7889): 429-433.

[2] Schmidt J, Weckesser P, Thielemann F, et al. Optical traps for sympathetic cooling of ions with ultracold neutral atoms[J]. Physical review letters, 2020, 124(5): 053402.

A 20.14 Wed 16:30 Empore Lichthof

Novel cryogenic planar resonators — •Fabian Raab[1], Jonathan Morgner[1], Tim Sailer[1], Fabian Heisse[1], Charlotte König[1], Jost Herkenhoff[1], Fatma Abbass[2], Christian Smorra[2], Sven Sturm[1], and Klaus Blaum[1] — [1]MPIK Heidelberg — [2]JGU Mainz

Resonators are at the core of many Penning trap experiments. They can be used to cool and detect trapped ions. This contribution presents a planar resonator design, using the high-temperature superconductor YBCO, allowing the resonator to be used in a LN2-cooled environment. Furthermore, the geometrical simplicity increases the reproducibility of this design. For frequencies in the range of 5-30 MHz, typical for the cyclotron motion of highly charged ions in a Penning trap experiment, this design is much smaller than previous toriodal resonators. Here, first results of these new types of resonators are presented.

A 20.15 Wed 16:30 Empore Lichthof

Preparation, detection and cooling of single Strontium atoms in optical tweezers — •Aaron Götzelmann[1], Christian Hölzl[1], Moritz Wirth[1], Sebastian Weber[2], and Florian Meinert[1] — [1]5. Physikalisches Institut, Stuttgart, Germany — [2]Institut für Theoretische Physik 3, Stuttgart, Germany

In recent years, ensembles of atoms individually trapped in optical tweezer arrays have proven excellent systems for quantum computing and quantum simulation. Here, I report on our endeavour to prepare, cool, and detect single Strontium atoms in optical tweezers. We have chosen to work at a tweezer wavelength that is magic for the metastable $^3P_2$ and $^3P_0$ fine-structure states, motivated by exploiting this pair of states as a fast qubit for gate-based quantum computing [1].

Atom cooling and detection strategies reported so far for tweezer-trapped Strontium typically exploit the narrow $^1S_0$ to $^3P_1$ laser-cooling transition under magic trapping conditions. I will present our results to control single atoms under conditions, for which the $^1S_0$ to $^3P_1$ transition is non-magic, comprising single-atom preparation, high-fidelity imaging and evidence for near ground state cooling.

[1] F. Meinert, T. Pfau, and C. Hölzl, Quantum computing device, use, and method, EU Patent Application No. EP20214187.5

A 20.16 Wed 16:30 Empore Lichthof

Towards entanglement transfer from external to internal degrees of freedom and holography of laser wave — •Florian Hasse, Deviprasath Palani, Apurba Das, Maharshi Pran Bora, Lucas Eisenhart, Tobias Spanke, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising platform for quantum simulations [1]. In our linear Paul trap, we switch the trapping potential of two $^{25}Mg^{+}$ ions fast enough to induce a non-adiabatic change of the ions' motional mode frequencies. Thereby, we prepare ions in a squeezed state of motion. This process is accompanied by the formation of entanglement in the ions' motional degree of freedom and can be interpreted as an experimental analogue to the particle pair creation during cosmic inflation in the early universe [2].

We aim at transferring this entanglement from the external to the internal degree of freedom. To improve the measured contrast, we established a phase coherent combination of our laser- and microwave fields. As benchmarking experiments, we reconstruct holographs of our laser light wave. Here we use Ramsey sequences consisting of two $\pi/2$ pulses, where the second pulse is stroboscopically measured. Additionally, we aim at squeezing the ion(s) wave function to further enhance contrast.

[1] T. Schaetz et al., New J. Phys. 15, 085009 (2013).

[2] M. Wittemer et al., Phys. Rev. Lett. 123, 180502 (2019).

A 20.17 Wed 16:30 Empore Lichthof

Dielectronic recombination in He-like oxygen ions investigated at CRYRING@ESR — •Weronika Biela-Nowaczyk[1], Pedro Amaro[2], Carsten Brandau[1,3], Sebastian Fuchs[3,4], Filipe Grilo[2], Michael Lestinsky[1], Esther B. Menz[1,5], Stefan Schippers[3,4], Thomas Stöhlker[1,5,6], and Andrzej Warczak[7] — [1]GSI Darmstadt — [2]LIBPhys-UNL, NOVA Univ. Lisbon — [3]JLU Gießen — [4]HFHF Campus Gießen — [5]HI Jena — [6]FSU Jena — [7]JU Kraków

Multielectron resonant processes like dielectronic recombination (DR) and trielectronic recombination (TR) are governed by the electron-electron interaction and are of great importance in plasmas. These processes are major cooling factors in plasmas and, therefore, especially affect the dynamics of astrophysical objects. A program for DR experiments was started at the low-energy heavy-ion storage ring CRYRING@ESR. One of the first species studied was O^{6+}. As oxygen is one of the most abundant elements in the universe experimental data are of particular importance. The stored ion beam is collinearly merged with the ultra-cold electron beam of the cooler, leading to electron-ion interactions. In our experiment, the resonant condition for dielectronic capture was achieved by detuning the electron energy. The signatures of recombination were O^{5+} product ions, which were directed onto a particle detector and counted with near-unity efficiency. We will discuss the experimental method and show preliminary results of our analysis.

A 20.18 Wed 16:30 Empore Lichthof

Deterministic transport of trapped ions across two-dimensional trap-array — •Deviprasath Palani, Florian Hasse, Apurba Das, Maharshi Pran Bora, Lucas Eisenhart, Tobias Spanke, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg, Deutschland

Radio-Frequency surface electrode traps are promising platforms for envisioning large-scale quantum systems with trapped ions to perform quantum simulations, metrology, and information processing. In our prototype setup, the trap chip is fabricated by Sandia National Laboratories. The generated three-dimensional potential landscape has 13 strongly confined sites for ion storage and intermittent weakly confined areas featuring transport channels. With the sites closer to the surface, forming an equilateral triangular array: local control of sites, 2D inter-site coupling, and floquet-engineered coupling via the motional degrees of freedom had been demonstrated [1-3]. We extend the methods to enable the deterministic redistribution of ions across the array via an ancilla site ~13 μm above the array. Via Ramsey spectroscopy, we reveal that the ion transport doesn't decrease the information stored within the electronic degrees of freedom. We discuss our efforts in addressing technical limitations [4] and the possibilities of three-dimensional coupling. [1] Mielenz, M. et al Nat. Commun. 7, 11839 (2016). [2] Hakelberg, F. et al. Phys. Rev. Lett. 123, 100504 (2019). [3] Kiefer, P. et al. Phys. Rev. Lett. 123, 213605 (2019). [4] Warring, U. et al. Adv. Quantum Technol. 1900137 (2020).

A 20.19 Wed 16:30 Empore Lichthof

Integration of a nano-Foil Target Positioning System for High-Power Laser Ion Acceleration — •Vitus Magin, Laura D. Geulig, Erin G. Fitzpatrick, Maximilian J. Weiser, Veronika Kratzer, and Peter G. Thirolf — Ludwig-Maximilians-Universität München

Over the last years, the laser-based acceleration of heavy ions has reached increasing interest due to their unique beam properties like very short bunch duration and ultra-high particle density [1]. At the High Field (HF) beamline at the Centre for Advanced Laser Applications (CALA) in Garching the acceleration of gold ions using the ATLAS3000 laser is investigated. A major prerequisite for the acceleration of gold ions is the precise positioning of the a few 10 to few 100 nm thin foils in the laser focus. For this, the nano-Foil Target Positioning System (nFTPS) was developed for the Laser-Driven ION (LION) beamline at CALA [2], offering a 5μm precision needed due to the short Rayleigh length of the laser. At HF this system is currently implemented, replacing the tedious task to register the precise positions manually with the required accuracy. Here, we report on the current progress of the related upgrade. For this, a new microscope for x-y positioning and a confocal sensor are set up, soon enabling an autonomous 30 minute routine for all 760 targets which also corrects for imperfections caused by the mounting of the 19 target holders.

[1] D. Habs et al., Appl. Phys. B 103, 471-484 (2011) [2] Y. Gao et al., HPLSE 5, e12 (2017)

A 20.20 Wed 16:30 Empore Lichthof

Towards fermionic weakly-bound open-shell RbSr molecules — •Digvijay Digvijay, Premjith Thekkeppatt, Simon Lepleux, Junyu He, Klaasjan van Druten, and Florian Schreck — Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam

Ultracold dipolar molecules are a promising platform for quantum simulation, precision measurement and quantum chemistry. Ultracold molecules produced so far are closed-shell molecules, which limits their range of applications. Our goal is to produce ultracold fermionic RbSr molecules, which are dipolar open-shell molecules, in order to extend the range of possibilities.

Here we present our progress along a novel approach to create these molecules. Our approach uses confinement induced resonances (CIR) in a strongly interacting Bose-Fermi mixture and overcomes the challenge that magnetic Feshbach resonances, which are typically used to create ultracold molecules, are extremely narrow between alkali and alkaline-earth atoms. CIRs couple an atom pair state in a tight trap to a very weakly bound molecule in an excited trap state. Adiabatically lowering the confinement transfers the atom pair into the molecular state. Our experiment will start by preparing a strongly interacting 87Rb-87Sr Bose-Fermi mixture. In order to suppress inelastic collisions we intend to first prepare an n=1 Mott insulator of Rb and then to overlap it with a spin polarized Fermi gas of Sr. After molecule creation by adiabatically ramping the lattice depth across a CIR, we plan to perform STIRAP to the molecular ground state.

A 20.21 Wed 16:30 Empore Lichthof

Engineering Inter-Layer Couplings in Thin-Film X-Ray Cavities — •Hanns Zimmermann[1,2], Petar Andrejić[3], and Adriana Pálffy[2] — [1]Universität der Bundeswehr München — [2]Julius-Maximilians-Universität Würzburg — [3]Friedrich-Alexander-Universität Erlangen-Nürnberg

The resonant interaction between x-rays and Mössbauer nuclei is a promising method for achieving quantum control of high-frequency photons. A particularly promising platform are thin-film cavities, with one or several embedded layers of resonant nuclei such as ^{57}Fe with a Mössbauer transition at 14.4 keV. At grazing incidence, incoming x-rays couple evanescently to the cavity. In turn, the cavity field drives the nuclear transitions. The resulting nuclear response is well described by a recently-developed quantum-optical model based on the electromagnetic Green's function [1,2].

Here, we investigate theoretically thin-film cavities with multiple ^{57}Fe layers and design structures which allow for engineering of the inter-layer coupling. Via geometrical properties and control of the evanescent field pattern, we aim at implementing alternating coupling strengths between the resonant layers. Such couplings could lead to localization of the nuclear excitation in certain embedded layers and could eventually be useful to observe topological effects in x-ray thin-film cavities.

[1] X. Kong, et al. Phys. Rev. A 102, 033710 (2020)

[2] P. Andrejić and A. Pálffy, Phys. Rev. A 104, 033702 (2021)

A 20.22 Wed 16:30 Empore Lichthof

Spectroscopic Real-Time Temperature Diagnostic for Laser Heated Thin Gold Foils — •Veronika Kratzer, Laura D. Geulig, Erin G. Fitzpatrick, Florian H. Lindner, Vitus Magin, Maximilian J. Weiser, and Peter G. Thirolf — Ludwig-Maximilians-Universität München, Munich, Germany

Aiming to investigate the properties of heavy, neutron-rich nuclei, the novel 'fission-fusion' nuclear reaction mechanism, requiring an effi- cient laser-driven acceleration of heavy ions to kinetic energies above 7MeV/u, was proposed [1]. Previously, it was found that target heat- ing significantly enhances the efficient acceleration of ions heavier than protons (in our case Au ions), by evaporating surface contaminants and thus suppressing namely the acceleration of protons and carbon ions [2,3]. For our setup at the Centre for Advanced Laser Applications in Garching we built a heating system that additionally allows us to determine (and thus control) the target surface temperature [4]. The gold foil is heated with a cw laser (532nm, max. 3W). The emitted thermal spectrum is measured with a NIR spectrometer allowing to measure the surface temperature by fitting Planck*s radiation law. So far, the setup has successfully been tested in air. In a next step it will be operated in vacuum to determine the effects of e. g. heating duration and laser power on the performance of gold ion acceleration. [1]

D. Habs et al., Appl. Phys. B 103, 471-484 (2011) [2] F. H. Lindner et al., Phys. Plasm. Contr. Fusion 61, 055002 (2019) [3] F. H. Lindner et al., Sci Rep 12, 4784 (2022) [4] M. J. Weiser, Master Thesis, LMU Munich, 2021

A 20.23 Wed 16:30 Empore Lichthof

A Coincidence Electron Velocity-Map-Imaging and Ion Microscopy Unit for Ultracold Atoms — •Jette Heyer[1,2], Julian Fiedler[1,2], Mario Grossmann[1,2], Amir Khan[2], Linn Hamester[2], Klaus Sengstock[1,2], Markus Drescher[1,2], Juliette Simonet[1,2], and Philipp Wessels-Staarmann[1,2] — [1]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

By combining an ultracold quantum gas of ^{87}Rb with local strong-field ionization in femtosecond laser pulses, we investigate many-body systems with long-range interaction and atom-ion hybrid systems.

A novel coincidence unit consisting of an ion microscope and a velocity-map-imaging (VMI) spectrometer is developed to detect the ionization products, allowing simultaneous resolution of the spatial distribution of the ions and the momentum of the photoelectrons. Simulations for the ion microscope suggest a resolution in the 100 nm range, surpassing the optical resolution limit of quantum gas microscopes. The VMI spectrometer is designed to detect electrons with a kinetic energy of 0.05 meV−3.2 eV, with a simulated resolution of $\Delta E/E \leq 10\,\%$ with angular resolution.

Additionally, a pulsed extraction of the ions and electrons allows a coincidence detection for investigating correlations as well as the dynamics of the many-body system.

A 20.24 Wed 16:30 Empore Lichthof

Realizing and probing programmable 2D optical lattices with flexible geometries and connectivity — •Suchita Agrawal[1,2], David Wei[1,2], Daniel Adler[1,2], Kritsana Srakaew[1,2], Pascal Weckesser[1,2], Immanuel Bloch[1,2,3], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

Over the past decade, ultracold atoms in optical lattices have become a vital platform for experimental quantum simulation, enabling precise studies of a variety of quantum many-body problems. For most experiments, the layout of the confining lattice beams restricts the accessible lattice configurations and thus the underlying physics. Here, we present a novel tunable lattice, which provides programmable unit cell connectivity and in principle allows for changing the geometry mid-sequence. Our approach builds on the generation of phase-stable realisation of a square or triangular base lattice combined with microscopically projected repulsive local potential patterns. With this technique, we realise Lieb and Kagome lattices, and benchmark the various configurations by exploring single particle quantum walks. We explore many-body physics in these lattices by observing parity fluctuations associated with the superfluid-to-Mott insulator transition. As an outlook, we will explore how the presented lattices can be applied for spin-selective imaging as well as doublon detection.

A 20.25 Wed 16:30 Empore Lichthof

Nonsequential double ionization of Ne with elliptically polarized laser pulses — •Fang Liu[1,2,3], Zhangjin Chen[4], and Stephan Fritzsche[1,2,3] — [1]Helmholtz-Institut Jena — [2]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [4]Department of Physics, College of Science, Shantou University

We show through simulation that the improved quantitative rescattering model (QRS) can successfully predict the nonsequential double ionization (NSDI) process by intense elliptically polarized laser pulses. Using the QRS model, we calculate the correlated two-electron and ion momentum distributions of NSDI in Ne exposed to intense elliptically polarized laser pulses with a wavelength of 788 nm at a peak intensity of 5.0×10^{14} W/cm^2. We analyze the asymmetry in the doubly charged ion momentum spectra observed by Kang et al. in going from linearly to elliptically polarized laser pulses. Our model reproduces the experimental data well. Furthermore, we find that the ellipticity-dependent asymmetry arises from the drift velocity along the minor axis of the elliptic polarization. We explain how the correlated electron momentum distributions along the minor axis provide access to the subcycle dynamics of recollision.

A 20.26 Wed 16:30 Empore Lichthof

Non-Dipole Effects in Strong Field Ionization using Few-Cycle Laser Pulses — •Danish Furekh Dar[1,2,3], Birger Böning[1,2], and Stephan Fritzsche[1,2,3] — [1]Helmholtz-Institut Jena, Fröbelstieg 3, D-07743 Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstrasse 1, D-64291 Darmstadt, Germany — [3]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, D-07743 Jena, Germany

We present the extension of non-dipole strong field approximation that incorporates few-cycle laser pulses. We investigate the non-dipole effects of strong-field ionization. To do so, an atomic gas target is irradiated by circularly-polarized mid-infrared few-cycle laser pulse. To the end, we compute the photo-electron momentum distribution of argon and deduce the peak shifts of transverse electron momentum distribution in the laser propagation direction. Compared to recent work by [Phys. Rev. A 99,053404(2019)], we demonstrate a better agreement between theory and experimental investigations.

A 20.27 Wed 16:30 Empore Lichthof

Vibrational energy transfer between trapped atoms via Rydberg Excitation — •Abhijit Pendse[1], Sebastian Wüster[2], Matthew Eiles[1], and Alexander Eisfeld[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Indian Institute of Science Education and Research (IISER), Bhopal, India

The study of heat transfer between spatially separated ultracold atoms serves as a fundamental probe of thermodynamics of mesoscopic quantum systems [1,2]. To study the basic dynamics of this heat transfer, we consider three collinear harmonically trapped ultracold atoms. Coupling the central atom to a high-lying Rydberg s-state ($l = 0$) creates interactions in the system due to scattering of trapped atoms by the Rydberg electron. We numerically study the exact dynamics of an excited oscillator state in this Rydberg-coupled system. It turns out that the time scale of excitation transfer dynamics is smaller than the lifetime of the Rydberg state thus enabling experimental observation. The weak excitation of the central Rydberg atom, when the Rydberg electron-atom interaction energy becomes comparable to the oscillator energy, is an interesting feature of the system dynamics. As the harmonic trapping frequency of the Rydberg excited atom is increased with respect to that of other two atoms, the probability of multi-phonon excitation transfer increases.

[1] Giazotto, et al. (2006), Rev. Mod. Phys., 78 (1), 217.
[2] Charalambous, et al. (2019), N. J. Phys., 21(8), 083037.

A 20.28 Wed 16:30 Empore Lichthof

The ARTEMIS Experiment: Determination of bound-electron magnetic moments in highly charged ions — •Arya Krishnan[1,2], Khwaish Anjum[1,4], Patrick Baus[2], Gerhard Birkl[2], Manasa Chambath[1,5], Jan Hellmann[1,6], Kanika Kanika[1,3], Jeffrey Klimes[1,3], Wolfgang Quint[1,3], Bianca Reich[1,3], and Manuel Vogel[1] — [1]GSI Helmholtz Center for Heavy Ion Research, Germany — [2]Technical University of Darmstadt, Germany — [3]University of Heidelberg, Germany — [4]University of Jena, Germany — [5]NITTE University, India — [6]University of Giessen, Germany

The ARTEMIS experiment at the HITRAP facility situated at GSI focuses on precision measurement of electron magnetic moments in highly charged ions as a benchmark of QED in extreme fields. The resistively cooled ions are detected using non-destructive techniques, followed by laser-microwave double-resonance spectroscopy on the desired few-electron heavy ions in a cryogenic Penning trap. The high magnetic fields leading to higher order Zeeman effects provide different outlooks to the theory of quantum electrodynamics for an atomic nucleus. The system has been commissioned with ions produced internally and is now being upgraded to dynamic capture and storage of ions produced from external sources like EBITs and the HITRAP facility. We present the current status of the experiment and recent results on ion cooling.

A 20.29 Wed 16:30 Empore Lichthof

An Atomic Source for an Ytterbium Optical Lattice Clock — •Julian Pick[1], Lion Günster[1], and Carsten Klempt[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Institut für Satellitengeodäsie und Inertialsensorik, Deutsches Zentrum für Luft-und Raumfahrt e.V., Callinstraße 30b, 30167 Hannover

Optical lattice clocks based on neutral ytterbium atoms belong to today's most precise frequency standards. Clock operation requires ultracold atoms trapped in an optical lattice, which demands the implementation of laser cooling techniques. In our setup, an atomic ytterbium beam emerges from an oven at a temperature of 500 °C. The atoms are decelerated by a transversal-field permanent-magnet Zeeman slower and subsequently redirected and recollimated by a 2D magneto-optical trap (MOT), for loading into a 3D MOT.

The cooling light at 399 nm operating at the $^1S_0 - ^1P_1$ transition is generated by two frequency-doubled external cavity diode lasers, of which the fundamental wavelengths are used for frequency stabilization. The primary laser is stabilized to an ultrastable optical resonator using the electronic sideband locking method. The secondary laser is stabilized to the primary laser with a frequency offset lock.

I will present the setup of the ytterbium source and the laser frequency stabilization scheme, as well as a characterization of the atomic flux and its velocity distribution behind the 2D MOT.

A 20.30 Wed 16:30 Empore Lichthof

A dedicated 2-dimensional array of metallic magnetic microcalorimeters to resolve the 29.18keV doublet of ^{229}Th — •A. Brunold, A. Abeln, S. Allgeier, J. Geist, D. Hengstler, A. Orlow, L. Gastaldo, A. Fleischmann, and C. Enss — Heidelberg University

The isotope ^{229}Th has the nuclear isomer state with the lowest presently known excitation energy, which possibly allows to connect the fields of nuclear and atomic physics with the potential application as a nuclear clock. In order to excite this very narrow transition with a laser a precise knowledge of the transition energy is needed. Recently the isomer energy (8.338 ± 0.024) eV [Kraemer et al., arXiv:2209.10276, 2022] could be precisely determined. To get additional valuable insights, we will improve our recent high-resolution measurement [Sikorsky et al., PRL 125, 2020] of the γ-spectrum following the α-decay of ^{233}U. This decay results in excited ^{229}Th with a nuclear state at 29.18 keV. Resolving the doublet, that results from subsequent de-excitation to the ground and isomer state, respectively, would allow an independent measurement of the isomer energy and the branching ratio of these transitions. To resolve this doublet, we develop a 2D detector array consisting of 8×8 metallic magnetic calorimeters (MMCs). MMCs are operated at millikelvin temperatures and convert the energy of a single incident γ-ray photon into a temperature pulse which is measured by a paramagnetic temperature sensor. The detector array features an active detection area of 4 mm^2, a stopping power of 63.2% for 30 keV photons and an energy resolution below 3 eV (FWHM).

A 20.31 Wed 16:30 Empore Lichthof

Closed-cycle noble gas recycling system for an extreme-ultraviolet frequency comb — •Nele Griesbach, Jan-Hendrik Oelmann, Lennart Guth, Tobias Heldt, Roman Hector, Nick Lackmann, Janko Nauta, Thomas Pfeifer, and José R. López-Urrutia — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

To perform ultra-high spectroscopy of highly charged ions in the extreme ultraviolet (XUV), we developed an XUV-frequency comb [1]. Focusing the fundamental comb into a gas jet, high harmonic generation converts the near-infrared spectrum into the XUV regime. Usually, noble gases such as xenon, neon or krypton are used because of their high ionization potentials. As the worldwide demand for noble gases is increasing strongly and the abundancy of most noble gases in air is very low, the costs have increased to a point where long-term experiments are impossible. Therefore, we have developed a gas recycling system. The gas is injected through a 30 μm nozzle into the laser focus and is collected by a differential pumping system [1] to maintain the vacuum and is then re-compressed to a pressure of up to 200 bar. A good vacuum with low contamination level is indispensable as the cavity mirrors are susceptible to degradation and XUV light is strongly absorbed by air. We present the technical design of the system as well as measurements of the leakage and contamination rates.

[1] J. Nauta, *An extreme-ultraviolet frequency comb enabling frequency metrology with highly charged ions*, Phd thesis, Universität Heidelberg (2020).

A 20.32 Wed 16:30 Empore Lichthof

VAUQSI: Second Generation Superconducting Radio-Frequency Trap for Highly Charged Ion Qubits — •Stepan Kokh, Elwin A. Dijck, Christian Warnecke, Claudia Volk, Alvaro Garmendia, Julia Eff, Andrea Graf, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max-Planck-Institut für Kernphysik, Heidelberg

Quantum computing is a rapidly developing field with the potential to revolutionize science and information technology by enabling previously intractable calculations. Qubits based on laser-cooled ions in Paul traps form one of the most promising implementations of a quantum computer. Using highly charged ions trapped and sympathetically cooled inside a Be^+ Coulomb crystal, the sensitivity to external noise, which generally limits coherent operations, could be reduced. Working towards the first quantum computer based on highly charged ion qubits, we are constructing a new cryogenic, superconducting Paul trap VAUQSI (Viel-Frequenz-Ansteuerung Ultrastabiler Qubits in Supraleitenden Ionenfallen). The trap further develops our existing design, which integrates a linear Paul trap with a superconducting radio-frequency resonator. The storage and interrogation of ions is improved through better thermalization, which increases the resonator quality factor, and the addition of further electrodes, which allows finer control of the trapping potential in multi-qubit operation. A redesign of the electrodes improves the recapture of injected highly charged ions. We will present the technical implementation of the trap and its improvement regarding our current trap.

A 21: Ultrafast Dynamics II (joint session MO/A)

Time: Thursday 11:00–13:00 Location: F102

See MO 14 for details of this session.

A 22: Atomic Clusters (joint session A/MO)

Time: Thursday 11:00–13:00 Location: F107

Invited Talk A 22.1 Thu 11:00 F107

Efficient and accurate simulation of wide-angle single-shot scattering — •Paul Tuemmler, Björn Kruse, Christian Peltz, and Thomas Fennel — Institute for Physics, University of Rostock, Albert-Einstein-Str. 23-24, D-18059 Rostock, Germany

In recent years coherent diffractive imaging has been established as a powerful method for the structural investigation of unsupported nanoparticles. A large number of studies have been successfully performed in the small angle regime, where the recorded scattering image is directly connected to the target's density projection along the optical axis. An established technique to invert the scattering image is the well-known phase retrieval algorithm. Single-shot 3d information only becomes available when scattering signal can be recorded at wide scattering angles, which typically requires wavelengths of several object diameters. However, in this scattering regime a direct inversion via phase retrieval is no longer possible and iterative forward fitting schemes have to applied. These schemes require many iterations and therefore heavily rely on an efficient method to calculate scattering images. Unfortunately, optical parameters in the long wavelength regime are typically quite far from vacuum parameters, such that absorption and multiple scattering effects become important. So far, available methods either lack the necessary accuracy (e.g. MSFT methods) or the numerical efficiency (e.g. FDTD).

Here we present a rigorous split step method that retains the efficiency of multislice methods, while yielding accuracy comparable to Mie and FDTD methods.

A 22.2 Thu 11:30 F107

3D Femtosecond Snapshots of Silver Nanoclusters — •Alessandro Colombo for the FLASH-SilverClusters-Collaboration — Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland

Thanks to X-ray Free-Electron Lasers, Coherent Diffraction Imaging (CDI) allows femtosecond snapshots of matter at the nanoscale. When the diffracted light is recorded up to a sufficiently wide scattering angle, a single two-dimensional diffraction pattern carries 3D structural information on the sample. However, the non-trivial mathematical link between the sample's 3D shape and the 2D diffraction pattern renders 3D single-shot CDI a scientific challenge. Here we present a reconstruction method [1] that unveils the intriguing three-dimensional architectures of free-flying silver nanoclusters, retrieved from single wide-angle scattering images acquired at the soft X-ray Free-Electron Laser FLASH in Hamburg. The retrieved shapes of the silver clusters show satisfactory reliability and consistency, also revealing new structural motifs. Thanks to its great versatility, the method is then further extended to nanocrystals agglomerates, allowing for the first time a direct 3D insight into their growth process and surprising structures. This work represents a strong proof of concept for this imaging approach, raising the bar of the capabilities of 3D coherent diffraction imaging from single shot.

[1] Colombo, A. , et al. arXiv:2208.04044 (2022).

A 22.3 Thu 11:45 F107

Quenching of photon emission in heterogeneous noble gas clusters — •Lutz Marder, Catmarna Küstner-Wetekam, Nils Kiefer, Dana Bloss, André Knie, Arno Ehresmann, and Andreas Hans — Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Noble gas clusters represent prototype systems suited for the investigation of fundamental atomic and molecular processes. The Van-der-Waals bonds enable new relaxation pathways not available in isolated systems. Many of these have been studied during the recent years, often using coincidence measurement techniques.

We present our state-of-the-art experiment where both electrons and photons were detected in coincidence, which allows for investigation of multi-particle decay pathways after ionization with synchrotron radiation. The results show that the addition of a heavier noble gas to clusters of a lighter noble gas strongly alters the emission by the opening of faster ionizing decay channels compared to the radiative decay.

A 22.4 Thu 12:00 F107

Electron-Photon Coincidence Measurements at Synchrotron Facilities with Arbitrary Filling Pattern — •Johannes Viehmann, Andreas Hans, Christian Ozga, and Arno Ehresmann — Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Coincidence measurements are an important experimental tool in atomic or molecular physics. Our group has used electron-photon coincidence measurements to investigate rare gas clusters after synchrotron irradiation. The clusters exhibit a plethora of local and non-local electronic relaxation processes after core hole excitation. Most of these pathways produce free electrons and/ or photons. In order to distinguish signals of certain pathways from the general background, coincidence measurements are very useful.

So far, the combination of coincidence techniques with synchrotron radiation has mainly been restricted to the single bunch operation mode of the synchrotron facility due to difficulties in data acquisition. Here, we present a solution to combine coincidence measurements with multi-bunch operation modes and an example of using such technique to study rare gas clusters.

A 22.5 Thu 12:15 F107

Quantum nanofriction in trapped ion chains with a topological defect — •Lars Timm[1], Luca A. Rüffert[2], Hendrik Weimer[1,3], Luis Santos[1], and Tanja E. Mehlstäubler[2,4] — [1]Institut für Theoretische Physik, Appelstr. 2, 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [3]Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin — [4]Institut für Quantenoptik, Welfengarten 1, 30167 Hannover

After an introduction into the fundamental properties of the Frenkel-Kontorova model, one of the paradigmatic models of nanofriction, I will present the observation of a sliding to pinned transition with the help of a topological defect inside a two-dimensional self-assembled ion crystal. Subsequently, I shortly introduce one major consequence of this so-called Aubry transition, i.e. the localization of energy in the pinned phase of the defect. In the main part of my talk I discuss the quantized version of the Frenkel-Kontorova model and the consequences for the Aubry transition inside an ion crystal. As for that matter, we make use of a simple single particle formalism treating the defect as a quasiparticle, which captures the important dynamics of the defect close to the Aubry transition. This convenient approach gives access to its quantum properties revealing its quantum tunneling on a micron length-scale in a range of trap configurations and lets us identify a transition into a quasi-classical regime away from the transition point. Lastly, we give estimates for the temperature requirements and strategies to observe these effects in an experiment.

A 22.6 Thu 12:30 F107

Experimental studies on Interatomic Coulombic Decay after inner-shell ionization of heterogeneous rare gas clusters — •Catmarna Küstner-Wetekam[1], Lutz Marder[1], Dana Bloss[1], Nils Kiefer[1], Uwe Hergenhahn[2], Arno Ehresmann[1], Přemysl Kolorenč[3], and Andreas Hans[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [3]Institute of Theoretical Physics, Charles University, V Holesovickach 2, 180 00 Prague, Czech Republic

Non-local decay mechanisms play an important role in the relaxation of electronic vacancies in dense media such as biological samples. To explore these mechanisms in a less complex environment, rare gas clusters can be used as a prototype system for experiments. The use of multi-coincidence spectroscopy enables the detection of core-level Interatomic Coulombic Decay (ICD), which is a comparatively weak process in relation to the local Auger decay followed by Radiative Charge Transfer (RCT). Here, we present the observation of changes in ICD efficiency when going from homogeneous Ar and Kr clusters to heterogeneous ArKr clusters and thereby introducing a different environment to the excited atom in the respective cluster.

A 22.7 Thu 12:45 F107

Electron-photon-coincidence investigations on neighbor in-duced photoelectron recapture in argon clusters — •Nils Kiefer, Carolin Honisch, Catmarna Küstner-Wetekam, Niklas Golchert, Arno Ehresmann, and Andreas Hans — 1Institute of Physics, University of Kassel, Kassel, Germany

Noble gas clusters are an ideal prototype system for fundamental research on atomic and molecular processes. The Van-der-Waals-bound atoms create an environment, which enables further decay pathways and scattering effects. These have been studied already with high resolution electron spectroscopy and multi-electron-coincidence spectroscopy. With use of a state-of-the-art experimental set-up, which allows coincident electron and photon detection, radiative and electronic processes after excitation of clusters with synchrotron radiation can be directly observed. Here, we present the results of electron-photon-coincidence measurements of a recent experiment on argon clusters. Here a slow photoelectron after 2p ionization is expected to be scattered on neighboring atoms in a "Bremsstrahlung"-like process. Thus, the scatted electron can be recaptured to the Ion and further decay in a resonant Auger-like process.

A 23: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Thursday 11:00–13:00 Location: F303

Invited Talk A 23.1 Thu 11:00 F303

Trapping Ions and Ion Coulomb Crystals in a 1D Optical Lattice — •Daniel Hoenig[1], Fabian Thielemann[1], Joachim Welz[1], Wei Wu[1], Thomas Walker[1], Leon Karpa[2], Amir Mohammadi[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs Universität, Freiburg, Germany — [2]Leibniz Universität, Hannover, Germany

The long-range Coulomb interaction between ions and the dependence of the trapping potential on the internal electronic state of the ions make optically trapped ion Coulomb crystals an interesting platform for quantum simulations. Optical lattices further extend this platform by providing arrays of individual microtraps for the ions.

In the past, we reported the successful trapping of a single ion in a one-dimensional optical lattice as well as of ion Coulomb crystals in a single-beam optical dipole trap. In this talk, we present recent advancements in trapping 138Ba+ ions in a one-dimensional optical lattice at a wavelength of 532nm and the first successful trapping of linear ion Coulomb crystals ($N \leq 3$) in such a trap array. The observed eigenfrequencies of the ions in the lattice and the increased robustness against axial electric fields provide evidence for the single-site confinement of the ions at individual lattice sites.

As optical lattices are extendable in size and dimension, they might allow for the realization of ion-microtrap structures in 2D and 3D. Additionally, the absence of micromotion in optical traps could give them an edge over rf-traps in applications, where heating and decoherence induced by micromotion become limiting factors, as for example, the study of atom-ion interactions at ultracold temperatures.

A 23.2 Thu 11:30 F303

Catalyzation of supersolidity in binary dipolar condensates — •Daniel Scheiermann[1], Luis Ardila[2], and Luis Santos[3] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

reakthrough experiments have newly explored the fascinating physics of dipolar quantum droplets and supersolids. The recent realization of dipolar mixtures opens further intriguing possibilities. We show that under rather general conditions, the presence of a second component catalyzes droplet nucleation and supersolidity in an otherwise unmodulated condensate. For miscible mixtures, droplet catalyzation results from the effective modification of the relative dipolar strength, and may occur even for a surprisingly small impurity doping. We show that different ground-states may occur, including the possibility of two coexisting interacting supersolids. The immiscible regime provides a second scenario for double supersolidity in an array of immiscible droplets. In addition, we will discuss how the superfluidity of this mixture can be tested.

A 23.3 Thu 11:45 F303

Controlling superfluid flows using dissipative impurities — •Martin Will[1], Jamir Marino[2], Herwig Ott[1], and Michael Fleischhauer[1] — [1]University of Kaiserslautern-Landau, Germany — [2]Johannes Gutenberg University Mainz, Germany

We propose and analyze a protocol to create and control the superfluid flow in a one dimensional, weakly interacting Bose gas by noisy point contacts. Considering first a single contact in a static or moving condensate, we identify three different dynamical regimes: I. a linear response regime, where the noise induces a coherent flow in proportion to the strength of the noise, II. a Zeno regime with suppressed currents, and III. a regime of continuous soliton emission. Generalizing to two point contacts in a condensate at rest we show that noise tuning can be employed to control or stabilize the superfluid transport of particles along the segment which connects them.

A 23.4 Thu 12:00 F303

Atom-number enhancement by shielding atoms from losses in strontium magneto-optical traps — •Vasiliy Makhalov[1], Jonatan Höschele[1], Sandra Buob[1], Antonio Rubio[1], and Leticia Tarruell[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]Pg. Lluís Companys 23, 08010 Barcelona, Spain

Strontium offers many exciting opportunities for ultracold-atom experiments. For example, the most precise atomic clocks to date utilize the ultra-narrow clock transition of ^{87}Sr. Strontium also finds applications in atom quantum computing, interferometers, superradiant lasers, the generation of continuous-wave BEC, and quantum simulations. Most of these applications can benefit from a higher number of atoms.

In my talk, I will present a method to enhance the atom number in a 461-nm MOT of strontium without increasing the experimental complexity. This is achieved via saturation of the $^1S_0 \rightarrow {}^3P_1$ intercombination-line transition with intense resonant light. This continuously populates a short-living reservoir in the $^3P_1$ state and shields part of the atoms from the intrinsic losses of the 461-nm MOT cooling cycle. Such enhancement approximately doubles the atom number of the MOT of bosonic (^{88}Sr and ^{84}Sr) or fermionic (^{87}Sr) isotopes. Most of the strontium experiments can readily apply this technique without changes in the apparatus. I will also discuss the application of the shielding mechanism to other atomic species.

A 23.5 Thu 12:15 F303

From single to binary dipolar supersolids: a platform offering possibilities beyond imagination — •Albert Gallemi — Institut für Theoretische Physik, Leibniz Universität Hannover

Recent breakthrough experiments on dipolar condensates have reported the creation of supersolids. Supersolids have been observed both in elongated and oblate geometries, where they display themselves as 1D and 2D array of quantum droplets. In a single-component dipolar system, two main parameters (the ratio between dipolar and contact interactions and the density) can trigger different ground state configurations, in terms of different density patterns. As a result, apart from droplet arrays, one can observe the formation of honeycomb patterns and other kind of structure subject to randomness under the presence of an external confinement providing finite-size effects.

When two dipolar components coexist, the miscible-immiscible transition (which now depends on the dipole-dipole interaction) and the quantum number m_F corresponding to the condensed components (both in modulus and sign) play a role. We will analyse the different paths that open thanks to these extra degrees of freedom. We will also comment about the particular case of coherently Rabi-coupled dipolar mixtures, where polarization becomes a key observable. Rabi coupling also provides an intriguing power to the beyond-mean-field Lee-Huang-Yang correction, which can make the physics of droplets and supersolids to behave in a dramatically different way.

A 23.6 Thu 12:30 F303

Quantum fluctuations in one-dimensional supersolids — •Chris Bühler, Tobias Ilg, and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Scienceand Technology, University of Stuttgart, DE-70550 Stuttgart, Germany

In one-dimension, quantum fluctuations prevent the appearance of long-range order in a supersolid, and only quasi long-range order can survive. We derive this quantum critical behavior and study its influence on the superfluid response and properties of the solid. The analysis is based on an effective low-energy description accounting for the two coupled Goldstone modes. We find that the quantum phase transition from the superfluid to the supersolid is shifted by quantum fluctuations from its mean-field prediction. However, for current experimental parameters with dipolar atomic gases, this shift is not observable and the transition appears to be mean-field like.

A 23.7 Thu 12:45 F303

Supersolidity and Bloch oscillations in dipolar quantum gases — •Manfred Mark — Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria

Since strongly dipolar quantum gases made from lanthanide atoms were successfully brought to degeneracy 10 years ago, they have proven to be a rich source of new and fascinating phenomena arising from the long-range and anisotropic dipole-dipole interactions. Here, we will present the latest results from our erbium and dysprosium quantum gas experiments in Innsbruck. Following the recent discovery of supersolid states, we have studied its lifecycle from the formation to its death [1]. We also discuss our latest observation of supersolidity in two dimensions [2]. Finally, we investigated the properties of strongly dipolar gases within an array of two-dimensional traps [3] using Bloch oscillations and detected a transition to a stable self-focusing state which occupies only a single lattice plane, and predict the possibility of preparing dipolar solitons.

[1] M. Sohmen et al., Phys. Rev. Lett. 126, 233401 (2021) [2] M. A. Norcia et al., Nature 596, 357-361 (2021) [3] G. Natale et al., Commun. Phys., 5, 227 (2022)

A 24: Interaction with Strong or Short Laser Pulses III (joint session A/MO)

Time: Thursday 14:30–16:00 Location: F107

Invited Talk A 24.1 Thu 14:30 F107

Intra-cavity photoelectron tomography with an intra-cavity velocity-map imaging spectrometer at 100 MHz repetition rate — •Jan-Hendrik Oelmann[1], Tobias Heldt[1], Lennart Guth[1], Janko Nauta[1,2], Nick Lackmann[1], Valentin Wössner[1], Stepan Kokh[1], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Current address: Department of Physics, Swansea University, Singleton Park, SA2, United Kingdom

In a first experiment, we used intra-cavity velocity-map imaging (VMI) at 100 MHz repetition rate to investigate multi-photon ionization (MPI) events of xenon with high count rates, even at very low intensities [1]. For that, ultrashort pulses from a near-infrared frequency comb laser were amplified in a passive femtosecond enhancement cavity that we now use for extreme-ultraviolet frequency comb generation [2].

For tomographic reconstruction of photoelectron angular distributions (PADs) [3], we developed a compact VMI spectrometer and a polarization-insensitive enhancement cavity [4]. We will present our new setup that collects electron-energy spectra at high rates and allows to tomographically reconstruct 3D PADs from intra-cavity xenon MPI.

[1] J. Nauta et al., Opt. Lett. 45(8), 2156 (2020). [2] J. Nauta et al., Opt. Exp. 29(2), 2624 (2021). [3] M. Wollenhaupt et al., Appl. Phys. B 95(4), 647-651 (2009). [4] J.-H. Oelmann et al., Rev. Sci. Instrum., accepted (2022).

A 24.2 Thu 15:00 F107

Free electron vortices in multiphoton ionization of molecules — •Darius Köhnke, Cornelia Opp, Tim Bayer, and Matthias Wollenhaupt — Carl von Ossietzky university Oldenburg, Institute of Physics, Germany

Since their theoretical proposal [1] and their first experimental demonstration [2], free electron vortices have attracted significant attention. So far, most of the theoretical and all of the experimental investigations were performed on atoms. Here, we present the first experimental demonstration of free electron vortices by multiphoton ionization (MPI) of molecules. Specifically, we study the creation of molecular vortices on C_{60} fullerenes using counter rotating circularly polarized femtosecond laser pulse sequences generated from a white-light supercontinuum. Since the discovery of the C_{60} molecule it has served as a benchmark system to study photo-induced dynamics in complex systems. Due to its high symmetry, the C_{60} molecule, is an ideal system to bridge the gap between atoms and more complex systems such as polyatomic molecules and clusters. It has been shown that C_{60} exhibits distinct atom-like electronic orbitals, termed superatomic molecular orbitals (SAMOS) [3], which play an important role in the MPI of fullerenes. By tomographic reconstruction of the three-dimensional photoelectron momentum distribution, we show that ionization from a SAMO with the polarization-tailored laser field creates a six-armed free electron vortex.

[1] J. M. Ngoko Djiokap et. al, Phys. Rev. Lett., 115(11), 2015 [2] D. Pengel et. al, Phys. Rev. Lett., 118(5), 2017 [3] M. Feng et. al, Science, 320(5874), 2008

A 24.3 Thu 15:15 F107

Intra-cavity multiphoton processes in a standing wave frequency comb — •Tobias Heldt[1], Jan-Hendrik Oelmann[1], Lennart Guth[1], Janko Nauta[1], Prachi Nagpal[1], Nick Lackmann[1], Nele Griesbach[1], Christoph Düllmann[2], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Johannes Gutenberg-Universität, 55099 Mainz, Germany

The coherence of frequency combs gives rise to a wide field of powerful spectroscopic techniques. Additionally, the high repetition rate of a comb leads to experimentally manageable count rates even for processes with low cross-sections. We use these properties to study the nonlinear regime of atomic and solid-state light-matter interaction. To reach the necessary field strengths, we enhance a frequency comb at 100 MHz in a cavity to intensities of over 10^{13} W/cm^2. The polarization insensitive bow-tie ring cavity supports counterpropagating pulses which collide in the focus, where they generate a standing wave for the time of the pulse overlap. This geometry is promising because not only does it reduce the interaction volume, enhancing the resolution of our velocity map imaging (VMI) spectrometer [1], but it also allows Doppler-free excitation of atoms. The

polarization of both pulses can be controlled independently and an additional third pulse renders versatile pump-probe experiments possible. Further, we plan to probe the field with nanometric tips and we investigate how plasmons could lead to an excitation of the nuclear isomeric state of thorium-229 on such tips.
[1] J.-H. Oelmann et al., Rev. Sci. Instrum., accepted (2022)

A 24.4 Thu 15:30 F107

Time-resolved three-body fragmentation of the CH2I2 molecule upon XUV irradiation — •Florian Trost[1], Severin Meister[1], Hannes Lindenblatt[1], Kirsten Schnorr[1], Sven Augustin[1], Yifan Liu[1], Farzad Hosseini[2], Mustafa Zmerli[2], Markus Braune[5], Marion Kuhlmann[5], Sergio Díaz-Tendero[4], Fernando Martín[4], Renaud Guillemin[2], Maria Novella Piancastelli[3], Marc Simon[2], Thomas Pfeifer[1], and Robert Moshammer[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Sorbonne Université, Paris — [3]Uppsala Universitet — [4]Universidad Autónoma de Madrid — [5]DESY, Hamburg

Knowledge of de-excitation, charge redistribution and fragmentation of molecules upon XUV irradiation is essential for our understanding of light-matter interaction. Here I present the sequential three-body fragmentation of diiodomethane (CH2I2) following 4d inner-shell ionisation of one iodine atom. The data was obtained by time-resolved XUV-XUV pump-probe measurements using the reaction microscope endstation at the free-electron laser FLASH2 at DESY. In the two-step dissociation of the CH2I2 molecule a rotating intermediary state is identified through time-resolved 3D momentum correlation of the fragments. These results are supported by classical as well as quantum-mechanical simulations.

A 24.5 Thu 15:45 F107

Time operator, real tunneling time in strong field interaction and the attoclock. — •Ossama Kullie — Institute for Physics, University of Kassel.

In the present work [1], we show that our real tunneling time relation derived in earlier works [2] can be derived from an observable or a time operator, which obeys an ordinary commutation relation. Moreover, we show that our real tunneling time can also be constructed from the well-known Aharonov-Bohm time operator. This shows that the specific form of the time operator is not decisive, and dynamical time operators relate identically to the intrinsic time of the system. It con- trasts the famous Pauli theorem, and confirms the fact that time is an observable, i.e. the existence of time operator and that the time is not a parameter in quantum mechanics. Furthermore, we discuss the relations with different types of tunneling times such as Eisenbud- Wigner time, dwell time and the statistically defined tunneling time. We conclude with the hotly debated interpretation of the attoclock measurement and the advantage of the real tunneling time picture versus the imaginary one. [1] O. Kullie, Phys. Rep. 2020,2, 233. [2] O. K. Phys. Rev. A. **92**, 052118 (2015), O. K. Ann. of Phys. **389**, 333 (2018),[4] O. K. Mathematics **6**, 192 (2018).

A 25: Cluster and Experimental Techniques (joint session MO/A)

Time: Thursday 14:30–16:30 Location: F142

See MO 18 for details of this session.

A 26: Precision Spectroscopy of Atoms and Ions III (joint session A/Q)

Time: Thursday 14:30–16:30 Location: F303

Invited Talk A 26.1 Thu 14:30 F303

Laser spectroscopy of the heaviest elements with the RADRIS technique — •Tom Kieck for the RADRIS-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — Helmholtz-Institut Mainz, Germany

Exploring atomic and nuclear properties in the region of the heaviest elements through laser spectroscopy became possible with the RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) technique at GSI. Fusion evaporation reaction products are separated from the primary beam in the velocity filter SHIP and then stopped in high-purity argon gas and collected onto a thin hafnium filament. Following re-evaporation, the released neutral atoms are probed by two-step resonance laser ionization. The resulting photo-ions are guided to a silicon detector for identification by their characteristic alpha radiation.

After a first observation and characterisation of an atomic ground-state transition in nobelium (Z = 102), the technique was applied to several nobelium and fermium isotopes. We present advancements of the RADRIS technique together with recent results from the FAIR phase-0 beamtime 2022 at GSI. The setup performance was optimised to achieve higher total efficiency, which is now up to 15%. Improved stability of the system allowed the search for atomic levels in lawrencium (Z = 103) for more than 400 hours. In addition, the short-lived isotope ^{251}No ($T_{1/2}$ = 0.8 s) was studied along with several fermium and californium isotopes. These results and further prospects will be discussed.

A 26.2 Thu 15:00 F303

Collinear laser spectroscopy in ^{12,13}C^{4+} — •Patrick Müller[1], Phillip Imgram[1], Kristian König[1], Bernhard Maass[2], and Wilfried Nörtershäuser[1] — [1]Institut für Kernphysik, TU Darmstadt, Germany — [2]Argonne National Laboratory, Chicago, IL, USA

Laser spectroscopy has since long been used to determine differential nuclear charge radii $\delta\langle r^2\rangle$ for stable and short-lived isotopes. Recently, much effort was put in improved atomic structure calculations of helium-like systems to be able to extract absolute nuclear charge radii from $1s2s\,^3\mathrm{S}_1 \rightarrow 1s2s\,^3\mathrm{P}_J$ transition frequencies [1]. This can be used in light He-like ions, i. e., Be to N, in which the metastable state has sufficient lifetime to perform collinear laser spectroscopy and the transition wavelengths are in the laser accessible region.

We report on high-precision collinear laser spectroscopy measurements of the $1s2s\,^3\mathrm{S}_1 \rightarrow 1s2s\,^3\mathrm{P}_{0,1,2}$ transitions in ^{12,13}C^{4+} using the **Co**llinear **A**pparatus for **L**aser Spectroscopy and **A**pplied Physics (COALA) at the Institute of Nuclear Physics, TU Darmstadt. Although theory has not reached the accuracy to directly extract $\langle r^2\rangle$ in He-like systems with competitive uncertainty yet, mass-shift calculations between ^{12,13}C^{4+} will provide $\delta\langle r^2\rangle^{12,13}$ with very high precision in the conventional approach. The measured hyperfine structure of ^{13}C^{4+} which is modulated by significant hyperfine mixing will serve as another benchmark for testing atomic-structure theory. This project is supported by DFG (Project-ID 279384907 - SFB 1245).

[1] Yerokhin *et al.*, Phys. Rev. A **106**, 022815 (2022)

A 26.3 Thu 15:15 F303

Laser photodetachment threshold spectroscopy at FLSR: first results — •Oliver Forstner[1,2], Vadim Gadelshin[3], Lothar Schmidt[4], Kurt Stiebing[4], Dominik Studer[3], and Klaus Wendt[3] — [1]Friedrich Schiller-Universität Jena — [2]Helmholtz-Institut Jena — [3]Institut für Physik, Johannes Gutenberg-Universität Mainz — [4]Institut für Kernphysik, Goethe-Universität Frankfurt

The Frankfurt Low-energy Storage Ring (FLSR) is a room-temperature electrostatic storage ring, which can reduce the internal energy of stored ions almost to the ambient temperature, being suitable for laser photodetachment threshold (LPT) spectroscopy to determine the electron affinity of negatively charged ions. The latter play a key role in accelerator mass spectrometry (AMS): lasers can selectively neutralize undesired isobars, providing a purified beam of an isotope of interest. To extend the range of available AMS nuclides, it is necessary to identify neutralization schemes for unwanted atomic and molecular negative ions.

To achieve this goal, a source for negative ions was installed at FLSR and a compact laser lab was constructed guiding laser beams into FLSR. The laser setup is based on a tunable Ti:Sapphire laser pumped by a high repetition Nd:YAG laser. The neutralized ions are further downstream detected by a position sensitive MCP detector.

An overview of the setup and first results of precision spectroscopy of O^- will be presented. An outlook of further LPT studies will be given.

A 26.4 Thu 15:30 F303

Laser spectroscopy of fermium across the deformed N=152 shell closure — •Elisabeth Rickert for the Fermium-Collaboration — GSI Darmstadt, Germany — JGU Mainz, Germany — HIM Mainz, Germany

The existence and stability of heavy nuclei is a forefront topic in nuclear physics. Modern laser spectroscopy techniques provide a unique tool to study nuclear shell effects by measuring isotope shifts to infer mean-square charge radii and hence deduce nuclear size and shape. Laser spectroscopy measurements of the isotope shift of an atomic transition of the actinide element fermium (Z=100) have been recently carried out covering isotopes across the N=152 shell closure. On-line and off-line laser spectroscopy experiments with direct and indirect production schemes and offline production methods were combined and methodologically pushed forward to measure isotope shifts in fermium isotopes. Previously inaccessible isotopes, short and long-lived, were covered, enabling experiments at atom-at-a-time quantities through newly developed detection concepts.

Changes in the mean-square charge radii were extracted for the longest chain of isotopes investigated in the region of the heavy actinides revealing a discontinuity around the N=152 shell closure.

A 26.5 Thu 15:45 F303

High-resolution spectroscopy of exotic silver with a cw OPO injection-seeded PDA — •Mitzi Urquiza-González[1], Volker Sonnenschein[1], Omorjit S. Khwairakpam[2], Bram van den Borne[3], Michael Heines[3], Ágota Koszorús[3], Katerina Chrysalidis[4], Ruben P. de Groote[3,5], Bruce Marsh[4], Korbinian Hens[1], and Klaus Wendt[6] for the CRIS-Collaboration — [1]Division HÜBNER Photonics, Hübner GmbH Co KG, Germany — [2]Istituto Nazionale di Fisica Nucleare LNL, Italy — [3]KU Leuven, Belgium — [4]CERN, Switzerland — [5]University of Jyväskylä, Finland — [6]Johannes Gutenberg Universität, Germany

Short-lived radioisotopes are of special interest for nuclear structure studies, as their characteristic provide valuable reference points for theoretical predictions far from stability. By using lasers, hyperfine transitions can be accessed, allowing direct measurement of nuclear observables. For such high-resolution spectroscopy, narrow-band pulsed lasers can be created by the pulsed amplification of a cw seed laser, keeping the amplifier's high power and short time profile whilst acquiring the seeder's spectral properties.

Spectroscopy on exotic Ag was performed at the CRIS experiment at CERN. A tunable cw single-mode OPO was employed as injection-seed for a two-stage pulsed dye amplifier. The hyperfine splitting of the ground-state $^2S_{1/2}$ to the level $^2P^O_{3/2}$ was measured and the hyperfine coupling constants were determined. For this work, ^{111,117}Ag are presented, showcasing this laser system's applicability for future high-resolution spectroscopy studies.

A 26.6 Thu 16:00 F303

Hyperfine structures of neptunium — •Magdalena Kaja[1], Mitzi Urquiza-González[2], Felix Berg[1], Korbinian Hens[2], Tobias Reich[1], Matou Stemmler[1], Dominik Studer[1], Felix Weber[1], and Klaus Wendt[1] — [1]Johannes Gutenberg University, 55099 Mainz — [2]Hübner GmbH & Co. KG, Kassel, Germany

Neptunium is of major concern for the long-term safety of a high-level nuclear waste repository due to the long half-life of 2.1·10^6 years and the high radiotoxicity of its isotope ^{237}Np. In this context, trace analysis of environmental samples is of high relevance. Resonance ionization mass spectrometry (RIMS) is an excellent tool for selective and sensitive ultra-trace analysis of radionuclides but requires efficient excitation schemes and a suitable tracer for quantification. For isotope ratio determination, it is important to take into account the isotope-related effects in ionization schemes stemming from hyperfine structure (HFS) and isotope shift. Thus, new two-step excitation schemes for analysis of ^{237}Np and ^{239}Np as a tracer were identified and investigated.

Narrow bandwidth spectroscopy on ^{237}Np and ^{239}Np has been carried out at RISIKO mass separator using the specific PI-LIST laser ion source geometry together with an injection-locked seeded Ti:sa laser system. The latter has a spectral bandwidth of 20 MHz, while also providing a high repetition rate pulsed operation with the high-power density required for RIS. The HFS of the atomic ground-state transitions to the levels at 25 075.15 cm^{-1} and 25 277.63 cm^{-1} has been measured and hyperfine coupling constants for both isotopes as well as the isotope shift between ^{237}Np and ^{239}Np have been determined.

A 26.7 Thu 16:15 F303

High-resolution laser spectroscopy on the isotopes $^{244-248}$Cm — •Nina Kneip[1], Felix Weber[2], Christoph E. Düllmann[2,3,4], Christian M. Marquardt[5], Christoph Mokry[2,3], Petra J. Panak[5], Sebastian Raeder[3,4], Jörg Runke[2,4], Dominik Studer[3], Clemens Walther[1], and Klaus Wendt[2] — [1]Leibniz University Hannover, 30060 Hannover — [2]Johannes Gutenberg University Mainz, 55099 Mainz — [3]Helmholtz Institute Mainz, 55099 Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt — [5]Karlsruhe Institute of Technology, 76131 Karlsruhe

The transuranium element curium ($Z = 96$) is one of the minor actinides present in spent nuclear fuel. It is produced during power reactor operation in a series of nuclear reactions from ^{238}U. The resonance ionization mass spectroscopy (RIMS) method was used at the RISIKO mass separator at Mainz University for off-line studies in the complex, highly dense atomic structure of Cm. Due to its high ionization efficiency and outstanding elemental selectivity, RIMS is an excellent tool for high-precision laser spectroscopy on these minuscule samples. The isotope shift was measured for the isotope chain $^{244-248}$Cm for two different energy levels with the electron configurations $5f^7 6d7s7p\ ^9D_3$ and $5f^8 6d7s\ ^9D_3$. The odd-A iostopes were present with only $10^{11} - 10^{12}$ atoms. A narrow band Ti:sapphire laser system was used for high-precision measurements specifically to resolve the hyperfine structures of ^{245,247}Cm with 15 hyperfine transitions each. Finally, the modified King plot was used to determine the missing mean square charge radius of ^{247}Cm.

A 27: Poster III

Time: Thursday 16:30–19:00 Location: Empore Lichthof

A 27.1 Thu 16:30 Empore Lichthof

Single ionization of an asymmetric diatomic system by relativistic charged projectiles — •Andreas Jacob, Carsten Müller, and Alexander Voitkiv — Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf

We study [1] the single ionization of a diatomic system by relativistic charged projectiles. The system is formed by two weakly bound different atomic species, A and B, with the ionization potential of A being smaller than an excitation energy in B. In such case, three ionization channels occur: (i) direct ionization of A, (ii) direct ionization of B, and (iii) two-center ionization of A. While (i) and (ii) represent the well-known mechanism of direct impact ionization of a single atom, in channel (iii) ionization of A proceeds via impact excitation of B with its subsequent relaxation in which the de-excitation energy is transmitted to A that ionizes it. We show that, close to the resonance energy, the two-center channel (iii) is so enormously strong that its contribution remains dominant even when considering a range of emission energies orders of magnitude broader than the resonance width. Furthermore, we demonstrate that relativistic effects, caused by a high collision velocity, can strongly influence the angular distribution of emitted electrons even at rather small values of the Lorentz factor.

[1] A. Jacob, C. Müller, and A. B. Voitkiv, Phys. Rev. A 103, 042804 (2021).

A 27.2 Thu 16:30 Empore Lichthof

A new apparatus for investigating collisions and chemical processes with ultracold NaK molecules — •Jakob Stalmann, Sebastian Anskeit, Fritz von Gierke, Kai K. Voges, and Silke Ospelkaus — Institute of Quantum Optics, Leibniz University Hannover

Ultracold molecular collisions feature many highly complex and still not understood phenomena, such as formation and loss of long-lived collisional complexes, molecular Feshbach resonances and chemical reactions.

Here, we present our efforts for the construction of a new experimental setup for the investigation of such collisional phenomena with ultracold ^{23}Na^{39}K ground-state molecules.

For ground-state molecule creation, we first produce optically trapped ultracold atomic ensembles from a dual-species Zeeman slower and MOT setup. The atoms are optically transported to a science chamber, where molecule preparation takes place by first creating weakly bound Feshbach molecules and subsequently transfering them into their ground state by a coherent Raman process. For detection of all educt and product particles of molecular collisions, our setup comprises a time of flight-velocity map imaging mass spectrometer in the science chamber. In combination with a state-selective pulsed laser ionization and fragmentation scheme this will allow us to resolve chemical reaction pathways, explore ultracold reaction dynamics and develop new quantum control techniques for chemical reaction steering.

A 27.3 Thu 16:30 Empore Lichthof

Towards high precision quantum logic spectroscopy of single molecular ions — •Till Rehmert[1], Maximilian J. Zawierucha[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesalnstalt, Braunschweig, Deutschland — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well- suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy, where a well-controllable atomic ion is co-trapped to the molecular ion, both coupled strongly via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Using a Ca ion, we implemented a quantum logic scheme to detect population transfer on a co-trapped spectroscopy ion, induced by a far detuned Raman laser setup. We present the latest progress of the experiment, aiming at high precision quantum logic spectroscopy of single molecular ions.

A 27.4 Thu 16:30 Empore Lichthof

A laser system setup for production and cooling of $^9Be^+$ in a cryogenic Penning trap for precision measurements with (anti-)protons — •Jan Schaper[1], Julia Coenders[1], Juan Manuel Cornejo[1], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, Riken, Japan — [4]Heinrich-Heine-Universität Düsseldorf, Germany

The BASE collaboration has extensively contributed to high precision CPT symmetry tests on protons and antiprotons by measuring their charge-to-mass ratio and g-factor in a Penning trap at cryogenic temperatures [1-3]. At BASE Hannover we are developing new approaches for cooling and detection of these particles through laser cooling and methods of quantum logic schemes [4]. Since (anti-)protons cannot be directly addressed with laser light, single laser-cooled $^9Be^+$ ions will be used for sympathetic cooling of single (anti-)protons in a double well potential. In this poster, new developments of the experimental setup will be introduced. The implementation of a dedicated photoionization laser that enables quick loading of a single $^9Be^+$ ion into the trap will be shown. In addition, a dedicated laser setup for axial cooling of $^9Be^+$ will be presented.

[1] G. Schneider et al., Science 358, 1081 (2017) [2] C. Smorra et al., Nature 550, 371 (2017) [3] M.J. Borchert et al., Nature 601, 53 (2022) [4] M Niemann et al 2020 Meas. Sci. Technol. 31 035003

A 27.5 Thu 16:30 Empore Lichthof

Charged ultralong-range Rydberg trimers and ion-Rydberg dynamics — •Daniel Bosworth[1,2], Frederic Hummel[3], and Peter Schmelcher[1,2] — [1]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

We show that the recently observed class of long-range ion-Rydberg molecules can be divided into two families of states, which are characterised by their unique electronic structures resulting from the ion-induced admixture of quantum defect-split Rydberg nP states with different low-field seeking high-l states. We predict that in both cases these diatomic molecular states can bind additional ground state atoms lying within the orbit of the Rydberg electron, thereby forming charged ultralong-range Rydberg molecules (ULRM) with binding energies similar to that of conventional non-polar ULRM. To demonstrate this, we consider a Rydberg atom interacting with a single ground state atom and an ion. The additional atom breaks the system's cylindrical symmetry, which leads to mixing between states that would otherwise be decoupled. The predicted trimer binding energies and excitation series are distinct enough from those of the dimer to be observed using current experimental techniques. Complimentary to this time-independent study, we have developed a semi-classical model for the dynamics of an s-state Rydberg atom in the presence of an ion.

A 27.6 Thu 16:30 Empore Lichthof

Construction of a versatile Rydberg atom platform — •Aaron Thielmann, Sven Schmidt, Suthep Pomjaksilp, Thomas Niederprüm, and Herwig Ott — Department of Physics and research center OPTIMAS, RPTU Kaiserslautern-Landau

In recent years, atomic arrays emerged as a ground-breaking platform in quantum physics. These setups do not only feature single-atom control, additionally exciting addressable atoms to Rydberg states introduces further possibilities to study physical problems in different geometric configurations.

We plan to realize arbitrarily arranged two-dimensional arrays with up to 100 lattice sites, each of them containing one or a few atoms. The arrays are holographically generated by an SLM in combination with a 1064 nm YAG-laser. Via a two-photon Rydberg transition, we collectively excite the atoms to Rydberg states. Due to the long-range character of the resulting Rydberg interactions, an interaction of the atoms in and between lattice sites is also intrinsically given. This setup is a prime candidate to investigate both topological systems of single atoms as well as effects arising from many-body properties in a controlled manner.

Adding controlled microwave transitions between different Rydberg states and the incorporation of a second atomic species open up possibilities to study even more complex physical systems in future research.

A 27.7 Thu 16:30 Empore Lichthof

A 1d-optical lattice for a crystal of cold ions — •Amir Mohammadi[1], Daniel Hoenig[1], Leon Karpa[2], and Tobias Schaetz[1] — [1]Albert-Ludwigs Universität, Freiburg, Germany — [2]Leibniz Universität, Hannover, Germany

Crystals of ions are a promising tool for implementing quantum simulation e.g., spin interaction in a solid. For decades rf-traps and Penning traps have confined Coulomb crystals using a ponderomotive force acting on charged particles. Despite stability and reasonable control over charged particles in these traps, they are driven into inherent energetic motion known as excess micromotion that heats up the ions and limits the applications of the system. As an alternative, it has been shown [1] that a chain of ions can also be trapped in a single optical beam that is spatially focused, similar to neutral atoms in an optical dipole trap, and can be seen as a platform for realizing a quantum simulation without any micromotion. As a next step in confining and localizing cold ions with light fields, we introduce the first successful trapping of a 138Ba ion Columb crystal up to three ions in a 1d-optical lattice featured by two counter-propagating 532nm laser beams of parallel polarization. We observe orders of magnitude enhancement in the axial trapping frequencies revealing single-site confinement for each individual trapped ion.

[1] Schmidt, J., et al., Phys. Rev. X 8, 021028 (2018)

A 27.8 Thu 16:30 Empore Lichthof

Assembling Fermi-Hubbard Systems for Random Unitary Observables — •Jin Zhang[1], Naman Jain[1], Daniel Dux[1,2], and Philipp Preiss[1,3] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Recent advances in probing complex many body systems allow us to raise incisive questions about their dynamics, which are classically hard to compute. Studying the Fermi-Hubbard model using random unitary operators enables the observations of global properties of the density matrix of delocalized systems.

We report progress on building a fermionic quantum simulator capable of realizing random unitary operations. Such a high performance simulator requires a fast cycle time and a high fidelity readout process. We will achieve a fast cycle time by evaporative cooling in an optical tweezer array, followed by simultaneously loading into a tunable lattice. Our readout process will reach single site resolution employing matter wave magnification and spin-resolved free-space imaging. This will enable us to measure, for example, entanglement entropy, out-of-time-order correlators, and state tomography.

A 27.9 Thu 16:30 Empore Lichthof

Nonlinear pulse compression in a gas-filled multi-pass cell — •Prachi Nagpal[1], Jan-Hendrik Oelmann[1], Tobias Heldt[1], Lennart Guth[1], Simon Angstenberger[2], Janko Nauta[3], Nick Lackmann[1], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max Planck Institut für Kernphysik, Heidelberg, Germany — [2]4th Physics Institute, University of Stuttgart, Germany — [3]Department of Physics, Swansea University, UK

A novel approach is proposed for nonlinear spectral broadening and temporal pulse compression well below the gain-bandwidth limitation of the laser gain medium [1]. We install, in a gas-filled multi-pass cell, a potassium dihydrogen phosphate (KDP) crystal, which exhibits anomalous dispersion around the central wavelength (1030 nm) of the seed laser [2]. The resulting total dispersion is adjusted by changing the pressure of a normal dispersive gas filling the cell. Chirped mirrors become unnecessary, and pulse compression can be tuned by adjusting the number of passes. Shorter pulses and a broader spectrum will enhance high harmonic generation for an extreme ultraviolet frequency comb which will be employed for quantum logic spectroscopy of highly charged ions [3].

[1] Anne-Lise Viotti et al., Optica 9, 197-216 (2022) [2] Zernike, J. Opt. Soc. Am. 54, 1215*1220 (1964) [3] L. Schmöger et al., Science 347, 1233 (2015)

A 27.10 Thu 16:30 Empore Lichthof

Rydberg spectroscopy in the strong driving limit for atoms and molecules — •Florian Binoth, Tanita Klas, Jana Bender, Patrick Mischke, Thomas Niederprüm, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We experimentally deform the 5S-6P potential of Rubidium atoms at large interatomic distances. This deformation leads to a potential shape that supports bound molecular states. To achieve this, we couple off-resonantly to an ultralong range Rydberg molecule potential using strong laser driving. Properties that are commonly associated with Rydberg molecules are optically admixed to the 5S-6P pair state.

We spectroscopically observe the photoassociated 5S-6P molecules. The change in binding energy for different experimental coupling parameters is in qualitative agreement with a simple theoretical model.

Another effect we investigate is the Autler-Townes splitting in multilevel systems. The strong coupling lifts degeneracies and mixes closely-spaced states. This results in complex spectra deviating from the symmetrical two-level Autler-Townes splitting.

We experimentally investigate these spectra in a thermal cloud of ^{87}Rb atoms by resonantly coupling the 6P3/2, $F = 3$ state to a Rydberg state with varying Rabi frequency. Our experiments confirm that multilevel effects have to be considered in the Autler-Townes regime.

A 27.11 Thu 16:30 Empore Lichthof

A cold atomic lithium beam via a 2D MOT — •Hendrik-Lukas Schumacher, Benedikt Tscharn, Marcel Willig, Gregor Schwendler, and Randolf Pohl — Johannes Gutenberg-Universität Mainz Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+

Laser spectroscopy of atomic ^{6,7}Li has been used to determine the (squared) rms charge radius difference of the stable Li nuclei [1]. One important systematic effect in this experiment, as well as in most other precision spectroscopy measurements, is the distortion and apparent shift of resonance line by quantum interference of close-lying states [2]. Li with its unresolved hyperfine structure is an excellent testbed for precision studies of quantum interference [3].

So we present the current performance and setup of a 2D MOT, used to create a source for a very high flux of cold atomic Li for precision spectroscopy [4], and for using trapped cold Li as a buffer gas to enable trapping of atomic hydrogen, deuterium and later tritium [1].

[1] S. Schmidt et al., J. Phys. Conf. Ser. accepted (2018), arXiv 1808.07240
[2] M. Horbatsch, E.A. Hessels, Phys.Rev. A 84, 032508 (2011)
[3] R. C. Brown et al., Phys.Rev. A 87, 032504 (2013)
[4] H. Schumacher, Johannes Gutenberg-Universität Mainz, Master Thesis (2022)

A 27.12 Thu 16:30 Empore Lichthof

Attosecond-precision dynamics of a laser-driven two-electron wave packet in helium — •Shuyuan Hu, Yu He, Gergana Borisova, Maximillian Hartmann, Paul Birk, Christian Ott, and Thomas Pfeifer — Saupfercheckweg 1, 69117 Heidelberg

We have combined attosecond transient absorption spectroscopy (ATAS) and attosecond streaking spectroscopy to simultaneously measure the resonant photoabsorption spectra of laser-coupled doubly excited states in helium, together with the streaked photoelectron spectra. The streaking measurement reveals the absolute time delay zero and the full temporal profile of the electric fields which is incorporated in a time-dependent few-level simulation of the laser-coupled states in helium. Comparing the 1-fs time-scale modulations across the 2s2p(1P) and sp2,3+(1P) doubly excited states between the time-delay-calibrated simulation and the measurement, we identify the sign convention of the transition dipole matrix elements for the laser-coupled autoionizing states 2s2p-2p2 and 2p2-sp2,3+ to be opposite of each other.

A 27.13 Thu 16:30 Empore Lichthof

Ultracold Plasma: Many-body dynamics across the ionization threshold — •Julian Fiedler[1,2], Mario Grossmann[1,2], Jette Heyer[1,2], Linn Hamester[2], Amir Khan[2], Klaus Sengstock[1,2], Markus Drescher[1,2], Philipp Wessels-Staarmann[1,2], and Juliette Simonet[1,2] — [1]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Ultrashort laser pulses provide pathways for manipulating atomic quantum gases on femtosecond timescales. We use a single ultrashort laser pulse of tunable wavelength to ionize a cloud of ultracold ^{87}Rb atoms via a two-photon process and detect the ionization fragments.

At high excess energies above the ionization threshold, fast electrons are created and we observe the formation of an ultracold microplasma with a rapid electron cooling on picosecond timescales, where the orbit of the electrons lies outside the dense ionic core. Lowering the electron excess energy allows creating a plasma were the electron trajectories predominantly lie inside the ionic core.

By tuning the two-photon excitation energy below the ionization threshold, we create a dense ensemble of Rydberg atoms, which circumvents the Rydberg blockade due to the large bandwidth of the laser pulse. The subsequent dynamics is governed by collisional ionization of the Rydberg atoms and formation of an ultracold plasma. The results are compared to classical molecular dynamics simulations.

A 27.14 Thu 16:30 Empore Lichthof

Interatomic Two-Electron-One-Electron decay following 4d ionization in Xe — •Christina Zindel[1], Catmarna-Sophia Küstner-Wetekam[1], Lutz Marder[1], Niklas Golchert[1], Jenni Autio[2], Teemu Salmela[2], Minna Patanen[2], Arno Ehresmann[1], and Andreas Hans[1] — [1]Institut für Physik and CINSaT, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Nano and Molecular Systems Research Unit, Faculty of Science, University of Oulu, Box 3000, FI-90014, Finland

The decay behavior of excited atomic systems is influenced by their environment such that new possible relaxation processes might emerge when changing from isolated particles to van-der-Waals bound rare gas clusters. The latter represent prototype systems, which allow the study of fundamental processes as a first step toward more complex structures. Here, we investigate an interatomic variant of the so-called Two-Electron-One-Electron (TEOE) process, also referred to as three-electron Interatomic or Intermolecular Coulombic Decay (ICD). After 4d photoionization of Xe and following Auger-Meitner decay, a two-vacancy $5s^0 5p^6$ state will be prepared. Subsequently, the simultaneous filling of both inner-valence holes leads to the emission of a third electron from a neighboring atom. Multi-coincidence spectroscopy will be used to analyze the characteristic electron signal.

A 27.15 Thu 16:30 Empore Lichthof

First experiments at the CRYRING@ESR low-energy heavy-ion storage ring — •Michael Lestinsky for the SPARC-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt

The CRYRING@ESR storage ring is a recent installation at the heavy ion accelerator complex of GSI, Darmstadt, and the first completed facility within the FAIR project. CRYRING@ESR provides a combination of access to isotopically pure, heavy, highly charged ions of all natural elements, even to the ultimate case of bare U^{92+}, as well as long storage times for the circulating ions and electron cooling to improve the beam quality. The machine is now in routine operation and commenced its service for experiments proposed by the scientific community through the Stored Particle Atomic Research Collaboration (SPARC). A new generation of experiments was proposed to address precision spectroscopy in the strong fields of highly charged ions, to study the dynamics of slow atomic collisions and on nuclear reactions within e.g. the Gamow window of *p*-process nucleosynthesis. In the years of 2020 to 2022, the first experiments have been installed and commissioning beamtimes could be completed, studying electron-ion collisions, ion-atom collisions, and with laser-spectroscopic methods. The first data confirm the high potential of CRYRING@ESR for precision experiments with highly charged ions.

Here, we will give an overview of our facility and the research program, discuss the first experimental data and preview the planned machine upgrades and the experiments for the coming years.

A 27.16 Thu 16:30 Empore Lichthof

A setup for extreme ultraviolet wave packet interferometry using tabletop high harmonic generation — •Sarang Dev Ganeshamandiram, Fabian Richter, Ianina Kosse, Ronak Shah, Lukas Bruder, Giuseppe Sansone, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Quantum interference techniques such as wave packet interferometry (WPI) in the extreme ultraviolet (XUV) regime set the basis for advanced nonlinear spectroscopy methods, such as multidimensional spectroscopy. These methods are however very difficult to implement at short wavelengths due to the required high phase stability and sensitivity. Recently, we have overcome these difficulties with the implementation of a special stabilization method based on acousto-optical phase modulation. We will present some of our recent results.

A 27.17 Thu 16:30 Empore Lichthof

XUV frequency comb for precision spectroscopy of trapped highly charged ions — •Lennart Guth[1], Jan-Hendrik Oelmann[1], Tobias Heldt[1], Janko Nauta[1,2], Nick Lackmann[1], Nele Griesbach[1], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [2]Department of Physics, Swansea University, Singleton Park, SA2, United Kingdom

Highly charged ions have a few tightly bound electrons, which allow to probe fundamental physics and develop new frequency standards. However, most transitions are in the extreme ultraviolet (XUV)[1]. To perform spectroscopy on these with unprecedented precision, we have built an XUV frequency comb by transferring the coherence and stability of a near-infrared (NIR) frequency comb to the XUV using high-harmonic generation [2]. To reach the required peak intensity, NIR frequency comb pulses (200 fs) are amplified to 80 W in a chirped pulse fiber amplifier and resonantly overlapped in a femtosecond enhancement cavity ($P_{\mathrm{avg}} \approx 25$ kW, $I_{\mathrm{peak}} \approx 3 \cdot 10^{14}$ W/cm^2) [3]. High harmonics up to the 35th order are coupled out of the cavity and will be used for future direct XUV spectroscopy of highly charged ions, trapped and sympathetically cooled in a superconducting Paul trap [4].

[1] M.S. Safronova et al., Phys. Rev. Lett. 113, 030801 (2014).
[2] G. Porat et al., Nat. Photon, 12, 387 - 391 (2018).
[3] J. Nauta et al., Nucl. Instrum. Meth. B 408, 285 (2017).
[4] J. Stark et al., Rev. Sci. Instrum., 92, 083203 (2021).

A 27.18 Thu 16:30 Empore Lichthof

Continuous cooling below the Doppler Temperature of Sr in a Two-Color Magneto-Optical Trap — •Shubha Deutschle, Milán Negyedi, Andreas Günther, Lörinc Sárkány, and József Fortágh — Physikalisches Institut, Universität Tübingen

We use the $5s^2\ ^1S_0$ ground state and the $5s5p\ ^3P_2$ metastable state of Sr for two-stage laser cooling in a two-color magneto-optical trap. ^{88}Sr atoms are precooled operating on the $5s^2\ ^1S_0$ - $5s5p\ ^1P_1$ transition. Cooling below the Doppler limit is achieved using the $5s5p\ ^3P_2$ - $5s5d\ ^3D_3$ transition.

A 27.19 Thu 16:30 Empore Lichthof

Development of and extreme-ultraviolet beamline for quantum logic spectroscopy of highly charged ions — •Nick Lackmann[1], Jan-Hendrik Oelmann[1], Janko Nauta[2], Tobias Heldt[1], Lennart Guth[1], Prachi Nagpal[1], Nele Griesbach[1], José R. Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]: Department of Physics, College of Science, Swansea University, Singleton Park, SA2, United Kingdom

Atomic clocks based on highly charged ions are prosperous candidates for quantum sensors with unprecedented precision, sensitive for physics beyond the Standard Model [1,2]. To drive the clock transitions, an extreme-ultraviolet frequency comb was constructed based on cavity-enhanced high-harmonic generation of the driving 100 MHz near-infrared frequency comb [3]. Harmonics up to 42 eV are generated in a gas jet and are subsequently guided through a beamline towards a superconducting Paul trap for direct XUV-comb spectroscopy [4, 5].

[1] M. G. Kozlov et al., Rev. Mod. Phys. 90, 045005 (2018)
[2] Safronova et al., Phys. Rev. Lett. 113, 030801 (2014)
[3] J. Nauta et al., Opt. Express 29, 2624 - 2636 (2021)
[4] P. Micke et al., Nature 578, 60 - 65 (2020)
[5] J. Stark et al., Rev. Sci. Instr. 92, 083203 (2021)

A 27.20 Thu 16:30 Empore Lichthof

Ion-atom-atom collisions: from plasma physics to cold chemistry — •Marjan Mirahmadi[1] and Jesús Pérez-Ríos[1,2,3] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Department of Physics, Stony Brook University, NY, USA — [3]Institute for Advanced Computational Science, Stony Brook University, NY, USA

We present a study on ion-atom-atom reaction A+A+B$^+$ in a wide range of systems and collision energies ranging from 100 μK to 10^5 K, analyzing the two possible products: molecules (A_2) and molecular ions (AB^+). The dynamics is performed via a direct three-body formalism based on a classical trajectory method in hyperspherical coordinates developed in [J. Chem. Phys. **140**, 044307 (2014)]. Our chief finding is that the dissociation energy of the molecular ion product acts as a threshold energy separating the low and high energy regimes. In the low energy regime, the long-range tail of the three-body potential dictates the main reaction product. On the contrary, in the high energy regime, the short-range of atom-atom and atom-ion interaction potential dominates the dynamics, enhancing molecular formation for the low energy regime. Moreover, we are able to confirm the previously derived threshold law for ion-neutral-neutral three-body recombination in [J. Chem. Phys. **143**, 041105 (2015); Phys. Rev. A **98**, 062707 (2018)] at low temperatures and establish the range of its validity.

A 27.21 Thu 16:30 Empore Lichthof

Multi-Sideband RABBIT in Argon and Helium — •Divya Bharti[1], Hemkumar Srinivas[1], Farshad Shobeiry[1], Kathryn Hamilton[2], Robert Moshammer[1], Thomas Pfeifer[1], Klaus Bartschat[2], and Anne Harth[1,3] — [1]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [2]Department of Physics and Astronomy, Drake University, Des Moines, USA — [3]Department of Optics and Mechatronics, Hochschule Aalen, Aalen, Germany

We present an experimental and theoretical study for three-sideband (3-SB) RABBIT (The reconstruction of attosecond beating by interference of two-photon transition) in argon and Helium. RABBIT is an interferometric technique in which an XUV pulse train ionizes the target, and an IR pulse interacts with the photoelectrons. In the 3-SB RABBIT scheme, the interaction with the IR photons leads to the formation of three sidebands in between any two main bands formed by two adjacent harmonics. The oscillation phases of the three SBs in the group are independent of a potential chirp in the harmonics. We compare the oscillation phases extracted from specific SB groups formed by two adjacent harmonics. We also compare their angle dependence and discuss the role of the propensity rule and the variation in the continuum-continuum coupling phase with the orbital angular momentum. Results from R-matrix (close-coupling) with time-dependence calculation on Argon and SAE calculations on Helium are also presented.

A 27.22 Thu 16:30 Empore Lichthof

Fluorescence Detection of Rydberg Atoms — •Dillen Lee, Eduard Braun, Moritz Hornung, Gerhard Zürn, and Matthias Weidemüller — Physikalische Institut Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Rydberg atom platforms are ideally suited to study the dynamics of closed quantum spin systems with giant interactions. Complementary to experiments with Rydberg spins excited from ground state atoms prepared in optical lattices or optical tweezers that are typically arranged in a ordered configuration, on our platform we excite Rydberg spins from a thermal gas of atoms with random distribution. To not only determine the number of Rydberg spins in the system which can be deduced from the detected number of ions after field ionisation we are heading towards a fluorescence detection scheme which will allow us to also determine not only the spatial distribution but also the spatial correlations of the spin system. In this poster we present a detection scheme for Rubidium Rydberg atoms that is based on free-space fluorescence detection which does not require the presence of a pinning lattice during exposure.

A 27.23 Thu 16:30 Empore Lichthof

Rymax-One: A neutral atom quantum processor to solve optimization problems — •Jonas Witzenrath[1], Niclas Luick[2,3], Benjamin Abeln[2], Daniel Adam[1], Kapil Goswami[4], Rick Mukherjee[4], Lennart Sobirey[2], Thomas Niederprüm[1], Henning Moritz[2,4], Herwig Ott[1], Peter Schmelcher[3,4], Artur Widera[1], and Klaus Sengstock[2,3,4] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, 22761 Hamburg, Germany — [4]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

Quantum computers are set to advance various domains of science and technology due to their ability to efficiently solve computationally hard problems, with a particular interest in combinatorial optimization problems. However, achieving a quantum advantage is still prevented by the quality and scale of the available quantum computing hardware.

Here, we present our project Rymax-One - which aims at building a quantum processor specifically designed to solve optimization problems that are intractable on classical devices. We use trapped arrays of ultracold ^{171}Yb atoms whose level structure enables qubit realizations with long coherence times, Rydberg-mediated interactions and high-fidelity gate operations. Solving open questions on the details of the interaction and excitation scheme will yield the high fidelities that allow us realize a scalable platform for quantum processing.

A 27.24 Thu 16:30 Empore Lichthof

Extended Mean-field Theory of strong coupling Bose polarons — •Nader Mostaan[1], Nathan Goldman[2], and Fabian Grusdt[1] — [1]Department of Physics and Arnold Sommerfeld Center for Theoretical Physics (ASC), Ludwig-Maximilians-Universität München, Theresienstr. 37, D-80333 München, Germany. Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany. — [2]CENOLI, Universite Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium.

A mobile quantum impurity resonantly coupled to a BEC forms a quasiparticle termed Bose polaron. In cold atom realizations of Bose polaron, the strength of the impurity-boson interactions is tunable via Feshbach resonances. At strong coupling, when an impurity-boson dimer exists, an unstable collective mode exists on top of the mean-field solution; thus, the impurity can bind a diverging number of non-interacting bosons. In this case, inter-boson interactions are crucial to stabilizing the Bose polaron. To describe Bose polaron, we employ an extension of coherent state variational ansatz, which accounts for beyond mean-field correlations of the bound mode. We find that the state of the bound mode is well described by a Fock-coherent state, and the impurity-boson resonance is shifted as a result of screening by the bosons bound to the impurity. In addition, we identify first-order phase transitions between Fock states with increasing occupation numbers. Our results corroborate the existence of multibody resonances between the attractive and repulsive polaron branches, which can be experimentally detected using impurity spectroscopy techniques.

A 27.25 Thu 16:30 Empore Lichthof

Towards Quantum Simulations of Light-Matter Interfaces with Strontium Atoms in Optical Lattices — •Felix Spriestersbach[1,2], Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Jan Trautmann[1,2], Sebastian Pucher[1,2], Immanuel Bloch[1,3,2], and Sebastian Blatt[1,3,2] — [1]MPQ, 85748 Garching, Germany — [2]MCQST, 80799 München, Germany — [3]LMU, 80799 München, Germany

With the recent development of quantum gas microscopes, quantum simulators can now control ultracold atomic systems with single-site resolution.

Here, we present the progress towards a new strontium-based quantum simulator.

We have developed in-vacuum build-up optical cavities to create two-dimensional optical lattices with large mode waists using low input power. We characterized the lattice potential using clock spectroscopy in a non-magic lattice.

Additionally, we further present precision spectroscopy of the ultra-narrow magnetic quadrupole transition $^1S_0$ - $^3P_2$ in Sr. Using a magnetic field gradient, we managed to trap ^{88}Sr atoms in a single two-dimensional layer within the optical lattice. Recently, our group successfully implemented single-site resolution fluorescence imaging of this two-dimensional layer.

By combining the advantage of a large system size and the realization of state-dependent optical lattices, we aim to emulate strongly coupled two-dimensional light-matter interfaces.

A 27.26 Thu 16:30 Empore Lichthof

FermiQP - A Fermion Quantum Processor — •Andreas von Haaren[1,2], Gleb Neplyakh[1,2], Er Zu[1,2], Robin Groth[1,2], Simon Krumm[1,2], Janet Qesja[1,2], Maximilian Schattauer[1,2], Timon Hilker[1,2], Philipp Preiss[1,2], and Immanuel Bloch[1,2,3] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Centre for Quantum Science and Technology, Munich, Germany — [3]Ludwig-Maximilians-Universität München, Munich, Germany

FermiQP is a demonstrator for a neutral atom lattice quantum processor based on ultracold fermionic lithium.

In its digital mode, it will serve as a fully programmable quantum computer with single qubit gates implemented as Raman rotations between hyperfine states and controlled collisions between atoms in the superlattice as two-qubit gates. Tweezer-based resorting techniques will enable entangling operations across the entire lattice.

In the analog mode, it will operate as a quantum simulator for the Fermi-Hubbard model with additional control over the starting configuration. As a quantum-gas-microscope, the experiment will feature single-site-resolved imaging and also spin-resolved state detection.

We are building the experiment using a single-chamber design with the goal to reduce cycle times. The compact vacuum chamber allows for easier maintenance and increases flexibility.

On the poster, we present the most recent developments on the experiment.

A 27.27 Thu 16:30 Empore Lichthof

Laser systems for quantum logic with molecular ions — •Guanqun Mu, Brandon Furey, Stefan Walser, Zhenlin Wu, Rene Nardi, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria

Multiple lasers are required for loading, photoionization, cooling, state preparation, and repumping trapped 40Ca+ ions. We installed these lasers, their distribution boards, and a wavemeter for frequency locking into a standard 19 inch rack. This reduced the footprint of these systems in our lab significantly. We have also installed an optical parametric amplifier (OPA) as a tunable ultrafast light source and a frequency comb for driving Raman transitions between molecular rotational states. Details of building and installing these systems will be discussed.

A 27.28 Thu 16:30 Empore Lichthof

Towards a continuous atom laser — •Junyu He[1], Noé Grenier[2], Rodrigo González Escudero[1], Chun-Chia Chen[1], Jiri Minář[3,4], Shayne Bennetts[1], Benjamin Pasquiou[5], and Florian Schreck[1,4] — [1]Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam, The Netherlands — [2]École normale supérieure Paris-Saclay, France — [3]Institute for Theoretical Physics, University of Amsterdam, The Netherlands — [4]QuSoft, The Netherlands — [5]Laboratoire de Physique des Lasers, Université Sorbonne Paris Nord, France

A continuous atom laser would be a promising source for quantum sensing, providing a high-flux, low-divergence beam while avoiding measurement dead time [1]. We plan to outcouple such a beam from a Bose-Einstein condensate that we can continuously sustain [2]. Our approach sends a Sr beam from an oven through a sequence of spatially separated laser cooling stages till the atoms accumulate in a protected area where they condense. Our next steps will be to enhance the purity of the BEC and to outcouple a continuous atom laser beam using a three-photon transfer to an untrapped state [3].

[1] Phys. Rep. 529, 265 (2013). [2] Nature 606, 683 (2022). [3] Phys. Rev. A 93, 053417 (2016).

A 27.29 Thu 16:30 Empore Lichthof

Cavity-mediated correlated pairs in both internal and external degrees of freedom — •Panagiotis Christodoulou, Fabian Finger, Rodrigo Rosa-Medina, Nicola Reiter, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Using a 87Rb spinor Bose-Einstein condensate inside a high-finesse optical cavity, we engineer correlated atom pairs in both their internal (spin) and external (momentum) degree of freedom. This mechanism has intrinsically many similarities with the parametric down-conversion process in optical systems and the binary spin-changing collisions in atom gases, as we verify in a series of experiments. At the same time, this mechanism provides new opportunities, like a deterministic controllability between the underlying coherent and dissipative processes, and an interplay of different intermediate channels for the production of such pairs which we can experimentally distinguish. The produced paired state is well placed to constitute the basis for a number of studies, ranging from proof-of-principle investigations of the mechanism of entanglement to fast quantum-enhanced interferometry to generating many-body models relevant to Quantum Information theory.

A 27.30 Thu 16:30 Empore Lichthof

Reversible mode shaping in a linear ion crystal via Rydberg excitation — •Robin Thomm[1], Harry Parke[1], Shalina Salim[1], Marion Mallweger[1], Natalia Kuk[1], Andre Cidrim[2], Alan Santos[2], and Markus Hennrich[1] — [1]Stockholm University, Sweden — [2]Departamento de Fisica, Universidade Federal de São Carlos, Brazil

We propose an experiment to shape the mode structure of one of the radial modes of a linear ion crystal confined in a linear Paul trap. Single phonons in one radial motional mode of a ground state cooled ion string exhibit a quantum random walk between the ions (Tamura *et al.* PRL 124, 200501 (2020)). Exciting one or multiple ions into Rydberg state will lead to a change in their trapping frequency, decoupling their motion from the other ions. This way, Ryberg excitation acts as a reversible barrier that can be adjusted by controlling population in the Rydberg state. This allows to restrict the movement of the phonons between the ions on the one hand, and spatially isolate parts of the ion crystals mode structure on the other hand (Li *et al.* PRL A 87, 052304 (2013)). With the techniques presented it is possible to both simplify and parallelize gate schemes based on common motional modes and to investigate bosonic transport in the presence of (adjustable) barriers.

A 27.31 Thu 16:30 Empore Lichthof

Passive vibration reduction of a femtosecond enhancement cavity — •Lukas Matt, Jan-Hendrik Oelmann, Tobias Heldt, Lennart Guth, Janko Nauta, Thomas Pfeifer, and José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

To perform spectroscopy of highly charged ions in the extreme ultraviolet (XUV), we developed an XUV-frequency comb [1]. Since high intensities are necessary for the high-harmonic generation producing the XUV and a high repetition rate of 100 MHz needs to be maintained, the use of an enhancement cavity is necessary. Which is vibration sensitive, because the cavity length has to be hold on resonance. Therefore the cavity has to be build very stable and decoupled from the noisy turbomolecular pumps. As no rigid connection between vacuum chamber and optical table is allowed, the realtive position between both has to be monitored, to avoid contact that would lead to vibrational coupling. We accomplish that with 6 laser-distance sensors. We present the technical realisation of this system. [1] (J. Nauta, A. Borodin, H. B. Ledwa, J. Stark, M. Schwarz, L. Schmöger, P. Micke, J. R. Crespo López-Urrutia and T. Pfeiffer, Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms 408, 285 (2017))

A 27.32 Thu 16:30 Empore Lichthof

Single-Pass Non-Destructive Ion Bunch Characterisation — •Stefan Ringleb[1], Markus Kiffer[1], Sugam Kumar[2], Manuel Vogel[3], Wolfgang Quint[3,4], Gerhard G. Paulus[1,5], and Thomas Stöhlker[1,3,5] — [1]Friedrich-Schiller-Universität Jena, Jena — [2]Inter-University Accelerator Center, Delhi — [3]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [4]Ruprecht Karls-Universität Heidelberg, Heidelberg — [5]Helmholtzinstitut Jena, Jena

In recent years, ion beam applications in research and industry increased much. Especially, low-energy beamlines have shrunk to tabletop size and can be set up fast and with comparably low financial effort.

In most applications each ion bunch passes the beamline only once and there is a need to characterise the ions non-destructively within a single pass. To this end, we have developed, built and tested two devices of different design based on the measurement of induced mirror charges of the passing ions in a set of pick-up electrodes. We have elaborated a robust evaluation procedure and have tested the devices in the energy regime of keV.

One device is capable of measuring the number and kinetic energy of an ion bunch and the second is used to determine the position of the ion beam with respect to the beamline centre.

We will present the device and its physical background as well as characterisation results.

A 27.33 Thu 16:30 Empore Lichthof

THz optics interfaced with hot vapors — •Daniel Rainer Häupl[1,2], Markus Lippl[1,2], Nicolas Couture[3], Jean-Michel Ménard[3], Robert Löw[4], and Nicolas Joly[1,2] — [1]University of Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [3]Department of Physics, University of Ottawa, Ottawa, ON K1N 6N5, Canada — [4]5th Physical Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Hollow-core photonic crystal (PCF) fibers filled with hot alkali vapor are a versatile platform for studying Rydberg physics at ambient temperature. In detail we discuss the possibility to use a Rydberg transition in rubidium to generate THz radiation. Previous work shows that even small hollow-core fibers can be rapidly and homogeneously filled with rubidium vapor [NJP, 24, 113017 (2022)]. Here, we excite the Rb atoms to the 17S1/2 Rydberg state, from where they decay with the highest probability to the 16P1/2 state, emitting during this atomic transition radiation at around 1.3 THz. The emitted light is expected to be narrowband and the wavelength can be tuned through the excitation scheme. To enhance the intensity of the generated THz radiation, the cell is nested in a tailored THz waveguide.

A 27.34 Thu 16:30 Empore Lichthof

X-ray Spectroscopy of U^{90+} Ions with a 64-pixel Metallic Magnetic Calorimeter Array — •A. Orlow[1], S. Allgeier[1], A. Abeln[1], A. Brunold[1], M. Friedrich[1], A. Gumberidze[2], D. Hengstler[1], F. M. Kröger[2,3,4], P. Kuntz[1], A. Fleischmann[1], M. Lestinsky[2], E. B. Menz[2,3,4], Ph. Pfäfflein[2,3,4], U. Spillmann[2], B. Zhu[4], G. Weber[2,3,4], Th. Stöhlker[2,3,4], and C. Enss[1] — [1]KIP, Heidelberg University — [2]GSI/FAIR, Darmstadt — [3]IOQ, Jena University — [4]HI Jena

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. MMCs convert the energy of each incident photon into a temperature pulse which is measured by a paramagnetic temperature sensor. The resulting change of magnetisation is read out by a SQUID magnetometer.

To investigate electron transitions in U^{90+} at CRYRING@FAIR within the framework of the SPARC collaboration, we developed the 2-dimensional maXs-100 detector array. It features 8x8 pixels with a detection area of 1 cm^2 and a stopping power of 40 % at 100 keV. Four on-chip thermometers allow to correct for temperature drifts and to achieve an energy resolution of 40 eV at 60 keV. We show preliminary X-ray spectra of the recent U^{90+} beamtime. Due to the small rate of emitted X-rays, a good supression of background radiation is mandatory, which was ensured by a coincidence measurement with a particle detector. To increase the stopping power to above 60 % at 100 keV we develop a new maXs-100 detector with 100 μm thick absorbers.

A 27.35 Thu 16:30 Empore Lichthof

Vanishing avoided crossings in Rydberg systems — •Matthew Eiles — Max Planck Institut für Physik komplexer Systeme, Dresden, Deutschland

The electronic potential energy curves describing a diatomic molecule repel one another rather than intersecting, as the conditions to find an exact crossing are not generically satisfied in a system depending on a single parameter. Diatomic long-range Rydberg molecules, however, provide an avenue to escape this restriction as their potential energy curves depend additionally on the principle quantum number of the Rydberg atom. Although this is not a continuous parameter, it can vary over such a wide range that it is possible to find nearly arbitrarily close avoided crossings, and with them, strong non-adiabatic coupling and the breakdown of the Born-Oppenheimer approximation. Here, we show several different ways that this behavior arises in Rydberg molecules and discuss its importance for their vibrational spectra.

A 27.36 Thu 16:30 Empore Lichthof

Impact of coherent phonon dynamics on high-order harmonic generation in solids — •Jinbin Li[1,2], Ulf Saalmann[2], Hongchuan Du[1], and Jan Michael Rost[2] — [1]School of Nuclear Science and Technology, Lanzhou University, Lanzhou, China — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We theoretically investigate the impact of coherent phonon dynamics on high-order harmonic generation (HHG), as recently measured [Hollinger et al, EPJ Web of Conferences 205, 02025 (2019)]. A method to calculate HHG in solids including phonon excitation is developed for a model solid. Within this model we calculate the signal of specific harmonics. The harmonic yields oscillate at the frequency of the optical phonon mode of the model system when the pump-probe delay increases. Further analysis shows that the phonons are excited by the electron density change induced by the laser field and then influence the band structure and harmonic yields. This work suggests that phonons can be manipulated by controlling electron density using laser fields.

A 27.37 Thu 16:30 Empore Lichthof

Compton polarimetry on Rayleigh scattering of highly linearly polarized hard x-rays on gold atoms — •Wilko Middents[1,2,3], Günter Weber[1,3], Alexandre Gumberidze[3], Thomas Krings[4], Philip Pfäfflein[1,2,3], Uwe Spillmann[3], Sophia Strnat[5,6], Andrey Surzhykov[5,6], and Thomas Stöhlker[1,2,3] — [1]Helmholtz Institut Jena — [2]Friedrich-Schiller-Universität Jena — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [4]Forschungszentrum Jülich — [5]Physikalisch-Technische Bundesanstalt Braunschweig — [6]Technische Universität Braunschweig

Rayleigh scattering of hard x-rays refers to the elastic scattering of photons on bound electrons [1]. State-of-the-art calculations in the framework of QED predict a strong dependence of the polarization characteristics of the scattered radiation on the scattering geometry [2].

We performed an experiment on the polarization transfer in Rayleigh scattering of a highly polarized hard x-ray beam on a thin gold target, extending on a previous study by Blumenhagen et al. [3]. A state-of-the-art Compton polarimeter [4] was used to precisely determine the linear polarization of the scattered radiation both within and out of the polarization plane of the incident synchrotron beam. In this contribution we will report on the setup and first results of the experiment.

[1] Kane, P. P. et al., (1986), Phys. Rep. 140(2), 75, [2] Strnat, S. et al., (2021), Phys. Rev. A, 103(1), 012801, [3] Blumenhagen, K. H. et al., (2016), New J. Phys. 18, 119601, [4] Vockert, M. et al., (2017), NimB 408, 313

A 27.38 Thu 16:30 Empore Lichthof

A new experiment on atomic tweezer arrays in a cryostat — Kai-Niklas Schymik[1], Bruno Ximenez[2], Etienne Bloch[2], •Davide Dreon[2], Adrien Signoles[2], Florence Nogrette[1], Daniel Barredo[1,3], Antoine Browaeys[1], and Thierry Lahaye[1] — [1]Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127 Palaiseau Cedex, France — [2]PASQAL SAS, 7 Rue Léonard de Vinci, 91300 Massy, France — [3]Nanomaterials and Nanotechnology Research Center (CINN-CSIC), Universidad de Oviedo (UO), Principado de Asturias, 33940 El Entrego, Spain

Optical-tweezer arrays are a powerful platform for realising analog and digital quantum simulators. However, they share the scalability problem common to all quantum hardware. Here, we present a new experimental setup that integrates the tweezer technology in a cryogenic environment.

At 4K, we are able to measure a vacuum-limited lifetime of more than 6000 seconds, which represents a two-order-of-magnitude improvement over room temperature setups. In addition, we have implemented an optimised trap loading equalisation procedure that, in combination with the extended lifetime, allows us to build arrays with more than 300 atoms while maintaining high accuracy of defect-free realisations.

These results are the first step towards Rydberg quantum simulators with more than a thousand particles.

A 27.39 Thu 16:30 Empore Lichthof

Imaging the Morphology of Rare Gas Clusters — •Mario Sauppe[1], Andre Al Haddad[2], Alessandro Colombo[1], Linos Hecht[1], Gregor Knopp[2], Katharina Kolatzki[1], Bruno Langbehn[3], Caner Polat[1], Kirsten Schnorr[2], Zhibin Sun[2], Paul Tümmler[4], Carl Frederic Ussling[1], Simon Wächter[1], Alex Weitnauer[1], Julian Zimmermann[1], Maha Zuod[1], Thomas Möller[3], Christoph Bostedt[2], and Daniela Rupp[1] — [1]ETH Zurich — [2]PSI Switzerland — [3]TU Berlin — [4]Uni Rostock

Rare gas clusters are an ideal testbed to probe the interaction of intense light with matter, in theoretical and experimental approaches. The dynamics may be altered by the clusters' structure, differing from an assumed ideal shape. Short wavelength free-electron lasers (FEL) allow to retrieve real-space images of nano-sized particles via coherent diffraction imaging (CDI). Recent CDI studies have shown that large rare gas clusters (100 nm radius), produced by a supersonic gas expansion, can have rather complex structures, not necessarily following an icosahedral or spherical shape, as known for smaller clusters. Instead, they may be agglomerates of two or three spheres or have a hailstone-like structure. To investigate the structure with a high spatial resolution, we performed a CDI-experiment on argon clusters at the SwissFEL with photon energies of up to 1 keV (1.24 nm). We find a great variety of structures, like complex agglomerates and protrusions connected to the main cluster only via a few nanometers thin neck, not contained in the current picture of cluster growth.

A 27.40 Thu 16:30 Empore Lichthof

Switching a subwavelength atomic array by a single Rydberg atom — •Pascal Weckesser[1,2], Kritsana Srakaew[1,2], Simon Hollerith[1,2], David Wei[1,2], Daniel Adler[1,2,3], Suchita Agrawal[1,2], Immanuel Bloch[1,2], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MC-QST), 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

Understanding and tuning light-matter interactions is essential for numerous applications in quantum science. Cooperative response between light-coupled atoms has recently led to the realization of a sub-radiant mirror formed by an atomic monolayer with strong light-matter coupling even down to the level of single photons. Here, we control the optical response of such an atomic mirror using a single ancilla atom excited to a Rydberg state. The switching behavior is controlled by admixing Rydberg character to the atomic mirror and exploiting strong dipolar Rydberg interactions with the ancilla. Driving Rabi oscillations on the ancilla atom, we demonstrate coherent control the degree of transmission and reflection. Finally, increasing the mirror size directly reveals the spatial area around the ancilla atom where the switching is effective. Our results pave the way towards novel quantum metasurfaces and the creation of controlled atom-photon entanglement.

A 28: Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Friday 11:00–12:45 Location: F107

Invited Talk A 28.1 Fri 11:00 F107

Coherent multidimensional spectroscopy of an ultracold gas — •Friedemann Landmesser[1], Tobias Sixt[1], Katrin Dulitz[1,2], Lukas Bruder[1], and Frank Stienkemeier[1] — [1]Institute of Physics, University of Freiburg, Germany — [2]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria

Femtosecond coherent multidimensional spectroscopy is demonstrated for an ultracold gas of Li atoms [1]. To this end, Li atoms are cooled in a magneto-optical trap and investigated using a phase-modulation time-domain spectroscopy technique, which is especially beneficial for dilute samples because of its high sensitivity [2]. The technique may offer the possibility to investigate time dependencies on the fs scale and coherent correlations in molecular systems with high frequency and time resolution [3]. Due to its quantum pathway selectivity, the technique is furthermore able to reveal multiphoton processes with specific numbers of interacting particles, as previously demonstrated in multiple quantum coherence experiments of weakly interacting thermal alkali atoms with mean interatomic distances in the micrometer-range [4-7].

[1] F. Landmesser et al., arXiv:2210.03023 (2022).
[2] P. Tekavec et al., J. Chem. Phys. 127, 214307 (2007)
[3] D. M. Jonas, Annu. Rev. Phys. Chem. 54, 425 (2003).
[4] L. Bruder et al., Phys. Rev. A 92, 053412 (2015).
[5] S. Yu et al., Opt. Lett. 44, 2795 (2019).
[6] L. Bruder et al., Phys. Chem. Chem. Phys. 21, 2276 (2019).
[7] B. Ames et al., New J. Phys. 24, 13024 (2022).

A 28.2 Fri 11:30 F107

Resonance lineshapes in Rydberg atom - ion interactions — •Neethu Abraham and Matthew T Eiles — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

Rydberg molecules, ranging from the so-called "trilobite" molecules to Rydberg macrodimers to Rydberg atom-ion molecules, are a stunning highlight of recent experimental progress in ultracold atomic physics. Various factors can contribute to the decay of such molecules, including radiative decay or associative ionization. One non-radiative mechanism is the non-adiabatic coupling between electronic potential energy curves. We investigate this mechanism here in the Rydberg-ion molecule system using the streamlined version of the R-matrix method to compute the resonant line shapes. We provide a detailed analysis of the profiles and widths of these resonances and characterize them using the Fano-Feshbach lineshape. This shows how non-adiabatic coupling shifts the resonance positions away from the binding energies predicted in the Born-Oppenheimer approximation, and indicates the lifetimes of these states with regard to non-adiabatic decay. We explore these resonances over a range of different principal quantum numbers. Such a study can be relevant to the other types of Rydberg molecules as well.

A 28.3 Fri 11:45 F107

Experimental investigation of multilevel Autler-Townes spectra — •Jana Bender, Patrick Mischke, Tanita Klas, Florian Binoth, Thomas Niederprüm, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

The Autler-Townes splitting in a strongly coupled two-level-system is a well-known effect in atomic physics. However, actual atomic systems seldom are perfect two-level-systems: Both hyperfine structure and magnetic sublevels result in closely spaced multilevel systems where two individual states can be coupled only for distinct combinations of laser polarization and quantum numbers. The coupling lifts degeneracies and mixes the states, resulting in complex spectra deviating from the symmetrical two-level Autler-Townes splitting.

We experimentally investigate these spectra in a thermal cloud of ^{87}Rb atoms by resonantly coupling the $6P3/2, F = 3$ state to a Rydberg state with varying Rabi frequency. We selectively probe the population of the resulting mixed states with a laser of adjustable polarization.

Our experiments confirm that multilevel effects have to be considered in the Autler-Townes regime. As a general rule, the splitting between peaks is not equal to the Rabi frequency if the coupling strength exceeds the energetic distance of adjacent states.

A 28.4 Fri 12:00 F107

Exploring the Many-Body Dynamics Near a Conical Intersection with Trapped Rydberg Ions — Filippo Gambetta[1,2], Chi Zhang[3], Markus Hennrich[3], Igor Lesanovsky[1,2,4], and •Weibin Li[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, United Kingdom — [3]Department of Physics, Stockholm University, 10691 Stockholm, Sweden — [4]Institut für Theoretische Physik, University of Tübingen, 72076 Tübingen, Germany

Conical intersections between electronic potential energy surfaces are paradigmatic for the study of nonadiabatic processes in the excited states of large molecules. However, since the corresponding dynamics occurs on a femtosecond timescale, their investigation remains challenging and requires ultrafast spectroscopy techniques. We demonstrate that trapped Rydberg ions are a platform to engineer conical intersections and to simulate their ensuing dynamics on larger length scales and timescales of the order of nanometers and microseconds, respectively; all this in a highly controllable system. Here, the shape of the potential energy surfaces and the position of the conical intersection can be tuned thanks to the interplay between the high polarizability and the strong dipolar exchange interactions of Rydberg ions. We study how the presence of a conical intersection affects both the nuclear and electronic dynamics demonstrating, in particular, how it results in the inhibition of the nuclear motion.

A 28.5 Fri 12:15 F107

Diffusive-like Redistribution in State-changing Collisions between Rydberg Atoms and Ground State Atoms — •Markus Exner, Philipp Geppert, Max Althön, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We report on inelastic collisions between Rydberg and ground state atoms. Our experiment starts with a cloud of ultracold Rubidium atoms in a crossed dipole trap. Using a three-photon excitation scheme, we photoassociate ultralong-range Rydberg molecules with huge bond lengths . These exotic molecular species are formed by a Rydberg atom and ground state atom, where the binding mechanism originates from scattering interaction between Rydberg electron and the ground state atom. We have observed the decay of these molecules in which the ground state atom tunnels toward the Rydberg core. During this collision a state-change of the Rydberg electron takes place. We found a redistribution of population over a wide range of final states. In addition, a decay into different orbital angular momentum states could be observed. These state-changing collisions can be described as a diffusive-like redistribution at short internuclear distances.

A 28.6 Fri 12:30 F107

The role of Coulomb anti-blockade in the photoassociation of long-range Rydberg molecules — Michael Peper[1,2], Edward Treu-Painter[1], Martin Trautmann[1], and •Johannes Deiglmayr[1] — [1]Universität Leipzig, Germany — [2]Princeton University, Princeton, USA

We present a new mechanism contributing to the detection of photoassociated long-range Rydberg molecules via pulsed-field ionization: ionic products, created by the decay of a long-range Rydberg molecule, modify the excitation spectrum of surrounding ground-state atoms and facilitate the excitation of further atoms into Rydberg states by the photoassociation light. Such an ion-mediated excitation mechanism has been previously called *Coulomb anti-blockade*. Pulsed-field ionisation typically doesn't discriminate between the ionization of a long-range Rydberg molecule and an isolated Rydberg atom, and thus the number of atomic ions detected by this mechanism is not proportional to the number of long-range Rydberg molecules present in the probe volume. By combining high-resolution UV and RF spectroscopy of a dense, ultracold gas of cesium atoms, theoretical modeling of the molecular level structures of long-range Rydberg molecules bound below $n\,^2P_{3/2}$ Rydberg states of cesium, and a rate model of the photoassociation and decay processes, we unambiguously identify the signatures of this detection mechanism in the photoassociation of long-range Rydberg molecules bound below atomic asymptotes with negative Stark shifts.

A 29: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Friday 11:00–12:45 Location: F303

Invited Talk A 29.1 Fri 11:00 F303

An elementary network of entangled optical atomic clocks — •Raghavendra Srinivas, Bethan Nichol, David Nadlinger, Peter Drmota, Dougal Main, Gabriel Araneda, Chris Ballance, and David Lucas — University of Oxford

Optical atomic clocks are our most precise tools to measure time and frequency. Precision frequency comparisons between atoms in separate locations can be used to probe the space-time variation of fundamental constants, the properties of dark matter, and for geodesy. Such frequency comparisons on independent systems are typically limited by the standard quantum limit (SQL). Here, we demonstrate the first quantum network of entangled optical clocks using two $^{88}Sr^{+}$ ions separated by a macroscopic distance (2 m), that are entangled using a photonic link. We use this network to perform entanglement-enhanced frequency comparisons beyond the SQL[1]. This two-node network could be extended to additional nodes, to other species of trapped particles, or to larger entangled systems via local operations.

[1] Nichol, Srinivas et al., Nature 609, 689-694 (2022)

A 29.2 Fri 11:30 F303

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesalnstalt, Braunschweig, Deutschland — [2]2Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well- suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy, where a well-controllable atomic ion is co-trapped to the molecular ion, both coupled strongly via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Using a Ca ion, we implemented a quantum logic scheme to detect population transfer on a co-trapped spectroscopy ion, induced by a far detuned Raman laser setup. We present the latest progress of the experiment, aiming at high precision quantum logic spectroscopy of single molecular ions.

A 29.3 Fri 11:45 F303

An aluminum ion clock with 1.1×10^{-18} estimated systematic uncertainty — •Johannes Kramer[1,2], Fabian Dawel[1,2], Marek Hild[1,2], Lennart Pelzer[1], Kai Dietze[1,2], Steven A. King[3], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Oxford Ionics Limited, Begbroke OX5 1PF, United Kingdom

A single trapped $^{27}Al^{+}$ ion is an excellent frequency reference for an optical clock, as it is largely insensitive to external field shifts. Achieved inaccuracies are below the 10^{-18} level and thus make aluminum clocks promising candidates for a re-definition of the SI second and enable for cm-scale height measurements in relativistic geodesy. We estimated the systematic uncertainty budget of PTB's Al^{+} clock using a single $^{40}Ca^{+}$ ion as a sensor. Included in the analysis are shifts by black body radiation, collisions with background gas molecules, residual kinetic energy from uncompensated micromotion and the ac Zeeman shift caused by fast oscillating magnetic fields. The latter shift is mainly induced by the applied radio frequency used to trap the ion. Measurements show that these fields are in the range of a few 10 μT in our trap and are therefore a non-negligible contribution to the systematic frequency uncertainty budget.

A 29.4 Fri 12:00 F303

Improved limits for the coupling of ultralight bosonic dark matter to photons from optical atomic clock comparisons — •Melina Filzinger, Martin Steinel, Joshua Klose, Sören Dörscher, Christian Lisdat, Ekkehard Peik, and Nils Huntemann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Ultralight bosonic dark matter is expected to display coherent-wave behaviour. A hypothetical coupling of such dark matter to photons would lead to oscillations in the value of the fine-structure constant [1]. The frequency of the $^2S_{1/2}(F = 0) \leftrightarrow {}^2F_{7/2}(F = 3)$ electric-octupole transition in $^{171}Yb^{+}$ is the most sensitive to variations of the fine structure constant among the atomic clocks currently in operation. We compare this frequency to that of the $^2S_{1/2}(F = 0) \leftrightarrow {}^2D_{3/2}(F = 0)$ electric-quadrupole transition of the same ion, as well as to that of the $^1S_0 \leftrightarrow {}^3P_0$ transition in ^{87}Sr, both of which feature small sensitivities to variations of α. Based on these long-term measurements, we present improved constraints on temporal variations of the fine-structure constant. In particular, constraints on an oscillation with a specific frequency are translated into constraints on the scalar coupling d_e of bosonic dark matter with a specific mass to photons.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project-ID 274200144 – SFB 1464 DQmat and Project-ID 390837967 – EXC-2123 QuantumFrontiers.

[1] A. Arvanitaki et al., Phys. Rev. D 91, 015015 (2015).

A 29.5 Fri 12:15 F303

An optical atomic clock based on correlation measurements of a two ion $^{40}Ca^{+}$ crystal — •Kai Dietze[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1], Fabian Dawel[1,2], Johannes Kramer[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

Trapped ion optical clocks reach high relative frequency accuracies but are often limited by quantum projection noise in their statistical uncertainty, thus requiring long averaging times. The statistical uncertainty can be reduced by increasing the number of ions and/or probing the ion(s) for a longer time with the clock laser. By extending the measurement to entangled states the statistical uncertainty can even surpass the quantum projection noise of classical interrogation protocols [1]. In our scheme classically and quantum correlated quantum states of a two-ion $^{40}Ca^{+}$ crystal are prepared in a so-called decoherence-free substate (DFS), which is insensitive to linear magnetic field fluctuations [2]. We present the results of these correlation measurements within the DFS, showing near lifetime limited coherence times. Furthermore, we demonstrate the stabilization of our clock laser using these classically correlated states. First steps towards the utilization of entangled states prepared with a Cirac-Zoller gate and the integration in the measurement protocol will be shown.

[1] E.M. Kessler et al., PRL 112, 190403 (2014)
[2] C. Roos et al., Nature 443, 316319 (2006)

A 29.6 Fri 12:30 F303

Progress of the $^{171}Yb^{+}$ single-ion optical clocks at PTB — •jian jiang, martin steinel, melina filzinger, ekkehard peik, and nils huntemann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Clocks based on optical reference transitions of single ions confined in radiofrequency traps or neutral atoms trapped in optical lattices are the most accurate measurement devices ever built. The $^2S_{1/2}(F = 0) \rightarrow {}^2F_{7/2}(F = 3)$ electric octupole transition of a single trapped $^{171}Yb^{+}$ ion is employed as the reference in our case. In this talk, we report on an improved end-cap ion trap with low-loss insulator material and high thermal conductivity to obtain a homogeneous temperature distribution. A thick gold coating of the electrodes should lead to a low ion heating rate, and a precise evaluation of shifts from residual fields promises a total uncertainty below 1×10^{-18}. For the latter, we make use of the $^2S_{1/2}(F = 0) \rightarrow {}^2D_{3/2}(F = 2)$ electric quadrupole transition of the same ion. This transition can also be used to efficiently cool the ion to the motional ground state and suppress corresponding Doppler shifts.

A 30: Highly Charged Ions and their Applications II

Time: Friday 14:30–16:30 Location: F107

Invited Talk A 30.1 Fri 14:30 F107

Investigation of Molecular Ions as Sensitive Probes for Fundamental Physics — •Carsten Zuelch, Konstantin Gaul, and Robert Berger — Fachbereich Chemie, Hans-Meerwein-Straße 4, Philipps-Universität Marburg

Small polar molecules provide large enhancements of $\mathscr{P}$, $\mathscr{T}$-odd effects due to large internal fields, which are further increased by using heavy elements as metal center. Molecular ions would give additional benefits: From an experimental point of view, ions have the advantage that they can be guided by electric fields, sympathetically cooled and trapped for long times, possibly opening a path for subsequent direct laser cooling. Further, with increasing charge the electronic spectra become typically compressed, which is favourable for the search of a spatio-temporal variation of fundamental constants. But with the compressed level structure arise different challenges like the need for an analysis of congested rovibronic spectra. At present, comparatively little is known about the detailed electronic structure of small molecular ions containing short-lived nuclei, since only recently advances in precision spectroscopy made the study of such systems possible. Therefore, an extensive theoretical investigation on different systems is needed to find suitable molecular ions for future fundamental physics research, faciliated by current developments in theory. Our estimations for symmetry-violating properties and laser-coolability are based on calculations on the level of two-component complex generalized Hartree-Fock (cGHF) and Kohn Sham (cGKS), with properties being subsequently obtained with our toolbox approach.

A 30.2 Fri 15:00 F107

High-resolution spectroscopy on core-excited lithium-like ions in the soft x-ray regime — •Moto Togawa[1,2], Steffen Kühn[1], Chintan Shah[3], Rene Steinbrügge[1], Sonja Bernitt[4], Thomas Baumann[2], Michael Meyer[2], Thomas Pfeifer[1], Maurice Leutenegger[3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck Institut für Kernphysik — [2]European XFEL — [3]Nasa Goddard Space Flight Center — [4]GSI Helmholtzzentrum für Schwerionenforschung

Two core-excited soft x-ray transitions, q and r of lithium-like oxygen, fluorine and neon were measured, and calibrated using several transitions of helium-like ions. After identification and removal of a systematic error by means of photo-electron spectroscopy, we achieved a relative accuracy of 1.5 parts-per-million, higher than that of current theory. This allows for a preliminary assessment of predictions including quantum electrodynamics and mass-shift corrections.

A 30.3 Fri 15:15 F107

Laser Spectroscopy of the Hyperfine Structure in $^{208}Bi^{82+}$ at the Experimental Storage Ring (ESR) @ GSI — •Max Horst for the LIBELLE/E128-Collaboration — Institut für Kernphysik, TU Darmstadt, Darmstadt — Helmholtz Akademie Hessen für FAIR HFHF, TU Darmstadt, Darmstadt

We present results of a laser spectroscopy experiment at the Experimental Storage Ring (ESR) at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt. During a beamtime in May 2022, we were able to measure the hyperfine splitting of hydrogen-like $^{208}Bi^{82+}$. The ions of the radioactive isotope were produced in-flight before injection into the ESR and a few 10^5 ions were stored at $\beta = v/c = 0.72$. This is the first time that an artificially produced isotope is successfully targeted by laser spectroscopy in a storage ring.

To excite the hyperfine transition ($\lambda_0 = 221$ nm) the ion beam was superimposed with a counterpropagating beam of a pulsed dye laser at $\lambda_{\text{lab}} = 548$ nm. Fluorescence detection was realized spatially separated from the laser interaction with a new detection region to obtain the required low background.

In combination with a measurement on lithium-like $^{208}Bi^{80+}$, which is in preparation, the result will provide the so-called specific difference [1] between the two hyperfine splittings, which will constitute the most stringent test of QED in strong magnetic fields.

Funding by BMBF under contract 05P21RDFA1 is acknowledged.

[1]: V. M. Shabaev, et al., Phys. Rev. Lett. 86, 3959 (2001).

A 30.4 Fri 15:30 F107

Precision x-ray spectroscopy of U90+ using novel microcalorimeter detectors — •G. Weber[1,2], Ph. Pfäfflein[1,3], F. Kröger[1,3], B. Zhu[1,3], M. O. Herdrich[1,3], S. Bernitt[1,2], Ch. Hahn[1,2], M. Lestinsky[2], U. Spillmann[2], A. Kalinin[2], B. Löher[2], T. Over[1,3], D. Hengstler[4], A. Fleischmann[4], S. Allgeier[4], P. Kuntz[4], E. B. Menz[1,2,3], M. Friedrich[4], Chr. Enss[4], and Th. Stöhlker[1,2,3] — [1]Helmholtz-Institut Jena — [2]GSI, Darmstadt — [3]IOQ, FSU Jena — [4]KIP, Universität Heidelberg

He-like ions are the simplest atomic multibody systems and the study of L -> K transitions along the isoelectronic sequence provides a unique testing ground for the interplay of the effects of correlation, relativity and quantum electrodynamics. However, for high-Z ions with nuclear charge Z > 54, where K transition energies reach up to 100 keV, there are currently no data available to challenge state-of-the-art theory.

We report on the study of Kα radiation in He-like uranium at the electron cooler of CRYRING@ESR at GSI, using novel microcalorimeters dedicated to high-precision x-ray spectroscopy. A spectral resolution of better than 100 eV FWHM was achieved over a wide range of x-ray energies from a few keV up to more than 100 keV, enabling for the first time to resolve the individual components of the Kα peaks in a heavy He-like system.

This work was conducted in the framework of the SPARC collaboration, exp. E138 of FAIR Phase-0 supported by GSI. We also acknowledge the support provided by ErUM FSP T05 "Aufbau von APPA bei FAIR" (BMBF n°05P19SJFAA and n°05P19VHFA1).

A 30.5 Fri 15:45 F107

An optical clock based on highly charged ions and its application for new physics searches — •Alexander Wilzewski[1], Lukas J. Spiess[1], Steven A. King[1], Malte Wehrheim[1], Shuying Chen[1], Michael K. Rosner[2], Andrey Surzhykov[1,4], Erik Benkler[1], Nils Huntemann[1], José R. Crespo Lopez-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Max-Planck-Instituts für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [4]Technische Universität Braunschweig, Universitätsplatz 2, 38106 Braunschweig, Germany

In our experiment, we extract highly charged ions (HCIs) from an electron-beam ion trap (EBIT) and transfer them to a linear Paul trap where they are recaptured and sympathetically cooled by laser-cooled Be^+ ions. Recently, we fully evaluated the systematic uncertainty of an optical clock based on Ar^{13+}. By comparison with the octupole transition in Yb^+ we determined the isotope shift of the optical transitions between $^{36}Ar^{13+}$ and $^{40}Ar^{13+}$ with sub-Hz accuracy [1]. Ca^{14+} offers five stable isotopes and a suitable optical transition [2] for a King plot analysis to search for a hypothetical fifth force when combined with isotope shifts of the clock transition in Ca^+. We present results on a laser ablation source for our EBIT, the Ca^{14+} clock laser system, and first isotope shift measurements. [1] S. A. King, L. J. Spiess *et al.*, Nature **611** (2022), [2] N. Rehbehn *et al.*, Phys. Rev. A **103** (2021)*et al.*, Phys. Rev. Research 2, (2020)

A 30.6 Fri 16:00 F107

Bound-Electron *g* Factor Measurement of Hydrogenlike Tin — •Jonathan Morgner, Charlotte M. König, Tim Sailer, Fabian Heisse, Bingsheng Tu, Vladimir A. Yerokhin, Bastian Sikora, Zoltán Harman, José R. Crespo López-Urrutia, Christoph H. Keitel, and Sven Sturm — Max-Planck Institut für Kernphysik, Heidelberg

Highly charged ions are a great platform to test fundamental physics in strong electric fields. The field strength experienced by a single electron bound to a high-Z nucleus reaches strengths exceeding 10^{15} V/cm. Perturbed by the strong field, the g factor of a bound electron is a sensitive tool that can be both calculated and measured to high accuracy. In the recent past, g-factor measurements of low-Z ions reached precisions below 5×10^{-11}. Following this route, the Alphatrap Penning-trap setup is dedicated to precisely measure bound-electron g factors of the heaviest highly charged ions.

In this contribution, our recent measurement of the bound-electron g factor in hydrogenlike tin will be presented. Comparison with the theoretical calculations allows a stringent test of bound-state QED in strong electric fields.

Additionallly we present the mass measurement of hydrogenlike tin-118, allowing to improve the literature mass by roughly a factor ten. Furthermore, developments for the Hyper-EBIT experiment are presented. This will eventually allow Alphatrap to inject even heavier highly charged ions in our Penning-trap apparatus.

A 30.7 Fri 16:15 F107

Parity violation in highly charged ions — •Jan Richter[1], Anna V. Maiorova[7], Anna V. Viatkina[1,2,3], Dmitry Budker[2,3,4], and Andrey Surzhykov[1,5,6] — [1]Physikalisch-Technische Bundesanstalt Braunschweig — [2]Helmholtz Institute Mainz — [3]Johannes Gutenberg University Mainz — [4]Department of Physics University of California — [5]Technische Universität Braunschweig — [6]Laboratory for Emerging Nanometrology Braunschweig — [7]Helmholtz Institute Jena

Atomic parity-violation phenomena arising due to the weak interaction of atomic electrons with nuclei have been in the focus of experimental and theoretical research for several decades [1,2].

In this study, the focus lies on the influence of the mixing of opposite-parity ionic levels on the excitation rates in highly charged ions. This mixture arises due to an external electric field and the weak interaction between electrons and the nucleus. In order to reinvestigate this "Stark-plus-weak-interaction" mixing, detailed calculations are performed in hydrogen- and lithium-like ions. In particular, we focus on the difference between the excitation rates obtained for right- and left-circularly polarized incident light. This difference arises due to the parity violating mixing of ionic levels.

[1] I. B. Khriplovich, Parity Nonconservation in Atomic Phenomena, Taylor Francis, Amsterdam 1991.
[2] M.-A. Bouchiat, C. Bouchiat, Rep. Prog. Phys. 1997, 60, 1351

A 31: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 14:30–16:30 Location: F303

Invited Talk A 31.1 Fri 14:30 F303

Observation of vibrational dynamics in an ion-Rydberg molecule by a high-resolution ion microscope — •Moritz Berngruber[1], Viraatt Anasuri[1], Yiquan Zou[1], Nicolas Zuber[1], Óscar Andrey Herrera Sancho[1,2], Ruven Conrad[1], Florian Meinert[1], Robert Löw[1], and Tilman Pfau[1] — [1]Universität Stuttgart — [2]Escuela de Física, Universidad de Costa Rica, San José

Vibrational dynamics in conventional molecules takes usually place on a timescale of picoseconds or shorter, therefore it is hard to observe. In this talk, we report on a direct spatial observation of vibrational dynamics in an ion-Rydberg atom molecule where the vibrational dynamics happens on much slower timescales and can therefore be directly studied.

Highly excited Rydberg atoms can form quite unusual bonds, which lead to long-range Rydberg molecules with exotic properties, here we study a molecular ion that is formed due to the interaction between an ionic charge and a flipping-induced dipole of a Rydberg atom. Due to the large bond length of the molecule, dynamical processes are slowed down drastically leading to vibrational dynamics in the microsecond regime that can be observed in real space by using a high-resolution ion microscope. By applying a weak external electric field of a few mV/cm, it is possible to control the orientation of the ionic ultralong-range Rydberg molecules directly during the creation process. When the field is quenched off in a subsequent step, the vibrational dynamics can be initialized and observed under the ion microscope in real space.

A 31.2 Fri 15:00 F303

Dynamics of a driven atomic Josephson junction — •Vijay Singh[1], Ludwig Mathey[2], and Luigi Amico[1] — [1]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE — [2]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany

Using classical-field simulations we study the dynamics of a Josephson junction created by separating two two-dimensional atomic clouds with a tunneling barrier. We explore various condensate geometries, as well as different barrier protocols. This allows us to characterize the DC to AC Josephson effect, which we compare with the prediction of the two-coupled equations. Furthermore, we consider a periodic driving of the barrier protocol to study the driving effect on the voltage-current characteristic, resulting in reminiscent Shapiro steps. We discuss these dynamical behaviors in both underdamped and overdamped regimes and describe them using the two-coupled equations.

A 31.3 Fri 15:15 F303

Quantum simulations with circular Rydberg atoms — •Christian Hölzl, Aaron Götzelmann, Moritz Wirth, and Florian Meinert — 5th Institute of Physics, Universität Stuttgart, Stuttgart, Germany

Highly excited low-L Rydberg atoms in configurable mircotrap arrayshave recently proven highly versatile for exploring quantum many-body systems with single particle control. We aim to increase the coherence time of the Rydberg platform by using high-L circular Rydberg states, which promise orders of magnitude longer lifetimes compared to their low-l counterparts. I will report on the status of a new experimental apparatus for realizing arrays of trapped and long-lived circular Rydberg atoms at room temperature. To this end, we have prepared single Strontium atoms inside a suppression capacitor made from indium tin oxide (ITO). The capacitor is designed to stabilize the circular Rydberg atoms against detrimental black-body radiation, while keeping excellent high-NA optical access for visible light. I will report on our progress to laser-excite Rydberg singlet F-states via a three-photon scheme. The latter serve as a suitable starting point for accessing circular Rydberg states via adiabatic state transfer.

A 31.4 Fri 15:30 F303

Time-resolved meausrements of the anomalous Hall velocity — •Alexander Ilin, Klaus Sengstock, and Juliette Simonet — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The anomalous velocity is a purely intrinsic interference effect that gives rise to many fascinating transport phenomena in solids, including the anomalous Hall effect (AHE), the spin Hall effect (SHE), and their quantized versions. However, measuring the anomalous velocity in real solid-state materials is challenging as a direct observation of electron wave-packet dynamics is usually impeded by inherent short times for scattering.

Here, we report on direct measurements of the anomalous velocity for condensates in an accelerated optical boron-nitride lattice. By tracing the coherent evolution of Bloch states in momentum space, we can precisely extract the time-dependent anomalous velocity along different paths in reciprocal space and infer the associated local Berry curvature. Using this method, we demonstrate geometric pumping and a bosonic counterpart of the valley Hall effect for condensates in the second Bloch band, where atoms in different valleys experience a net anomalous transport into opposite direction.

A 31.5 Fri 15:45 F303

Tuneable Long-range Interaction by Coupling Opposite Parity Rydberg States — •Philip Osterholz, Lea Steinert, Arno Trautmann, Ludwig Müller, Roxana Wedowski, and Christian Gross — Physikalisches Institut, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

Rydberg atoms in optical tweezers have proven to be a major working horse in studying long-range interacting systems. The tunability of the interaction allows for exploring large regions of phase diagrams and novel physics in various experimental settings. Here, we present how the dipolar coupling between opposite parity rydberg states can extend the interaction range in current rydberg tweezer experiments. This paves the way for studying quantum spin systems with an enriched variety of interactions in state-of-the-art quantum simulators.

A 31.6 Fri 16:00 F303

Tailoring the Phonon Environment of Embedded Rydberg Aggregates — •Sidharth Rammohan[1], Alexander Eisfeld[2], and Sebastian Wüster[1] — [1]IISER Bhopal, Madhya Pradesh, India. — [2]MPIPKS, Dresden, Germany.

State-of-the-art experiments can controllably create Rydberg atoms inside a Bose-Einstein condensate (BEC) [1], where the electron-atom interactions can be tuned making the hybrid system suitable for quantum simulation. In our work we study the dynamics of a single or multiple Rydberg atoms embedded inside a BEC, to assess their utility for controlled studies of excitation transport. For this, we first develop a theoretical framework to calculate the input parameters like the bath correlation function, initially for a single Rydberg atom, possibly in two internal states in a BEC [2]. The electron-atom contact interactions lead to Rydberg-BEC coupling, which creates phonons in the BEC. Using the spin-boson model with the calculated parameters, we examine the decoherence dynamics of a Rydberg atom in a superposition of the states, resulting from the interaction with its condensate environment and also study the emergence of Non-Markovian features in the system [3]. The scenario with a single Rydberg atom is then extended to the aggregate case, where one of the atoms in the aggregate is in the p state, while the rest are in the s state, allowing us to set up dynamics similar to those found in light-harvesting complexes. References: [1] J. B. Balewski, et.al,. Nature 502 664 (2013). [2] S. Rammohan, et.al,. Phys. Rev. A 103, 063307 (2021). [3] S. Rammohan, et.al,. Phys. Rev. A 104, L060202 (2021).

A 31.7 Fri 16:15 F303

Sympathetic cooling of charged particles in separate Penning traps via image currents — •Hüseyin Yildiz[1], Peter Micke[2,3], Markus Wiesinger[2], Christian Will[2], Fatma Abbass[1], Stefan Erlewein[2,4], Julia Jäger[2,4,5], Barbara Latacz[4], Andreas Mooser[2], Daniel Popper[1], Gilbertas Umbrazunas[4,6], Elise Wursten[4], Klaus Blaum[2], Christian Ospelkaus[5,7], Wolfgang Quint[8], Jochen Walz[1,9], Christian Smorra[1,4], and Stefan Ulmer[4,10] — [1]Johannes Gutenberg-Universität Mainz — [2]Max-Planck-Institut für Kernphysik — [3]CERN — [4]RIKEN — [5]Physikalisch-Technische Bundesanstalt — [6]Eidgenössisch Technische Hochschule Zürich — [7]Leibniz Universität Hannover — [8]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [9]Helmholtz-Institut Mainz — [10]Heinrich-Heine-Universität Düsseldorf

Cooling of trapped charged particles to the mK range or even below is crucial in many precision experiments, but can be a challenge when suitable laser transitions are missing. We recently demonstrated a new sympathetic cooling method to cool a single proton via image currents of a laser-cooled Be^+ cloud located in a separate trap. This concept is promising, because it is not limited to small distances and is generally scalable. In particular, any kind of charged particles can be cooled, including antimatter and highly charged ions.

This talk summarizes our previous work and reports about our recent progress towards an advanced coupling scheme based on a detuned LC-circuit.

A 32: Precision Measurements: Atom Interferometry II (joint session Q/A)

Time: Friday 14:30–16:30 Location: F342

See Q 70 for details of this session.

A 33: Precision Spectroscopy of Atoms and Ions V (joint session A/Q)

Time: Friday 14:30–16:00 Location: B302

A 33.1 Fri 14:30 B302

Superconducting magnetic shielding for trapped ion qubits — •Elwin A. Dijck[1], Christian Warnecke[1,2], Claudia Volk[1], Stepan Kokh[1], Kostas Georgiou[1,3], Lakshmi P. Kozhiparambil Sajith[1,4,5], Christopher Mayo[1,3], Andrea Graf[1], José R. Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Heidelberg University — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen — [5]Humboldt University of Berlin

Merging a linear Paul trap with a superconducting RF resonator produces a trapping environment with minimal magnetic field noise, ideal for precision spectroscopy and (highly charged) ion qubits. We characterize our ion trap of this type built from niobium [1] using microwave spectroscopy of Be^+ hyperfine qubits, determining the magnetic field stability and shielding factor. Due to flux trapping, the magnetic field applied during cooldown remains present in the ion trap and no external field needs to be applied during subsequent trap operation at cryogenic temperature. We find the trapped magnetic field to be stable over a period of months with relative changes at the 10^{-10} s^{-1} level. Additionally, magnetic field noise, which often limits qubit coherence, is passively shielded by the superconductor at all frequencies down to DC. Using Ramsey interferometry and spin echo measurements, we find coherence times of >100 ms without active field stabilization.

[1] J. Stark et al., Rev. Sci. Instrum. **92**, 083203 (2021)

A 33.2 Fri 14:45 B302

Progress toward direct frequency comb spectroscopy of ^{229m}Th — •Lars von der Wense[1], Chuankun Zhang[2], John F. Doyle[2], and Jun Ye[2] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]JILA, University of Colorado, Boulder, USA

Laser spectroscopy of the first excited nuclear state of ^{229}Th poses a long-standing challenge. Several groups worldwide are aiming for this goal, since success promises the development of a first nuclear optical clock of highest accuracy [1]. In this talk I will present the most recent progress of the efforts at JILA in Boulder, where direct frequency comb spectroscopy of ^{229m}Th is targeted [2]. For this purpose, a tunable VUV frequency comb has been developed [3] and new ^{229}Th targets were produced. Also, planned investigations within the new NuQuant project at MPQ will be addressed.

[1] L.v.d.Wense, B.Seiferle, Eur.Phys.J.A 56:277 (2020).
[2] L.v.d.Wense, C.Zhang, Eur.Phys.J.D 74:146 (2020).
[3] C. Zhang et al., Optics Letters 47, 5591 (2022).

Supported by NSF (PHY-1734006); NIST; ARO (W911NF2010182); AFOSR (FA9550-19-1-0148); Alexander von Humboldt Foundation; BMBF (13N16295).

A 33.3 Fri 15:00 B302

BASE-STEP and the Permanent Magnet Trap — •Daniel Popper[1], Fatma Abbass[1], Hüseyin Yildiz[1], Markus Wiesinger[4], Christian Will[4], Björn-Benny Bauer[1,2], Jack Devlin[2,3], Stefan Erlewein[2,4], Julia Jäger[2,4,6], Barbara Latacz[2,3], Peter Micke[3,4], Elise Wursten[3], Gilbertas Umbrazunas[2,9], Klaus Blaum[4], Christian Ospelkaus[5,6], Wolfgang Quint[7], Jochen Walz[1,8], Stefan Ulmer[2,10], Christian Smorra[1], and Matthew Bohman[2,4] — [1]JGU Mainz, Germany — [2]Fundamental Symmetries Laboratory, RIKEN, Wako-shi, Japan — [3]CERN, Geneva, Switzerland — [4]MPI for Nuclear Physics, Heidelberg, Germany — [5]Leibniz Universität Hannover, Germany — [6]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [7]GSI, Darmstadt, Germany — [8]Helmholtz Intitute Mainz, Germany — [9]ETH Zürich, Switzerland — [10]Heinrich-Heine-Universität Düsseldorf, Germany

The ERC Project BASE-STEP is dedicated to the development of transportable antiproton traps to enhance the sensitivity of CPT invariance tests with antiprotons that are conducted in the BASE collaboration. For this, STEP uses a transportable superconducting magnet with a Penning trap system on a portable experiment frame. We have started commissioning the setup at CERN, and successfully tested our 90° defelctor at the end of 2022. In addition, we designed a permanent magnet set-up, consisting of two aubert- magnets that was conceived as an alternative to a superconducting magnet in the STEP concept that is more compact. Within the comissioning of the permanent magnet trap We succeeded in detecting He^+ ions in EBIT operation.

A 33.4 Fri 15:15 B302

Nuclear moments and isotope shifts of $^{249-253}$Cf probed by laser spectroscopy — •Dominik Studer for the Cf-Collaboration — Institut für Physik, JGU Mainz — GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — Helmholtz-Institut Mainz

Obtaining a comprehensive picture of nuclear phenomena in heavy nuclei requires precise measurements of, e.g., spins, electromagnetic moments and charge radii. These provide important data to pin down shell closures and to reveal their effect on observables, and serve as benchmarks for theory. However, experiments at the heavy-element frontier are challenging due to of limited sample sizes or production yields, and scarcity of atomic structure information. In this contribution we report on high-resolution laser spectroscopy of $^{249-253}$Cf across the $N = 152$ shell closure. A sample containing $^{249-252}$Cf was produced in the HFIR reactor at Oak Ridge National Laboratory, USA. Part of this sample was later re-irradiated at the high-flux reactor at ILL to obtain ≈20 fg of ^{253}Cf. The spectroscopic measurements were carried out at the RISIKO mass separator in Mainz. Spectrocopy with the laser perpendicular to the atomic beam using the PI-LIST ion source proved to be feasible with sample sizes on the femtogram level. Isotope shifts and hyperfine structures were measured for three ground-state transitions with linewidths in the order of 100 MHz, allowing the determination of the nuclear magnetic dipole moments of ^{249}Cf, ^{251}Cf and ^{253}Cf. The spectroscopic measurements are presented and the results are compared to state-of-the-art theoretical calculations.

A 33.5 Fri 15:30 B302

Towards Coulomb coupling of a proton and a single $^9Be^+$ ion by using a microfabricated Penning trap — •Julia-Aileen Coenders[1], Jan Schaper[1], Juan Manuel Cornejo[1], Jacob Stupp[1], Amado Bautista-Salvador[2], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]PTB, Bundesallee 100, 38116 Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN, Wako, Saitama 351-0198, Japan — [4]HHU Düsseldorf, Universitässtraße 1, 40225 Düsseldorf, Germany

The BASE collaboration has allowed to measure the g-factor of single (anti-)protons stored in Penning traps with an unprecedented precision. At BASE Hannnover, we want to contribute to this goal by developing cooling and detection techniques based on the coupling of single (anti-)protons to single $^9Be^+$ ions that are laser cooled to their motional ground state.

For the planned coupling and sympathetic cooling of a proton with a laser cooled $^9Be^+$ ion, we need an asymmetric double well potential, due to the different masses of the particles. To generate this potential, a miniaturized trap geometry needs to be developed. Here we present the microfabrication steps that we applied to fused silica wafers to fabricate the cylindrical electrodes of our micro coupling Penning trap with an inner diameter of 0.8 mm and an axial length of 0.2 mm. In addition, we will show our latest results on adiabatic transport of single laser cooled $^9Be^+$ ions, as well as the current work on the coupling of two $^9Be^+$ ions in a macro coupling trap of 8 mm inner diameter.

A 33.6 Fri 15:45 B302

Accurate isotope shift measurements in the D1 and D2 lines of Sr^+ — •Julian Palmes, Phillip Imgram, Hendrik Bodnar, Kristian König, Patrick Müller, Imke Lopp, and Wilfried Nörtershäuser — Institut für Kernphysik, TU Darmstadt, Germany

Accurate measurements of different transition frequencies in multiple isotopes allow for the determination of the isotope shift and thus the calculation of the field shift ratio f, which is an important parameter to compare experimental results with state-of-the-art atomic structure calculations. After previous measurements of the corresponding lines in isotopes of the other alkaline-earth metals Ca^+ and Ba^+, absolute frequency measurements of the stable Sr^+ isotopes will be performed to be followed later by investigations of the $4d \rightarrow 5p$ transitions. Information on these transitions is required for an experiment on stable and short-lived Sr^+ ions in a Paul trap, currently being prepared at the KU Leuven. We report on measurements of the D1 and D2 transitions, using the quasi-simultaneous collinear/anticollinear laser spectroscopy (CLS). These were carried out with the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA) at the Technical University of Darmstadt. Additionally, this method allowed for a precise observation of the hyperfine splitting of the $^{87}Sr^+$ isotope. Funding by BMBF under contract 05P21RDFN1 is acknowledged.

A 34: Ultrafast Dynamics III (joint session MO/A)

Time: Friday 14:30–16:30 Location: F102

See MO 23 for details of this session.

Molecular Physics Division
Fachverband Molekülphysik (MO)

Jochen Küpper
Center for Free-Electron Laser Science
Deutsches Elektronen-Synchrotron DESY
Hamburg
and
Department of Physics
Universität Hamburg
jochen.kuepper@cfel.de

Overview of Invited Talks and Sessions

(Lecture halls F102 and F142; Poster Empore Lichthof)

Invited Talks

MO 4.1	Tue	11:00–11:30	F102	**Revealing chiral charge migration in UV-excited molecules** — •Vincent Wanie, Etienne Bloch, Erik P. Månsson, Lorenzo Colaizzi, Sergey Ryabchuk, Krishna Saraswathula, Andrea Trabattoni, Valérie Blanchet, Nadia Ben Amor, Marie-Catherine Heitz, Yann Mairesse, Bernard Pons, Francesca Calegari
MO 7.1	Wed	11:00–11:30	F142	**Augmenting basis with normalizing flows for solving Schrödinger equations: theoretical analysis** — •Yahya Saleh, Armin Iske, Andrey Yachmenev, Jochen Küpper
MO 9.1	Wed	14:30–15:00	F102	**Full Angle-Resolved Mapping of Electron Rescattering Probabilities in the Molecular Frame** — Federico Branchi, Lingfeng Ge, Felix Schell, Killian Dickson, Mark Mero, Horst Rottke, Serguei Patchkovskii, Marc Vrakking, Varun Makhija, •Jochen Mikosch
MO 15.1	Thu	11:00–11:30	F142	**Excited state dipole moments from rotationally resolved Stark spectroscopy** — •Michael Schmitt, Matthias Zajonz, Marie-Luise Hebestreit
MO 22.1	Fri	11:00–11:30	F142	**A QED Theory of Mediated RET Between a Pair of Chiral Molecules** — •Akbar Salam

Invited Talks of the joint Symposium Precision Physics with Highly Charged Ions

See SYHC for the full program of the symposium.

SYHC 1.1	Mon	11:00–11:30	E415	**First experiments at CRYRING@ESR** — •Esther Babette Menz, Michael Lestinsky, Håkan Danared, Claude Krantz, Zoran Andelkovic, Carsten Brandau, Angela Bräuning-Demian, Svetlana Fedotova, Wolfgang Geithner, Frank Herfurth, Anton Kalinin, Ingrid Kraus, Uwe Spillmann, Gleb Vorobyev, Thomas Stöhlker
SYHC 1.2	Mon	11:30–12:00	E415	**Testing quantum electrodynamics in the simplest and heaviest multi-electronic atoms** — •Martino Trassinelli
SYHC 1.3	Mon	12:00–12:30	E415	**Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings** — •Beatriz Jurado
SYHC 1.4	Mon	12:30–13:00	E415	**Laboratory X-ray Astropohysics with Trapped Highly Charged Ions at Synchrotron Light Sources** — •Sonja Bernitt
SYHC 2.1	Mon	17:00–17:30	E415	**Observation of metastable electronic states in highly charged ions by Penning-trap mass spectrometry** — •Kathrin Kromer, Menno Door, Pavel Filianin, Zoltán Harman, Jost Herkenhoff, Paul Indelicato, Christoph H. Keitel, Daniel Lange, Chunhai Lyu, Yuri N. Novikov, Christoph Schweiger, Sergey Eliseev, Klaus Blaum
SYHC 2.2	Mon	17:30–18:00	E415	**Towards extreme-ultraviolet optical clocks** — •José R. Crespo López-Urrutia
SYHC 2.3	Mon	18:00–18:30	E415	**Coupling atomic and nuclear degrees of freedom in highly charged ions** — •Adriana Pálffy
SYHC 2.4	Mon	18:30–19:00	E415	**Laser Spectroscopy at the Storage Rings of GSI/FAIR** — •Wilfried Nörtershäuser

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2023

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Invited Talks of the joint Symposium Machine Learning in Atomic and Molecular Physics

See SYML for the full program of the symposium.

SYML 1.1	Tue	11:00–11:30	E415	**Imaging a complex molecular structure with laser-induced electron diffraction and machine learning** — •Katharina Chirvi, Xinyao Liu, Kasra Amini, Aurelien Sanchez, Blanca Belsa, Tobias Steinle, Jens Biegert
SYML 1.2	Tue	11:30–12:00	E415	**Physics-inspired learning algorithms for optimal shaping of atoms with light** — •Maximilian Prüfer
SYML 1.3	Tue	12:00–12:30	E415	**Machine-Learning assisted quantum computing and interferometry** — •Ludwig Mathey, Lukas Broers, Nicolas Heimann
SYML 1.4	Tue	12:30–13:00	E415	**Efficient quantum state tomography with convolutional neural networks** — •Moritz Reh, Tobias Schmale, Martin Gärttner

Prize Talks of the joint Awards Symposium

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich
SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt
SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Invited Talks of the joint Symposium Molecules in Helium Droplets

See SYHD for the full program of the symposium.

SYHD 1.1	Wed	11:00–11:30	E415	**Structure and field-induced dynamics of small helium clusters** — •Maksim Kunitski, Jan Kruse, Qingze Guan, Dörte Blume, Reinhard Dörner
SYHD 1.2	Wed	11:30–12:00	E415	**Coherent Diffraction Imaging of isolated helium nanodroplets and their ultrafast dynamics** — •Daniela Rupp
SYHD 1.3	Wed	12:00–12:30	E415	**Clustering dynamics in superfluid helium nanodroplets: A theoretical study** — •Nadine Halberstadt, Ernesto García Alfonso, Martí Pi, Manuel Barranco
SYHD 1.4	Wed	12:30–13:00	E415	**Messenger spectroscopy of molecular ions – Development of a new experimental setup** — •Elisabeth Gruber

Invited Talks of the joint Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit

See SYCC for the full program of the symposium.

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Invited Talks of the joint Symposium Quantum Optics and Quantum Information with Rigid Rotors

See SYQR for the full program of the symposium.

SYQR 1.1	Fri	11:00–11:30	E415	**Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets** — •Henrik Stapelfeldt
SYQR 1.2	Fri	11:30–12:00	E415	**Quantum toolbox for molecular state spaces** — Eric Kubischta, Shubham Jain, Ian Teixeira, Eric R. Hudson, Wesley C. Campbell, Mikhail Lemeshko, •Victor V. Albert
SYQR 1.3	Fri	12:00–12:30	E415	**Coherent rotational state control of chiral molecules** — •Sandra Eibenberger-Arias
SYQR 1.4	Fri	12:30–13:00	E415	**Optically levitated rotors: potential control and optimal measurement** — •Martin Frimmer
SYQR 2.1	Fri	14:30–15:00	E415	**Rotational optomechanics with levitated nanodumbbells** — •Tongcang Li
SYQR 2.2	Fri	15:00–15:30	E415	**Quantum rotations of nanoparticles** — •Benjamin A. Stickler
SYQR 2.3	Fri	15:30–16:00	E415	**Quantum control of trapped molecular ions** — •Stefan Willitsch
SYQR 2.4	Fri	16:00–16:30	E415	**Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables** — •Monika Leibscher

Sessions

MO 1.1–1.8	Mon	11:00–13:00	F102	**Cold Molecules (joint session MO/Q)**
MO 2.1–2.8	Mon	11:00–13:00	F142	**Photochemistry**
MO 3.1–3.7	Mon	11:00–13:00	F303	**Interaction with Strong or Short Laser Pulses I (joint session A/MO)**
MO 4.1–4.7	Tue	11:00–13:00	F102	**Ultrafast Dynamics I (joint session MO/A)**
MO 5.1–5.8	Tue	11:00–13:00	F142	**Electronic Spectroscopy**
MO 6.1–6.23	Tue	16:30–19:00	Empore Lichthof	**Poster I**
MO 7.1–7.7	Wed	11:00–13:00	F142	**Machine Learning and Computational and Theoretical Molecular Physics**
MO 8	Wed	13:15–14:00	F142	**Members' Assembly**
MO 9.1–9.7	Wed	14:30–16:30	F102	**Molecules in Intense Fields and Quantum Control (joint session MO/A)**
MO 10.1–10.7	Wed	14:30–16:15	F142	**Collisions (joint session MO/Q)**
MO 11.1–11.7	Wed	14:30–16:30	E214	**Quantum Technologies (joint session Q/MO/QI)**
MO 12.1–12.6	Wed	14:30–16:15	F107	**Interaction with Strong or Short Laser Pulses II (joint session A/MO)**
MO 13.1–13.19	Wed	16:30–19:00	Empore Lichthof	**Poster II**
MO 14.1–14.8	Thu	11:00–13:00	F102	**Ultrafast Dynamics II (joint session MO/A)**
MO 15.1–15.7	Thu	11:00–13:00	F142	**Rotational- and Vibrational-resolution Spectroscopy**
MO 16.1–16.7	Thu	11:00–13:00	F107	**Atomic Clusters (joint session A/MO)**
MO 17.1–17.8	Thu	14:30–16:30	F102	**Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)**
MO 18.1–18.8	Thu	14:30–16:30	F142	**Cluster and Experimental Techniques (joint session MO/A)**
MO 19.1–19.5	Thu	14:30–16:00	F107	**Interaction with Strong or Short Laser Pulses III (joint session A/MO)**
MO 20.1–20.19	Thu	16:30–19:00	Empore Lichthof	**Poster III**
MO 21.1–21.8	Fri	11:00–13:00	F102	**Molecular Physics with X-rays**
MO 22.1–22.8	Fri	11:00–13:15	F142	**Theoretical and Computational Molecular Physics**
MO 23.1–23.8	Fri	14:30–16:30	F102	**Ultrafast Dynamics III (joint session MO/A)**

Members' Assembly of the Molecular Physics Division

Wednesday 13:15–14:00 F142

Sessions

– Invited Talks, Contributed Talks, and Posters –

MO 1: Cold Molecules (joint session MO/Q)

Time: Monday 11:00–13:00 Location: F102

MO 1.1 Mon 11:00 F102

A Continuous Source of Aluminium Monofluoride Molecules — •Maximilian Doppelbauer[1], Sidney C. Wright[1], Simon Hofsäss[1], José Eduardo Padilla-Castillo[1], Sebastian Kray[1], Russell Thomas[1], Boris Sartakov[1], Stefan Truppe[1,2], and Gerard Meijer[1] — [1]Molecular Physics, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Centre for Cold Matter, Blackett Laboratory, Imperial College London, Prince Consort Road, London SW7 2AZ, United Kingdom

The aluminium monofluoride (AlF) molecule is a unique candidate for laser cooling and trapping experiments. As a starting point, we require a high-density molecular source. In our original setup, we can generate AlF by reaction of laser-ablated aluminium atoms with NF_3 in a pulsed cryogenic buffer gas source with more than 10^{12} molecules per steradian per ablation shot. By exploiting the reaction of AlF_3 and Al in a UHV oven above 600°C, we can generate a continuous thermal AlF beam with a total brightness of about 10^{16} molecules per steradian per second.

In this contribution, we present spectroscopic information on vibrational levels up to $v'' = 4$ and rotational levels to above $J'' = 80$ in the $X^1\Sigma^+$ electronic ground state that we obtained using the oven source as well as first experiments laser cooling AlF.

MO 1.2 Mon 11:15 F102

Cryo-cooled beams of "small" macromolecules — •Jingxuan He[1,2,3], Lena Worbs[1,2], Surya Kiran Peravali[1,4], Armando D. Estillore[1], Amit K. Samanta[1,3], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Germany — [3]Center for Ultrafast Imaging, Universität Hamburg, Germany — [4]Fakultät für Maschinenbau, Helmut-Schmidt-Universität,Germany

We have demonstrated the preparation of cold and controlled dense beams of nanoparticles and macromolecules designed for x-ray single-particle diffractive imaging (SPI). We exploit buffer-gas cell cooling and aerodynamic focusing techniques [1-2]. We are extending the cooling and control techniques developed for SPI to experimental investigations of ultrafast electron dynamics in complex biomolecules. We aim at disentangling charge and energy transfer following electronic excitation, which still has important open questions [3].

Here, we present our approach to prepare appropriate samples of cryogenically-cooled proteins to study these also biologically important elemantary processes, for instance, using photofragmentation mass spectrometry and velocity map imaging.

[1]A. K. Samanta, et al., *Structural dynamics* **7** , 024304 (2020)
[2]L. Worbs, et al., *In preparation*, (2022)
[3]H. Duan, et al., *PNAS* **114** , 8493 (2017)

MO 1.3 Mon 11:30 F102

Zeeman slowing of CaF — •Mariia Stepanova, Timo Poll, Paul Kaebert, Supeng Xu, Mirco Siercke, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover

Our Zeeman slowing scheme for laser-cooling of molecules with favorable Franck-Condon factors promises a substantial increase in molecular number in the velocity range of under 20 m/s, which is required for loading a Magneto-Optical Trap (MOT). The scheme stands out in its ability to not only lower the initial mean velocity of the molecular beam, but also to compress the velocity distribution in a continuous fashion. In this talk, we will present our most recent status on the experiment to achieve the goal of slowing and cooling CaF molecules generated from a buffer gas cell source, followed by our efforts to implement a dual-frequency MOT without sub-Doppler heating, discussed in [1].

[1] S. Xu, P. Kaebert, M. Stepanova, T. Poll, M. Siercke and S. Ospelkaus, DOI: https://doi.org/10.1103/PhysRevResearch.4.L042036

MO 1.4 Mon 11:45 F102

Ortho ground state preparation of cooled and trapped formaldehyde molecules — •Maximilian Löw, Martin Ibrügger, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Methods to directly cool polar molecules to ultracold temperatures saw remarkable progress in recent years. One of the most promising techniques in this field is optoelectrical Sisyphus cooling which can provide a large number of electrically trapped molecules at the sub-millikelvin level [1]. However, molecules in their absolute ground state cannot be addressed with this approach.

Cold ground state molecules can still be created by first applying Sisyphus cooling to, e.g., formaldehyde (H_2CO) molecules in the rotational states $|J=3,K_a=3,K_c=0\rangle$ and $|4,3,1\rangle$. Then, we use optical pumping to transfer them via a vibrational transition to their ortho ground state $|1,1,0\rangle$. In a proof-of-principle experiment trapped ground state molecules with a temperature of 65 mK and trapping times of several seconds were obtained. There is no fundamental obstacle to achieving lower temperatures in the future.

As formaldehyde in this state is stable against inelastic two-body collisions this fulfills an important requirement for evaporative or sympathetic cooling of this species in, e.g., a microwave trap which takes one a step closer to the long-term goal of quantum degeneracy.

[1] A. Prehn *et al.*, *Phys. Rev. Lett.* **116**, 063005 (2016).

MO 1.5 Mon 12:00 F102

Towards direct laser cooling of barium monofluoride — •Marian Rockenhäuser, Felix Kogel, Einius Pultinevicius, Tatsam Garg, and Tim Langen — UNI Stuttgart, 5. Physikalisches Insitut, IQST

We report on our progress towards the laser cooling of BaF molecules. This molecular species shows high promise for various types of precision measurement applications. However, due to its high mass, complex hyperfine structure and branching losses through intermediate states, it is also notoriously difficult to cool. In an effort to realize laser cooling, we have performed high-resolution absorption spectroscopy of the lowest rovibrational states to determine an improved set of molecular constants. This has allowed us to identify missing cooling and repumping transitions necessary to realize laser cooling of BaF, as well as to realize near background-free fluorescence imaging of a cold molecular beam

MO 1.6 Mon 12:15 F102

Optical properties of the Si_2O^+ cation — •Emil Mickein, Taarna Studemund, Kai Pollow, Marko Förstel, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

The emission of SiO from stars is well-known and proven. Moreover, the existence of different μm-sized silicate grains in interstellar dust is observed, but the formation pathway is unknown and information concerning larger molecules and their ions is missing.

In our project we are looking for transitions of cluster and characterize them via their measured optical spectrum.

In this talk, experimental data and quantum chemical calculations on the absorption and dissociation properties of Si_2O^+ are presented. The spectrum of Si_2O^+, which are created in a laser vaporization source, was obtained by photodissociation of mass-selected Si_2O^+ cations in a tandem mass spectrometer. The experimental results are discussed and compared with theoretical results of TD-DFT calculations.

Significantly, our optical spectrum provides the first spectroscopic information for this simple triatomic cation.

MO 1.7 Mon 12:30 F102

Threshold photodetachment spectroscopic studies of C_2^- — •sruthi purushu melath, christine maria lochmann, markus nötzold, robert wild, and roland wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria

Photodetachment spectroscopy is a powerful spectroscopic technique for determining the internal state distribution of a molecular anion. The dicarbon anion, our current molecule of interest, is a well-studied system due to its stable electronic level structure and potential laser cooling transition [1].

Here we present the photodetachment spectroscopy of C_2^- near threshold in a radiofrequency 16-pole wire trap at 8 K. The main goal of the experiment is to analyze the behavior of the cross section near the threshold, determine the electron affinity more precisely than previously measured [2,3], and if possible, obtain a rotationally resolved photodetachment signal as a function of photon energy. The status of the project will be presented.

[1]. M. Nötzold *et al.*, Phys. Rev. A 106, 023111 (2022) [2]. K. M. Ervin, *et al.*, J. Phys. Chem. 95, 2244 (1991) [3]. B. A. Laws *et al.*, Nat. Commun. 10, 1(2019)

MO 1.8 Mon 12:45 F102

Theoretical study of photoassociation of ultracold $^{23}Na^{39}K$ and ^{39}K — •Baraa Shammout[1], Charbel Karam[2], Leon Karpa[1], Eberhard Tiemann[1], Silke Ospelkaus[1], and Olivier Dulieu[2] — [1]Institut für Quantenoptik, Universität Hannover — [2]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton

Understanding the physics underlying ultracold alkali atom-diatom collisions is essential for full quantum control on ultracold molecules. The long-range photoassociation (PA) process of loosely-bound ultracold trimers from a scattering state of atom-diatom is a possible pathway to investigate their collisional properties. In this work, we present a long-range model for modeling photoassociation of ultracold $^{23}Na^{39}K$ and ^{39}K close to the molecular resonant excitation $NaK(X^1\Sigma) \rightarrow NaK(b^3\Pi)$. We have calculated potential energy surfaces (PESs) for the low-lying doublet excited states of NaK_2 up to the $NaK(b^3\Pi)$+K(4s) dissociation limit. We extracted the energy of vibrational-rotational levels using the time-independent close-coupling method, restricted to the long-range PESs. Finally, we demonstrate the possibility of experimental observation of trimer photoassociation by estimating trimer PA-rates.

MO 2: Photochemistry

Time: Monday 11:00–13:00 Location: F142

MO 2.1 Mon 11:00 F142

Time-resolved transient absorption spectroscopy of oxindole-based molecular motors and switches — •Camilo Granados[1,2], Matthew Mgbukwu[2], Dan Doellerer[3], Daisy Pooler[3], Alina Khodko[1,4], Ben L. Feringa[3], Jérémie Léonard[2], Oleg Kornilov[1], and Stefan Haacke[2] — [1]Max Born Institute, Max-Born-Straße 2A, 12489 Berlin, Germany — [2]Université de Strasbourg, CNRS, Institut de Physique et Chimie des Matériaux de Strasbourg, UMR 7504, F-67034 Strasbourg, France — [3]Stratingh Institute for Chemistry, Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands — [4]Institute of Physics NAS of Ukraine, Nauky Ave, 46, 03028, Kyiv, Ukraine

The design and characterization of synthetic molecules (motors and switches) is of vital importance for the construction of larger artificial structures that can be used for harvesting light energy and for other light-induced functionality [1]. However, the isomerisation quantum yields of the existing synthetic systems [1], are still low compared to the natural chromophores. Time-resolved transient absorption spectroscopy (TAS) can map the evolution of the relaxation of the molecule along the potential energy surfaces [1] and reveal the mechanisms affecting the isomerisation quantum yields. We will present recent TAS experiments on oxindole-based molecular motors and switches dissolved in different solvents. We will further present plans to investigate these synthetic molecular systems using TRPES. [1] DRS Pooler et. al., Chem. Sci., 12, 7486 - 7497 (2021).

MO 2.2 Mon 11:15 F142

Unraveling the photochemistry of $Ti^{IV}(Cp)_2(NCS)_2$ — •Jonas Schmidt, Luis Ignacio Domenianni, and Peter Vöhringer — University of Bonn, DE

Recently, the complex, $Cp_2Ti(Cl)_2$, has been used as a photo-redox-catalyst for atom economical transformations in one-electron steps.[1] We investigated the initial excitation and quenching of the catalyst using time-correlated single-photon-counting and femtosecond ultraviolet-pump mid-infrared-probe spectroscopy (UVmIR). The chlorido ligands were substituted with isothiocyanato ligands to render the catalyst amenable to UVmIR.

We recorded the emission spectrum and determined luminescence lifetimes of $Cp_2Ti(NCS)_2$ in liquid tetrahydrofuran solution at room temperature. The bi-exponential nature of the luminescence decay is highly indicative of thermally activated delayed fluorescence in addition to prompt fluorescence from the optically prepared singlet excited state. The triplet state was successfully quenched with triphenylamine and a Stern-Vollmer quenching constant of $9.4\text{x}10^9\ \frac{L}{mol\,s}$ was determined

UVmIR data obtained continuously from 50 femtoseconds to several microseconds supported this interpretation and the vibrational signatures of the S_1- and T_1-states were obtained by performing a target analysis of the time- and frequency-dependent pump-probe data set.

[1] Z. H. Zhang et al., *Angew. Chem. Int.* **2020**, *59*, 9355–9359.

MO 2.3 Mon 11:30 F142

Ultrafast Photochemistry of Metallo-Nitrenes — •Markus Bauer[1], Till Schmidt-Räntsch[2], Luis Domenianni[1], Sven Schneider[2], and Peter Vöhringer[1] — [1]Clausius Institut für physikalische Chemie, Rheinische Friedrich-Wilhelms-Universität Bonn, Deutschland — [2]Institut für Anorganische Chemie, Georg-August-Universität Göttingen, Deutschland

Metallo-nitrenes, formed by the photochemical decomposition of metallo-azides, have recently shown to be promising complexes for chemical catalysis, specifically for nucleophilic metallo-nitrene C-H insertion.[1] The exact reaction pathways, as well as the electronic structures of intermediate species remain so far largely unknown.

In this work, the photochemistry of the square-planar $[M(N_3)(PNP)]$ $(PNP{=}N(CHCHP^tBu_2)_2$, M=Pd, Pt) complexes after excitation with 320 nm light were investigated using ultrafast UV-pump mIR-probe and time resolved Fourier transform IR-spectroscopy.

The data reveal that dinitrogen cleavage from the photolabile azide group occurs from the triplet state on a time scale in excess of 1 ns. The quantum yield for nitrene formation depends on the nature of the metal.

[1] T. Schmidt-Räntsch, H. Verplancke, J. N. Lienert, S. Demeshko, M. Otte, G. P. Van Trieste, K. A. Reid, J. H. Reibenspies, D. C. Powers, M. C. Holthausen, S. Schneider, Angew. Chem. Int. Ed. 2022, 61, e202115626;

MO 2.4 Mon 11:45 F142

Photodynamics of arylazopyrazole derivatives: new insights from molecular dynamics studies — Helena Osthues, •Marcus Böckmann, and Nikos Doltsinis — Institut für Festkörpertheorie, Westfälische Wilhems-Universität, Münster, Germany

In the realm of photoswitches, azobenzene is an archetype for studying photodynamics primarily due to its fatigue resistance, simplicity, and tuneability by substitutions at the phenyl rings [1]. Here, we could demonstrate that the time scale of photoisomerisation can be drastically changed upon chemical modification [2]. Recently, the discovery of quantitative arylazopyrazole (AAP) photoswitches with long thermal lifetimes has pushed into focus this class of azobenzene derivatives, where one phenyl ring is replaced by a less bulky five-membered ring [3]. In this contribution, we report on dynamical photoisomerisation simulations of AAP derivatives elucidating the effect of different substituents and solvents on nonradiative lifetimes [4].

[1] H. M. D. Bandara, S. C. Burdette, *Chem. Soc. Rev.* **41**, 1809-1825 (2012)
[2] M. Böckmann, N. L. Doltsinis, D. Marx, *J. Chem. Phys.* **137**, 22A505 (2012)
[3] L. Stricker, M. Böckmann, T. M. Kirse, N. L. Doltsinis, B. J. Ravoo, *Chemistry – A European Journal*, **24**, 8639-8647 (2018).
[4] H. Osthues and N. L. Doltsinis, *J. Chem. Phys.* in press.

MO 2.5 Mon 12:00 F142

Multireference Chlorophyll Nuclear and Electron Q-Band Dynamics: a Theoretical XAS Study — •Lena Bäuml, Sebastian Reiter, Florian Rott, Bastian Michels, and Regina de Vivie-Riedle — Department of Chemistry, LMU Munich, Germany

Chlorophylls play a vital role during photosynthetic light-harvesting. Here, the nonradiative relaxation of high-energy excited states to the lowest excited state is of central importance.

We simulate the ultrafast relaxation process in the Q-bands of chlorophyll in a representative 2D space using grid-based wave packet quantum dynamics. The excited state energies and potential energy surfaces are computed at the XMS-CASPT2 level of theory to capture the multi-reference character of chlorophyll excitations. We propose a possibility to observe the wave packet dynamics, as well as the strong coupling between the Q_x and Q_y state via magnesium K-edge X-ray absorption spectra. Following the RASPT2 procedure outlined by Rott *et al.*[1] our results show from a fully quantum mechanical point of view how the Q_x and Q_y band are strongly coupled by internal vibrations,[2] in contrast to the Gouterman model. Thus the absorption intensity should be spread over the whole Q-band, influencing charge and energy transfer in photosynthetic light-harvesting complexes, such as photosystem 1.

[1] F. Rott *et al.*, *Struct. Dyn.*, **8**, 034104 (2021).
[2] L. Bäuml *et al.*, *Phys. Chem. Chem. Phys.* **24**, 27212 (2022).

MO 2.6 Mon 12:15 F142

The role of dephasing for dark states and polaritonic chemistry — •Eric Davidsson and Markus Kowalewski — Department of Physics, Stockholm University, Albanova University Center, SE-106 91 Stockholm, Sweden

Common quantum-mechanical models for chemistry in optical cavities lack a mechanism to populate collective dark states. In this work, we explicitly model a process that does populate these states; i.e. disorder from loss of phase information (decoherence) in the matter sub-systems. Such processes arise due to local environment interactions, and the effect enters into the equations of motion as dephasing operators. Viewed through the lens of polaritonic states, a reservoir of previously inaccessible states has thus opened up. Since these states are superpositions of excitations in only matter sub-systems, one would expect that dephasing can protect excited states from photon decay. In this work, we find that dephasing indeed does that quite effectively. We also discuss how to understand the same physical result in a standard product basis, where there are no dark states.

MO 2.7 Mon 12:30 F142

Cavity-induced effects on the ground-state chemical reactivity of the click reaction — •Thomas Schnappinger and Markus Kowalewski — Department of Physics, Stockholm University, Sweden

If a molecule interacts with the vacuum field of a nanoscale cavity, strong coupling reshapes the potential energy surfaces, forming hybrid light-matter states, termed polaritons. Recent experiments show that this strong coupling between light and matter is capable of modifying chemical and physical properties. The situation in which the quantized cavity modes are coupled via their characteristic frequency to vibrational degrees of freedom of molecules is called vibrational strong coupling (VSC). In the VSC regime, the chemistry of a single electronic state (mostly the ground-state) and its vibrational spectroscopy are influenced by the cavity interaction.

In this theoretical contribution, we study different aspects to see to what extent and how the chemical reactivity can be altered by VSC in the single-molecule case. As an illustrative example, we are investigating the azide-alkyne Huisgen cycloaddition, which is better known as the prototypical click reaction. We describe the hybrid light-molecule matter system with the help of an extended Jaynes-Cummings-like model taking into account the counter-rotating terms and the dipole-self-energy terms. In this setup, we can realize coupling to multiple cavity modes and study the cavity-induced changes of ground-state energies, geometries, and activation energies.

MO 2.8 Mon 12:45 F142

Suppressing non-radiative decay of photochromic organic molecular systems in the strong coupling regime — •Markus Kowalewski and Rafael C. Cuoto — Stockholm University, Stockholm, Sweden

Organic solar cells and related optoelectronic applications rely on molecules with long-lived electronic states. Non-radiative decay channels, which are caused, for example, by non-adiabatic processes in the molecule can have a significant impact on the efficiency of the these devices. More favorable lifetimes are in practiced, achieved by chemical substitution of particular base compound.

In this contribution, we investigate meso-tert-butyl-BODIPY, which is known to for its low fluorescence yield, caused by the non-radiative decay through a conical intersection [1]. We show theoretically that strong light-matter coupling by means of an optical nano-cavity may be used to modify the excited state lifetime.

[1] R. C. Couto, M. Kowalewski, Phys. Chem. Chem. Phys, **24**, 19199 (2022).

MO 3: Interaction with Strong or Short Laser Pulses I (joint session A/MO)

Time: Monday 11:00–13:00 Location: F303

See A 3 for details of this session.

MO 4: Ultrafast Dynamics I (joint session MO/A)

Time: Tuesday 11:00–13:00 Location: F102

Invited Talk MO 4.1 Tue 11:00 F102

Revealing chiral charge migration in UV-excited molecules — •Vincent Wanie[1], Etienne Bloch[2], Erik P. Månsson[1], Lorenzo Colaizzi[1,3], Sergey Ryabchuk[3], Krishna Saraswathula[1,3], Andrea Trabattoni[1,4], Valérie Blanchet[2], Nadia Ben Amor[5], Marie-Catherine Heitz[5], Yann Mairesse[2], Bernard Pons[2], and Francesca Calegari[1,3] — [1]DESY, Germany — [2]Université de Bordeaux - CNRS - CEA, CELIA, France — [3]Universität Hamburg, Germany — [4]Leibniz Universität Hannover, Germany — [5]CNRS, France

Electron-driven charge migration occurs following photoexcitation of a molecule, leading to a charge density traveling rapidly along the molecular structure. We report our most recent works devoted to the investigation of charge migration in neutral molecules and its applications to manipulate the outcome of photochemical and photophysical processes. We exploited our new light source delivering few-femtosecond UV pulses in order to photoexcite below the ionization threshold and trigger electronic dynamics in chiral methyl-lactate. We used time-resolved photoelectron circular dichroism (TR-PECD) to image electronic coherences driving charge migration and disclose - for the first time - their impact on the molecular chiral response, allowing for an ultrafast chiroptical switching effect where the amplitude and direction of the photoelectron current generated by PECD can be controlled on a sub-10 fs timescale. The results provide important perspectives to exploit charge-directed reactivity for controlling the chiral properties of matter at the molecular scale. [1] V. Wanie et al., 'Ultrafast chiroptical switching in UV-excited molecules,' (under review, 2022).

MO 4.2 Tue 11:30 F102

UV and Mid-IR Photo-induced Dissociation Dynamics of Solvated (Bio)Molecular Complexes — •Mukhtar Singh[1,2,3], Matthew Scott Robinson[1,2,3], Hubertus Bromberger[1,2], Jolijn Onvlee[1,3], Sebastian Trippel[1,2], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Center for Ultrafast Imaging, Universität Hamburg — [3]Department of Physics, Universität Hamburg

We present the imaging of ultrafast UV- and thermal-energy-induced chemical dynamics of micro-solvated (bio)molecular complexes probed with strong-field ionization techniques [1]. We produce a pure gas-phase indole-water sample using a combination of a cold molecular beam and the electrostatic deflector [2]. To study the induced dynamics, we set up both a UV and a mid-IR pump-probe experiment, in which a 269 nm and 2.9 μm laser pulses were used to excite the system, respectively. A 1.3 μm laser pulses was used for ionizing the system. First experiments focused on the ion imaging of t he UV and mid-IR-triggered systems. Furthermore, we will report on efforts to use laser-induced electron diffraction (LIED) [3,4] to probe the molecular dynamics to obtain structural information with atomic resolution.

[1] J Onvlee, *et al., Nat Commun.,* DOI: 10.1038/s41467-022-33901-w
[2] S. Trippel, *et al., Rev. Sci. Instrum.* **89**, 096110 (2018)
[3] J. Wiese, *et al., Phys. Rev. Research* **3**, 013089 (2021)
[4] E. T. Karamatskos, *et al., J. Chem. Phys.* **150**, 244301(2019)

MO 4.3 Tue 11:45 F102

Supramolecular dynamics investigated on hydrogen bonded pyrrole-water clusters upon site-specific x-ray photoionization — •Ivo S. Vinklárek[1], Hubertus Bromberger[1], Wuwei Jin[1], Rebecca Boll[2], Michael Meyer[2], Sebastian Trippel[1], and Jochen Küpper[1,3,4] — [1]Center forFree-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY,Hamburg — [2]European XFEL GmbH, Schenefeld — [3]Department of Physics, Universität Hamburg — [4]Center for Ultrafast Imaging, Universität Hamburg

Solvation of molecules crucially affects their photostability and opens additional pathways for the relaxation dynamics compared to isolated molecules. We intend to get molecular-level insight into the solvation effect in photofragmentation dynamics of a supramolecular system through our molecular beam experiments with stoichiometrically well-defined pyrrole-water (Pyr-H_2O) clusters [1]. Concretely, the dissolvation dynamics of the spatially separated pure sample of Pyr-H_2O clusters prepared by the electric deflector was investigated through an IR-pump-x-ray-probe experiment. The singly ionizing IR-pulse triggers the $(Pyr\text{-}H_2O)^+$ fragmentation, which is then site-specifically probed by x-ray free-electron laser pulses [2] at different times of the pyrrole-H_2O separation. The study of the hydrogen-bound Pyr-H_2O system is especially relevant to abundant pyrrole-containing biomolecules and establishes a novel approach for investigating the key role of intermolecular interactions in supramolecular dynamics.

[1] Johny, M. et al. *Chem. Phys. Lett.*, **2019**, 721, 149-152. [2] Onvlee, J. et al., *Nat. Commun.*, in press, arXiv:2103.07171 [physics]

MO 4.4 Tue 12:00 F102

Real time tracking of ultrafast dynamics in liquid water — •Gaia Giovannetti[1], Ammar bin Wahid[1], Sergey Ryabchuk[1], Hui-Yuan Chen[2], Vincent Wanie[1], Andrea Trabattoni[1,3], Erik Maansson[1], Hugo Marroux[4], Majed Chergui[2], and Francesca Calegari[1,5] — [1]Center for Free-Electron Laser Science, DESY, Notkestr. 85, 22607 Hamburg, Germany — [2]Ecole Polytechnique Fédérale de Lausanne, Rte Cantonale, 1015 Lausanne, Switzerland — [3]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [4]Laboratoire Interactions, Dynamiques et Lasers, CEA-Saclay, 91191 Gif-sur-Yvette, France — [5]The Hamburg Centre for Ultrafast Imaging, Universitaet Hamburg, 22761 Hamburg, Germany

Understanding the properties of water is key to determinate the effects of the liquid environment on the dynamics of biological systems. In our experiment, a 3 fs visible pump impulsively creates a vibrational wave-packet, whose evolution is probed by a time-delayed sub-2 fs UV pulse [1]. As a result of the wave-packet dynamics, the probe signal is modulated in time and the vibrational spectrum can be obtained by a Fourier analysis of the temporal interferogram. A preliminary analysis of our data shows a transient signal whose oscillation period

(~11 fs) and decay time (~70 fs) match the values expected for the O-H stretching mode in the ground electronic state of liquid bulk water [2]. Further theoretical insights will allow us to assign specific contributions from the ground, excited and ionized states. [1] Opt. Lett. 44, 1308-1311 (2019) [2] J. Chem. Phys. 135, 244503 (2011).

MO 4.5 Tue 12:15 F102

Systematic variation of triplet chromophore energies in iron(II) complexes linked to organic chromophores — •Moritz Lang[1], Philipp Dierks[2], Miguel Argüello Cordero[1], Matthias Bauer[2], and Stefan Lochbrunner[1] — [1]Institute for Physics, University of Rostock, Germany — [2]Faculty of Science, CSSD, Paderborn University, Germany

For the efficient conversion of solar light, photosensitizers with appropriate absorption properties and long living excited states are crucial. Iridium and ruthenium complexes stand out due to their extraordinary stable triplett metal-to-ligand charge transfer (3MLCT) excited states but are expensive and toxic. To find sustainable alternatives, iron-based metal complexes are intensely studied. But due to an efficient internal conversion pathway mediated by metal centered states, the MLCT lifetime and therefore the performance of these types of complexes are still limited. In a systematic study the influence of various chromophores attached to homoleptic iron complexes was investigated. The excited state dynamic was studied by ultrafast transient absorption spectroscopy. For particular chromophores an additional decay component was observed, exceeding the lifetime of the otherwise predominant 3MLCT state by an order of magnitude. With fitting energy levels, a triplet state of the chromophore is populated during the relaxation process, achieving a comparably stable intermediate configuration. A better understanding and further improvement of these systems will contribute to the ultimate goal of developing efficient iron based photosensitizers for solar energy conversion.

MO 4.6 Tue 12:30 F102

Ultrafast dynamics of photochemical nitrile imine formation — •Stefan Flesch and Peter Vöhringer — Clausius-Institut für Physikalische und Theoretische Chemie, Rheinische Friedrich-Wilhelms-Universität Bonn, Wegelerstr. 12, D-53115 Bonn

The chemical reactivity of nitrile imines is of great utility in organic synthesis with applications rapidly expanding into the materials and life sciences.[1] Yet, our understanding of the electronic and molecular structures of nitrile imines remains incomplete and the elementary mechanism of their photoinduced generation is entirely unknown. Here, femtosecond infrared spectroscopy after 266 nm-excitation of 2,5-diphenyltetrazole has been carried out to temporally resolve the formation and structural relaxation dynamics of the nascent diphenylnitrile imine in liquid solution under ambient conditions.[2] An initial sequence of intersystem crossings within 250 fs is followed by the cleavage of N_2 with formation of a structurally relaxed nitrile imine on the adiabatic ground-state singlet surface within a few tens of picoseconds. The infrared spectrum supports the notion of a "floppy" nitrile imine molecule whose equilibrium character ranges from fully propargylic to fully allenic under these conditions.

1 G. Bertrand, C. Wentrup, *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 527-545.
2 S. Flesch, P. Vöhringer, *Angew. Chem. Int. Ed.* **2022**, e202205803.

MO 4.7 Tue 12:45 F102

Investigating the oxidation states of a perylene bisimide cyclophane with ultrafast spectroelectrochemistry — •Rebecca Fröhlich[1], Jessica Rühe[2], Michael Moos[2], Frank Würthner[2], Christoph Lambert[2], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

From photosynthesis to optoelectronic devices, charged species fulfill essential roles in our everyday world. With spectroelectrochemistry the oxidation states of molecules can be generated and investigated under potential control. In our setup we combine spectroelectrochemistry with femtosecond transient absorption spectroscopy to investigate the dynamics of charged species on an ultrafast timescale [1].

Here we show new data on the oxidation states of a perylene bisimide cyclophane [2]. A fit of the cyclic voltammetry data of the molecule shows four reduction steps with closely lying redox potentials. The four reduced states show a change in absorption which is highlighted by the deconvolution of the absorption spectroelectrochemistry data. Through the fits of the absorption spectra the charged species can be distinguished in a set of transient absorption spectroelectrochemistry maps. The excited state lifetimes of the reduced molecule are analyzed with global fitting and change according to their oxidation state.

[1] J. Heitmüller et al., Spectrochim. Acta Part A, 253, 119567 (2021)
[2] J. Rühe et al., Organic Materials, 2, 149-158 (2020)

MO 5: Electronic Spectroscopy

Time: Tuesday 11:00–13:00 Location: F142

MO 5.1 Tue 11:00 F142

Highly-resolved Stark effect measurements of Rydberg states in nitric oxide — •Fabian Munkes[1,4], Patrick Kaspar[1,4], Philipp Neufeld[1,4], Alexander Trachtmann[1,4], Yannick Schellander[2,4], Lars Baumgärtner[3,4], Robert Löw[1,4], Tilman Pfau[1,4], and Harald Kübler[1,4] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [3]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [4]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart

We demonstrate Stark effect measurements at room temperature of high-lying Rydberg states in nitric oxide. These states are generated using a three-photon continuous-wave excitation scheme. The readout is based on the detection of charged particles created by collisional ionization of Rydberg molecules. A theoretical discussion of the gained experimental results is given.

MO 5.2 Tue 11:15 F142

Threshold Photoelectron Spectra of fragments of AsMe3 and SbMe3 — •Emil Karaev[1], Marius Gerlach[1], Patrick Hemberger[2], and Ingo Fischer[1] — [1]Julius-Maximilians-Universität. Würzburg, Germany — [2]Swiss Light Source, Villigen, Switzerland

Our group already investigated the pyrolysis products of methylated group V compounds X = N[1], P[2], Bi[3]. While for the single methylated isomers of nitrogen we observed H-N-CH_2, N-CH_2 and H-N-CH, bismuth showed only Bi-CH_3. For phosphorus the isomers H-P-CH_2, P-CH_3 and P-CH_2 were detected. To complete our investigation of the 5^{th} main group, trimethylarsenic and trimethylantimony were pyrolyzed. The emerging reactive species were characterized with the PEPICO setup of the VUV beamline of the synchrotron SLS in Switzerland. The resulting mass-selected threshold photoelectron spectra were interpreted using quantum chemical calculations and Franck-Condon simulations.

Our results show that antimony behaves similarly to bismuth, forming only Sb-CH_3. Arsenic on the other hand showed H-As-CH_2, As-CH_3 and As-CH_2, which is analogous to phosphorus.

MO 5.3 Tue 11:30 F142

Optical Absorption and Photodissociation Properties of $Si_nO_m^+$ — •Taarna Studemund, Marko Förstel, Kai Pollow, Emil Mickein, and Otto Dopfer — IOAP, TU Berlin, Germany

The formation mechanisms of interstellar dust grains are still poorly understood. It is known, however, that these contain a significant amount of μm-sized silicate material [1]. So far only silicon monoxide (SiO) is identified in the interstellar medium [2]. We compare experimental data to quantum chemical calculations to understand photodissociation and optical absorption behavior, structures, and energies of possible $Si_nO_m^+$ molecules that are potential and promising precursors. The experimental setup relies on action spectroscopy via mass spectrometry and resonant laser photodissociation of size-selected $Si_nO_m^+$ clusters. These are generated via laser vaporization in a molecular beam expansion coupled to a quadrupole/time-of-flight tandem mass spectrometer and a broadly tuneable UV/VIS-OPO laser [3]. Preliminary data reveal competing fragmentation channels, their appearance energies and branching ratios, and the abundance and stability of neutral fragments. We highlight especially the spectrum of $Si_3O_2^+$ measured by photodissociation and discuss it in an astrophysical context.

[1] K. Nagashima et al. Nat., 2004, 428, 921-924
[2] R. Wilson et al. Astrophys. J., 1971 167, L97
[3] M. Förstel et al., Rev. Sci. Instrum., 2017, 88, 123110

MO 5.4 Tue 11:45 F142

The Electronic Spectrum of Si_2^+ — •Kai Pollow, Taarna Studemund, Sophie Verhoeven, Emil Mickein, Otto Dopfer, and Marko Förstel — IOAP, TU Berlin, Germany

The first absorption lines of neutral Si_2 were measured 75 years ago. However, experimental information on the cation is rare. We recently measured the first optical spectrum of Si_2^+ via photodissociation spectroscopy[1]. We observe two vibronic band systems near 430 and 270 nm that are in very good agreement with high-level quantum-chemical calculations[2]. The measured vibronic transitions allow for determination of molecular constants in the ground and respective excited states. The optical spectrum of Si_2^+ may enable astrophysical searches for this potential building block of interstellar silicate dust. We present the mea-

sured optical spectrum and compare it to quantum-chemical calculations.
[1] T. Studemund, K. Pollow, S. Verhoeven, E. Mickein, O. Dopfer and M. Förstel J.Phys.Chem.Lett. 2022, 13 (33), 7624-7628.
[2] Y. Liu; H. Zhai; X. Zhang; Y. Liu Ab initio calculation on the low-lying excited states of Si_2^+ cation including spin-orbit coupling. Chem. Phys. 2013, 425, 156-161.

MO 5.5 Tue 12:00 F142

State selective diagnostics and spectroscopy of H_3^+ in a heavy ion storage ring — •Aigars Znotins[1], Lukas Berger[1], Florian Grussie[1], Damian Müll[1], Oldrich Novotny[1], Felix Nuesslein[1], Andreas Wolf[1], Arnaud Dochain[2], Xavier Urbain[2], and Holger Kreckel[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Institute of Condensed Matter and Nanoscience, Louvain-la-Neuve, Belgium

The significance of the triatomic hydrogen ion H_3^+ for astrochemistry is well-established. It is a key contributor in a network of ion-neutral reactions that govern interstellar chemistry at low temperature and density. Additionally, as the simplest polyatomic molecule, H_3^+ is an important benchmark system for theoretical calculations.

Due to a lack of a permanent dipole moment, laboratory spectroscopy of H_3^+ remains a non-trivial endeavor. The highest-lying H_3^+ levels experimentally reported have been identified by transitions from the H_3^+ ground state to energies around 16500 cm^{-1}. Considering that the dissociation limit of H_3^+ is at approximately 35000 cm^{-1}, more than half of the energetic landscape remains unexplored.

In this work, we discuss the possibility and requirements to extend H_3^+ spectroscopy into the energy region above 20000 cm^{-1}. An approach for multi-color action spectroscopy is proposed to state-selectively investigate highly excited states of H_3^+ in a cryogenic ion storage ring environment. We present model calculations describing the laser diagnostic schemes, based on a comprehensive H_3^+ linelist.

MO 5.6 Tue 12:15 F142

Electronic Photodissociation Spectroscopy of Diamondoid Cations in a Cryogenic Trap — •Parker Crandall, Simone Stahl, Viktoria Lovasz, Marko Förstel, and Otto Dopfer — Technische Universität Berlin, Berlin, Germany

Similarities have been observed between the infrared spectra of diamondoids and unidentified IR emission bands seen in the spectra of young stars with circumstellar disks.[1,2] It is also suggested that their radical cations could contribute to features in the largely unassigned diffuse interstellar bands due to their low ionization energy and absorption in the visible range.[3] However, the optical spectra of these cations have only recently begun to be measured experimentally, which is required for astronomical identification. Here, we present the optical spectra of the radical cations of adamantane ($C_{10}H_{16}^+$)[4], diamantane ($C_{14}H_{20}^+$)[5], and 1-cyanoadamantane ($C_{11}H_{15}N^+$). These spectra were recorded by photodissociation of mass-selected ions in the gas phase at 5 K using a tandem mass spectrometer coupled to a cryogenic 22-pole ion trap. The experimental results are compared to photoelectron spectra and time-dependent DFT calculations for interpretation. All spectra reveal broad structures that are attributed to lifetime broadening and Franck-Condon congestion arising from geometric changes and/or Jahn-Teller distortion. The astrophysical implications of these ions will also be discussed.

MO 5.7 Tue 12:30 F142

Measuring fluorescence-detected two-quantum photon echoes using cogwheel phase cycling — •Ajay Jayachandran, Stefan Müller, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

We describe two-quantum photon echo spectroscopy, a new technique that enables one the selective characterization of doubly excited states. This technique is analogous to the popular 'photon echo' experiment [1], which encodes the dynamic information associated with singly excited states.

We transfer the core principle, i.e., a rephasing contribution that removes the effect of inhomogeneous broadening, to doubly excited states, and we extract the signal experimentally using cogwheel phase cycling of three-pulse sequences and fluorescence detection. We verify the applicability of cogwheel phase cycling, which has proven useful in two-dimensional nuclear magnetic resonance spectroscopy to reduce overall measurement time in comparison to nested phase cycling [2], by extracting the two-quantum photon echo without any signal aliasing.

We study how exciton–exciton annihilation of squaraine molecular aggregates of varying chain length [3] can be quantified by accessing the homogenous linewidth of the biexciton state which is obtained from the two-quantum photon echo.

[1] S. Asaka et al., Phys. Rev. A. **29**, 2286-2289 (1984).
[2] M. H. Levitt et al., J. Magn. Reson. **155**, 300-306 (2002).
[3] P. Malý et al., Chem. Sci. **11**, 456-466 (2020).

MO 5.8 Tue 12:45 F142

Near-field scanning optical microscopy of topologically protected excitons in molecular aggregates — •Sidhartha Nayak, Christopher W. Wächtler, and Alexander Eisfeld — MPIPKS, Dresden, Germany

Delocalized excitonic eignestates of molecular aggregates are responsible for the energy transfer from an incoming radiation into the aggregate. Static disorder, which can arise from an imperfect environment of each molecule, reduces the exciton transport and large disorders can even localize the exciton. It has been shown theoretically that a two-dimensional periodic array of tilted and interacting molecules in a homogeneous magnetic field shows topologically protected edge states [1] which are robust under local disorder. With a scattering scanning near-field optical microscope setup, one can not only record position dependent absorption spectra [2] but also reconstruct the wavefunctions from these specta [3]. In this contribution we study theoretically the near field spectra of the aforementioned 2D aggregates in which the molecules experience a disordered environment because of the probing metallic tip. Due to the topological protection, the edge states are robust even in the presence of the metallic nanoparticle, such that the recorded spectrum shows clear signatures of these edge states.

[1] J. Y. Zhou, S. K. Saikin, N. Y. Yao and A. Aspuru-Guzik, *Nature materials* 13, 1026-1032 (2014)
[2] X. Gao and A. Eisfeld, *J. Phys. Chem. Lett.* 9, 6003 (2018)
[3] F. Zheng, X. Gao and A. Eisfeld, *Phys. Rev. Lett.* 123, 163202 (2019)

MO 6: Poster I

Time: Tuesday 16:30–19:00 Location: Empore Lichthof

MO 6.1 Tue 16:30 Empore Lichthof

Boundary effects in sensory adaptation & interacting sensory systems — •Vansh Kharbanda — Cell Biophysics and Statistical Physics, Faculty of Veterinary Medicine, LMU Munich

Sensory adaptation is vital to all living organisms. An adaptive sensory system can be modelled as a stochastic, nonlinear feedback network. Using a generic framework, we study the accuracy of adaptive mechanisms and its energetic cost. Recently, it has been suggested that the steady-state dissipation rate associated to maintenance of an adaptive state increases logarithmically with the adaptation accuracy. We present results that demonstrate that this logarithmic scaling does not hold generally, but appears to be linear when the state of the system is close to the phase-space boundaries. Our numerical results also suggest that boundaries in the phase space of system variables limit the capacity of the system to dissipate. Moreover, we conjecture a new empirical expression relating the steady-state dissipation rate and the strength of the input signal if the state lies in the vicinity of the boundaries. Finally, the combined adaptation accuracy of two linearly coupled systems is studied. We show that a coupling the outputs of the systems deteriorates the overall adaptation accuracy while the associated energy cost is also reduced. In contrast, a coupling of the control elements reduces the dissipation rate without compromising on the adaptation accuracy.

MO 6.2 Tue 16:30 Empore Lichthof

Time-resolved study of the photogeneration of the phenylselenium cation from diphenyl diselenide and subsequent use for covalent activation in organic reactions — •Daniel Grenda[1], Anna Tiefel[2], Carina Allacher[1], Alexander Breder[2], and Patrick Nürnberger[1] — [1]Institute of Physical and Theoretical Chemistry, University of Regensburg, Regensburg — [2]Institute of Organic Chemistry, University of Regensburg, Regensburg

Using a pump-probe setup on a μs-timescale with a streak-camera detector [1], one can investigate light-induced chemical reactions with long-lived intermediates. We apply this technique to organoselenium compounds, which are useful catalysts in organic synthesis due to their stability towards oxygen and their rich radical chemistry [2]. Especially diphenyl diselenide is a versatile precursor for organic synthesis, as it is often used to generate phenylselenyl radicals by photolytic cleavage of the selenium-selenium bond [3]. However, we demonstrate that given the right reaction conditions, the phenylselenium cation can be generated in a similar way, which then is utilizable for covalent activation of allylic selenium species [4].

[1] R. J. Kutta *et al.*, *Appl. Phys. B* **111**, 203-216 (2013).
[2] A. Breder *et al.*, *Tetrahedron Lett.* **56**, 2843-2852 (2015).
[3] O. Ito *et al.*, *J. Am. Chem. Soc.*, **105**, 850-853 (1983).
[4] M. Tingoli *et al.*, *J. Org. Chem.* **61**, 7085-7091 (1996).

MO 6.3 Tue 16:30 Empore Lichthof

Photoemission delays in similiarly sized molecules — •Maximilian Forster, Christian Schröder, Maximilian Pollanka, Pascal Scigalla, Michael Mittermair, Andreas Duensing, and Reinhard Kienberger — Chair for laser and x-ray physics, E11, Technische Universität München, Germany

In the gas phase we measure the relative photoemission delay between the Helium 1s and the Iodine 4d state in Iodobenzene and Iodocyclohexane. This allows us to determine the absolute timing of the Iodine 4d photoelectrons.

Iodine as a substituent was chosen for its giant resonance and therefore high cross section in the I4d state which is expected to be unaffected by its chemical surrounding. Measurements on a variety of different iodoalkanes have shown an unexpected variation of the I4d delay for different molecules, with no clear correlation with the molecular size, showing that the chemical environment may play a role in forming the observed photoemission delay. Therefore performing measurements on molecules with similar size and yet significant differences in their bonding structure yields further information about the possible underlying effects causing the delay.

MO 6.4 Tue 16:30 Empore Lichthof

Femtosecond Transient Absorption Spectro-Microscopy with High Spatial Resolution on Dye Microcrystals — •Magnus Frank, Chris Rehhagen, and Stefan Lochbrunner — Institute for Physics and Department of Life, Light and Matter, University of Rostock, 18051 Rostock, Germany

Solid organic materials open a promising pathway for further improvement of optoelectronic devices like OLEDs or organic photovoltaics. The interaction of light and matter in such systems is essential for potential applications. For instance, in organic solar cells, excitons need to diffusive to an interface for charge separation - a dynamic process competing with other decay channels on the femto- and picosecond timescale. Femtosecond transient absorption is still the hallmark of dynamics determination in molecular systems, but though a lot of research has been done on the dynamics of organic solids, many fundamental aspects are still unclear. This is because measuring not only dynamics on the femtosecond timescale but also ensuring high spatial and spectral resolution is challenging. In this work, we combine classical transient absorption with microscopy allowing for spectroscopy with both high spatial and time resolution, 2.5 μm and sub-100fs respectively. We demonstrate the performance by measuring the dynamics of single microcrystals of a perylene dye, a material class known for its outstanding potential in optoelectronics.

MO 6.5 Tue 16:30 Empore Lichthof

Phase-modulated transient-absorption spectroscopy in the liquid phase — •Jakob Gerlach, Yilin Li, Arne Morlok, Ulrich Bangert, Frank Stienkemeier, and Lukas Bruder — Institute of Physics, University of Freiburg, Germany

In our group a setup for two-dimensional electronic spectroscopy has previously been developed and used to study dynamics of nanosystems trapped in helium nanodroplets [1]. The action-detected spectroscopy is based on phase modulation of the laser pulses [2]. Many processes relevant in the field of photochemistry take place in a liquid environment, which significantly impacts the investigated dynamics. Therefore, a new setup is assembled to allow the examination of a probe in the liquid phase using transient-absorption spectroscopy. We plan to combine this setup with the phase modulation technique in order to improve the signal-to-noise. The design of the setup and a first characterization of its implementation will be presented.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018).

[2] P. F. Tekavec, G. A. Lott, and A. H. Marcus, J. Chem. Phys. 127, 214307 (2007).

MO 6.6 Tue 16:30 Empore Lichthof

Dependence of photoelectron circular dichroism on the distance between marker atom and stereocenter in chiral molecules — •Emilia Heikura[1], Florian Trinter[2], Lutz Marder[1], Catmarna Küstner-Wetekam[1], Dana Bloss[1], Nils Kiefer[1], Johannes Viehmann[1], Christina Zindel[1], Markus Ilchen[2], Andreas Hans[1], and Arno Ehresmann[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Deutsches Elektronen-Synchrotron, DESY, Notkestraße 85, 22607 Hamburg, Germany

Photoelectron circular dichroism (PECD) is one of the most powerful methods to investigate molecular chirality in the gas phase. PECD arises from the asymmetry of the angular distribution of photoelectrons (probe electrons) scattered on the chiral backbone of the molecule even from randomly oriented molecules after interaction with circularly polarized light. One still unclear aspect of PECD is, how the distance between the probe electron emitter site and the center of a point-chiral molecule affects the magnitude of the PECD asymmetry. For detection of these forward-backward asymmetries of emitted photoelectrons a velocity map imaging (VMI) electron spectrometer was used. Measurements were performed on sec-butyl trimethylsilylether and its derivatives.

MO 6.7 Tue 16:30 Empore Lichthof

Ultrafast Transient Absoprtion Spectroscopy of Metal Complexes with 10 fs Probe Pulses — •Marvin Krupp, Moritz Lang, Chris Rehhagen, and Stefan Lochbrunner — Institut für Physik, Uni Rostock, Deutschland

Most of the photoactive complexes used in chemical applications are based on rare metals like iridium or ruthenium. Replacing them with abundant metals e.g. iron is of long-standing interest, but the resulting complexes are currently limited by their photoactive properties. To analyze newly prepared iron complexes femtosecond transient absorption spectroscopy is typically used to determine the dynamics upon photoexcitation with short pump pulses and a few hundred femtoseconds long white light continuum for probing. Increasing the time resolution by reducing the pulse duration of the probe can make it possible to observe extremely fast processes below the current time resolution and give insights into the very first relaxation steps in the metal complexes such as intersystem crossing. In this work a broadband noncollinear optical parametric amplifier (NOPA) is used to generate broadband pulses with a duration below 10 fs. These pulses are used as probe light improving the time resolution in comparison to the usual CaF_2 white light. The setup was characterized with transient grating frequency-resolved optical gating (TG FROG) and first measurements on Fe-complexes are compared with respect to the two probe sources.

MO 6.8 Tue 16:30 Empore Lichthof

THz-Streaking for Detecting Inner-valence-shell Correlation-induced Time-delays in the Ionization of PAHs. — •Mohamed Abdelrasoul, Mark Prandolini, Marek Wieland, and Markus Drescher — Institute of Experimental Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany.

Photoionization delays (Wigner time delay) in outer molecular shells occur in the range of a few ten attoseconds. This delay increases for inner valence shell photoionization due to strong correlation effects, namely, shake-up/down and knock-up/down processes, leading to markedly longer relaxation times, and raising an interesting question: how long does it take to remove an electron from the molecular inner shell relative to the outermost shell? Most polycyclic aromatic hydrocarbons (PAHs) have relatively high photoelectron emission cross sections in the energy range typically between 15 and 25 eV, and to access both inner and outer photoelectron spectra, an Extreme Ultraviolet (XUV) photon energy in that range is required. A laser-based setup is presented, combining a high harmonic XUV source with THz streaking for measuring the photoelectron emission delay in PAHs of different sizes.

MO 6.9 Tue 16:30 Empore Lichthof

Photodissociation dynamics of $CHCl_2$ — •Jonas Fackelmayer, Christian Matthaei, and Ingo Fischer — Julius-Maximilians-Universität Würzburg, 97074 Würzburg, Germany

Recent studies suggest that the depletion of atmospheric O_3 is not only caused by the banned CFCs and HCFCs but also catalysed by commonly used solvents such as dichloromethane.[1] Photodissociation of these compounds often results in the release of highly reactive halogen radicals. While the dissociation dynamics of molecular halocarbons have been studied in detail in the past, less is known about their open shell counterparts.

The photofragmentation of the open shell $CHCl_2$, generated by pyrolysis from the bromide precursor $CHCl_2Br$, was investigated in a free jet utilising time-of-flight mass-spectrometry and velocity map imaging. Photodissociation was achieved by a pulsed dye laser in the range of 230 - 250 nm mainly producing CHCl and Cl fragments, while ionisation was provided by either a second dye laser (REMPI) or a frequency multiplied solid state laser at 118 nm (SPI). First insights into the involved dissociation mechanisms are discussed.

[1] Hossaini, R. et al., *Nat. Commun.* **2017**, *8*, 15962.

MO 6.10 Tue 16:30 Empore Lichthof

Probing conical intersection dynamics in the dissociative photoionization of formaldehyde — •David Chicharro Vacas, Weiyu Zhang, Thomas Pfeifer, and Robert Moshammer — 1Max-Planck-Institute für Kernphysik, Heidelberg, Germany

Conical intersections (CI) between electronic states often govern the photochemistry of molecules and radicals. Their role and characteristics have been largely studied before both theoretically and experimentally. It has been proven that CI are crucial in different photochemical reactions and are characterized by coupled electronic and nuclear dynamics, breaking the Born-Oppenheimer approximation. The neutral photofragmentation of formaldehyde has been widely studied in the past years mainly because of a great interest for the roaming pathway producing H2. However, the photoionization and dissociative photoionization (DPI) has been less studied. Experimentally, the DPI of formaldehyde has been studied and two main DPI processes were found: The H-atom loss and the molecular channel. More recently, experimental and theoretical findings allowed to predict the mechanism involved in the DPI of formaldehyde, suggesting the presence of a conical intersection that controls this mechanism. The aim of this work is to directly observe the presence of this conical intersection by using pump-probe schemes along with the reaction microscope. The 3D-ion-electron momentum coincidence measurements in a pump-probe experiment provides enough information to fully understand this process and to directly visualize the presence of the conical intersection in the experimental results.

MO 6.11 Tue 16:30 Empore Lichthof

Ultrafast coherent control of single molecules via two-photon excitation at room temperature — •Xinpeng Xu[1], Ullrich Scherf[2], and Richard Hildner[1] — [1]Zernike Institute for Advanced Materials, University of Groningen, The Netherlands — [2]Institut für Polymertechnologie, Universität Wuppertal, Germany

Quantum coherent control has been a powerful technique to understand and manipulate ultrafast photoinduced processes occurring at the inter-/intra-molecular level for more than twenty years. In a coherent control experiment, one can exploit quantum interference between competing pathways of multi-photon transitions toward the desired outcome by tailoring the spectral phase, amplitude, or polarization of the electromagnetic field of the exciting laser. For larger functional molecules in condensed phase, the influence of the (often disordered) surrounding environment varies between molecules. Hence, ensemble measurements do typically not allow to exert full control over competing pathways. Here, we demonstrate that the two-photon transition of single molecules can be controlled by a sequence of shaped pulses at room temperature. Varying the spectral phase of the pulses, we observe phase-dependent photoluminescence signals corresponding to the two-photon excitation probability. We assign this phase dependence to the combination of quantum photon interference and coherence between the incident laser spectrum and the single molecule absorption spectrum. Notably, cancellation of the transition probability by so-called *dark pulses* is observed in some molecules, which shows the ability to fully coherent control of single molecules in condensed phase.

MO 6.12 Tue 16:30 Empore Lichthof

Attosecond Chronoscopy of organic iodine compounds on Pt111 — •Sven Paul[1], Pascal Scigalla[1], Christian Schröder[1], Peter Feulner[2], and Reinhard Kienberger[1] — [1]Chair for laser and x-ray physics, E11, Technische Universität München, Germany — [2]Surface and Interface Physics, E20, Technische Universität München, Germany

We report on attosecond streaking measurements of the relative photoemission delay between the Iodine 4d state in organic iodine compounds like Iodoethane and -methane adsorbed on a Pt111 surface in respect to the Pt valence band. Iodine was chosen as a substituent in these organic molecules because of its giant dipole resonance in the 4d state, which results in a high cross section that is mostly unaffected by the rest of the molecule. The surface coverage of the organic iodine compounds on the Pt crystal is controlled via thermal programmed desorption. This is important because the orientation, i.e. horizontal and vertical configuration, of these adsorbents on the surface depends on the surface coverage. By using those two effects, we can ensure whether the detected photoelectrons have been perturbed by the whole organic chain or only by parts of it. A change in photoemission delay between both configurations is expected, as suggested by previous measurements for Iodoethane. Similar measurements are now made for Iodomethane as part of my master thesis, as we want to study the correlation of the photoemission delay with the length of the organic chain.

MO 6.13 Tue 16:30 Empore Lichthof

Lamellar and amorphous Alucones as Nanoscaffolds for Cellular Response; A Route for Building Nature-Inspired Materials. — •Mabel Moreno[1], Angélica Zacarias[2], Simón Guerrero[1], Luis Velasquez[1], Yusser Olguin[3,4], and Eberhard Gross[5] — [1]Universidad SEK, Instituto de Investigación Interdisciplinar en Ciencias Biomédicas SEK (I3CBSEK). — [2]Max Planck Institute of Microstructure Physics, Weinberg 2, D 06120, Halle, Germany, and ETSF. — [3]Universidad Técnica Federico Santa María, Centro de Biotecnología, Avenida España 1680, Valparaíso, Chile. — [4]Universidad Técnica Federico Santa María, Departamento de Física, Avenida España 1680, Valparaíso, Chile — [5]Fritz Haber Research Center for Molecular Dynamics and Institute of Chemistry, The Hebrew University of Jerusalem, Jerusalem 91904, ISRAEL.

We present our study of the growth of alucone thin films (AlO-T and AlO-A, T: terephthalate and A: adipate) by atomic layer deposition (ALD) and molecular layer deposition (MLD). Stoichiometric thin films with large area uniformity were obtained in both cases, as shown in SEM/Focus Ion Beam (FIB), transmission electron microscopy (TEM), X-ray diffraction (XRD), X-ray reflectometry (XRR), Atomic force microscopy (AFM), reflectance diffuse by UV-Visible, and attenuated total reflectance (ATR) data. Quantum information (QI), C2C12 cells cultured test and antibacterial activity were performed to prove the QI and biocompatibility concepts on such thin films, making them possible candidates for bioinspired-quantum devices.

MO 6.14 Tue 16:30 Empore Lichthof

Long-lasting XUV-induced ignition of avalanche ionization of helium nanodroplets — •C. Media[1], A. Ø. Laegdsmand[2], L. Ben Ltaief[2], Z Hoque[3], A. H. Roos[3], M. Jurkovic[3], O. Hort[3], O. Finke[3], M. Albrecht[3], J. Nejdl[3], F. Stienkemeier[1], E. Klimesova[3], M. Krikunova[3], A. Heidenreich[4], and M. Mudrich[2] — [1]Institute of Physics, University of Freiburg, Freiburg, Germany — [2]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark — [3]ELI Beamlines Centre, FZU- Institute of Physics of the Czech Academy of Sciences, Na Slovance 2, 182 21 Prague, Czechia — [4]IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, Spain

We study the dynamics of avalanche ionization of pure helium nanodroplets activated by a weak extreme-ultraviolet (XUV) pulse and driven by an intense near-infrared (NIR) pulse. In addition to a transient enhancement of the droplet ignition probability at short delay times ~200~fs, long-term activation of the nanodroplets lasting up to a few nanoseconds is observed. Molecular dynamics simulations suggest that the short-term activation is caused by the injection of seed electrons into the droplets by XUV photoemission. Long-term activation is due to electrons remaining loosely bound to photoions which form stable 'snowball' structures in the droplets. Thus, we show that XUV irradiation can induce long-lasting changes of the strong-field optical properties of nanoparticles, potentially opening new routes to controlling avalanche-ionization phenomena in nanostructures and condensed-phase systems.

MO 6.15 Tue 16:30 Empore Lichthof

Bidirectional photorearrangement reaction of a xanthine derivative — •Thomas Rittner[1], Karina Heilmeier[1], Rafael E. Rodríguez-Lugo[2], Simon Dietzmann[2], Svenja Wortmann[1], Roger Jan Kutta[1], Robert Wolf[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93053 Regensburg — [2]Institut für Anorganische Chemie, Universität Regensburg, 93053 Regensburg

7-Aryl-8-pyridyl substituted theophyllines exhibit a remarkable photoreaction. Our studies show that upon excitation with ultraviolet light, the anisyl substituted 7-(4-methoxyphenyl)-1,3-dimethyl-8-(pyridin-2-yl)-3,7,8,9-tetrahydro-1H-purine-2,6-dione undergoes a rearrangement. The anisol moiety migrates from the 7-nitrogen on the purine skeleton of the theophylline to the 1'-nitrogen of the pyridine, yielding a zwitterionic isomer. Both isomers could be isolated and subsequently characterized by NMR spectroscopy and single-crystal X-ray scattering. Time-resolved and steady-state absorption and emission spectroscopies in the visible spectral range were used to investigate the photorearrangement mechanism. Together with quantum-chemical calculations a detailed picture on a molecular level could be obtained. We further demonstrate that also a photo-induced back-isomerization is feasible, enabling in principle a general design for photo-switchable molecular structures.

MO 6.16 Tue 16:30 Empore Lichthof

Coverage-dependent agglomeration in molecular films on atomically flat surfaces — •Erik von der Oelsnitz, Tim Völzer, Julian Schröer, Rico Schwartz, Tobias Korn, and Stefan Lochbrunner — Institute of Physics, Albert-Einstein-Straße 23-25, 18059 Rostock, Germany

The deposition of a thin, monomeric molecular layer on an atomically flat surface, as it is provided by Van-der-Waals crystals, is crucial to the functionalization of such layered materials and the fabrication of corresponding hybrid structures. In this work, Perylene Orange (PO) molecules were coated onto a thin exfoliated hexagonal boron nitride layer using thermal vapor deposition (TVD) at various evaporation temperatures. The resulting hybrid structures were examined by a fluorescence lifetime imaging microscope, revealing a bi-exponential fluorescence decay, as well as by micro-photoluminescence spectroscopy, proving for low evaporation temperatures the monomeric nature of the PO layer. Upon increasing the temperature, the fluorescence intensity rises and at the same time the fast decay component becomes dominant and a low-energy band emerges in the emission spectrum. Interestingly, the slow decay time remains pretty constant. Therefore, this slow component can be assigned to the fluorescence decay of PO monomers, whereas the fast decay component can be attributed to agglomerates that form at higher coverage and provide additional decay channels such as the relaxation into excimer states. From these findings, an optimum for the vaporization temperature can be determined, which will be used in future applications.

MO 6.17 Tue 16:30 Empore Lichthof

Effect of vibropolariton formation on ground-state reactivity of Diels-Alder cycloaddition reaction — •Berna Arslanoglu, Thomas Schnappinger, and Markus Kowalewski — Stockholm University, Sweden

It has been experimentally demonstrated that ground-state reaction mechanisms can be modified by an optical cavity at room temperature. It has been shown by Thomas et al. [1], that coupling a Si-C bond resonantly to a quantized field mode can change the chemical reaction rate of the silyl bond cleavage reaction.

We present ab initio simulations of the ground state Diels-Alder reaction in the presence of an optical cavity field. The vibrational modes of the reactants are strongly coupled to the light field. The change of the reaction barrier in the presence of the field is studied for varying vacuum field strengths as well as for different resonance conditions. Additionally, we study how the dipole self-energy term influences stationary points of the reaction.

[1] A.Thomas et al., Science 363, 615 (2019)

MO 6.18 Tue 16:30 Empore Lichthof

Classification of noisy spectra using machine learning — •Aritra Mishra and Alexander Eisfeld — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

A general problem in quantum mechanics is to obtain information of the eigenstates from the experimental measured data which consists inherent noises. In particular, we consider molecular aggregates, where information about excitonic eigenstates is vitally important to understand their optical and transport properties [1,2]. It has been shown that it is possible to reconstruct the underlying delocalised aggregate eigenfunctions from near-field spectra using convolution neural networks [3].

In this work, we also use a convolution neural network but ask a question related to the eigenstate based classification of the spectra in the presence of noise. Given that each eigenstate correspond to a distinct spectrum, we can assign a class to each of the eigenstate. We add a random noise to these spectra and build a network that can classify the spectra into these classes, in the presence of the noise. We find that the network is also able to classify the spectra of different noise strengths along with the one it has been trained for.

[1] X. Gao and A. Eisfeld, J. Phys. Chem. Lett. 9, 6003 (2018)
[2] S. Nayak, F. Zheng and A. Eisfeld, J. Chem. Phys. 155, 134701 (2021)
[3] F. Zheng, X. Gao and A. Eisfeld, Phys. Rev. Lett. 123, 163202 (2019)

MO 6.19 Tue 16:30 Empore Lichthof

Photoelectron Circular Dichroism for Chiral Helium — •Marec Heger, Manel Mondelo-Martell, and Daniel Reich — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

Chiral molecules, i.e. molecules that cannot be superimposed by its mirror image by rotations and translations, show different reactions to other chiral systems depending on their handiness. A prominent example is the interaction of chiral molecules with left and right-circularly polarized light which leads to differences in the photoelectron angular emission spectrum. This difference is called photoelectron circular dichroism(PECD) which can be used as a tool to detect and distinguish chiral signatures of molecules in the gas phase.

Understanding the precise origin and the relationship between the chiral molecular scaffold and the PECD signal is still an ongoing theoretical challenge, particularly when it comes to the role of electron correlation. Numerical simulations for large molecules are particularly challenging in this context. For this reason we perform ab initio simulations for an elementary system - helium with an artificial external chiral potential - and investigate the relationship between PECD and the chiral potential. Finally, by considering theoretical simulations involving various degrees of electron correlation - from single-active electron approaches to full configuration interaction - we also aim to elucidate the role of electron correlation systematically.

MO 6.20 Tue 16:30 Empore Lichthof

Towards understanding the enhancement of the circular dichroism in the ion yield of 3-methylcyclopentanone via tailored femtosecond laser pulses — •Sagnik Das, Jayanta Ghosh, Sudheendran Vasudevan, Hangyeol Lee, Nicolas Ladda, Simon Ranecky, Tonio Rosen, Arne Senftleben, Thomas Baumert, and Hendrike Braun — Institut für Physik, Universität Kassel, Heinrich-Plett-Strasse 40, 34132 Kassel, Germany

One of the methods to differentiate between the two enantiomers of a chiral molecule is Circular Dichroism (CD). It arises due to the difference in absorption of left and right circularly polarised light. The difference in absorption can also be mapped to the difference in ionisation of the enantiomers and is known as CD in ion yield [1]. We use our home-built Time of Flight (ToF) mass spectrometer with twin peak [2] measurement setup to study the effect of linear chirp (GDD) on the anisotropy. The candidate molecule for this experiment is 3-methylcyclopentanone (3-MCP). We perform all the experiments at 309 nm, where 3-MCP shows enhancement of anisotropy, upto 10%. At this wavelength, a 1+1+1 resonance-enhanced multi-photon ionisation (REMPI) takes place in 3-MCP through the $\pi^* \leftarrow n$ transition. We observed enhancement of anisotropy for chirped pulses, which we have compared to bandwidth limited pulses of equal peak intensity. Furthermore, we perform a pump-probe experiment to investigate the intermediate state dynamics.

[1] U. Boesl and A. Bornschlegl, ChemPhysChem, 7, 2085, 2006
[2] T. Ring et al., Rev. Sci. Instrum., 92, 033001, 2021

MO 6.21 Tue 16:30 Empore Lichthof

Excited-state dynamics of aqueous aminoazobenzene Metanil Yellow studied by time-resolved transient absorption spectroscopy — •Alina Khodko[1,5], Matthew Mgbukwu[4], Camilo Granados[1,4], Evgenii Titov[2,3], Stefan Haacke[4], Oleg Kornilov[1], and Jérémie Léonard[4] — [1]Max Born Institute, Max-Born-Straße 2A, 12489 Berlin, Germany — [2]Institute of Physical and Theoretical Chemistry, University of Würzburg, Germany — [3]Institute of Chemistry, University of Potsdam, Germany — [4]Institut de Physique et Chimie des Matériaux de Strasbourg, Université de Strasbourg, CNRS UMR 7504, Strasbourg, France — [5]Institute of Physics NAS of Ukraine, Nauky Ave, 46, 03028, Kyiv, Ukraine

The excited-state dynamics of the aminoazobenzene Metanil Yellow in aqueous solutions was studied using ultrafast time-resolved transient absorption spectroscopy in both the UV-visible and the NIR regions. The different solutions were studied with different excitation wavelengths to investigate the protonated and non-protonated forms of the molecule and reveal differences in the corresponding dynamics. The relaxation dynamics of the non-protonated form was previously studied by time-resolved photoelectron spectroscopy and TDDFT calculations and revealed transitions from the bright S2 to the ground state S0 via the dark S1 state. As a first interpretation, the present results for the protonated form could be explained by direct excitation of S1 followed by the proton ejection during the first 0.5-1.0 ps. After 1 ps the excited state absorption looks similar for both forms and reflects the internal conversion to the trans ground state along the torsional coordinate.

MO 6.22 Tue 16:30 Empore Lichthof

Ultrafast dynamics and reversible switching of azobenzene-copper complexes — •Marcel J. P. Schmitt[1], Justin Hornbogen[2], Raphael I. Petrikat[1], Sabine Becker[1], Rolf Diller[2], and Christoph Riehn[1,3] — [1]Dept. of Chemistry, RPTU Kaiserslautern — [2]Dept. of Physics, RPTU Kaiserslautern — [3]Forschungszentrum OPTIMAS, 67663 Kaiserslautern (Germany)

Azobenzenes and their derivatives are known for their reversible *E*-*Z*-photoisomerization around the N=N bond.[1,2] Their usage as photoswitchable ligands in metal complexation has also been explored.[3] We present preliminary spectroscopic and ultrafast dynamic results in solution and gas phase of a newly synthesized cyclic $[Cu_2L_2]^{2+}$ complex, comprised of two pyridyl-substituted azobenzene ligands (L) in conjunction with Cu(I). We focus on the photoswitching dynamics and possible cooperative effects involving the ligands and metal cores. Therefore, we have examined the dynamics in parallel in solution by transient absorption and in gas phase by femtosecond transient photodissociation using an electrospray ionization mass spectrometer. The resulting ultrafast dynamic spectra reveal multiexponential electronic decay with lifetimes in the sub-ps and ps time ranges for both *E* and *Z* configurations. For comparison with UV/Vis and mIR spectra, the binding situation of the copper centers (tetrahedral vs. planar) in the (*E,E*), (*E,Z*) and (*Z,Z*) complexes was quantum chemically modelled by RI-DFT/TD-DFT calculations.

[1] Nat. Rev. Chem. 2019, 3, 133. [2] Chem. Soc. Rev. 2012, 41, 18091825. [3] J. Phys. Chem. Lett. 2019, 10, 6048.

MO 6.23 Tue 16:30 Empore Lichthof

Femtosecond Spectroscopy of a highly strained benzene isomer — •Lukas Faschingbauer[1], Tobias Preitschopf[1], Jens Petersen[1], Lou Barreau[2], Lionel Poisson[2], Roland Mitric[1], and Ingo Fischer[1] — [1]Institut für Physikalische und Theoretische Chemie, Würzburg, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Orsay, France

As a highly strained benzene isomer, 3,4-dimethylenecyclobutene (DMCB) forms an intriguing system to study the dynamics of its excited states, both from an experimental and a theoretical point of view. The formally Woodward-Hoffmann allowed electrocyclic ring opening to 1,2,4,5-hexatetraene is not observed, in contrast to the thermal counterpart, which has been observed in pathways to benzene in flames. Nevertheless, as indicated by a very broad and diffuse gas-phase UV/VIS absorption spectrum, ultrafast non-radiative decay is observed by femtosecond time-resolved photoelectron and time-of-flight mass spectrometry. To explore the underlying mechanism, ab initio calculations and mixed quantum-classical surface hopping molecular dynamics simulations have been performed.

MO 7: Machine Learning and Computational and Theoretical Molecular Physics

Time: Wednesday 11:00–13:00 Location: F142

Invited Talk MO 7.1 Wed 11:00 F142

Augmenting basis with normalizing flows for solving Schrödinger equations: theoretical analysis — •Yahya Saleh[1,2], Armin Iske[2], Andrey Yachmenev[1,4], and Jochen Küpper[1,3,4] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Mathematics, Universität Hamburg — [3]Department of Physics, Universität Hamburg — [4]for Ultrafast Imaging, Universität Hamburg

Spectral methods are a popular class for solving time-independent Schrödinger equations. Here, one approximates the wavefunctions in the linear span of standard basis sets of L2. In spite of the well-posedness and the convergence guarantees of such methods, they suffer from the curse of dimenionality, as the computational expenses grow exponentially with the size of the quantum system.

Recently, nonlinear functions, e.g., neural networks have been proposed to model ground states and low-lying excited states of Schrödinger equations. Although they promise accurate results with smaller scaling than standard methods, extensions of such models to the simultaneous computation of many states are still lacking.

Here, we propose to model excited states of Schrödinger equations via augmented basis sets, where standard basis sets are composed with normalizing flows. We show that such a numerical scheme is well-posed and defines a richer approximation space than standard methods. Moreover, we provide convergence guarantees.

MO 7.2 Wed 11:30 F142

A machine learning full dimensional potential energy surface for AlF-AlF: lifetime of the intermediate complex — Weiqi Wang[1], •Xiangyue Liu[1], and Jesús Pérez-Ríos[2] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Institute for Advanced Computational Science, Stony Brook University, Stony Brook, NY 11794-3800, USA

AlF is a promising candidate in the quest of finding the most efficient molecule for laser cooling. In this work, a full-dimensional potential energy surface of AlF-AlF dimer has been constructed by machine learning methods. In particular, we analyze the reliability and efficiency of different active learning schemes developed for this system. The potential energy surface has been employed in calculating the four-body complex lifetime relevant to the stability of molecules in the ultracold regime via molecular dynamics simulations.

MO 7.3 Wed 11:45 F142

Quantum flows neural network for variational solutions of the Schrödinger equation — •Álvaro Fernández[1,3], Yahya Saleh[1,4], Andrey Yachmenev[1,2], Armin Iske[4], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Center for Ultrafast Imaging, Universität Hamburg — [3]Department of Physics, Universität Hamburg — [4]Department of Mathematics, Universität Hamburg

Recently, a few deep neural network models for solving the electronic Schrödinger equation were developed, demonstrating both outstanding computing efficiency and accurate results.

Here, we present a new quantum-flow-neural-network approach for obtaining variational solutions of the stationary Schrödinger equation. At the core of the method is an invertible neural network composed with the general basis of orthogonal functions, which provides a more stable framework for simultaneous optimization of the ground state and excited states. This approach is applied in calculations of the vibrational energy levels of polyatomic molecules as well as of electronic energies in a single-active-electron approximation. The results show a considerable improvement of variational convergence for the ground and the excited states. In addition, we extend our approach for solving the time dependent problems using recurrent flows.

MO 7.4 Wed 12:00 F142

Electronic excited states in deep variational Monte Carlo — •Mike Entwistle[1], Zeno Schätzle[1], Paolo Erdman[1], Jan Hermann[2,1], and Frank Noé[2,1,3] — [1]Freie Universität Berlin, Berlin, Germany — [2]Microsoft Research AI4Science, Berlin, Germany — [3]Rice University, Houston, USA

Obtaining accurate ground and low-lying excited states of electronic systems is crucial in a multitude of important applications. One ab initio method for solving the Schrödinger equation that scales favorably for large systems is variational quantum Monte Carlo (QMC). The recently introduced deep QMC approach uses ansatzes represented by deep neural networks and generates nearly exact ground-state solutions for molecules containing up to a few dozen electrons, with the potential to scale to much larger systems where other highly accurate methods are not feasible. Here, we extend one such ansatz (PauliNet) to compute electronic excited states. We demonstrate our method on various small atoms and molecules and consistently achieve high accuracy for low-lying states. To highlight the potential of our method, we compute the first excited state of the much larger benzene molecule, as well as the conical intersection of ethylene, with PauliNet matching results of more expensive high-level methods.

MO 7.5 Wed 12:15 F142

The performance of CCSD(T) for the calculation of dipole moments in diatomics — •Xiangyue Liu[1], Laura McKemmish[2], and Jesús Pérez-Ríos[3] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]School of Chemistry, UNSW Sydney, Sydney, NSW 2052, Australia — [3]Department of Physics and Astronomy, Stony Brook University, Stony Brook 11794, New York, USA

Electric dipole moment plays an important role in understanding intermolecular interactions. High-quality electric dipole moments are essential for accurate predictions of vibrational and rotational spectroscopy. In this work, the performance of CCSD(T) (coupled cluster with single, double, and perturbative triple excitations) has been evaluated with accurate experimental data of diatomic molecules. In particular, CCSD(T) accuracy for the equilibrium bond length, vibrational frequency, and dipole moments has been discussed. We find that CCSD(T) gives accurate predictions on dipole moments for most of the molecules in the test set. However, disagreements have been found for a few molecules, which can hardly be explained by relativistic or multi-reference effects. The impacts of basis set family and size have also been discussed.

MO 7.6 Wed 12:30 F142

Non-Local Polarizability Density as a Building Block for Dispersion Density Functionals — •Szabolcs Goger[1], Peter Szabo[2,3], Dmitry Fedorov[1], and Alexandre Tkatchenko[1] — [1]University of Luxembourg, 1511 Luxembourg, Luxembourg — [2]Katholieke Universiteit Leuven, 3000 Leuven, Belgium — [3]Royal Belgian Institute for Space Aeronomy, 1180 Uccle, Belgium

Dispersion interactions, stemming from long-range electron correlations, are not properly captured by many electronic structure methods. A proper framework to tackle this problem requires determining the correlation energy via the adiabatic-connection dissipation-fluctuation theorem, but a robust unified formalism is yet to be developed [1]. In this work, we attempt to build such a general method based on the non-local polarizability, which is expressed as a polarization-polarization correlation function. This quantity is evaluated for a number of model systems and contrasted to real atoms and molecules. The model studies presented here, along with prior work on semi-local polarizability functionals [2], pave the way toward developing a unified non-local polarizability functional for molecules and materials, aimed to describe the short-range and long-range correlations on equal footing.

[1] Hermann and Tkatchenko, Phys. Rev. Lett. 124, 146401 (2020)
[2] Vydrov and Van Voorhis, Phys. Rev. Lett. 103, 063004 (2009)

MO 7.7 Wed 12:45 F142

Few-Body Physics of the Trapped Atoms: The Configuration Interaction Approach — •Matee ur Rehman[1], Alejandro Saenz[1], Fabio Revuelta Peña[2], Paul Winter[1], and Simon Sala[1] — [1]Humboldt-Universität zu Berlin — [2]Universidad Politécnica de Madrid

Two independent theoretical approaches are developed for the computational treatment of interacting ultracold atoms in versatile trap potentials. One approach considers the two-body system in centroid and relative coordinates have recently successfully demonstrated the inelastic confinement-induced resonances occurs due to the anharmonicity of the trap potentials, however an extension beyond two particles is not possible, but evidently of interest. This motivates to consider an alternative approach in absolute coordinates based on standard quantum-chemistry approaches, that uses cartesian Gaussians (GTOs) as basis functions and performs the configuration interaction calculations with a flexible choice of interaction potentials, hence allow considering arbitrary optical tweezer arrays. As the delta-pseudopotential does not work in beyond-mean field description, the Gaussian interaction potential using GTOs allows an efficient solution of multi-centered six-dimensional interaction integrals, but its validity has to be investigated. So this talk will demonstrate both theoretical models by focusing on their pros and cons for different interatomic interaction potentials, and then address the question that, Is the Gaussian interaction potential is sufficient (respectively in which parameter regime is it sufficient) to be used (or within which accuracy it can used).

MO 8: Members' Assembly

Time: Wednesday 13:15–14:00 Location: F142

All members of the Molecular Physics Division are invited to participate.

MO 9: Molecules in Intense Fields and Quantum Control (joint session MO/A)

Time: Wednesday 14:30–16:30 Location: F102

Invited Talk MO 9.1 Wed 14:30 F102

Full Angle-Resolved Mapping of Electron Rescattering Probabilities in the Molecular Frame — Federico Branchi[1], Lingfeng Ge[2], Felix Schell[1], Killian Dickson[3], Mark Mero[1], Horst Rottke[1], Serguei Patchkovskii[1], Marc Vrakking[1], Varun Makhija[3], and •Jochen Mikosch[2] — [1]Max-Born-Institut, Berlin, Germany — [2]Universität Kassel, Kassel, Germany — [3]Univ. of Mary Washington, Fredericksburg, USA

A reaction microscope experiment on strong-field ionization and laser-driven electron rescattering of the asymmetric top molecule 1,3-butadiene is presented. Importantly, by virtue of the ion-electron coincidence detection, our experiments separate the ground-state (D0) and first excited state (D1) ionization channel. In this way two scattering experiments on the same target are performed simultaneously with two very different continuum electron wavepackets.

By analyzing lab frame coherent rotational wavepacket evolution following a non-adiabatic alignment laser pulse we achieve both polar and azimuthal angle-resolved molecular frame information.

Our results indicate that the nodal structure of the ionizing orbitals is more strongly reflected in the electron rescattering probability rather than in the ionization probability. Propagation of the wavepacket influences the differential cross section that is measured for the two channels. Experimental results are compared with results from a TD-RIS ab-initio simulation.

MO 9.2 Wed 15:00 F102

Pulse length dependence of photoelectron circular dichroism — •Hangyeol Lee[1], Simon Ranecky[1], Sudheendran Vasudevan[1], Nicolas Ladda[1], Tonio Rosen[1], Sagnik Das[1], Jayanta Ghosh[1], Hendrike Braun[1], Daniel Reich[2], Arne Senftleben[1], and Thomas Baumert[1] — [1]Institut für Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany. — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany.

We studied the dependence of photoelectron circular dichroism (PECD) of fenchone on the duration of ionizing laser pulses from 30 fs to 5 ns. The laser pulses were centered at 380 nm to induce 2+1 resonant-enhanced multiphoton ionization of fenchone via 3s and 3p intermediate states. The photoelectrons from each intermediate state were distinguished by their different kinetic energies. As the pulse duration increases, the effect of relaxation dynamics was observed as a change in the ratio of photoelectron contributions from the 3s and the 3p intermediate states. The PECD measured via the 3s intermediate resonance was about 15 % and robust despite ongoing molecular dynamics such as rotation, vibration, and internal conversion. We simulated the observed relaxation dynamics using a simplified model system and estimated the lifetimes of the intermediate states.

MO 9.3 Wed 15:15 F102

Influence of laser properties on the high-order harmonic generation process in benzene — •Samuel Schöpa and Dieter Bauer — Institute of Physics, University of Rostock, Rostock, Germany

We solve the Schrödinger equation for benzene by expanding the wave function in a linear combination of ground-state Kohn-Sham orbitals. Those have been calculated previously via ground-state density functional theory. This method is orders of magnitude faster than comparable full time-dependent density functional theory simulations but neglects the update of the Hartree-exchange-correlation potential during time evolution. The selection rules stemming from the 6-fold symmetry of the benzene molecule as well as the opposite polarization of each harmonic couple are observed for a laser field at normal incidence that is circularly polarized in the molecular plane. We investigate how ellipticity and angle of incidence of the laser influence the spectrum. The selection rules are broken already for small deviations from normal incidence.

MO 9.4 Wed 15:30 F102

Nondipole time delay and double-slit interference in tunneling ionization — •Peilun He, Karen Hatsagortsyan, and Christoph Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

The photon takes zeptoseconds time to travel through the bond length of a molecule, which results in the fringe shift of the photoelectron momentum distribution. We investigate the possibility of decoding this nondipole time delay signal in tunneling ionization. With the newly developed Coulomb-corrected nondipole molecular strong-field approximation [PRL **128**, 183201 (2022)], we derive and analyze the photoelectron momentum distribution, the signature of nondipole effects, and the role of the degeneracy of the molecular orbitals. We show that the ejected electron momentum shifts and interference fringes efficiently imprint both the molecule structure and laser parameters. The corresponding nondipole time delay value significantly deviates from that in single-photon ionization. In particular, when the two-center interference in the molecule is destructive, the time delay is independent of the bond length. We also identify the double-slit interference in tunneling ionization of atoms with nonzero angular momentum via a nondipole momentum shift.

MO 9.5 Wed 15:45 F102

Strong coupling to a phonon bath enhances adiabatic population transfer — •Frank Grossmann and Michael Werther — Technische Universität Dresden, Institut für Theoretische Physik, 01062 Dresden

We present a study on the influence of an environmental heat bath on the rapid adiabatic passage scheme for optimal population transfer in a two-level system, originally invented in nuclear magnetic resonance [1].

To cope with strong coupling to an external phonon bath with superohmic spectral density, we are solving the time-dependent Schrödinger equation of the extended system, including a carefully chosen finite number of bath modes, using the multi-Davydov D2-Ansatz [2], which will be briefly reviewed. This Ansatz allows for the treatment of the non-Markovian reduced dynamics of the two-level subsystem. We find that strong system-bath coupling stabilizes the transition probability from the lower to the upper level as a function of the area under the laser pulse. This dissipative engineering effect could only be uncovered by a non-Markovian treatment. For strong coupling, the transition probability then becomes a monotonically increasing function of the pulse area at zero temperature of the heat bath. Finite temperatures break the monotonicity in the range of pulse areas that we studied but not the stability of the observed effect.

[1] M. Werther and F. Grossmann, Phys. Rev. A 102, 063710 (2020)
[2] M. Werther and F. Grossmann, Phys. Rev. B 101, 174315 (2020)

MO 9.6 Wed 16:00 F102

Optimization of selective two-photon absorption in cavity polaritons — •Edoardo Carnio[1,2], Andreas Buchleitner[1,2], and Frank Schlawin[3,4,5] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Luruper Chaussee 149, D-22761 Hamburg, Germany — [4]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany — [5]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

We investigate optimal states of photon pairs to excite a target transition in a multilevel quantum system. From the optimal control theory of entangled two-photon absorption we infer the maximal population achievable by optimal entangled vs. separable states of light. Interference between excitation pathways, as well as the presence of nearby states, may hamper the selective excitation of a particular target state, but we show that quantum correlations can help overcome this problem, and enhance the achievable "selectivity" between two target energy levels, i.e. the relative difference in population transferred into each of them.

[1] E. G. Carnio, A. Buchleitner, F. Schlawin, J. Chem. Phys. 154, 214114 (2021).

MO 9.7 Wed 16:15 F102

Quantized fields for optimal control in the strong coupling regime — •Frieder Lindel[1], Edoardo Carnio[1], Stefan Yoshi Buhmann[2], and Andreas Buchleitner[1] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany

The control of quantum systems lies at the core of many quantum technologies. In the field of coherent control, classical fields coherently drive the quantum system from a given initial state into a target state. Exploiting the quantum nature of the field to improve these control protocols has so far been mostly limited to the weak coupling regime. Here we will discuss how the quantum statistics of a bosonic field can be optimally tailored in order to drive a weakly or (ultra-)strongly coupled quantum system, such as an atom or a molecule in a cavity, towards a desired target state. This extends optimal control theory to control and target systems that are both quantized and strongly coupled.

MO 10: Collisions (joint session MO/Q)

Time: Wednesday 14:30–16:15 Location: F142

MO 10.1 Wed 14:30 F142

Gas phase investigations on dynamics of the reaction of tantalum cation Ta^+ with carbon dioxide CO_2 — •Marcel Meta[1], Maximilian Huber[1], Maurice Birk[1], Atilay Ayasli[2], Tim Michaelsen[2], Roland Wester[2], and Jennifer Meyer[1] — [1]RPTU Kaiserslautern-Landau, Fachbereich Chemie, Kaiserslautern, Germany — [2]Universität Innsbruck, Institut für Ionenphysik und Angewandte Physik, Innsbruck, Austria

The dynamics of the *oxygen atom transfer* (OAT) reaction $Ta^+ + CO_2 \rightarrow TaO^+ + CO$ in gas phase could be investigated under single collision conditions. The measured energy and angle differential cross sections allow us to probe the rearrangement of atoms during reaction, i.e. the atomistic dynamics [1]. The preset results were measured with our new 3D velocity map imaging setup in Kaiserslautern. The reaction is exothermic and spin forbidden in the ground state but takes place due to an efficient crossing from the quintet surface over to the triplet surface. Hence, it was found that the reaction almost proceeds with collision rate at room temperature [2-4]. The TaO^+ velocity map images shows dominant indirect dynamics even at high collision energies with most of the additional collision energy partitioned into internal excitation.

[1] J. Meyer, R. Wester, Annu. Rev. Phys. Chem. 2017, 68, 333; [2] R. Wesendrup, H. Schwarz, Angew. Chem. Int. Ed. 1995, 34, 2033; [3] G. K. Koyanagi, D. K. Bohme, J. Phys. Chem. A 2006, 110, 1232; [4] N. Levin, J. T. Margraf, J. Lengyel, K. Reuter, M. Tschurl, U. Heiz, Phys. Chem. Chem. Phys. 2022, 24, 2623

MO 10.2 Wed 14:45 F142

Dissociative recombination of ArH^+ at the Cryogenic Storage Ring — •Ábel Kálosi[1,2], Manfred Grieser[2], Leonard W. Isberner[3,2], Daniel Paul[1,2], Daniel W. Savin[1], Stefan Schippers[3], Viviane C. Schmidt[2], Andreas Wolf[2], and Oldřich Novotný[2] — [1]Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany

ArH^+ is an important probe of the cosmic ray flux in interstellar space. Cosmic rays are the dominant ionization source for H and H_2 in the cold interstellar medium (ISM). This ionization initiates astrochemistry in the cold phases of the ISM. The cosmic ray ionization rate (CRIR) is thus an important parameter for both chemical and dynamical models of the ISM. ArH^+ forms via cosmic ray ionization of Ar, but can be destroyed via dissociative recombination (DR) with free electrons. Astronomical observations of ArH^+, combined with chemical models, enable one to quantitatively estimate the CRIR. Such models require reliable rate coefficients that take into account the low internal excitation of the ArH^+, as occurs in the cold ISM. To this end, we have performed merged-beams DR experiments with ArH^+ in the Cryogenic Storage Ring where, at an ambient temperature of ~ 10 K, the ions relaxed to their lowest rotational states.

MO 10.3 Wed 15:00 F142

Laser induced forced evaporative cooling of molecular anions — •Eric Endres[1], Jonas Tauch[2], Saba Hassan[2], Markus Nötzold[1], Roland Wester[1], and Matthias Weidemüller[2] — [1]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria — [2]Physikalisches Institut, Universität Heidelberg, Germany

Cooling molecular anions is key for the production of cold antihydrogen and the creation of anionic coulomb crystals and would open up new fundamental research areas in modern physics and chemistry. An established technique to store and cool anions are collisions with buffer gas in multipole radio frequency ion traps. However, the temperature is limited by the temperature of the used cryogenic cooling medium.

In this contribution we present forced evaporative cooling down to 2.2(8) K by means of photodetachment of an anionic OH^- ensemble, confined in a multipole wire trap. [1] This enables a phase space density approaching the near-strong Coulomb coupling regime. The anion cooling dynamics are described by a quantitative analysis of the experimental results with a full thermodynamic model [2] without any fitting parameters. In principle, this technique can be used for cooling basically any anionic species below the temperature of liquid helium.

[1] J. Tauch, et al. arXiv preprint arXiv:2211.11264 (2022).
[2] A. Crubellier. J. Phys. B, 23(20), 3585 (1990).

MO 10.4 Wed 15:15 F142

Product spin and binding energy propensities for three-body recombination of ultracold atoms — •Jinglun Li[1], Shinsuke Haze[1], José P. D'Incao[1,2], Dominik Dorer[1], Markus Deiss[1], Eberhard Tiemann[3], Paul S. Julienne[4], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie, Universität Ulm, Germany — [2]JILA, University of Colorado, USA — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [4]JQI, University of Maryland, USA

Three-body recombination (TBR) is an elementary chemical reaction process, in which free atoms collide to form a molecule and release the binding energy E_b into the translational movement of the molecule and the third atom. Knowing favored molecular products in TBR is crucial for various fields such as astrophysics, atmospheric physics, and physical chemistry. In recent years we have been working experimentally and theoretically on TBR of ultracold atoms and have achieved great progress in identifying the molecular product distribution on a full quantum state resolution level. In particular, for ultracold Rb atoms we find that TBR intends to produce a molecule preserving the initial spins of two atoms that form it and that the state-to-state reaction rate follows roughly a power-law scaling $L_3 \propto 1/E_b$. Our numerical simulations predict that the $1/E_b$ propensity even holds, with a different prefactor, for two specific groups of molecular products disfavored by the spin propensity. We further elaborate a more comprehensive theoretical investigation on different alkali-metal species to explore the modifications and breakdowns of these propensities.

MO 10.5 Wed 15:30 F142

Two-photon optical shielding of collisions between ultracold polar molecules. — •Charbel Karam[1], Mara Meyer zum Alten Borgloh[3], Romain Vexiau[1], Maxence Lepers[2], Silke Ospelkaus[3], Nadia Bouloufa-Maafa[1], Leon Karpa[3], and Olivier Dulieu[1] — [1]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, Orsay 91400, France — [2]Laboratoire interdisciplinaire Carnot de Bourgogne, Cedex F-21075 Dijon, France — [3]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

We propose a method to engineer repulsive long-range interactions between ultracold ground-state molecules using optical fields, thus preventing short-range collisional losses. It maps the microwave coupling recently used for collisional shielding onto a two-photon transition, and takes advantage of optical control techniques. In contrast to one-photon optical shielding [Phys. Rev. Lett. 125, 153202 (2020)], this scheme avoids heating of the molecular gas due to photon scattering. The proposed protocol, exemplified for 23Na39K, should be applicable to a large class of polar diatomic molecules.

MO 10.6 Wed 15:45 F142

Light controlled engineering of long-range molecular states — •Patrick Mischke, Jana Bender, Tanita Klas, Florian Binoth, Thomas Niederprüm, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We experimentally engineer the deformation of the 5S-6P potential of Rubidium atoms at large interatomic distances on the order of several hundred Bohr radii. This deformation leads to a potential shape that supports bound molecular states.

To achieve this, we couple off-resonantly to an ultra-long range Rydberg molecule potential using strong laser driving. Properties that are commonly associated with Rydberg molecules, usually formed by an Rydberg atom and a ground state atom, are optically admixed to the 5S-6P pair state.

We spectroscopically observe the photoassociated 5S-6P molecules. The change in binding energy for different experimental coupling parameters is in qualitative agreement with a simple theoretical model.

MO 10.7 Wed 16:00 F142

Electric-field-controlled dipolar collisions between trapped polyatomic molecules — •Florian Jung, Manuel Koller, Jindaratsamee Phrompao, Martin Zeppenfeld, Isabel M. Rabey, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Polar symmetric top molecules exhibit a permanent electric dipole moment which creates strong anisotropic interactions, and allows them to be manipulated with moderate electric fields. This, together with their multitude of internal states, renders them promising for applications in e.g. quantum information processing or cold chemistry. For these applications reaching high-density low-temperature ensembles is imperative. This requires the capability to control collisional losses, which is a challenging task.

By combining a cryogenic buffer-gas cell with a centrifuge decelerator and an electrostatic trap, we can now confine up to 2×10^7 CH_3F molecules at a temperature of ~ 350 mK for several seconds, achieving densities of up to $10^7/cm^3$, which allows for the observation of collisions [1]. We employ a homogeneous control field, covering a large fraction of our trap to mitigate collisional losses and obtain inelastic loss coefficients below $4 \times 10^{-8} cm^3/s$. An ab-initio theory shows excellent agreement with our experiment and highlights dipolar relaxation as the major loss mechanism. These findings are immediately relevant for cold molecular collision studies and an important step towards the observation of re-thermalisation between polyatomic molecules.

[1] M. Koller *et al.*, Phys. Rev. Lett. **128**, 203401 (2022).

MO 11: Quantum Technologies (joint session Q/MO/QI)

Time: Wednesday 14:30–16:30 Location: E214

Invited Talk MO 11.1 Wed 14:30 E214

BMBF-Förderprogramm: Wissenschaftliche Vorprojekte — •Bernhard Ihrig und Johannes Mund — VDI Technologiezentrum GmbH

Die zweite Quantenrevolution und die schnell voranschreitenden Entwicklungen in der Photonik bieten großes Potenzial für Anwendungen in Ökonomie, Ökologie und Gesellschaft. Zugleich sind neue Erkenntnisse aus der Grundlagenforschung in einem frühen Stadium hinsichtlich der Herausforderungen und Risiken bei der Umsetzung oftmals kaum zu beurteilen. Daher müssen wissenschaftlich-technische Vorarbeiten eine Grundlage schaffen, die es ermöglicht, das Potenzial einer neuen Erfindung bzw. der neuen wissenschaftlichen Erkenntnis zu bewerten.

Das Bundesministerium für Bildung und Forschung (BMBF) beabsichtigt daher, sogenannte Wissenschaftliche Vorprojekte (WiVoPro) im Bereich der Photonik und der Quantentechnologien auf Grundlage des Forschungsprogramms Quantensysteme zu fördern. Das Ziel dieser Vorprojekte besteht darin, wissenschaftliche Fragestellungen im Hinblick auf zukünftige industrielle Anwendungen in den Quantentechnologien und der Photonik zu untersuchen. Sie sollen die bestehende Forschungsförderung ergänzen und eine Brücke zwischen Grundlagenforschung und industriegeführter Verbundförderung schlagen.

Wir als Projektträger VDI Technologiezentrum GmbH möchten die Maßnahme in diesem Rahmen vorstellen, bewerben und Ihre Fragen für eine mögliche Förderung beantworten.

MO 11.2 Wed 15:00 E214

Mikrofabrikation von Ionenfallen für einen skalierbaren Quantencomputer — •Eike Iseke[1,2], Friederike Giebel[1,2], Nila Krishnakumar[1,2], Konstantin Thronberens[1,2], Jacob Stupp[1,2], Amado Bautista-Salvador[1,2] und Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Hannover, Deutschlad — [2]Physikalisch Technische Bundesanstalt, Braunschweig, Deutschland

Die Ionenfallentechnologie ist eine vielversprechende Option auf dem Weg zur Entwicklung eines skalierbaren Quantencomputers. Eine mögliche Realisierung stellt die Multilagen-Ionenfalle dar [1]. Durch multiple Lagen wird die Integrationsdichte entscheidend erhöht und es können neuartige Ionenfallendesigns realisiert werden.

Die zunehmende Komplexität der Fallen stellt neue Anforderungen an die Mikrofabrikationsmethoden. Forschung und Entwicklung in diesem Feld fokussieren sich unter anderem auf die Interposer-Technologie, das Thermokompressionsbonden und die Substratdurchkontaktierung mittels TSVs (through silicon vias).

Diese fortschrittlichen Fabrikationsmethoden ermöglichen die Skalierung der Plattform sowohl durch die Möglichkeit die Anzahl der geführten Signale zu erhöhen, als auch durch die gesteigerte Zuverlässigkeit der Verbindungstechnologie.

MO 11.3 Wed 15:15 E214

Squeezed States of Light for Future Gravitational Wave Detectors at a Wavelength of 1550 nm — •Fabian Meylahn[1,2], Benno Willke[1,2], and Henning Vahlbruch[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany

The generation of strongly squeezed vacuum states of light is a key technology for future ground-based gravitational wave detectors (GWDs) to reach sensitivities beyond their quantum noise limit. For some proposed observatory designs, an operating laser wavelength of 1550 nm or around 2 μm is required to enable the use of cryogenically cooled silicon test masses for thermal noise reduction. Here, we present the first the direct measurement of up to 11.5 dB squeezing at 1550 nm over the complete detection bandwidth of future ground-based GWDs ranging from 10 kHz down to below 1 Hz. Furthermore, we directly observe a quantum shot-noise reduction of up to 13.5 dB at megahertz frequencies. This allows us to derive a precise constraint on the absolute quantum efficiency of the photodiode used for balanced homodyne detection. These results hold important insight regarding the quantum noise reduction efficiency in future GWDs, as well as for quantum information and cryptography, where low decoherence of nonclassical states of light is also of high relevance.

MO 11.4 Wed 15:30 E214

A single-photon source based on hot Rydberg atoms — •Jan Reuter[1,2], Max Mäusezahl[3], Felix Moumtsilis[3], Tilman Pfau[3], Tommaso Calarco[1,2], Robert Löw[3], and Matthias Müller[1] — [1]Forschungszentrum Jülich GmbH — [2]Universität zu Köln — [3]Universität Stuttgart

The leading effects of a single-photon source based on Rydberg atoms are the strong van-der-Waals interaction between the atoms as well as the collective decay of the atom ensemble. Our setup is a vapor cell filled with Rubidium atoms which we excite via three different laser pulses. The decay of this excitation will then lead to the emission of a single photon. To ensure robustness, we investigated the behavior of moving Rydberg atoms and optimized the laser pulse sequence. For that, we simulated the transitions of Rubidium atoms from the ground state over the Rydberg state up to the singly-excited collective states. We can show that the collective decay of the single excitations leads to a fast and directed photon emission, while double excitations show no or only weak collective properties.

MO 11.5 Wed 15:45 E214

Resolving photon numbers using ultra-high-resolution timing single-channel electronic readout of a conventional superconducting nanowire single photon detector — •Gregor Sauer[1,2], Mirco Kolarczik[3], Rodrigo Gomez[1,2], Helmut Fedder[3], and Fabian Steinlechner[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [3]Swabian Instruments GmbH, 70435 Stuttgart, Germany

Photon-number-resolving (PNR) detectors are indispensable building blocks for applications in quantum communications, computing, and sensing. PNR is commonly achieved by multiplexing onto several superconducting nanowire single-photon detectors (SNSPD) or using transition-edge sensors with energy- and photon-number resolution. This comes at the cost of resource overhead (for multiplexing) or long recovery times (for transition-edge sensors).

Here, we show how ultra-high-resolution timing measurements of the rising and falling edge of electrical pulses generated from the SNSPDs enable to distinguish photon numbers of up to 5 in a single-shot measurement. This provides a practical and comparably low-cost PNR detector, offering high detection efficiency and operational repetition rate. We present the implementation of such a PNR detector system (in the telecom C-band) and its characterization by measuring the photon-number statistics of a 300fs-pulsed coherent input source with tunable average photon number and repetition rate.

MO 11.6 Wed 16:00 E214

N00N-states for super-resolving quantum imaging and sensing — •Gil Zimmermann[1] and Fabian Steinlechner[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany

Quantum measurement techniques can serve to improve precision imaging and sensing through entanglement. Employing N00N-states, i.e., maximally path-entangled photon-number states of two modes, the Heisenberg limit 1/N with N photons can be reached in precision phase measurements, thus overcoming the shot-noise limit. Furthermore, the Rayleigh diffraction limit can be overcome by a factor N. Therefore, the goal is to efficiently generate high N00N-states with N>2 to improve current sensing schemes achieving super-resolution and super-sensitivity. High-N00N states with N=5 photons have already been generated experimentally with high fidelity, as shown by Afek et al. This talk will focus on schemes with relatively low complexity to generate high N00N-states. In addition, applications of high-N00N states, e.g., in the context of quantum-enhanced lidar systems or quantum microscopy, are discussed, taking into account their high fragility due to interactions with the environment.

MO 11.7 Wed 16:15 E214

Non-destructive measurement of phonon number states using the Autler-Townes effect — •Marion Mallweger[1], Murilo de Oliveira[2], Robin Thomm[1], Harry Parke[1], Natalia Kuk[1], Gerard Higgins[1,3], Romain Bachelard[2,4], Celso Villas-Boas[2], and Markus Hennrich[1] — [1]Department of Physics, Stockholm University, Sweden — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil — [3]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Sweden — [4]Université Côte d'Azur, CNRS, Institut de Physique de Nice, France

Quantum technologies employing trapped ion qubits are currently some of the most advanced systems with regards to experimental methods in quantum computation, simulation and metrology. This is primarily due to the excellent control available over the ions' motional and electronic states. In this work we present a new method to measure the distribution of motional number states in a non-destructive manner. The technique can be applied to all platforms where a quantum harmonic oscillator is coupled to a three level system. We demonstrate the technique using a single trapped $^{88}Sr^+$ ion. The method relies on the Autler-Townes effect that arises when two levels are strongly coupled while being probed by a third level. If the two levels are coupled on a sideband transition, then the magnitude of the Autler-Townes splitting depends on the phonon number state. This new method provides a robust and efficient way of measuring motional states of quantum harmonic oscillators. It can even be applied to perform single shot measurements of phonon number states in a non-destructive way.

MO 12: Interaction with Strong or Short Laser Pulses II (joint session A/MO)

Time: Wednesday 14:30–16:15 Location: F107

See A 17 for details of this session.

MO 13: Poster II

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

MO 13.1 Wed 16:30 Empore Lichthof

Towards the production of groundstate RbYb — •Christian Sillus, Bastian Pollklesener, Arne Kallweit, Céline Castor, and Axel Görlitz — Heinrich-Heine Universität

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information. Here we report on first experiments in our apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively [1,2]. In the new setup a major goal is the efficient production of ground state RbYb molecules. We employ optical tweezers to transport individually cooled samples of Rb and Yb from their separate production chambers to a dedicated science chamber. Here we start to study interspecies interactions of different isotopes by overlapping crossed optical dipole traps. To explore the pathways towards ground state molecules we start with photoassociation spectroscopy near the intercombination line of Yb.

[1] M. Borkowski et al., PRA 88, 052708 (2013)
[2] C. Bruni et al., PRA 94, 022503 (2016)

MO 13.2 Wed 16:30 Empore Lichthof

Merged-beams experiments on molecular ion-neutral reactions for astrochemistry — •Pierre-Michel Hillenbrand[1], Xavier Urbain[2], and Daniel Wolf Savin[3] — [1]Justus-Liebig Universität, Giessen, Germany — [2]Université catholique de Louvain, Louvain-la-Neuve, Belgium — [3]Columbia University, New York, USA

The gas-phase formation of complex molecules in the interstellar medium proceeds dominantly through barrierless ion-neutral reactions at typical temperatures of 10 − 100 K. Our merged-beams apparatus at Columbia University in New York City enables us to measure energy-dependent absolute cross sections of molecular formation processes for reactions of singly-charged molecules with neutral atoms and derive temperature-dependent thermal rate coefficients for individual product channels. Focusing on key reactions implemented in astrochemical models as well as on systems of fundamental interest, we have recently studied the reactions

$D + H_3^+ \rightarrow H_2D^+ + H$ [1],
$D + H_2D^+ \rightarrow D_2H^+ + H$ and $D + D_2H^+ \rightarrow D_3^+ + H$ [2],
$C + H_2^+ \rightarrow CH^+ + H$ and $C + D_2^+ \rightarrow CD^+ + D$ [3],
$O + H_3^+ \rightarrow OH^+ + H_2$ and $O + H_3^+ \rightarrow H_2O^+ + H$ [4].

For example, the branching ratio for the two product channels of the $O + H_3^+$ reaction is relevant for accurately modeling the gas-phase formation of water in the diffuse and dense molecular clouds.

[1] Astrophys. J. **877**, 38 (2019). [2] J. Chem. Phys. **154**, 084307 (2021). [3] Phys. Chem. Chem. Phys. **22**, 27364 (2020). [4] Astrophys. J., **927**, 47 (2022).

MO 13.3 Wed 16:30 Empore Lichthof

UV Photoexcitation-Photoemission Map of the Hydrogen Molecule — •Gabriel Klassen[1], Andreas Hans[1], Philipp Schmidt[2], Catmarna Küster-Wetekam[1], Johannes Viehmann[1], and Arno Ehresmann[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]European XFEL, Holzkoppel 4, 22869 Schenefeld, Germany

The hydrogen molecule, the simplest molecule we know, has been studied extensively in the past. Although most of the details of its electronic potentials are well understood, there is no complete set of experimentally determined absolute data with quantitative absorption and dispersed emission cross sections. These cross sections, however, are necessary to interpret spectra of gaseous clouds in space, where H2 may be used as a probe molecule, once its cross sections are known.

On the road towards such a full data set for the hydrogen molecule we are performing experiments where H2 is excited by small-bandwidth monochromatized synchrotron radiation and its emission is recorded dispersedly with high resolution. By scanning synchrotron radiation over parts of the UV spectrum and measuring the consecutive fluorescence we are able to construct a 2d-map with distinct features being representative for the H2 rovibronic structure.

MO 13.4 Wed 16:30 Empore Lichthof

Ultrafast spectroscopy of intramolecular dynamics and photodissociation of a single trapped molecular ion — •Zhenlin Wu, Brandon Furey, Stefan Walser, Guanqun Mu, René Nardi, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria

Trapped atomic ions are one of the most promising platforms for quantum simulation and quantum computation. By co-trapping molecular ions with atomic ions, quantum logic spectroscopy can be performed to investigate the rovibrational structure of various molecular species, as demonstrated recently with diatomic molecular ions including CaH^+ and N_2^+. In a similar system, we plan to explore ultrafast intramolecular dynamics in complicated polyatomic molecular ions with femtosecond laser pulses. In particular, we will measure the net momentum transfer of the pump and the delayed probe pulse. Such momentum change can be detected by preparing the common motion of the ion crystal in a non-classical state. With this scheme, we aim to study the evolution of vibrational excitations inside a single polyatomic molecule of chemical or biological importance.

We are currently investigating the interaction between ultrafast laser pulses and molecular ions by measuring the photodissociation threshold of $CaOH^+$. The molecules are generated by chemical interactions between trapped Ca^+ ions and water molecules that can be introduced with a gate valve into the main experimental chamber. After the reaction, a Ca^+ ion turns “dark” and femtosecond laser pulses with variable wavelength are applied to dissociate it back to a “bright” Ca^+ ion.

MO 13.5 Wed 16:30 Empore Lichthof

Spectroscopic and collision studies of the laser-cooling candidate C_2^- — •Christine Maria Lochmann, Markus Nötzold, Sruthi Purushu Melath, Robert Wild, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria

The precise control of the external and internal motion of negative ions has been of increasing interest in the past decades. One possible method to reach this control is through laser cooling, which has never been achieved for a negatively charged particle, as only a few anions provide the strongly bound electronic excited and adequate internal energy states suitable for laser cooling schemes. One such candidate is the molecular carbon anion C_2^-. Here, we present our studies on the spectroscopy of C_2^- carried out in a cryogenic 16-pole RF wire trap at 6 K to determine precise laser cooling transition frequencies. We are able to resolve the spin-rotation splitting in C_2^- with an accuracy of 20 MHz and determine the rotational and translational temperature of the ions [1]. A useful method to repopulate the ground state of the molecule could be through vibrational quenching. We studied the quenching rate into the vibrational ground state of C_2^- in cold collisions with H_2. At high H_2 densities the collision also leads to a three-body reaction which forms C_2H^-. We measured the temperature dependent three-body rate between 10 K and 28 K to benchmark quantum calculations.

[1] M. Nötzold et al., Phys. Rev. A 106, 023111 (2022)

MO 13.6 Wed 16:30 Empore Lichthof

State-to-state ion-molecule reaction dynamics — •Tim Michaelsen, Dasarath Swaraj, Arnab Khan, Robert Wild, and Roland Wester — Institut f. Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstraße 25/3 A-6020 Innsbruck, Austria

The study of reaction dynamics aims to gain a mechanistic understanding how chemical reactions occur on an atomistic level. The combination of crossed beam experiments with velocity map imaging [VMI], especially in comparison with trajectory calculations, are a powerful tool to observe these dynamics [1]. Product state detection for ion-molecule reactions were limited by energy resolution, at least for non di-atomic products [2].

Here we present a new setup, that aims push the required resolution towards product vibrational state detection in larger systems, which combined with prepared ground state reactants prior to the reactive collision, will let us obtain state-to-state differential cross sections. This is achieved by a newly designed laser-ionization source for H_2^+ and implementation of a Rydberg-tagging scheme to detect neutral hydrogen atom products in coincidence [3]. First reactions of interest are H_2^+ + Ne and H_2, where little is known experimentally about the energy partitioning and dynamics.

[1] J. Meyer, E. Carrascosa, et al. Nat. Chem. 13, 977-981 (2021)
[2] T. Michaelsen, et al., J. Chem. Phys. 147, 013940 (2017)
[3] M. Qiu, et al., Science 311 5766, 1440-1443 (2006)

MO 13.7 Wed 16:30 Empore Lichthof

Towards state-to-state ion-molecule reaction dynamics — •Tim Michaelsen, Dasarath Swaraj, Florian Trummer, Arnab Khan, Robert Wild, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Technikerstraße 25/3, A-6020 Innsbruck, Austria

The study of reaction dynamics aims to gain an understanding how chemical reactions occur on an atomistic level. Experiments combining crossed beams with velocity map imaging [VMI] are a powerful tool to observe these dynamics [1]. In the past product state detection for ion-molecule reactions was limited by energy resolution, at least for non-diatomic products [2].

Here we present a new setup, that aims to push the required resolution towards product vibrational state detection in larger systems, which combined with prepared ground state reactants prior to the reactive collision, will let us obtain state-to-state differential cross sections. This is achieved by a newly designed laser-ionization source for H_2^+ and implementation of a Rydberg-tagging scheme to detect neutral hydrogen atom products in coincidence [3]. First reactions of interest are H_2^+ + Ne and H_2, where interesting quantum dynamics have been predicted and little is known experimentally about the energy partitioning.

[1] J. Meyer, E. Carrascosa, et al. Nat. Chem. 13, 977-981 (2021)
[2] T. Michaelsen, et al., J. Chem. Phys. 147, 013940 (2017)
[3] M. Qiu, et al., Science 311 5766, 1440-1443 (2006)

MO 13.8 Wed 16:30 Empore Lichthof

Development of a Cryogenic Beam Source for Cold Calcium Monofluoride Molecules — •Phillip Gross, Ole Prochnow, Alexandra Köpf, and Tim Langen — 5. Physikalisches Institut, Universität Stuttgart

The production of ultracold molecular quantum gases promises to add long-range dipolar interactions to the quantum simulation toolbox. Here we first show theoretically that such dipolar interactions can lead to the formation of new phases of matter in bulk molecular Bose-Einstein condensates, such as droplet states and supersolids. Second, we present a new setup to realize these phases of matter in an experiment. In this setup we work with calcium monofluoride molecules, which are characterized by large electric dipole moments and well-established laser cooling strategies. In a first step to create a gas of these molecules with high phase space density, we present the design of a cryogenic buffer gas beam source, as well as extensive simulations of transversal and longitudinal laser cooling of the resulting molecular beam.

MO 13.9 Wed 16:30 Empore Lichthof

Imaging Photoelectron Circular Dichroism in Mass-Selected Chiral Anions — •Viktoria Katharina Brandt, Jenny Triptow, André Fielicke, Gerard Meijer, and Mallory Green — Molecular Physics Department of the Fritz Haber Insitute of the Max Planck Society

Photoelectron Circular Dichroism (PECD) is a chiral effect that manifests in the angle-dependent photoemission of an electron upon irradiation of a chiral molecule by circularly polarized light. The use of anions in this technique allows for mass-selectivity and eliminates the need for X-ray based ionization sources, thus leading to a potentially robust analytical tool for chiral discrimination of multicomponent gas-phase samples. PECD spectroscopy of neutral chiral species has flourished over the past decades. A PECD effect in anions, however, has only been observed recently. By coupling pre-photodetachment mass selection, tuneable detachment, and velocity-map imaging anion photoelectron spectroscopy, we provide an energy-resolved PECD signal for mass-selected anions. We have recently demonstrated this successfully in the study of the deprotonated 1-indanol anion, where we observed a PECD effect for several detachment channels and a maximum PECD effect of 11%. Current aims of the project are focused on improving the resolution for spectroscopic PECD measurements. Such improvements will pave a way to an understanding of the underlying cause in the difference in electron scattering dynamics of neutral and charged molecules, as well as work towards a robust analytical method for the chiral analysis of dilute, but complex, chemical samples.

MO 13.10 Wed 16:30 Empore Lichthof

Implementation of time-correlated single photon counting for studying photo-activated processes in aggregates of organic molecules attached to rare gas clusters — •Aleksandr Demianenko, Moritz Michelbach, Sebastian Hartweg, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Collective effects in organic semiconductors affect excited state lifetimes, important for organic optoelectronic and photovoltaic applications. Previous studies addressed radiative and non-radiative decay mechanisms of the processes connected to the collective effects in aggregates of polyacenes attached to the surface of solid Ne and Ar clusters. Fluorescence quantum yield and excited singlet state's lifetime decreased upon increasing sample molecules surface density [1,2]. The limited temporal resolution of a few ns, due to the ns-laser excitation and PMT detection, made disambiguation of different contributions to the lifetime reduction challenging.

This project is aimed at enhancing the temporal resolution of fluorescence measurements by implementing time correlated single photon counting. This technique allows us to cover the sub-ns lifetime region currently not achievable in our cluster doping apparatus. We present the current status of the ongoing upgrade of our setup and discuss advantages and implementation challenges.

[1] M. Bohlen et al. J. Chem. Phys. 156, 034305 (2022).
[2] S. Izadnia et al. J. Phys. Chem. Lett. 8, 2068 (2017).

MO 13.11 Wed 16:30 Empore Lichthof

Learning potential energy surfaces for collisions of H2+ molecules and rare gas atoms — •Karl P. Horn[1], Luis Itza Vazquez-Salazar[2], Christiane P. Koch[1], and Markus Meuwly[2] — [1]Theoretische Physik, Freie Universität Berlin, Germany — [2]Department of Chemistry, Universität Basel, Switzerland

The latest developments in experimental techniques and coupled channel calculations have lead to measurements and theoretical simulations of ever increasing accuracy, such as in the case of Helium/Neon and H2 cold collisions. The utilisation of methods such as multi-reference configuration interaction (MRCI) and full configuration interaction (FCI) ab-initio calculations has already resulted in potential energy surfaces(PESs) of very high quality [1]. Whilst experiment and theory already show good agreement using these existing potentials, high resolution measurements unlock the enticing possibility of exploiting experimental data for the purpose of improving existing PESs. In this work, we employ a closed loop parameter optimisation in order to morph [2] He-H2+ PESs determined at several levels of theory, including second order Moller Plesset, MRCI and FCI by minimising the difference between collision cross sections from quantum wavepacket simulations and experiment. This yields a collection of PESs all consistent with experimental observables within certain error bounds and provides insight into which regions of the PES are sampled and which require further probing by new experiments.

[1] Phys. Chem. Chem. Phys., 21, 24976-24983, 2019
[2] J. Chem. Phys., 110, 8338, 1999

MO 13.12 Wed 16:30 Empore Lichthof

Reactive Scattering of the oxygen atom transpher reaction between Carbondioxide and group V cations — •Maximilian Huber[1], Marcel Meta[1], Atilay Ayasli[2], Tim Michaelsen[2], Roland Wester[2], and Jennifer Meyer[1] — [1]RPTU Kaiserslautern-Landau Fachbereich Chemie, Kaiserslautern, Germany — [2]Universität Innsbruck Institut für Ionenphysik und angewandte Physik, Innsbruck, Austria

With our method we investigate the atomistic dynamics of elementary reactions like the oxygen atom transfer of CO_2 with transition metal cations under single collision conditions. We achieve this by recording energy and angle differential cross sections by means of product ion velocity distributions after a reactive collision. [1]

Here, we present our first results for the oxygen atom transfer reaction $Nb^+ + CO_2 \longrightarrow NbO^+ + CO$ measured with our 3D crossed beam velocitiy map imaging experiment. The reaction is exothermic by 1.68 eV and is spin forbidden in its electronic ground state. Nevertheless the reaction was found to have relativ high reaction efficiencies at room temperature. [2,3] We recorded energy dependent velocity map images of the Niobium reaction at different energies. Also, we compared these results to the reaction of the heavier homologue tantalum $Ta^+ + CO_2 \longrightarrow TaO^+ + CO$.

[1] J. Meyer, R. Wester, Annu. Rev. Phys. Chem. 2017, 68, 333. [2] M.R. Sievers, P.B. Armentrout, Int. J. Mass. Spec., 1998, 179/180, 103. [3] G. K. Koyanagi, D. K. Bohme, J. Phys. Chem. A 2006, 110, 1232.

MO 13.13 Wed 16:30 Empore Lichthof

Absorption spectroscopy and modeling laser cooling of barium monofluoride — •Felix Kogel, Marian Rockenhäuser, Einius Pultinevicius, and Tim Langen — 5. Physikalisches Institut, Universität Stuttgart

Cold molecular gases are the starting point for studies of cold chemistry, quantum simulation and precision measurements of fundamental physics. Here, we report on our effort towards direct laser cooling of BaF molecules. We perform high-resolution absorption spectroscopy to derive an improved set of molecular constants for the bosonic isotopologues ^{138}BaF and ^{136}BaF and use these constants to model laser cooling using simulations based on the optical Bloch equations. We find effective Doppler, sub-Doppler, and coherent cooling strategies for the bosonic, as well as for the fermionic BaF isotopologues. This provides important guidance for the corresponding experiments ongoing in our group, and paves the way for tests of fundamental symmetries using these molecules.

MO 13.14 Wed 16:30 Empore Lichthof

Readout techniques for the implementation of a trace-gas sensor for nitric oxide — •Maurice Schamber[1,4], Yannick Schellander[2,4], Fabian Munkes[1,4], Patrick Kaspar[1,4], Philipp Neufeld[1,4], Alexander Trachtmann[1,4], Marius Winter[2,4], Patrick Schalberger[2,4], Norbert Frühauf[2,4], Hassan Hayeri[3,4], Philipp Hengel[3,4], Lars Baumgärtner[3,4], Jens Anders[3,4], Robert Löw[1,4], Tilman Pfau[1,4], and Harald Kübler[1,4] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [3]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [4]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart

Two different readout techniques for nitric oxide spectroscopy are presented. The first approach is based on the detection of charged particles created by collisional ionization of Rydberg molecules in a low-pressure through-flow gas cell setup, whereas the second enables the detection of photons in the deep UV based on a-IGZO semiconductor technology. Both methods are presented within the scope of the development of a trace-gas sensor for nitric oxide.

MO 13.15 Wed 16:30 Empore Lichthof

Collisions in a quantum gas of bosonic ^{23}Na^{39}K molecules — •Mara Meyer zum Alten Borgloh[1], Philipp Gersema[1], Leon Karpa[1], Kai Konrad Voges[1], Jule Caroline Heier[1], Silke Ospelkaus-Schwarzer[1], Charbel Karam[2], and Olivier Dulieu[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton

We report about our experiments with quantum gases of polar ^{23}Na^{39}K molecules. We discuss both atom-molecule and molecule-molecule collisions including the origin of loss processes in a cloud of chemically stable ^{23}Na^{39}K molecules.

Furthermore, we discuss a method for suppressing molecular loss using two optical photons at Raman resonance, leading to a potential barrier that protects the colliding molecules from reaching the short range.

MO 13.16 Wed 16:30 Empore Lichthof

Surface charge removal by UV illumination in a microstructured electrostatic trap for cold molecule research — •Jindaratsamee Phrompao, Michael Ziemba, Yvan Briard, Florian Jung, Martin Zeppenfeld, Isabel Rabey, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Polar molecules are an excellent platform to conduct fascinating research ranging from cold chemistry to tests of fundamental physics. Precise determination of molecular constants is essential for these applications. Toward this end, long observation time [1] is beneficial, which can be achieved by trapping the cold molecules. In our experiment, we employ a microstructured electrostatic trap [2] to confine the molecules for several seconds. The trap potential is created by applying high voltages to the trap electrodes. This, however, induces surface charges that can broaden the electric-field distribution, which renders precise addressing and controlling of the trapped molecules difficult. Thus, surface charge removal is crucial to overcome these problems.

Here, we will highlight the working principles of the electrostatic trap. The characteristics of high-voltage-induced surface charge build up will be described. Furthermore, surface charge removal by UV illumination will be presented. We found that the surface charge removal efficiency depends on the applied UV intensity and wavelength in a nontrivial way.

[1] A. Prehn et al., Phys. Rev. Lett. 127, 173602 (2021).
[2] B.G.U. Englert et al., Phys. Rev. Lett. 107, 263003 (2011).

MO 13.17 Wed 16:30 Empore Lichthof

Challenges and solutions in dispersed fluorescence measurements and determining their absolute cross sections — •Robin Ise[1], Johannes Viehmann[1], Philipp Schmidt[2], Arne Schröder[1], Andreas Hans[1], and Arno Ehresmann[1] — [1]University of Kassel, Kassel, Germany — [2]European XFEL, Hamburg, Germany

Measurements of the absorption and emission of electromagnetic radiation have always been a key contribution to the understanding of the fundamental structure of atoms and molecules. While the experimental setup used for these measurements, called PIFS (**P**hoton **I**nduced **F**luorescence **S**pectroscopy) and developed by our group, has seen great success in the past, in obtaining large-scale emission maps of H_2 in the near to vacuum ultraviolet spectral range, the improvement of the experimental methods may allow to determine absolute cross sections of the measured process. This ongoing optimization process of the experimental setup shall be illustrated in this work, including the reconfiguration of the setup to accommodate for measurements in the magic angle and an improved method of acquiring absolute pressure data of the medium in question.

MO 13.18 Wed 16:30 Empore Lichthof

A Reaction Microscope for the Cryogenic Storage Ring CSR — •Felix Herrmann, David V. Chicharro, Robert Moshammer, Claus Dieter Schröter, and Thomas Pfeifer — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

For studying molecular break-up reactions on slow and cold molecular ions and clusters at the cryogenic storage ring CSR, we have designed a dedicated in-ring reaction microscope (ReMi). The ReMi is a combined electron and ion spectrometer for energy and angular resolved particle detection created in an elementary collision process. This spectrometer will deliver kinematically complete data on the reaction dynamics. The implementation into the storage ring of this first cryogenic ReMi worldwide started in May 2022. Its finalization is expected for spring 2023. Subsequently, first fundamental in-ring experiments, reactions like electron transfer, molecular break-up or proton transfer at room temperature conditions, followed by measurements at cryogenic conditions (< 10 K) in a future beamtime period are envisaged. The setup of the complex apparatus, in detail one of the MCP detectors with time and position sensitive delay-line readout along with the design adaptation for operation at cryogenic temperatures, the supersonic gas jet and laser incouplings, as well as first test measurements will be shown.

MO 13.19 Wed 16:30 Empore Lichthof

New apparatus for synchrotron-based photoelectron spectroscopy of cold and mass-selected ions in the gas phase — Stöcks Phillip, Bär Fabian, Weise Lukas, and •von Issendorff Bernd — Insitute of Physics at the University of Freiburg, Freiburg i.Br., Germany

We present the development and construction of a new apparatus for cluster research at the BESSY II synchrotron at the Helmholtz Centre in Berlin (HZB). A magnetron sputter source provides the clusters for the apparatus. The setup allows mass selection with a Quadrupole Mass Spectrometer (QMS) before the clusters are stored. The trap is a linear Radio Frequency (RF) trap. Photoelectrons are emitted through interaction with the synchrotron beam. These are forced out of the trap with a magnetic field using the principle of the magnetic bottle on parallel trajectories in one direction. In this way, sufficient intensities can be achieved. The photoelectrons then pass through a magnetic guiding field and experience a deflection from the synchrotron axis. Subsequently, the photoelectrons are directed and focused by electric ion optics so that the photoelectrons can be guided into the Hemispherical Spectrum Analyser (HSA) as magnetic field-free as possible. At the current state of the project we will especially focus on the simulated photoelectron paths guided and focused by our newly developed photoelectron extractor. Furthermore the detailed design of the whole experiment will be introduced.

MO 14: Ultrafast Dynamics II (joint session MO/A)

Time: Thursday 11:00–13:00 Location: F102

MO 14.1 Thu 11:00 F102

Isosteric molecules in the time-domain — •Maximilian Pollanka, Christian Schröder, and Reinhard Kienberger — Chair for Laser and X-ray Physics, E11, Technische Universität München, Germany

We report on photoemission timing measurements performed on isosteric molecules in the gas phase on attosecond timescales. Comparing the photoemission time delay between the respective σ and π orbitals in the inner and outer valence states of CO2 and N2O leads to a deeper insight into the characteristics of isosterism in the time-domain. Additionally, the isoelectronicity of CO and N2 is investigated in detail as a complementary study. Due to the similarities in molecular structure (isostericity) and electronic configurations (isoelectronicity) the pure effect of the specific molecular/orbital characteristics is expected to be probed. We are not only able to experimentally assess the relative photoemission delay between respective outer and inner valence states, but also performing absolute photoemission timing via attosecond streaking spectroscopy using iodomethane (I4d state) as a reference. The experimental data show great similar tendencies but also differences between the compared molecular orbitals, which are determined but not completely understood up to now. Therefore, further theoretical considerations and accurate modelling of the process of laser-dressed photoionization and the information encoded in photoemission timing measurements on molecular targets are necessary. This will help us gaining a greater understanding of the correlations between molecular geometry and photoemission time and therefore the isosteric influence.

MO 14.2 Thu 11:15 F102

RABBITT experiments in a vibrationally active ammonia molecule — •Lisa-Marie Koll[1], David Sorribes Ortiz[2], Ignacio Martínez Casasús[2], Tobias Witting[1], Lorenz Drescher[1,4], Oleg Kornilov[1], Marc JJ Vrakking[1], Fernando Martin[3], and Luis Bañares[2] — [1]Max Born Institute, Berlin — [2]Universidad Complutense de Madrid — [3]Universidad Autónoma de Madrid and IMDEA Nanociencia — [4]University of California, Berkeley

Many RABBITT (Reconstruction of Attosecond Beatings By Interferences of Two-photon Transitions) experiments have been carried out so far for (rare gas) atoms to disentangle the evolution of an electronic wave packet by measuring the photoemission time delays. In molecules, the experiments are more complicated due to the nuclear degrees of freedom. Previously, RABBITT experiments could resolve vibrations in the photoelectron spectrum of N2 [1], and N2O [2]. Here, we present RABBITT experiments on NH3 using the velocity map imaging (VMI) technique. NH3 belongs to the C3v symmetry group and, as a result of the photoionization process, symmetry is shifted to the D3h conformation in NH3+. The ionization of ammonia is accompanied by rich vibrational structure, such as the long vibrational progression in the v2 umbrella inversion mode of the X2A2 state. These RABBITT experiments present an interesting and challenging case for full-dymensional theoretical calculations and help to demonstrate the capability of the RABBITT method to study in depth vibronic dynamics in polyatomic molecules. [1] S. Haessler et al., Phys. Rev. A 80, 01140R (2009) [2] L. Cattaneo et al., Nature Phys. 14, 733 (2018)

MO 14.3 Thu 11:30 F102

Control of ion+photoelectron entanglement in an attosecond pump-probe experiment — •Lisa-Marie Koll, Tobias Witting, and Marc JJ Vrakking — Max Born Institute, Berlin, Germany

Quantum mechanical entanglement is a vibrant topic, culminating in this year's Nobel price award. In attosecond science, it is common to use radiation in the extreme ultra-violet (XUV) regime to study atomic and electronic dynamics. Due to their high photon energy any sample (solid, liquid or gaseous) placed in their path is ionized, creating a bipartite quantum system, i.e. an ion+photoelectron. Entanglement between those sub-systems can have measurable consequences for any attosecond experiment [1]. To illustrate the role of entanglement in photoionization we designed an experimental protocol, which utilizes a pair of phase-locked XUV pulses [2] and an IR pulse to ionize hydrogen molecules. The initially entangled ion+photoelectron system created by the XUV photoionization process is converted by the IR pulse into a coherent superposition of the gerade and ungerade electronic state of the ionic molecule leading to the observation of electronic localization [3]. By changing the time delay between the two XUV pulses the degree of ion+photoelectron entanglement is controlled and as a consequence the degree of electronic coherence. This can lead to the suppression of the observable electronic localization for certain time delays.

[1] L.-M. Koll et. al., Physical Review Letters 128, 043201 (2022)
[2] L.-M. Koll et al., Optics Express 30, 7082-7095 (2022)
[3] G. Sansone et al., Nature 465, 763-766 (2010)

MO 14.4 Thu 11:45 F102

High-order spectroscopy at 100 kHz repetition rate — •Katja Mayershofer[1], Simon Büttner[1], Tim Schembri[2,3], Matthias Stolte[2,3], Frank Würthner[2,3], and Tobias Brixner[1,3] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [3]Center for Nanosystems Chemistry (CNC), Universität Würzburg, Theodor-Boveri-Weg, 97074 Würzburg

With our new laser setup we can carry out shot-to-shot femtosecond spectroscopy experiments at 100 kHz repetition rate, which decreases the measurement time to a few seconds for conventional coherent two-dimensional spectroscopy experiments. For the shot-to-shot measurements an acousto-optical modulator pulse shaper was implemented, which can arbitrarily shape pulses at 100 kHz repetition rate, and we detect full spectra with a line camera at 100 kHz. The increase in repetiton rate and the ability to measure shot-to-shot also leads to a better signal-to noise ratio as a larger number of averages can be measured in the same time frame as previous measurements. As an examplary measurement, we show data taken using the new development of fifth-order transient absorption spectroscopy. This method can be used to analyze the exciton dynamics in J-type coupled merocyanine dye films, which are interesting in view of their optoelectronic properties.[1]

[1] A. Liess, et al., Adv. Funct. Mater. **2019**, *29*, 1805058.

MO 14.5 Thu 12:00 F102

High-resolution rapid-scanning two-dimensional electronic spectroscopy — •Nicolai Gölz, Friedemann Landmesser, Daniel Uhl, Frank Stienkemeier, and Lukas Bruder — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Two-dimensional electronic spectroscopy (2DES) is an effective ultrafast spectroscopic technique to study dynamics of matter with a high spectro-temporal resolution. Extending the method to weakly perturbed molecular and cluster species in the gas phase permits very high spectral resolution [1,2]. However, in this case, the attainable resolution is limited by the acquisition time of corresponding long delay scans. To solve this problem, we have implemented a rapid-scanning method developed by the Ogilvie group [3] which reduces the acquisition time by up to 2 orders of magnitude. First results will be presented.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018)
[2] U. Bangert et al., Nature Communications 13:1, 3350 (2022)
[3] D. Agathangelou et al., J. Chem. Phys.155, 094201 (2021)

MO 14.6 Thu 12:15 F102

Coherent multidimensional spectroscopy of molecular and cluster beam samples — •Yilin Li, Arne Morlok, Ulrich Bangert, Daniel Uhl, Frank Stienkemeier, and Lukas Bruder — Institute of Physics, University of Freiburg, Germany

Coherent multidimensional spectroscopy is a versatile technique enabling further insights into intra- and inter-molecular couplings on ultrashort time scales. We have extended the method to molecular nanosystems prepared in the gas phase [1,2]. Recently we started analysing 2D beating maps to obtain information about the electronic and vibrational coherences in the systems, which are otherwise covered by linebroadening mechanisms. First results will be presented.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018)
[2] U. Bangert, F. Stienkemeier, L. Bruder, Nat Commun 13, 3350 (2022)

MO 14.7 Thu 12:30 F102

Simplifying the Analysis of Transient Absorption Data by Polarization Control — •Yi Xu[1], Lars Mewes[1], Erling Thyrhaug[1], Heinz Langhals[2], and Jürgen Hauer[1] — [1]Dynamical Spectroscopy, Department of Chemistry, Technical University of Munich, 85748 Garching, Germany — [2]Department of Chemistry, Ludwig-Maximilians-Universität München, 81377 Munich, Germany

Ultrafast energy transfer in donor-acceptor (D-A) systems with orthogonal transition dipole moments (TDMs) is of fundamental interest due to its incompatibility with Förster theory. An in-depth theoretical treatment calls for specific experimental tools, which we provide by polarization-controlled transient absorption (TA) spectroscopy with broadband detection. We isolate pure donor and acceptor parts of the total signal. This provides a strategy to greatly reduce spectral congestion in complex systems. The polarization-associated spectra can be isolated to the contributions either parallel (S_z) or orthogonal (S_y) to the excitation TDM. The derived expressions read $S_z = 3 \cdot S_{MA} \cdot V_z(r(\lambda,t),\beta)$ and $S_y = 3 \cdot S_{MA} \cdot V_y(r(\lambda,t),\beta)$, where S_{MA} represents the magic angle spectra. The corresponding unit vectors $V_z(r(\lambda,t),\beta)$ and $V_y(r(\lambda,t),\beta)$ are both functions of the time resolved anisotropy $r(\lambda,t)$ and the angle β stands for differences between the TDMs defining the first and last light-matter interaction in a TA-sequence. We find that $\beta \approx 30^\circ$ is an optimal choice to disentangle the D and A-signals. This proves the non-orthogonality within the *"orthogonal"* D-A system.

MO 14.8 Thu 12:45 F102

Probing Nonadiabatic Dynamics with Attosecond Pulse Trains and soft X-ray Raman Spectroscopy — •Lorenzo Restaino, Deependra Jadoun, and Markus Kowalewski — Department of Physics, Stockholm University, Albanova University Centre, SE-106 91 Stockholm, Sweden

Ultrafast electronic coherences, generated by a photoexcited wave packet passing through a conical intersection, can be detected by linear off-resonant X-ray Raman probes. A hybrid femtosecond or attosecond probe pulse can be employed to generate a Raman spectrum that maps the energy difference between the involved electronic states. We investigate how attosecond pulse trains perform as probe pulses in the framework of this spectroscopic technique, instead of single Gaussian pulses. We explore different schemes for the probe pulse, as well as the impact of parameters of the pulse trains on the signals. We use two different model systems, representing molecules of different symmetry, and quantum dynamics simulations to study the difference in the spectra. The results suggest that such pulse trains are well suited to capture the key features associated with the electronic coherence.

MO 15: Rotational- and Vibrational-resolution Spectroscopy

Time: Thursday 11:00–13:00 Location: F142

Invited Talk MO 15.1 Thu 11:00 F142

Excited state dipole moments from rotationally resolved Stark spectroscopy — •Michael Schmitt, Matthias Zajonz, and Marie-Luise Hebestreit — Heinrich-Heine-Universität Düsseldorf, Institut für Physikalische Chemie I, Universitätsstraße 26.43.02

Rotationally resolved electronic Stark spectroscopy is a versatile tool for the accurate determination of rotational constants of molecules in both electronic states, connected by the electronic transition, centrifugal distortion constants, barriers to hindered internal motions, transition dipole moments, and the permanent dipole moments of both states. The latter provide an easy access to the electronic nature of the excited state, because they differ in size and in direction for different electronic states. The most reliable values for dipole moments of ground and electronically excited states are obtained from gas phase electronic Stark experiments, since the dependence of the frequency shift of individual rovibronic lines from the electric field strength yields immediately the dipole moment in ground and excited state. A variation of the solvatochromic effect will be presented, namely the thermochromic effect, which is able to yield dipole moment changes upon electronic excitation of molecules in solution that are largely independent of the solvent used, to close the gap between gas phase dipole moment changes and those obtained in solutions. Although used for many years in organic chemistry, the Lippert-Mataga theory has severe deficiencies, which will be highlighted in the contribution. We will present a thorough analysis of the photo-physics of the six different positional isomers of cyanoindole in the gas phase and in solution.

MO 15.2 Thu 11:30 F142

High resolution continuous wave spectroscopy on the A $^2\Sigma^+ \leftarrow X\,^2\Pi_{3/2}$ transition in nitric oxide — •Philipp Neufeld[1,3], Patrick Kaspar[1,3], Fabian Munkes[1,3], Alexander Trachtmann[1,3], Yannick Schellander[2,3], Robert Löw[1,3], Tilman Pfau[1,3], and Harald Kübler[1,3] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [3]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart

Within the scope of the development of a new kind of gas sensor [1,2], we employ Doppler-free saturated absorption spectroscopy on the A $^2\Sigma^+ \leftarrow X\,^2\Pi_{3/2}$. transition in nitric oxide (NO) for different total angular momenta J on the P_{12} branch. Spectroscopy is performed in continuous wave operation at 226 nm in a 50 cm long through-flow cell. Via phase sensitive detection by a lock-in amplifier the hyperfine structure of the X $^2\Pi_{3/2}$ state of NO is partially resolved. The data is compared to previous measurements, showing good agreement. Investigation of the dependence of the spectroscopic feature on power and pressure, should yield hyperfine constants, natural transition linewidth and the collisional cross-section between NO molecules. [1] P. Kaspar et. al., OSA Optical Sensors and Sensing, 19-23 July, 2021 [2] J. Schmidt et. al., Appl. Phys. Lett. 113, 01113 (2018)

MO 15.3 Thu 11:45 F142

Determination of the ortho-to-para ratio of H_3^+ in a cryogenic ion trap — Philipp Schmid, Carsten Czapczyk, Thomas Salomon, Oskar Asvany, and •Stephan Schlemmer — I. Physikalisches Institut der Universität zu Köln, Köln, Germany

A clean sample of ortho (o) and para (p) H_3^+ is prepared in a cryogenic 22-pole ion trap by removing one nuclear spin species. This isolation is reached on time scales below one second by a selective excitation of the ν_2 vibrational mode of H_3^+ addressing a rotational state associated with one of the two species. In subsequent collisions of the excited H_3^+ with He the vibration-to-translation (V-T) energy transfer produces fast H_3^+ of the addressed spin configuration which then leaves the trap via a small electrostatic barrier. Following this protocol the o/p-ratio of H_3^+ coming from the ion source is determined to be 1:1, as expected. In the presence of normal hydrogen, n-H_2, in the cryogenic ion trap the o/p-ratio of H_3^+ reaches a stationary value close to 1:3 which is rationalized by the ordering of the lowest energy states of o-H_3^+ and p-H_3^+ . This work shows that nuclear spin specific and also structural isomer specific preparation and analysis is now possible in cryogenic ion traps. With this aid action spectra of isomer mixtures can be disentangled and it will become possible to determine isomer branching ratios of chemical reactions, as well as to study state-specific reactions like for the fundamental H_3^+ + H_2 collision system considered in this work.

MO 15.4 Thu 12:00 F142

Leak-out spectroscopy: a new, universal action spectroscopy method — •Philipp C. Schmid, Thomas Salomon, Sven Thorwirth, Oskar Asvany, and Stephan Schlemmer — I. Physikalisches Institut, Universität zu Köln, Köln, Germany

Rotational-resolved vibrational spectra of molecular ions are recorded using action spectroscopy techniques in cryogenic ion traps [1]. Thereby the spectrum is identified as a change of the ion mass by fragmentation upon photon absorption, pre-dissociation of tagged ions or via laser induced chemical reactions. Although all these techniques have advanced significantly, action spectroscopy cannot be applied to many ions when the aforementioned methods fail to work.

Here, we present a new method of action spectroscopy, called leak-out spectroscopy (LOS) [2]. LOS does not rely on a change in the mass of the ion, but on the transfer of internal energy of an excited ion to its translation energy upon the collision with a neutral partner. This allows the fast ions to escape the trap potentials and thus the spectrum can be recorded by detecting the ions leaving the trap. Based on this principle, LOS is intrinsically background free and suitable for virtually any ion. In recent measurements we used LOS to record the rovibrational resolved ν_1 C-H stretching vibration spectrum of l-C_3H^+. [1] B.A. McGuire et al., Nature Review Physics 2(2020)402. [2] P.C. Schmid et al., J. Phys. Chem. A 126(2022)8111.

MO 15.5 Thu 12:15 F142

Spectroscopic studies of acylium- and thioacylium ions — •Sven Thorwirth[1], Oskar Asvany[1], Thomas Salomon[1], Marcel Bast[1], Philipp C. Schmid[1], Michael E. Harding[2], Igor Savic[3], José L. Doménech[4], and Stephan Schlemmer[1] — [1]I. Physikalisches Institut, Universität zu Köln, Köln Germany — [2]Institut für Nanotechnologie, Karlsruher Institut für Technologie (KIT), Karlsruhe, Germany — [3]Department of Physics, Faculty of Sciences, University of Novi Sad, Novi Sad, Serbia — [4]Instituto de Estructura de la Materia (IEM-CSIC), Madrid, Spain

Acylium- and thioacylium ions, R-CO^+ and R-CS^+, are classes of astrochemically relevant molecular ions that have received relatively little attention from molecular spectroscopy so far. Triggered by recent laboratory and astronomical observations of the polyatomic HC_3O^+, HC_3S^+, and CH_3CO^+ species (see, Thorwirth et al. 2020, Cernicharo et al. 2021 and references therein) our laboratory investigations have now been extended towards other selected (thio)acylium species. Here, we would like to present a status report on our studies performed using various action spectroscopy schemes in combination with state-of-the-art ion traps.

Thorwirth, S., Harding, M. E., Asvany, O. et al. 2020, Mol. Phys. 118, e1776409
Cernicharo, J., Cabezas, C., Bailleux, S. et al. 2021, Astron. Astrophys. 646, L7

MO 15.6 Thu 12:30 F142

Luminescent and excited state properties of bimetallic coinage metal NHC-complexes — •Daniel Marhöfer[1], Pit Boden[1], Sophie Steiger[1], Christoph Kaub[2], Peter Roesky[2], and Gereon Niedner-Schatteburg[1] — [1]Dept. of Chemistry, TUK, Erwin-Schrödinger-Str. 52-54, 67663 Kaiserslautern — [2]Institute of Inorganic Chemistry, KIT, Engesserstr. 15, 76131 Karlsruhe

A series of bimetallic coinage metal complexes containing a specific, bipyridyl substituted, N-heterocyclic carbene ligand was investigated via luminescence spectroscopy as well as step-scan FTIR spectroscopy. The series contains the monometallic and the heterobimetallic gold complexes as well as the homobimetallic silver and copper compounds. The luminescence measurements were performed both in potassium bromide matrix and in (conditionally frozen) ethanoic solution. The emission lifetimes were determined via time-correlated single photon counting in the temperature range between 5 K and 290 K. The excited state structures were studied by electronic excitation by a pulsed UV laser followed by step-scan FTIR probing, allowing the determination of the IR absorption of the electronically excited molecules. The obtained excited state spectra were then compared to both the ground state vibrational spectrum as well as the quantum-chemically calculated lowest energy singlet and triplet states' vibrational spectra. A pronounced dependence of the excited state IR absorption, the emission colour and the excited state lifetimes on the metal centers could be observed and finally assigned to cooperative effects in specific metal combinations.

MO 15.7 Thu 12:45 F142

2DIR Spectroscopy of an Organic Azide Model — •Claudia Gräve, Jörg Lindner, and Peter Vöhringer — Clausius-Institut für Physikalische und Theoretische Chemie, Rheinische Friedrich-Wilhelms-Universität Bonn, Wegelerstraße 12, 53115 Bonn, Germany

The photoinduced dynamics of azides is of great importance in organic chemistry but not yet understood, even at a qualitative level. We are currently utilizing ultrafast spectroscopy to address these dynamics.

Here, we report on first results from femtosecond two-dimensional infrared (2DIR) spectroscopy of 1-cyano-2-(4-azidophenyl)-acetylene to understand vibrational energy transfer (VET) to the solvent and intramolecular vibrational energy redistribution (IVR). Our 2DIR data show that IVR from the azide moiety through the phenyl ring onto the para-positioned cyano-acetylene group occurs on a time scale of 3.5 ps. In contrast, VET in chloroform solution requires 20 ps. Finally, a coherent vibrational quantum beat can be detected, which dephases within roughly 1 ps.

MO 16: Atomic Clusters (joint session A/MO)

Time: Thursday 11:00–13:00 Location: F107

See A 22 for details of this session.

MO 17: Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)

Time: Thursday 14:30–16:30 Location: F102

MO 17.1 Thu 14:30 F102

Cooling and control of the translational and rotational motion of a nano rotor — •Peter Barker[1], Antonio Pontin[1], Marko Toros[2], Hayden Fu[1], Tania Monteiro[1], Jonathan Gosling[1], and Markus Rademacher[1] — [1]University College London, UK — [2]University of Glasgow, Glasgow, UK

There has been significant interest in controlling the motional degrees of isolated, single nanoparticles, trapped within optical fields in high vacuum. They are seen as ideal candidates for exploring the limits of quantum mechanics in a new mass regime while they are also massive enough to be considered for future laboratory tests of the quantum nature of gravity. In this talk I will report on the control and cooling of all translational and rotational degrees of freedom of a nanoparticle trapped in an optical tweezer using cooling via coherent elliptic scattering where translational temperatures in the 100 μK range were reached, while temperatures as low as 5\,mK were attained in the librational degrees of freedom. I will also outline nanoparticle characterisation techniques based on the control and measurement of the librational and translational motion. This work opens up future applications in quantum science and the characterisation of single isolated nanoparticles free of interference from a substrate.

MO 17.2 Thu 14:45 F102

Polarization control of optically levitated nanoparticles — •Yanhui Hu, James Sabin, Mudassar Rashid, and James Millen — Department of Physics, King's College London, Strand, London

The optical control of anisotropic particles opens up applications in torque sensing and the study of rotational quantum mechanics. The angular modes of a levitated particle are markedly different from the linear modes, and new tools are required to achieve full control. In the Levitated Nanophysics Group at King's College London we work with nanofabricated silicon nanorods, which allow enhanced control over all degrees-of-freedom. We control the rotation of the nanorods through a recently discovered method for generating transverse optical vortices, which can be used to exert a large torque on an array of levitated nanoparticles. We also present a method to simultaneously cool all of the linear and angular modes of levitated, anisotropic particles, without the necessity for a delicate optical cavity.

MO 17.3 Thu 15:00 F102

Surface-induced decoherence and heating of charged rigid rotors — •Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — University of Duisburg-Essen

Levitating charged particles in ultrahigh vacuum provides a preeminent platform for quantum information processing, for quantum-enhanced force and torque sensing, for probing physics beyond the standard model, and for high-mass tests of the quantum superposition principle. Existing setups, ranging from single atomic ions to ion chains and crystals to charged molecules and nanoparticles, are crucially impacted by fluctuating electric fields emanating from nearby electrodes used to control the motion. In this article, we provide a theoretical toolbox for describing the rotational and translational quantum dynamics of charged nano- to microscale objects near metallic and dielectric surfaces, as characterized by macroscopic dielectric response functions. The resulting quantum master equations describe the coherent surface-particle interaction due to image charges and Casimir-Polder potentials as well as surface-induced decoherence and heating with the experimentally observed frequency and distance scaling. We explicitly evaluate the master equations for relevant setups, thereby providing the framework for describing and mitigating surface-induced decoherence as required in future quantum technological applications.

MO 17.4 Thu 15:15 F102

Decoherence-Free Rotational Degrees of Freedom for Quantum Applications — •Julen S. Pedernales, Francesco Cosco, and Martin B. Plenio — Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, D-89081 Ulm, Germany

I will describe the use of spherical t-designs for the systematic construction of solids whose rotational degrees of freedom can be made robust to decoherence due to external fluctuating fields while simultaneously retaining their sensitivity to signals of interest. Specifically, the ratio of the signal phase accumulation rate from a nearby source to the decoherence rate caused by fluctuating fields from more distant sources can be incremented to any desired level by using increasingly complex shapes. This allows for the generation of long-lived macroscopic quantum superpositions of rotational degrees of freedom and the robust generation of entanglement between two or more such solids with applications in robust quantum sensing and precision metrology as well as quantum registers.

[1] J. S. Pedernales, F. Cosco, and M. B. Plenio, Phys. Rev. Lett. 125, 090501 (2020).

MO 17.5 Thu 15:30 F102

Group report: Precision spectroscopy and quantum information with trapped molecules — •Brandon Furey, Stefan Walser, Zhenlin Wu, Guanqun Mu, Rene Nardi, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Österreich

The quantum molecules group at the University of Innsbruck utilizes a range of innovative advances in molecular spectroscopy and quantum logic spectroscopy (QLS) to study molecular rovibrational structure and explore quantum information processing with trapped molecules. The efforts of our group are divided into three projects. The first is pump-probe recoil spectroscopy, where we measure the rovibrational population dynamics excited by a pump pulse by mapping them to the electronic state of an atomic ion via QLS. The second project investigates state-dependent force spectroscopy, where an optical tweezer generates a state-dependent force on a trapped molecule. Our third project is demonstrating superpositions of rotational states in a diatomic molecular ion built using stimulated Raman transitions driven by two beams from an optical frequency comb. This could pave the way for using quantum error correction to realize the use of trapped molecules for quantum information or memory. We are interested in creating the rotational superposition states that form the codewords of a truncated $Z_3 \subset Z_6$ linear rotor code. In order to demonstrate ultrafast light-matter interaction in our system, we have measured the photodissociation spectrum of $CaOH^+$ using an optical parametric amplifier.

MO 17.6 Thu 15:45 F102

From the rotation of a planar rigid rotor in electric fields to the semifinite-gap structure of an optical superlattice — •Marjan Mirahmadi[1], Bretislav Friedrich[1], Burkhard Schmidt[2], and Jesús Pérez-Ríos[1,3,4] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Weierstraß-Institut, Berlin, Germany — [3]Department of Physics, Stony Brook University, NY , USA — [4]Institute for Advanced Computational Science, Stony Brook University, NY, USA

We show that two seemingly unrelated problems – the trapping of an atom in a one-dimensional optical superlattice (OSL) formed by the interference of optical lattices whose spatial periods differ by a factor of two, and the libration of a polar polarizable planar rotor (PR) in combined electric and optical fields – have isomorphic Hamiltonians. It is possible to establish a map between the translations of atoms in the former system and the rotations of the rotor due to the coupling of its permanent and induced electric dipole moments to the external fields. The latter system belongs to the class of conditionally quasi-exactly solvable problems in quantum mechanics and exhibits intriguing spectral properties. We make use of our findings to explain the *semifinite-gap* band structure of the OSL. This band structure follows from the eigenenergies obtained as solutions of the Whittaker-Hill equation and their genuine and avoided crossings. Furthermore, the mapping makes it possible to establish correspondence between concepts, such as localization on the one hand and orientation/alignment on the other.

MO 17.7 Thu 16:00 F102

Experimental advances in the quest for perfect enantiomer-specific state control of cold molecules — •Juhyeon Lee[1], Johannes Bischoff[1], Alicia. O. Hernandez-Castillo[2], Boris Sartakov[1], Gerard Meijer[1], and Sandra Eibenberger-Arias[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Harvey Mudd College, Claremont, Callifornia, USA

Enantiomer-specific state transfer (ESST) was recently developed using tailored microwave fields [1]. This technique enables the population or depopulation of a rotational state of a chosen enantiomer, providing a way of quantum-controlled chiral separation. Recently, we have explored spectroscopic schemes to overcome previous limitations in the transfer efficiency of ESST: thermal population of the rotational levels and M_J degeneracy [2]. We improved the transfer efficiency up to 50%, and quantitatively studied ESST for the first time [3]. The experimental ESST efficiency was ~ 20% lower than theoretically expected. We attribute this partially to imperfections in the microwave polarizations and their respective orthogonality. We show a method to experimentally determine the polarization of microwave fields in-situ by quantitative analysis of molecular Rabi oscillations.

[1] S. Eibenberger, et al., Phys. Rev. Lett. 118, 123002 (2017)
[2] M. Leibscher, et al., Commun. Phys. 5, 1 (2022).
[3] J. H. Lee, et al., Phys. Rev. Lett. 128, 173001 (2022)

MO 17.8 Thu 16:15 F102

Photoelectron circular dichroism in rotationally excited mixtures — •Alexander Blech[1], Loren Greenman[2], Reinhard Dörner[3], and Christiane P. Koch[1] — [1]Fachbereich Physik, Freie Universität Berlin, Berlin, Germany — [2]Department of Physics, Kansas State University, Manhattan, KS, USA — [3]Institut für Kernphysik, Goethe-Universität, Frankfurt am Main, Germany

Gas phase experiments with chiral molecules may be carried out with randomly oriented molecules because there exist enantiomer-sensitive observables that survive orientational averaging. The strength of these observables is directly related to the enantiomeric excess and vanishes in the limit of a racemic mixture. Here we turn the perspective around and investigate whether it is possible to detect chiral signatures from racemic, but rotationally excited mixtures. We focus on photoelectron circular dichroism (PECD), which is the forward-backward asymmetry in the photoelectron angular distributions of chiral molecules upon ionization with circularly polarized light. Based on an analysis of the electric dipole response in rotationally excited molecular ensembles, we show that PECD can be observed in racemic mixtures by breaking the isotropy of the orientational distribution.

MO 18: Cluster and Experimental Techniques (joint session MO/A)

Time: Thursday 14:30–16:30 Location: F142

MO 18.1 Thu 14:30 F142

Characterization of a simple supersonic expansion source for small molecular ions — •Lukas Berger[1], Aigars Znotins[1], Florian Grussie[1], Damian Müll[1], Felix Nuesslein[1], Arnaud Dochain[2], Joffrey Fréreux[2], Xavier Urbain[2], and Holger Kreckel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Institute of Condensed Matter and Nanosciences, Université Catholique de Louvain, Louvain-la-Neuve, B-1348 Belgium

The Cryogenic Storage Ring (CSR) [1] at the MPI for Nuclear Physics allows for the storage of molecular ions of almost arbitrary mass at extreme vacuum (residual gas densities on the order of 1000 cm-3) and at low temperature (T < 5K). In this environment, small infrared-active molecular ions will cool to their lowest rotational states within minutes. However, some astrophysically relevant molecular ions lack a permanent dipole moment (e.g.: H_2^+, H_3^+, H_3O^+) and have to be produced in cold ion sources prior to injection, as they do not cool on experimentally accessible time scales. Here we present the design of a simple supersonic expansion source based on a commercial pulsed valve and an electric discharge. It allows for the production of intense pulses of small molecular ions. We use high-resolution photodissociation spectroscopy of N_2O^+, employing the STARGATE setup [2] at the Université Catholique de Louvain, to characterize the internal excitation of the molecular ions and extract their rotational temperature.

[1] Von Hahn et al., Rev. Sci. Instrum. 87, 063115 (2016)
[2] Bejjani et al., Rev. Sci. Instrum. 92, 033307 (2021)

MO 18.2 Thu 14:45 F142

OH^+He as simple example to illustrate fundamental concepts of intermolecular interactions. — •Nima-Noah Nahvi, David Müller, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The OH^+He dimer is a simple cluster for which many concepts of intermolecular interactions can be demonstrated. Nowadays, OH^+He can be understood quite well, which makes it an interesting and encompassing example for educational purposes.

OH^+He_n ($n \leq 6$) clusters are grown inside a cryogenic 22-pole ion trap and detected using a reflectron mass spectrometer. The resulting mass spectra are explained with cluster structures determined by CCSD(T) calculations using CFOUR. We investigate and explain certain features of OH^+He_n to illustrate concepts like solvation shells, potential energy functions, binding energies and vibrational frequencies, charge- and dipole-induced interactions, dispersion contribution, complete basis set limits and BSSE corrections. The results will be compared to those of $H_2O^+He_n$ and $H_3O^+He_n$ [1] to establish the effect of the number of protons on the interaction potential and cluster growth.

[1] Müller and Dopfer, Phys. Chem. Chem. Phys., 2022, 24, 11222-11233. https://doi.org/10.1039/D2CP01192A

MO 18.3 Thu 15:00 F142

Investigation of the homogeneous line width of organic molecules attached to rare-gas clusters — •Arne Morlok, Ulrich Bangert, Lukas Bruder, Ylin Li, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Two-dimensional spectroscopy (2DES) is a powerful method to study dynamics of atoms and molecules with a high spectro-temporal resolution. In our group, we apply the technique to doped cluster beams, which act as miniature cryostats for different organic molecules [1,2]. Previous 2DES experiments on phthalocyanine (Pc) on neon clusters allowed resolution of the homogeneous linewidth of Pc and distinguished fluorescence from the C12 and C13 isotope [3]. We extended this investigation in varying the species of the spectroscopic matrix, hence the clusters, and the probed organic molecules. First results are presented, which suggest differences in the homogenous linewidth and coherence times depending on the coupling between dopant and cluster environment.

[1] L. Bruder et al., Nat. Commun. 9 4823 (2018).
[2] L. Bruder et al., J. Phys. B: At. Mol. Opt. Phys. 52 183501 (2019).
[3] U. Bangert et al., Nat. Commun. 13 3350 (2022).

MO 18.4 Thu 15:15 F142

Experimental cross sections for the uptake of alkyl alcohols by binary HNO3/H2O clusters — Yihui Yan[1], Andriy Pysanenko[2], Karolina Farnikova[2], Eva Pluharova[2], Michal Farnik[2], and •Jozef Lengyel[1] — [1]TUM School of Natural Sciences, Technical University of Munich, Garching, Germany — [2]Heyrovsky Institute, Czech Academy of Sciences, Prague, Czech Republic

The uptake of oxidized organic compounds by hydrated acid clusters accounts for a substantial portion of atmospheric aerosol particles. Through joint experimental and computational studies, we investigate the uptake of alkyl alcohols on pre-existing hydrated HNO3 clusters. In our experiments, the HNO3/H2O clusters pass through a chamber filled with a particular gas, the molecules collide with the clusters and can stick to the surface. The efficiency of this process is given by the uptake cross section, which is determined experimentally by a combination of mass spectrometry and velocity measurements in a molecular beam. Our previous experiments have shown that the uptake probabilities for the oxidized molecules are significantly larger than for the corresponding volatile organic compounds (VOCs). This increase is attributed to hydrogen bonds between the molecules and clusters, whereas the interactions of the parent VOCs are weaker and nonspecific. In this study, we examine the effect of different O-H bond positions in the oxidized molecule and different carbon chain length on the pickup probability. To learn the details of the pickup process, all experimental measurements are supplemented by MD simulations.

MO 18.5 Thu 15:30 F142

Femtosecond pump-probe spectroscopy of tetracene in the gas phase and in helium nanodroplets — Audrey Scognamiglio, Nicolas Rendler, •Sebastian Hartweg, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Acenes, specifically tetracene and pentacene, are promising candidates for applications in organic photovoltaics since ensembles of these molecules can undergo singlet fission to produce two triplet excitations from a single singlet excitation. This process may thus allow to produce multiple charge carriers from a single absorbed photon. The potential applications motivate the fundamental study of the ultrafast excitation dynamics of these molecules and their aggregates to provide a fundamental understanding of the underlying processes and energetics. We will present a study of femtosecond pump-probe photoelectron spectroscopy and mass spectrometry of the excited state dynamics of tetracene excited to its brightest singlet state using UV photons. We will compare results for effusive tetracene with preliminary data for tetracene and its clusters in superfluid helium nanodroplets. The doping of organic molecules into superfluid helium nanodroplets offers a promising path to extend the study from isolated molecules to clusters of acenes, but also imposes additional challenges.

MO 18.6 Thu 15:45 F142

Plasmon quenching of a single gold nanoparticle in the gas phase — •Björn Bastian, Benjamin Hoffmann, Sophia Leippe, and Knut R. Asmis — Universität Leipzig, Wilhelm-Ostwald-Institut, Linnéstraße 2, D-04103 Leipzig

A split-ring electrode trap design has been optimized to quasi-continuously monitor the mass of single nanoparticles for action spectroscopy, fluorescence spectroscopy and temperature-programmed desorption experiments. The aim is to investigate inherent properties of individual particles and their relation to parameters such as size, shape, temperature, charge state or surface functionalization. One example is a collective electron oscillation of metallic nanoparticles called *localized surface plasmon resonance*. New results are presented that show electronic action spectra of the plasmon resonance of a single 50 nm diameter gold particle and its stepwise quenching by radiative heating.

The particle mass is proportional to its secular frequency in the trap, which is typically monitored by resonant excitation. The resonance frequency is observed as a dip in the intensity of light scattered from the particle when sweeping an excitation frequency. Cryogenic cooling allows to control the adsorption of a messenger gas. Action spectra are obtained by observing the mass loss from desorption of the messenger due to absorption of light in the visible or infrared range.

We present results on plasmon quenching and current progress in implementing infrared action spectroscopy and to better characterize the particle temperature, adsorption and desorption dynamics.

MO 18.7 Thu 16:00 F142

Setup Of A Spectrometer To Detect Raman Optical Activity — •Klaus Hofmann and Ingo Fischer — Universität Würzburg, 97074 Würzburg, Germany

Raman Optical Activity (ROA) is a type of vibrational circular dichroism: chiral samples show different Raman intensities when utilizing circular polarized light. The ROA signal is very sensitive to the molecular geometry and environment of the sample, which can be analyzed by comparing the spectrum with quantum chemical calculations. ROA spectra exhibit high levels of noise and are prone to false signals, since the intensity difference is roughly 0.1% of the corresponding Raman peak.[1]

For this project, a Raman spectrometer was custom-built and modified to detect ROA. A modulation scheme repeatedly converts linear to right and left circular polarized light for excitation. Python was used to automate the experiment, data acquisition and post-processing. The beampath of the spectrometer and its implemented error reduction schemes[2] are shown. Post-processing is used to evaluate the signal. Literature known samples were measured to validate the spectrometer.

[1] V. Parchaňský, J. Kapitán, P. Bouř, RSC Adv. 2014, 4, 57125.
[2] W. Hug, Appl. Spectrosc. 2003, 57, 1.

MO 18.8 Thu 16:15 F142

Salt effects on the translocation dynamics of polycationic peptide nucleic acids through a protein nanopore — •Ioana Cezara Bucataru[1], Alina Asandei[2], Loredana Mereuta[1], and Tudor Luchian[1] — [1]Department of Physics, *Alexandru I. Cuza* University, Iasi, Romania. — [2]Sciences Department, Interdisciplinary Research Institute, *Alexandru I. Cuza* University, Iasi, Romania

Peptide nucleic acids (PNAs) are synthetic molecular constructs that mimic DNA in structure, but with an uncharged pseudopeptide backbone made of N-(2-aminoethyl)-glycine, having the ability to form Watson-Crick complementary duplexes with regular DNA. Due to its distinctive properties, PNAs displayed considerable potential for application in molecular diagnostics and antisense therapies. The addition of different charged sidechains to the neutral PNA structure plays an essential part in addressing solubility-related issues that are linked with the use of these molecules. The single-molecule investigations used here focus on the interactions of different length polyarginine-conjugated PNAs (poly(Arg)-PNAs) with the α-hemolysin (α-HL) nanopore, under an applied transmembrane voltage. The effect of ionic strength on the translocation kinetics is demonstrated by using different salt concentrations in the recording buffer. Our results indicate that low ionic strength increases the electrophoretic mobility of poly(Arg)-PNA probes as they pass through the nanopore and reduces their volume. The current findings highlight the intricate interplay between conformation and ion environment that influences the inherent flexibility and function of poly(Arg)-functionalized PNAs.

MO 19: Interaction with Strong or Short Laser Pulses III (joint session A/MO)

Time: Thursday 14:30–16:00 Location: F107

See A 24 for details of this session.

MO 20: Poster III

Time: Thursday 16:30–19:00 Location: Empore Lichthof

MO 20.1 Thu 16:30 Empore Lichthof

Photoelectron Circular Dichroism of fenchone induced by coherent broadband laser pulses — •Eric Kutscher, Anton Artemyev, and Philipp Demekhin — Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Angular distributions of photoelectrons ionized by circularly polarized light from randomly oriented chiral molecules are asymmetric with respect to the propagation direction of the light [1]. This Photoelectron Circular Dichroism (PECD) appears also in the multiphoton ionization regime [2], which opens up a possibility for the coherent control of the effect. So far, the quantum control of PECD has only been discussed in a pump-probe excitation scheme with narrowband pulses [3]. Broadband (bb) laser pulses support photons in a large energy interval [4] and can be tailored in their amplitude and phase with pulse-shaping techniques. Here, the multiphoton PECD induced by coherent bb pulses with a 1-3 eV energy spectrum is studied theoretically for R(-)-fenchone molecules with different chirps and intensites of the pulses by utilizing the time-dependent single-center method [5]. Our results confirm a possibility to control the multiphoton PECD by tailored coherent bb pulses.

[1] B. Ritchie, Phys. Rev. A **13**, 1411 (1976).
[2] C. Lux *et. al.*, Angew. Chem. Int. Ed. **51**, 5001 (2012).
[3] R. E. Goetz *et. al.*, Phys. Rev. Lett. **122**, 013204 (2019).
[4] H. Hundertmark *et. al.*, Opt. Express **17**, 1919 (2009).
[5] A.N. Artemyev *et. al.*, J. Chem. Phys. **142**, 244105 (2015).

MO 20.2 Thu 16:30 Empore Lichthof

Nondipole-Induced Asymmetry in the photoelectron emission distribution from fixed-in-space CO molecules — •Dmitrii Rezvan[1], Kim Klyssek[2], Sven Grundmann[2], Andreas Pier[2], Nikolay Novikovskiy[1], Nico Strenger[2], Dimitrios Tsitsonis[2], Max Kircher[2], Isabel Vela-Perez[2], Kilian Fehre[2], Florian Trinter[2], Markus Schöffler[2], Till Jahnke[2], Reinhard Dörner[2], and Philipp Demekhin[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Institut für Kernphysik, J.W. Goethe-Universität, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany

A nondipole-induced asymmetry in the angular distributions of C and O 1s-photoelectrons of fixed-in-space CO molecules is studied experimentally and theoretically at a photon energy of 905 eV. We demonstrate how scattering and nondipole effects determine the final emission distributions. The calculations were carried out in the frozen-core Hartree-Fock approximation using the stationary single center method [1], while the experiment was carried out using the COLTRIMS reaction microscope [2] available at beamline P04 of PETRA III, DESY. The emission distributions possess a strong scattering peak in the direction of the neighboring atom. This peak is either enhanced or suppressed by the nondiope contributions, respectivelly, if the scaterrer points to the forward or backward direction with respect to the light propagation.

[1] Ph. V. Demekhin *et. al.*, J. Chem. Phys. **134**, 024113 (2011).
[2] R. Dörner *et. al.*, Phys. Rep. **330**, 95 (2000).

MO 20.3 Thu 16:30 Empore Lichthof

Measuring discriminatory optical forces on chiral molecules — •Tianyu Fang, Nick Vogeley, Kilian Singer, and Daqing Wang — Institute of Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

We aim at a proof-of-principle experimental demonstration of enantiomer separation using optical forces created by a spatially tailored optical field. Chiral molecules with opposite handedness scatter polarized light differently. Consequently, the scattering of a photon exerts a force on the scatterer. This force can be tailored to be enantiomer specific, such that molecules of opposite handedness are pushed to opposite directions. In this poster, we outline an experiment, in which such discriminatory forces will spatially separate enantiomers in a propagating molecular beam.

MO 20.4 Thu 16:30 Empore Lichthof

Information theoretical approach to coupled electron-nuclear wave packet dynamics: Time-dependent differential Shannon entropies — •Peter Schürger and Volker Engel — Universität Würzburg, Institut für Physikalische und Theoretische Chemie, Emil-Fischer-Str. 42, 97074 Würzburg, Germany

We study differential Shannon entropies determined from position space quantum probability densities in a coupled electron-nuclear system. In calculating electronic and nuclear entropies, one gains information about the localization of the respective particles and also about the correlation between them. For a Born-Oppenheimer (BO) dynamics the correlation decreases at times when the wave packet reaches the classical turning points of its motion. If a strong non-adiabtic coupling is present, leading to a large population transfer between different electronic states, the electronic entropy is approximately constant. Then, the time-dependence of the entropy reflects theinformation on the nucleus alone, and the correlation is absent. A decomposition of the entropy into contributions from the participating electronic states reveals insight into the state-specific population and nuclear wave packet localization.

MO 20.5 Thu 16:30 Empore Lichthof

Spectroscopy of the $(2)^1\Sigma_u$ state in Rb2 — •Dominik Dorer[1], Shinsuke Haze[1], Markus Deiss[1], Eberhard Tiemann[2], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie, Universität Ulm — [2]Institut für Quantenoptik, Leipniz Universität Hannover

We report a systematic study of the $(2)^1\Sigma_u$ electronic state of the rubidium dimer. For this we carried out single-photon photoassociation spectroscopy with an ultracold sample of ground state atoms. Using either a pulsed or a more narrow cw laser we investigated the vibrational and rotational structure for both isotopologues, ^{87}Rb and ^{85}Rb. From a theoretical analysis including also previously recorded data from other experiments, we got new insights of spin-orbit and rotational interactions for the $(2)^1\Sigma_u$ state. These results are also of interest for state-selective molecule detection schemes on the basis of resonance-enhanced multiphoton ionization (REMPI) as the $(2)^1\Sigma_u$ can serve as an appropriate intermediate state.

MO 20.6 Thu 16:30 Empore Lichthof

Spectroscopic Characterization of Aluminum Monofluoride — •Nicole Walter[2,1], Johannes Seifert[1], Bosis Sartakov[1], and Gerard Meijer[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin — [2]Humboldt University of Berlin

Aluminum monofluoride (AlF) possesses highly favorable properties for laser cooling, both via the $A^1\Pi$ and $a^3\Pi$ states. Determining efficient pathways between the singlet and the triplet manifold of electronic states will be advantageous for future experiments at ultralow temperatures. The lowest rotational levels of the $A^1\Pi, v = 6$ and $b^3\Sigma^+, v = 5$ states of AlF are nearly iso-energetic and interact via spin-orbit coupling. These levels thus have a strongly mixed spin-character and provide a singlet-triplet doorway. We here present a hyperfine resolved spectroscopic study of the $A^1\Pi, v = 6$ // $b^3\Sigma^+, v = 5$ perturbed system in a jet-cooled, pulsed molecular beam. From a fit to the observed energies of the hyperfine levels, the fine and hyperfine structure parameters of the coupled states, their relative energies as well as the spin-orbit interaction parameter are determined. The standard deviation of the fit is about 15 MHz. We experimentally determine the radiative lifetimes of selected hyperfine levels by time-delayed ionization, Lamb dip spectroscopy and accurate measurements of the transition lineshapes. The measured lifetimes range between 2 ns and 200 ns, determined by the degree of singlet-triplet mixing for each level.

MO 20.7 Thu 16:30 Empore Lichthof

Photoelectron Spectroscopy of Simple Diamondoids — •Simone Stahl, Parker Crandall, Marko Förstel, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Germany

Diamondoids are a class of aliphatic molecules with cage-like structures and are a bridge between small hydrocarbons and large nanodiamond macromolecules. Extrasolar nanodiamonds have been discovered in carbonaceous chondrites and could account for more than 5% of cosmic and 40% of tertiary carbon in the interstellar medium.[1] Due to similarities between their infrared spectra and the unidentified infrared emission bands of young stars, diamondoids could be present in these environments.[2] However, laboratory measurements of the optical properties of diamondoids, particularly of their cations and functionalized variants, remains incomplete and are necessary for astronomical observations. Here, we present the first photoelectron spectra of cyanoadamantane and amantadine. These are compared to newly measured spectra of adamantane, diamantane, and urotropine, with improved resolution and a more thorough assignment of spectral features with the aid of TD-DFT calculations.[3,4] The effect of functionalization on the ionization potential, as well as the size and shape of the cage structure on the PES spectrum will be discussed.

1. Henning, Th. & Salama, F. Science 282, 2204-2210 (1998).
2. Pirali, O. et al. ApJ 661, 919-925 (2007).
3. Schmidt, W. Tetrahedron 29, 2129-2134 (1973).
4. Rander, T. et al. J. Chem. Phy. 138, 024310 (2013).

MO 20.8 Thu 16:30 Empore Lichthof

Analysis of statistical moments – a new technique to find Legendre coefficients in photoelectron distributions with increased precision — •Simon Ranecky, Sagnik Das, Sudheendran Vasudevan, Tonio Rosen, Han-gyeol Lee, Jayanta Ghosh, Hendrike Braun, Arne Senftleben, and Thomas Baumert — Uni Kassel, Experimentalphysik III

The ionisation of isotropically aligned molecules with linear or circular polarized light leads to a characteristic distribution of the photoelectrons. The radial part of the distribution relates to the energy of the photons and the ionisation potential of the molecules. The angular part can be described by Legendre polynomials of the order up to twice the number of photons involved in the ionisation [1].

In velocity map imaging, which we use to detect photoelectrons, the 3d electron distribution is projected electrostatically on a phosphorous screen. The right orientation of the spectrometer leads to no information loss in the Abel-projection, but an Abel-inversion like rbasex [2] is necessary to find out the distribution of the Legendre coefficients.

As an alternative way to retrieve the Legendre coefficients, the centroid and higher moments of the photoelectron projection can be used. With the calculated moments of single Legendre polynomials, a linear system of equations can be compiled that makes the Legendre coefficients accessible. For simple photoelectron distributions, we will demonstrate smaller uncertainties as compared to rbasex.

[1] Yang, Phys. Rev. 74, 764; Dixit et al., J Chem. Phys, 82, 3546
[2] Hickstein et al., Rev. Sci. Instrum. 90, 065115

MO 20.9 Thu 16:30 Empore Lichthof

Photoelectron circular dichroism on fenchone: from multiphoton to the tunnel ionization regime using near-infrared femtosecond laser pulses. — •Sudheendran Vasudevan, Han-gyeol Lee, Simon T. Ranecky, Nicolas Ladda, Tonio Rosen, Sagnik Das, Jayanta Ghosh, Hendrike Braun, Arne Senftleben, and Thomas Baumert — Institut für Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel

Photoelectron circular dichroism (PECD) is a pronounced forward/backward asymmetry in the ionization of chiral molecules by circularly polarized light. PECD is dominated by the electric-dipole effect, which gives rise to a larger magnitude of asymmetry as compared to circular dichroism in absorption. In this contribution, We use nearly Fourier-limited near-infrared pulses directly from a titanium sapphire femtosecond laser to excite electronic intermediate states in fenchone molecule via a (3+1+1+1) resonance-enhanced multiphoton ionization (REMPI) scheme. We scanned the intensity of the laser and measured the angular distribution of the photoelectrons from the multiphoton almost to the tunnel ionization regime. Herein we present our measured photoelectron spectra, PECD, and mass spectra during the intensity scan.

MO 20.10 Thu 16:30 Empore Lichthof

Temperature-dependant Luminescence and Step-scan FTIR Investigations of Tetranuclear Cu(I) Complexes — •Sophie Steiger[1], Pit Boden[1], Jasmin Busch[2], Daniel Marhöfer[1], Stefan Bräse[2], and Gereon Niedner-Schatteburg[1] — [1]Department of Chemistry, TUK, Germany — [2]IOC, KIT, Germany

In this contribution, we present the investigation of the temperature-dependent luminescence and the luminescent states of tetranuclear copper(I) complexes. The investigations were performed by (time-resolved) luminescence and static as well as step-scan FTIR spectroscopy. The measurements were performed in a temperature range of 290 K to 10 or 5 K in KBr matrix or pure powder. The complexes contain a tetranuclear Cu_4X_4 (X=Cl, Br, I) core and two 2-(diphenylphosphino)-pyridine ligands with or without a methyl substituent in 4-position of the pyridine ring units. As known from previous work[1], the same type of complexes with ligands with a methyl group in 6-position shows a pronounced thermochromism, which was not detected for the Cu_4I_4 complex with methyl group in 4-position in KBr matrix. The Cu_4I_4 complex without methyl group shows the thermochromism in powder measurements but it is less resolved in KBr matrix. All other investigated complexes have only slight temperature-dependent shifts in the luminescence. With step-scan FTIR spectroscopy in comparison with quantum chemical calculation, the excited states were assigned to the different excited state structures.

[1] Chem. Eur. J. 2021, 27, 5439-5452.

MO 20.11 Thu 16:30 Empore Lichthof

Calculation of the Stark effect of Rydberg states in nitric oxide — •Alexander Trachtmann[1,4], Fabian Munkes[1,4], Patrick Kaspar[1,4], Philipp Neufeld[1,4], Yannick Schellander[2,4], Lars Baumgärtner[3,4], Robert Löw[1,4], Tilman Pfau[1,4], and Harald Kübler[1,4] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [3]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [4]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart

We demonstrate Stark effect calculations of high-lying Rydberg states in nitric oxide and compare them to measurements at room temperature. These states are generated using a three-photon continuous-wave excitation scheme. The readout is based on the detection of charged particles created by collisional ionization of Rydberg molecules. Details of the calculation techniques are given.

MO 20.12 Thu 16:30 Empore Lichthof

Decoherence estimates for spin-boson systems from semiclassical Gaussian wavepacket propagation — •Sreeja Loho Choudhury[1], Caroline Lasser[2], Rocco Martinazzo[3,4], and Irene Burghardt[1] — [1]Institute of Physical and Theoretical Chemistry, Goethe University Frankfurt — [2]Technische Universität München, Zentrum Mathematik, Deutschland — [3]Department of Chemistry, Università degli Studi di Milano, Italy — [4]Instituto di Scienze e Tecnologie Molecolari, CNR, Milano, Italy

We investigate the time scale of decoherence in spin-boson type systems, by calculating the subsystem purity as a measure of decoherence. For a general system-bath setting, the decoherence time can be expressed in terms of a universal Gaussian decay of the purity [O. Prezhdo and P. Rossky, Phys. Rev. Lett. **81**, 5294 (1998)], but exponential decay is often predicted from Markovian master equations. The transition between these forms of decoherence has recently been discussed [B. Yan and W. H. Zurek, N. J. Phys. **24**, 113029 (2022)]. Against this background, we investigate the pure dephasing case in a spin-boson system using semiclassical Gaussian wavepackets, notably relying on the variational multiconfigurational Gaussians (vMCG) [G. A. Worth and I. Burghardt, Chem. Phys. Lett. **368**, 502 (2003)] and multiconfiguration time-dependent Hartree (MCTDH) [M. H. Beck, A. Jäckle, G. A. Worth, H.-D. Meyer, Phys. Rep. **324**, 1 (2000)] formalism for wavefunction propagation. We further consider quantum-semiclassical hybrid wavefunctions and examine the effect of semiclassical scaling on the subsystem purity.

MO 20.13 Thu 16:30 Empore Lichthof

Photoelectron spectroscopy study of anthracene anions — •Kevin Schwarz, Aghigh Jalehdoost, and Bernd v. Issendorff — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

As semiconducting organic materials generate more and more interest, there are still properties of said materials left to be investigated more in depth. After the development of a high temperature-suited pulsed valve to produce clusters of organic material such as anthracene has been concluded recently, first results of energy-resolved photoelectron spectroscopy (PES) studies on anthracene anions ($C_{14}H_{10}^-$) are shown.

MO 20.14 Thu 16:30 Empore Lichthof

Action Spectroscopic Infrared Detection of NCCO$^+$ — •Marcel Bast[1], Thomas Salomon[1], Oskar Asvany[1], Igor Savić[2], Sandra Brünken[3], Mathias Schäfer[4], Stephan Schlemmer[1], and Sven Thorwirth[1] — [1]I. Physikalisches Institut, Universität zu Köln, Köln, Germany — [2]Department of Physics, Faculty of Sciences, University of Novi Sad, Serbia — [3]FELIX Laboratory, Institute for Molecules and Materials, Radboud University, Nijmegen, the Netherlands — [4]Institute of Organic Chemistry, Department of Chemistry, University of Cologne, Köln, Germany

The linear NCCO$^+$ ion has been studied spectroscopically for the first time using the Free Electron Laser for Infrared eXperiments (FELIX) in combination with the 4K 22-pole ion trap facility FELion. The vibrational spectrum of NCCO$^+$ was observed in the range from 500 to 1400 and 2000 to 2500 cm^{-1} using resonant photodissociation of the correponding Ne-complex. Spectroscopic assignments are in very good agreement with high-level quantum-chemical calculations.

In a consecutive study, the rotationally resolved ν_2 band of the bare NCCO$^+$ ion was measured around 2150 cm^{-1} using the COLTRAP2 instrument in Cologne. Here, the recently developed action spectroscopic method Leak-Out Spectroscopy (LOS)[a] was used, that traces the bare ion rather than a weakly bound complex. In this manner, as will be shown on this poster, a nearly background-free absorption spectrum with a large signal-to-noise ratio was obtained.

[a] Schmid et al. 2022, J. Phys. Chem. A 126, 43, 8111-8117

MO 20.15 Thu 16:30 Empore Lichthof

Towards probing vibrational dynamics in methyl p-tolyl sulfoxide via time-resolved PECD — •Nicolas Ladda, Sudheendran Vasudevan, Tonio Rosen, Han-gyeol Lee, Sagnik Das, Jayanta Ghosh, Hendrike Braun, Arne Senftleben, and Thomas Baumert — Institut für Physik, Universität Kassel, Heinrich-Plett-Strasse 40, 34132 Kassel, Germany

The goal is to investigate the dynamic change of chiral character upon laser-induced vibrational motion in methyl p-tolyl sulfoxide (MTSO). To this end, we aim to measure the forward/backward asymmetry of the photoelectron angular distribution with respect to the propagation direction of the ionizing circularly polarized light of the randomly oriented chiral molecule, known as photoelectron circular dichroism (PECD) [1]. The vibrational motion - the umbrella motion of the sulfoxide molecule - changes the chiral character of the molecule, which can be investigated by studying the time-resolved PECD with UV femtosecond laser pulses. For this purpose, a two-color pump-probe setup consisting of the 3rd and 4th harmonics of a Ti:Sa laser system is used. The experimental setup has already been tested with static PECD measurements on fenchone and MTSO.

[1] N. Böwering, T. Lischke, B. Schmidtke, N. Müller, T. Khalil, and U. Heinzmann Phys. Rev. Lett. 2001, 86, 1187

MO 20.16 Thu 16:30 Empore Lichthof

Two-photon excitation spectroscopy of metal-organic frameworks — •Hongxing Hao[1], Yang Cui[1], Ferdinand Bergmeier[2], Simon N. Deger[3], Alexander Pöthig[3], Eberhard Riedle[2], Roland A. Fischer[3], and Jürgen Hauer[1] — [1]Dynamical Spectroscopy, Department of Chemistry, Technical University of Munich, 85748 Garching, Germany — [2]Lehrstuhl für BioMolekulare Optik, Ludwig-Maximilians-Universität München, 80538 München, Germany — [3]Chair of Inorganic and Metal-Organic Chemistry, Department of Chemistry, Technical University of Munich, 85748 Garching, Germany

Metal-organic frameworks (MOFs) or coordination polymers (CPs) constitute a novel class of materials and have several interesting photophysical properties such as a high multiphoton absorption cross section. Here, we introduce a spectroscopic experiment to measure two-photon excitation spectra from the visible to the near infrared based on a non-collinear optical parametric amplifier and a phase-stable common-path birefringent interferometer via nonlinear Fourier-transform spectroscopy. We present two-photon excitation spectra in the range between 380 to 470 nm with a data acquisition time of under one minute per spectrum.

We demonstrate the feasibility of this approach by using standard dyes as test samples. After incorporating two-photon absorption active organic linker molecules in crystalline CPs or MOFs, the spectra show a shift of oscillator strength. We suggest excitonic coupling between the linkers as the mechanism behind this targeted modification of two-photon absorption property.

MO 20.17 Thu 16:30 Empore Lichthof

Control of (bio-) nanoparticles with external fields — •Jingxuan He[1,2,3], Lena Worbs[1,2], Jannik Lübke[1,2,3], Surya Kiran Peravali[1,4], Armando D. Estillore[1], Amit K. Samanta[1,3], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Germany — [3]Center for Ultrafast Imaging, Universität Hamburg, Germany — [4]Fakultät für Maschinenbau, Helmut-Schmidt-Universität,Germany

Unraveling the elementary steps of biological processes and chemical reactions is a long-time goal of the scientific community. By using x-ray single-particle diffractive imaging, we can investigate the three-dimensional molecular structure of individual nanoparticles at atomic resolution through reconstructing a series of two-dimensional diffraction patterns [1]. However, because of the typically low signal-to-noise ratio, this requires the collection of a large amount of individual diffraction patterns. Since every intercepted particle is destroyed by the intense x-ray pulse, a new and preferably identical sample particle has to be delivered to every pulse. Here, we present an approach to prepare dense beams of cold and controlled nanoparticles and macromolecules with buffer-gas-cell-cooling and aerodynamic-focusing techniques. Besides, we demonstrated several control mechanisms with external fields that can help to realize a stream of pure, identical particles. We also showed that the particles' arbitrary orientation in space can be controlled by applying laser alignment.

[1] M. M. Seibert, *et al.*, *Nature* **470**, 78 (2011)

MO 20.18 Thu 16:30 Empore Lichthof

TrapREMI: A reaction microscope inside an electrostatic ion beam trap — Frans Schotsch[1], •Ilja Zebergs[1], Sven Augustin[1,2], Hannes Lindenblatt[1], Ludwig Hoibl[3], Denis Djendjur[3], Claus Dieter Schröter[1], Thomas Pfeifer[1], and Robert Moshammer[1] — [1]Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Baden-Württemberg, Germany — [2]Paul Scherrer Institut, Forschungsstrasse 111, 5232 Villigen, Switzerland — [3]Department of Physics and Astronomy, Ruprecht-Karls University, 69120 Heidelberg, Baden-Württemberg, Germany

A novel setup has been developed to investigate the reaction dynamics of (molecular) ions with a variety of projectiles in kinematically complete crossed-beam experiments. The setup combines an electrostatic ion beam trap (EIBT) with a reaction microscope (REMI).

The EIBT stores ions in oscillatory motion at several keV and allows further preparation e.g. cooling, relaxation, pulsing of the beam, mass selection. Reactions are induced by crossing the ion beam with another beam in the field-free region of the EIBT, where the REMI is located. The REMI, oriented along the target beam axis, allows for detection of all fragments in coincidence, including neutral particles, and reconstruction of their 3D-momenta.

During first REMI tests a laser pulse was used as the projectile to induce photodissociation in molecular ions. Currently a gas jet was assembled to provide an atomic/molecular beam and first simple ion-atom/molecule collision experiments are conducted.

MO 20.19 Thu 16:30 Empore Lichthof

Collisional excitation and dissociaton of CO molecules by ion impacts and aplications to astrophysics — •Masato Nakamura — College of Science and Technology, Nihon University, Funabashi, Japan

The CO molecule is one of the most abundant molecules in interstellar space and a major component of the stellar (solar) winds is proton. Thus, the collisional excitation and collision-induced dissociation (CID) by proton impacts are expected play important roles in the chemical evolution of interstellar molecules. Here we present a theoretical work on the energy transfer and fragmentation of CO molecule by proton impact at hyperthermal energies. The classical trajectory calculation and the sudden-limit model are applied to estimate the energy transfer from translational to internal degrees of freedom. The threshold energy for the dissociaton is calcuted by for the impact of singly charged ions. For comparison, the calculation is performed also for nitrogen molecule. The nitrogen molecule is a major component of atomosphere of Titan.

MO 21: Molecular Physics with X-rays

Time: Friday 11:00–13:00 Location: F102

MO 21.1 Fri 11:00 F102

X-ray induced luminescence for DNA molecules in aqueous solution via nitrogen core ionization — •Yusaku Terao[1], Yoshiaki Kumagai[1], Issei Suzuki[1], Takahiro Tsuchiya[1], Masatoshi Ukai[1], Akinari Yokoya[2], Kentaro Fujii[2], Yoshihiro Fukuda[3], and Yuji Saitoh[4] — [1]Dept. of Applied Physics, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan — [2]Institute for Quantum Life Science, Naka-gun, 319-1195, Ibaraki, Japan — [3]SPring-8 Service Co. Ltd., Tatsuno-shi, Hyogo 679-5165, Japan — [4]Synchrotron Radiation Research Center, Hyogo 679-5148, Japan

Radiation effect to biological matter can lead to various kinds of damages on a molecular level. However, a protective environmental effect of surrounding water is expected to play an important role to suppress damage inductions. To get to know about the protective environmental effect, we studied intermediate species along the reaction pathway of core ionized DNA molecules in aqueous solution. We conducted X-ray induced luminescence spectroscopy for nucleotides in aqueous solution using monochromatic soft X-rays in the nitrogen K-shell region at SPring-8 BL23SU. We obtained the excitation spectra of total luminescence yields for four nucleotides samples and the filtered luminescence spectra as well. Those results indicated the luminescence from parent base species which are maintained even after the Auger ionization of core-hole state, implying significant emission processes of their excess charge and energy can take place in the relaxation pathway.

MO 21.2 Fri 11:15 F102

Experimental investigation of solvated metal ions after X-ray-induced ionization — •Dana Bloss[1], Florian Trinter[2,3], Uwe Hergenhahn[2], Arno Ehresmann[1], and Andreas Hans[1] — [1]Institut für Physik und Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel — [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin — [3]Institut für Kernphysik, Goethe-Universität, Max-von-Laue-Str.1, 60438 Frankfurt am Main

Exploration of the microscopic response of biological systems to ionizing radiation is a key to understanding radiation damage on a molecular level. Of special interest in this context are low-energy electrons (LEEs) with energies below 30 eV, which are known to be genotoxic. One source of these LEEs upon X-ray irradiation are secondary processes like the interatomic Coulombic decay (ICD) - an energy-transfer process - or the electron-transfer-mediated decay (ETMD) - a charge-transfer process. Both have attracted attention as a source of efficient localized emission of LEEs close to the site of ionization and been studied intensely throughout the last decades in clusters and solutions. A multi-step cascade of ICD and ETMD processes upon X-ray ionization of microsolvated metal ions, e.g., Mg^{2+}, was predicted. We experimentally investigate this theoretically predicted LEE emission for Mg^{2+}, Ca^{2+} and Al^{3+} solutions at different synchrotron facilities with a combination of liquid microjets and coincident electron detection.

MO 21.3 Fri 11:30 F102

Tracking the birth of the solvated electron with x-rays — •Arturo Sopena Moros[1], Ludger Inhester[1], and Robin Santra[1,2] — [1]Center for Free-Electron Laser Science, DESY — [2]Department of Physics, Universität Hamburg

The attention that the solvated electron, e^{-}(aq), has received over the past half century, both from theory and experiment, is well justified due to its fundamental role in the chemistry of water. Its high reactivity and its role in radiation damage of DNA [1] have important implications in physics, chemistry, and biology. Albeit the apparent simplicity of this system, a unified picture of the solvation process remains elusive. In this theoretical study, we explore the capabilities of time-resolved x-ray absorption spectroscopy (XAS) as a new tool to investigate the ultrafast dynamics of the formation of the solvated electron.

We used classical and ring-polymer molecular dynamics together with a recently published neural network-based force field trained on MP2 electronic structure calculations [2] to simulate the evolution of an excess electron placed in bulk water. The simulations reveal that e^{-}(aq) localizes in a cavity with a radius of 2.4 Å within 1.6 ps. For snapshots of the simulations, we have calculated the XAS using the ab-initio electronic structure toolkit XMOLECULE [3]. The calculations reveal that it is possible to trace the solvation dynamics of the electron in liquid water by inspecting distinct features in the time-resolved XAS.

[1] Chem. Rev. 112, 5553 (2012). [2] Nat. Commun. 12, 766 (2021). [3] Struct. Dyn. 2, 041707 (2015)

MO 21.4 Fri 11:45 F102

Chemical effects on the dynamics of organic molecules irradiated with high intensity x rays — •Sourav Banerjee[1,2], Zoltan Jurek[1,2,3], Malik Muhammad Abdullah[2], and Robin Santra[1,2,3,4] — [1]Center for Free-Electron Laser Science (CFEL), Notkestr. 85, 22607 Hamburg, Germany — [2]Deutsches Elektronen-Synchrotron (DESY), Notkestr. 85, 22607 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]Department of Physics, Universität Hamburg, Notkestr. 9-11, 22607 Hamburg, Germany

High intensity ultra-short x-ray pulses, produced by X-ray free-electron lasers (XFEL), induce complex dynamics in matter. Over the past several years, numerical simulations for various molecular systems and clusters have successfully been performed with the classical molecular dynamics (MD) based hybrid code XMDYN.

The present study [1] extends the XMDYN toolkit to capture the effect of charge transfer and chemical bonds. The chemical bonds are approximated by the reactive force field (ReaxFF) description. The system under examination is a small organic molecule, glycine, which, being an amino acid, has relevance to general biological systems. Effects on key quantities, e.g., time dependent charge states, etc. are analyzed. The present study suggests that the chemical effects are of importance for realistically achievable fluences, whereas bondless simulation is accurate for high fluence.

[1] S. Banerjee et al., Struct. Dyn. 9, 054101 (2022) and references therein.

MO 21.5 Fri 12:00 F102

Probing the UV-induced ultrafast dynamics of thionucleobases with time-resolved x-ray absorption at the Free Electron Laser FLASH — •F Lever[1,2], D Mayer[1,2], D Picconi[6], S Alisauskas[2], F Calegari[2], S Duesterer[2], C Ehlert[4], R Feifel[3], M Kuhlmann[2], T Mazza[7], J Metje[1], M Robinson[1,2], R Squibb[3], A Trabattoni[2,8], M Ware[5], P Saalfrank[1], T Wolf[5], and M Ghuer[1,2] — [1]Universität Potsdam, Germany — [2]DESY, Germany — [3]University of Gothenburg, Sweden — [4]Heidelberg Institute for Theoretical Studies, Germany — [5]SLAC, USA — [6]University of Groningen, Netherlands — [7]XFEL, Germany — [8]IQO, Germany

Light-induced ultrafast reactions play a fundamental role in the photophysics of DNA, as they can lead to the formation of lesions in the genetic code. Thionucleobases are sulfur- substituted nucleobases that show an increased rate of UV-induced lesion formation. In a previous work by this group, we have investigated the photoinduced dynamics of 2-thiouracil (2-tUra) via time resolved x-ray photoemission [1,2]. In this work, we study the ultrafast dynamic 2-thiouracil in a UV-pump, x-ray probe experiment at the Free Electron Laser FLASH. The molecule is excited by the pump pulse in the S2 state ($\pi\pi^*$ character), and its dynamic is probed by a delayed x-ray pulse that is resonant with 2p and 2s excitations of the sulfur atom. The localized probe on the sulfur allows us to image the excitation of the dark S1 (nπ) state within a 100fs time scale, and to follow oscillations in its population fraction with a period of 200fs. [1] Mayer et al. Nat Comm 13, 198 (2022) [2] Lever et al. J. Phys. B 54 014002 (2021)

MO 21.6 Fri 12:15 F102

Creating Electronic Molecular Movies Using Time-Resolved X-Ray Photoelectron Spectroscopy at Free-Electron Lasers — •Dennis Mayer[1], Fabiano Lever[1], David Picconi[2], Skirmantas Alisauskas[1], Agata Azzolin[5], Francesca Calegari[3,4,5], Giovanni Cirmi[1,4], Stefan Düsterer[1], Ulrike Frühling[1], Alice Green[6,7], Ingmar Hartl[1], Marion Kuhlmann[1], Tommaso Mazza[6], Steffen Palutke[1], Sebastian Schulz[1], Andrea Trabbatoni[3,8], Atia Tul Noor[1], and Markus Gühr[1] — [1]DESY, Hamburg, Germany — [2]University of Groningen, The Netherlands — [3]CFEL, DESY, Hamburg, Germany — [4]The Hamburg Centre for Ultrafast Imaging, Germany — [5]University of Hamburg, Germany — [6]European XFEL, Schenefeld, Germany — [7]Stanford PULSE Institute, Menlo Park, USA — [8]University of Hannover, Germany

Recently, we were able to extend the chemical shift concept to excited state molecular dynamics [1]. Here, we present a follow-up experiment performed at FLASH, showing C 1s time-resolved photoelectron spectra of 2-thiouracil after UV excitation. The photoelectron spectra show a strong shift towards lower binding energies suggesting a charge movement towards the pyrimidine ring. These measurements verify the concept of the excited-state chemical shift [1] and pave the way to create electronic molecular movies for the UV-induced relaxation using time-resolved x-ray photoelectron spectroscopy.

[1] Mayer et al., Nature Communications 13, 198 (2022)

MO 21.7 Fri 12:30 F102

Tracking Conical Intersections with Nonlinear X-ray Raman Spectroscopy — •Deependra Jadoun and Markus Kowalewski — Department of Physics, Stockholm University, Albanova University Centre, SE-106 91 Stockholm, Sweden

Conical intersections (CIs) play a vital role in processes such as the event of vision, and DNA damage from sunlight. A CI appears in a molecule when electronic and nuclear motions are strongly coupled, and it acts as a funnel that guides a molecule from one electronic state to another. Substantial efforts have been made toward understanding such non-adiabatic phenomena. X-ray Raman techniques have been proposed in the past to investigate the presence of a CI in molecules.

We propose a two-dimensional Raman probe scheme that uses a visible/infrared pulse and an ultra-short X-ray Raman probe pulse. The visible/infrared pulse interaction creates a coherent superposition of electronic states in the molecule. Probing the coherent superposition using ultra-short X-ray pulses allows to visualize the dynamic energy separation between electronic states throughout the photochemical process. The lifetime of the coherent superposition created using the infrared pulse can be read directly from two-dimensional Raman spectra. Therefore, the method aids to the observation of multiple indicators of a conical intersection and may allow for a more detailed study of non-adiabatic dynamics in molecules.

MO 21.8 Fri 12:45 F102

X-FEL induced Coulomb explosion: Advanced analysis of coincident ion momenta — •Benoît Richard[1,2,3], Robin Santra[1,2,3], and Ludger Inhester[1,2,3] — [1]CFEL, DESY, Hamburg, Germany — [2]CUI, Hamburg, Germany — [3]Universität Hamburg, Hamburg, Germany

Intense x-ray pulses from x-ray free-electron lasers (X-FEL) ionize small molecular systems leading to their violent dissociation into several atomic fragments on a femtosecond time scale. Recent experiments with the 2-iodopyridine molecule have demonstrated that measuring the momenta of only 3 fragments in coincidence is sufficient to distinguish individual ion contributions. [1] However, combining all the different n-particle coincidence data, where in each a different subset of ion fragments is detected, into a joint distribution is not trivial.

We present a general method to perform such analysis. We demonstrate its application using simulation data of the X-FEL-induced Coulomb explosion of 2-iodopyridine and use it to extract correlations between ion momenta. We show that such correlations contain fingerprints of collisions during the explosion. [2] Moreover, we demonstrate that this data is related to the structure of the molecule just before being hit by the x-ray pulse that destroyed it.

[1] R. Boll, J. Schäfer, B. Richard et al. 2022. Nat. Phys. 18, 423-428
[2] B. Richard et al. 2021. J. Phys. B: At. Mol. Opt. Phys. 54 194001

MO 22: Theoretical and Computational Molecular Physics

Time: Friday 11:00–13:15 Location: F142

Invited Talk MO 22.1 Fri 11:00 F142

A QED Theory of Mediated RET Between a Pair of Chiral Molecules — •Akbar Salam — Department of Chemistry, Wake Forest University, Winston-Salem, NC 27109, USA

A QED [1] theory of relayed resonance energy transfer (RET) [2] between a pair of identical chiral molecules by one or two neutral, passive, electric dipole polarizable bodies, is developed. Migration of excitation energy occurs via the exchange of a single virtual photon between any two interacting particles. Isotropic Fermi golden rule transfer rates are evaluated for direct and bridge-mediated pathways. Rates from both routes depend on the chirality of the donor and acceptor moieties [3-5]. For conveyance of energy to take place indirectly, a multi-level model must be adopted for each mediator polarizability. Furthermore, the rate is found to be a maximum when the three or four particles are collinear. Useful understanding is achieved of propagation of energy between optically active entities in a medium with uniform dielectric constant [6]. [1]*A. Salam, Molecular Quantum Electrodynamics, John Wiley & Sons, Inc., 2010. [2]*A. Salam, Atoms 6, 56 (2018). [3]*D. P. Craig and T. Thirunamachandran, J. Chem. Phys. 109, 1258 (1998). [4]*A. Salam, J. Phys. Chem. A 125, 3549 (2021). [5]*A. Salam, J. Chem. Phys. 157, 104110 (2022). [6]*J. Franz, S. Y. Buhmann and A. Salam, arXiv:2209.15400 [quant-ph].

MO 22.2 Fri 11:30 F142

Excitation transport in molecular aggregates with thermal motion — •Ritesh Pant and Sebastian Wüster — Indian institute of science education and research, Bhopal, India

Molecular aggregates can under certain conditions transport electronic excitation energy over large distances due to the long range dipole-dipole interactions. These interactions are also the characteristics of Rydberg aggregates which have been proved as the quantum simulators for molecular aggregates. An idea that naturally arises in Rydberg aggregates, is adiabatic excitation transport through atomic motion, where slow motion of the atoms combined with excitation transport can result in efficient and guided transport of the excitation from one end of an atomic chain to the other. Based on the analogy between Rydberg- and Molecular aggregates, in ref. [1] we explore whether the adiabatic excitation transport can play a functional role in molecular aggregates in the absence of intra-molecular vibrations. But because the transport is partially adiabatic and because it involves transitions between non-eigenstates, it is challenging to estimate the adiabaticity of transport in molecular aggregates. Hence, in ref [2] we established a measure to quantify the adiabatic character of quantum transitions in general. Next, the effect of intramolecular vibrations is included by extending our calculation for excitation transport to an open-quantum-system technique [3].

[1] R. Pant and S. Wüster, Physical Chemistry Chemical Physics 22, 21169 (2020). [2] R. Pant, et al., https://arxiv.org/abs/2007.10707. [3] R. Pant, et al., (Manuscript in preparation)

MO 22.3 Fri 11:45 F142

Rotational and vibrational decay of diatomic molecules near a surface — •Nicolas Schüler, Omar Jesús Franca Santiago, and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We study the rotational and vibrational motion of chiral diatomic molecules near a dielectric surface [1]. We use macroscopic quantum electrodynamics [2] to obtain the decay rate of the molecule. We determine the critical distances at which retarded (nonretarded) interactions with the surface become dominant, which happens when the distances are much larger (smaller) than the atomic transition wavelengths, respectively. We explore potential links of the rotational and vibrational dynamics with quantum friction.

[1] Stefan Yoshi Buhmann, M. R. Tarbutt, Stefan Scheel, and E. A. Hinds, Phys. Rev. A 78, 052901 (2008).
[2] D.T. Butcher, S.Y. Buhmann, and S. Scheel, New J. Phys. 14, 113013 (2012).

MO 22.4 Fri 12:00 F142

Medium-assisted chiral discrimination via resonance energy transfer — •Janine Chirstine Franz[1], Stefan Yoshi Buhmann[2], and Akbar Salam[3] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany — [3]Wake Forest University, Winston-Salem, USA

Resonance energy transfer between two chiral molecules can be used in principle to discriminate enantiomers [1]. Using macroscopic quantum electrodynamics, we study how to enhance and control this effect by means of an intervening medium and propose a distinct, but related way to discriminate between enantiomers by using a medium with known chirality [2].

When embedding molecules in a macroscopic medium, the microscopic structure of the medium close to the embedded molecule needs to be taken into account; we achieve this by using the so-called local-field correction. We present the influence of a magneto-(di)electric medium surrounding the energy-exchanging molecules, where exotic media have a non-trivial impact on the degree of discrimination [3]. When considering a chiral medium that takes an active part in the chiral discrimination, we find that considering local-field effects results in a surprising prediction for the discrimination.

[1] D. P. Craig et al., J. Chem. Phys. 109, 1258 (1998)
[2] S. Y. Buhmann et al., New J. Phys. 14 083034 (2012)
[3] J. Franz et al., arXiv:2209.15400 [quant-ph]

MO 22.5 Fri 12:15 F142

Analysis of the dopamine D2 receptors interaction with three radiopharmaceuticals using molecular dynamics techniques — Nastasia-Sanda Moldovean-Cioroianu, •Diana-Gabriela Timaru, and Vasile Chis — Babes-Bolyai University, Faculty of Physics, Cluj-Napoca, Romania

It is widely known that the dopamine neurotransmitter and its receptors play a pivotal role in neuronal signal transduction and other metabolic processes. Using molecular dynamics (MD) techniques, this study seeks to find and describe the optimal binding positions between the D2 dopamine receptor (D2DR) and three [11C]-labeled synthetic compounds: [11C]-FLB 457, raclopride ([11C]-RACL), and halobenzazepine ([11C]-SCH).

Previous research has demonstrated that the FLB 457 molecule has a high affinity for the D2 dopamine subunit. In addition, [11C]-tagged RACL is already employed as a PET scan radiotracer.

Our analysis showed, in good agreement with experimental results, that RACL ligand bound at the upper portion of the D2 dopamine receptor had the highest interaction energy patterns. In addition, these discoveries pave the path for future research. Perspectives include more MD studies as well as thorough production time and free energy estimates. The same set of radiopharmaceuticals will be docked in the receptor's top pocket, with the D2DR structure encased in a DOPC/phospholipid bilayer membrane.

MO 22.6 Fri 12:30 F142

Molecules for photodynamic therapy. Photophysical properties of 1O2 and1,3-diphenylsobenzofuran — •Stefan Stan and Vasile Chis — Babes-Bolyai University, Faculty of Physics, Cluj-Napoca, Romania

The first part of the study focuses on the calculation of the excitation energies of the O2 molecule in the first and second excited states, using the [8,6]-CASSCF method and the complete basis set extrapolation technique. The calculated energies are 0.983 and 1.671 eV, in excellent agreement with the available experimental data (0.98 and 1.63 eV). As a result of the transition to the first excited state, the DPBF molecule is significantly planarized, and the bond lengths undergo significant changes only in the benzofuran group.

Several density functionals were tested for the reproduction of the photophysical parameters of the molecule, and the results clearly show that the cam-B3LYP functional provides the best agreement with the experimental data, for all photophysical parameters.

The first excited state of the molecule is due to the π-π^* transition between the HOMO-LUMO orbitals. The transition was described based on the natural transition orbitals and the difference between the electronic densities corresponding to the excited state and the fundamental one. An excellent agreement has been obtained between the experimental radiative lifetime (5.52 ns) and the calculated calculated counterpart (5.34 ns) at PCM(DMSO-cam-B3LYP/6-311G(2d,p)//APFD/6-311+G(2d,p) level of theory.

MO 22.7 Fri 12:45 F142

Gas phase sugar sythesis: the formation of glycolaldehyde — •Weiqi Wang[1], Xiangyue Liu[1], and Jésus Pérez-Ríos[2] — [1]Fritz-Haber Institute, Max-Planck Society, Berlin — [2]Stony Brook University, Stony Brook, New York

Gas-phase sugar synthesis is one of the most important reactions for the understanding of prebiotic chemistry in space. In this work, ab initio molecular dynamics has been employed to study the formation of glycolaldehyde from protonated formaldehyde, which is the first step of the carbon chain growth reaction. In particular, the isomerization of neutral formaldehyde molecule has been discussed. The reaction networks between neutral formaldehyde and protonated formaldehyde has been constructed to understand the formation of glycolaldehyde.

MO 22.8 Fri 13:00 F142

Kinetic and thermodynamic theory study of sequential reaction of Koop type hydroamination and [3 and 2] Meisenheimer rearrangement — •Morteza Farahani — Department of Physical Chemistry, Islamic Azad university, Malayer Branch, Malayer, Iran Farahanijokar@yahoo.com

Koop Norborne type hydroamination using N-allyl-N-methylhydroxylamine at 120 * and tetrahydrofuran solvent leads to the production of unstable dipolar N-oxide intermediate which turns into a neutral product with higher stability after [3 and 2] Meisenheimer rearrangement. The kinetics and thermodynamics of this sequential reaction have been studied at the computational level of MN15L/aug-cc-pVTZ. The first stage of the reaction is exothermic and non-spontaneous, while the second stage is exothermic and spontaneous. The adverse effects of entropy and high temperature make the rate constant of the first stage, despite the lower activation energy, smaller than the second stage, and the balance is not towards the production of the dipolar N-oxide intermediate.

MO 23: Ultrafast Dynamics III (joint session MO/A)

Time: Friday 14:30–16:30 Location: F102

MO 23.1 Fri 14:30 F102

Photodissociation dynamics of CH_2Br — •Lilith Wohlfart, Christian Matthaei, and Ingo Fischer — Julius-Maximilians-Universität Würzburg, 97074 Würzburg, Germany

Bromomethyl belongs to the class of organic halogen radicals. Therefore, it can potentially influence the atmosphere by reacting with the ozone layer and causing its depletion similar to HCFCs. The photoionization of bromomethyl was already investigated by several groups, including Steinbauer and coworkers. They determined the ionization energy and structure with VUV synchrotron radiation and investigated the dissociative photoionization. To obtain further insights into the dissociation of bromomethyl, we analyzed the fragments of the radical using velocity map imaging (VMI).

CH_2Br-NO_2 was used as a precursor for the halogenated methyl radical, because the weaker C-NO_2 bond can be cleaved through pyrolysis. Subsequently, laser light with 235 nm was deployed to dissociate the formed CH_2Br radical. The major dissociation pathway gave the methylene and bromine fragments which were detected with SPI at 118 nm and [1+1']-REMPI at 356 nm respectively. With velocity map ion imaging, the translational kinetic energy distribution of the photofragments was determined. The recorded images of the bromine and methylene photofragments showed an anisotropic distribution, implying a direct dissociation.

MO 23.2 Fri 14:45 F102

Fragmentation of fulminic acid, HCNO, following core excitation and ionization — •Dorothee Schaffner[1], Marius Gerlach[1], Tobias Preitschopf[1], Emil Karaev[1], Fabian Holzmeier[2], John Bozek[3], and Ingo Fischer[1] — [1]Universität Würzburg, 97074 Würzburg — [2]imec, 3001 Leuven, Belgium — [3]Synchrotron SOLEIL, 91190 Saint-Aubin, France

In 2008 fulminic acid, HCNO, was first detected in space in the starless cores B1, L1544 and L183.[1] Its isomer HNCO is also ubiquitous in interstellar systems.[2] Due to their composition of biogenic elements, the CHNO isomers have been proposed to play a prebiotic role as intermediates for organic life. Investigating the molecules' interaction with X-ray radiation is critical to understand their fate in space.

Here we report a study of the fragmentation of fulminic acid in the gas phase after resonant core excitation and core ionization on the K-edge of carbon, oxygen and nitrogen. The ionic fragmentation products formed after the auger decay were investigated at the PLEIADES beamline at the synchrotron SOLEIL using Auger-electron/photoion coincidence spectroscopy. Branching ratios were determined which show a site-selective fragmentation upon ionization and excitation. Different fragmentation tendencies could be related to differences in the occupation of the auger final states.

[1] N. Marcelino, J. Cernicharo, B. Tercero, E. Roueff, *Astrophys. J.* **2008**, 690, L27-L30.

[2] Nguyen-Q-Rieu, C. Henkel, J. M. Jackson, R. Mauersberger, *Astron. Astrophys.* **1991**, 241, L33-L36.

MO 23.3 Fri 15:00 F102

Ultrafast dynamics of OCS — •Wuwei Jin[1], Sebastian Trippel[1,3], Hubertus Bromberger[1,3], Tobias Röhling[1], Karol Dlugolecki[1], Sergey Ryabchuk[1], Erik Månsson[1], Andrea Trabattoni[1], Vincent Wanie[1], Ivo Vinklárek[4], Francesca Calegari[1], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Physics, Universität Hamburg — [3]Center for Ultrafast Imaging, Universität Hamburg — [4]Department of Chemical Physics and Optics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

Imaging ultrafast photochemical reactions with atomic-spatial and femtosecond-temporal resolution is one of the ultimate goals of physical chemistry and the molecular sciences [1]. We will discuss our ultrafast (sub 10 fs) time-resolved study of the photodissociation dynamics of carbonyl sulfide (OCS) after UV-photoexcitation at λ = 267 nm. OCS was purified and separated from the helium seed gas using the electrostatic deflector [2]. The UV-induced dynamics was studied through strong field ionization using a velocity map imaging spectrometer in combination with a Timepix3 camera [3].

[1] J Onvlee, S Trippel, and J Küpper, *doi:10.1038/s41467-022-33901-w*, arXiv:2103.07171 [physics]

[2] YP Chang, D Horke, S Trippel, and J Küpper, *Int. Rev. Phys. Chem.* 34, 557 (2015), arXiv:1505.05632 [physics]

[3] H Bromberger, *et al., J. Phys. B Atomic Mol. Opt. Phys.* 55, 144001 (2022), arXiv:2111.14407 [physics]

MO 23.4 Fri 15:15 F102

Ultrafast dynamics in iodomethane induced by few-fs ultraviolet pulses — •Sergey Ryabchuk[1,2], Lorenzo Colaizzi[2,3], Erik P. Månsson[3], Krishna Saraswathula[3], Jesús González-Vázquez[4], Vincent Wanie[3], Andrea Trabattoni[3,5], Fernando Martin[4,6,7], and Francesca Calegari[1,2,3] — [1]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [2]Universität Hamburg, Hamburg, Germany — [3]DESY, Hamburg, Germany — [4]Universidad Autonoma de Madrid, Madrid, Spain — [5]Leibniz Universität Hannover, Hannover, Germany — [6]IMDEA-Nanoscience, Madrid, Spain — [7]IFIMAC, Madrid, Spain

Iodomethane has been extensively used as a model system to study photodissociation dynamics by ultraviolet (UV) light excitation. The molecule is prompted to rapid fragmentation along the C-I bond due to the repulsive character of the neutral states accessed by single UV photon absorption in the energy range of 4.1-5.4 eV. In this work, we used 4 fs UV pulses with central energy of 4.9 eV as a pump with delayed few-cycle infrared pulses, probing the dynamics via multi-photon ionization. The dynamics of methyl and iodine fragments allow us to track the field-free wavepacket evolution on the neutral states with unprecedented time resolution. Moreover, the experimental observations combined with a theoretical study revealed that the implementation of such ultrashort pulses allows for the production of an intact parent ion with a 5-fs lifetime, preventing molecular cleavage. This becomes possible only in a narrow time window close to the Frank-Condon regime before the dissociation takes place.

MO 23.5 Fri 15:30 F102

Photoemission chronoscopy of the Iodoalkanes — •Christian Schröder, Maximilian Pollanka, Pascal Scigalla, Andreas Duensing, Michael Mittermair, Maximilian Forster, Matthias Ostner, and Reinhard Kienberger — Physik Department, Technische Universität München, James-Franck-Str. 1, 85748 Garching, Germany

Photoemission timing measurements on primary and secondary iodoalkanes up to 2-iodobutane are performed in the gas phase and reveal an unexpected and yet unexplained dependency of the I4d photoemission time delay τ_{I4d} on the molecular species.

The experiment is is carried out at photon energies around the giant resonance in the I4$d \rightarrow \varepsilon f$ channel, which is expected to be largely indifferent to its chemical environment. If true, observable differences in the I4d photoemission time between molecules should be a direct consequence of differences experienced by the leaving photoelectron during its propagation alone, and not due to a distortion of its initial bound state.

We find a strong variation of τ_{I4d} between different molecules, but no clear correlation with the attached functional group's size as it has been suggested by previous theoretical studies (S. Biswas et al., Nature Physics **16** (2020)).

MO 23.6 Fri 15:45 F102

X-ray diffractive imaging of UV-induced ultrafast dynamics in CF_2I_2 — •Nidin Vadassery[1,3], Sebastian Trippel[1,2], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science CFEL, Deutches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Physics, Universität Hamburg — [3]Department of Chemistry, Universität Hamburg

Disentangling chemical dynamics, including the traversal of transition states, provides important insight into (bio)chemical processes. Roaming for example, a proposed ultrafast mechanism occurring in unimolecular photodissociation, follows an unusual reorientation motion after the excitation near bond dissociation energies [1]. Difluorodiiodomethane (CF_2I_2), has shown roaming mechanism following excitation with 350 nm light.

X-ray pulses generated at XFELs provide the opportunity to study such ultrafast rearrangements on the atomic scale with femtosecond resolution by diffractive imaging. Here, we present a computational proposal of the time-resolved coherent x-ray diffractive imaging of the photodissocaition of CF_2I_2 using CMIdiffract, an in-house python software to predict and analyze molecular-ensemble diffraction patterns[2]. We also detail efforts to produce a pure sample of CF_2I_2 using the electric deflector in the eCOMO end-station, in preparation for UV-pump x-ray-probe studies at EuXFEL.

[1] D. Townsend, *et al.*, *Science* **306**, 1158, (2004)

[2] J. Küpper, *et al.*, *Phys. Rev. Lett.* **112**, 083002, (2014), arXiv:1307.4577

MO 23.7 Fri 16:00 F102

Dynamics of H_2-roaming processes, H_3^+ formation, and cationic fragmentation in ethanol and aminoethanol initiated above and below the double-ionization threshold — •Aaron Ngai[1], Jakob Asmussen[2], Björn Bastian[2], Matteo Bonanomi[3,4], Carlo Callegari[5], Michele di Fraia[5], Katrin Dulitz[1,6], Raimund Feifel[7], Sarang Ganeshamandiram[1], Sebastian Hartweg[1], Sivarama Krishnan[8], Aaron LaForge[9], Friedemann Landmesser[1], Ben Ltaief Ltaief[2], Moritz Michelbach[1], Nitish Pal[5], Oksana Plekan[5], Nicolas Rendler[1], Fabian Richter[1], Audrey Scognamiglio[1], Tobias Sixt[1], Richard Squibb[7], Akgash Sundaralingam[2], Frank Stienkemeier[1], and Marcel Mudrich[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [2]Department of Physics and Astronomy, Aarhus University, Denmark — [3]Dipartimento di Fisica and CIMaINa, Universitá degli Studi di Milano, Italy — [4]Istituto di Fotonica e Nanotecnologie, CNR-IFN, Milano, Italy — [5]Elettra - Sincrotrone Trieste S.C.p.A., Basovizza, Trieste, Italy — [6]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria — [7]Department of Physics, University of Gothenburg, Sweden — [8]Department of Physics, Indian Institute of Technology Madras, Chennai, India — [9]Department of Physics, University of Connecticut, US

The trihydrogen cation (H_3^+) is the simplest and one of the most abundant triatomic cation in the universe. It plays a crucial role in interstellar gas-phase chemistry as it facilitates molecule-forming chemical reactions. Building upon the work of Ekanayake [1], we further investigated the competition between pathways leading to H_3^+ formation in doubly ionized ethanol and 2-aminoethanol molecules and their respective clusters using time-resolved XUV-UV pump-probe spectroscopy. While formation of H_3^+ in doubly-ionized alcohol molecules is due to intramolecular H_2-roaming, H_3^+ formation in clusters likely occurs via more complicated intermolecular pathways involving fragmentation and recombination of excited ionic fragments e.g. in nanoplasmas [2]. We compare results between XUV-photoionization below and above the double-ionization threshold, including the lifetimes of intermediate states. Notably, we report the absence of H_3^+-formation in aminoethanol, and the suppression of H_2-roaming in ethanol clusters.

[1] Ekanayake, N. *et al. Nature Comm.* **9**, 5186 (2018).

[2] Michiels, R. *et al. Phys. Chem. Chem. Phys.* **22**, 7828 (2020).

MO 23.8 Fri 16:15 F102

Probing well aligned molecular enviroments on surfaces in the time-domain — •Pascal Scigalla[1], Christian Schröder[1], Sven Paul[1], Peter Feulner[2], and Reinhard Kienberger[1] — [1]Chair for laser and x-ray physics, E11, Technische Universität München, Germany — [2]Surface and Interface Physics, E20, Technische Universität München, Germany

We report on the photoemission timing measurements of well-aligned iodomethane and -ethane molecules on a Pt111 surface. In this set of experiments we clock the I4d photoemission of iodine against the Platinum valence photoemission using the attosecond streak camera technique, allowing the extraction of a relative photemission delay. As the $I4d$ photoemission in the selected energy range is dominated by a giant resonance in the $I4d \rightarrow ef$ channel its photoemission time is mostly unaffected by its chemical environment. Thus any observed change in the photoemission delay can be attributed to the traversed potential landscape of the molecule. By carefully selecting the detection angle and crystal surface coverage we can reliably choose whether only parts of the molecule or its entirety was traversed by the detected photoelectron wavepackets. It is furthermore possible to investigate the influence of slight coverage variations onto the observed photoemission delay. Planned, complementary scattering simulations will be used to gain deeper insight into the observations with the goal to establish photoemission timing experiments as an efficient and accurate means to study molecular environments on surfaces.

Mass Spectrometry Division
Fachverband Massenspektrometrie (MS)

Yury A. Litvinov
GSI Helmholtzzentrum für Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt
y.litvinov@gsi.de

Overview of Invited Talks and Sessions

(Lecture hall F128; Poster Empore Lichthof)

Invited Talks

MS 1.1	Tue	11:00–11:30	F128	**Lasers against barium – Detection of ^{135}Cs in the environment by AMS** — •Alexander Wieser, Johannes Lachner, Silke Merchel, Martin Martschini, Anaëlle Magre, Judith Kobler Waldis, Oscar Marchhart, Robin Golser
MS 3.1	Wed	14:30–15:00	F128	**Durable, low-temperature and highly-selective catalysis in NO reduction and CO oxidation driven by uni-sized Pt clusters supported on Si and SiC substrates** — •Hisato Yasumatsu
MS 4.1	Thu	11:00–11:30	F128	**Observation of the radiative decay of the thorium-229 nuclear clock isomer** — •Sandro Kraemer
MS 4.2	Thu	11:30–12:00	F128	**Mass measurements of heavy and superheavy nuclides and isomers with SHIPTRAP** — •Manuel J. Gutiérrez
MS 8.1	Fri	11:00–11:30	F128	**Two color resonant laser SNMS for isotope micro imaging of nuclear fuel debris** — •Tetsuo Sakamoto
MS 9.1	Fri	14:30–15:00	F128	**Developments to improve antiproton and other mass measurements** — •Christian Smorra on behalf of the BASE collaboration

Invited Talks of the joint Symposium Precision Physics with Highly Charged Ions

See SYHC for the full program of the symposium.

SYHC 1.1	Mon	11:00–11:30	E415	**First experiments at CRYRING@ESR** — •Esther Babette Menz, Michael Lestinsky, Håkan Danared, Claude Krantz, Zoran Andelkovic, Carsten Brandau, Angela Bräuning-Demian, Svetlana Fedotova, Wolfgang Geithner, Frank Herfurth, Anton Kalinin, Ingrid Kraus, Uwe Spillmann, Gleb Vorobyev, Thomas Stöhlker
SYHC 1.2	Mon	11:30–12:00	E415	**Testing quantum electrodynamics in the simplest and heaviest multi-electronic atoms** — •Martino Trassinelli
SYHC 1.3	Mon	12:00–12:30	E415	**Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings** — •Beatriz Jurado
SYHC 1.4	Mon	12:30–13:00	E415	**Laboratory X-ray Astropohysics with Trapped Highly Charged Ions at Synchrotron Light Sources** — •Sonja Bernitt
SYHC 2.1	Mon	17:00–17:30	E415	**Observation of metastable electronic states in highly charged ions by Penning-trap mass spectrometry** — •Kathrin Kromer, Menno Door, Pavel Filianin, Zoltán Harman, Jost Herkenhoff, Paul Indelicato, Christoph H. Keitel, Daniel Lange, Chunhai Lyu, Yuri N. Novikov, Christoph Schweiger, Sergey Eliseev, Klaus Blaum
SYHC 2.2	Mon	17:30–18:00	E415	**Towards extreme-ultraviolet optical clocks** — •José R. Crespo López-Urrutia
SYHC 2.3	Mon	18:00–18:30	E415	**Coupling atomic and nuclear degrees of freedom in highly charged ions** — •Adriana Pálffy
SYHC 2.4	Mon	18:30–19:00	E415	**Laser Spectroscopy at the Storage Rings of GSI/FAIR** — •Wilfried Nörtershäuser

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2023

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Prize Talks of the joint Awards Symposium

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich
SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt
SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Invited Talks of the joint Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit

See SYCC for the full program of the symposium.

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Sessions

MS 1.1–1.7	Tue	11:00–13:00	F128	**Accelerator Mass Spectrometry I**
MS 2.1–2.5	Wed	11:00–12:15	F128	**Multi-Reflection Time-of-Flight Spectrometers**
MS 3.1–3.5	Wed	14:30–16:00	F128	**Mass Spectrometry Applications**
MS 4.1–4.6	Thu	11:00–13:00	F128	**Heavy and Superheavy Elements**
MS 5	Thu	13:00–13:30	F128	**Members' Assembly**
MS 6.1–6.8	Thu	14:30–16:30	F128	**Accelerator Mass Spectrometry II**
MS 7.1–7.13	Thu	16:30–19:00	Empore Lichthof	**Poster**
MS 8.1–8.6	Fri	11:00–12:45	F128	**Accelerator Mass Spectrometry III**
MS 9.1–9.7	Fri	14:30–16:30	F128	**Penning traps, highest precision, neutrino physics, storage rings, new facilities and approaches**

Members' Assembly of the Mass Spectrometry Division

Thursday 13:00–13:30 Raum F128

- Report
- Miscellaneous

Sessions

– Invited Talks, Contributed Talks, and Posters –

MS 1: Accelerator Mass Spectrometry I

Time: Tuesday 11:00–13:00 Location: F128

Invited Talk MS 1.1 Tue 11:00 F128

Lasers against barium – Detection of ^{135}Cs in the environment by AMS — •Alexander Wieser[1], Johannes Lachner[1,2], Silke Merchel[1], Martin Martschini[1], Anaëlle Magre[3], Judith Kobler Waldis[4], Oscar Marchhart[1], and Robin Golser[1] — [1]University of Vienna, Isotope Physics, Vienna, Austria — [2]HZDR, Accelerator Mass Spectrometry and Isotope Research, Dresden, Germany — [3]Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France — [4]Universität Basel, Departement Umweltwissenschaften, Basel, Schweiz

^{137}Cs ($T_{1/2} \approx 30$ yrs) is a high-yield product of nuclear fission and easily detectable via its gamma decay but ^{137}Cs alone without further information is not assignable to an anthropogenic source. The measurement of ^{135}Cs ($T_{1/2} \approx 2$ Myrs) can help identifying the origin of radiocesium. While it is impossible to measure ^{135}Cs radiometrically in the presence of ^{137}Cs, mass spectrometric methods need to suppress stable isobars ^{135,137}Ba and molecules of similar mass. The Ion-Laser Interaction Mass Spectrometry (ILIAMS) setup at the Vienna Environmental Research Accelerator (VERA) does exactly that. Overlapping a 10 W laser beam with the ion beam in a radiofrequency quadrupole, the interfering isobars ^{135,137}Ba are suppressed by seven orders of magnitude, realizing detection limits of $7 \cdot 10^6$ atoms, i.e. ≈ 5 mBq of ^{137}Cs per sample. We will present the progress of our ILIAMS measurements at VERA, with our struggles to reduce cross contamination in the ion source and a focus on Cs measurements of environmental sediment samples prepared from 100 g of soil.

MS 1.2 Tue 11:30 F128

Thickness measurement of thin foils using a Time of Flight spectrometer — •Elisa Chopan, Gereon Hackenberg, Markus Schiffer, Stefan Heinze, Martina Gwozdz, Timm-Florian Pabst, Carlo Baddeliyanage, Tom Sittig, Alfred Dewald, and Dennis Mücher — Institut für Kernphysik, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Deutschland

In many nuclear physics experiments, a target foil is shot at, whereby the precise thickness is often unknown. A Time of Flight setup at the AMS setup of the Cologne FN tandem accelerator (10 MV) was established, with which the thickness of thin target foils can be determined. The setup can use ions of different charges and energies to measure the ToF between a start and stop detector. The foil of interest is placed in front of the start and stop detector and hence induces an energy loss of the ions. Using known stopping powers then allows to determine the thickness of the foil. In this contribution, we present the setup consisting of multichannel plate (MCP) detectors and show the achieved accuracy for different combinations of foils and ions. We have found good agreement of our results with measurements using standard techniques.

MS 1.3 Tue 11:45 F128

Status of the advanced radiofrequency quadrupole for AMS - first results from the test bench setup of VERA — •Oscar Marchhart[1,2], Markus Schiffer[3], Alfred Priller[1], Susan Herb[3], Peter Steier[1], Gereon Hackenberg[3], Martin Martschini[1], Dennis Mücher[3], Alfred Dewald[3], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics, Isotope Physics, Vienna, Austria — [2]University of Vienna, Vienna Doctoral School in Physics, Vienna, Austria — [3]University of Cologne, Institute for Nuclear Physics, Cologne, Germany

Accelerator Mass Spectrometry (AMS) is the most sensitive method for the detection of trace amounts of long-lived radionuclides. The Ion-Laser InterAction Mass Spectrometry (ILIAMS) setup at the Environmental Research Accelerator (VERA) has demonstrated great isobar suppression capabilities using laser photodetachment in a gas-filled radiofrequency quadrupole (RFQ). With the ILIAMS technique, new AMS isotopes for research on environmental radioactivity (^{90}Sr, ^{135}Cs) and astrophysics (^{182}Hf) become accessible.

An advanced RFQ ion cooler based on ILIAMS has been developed and built. Its performance is currently being studied at the test bench setup of VERA. The new design consists of elliptically shaped injection and extraction electrodes and a new guiding field structure that uses hybrid-electrodes. These changes intend to solve the technical challenges of decelerating and trapping ion beams with high emittance which typically arise when using fluoride anions like SrF_3^- and result in significant transmission losses up to 90%.

MS 1.4 Tue 12:00 F128

Towards ^{41}Ca AMS measurements at low energies with laser-based isobar suppression — •Carlos Vivo-Vilches[1], Martin Martschini[2], Silke Merchel[2], Johannes Lachner[1], and Anton Wallner[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Accelerator Mass Spectrometry and Isotope Research, Germany — [2]University of Vienna, Faculty of Physics, Isotope Physics, Austria

In 2023, a new 1 MV AMS facility including laser-based isobar suppression capabilities, HAMSTER, will be installed at HZDR. Because of the successful use of this suppression technique to ^{41}Ca AMS measurements at VERA (Vienna, Austria), preliminary tests were performed there at a terminal voltage of 1.2 MV.

The transmission through the He gas stripper for charge states 1+, 2+ and 3+ at different stripping energies was studied. A transmission of 38% for the 2+ state at 1.2 MV was measured. While molecular ions survive the interaction with the buffer gas and the 355 nm laser, these can be totally discriminated by the gas ionization chamber, even for the 2+ state (2.9 MeV). Hence, a higher stripper pressure to suppress these molecular ions is not required.

After collision- and photo-induced KF_3^- dissociation, the final $^{41}K/^{40}Ca$ interference was $(2.0 \pm 1.0) \times 10^{-13}$. Looking for suppression based on electron photodetachment, the stability of CaF^- and KF^- ions interacting with laser light of different wavelengths might be worth to be studied in the future.

MS 1.5 Tue 12:15 F128

Improving the ^{10}Be detection efficiency with DREAMS — •Johannes Lachner, Carlos Vivo Vilches, Dominik Koll, Georg Rugel, Konstanze Stübner, and Anton Wallner — Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Accelerator Mass Spectrometry & Isotope Research

^{10}Be measurements presently take up the largest fraction of the DREAMS (DREsden AMS) beamtimes at the 6 MV accelerator of HZDR. We investigated the advantages of increasing the accelerator terminal voltage in order to improve the ^{10}Be counting efficiency. Stripping of the BeO^- ions extracted from the ion source to Be^{2+} is done using Ar stripper gas at a gas density below the level required for an equilibrium charge state distribution. The positive ions are directed towards a 1 μm thin silicon nitride foil that helps to suppress the ^{10}B interference by differential energy loss and separation in the following electrostatic analyser. After passage through the absorber foil the mean charge state of Be ions is increased and the 4+ charge state is selected and transported to the detector. Because of the higher ion energy, the yield for this charge state gets higher and the efficiency of ^{10}Be measurements is improved with higher terminal voltage.

At 5.8 MV terminal voltage ca. 32.5% of the ^{10}Be extracted from the ion source are transported to the detector compared to 23% at the previous setting of 4.5 MV. We furthermore present data of samples with known B concentration and give values for the ^{10}B suppression related to the different effects of separation, via the energy loss and via the gas ionization chamber.

MS 1.6 Tue 12:30 F128

The Anion Laser Isobar Separator - ALIS — •Markus Schiffer[1], Oscar Marchhart[2,3], Gereon Hackenberg[1], Peter Steier[2], Alfred Priller[2], Susan Herb[1], Timm-Florian Pabst[1], Elisa Chopan[1], Carlo Baddeliyanage[1], Martin Martschini[2], Robin Golser[2], Alfred Dewald[1], and Dennis Mücher[1] — [1]University of Cologne, Institute of Nuclear Physics, Cologne, Germany — [2]University of Vienna, Faculty of Physics, Isotope Physics, Vienna, Austria — [3]University of Vienna, Vienna Doctoral School in Physics, Vienna, Austria

Low energy isobar suppression has taken on increasing importance and has demonstrated a new access to environmental (^{90}Sr, ^{135}Cs), and cosmogenic isotopes (^{26}Al, ^{41}Ca). For this purpose, a new injector for the Cologne 6 MV AMS-System was developed. This "Anion Laser Isobar Separator" (ALIS) uses an advanced gas-filled radio frequency quadrupole (RFQ) ion cooler to suppress isobars by use of laser photodetachment in combination with gas reactions.

ALIS will use a 134 sample MC-SNICS ion source and a double focusing magnet for the ion cooler injection. The system is designed to separate the ion beam by slits before it is focused into the deceleration section of the RFQ. The ion cooler extraction section is designed to couple the ion beam to the ion optics of the AMS-System, or alternatively to a diagnose setup for stand-alone operation. For the element selective isobar suppression by laser photodetachment a 532 nm continuous wave laser with 18 W will be used.

MS 1.7 Tue 12:45 F128

Implementation of an EA-IRMS-GIS system to CologneAMS — •Martina Gwozdz, Stefan Heinze, Markus Schiffer, Alexander Stolz, Carlo Baddeliyanage, Elisa Chopan, Gereon Hackenberg, Devin Hymers, Timm-Florian Pabst, Tom Sittig, Alfred Dewald, and Dennis Mücher — Universität zu Köln, Germany

As part of the CRC1211 project "Earth - Evolution at the dry limit" ^{14}C dating analysis is asked for soil samples from the Atacama desert, resulting in ultra-small samples with a carbon content of 2-20μg. The ultra-small-scale AMS ^{14}C analysis will be used for the determination of ages of organic compounds isolated from the desert soils.

For this reason a new elemental analyser (EA) and an isotope ratio mass spectrometer (IRMS) have been coupled to the 6MV AMS system of CologneAMS. The EA oxidises solid samples and measures the nitrogen and carbon content. For the measurement of $\delta^{13}C$ and $\delta^{15}N$ the sample is transported to the IRMS.

The EA-IRMS has been set up with a direct connection to the existing gas injection system (GIS) and has been implemented into the software which is controlling the measurements. In this way it is possible to measure quasi-simultaneously the ^{14}C concentration with the 6MV AMS system and the $\delta^{13}C$ value with the IRMS.

We will investigate whether this new set-up will enable improved fractionation correction which are used in the ^{14}C data evaluation. This will increase the measurement accuracy and therefore will contribute to solve dating problems in different archives of the desert.

MS 2: Multi-Reflection Time-of-Flight Spectrometers

Time: Wednesday 11:00–12:15 Location: F128

MS 2.1 Wed 11:00 F128

Disentangling poly-cationic fullerenes with multi-reflection time-of-flight MS — •Paul Fischer and Lutz Schweikhard — Institut für Physik, Universität Greifswald, 17487 Greifswald, Germany

Large carbon-cluster cations of size-to-charge ratios $n/z \approx 40$ to ≈ 600 are observed after laser ablation of a glassy carbon target without additional aggregation gas. Their size distribution is well described by a log-normal function, implying an underlying coalescent growth mechanic. Resolving isotopologues via multi-reflection time-of-flight mass spectrometry (MR-ToF MS) confirms the clusters to be fullerenes as well as the presence of doubly- and triply-charged species. Comparing size- and charge-state-resolved abundances with results from a statistical simulation suggests charge aggregation through ion-ion collisions during the coalescent fusion processes. This is contrary to the assumption that poly-cations are formed primarily by subsequent photoionization under these conditions.

MS 2.2 Wed 11:15 F128

A setup for the study of clusters from a magnetron sputter source by MR-ToF mass spectrometry — •Paul Florian Giesel, Paul Fischer, and Lutz Schweikhard — Institut für Physik, Universität Greifswald, 17487 Greifswald, Germany

The Greifswald multi-reflection time-of-flight (MR-ToF) mass-spectrometer experiment investigates the properties of atomic clusters. So far, a pulsed laser-ablation source has been used to produce cluster ions with sizes up to about ten atoms from a solid target without the use of aggregation gas. The setup has now been expanded by a magnetron sputter source capable of producing considerably larger clusters. In order to incorporate this new source, a linear Paul trap has been installed to accumulate and bunch the continuous ion beam for injection into the MR-ToF analyzer. First measurements to characterize the new components as well as the system's capability to handle large clusters with masses up to 40,000 u have been performed.

MS 2.3 Wed 11:30 F128

Ion beam purification with the PUMA multi-reflection time-of-flight mass spectrometer — •Moritz Schlaich[1], Alexandre Obertelli[1], Frank Wienholtz[1], and Clara Klink[1,2] — [1]Institut für Kernphysik, TU Darmstadt, Darmstadt, Deutschland — [2]CERN, Genf, Schweiz

Using low-energy antiprotons provided by the Extra Low Energy Antiproton ring (ELENA) at CERN, the antiProton Unstable Matter Annihilation (PUMA) experiment aims to probe the isospin composition in the density tail of radioactive nuclei. For this purpose, PUMA intends to trap one billion antiprotons at ELENA in a portable Penning trap and transport them to the Isotope mass Separator On-Line DEvice (ISOLDE) at CERN. By analyzing the annihilation reactions of antiprotons with radioactive nuclei, the experiment plans to study neutron skin formation of neutron-rich nuclei and halo nuclei.

Reference measurements and the investigation of the neutron skin evolution along isotopic chains of stable nuclei (e.g. Ca, Sn or Xe) preceding the application to radioactive nuclei require a versatile offline ion source setup. In addition to a linear Paul trap used for ion cooling and accumulation, it includes a multi-reflection time-of-flight mass spectrometer (MR-ToF MS) for ion beam purification. By using electrostatic fields only, the MR-ToF MS can prolong the ion flight path by up to three orders of magnitude. This allows ion ejection with a mass resolving power up to 10^5, thus separating only the mass-over-charge value of interest. The talk will provide an overview of the experimental setup as well as first results of ion beam purification experiments.

MS 2.4 Wed 11:45 F128

A laser ablation carbon cluster ion source for the MR-TOF-MS of the FRS Ion Catcher — •Jiajun Yu[1,3], Christine Hornung[1,2], Timo Dickel[1,2], Zhuang Ge[1], Hans Geissel[1,2], Gabriella Kripko-Koncz[2], Meetika Narang[2], Wolfgang Plass[1,2], Christoph Scheidenberger[1,2], and FRS Ion Catcher Collaboration[1,2,3] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [2]Justus-Liebig-Universität Gießen, Gießen — [3]Jinan University, Guangzhou, China

A laser ablation carbon cluster ion source (LACCI) has been built and commissioned. It is capable of providing closely-spaced calibrant ions in the mass range up to ~300 u for highly accurate mass measurements of exotic nuclei (δm/m ~10^{-8}) and systematic studies of the mass uncertainties with the MR-TOF-MS of the FRS Ion Catcher at GSI Darmstadt, Germany. The LACCI contains newly developed advanced techniques, including a special ion optics design and a 2D movable target table to ensure stable long-term (weeks) operation, a laser-spot/target monitoring system, and a dedicated re-capture unit, which will be reported. A study of the laser energy, repetition rates and long-term measurements, has been carried out with carbon targets (Sigradur, Fullerene) and metallic targets (Ag, W, Au, Cu, Pt). The commissioning results of LACCI coupled via a radio frequency switchyard to merge ions from different sides and transport them through a quadrupole mass filter into an MR-TOF-MS will be reported in this contribution.

MS 2.5 Wed 12:00 F128

Mass measurements of neutron-rich nuclides at the N=126 shell with the FRS Ion Catcher — •Kriti Mahajan[1], Daler Amanbayev[1], Alison Bruce[3], Timo Dickel[1,2], Tuomas Grahn[4], Gabriella Kripko-Koncz[1], Ali Akbar Mehmandoost-Khajeh-Dad[5], Stephane Pietri[2], Wolfgang Plass[1,2], and Christoph Scheidenberger[1,2] — [1]JLU Gießen — [2]GSI Darmstadt — [3]University of Brighton, UK — [4]University of Jyvaskyla, Finland — [5]University of Sistan and Baluchestan, Zahedan, Iran

At GSI, experiments with exotic nuclides can be performed, including direct mass measurements. For such mass measurements, the nuclei can be produced at relativistic velocities by projectile fragmentation, separated, range-focused and slowed down in the fragment separator FRS and precise mass measurements are done with the FRS Ion Catcher. The beam from the FRS is injected into the cryogenic stopping cell (CSC), thermalized and transmitted to the multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS). The MR-TOF-MS features a high resolving power of up to 1,000,000, short cycle times of a few ten milliseconds, and mass accuracies down to a few 1E-8.

Mass measurements were performed in the region "south" of the doubly magic nucleus ^{208}Pb close to the N=126 line, which is of key importance for the study of nuclear structure and nuclear astrophysics and can help us to better understand the r-process, in particular the third abundance peak. The preliminary results of these mass measurements will be presented along with comparisons with different mass models, including the first mass measurements of ^{204}Au and ^{205}Au.

MS 3: Mass Spectrometry Applications

Time: Wednesday 14:30–16:00 Location: F128

Invited Talk MS 3.1 Wed 14:30 F128
Durable, low-temperature and highly-selective catalysis in NO reduction and CO oxidation driven by uni-sized Pt clusters supported on Si and SiC substrates — •Hisato Yasumatsu — Toyota Technological Institute, Ichikawa, Chiba, Japan

It has been found that Pt clusters are fixed to a Si substrate as Pt cluster disks by impact of Pt cluster ions onto the substrate. Electrons accumulated at the subnano interface between the Pt cluster and the Si substrate surface enable catalytic NO reduction and CO oxidation at low temperatures with high selectivity.

When the substrate is changed to silicon carbide, SiC, which is well known to possess high chemical and thermal stability, one can obtain durable catalysis as high as 1200 K with maintaining the low-temperature and highly-selective catalytic performance. This study shows a way to utilize this unique and high-performance catalysis driven by the electron accumulation as practical catalysts of electron donation including the gas treatment, and further extension to water-splitting hydrogen production and fuel-cell oxygen reduction reaction (ORR) as well.

Size-selected clusters by passing through a mass filter and cooled through a He collision cell were allowed to collide onto the substrate. Geometry and electron distribution were studied by means of scanning-tunneling microscopy. Electronic structures were obtained through X-ray photoelectron spectroscopy. Catalytic activity was measured with surface-chemistry techniques and fixed-bed gas-flow reaction analysis in combination of mass spectroscopy.

MS 3.2 Wed 15:00 F128
Multi-element isotopic analysis of hot particles from Chornobyl — •Darcy van Eerten[1], Manuel Raiwa[1], Paul Hanemann[1], Laura Leifermann[1], Tobias Weissenborn[1], Wolfgang Schulz[1], Martin Weiss[1], Danielle Ziva Shulaker[2], Peter Boone[2], David Willingham[2], Keenan Thomas[2], Brian Sammis[2], Brett Isselhardt[2], Mike Savina[2], and Clemens Walther[1] — [1]Institut für Radioökologie und Strahlenschutz, Leibniz Universität Hannover, Herrenhäuser Str. 2, 30419 Hannover, Germany. — [2]Chemical and Isotopic Signatures Group, Lawrence Livermore National Laboratory, Livermore, USA.

Nuclear materials that contaminate the environment present an ongoing challenge to characterize due to their small size and diverse morphology. The analysis of isotope ratios in actinides and fission products can provide determination of origin, age and environmental weathering of these materials. Resonance ionisation mass spectrometry (RIMS) utilizes selective laser ionization to target single elements and suppress the isobaric interferences typically found in mass spectrometry. Two specialized instruments were used to analyse single hot particles from Chornobyl: rL-SNMS at the IRS in Hannover, Germany, and LION at LLNL in Livermore, USA. Results from multiple particles are presented with interpretations of isotope ratios in U, Pu, Cs, Rb, Sr and Ba.

MS 3.3 Wed 15:15 F128
Mass spectrometric determination of the speciation of radium in the human digestive tract using ESI-MS — •Linus Holtmann, Ahmadabdurahman Shamoun, Beate Riebe, and Clemens Walther — Institut für Radioökologie und Strahlenschutz, Leibniz Universität Hannover, Hannover, Germany

Radionuclides pose a potential radio- and chemotoxic hazard to humans when ingested. Knowledge of radionuclide interaction in the digestive tract at the molecular and cellular level is necessary for risk assessment and to contribute to an element-specific decontamination strategy.

Synthetic biofluids prepared according to the UBM protocol (BARGE) are used to investigate the speciation of radium in the human digestive tract. The biofluids are analyzed in the presence and absence of Ra(II)/Ba(II) by mass spectrometry using electrospray ionization (ESI-MS). In our experiments, an Orbitrap mass spectrometer allows the measurement of the speciation without any chemical separation. The identification of barium-containing species takes place via specific isotope pattern signatures. Algorithms specifically tailored to the evaluation of complex mass spectra are used.

In addition, the influence of different decorporation and complexing agents on the speciation of Ra(II)/Ba(II) in the simulated digestive process is studied. This way, element-specific decorporation strategies are investigated for their potential efficacy after oral ingestion of radium.

MS 3.4 Wed 15:30 F128
ALPINAC - A non-target screening algorithm for high-resolution mass spectra and its application to the detection of halogenated greenhouse gases. — •Katharina Höveler, Lionel Constantin, Myriam Guillevic, Paul Schlauri, Martin K. Vollmer, and Stefan Reimann — Swiss Federal Laboratories for Materials Science and Technology (Empa), Dübendorf, Schweiz

Efficient and automated screening of gaseous or liquid samples to detect novel compounds based on their mass spectral fingerprints (non-target screening) is an ongoing computational challenge that goes beyond standard library-based approaches. We present a novel algorithm that uses combinatorial and directed graph methods, taking into account chemical rules, to automatically assign high-resolution mass spectral peaks from gas-chromatography-separated time-of-flight mass-spectroscopy (GC-TOF MS) measurements to possible chemical formulas by considering possible fragmentation pathways. In a further step, this information is used to reconstruct the chemical formula of likely molecular parent ions. We show how this technique can be used to detect unknown contaminants in pre-concentrated air samples and how the algorithm can be extended to reconstruct not only the molecular formula but also the chemical structure of the parent ion.

MS 3.5 Wed 15:45 F128
Analysis of the cutting edge of individual 'hot particles' from the Chernobyl Exclusion Zone — •Laura Leifermann[1], Martina Klinkenberg[2], Felix Brandt[2], Paul Hanemann[1], Tobias Weissenborn[1], Sandra Reinhard[1], Manuel Raiwa[3], Wolfgang Schulz[1], and Clemens Walther[1] — [1]IRS, Hannover, Deutschland — [2]FZJ IEK-6, Jülich, Deutschland — [3]LLNL, Livermore, USA

During the Chernobyl reactor accident on April 26, 1986, radioactivity was in part released in the form of nuclear fuel particles. These so-called 'hot particles' have various structures that belong to specific oxidation states of uranium. These oxidation states behave differently in the environment. We obtain individual particles by density separation with a poly tungsten solution. Via radiometric scanning with a Geiger counter we locate the particles. The extraction is performed on tungsten needles with a micromanipulator in a scanning electron microscope (SEM). The particle surface was analyzed by different nondestructive methods such as SIMS, rL-SNMS and EDX. Gamma measurements and optical analyses in SEM were also performed. Micrometer sized particles glued to needles are cut in half with a focused ion beam. We can thus extend our mass spectrometric analysis to the cutting edge and study the particle cross section. Since the particles have been exposed to the environment for over 30 years, weathering effects from outside to inside can be investigated. In addition, it is possible to test to what extent the elemental and isotopic composition of the particles is homogeneous.

MS 4: Heavy and Superheavy Elements

Time: Thursday 11:00–13:00 Location: F128

Invited Talk MS 4.1 Thu 11:00 F128
Observation of the radiative decay of the thorium-229 nuclear clock isomer — •Sandro Kraemer for the ISOLDE-IS658-Collaboration — Instituut voor Kern- en Stralingsfysica, KU Leuven, Belgium — Fakultät f. Physik, LMU München, Germany

A unique feature of thorium-229 is its isomeric first excited state with an exceptionally low excitation energy, proposed as a candidate for future nuclear optical clocks. The development of such an optical clock requires, however, knowledge of the excitation energy by at least an order of magnitude more precise. Additionally, spectroscopic experiments searching for a direct signature of the radiative decay have so far been unsuccessful.

In this work, an alternative approach using the beta decay of actinium-229 is studied as a novel method to populate the isomer with high efficiency and in low background conditions. Produced online at the ISOLDE facility at CERN, actinium is laser-ionized and implanted into a large-bandgap crystal.

A vacuum-ultraviolet spectroscopic study of implanted mass 229 beams at the ISOLDE facility will be presented. From the results obtained during a first measuring campaign it can be concluded that the radiative decay of the thorium-229 isomer has been observed for the first time, the excitation energy of the isomer has been determined with a factor of 5 improved uncertainty and the ionic lifetime in a crystalline environment was constrained.

Invited Talk MS 4.2 Thu 11:30 F128
Mass measurements of heavy and superheavy nuclides and isomers with SHIPTRAP — •Manuel J. Gutiérrez for the SHIPTRAP-Collaboration — GSI Darmstadt, Germany — HIM Mainz, Germany

The existence of superheavy elements is due to quantum shell effects, which stabilize them against spontaneous fission. Several theoretical models exist to describe these very complex nuclear systems. By providing nuclear binding energies, direct mass measurements can benchmark these models.

The Penning-trap mass spectrometer SHIPTRAP is devoted to performing mass measurements of heavy and superheavy nuclei produced via fusion-evaporation reactions with minute yields. Mass resolving powers in the 10^7 range, which are achieved with the Phase-Imaging Ion-Cyclotron-Resonance technique, enable the study of low-lying, long-lived isomeric states. Within the FAIR Phase-0 campaign, the latest measurements focused on several nuclides with such isomeric states, ranging from ^{241}Cf to ^{258}Db. Additionally, measurements were carried out on the ^{206}Fr–^{202}At–^{198}Bi chain, aiming to pin down the absolute excitation energies of two known isomers for the first time.

In this contribution, selected results from the analysis of the 2021 beamtime data will be presented, with emphasis on the studies of isomeric states.

MS 4.3 Thu 12:00 F128

Progress of the Laser Resonance Chromatography — •Eunkang Kim[1,2], Michael Block[1,2,3], Biswajit Jana[1,2], Sebastian Raeder[2,3], Harry Ramanantoanina[1], Elisabeth Rickert[1,2,3], Elisa Romero Romero[1,2,3], and Mustapha Laatiaoui[1,2] — [1]Department Chemie, Johannes Gutenberg-Universität, Fritz-Strassmann Weg 2, 55128 Mainz, Germany — [2]2Helmholtz-Institut Mainz, Staudingerweg 18, 55128 Mainz, Germany — [3]3GSI, Planckstraße 1, 64291 Darmstadt, Germany

Optical spectroscopy of superheavy elements is experimentally challenging as their production yields are low, half-lives are very short, and their atomic structure is barely known. Conventional spectroscopy techniques such as fluorescence spectroscopy are no longer suitable since they lack the sensitivity required in the superheavy element research. A new technique called Laser Resonance Chromatography (LRC) could provide sufficient sensitivity to study superheavy ions and overcome difficulties associated with other methods. In this contribution, I will introduce the LRC technique and report the progress and the results from the first LRC test experiments. This work is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

MS 4.4 Thu 12:15 F128

Status of the gas-jet apparatus for laser spectroscopy of the heaviest elements — •Matou Stemmler for the JetRIS-Collaboration — Institute of Physics, Johannes Gutenberg University Mainz, Germany

Laser spectroscopy measurements can provide information about fundamental properties of both atomic and nuclear structure. Such measurements are of particular importance for the heaviest actinides and superheavy elements, where data is sparse. In recent resonance-ionization-spectroscopy experiments on nobelium isotopes at GSI, Darmstadt, Germany, have been carried out with the in-gas-cell technique RADRIS [1,2]. However its limited spectral resolution hampers the precision, and occasionally renders the precise determination of nuclear moments and spins impossible. Furthermore, the inherent collection and measurement cycle precludes studies of isotopes with half-lives below ≈ 1 s. To overcome these limitations, a new JetRIS apparatus has been built to perform laser spectroscopy on atoms in a hypersonic jet [3].

This presentation will give an update on the JetRIS apparatus and discuss results from the 2022 beam time.

1 M. Laatiaoui, et al., Nature 538, 495-498 (2016)
2 S. Raeder, et al., Phys. Rev. Lett. 120, 232503 (2018)
3 S. Raeder, et al., Nucl. Instrum. Meth. Res. B, 463, 272-276 (2020)

MS 4.5 Thu 12:30 F128

Status of Development of MR-ToF MS for JetRIS for laser spectroscopy of the heavy actinides at GSI/HIM — •Danny Münzberg[1,2,3], Michael Block[1,2,3], Arno Claessens[4], Piet van Duppen[4], Rafael Ferrer[4], Jeremy Lantis[3], Mustapha Laatiaoui[3], Steven Nothhelfer[1,2,3], Sebastian Raeder[1,2], Moritz Schlaich[5], Lutz Schweikhard[6], Matou Stemmler[3], Thomas Walther[5], and Klaus Wendt[3] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE — [2]Helmholtz-Institut, Mainz, DE — [3]Department Chemie, Johannes Gutenberg-Universität, Mainz, DE — [4]Institut voor Kern- en Stralingsfysica, KU Leuven, Leuven, Belgium — [5]Technische Universität Darmstadt, DE — [6]Universität Greifswald, DE

At GSI-Darmstadt we use the in gas-Jet Resonant Ionization Spectroscopy (JetRIS) apparatus to perform laser spectroscopy of elements in the heavy actinide region to determine their nuclear and atomic properties. JetRIS utilizes α-decay detection to maximize sensitivity while minimizing the background from unwanted ions. However, for long-lived nuclides ($t_{\frac{1}{2}} > 10$ h) a decay-based detection will not be practical. Thus, a multi-reflection time-of-flight mass seperator (MR-ToF MS) is being developed for the JetRIS apparatus, allowing a separation of ions according to their mass to charge ratios with a high mass-resolving power, opening the possibility of direct ion detection. This will allow measuring β-decaying species and long-lived isotopes. An overview of the MR-ToF MS design and its integrations into the system will be given. Prospects for measurements will be discussed.

MS 4.6 Thu 12:45 F128

Relativistic calculation of binding energies of highly charged ions for precision mass spectroscopy — •Zoltán Harman, Chunhai Lyu, Vincent Debierre, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Heidelberg

Penning-trap mass spectrometry has recently enabled a novel determination of electron binding energies through the comparison of ionic masses. The collaboration of experiment and our multiconfiguration Dirac-Hartree-Fock theory has enabled the discovery of ultra-narrow ionic transitions, suitable for constructing future atomic clocks: in the Re 29+ ion, a long-lived electronic state with an excitation energy of 202 eV was observed via the mass difference of excited and ground-state ions [1]. A further application of such investigations is the determination of the Q value of the beta decay of various atomic isotopes, relevant for the determination of the neutrino mass [2]: experimentally, the masses of Re and Os ions could be determined to high precision, and our calculations have delivered the accurate binding energies of the electrons missing from the neutral atoms. Finally, mass spectrometry has largely contributed to a comparison of the magnetic moments of two isotopically different neon ions, allowing to set upper bounds on the coupling strength of new scalar bosons that might mediate a hypothetical interaction between electrons and nucleons [3].

[1] R. X. Schüssler, et al., Nature 581, 42 (2020);
[2] P. E. Filianin, et al., Phys. Rev. Lett. 127, 072502 (2021);
[3] T. Sailer et al., Nature 606, 479 (2022).

MS 5: Members' Assembly

Time: Thursday 13:00–13:30 Location: F128

All members of the Mass Spectrometry Division are invited to participate.

MS 6: Accelerator Mass Spectrometry II

Time: Thursday 14:30–16:30 Location: F128

MS 6.1 Thu 14:30 F128

Status and development of Sr-90 measurements at CologneAMS — •Gereon Hackenberg[1], Markus Schiffer[1], Susan Herb[1], Dominik Elchine[2], Stefan Heinze[1], Carlo Baddeliyanage[1], Elisa Chopan[1], Devin Hymers[1], Martina Gwozdz[1], Tom Sittig[1], Erik Strub[2], Alfred Dewald[1], and Dennis Mücher[1] — [1]Institute for Nuclear Physics, University of Cologne — [2]Division of Nuclear Chemistry, University of Cologne

^{90}Sr is produced by nuclear fission and is a prominent nuclide in nuclear waste and fallout. Since the decay of ^{90}Sr produces no γ rays, but only low energy β rays, the detection mainly depends on the β decay of the daughter nucleus ^{90}Y. This demands a complex chemical treatment, because a probe has to be free of other beta emitters.

Using accelerator mass spectrometry ^{90}Sr can be measured directly. Here main efforts are a high sputter efficiency and the suppression of the stable isobar ^{90}Zr.

Measurements have been performed at the 10MV tandem accelerator in Cologne using standards produced at the department of nuclear chemistry. At 9MV a full separation of ^{90}Sr and ^{90}Zr was achieved. This contribution will present charge state distributions behind the stripper, transmission measurements, dE/dx-measurements with our multi anode gas ionization detector and sensitivity limits of the current setup for multiple energies.

This technique will be applied to characterize soil samples from the AVR Jülich.

MS 6.2 Thu 14:45 F128

Slow ions for heavy nuclei: The quest to find interstellar ^{182}Hf on Earth — •Michael Kern[1,2], Martin Martschini[1], Silke Merchel[1], Peter Steier[1], Anton Wallner[3], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics, Isotope Physics, Austria — [2]Vienna Doctoral School in Physics, University of Vienna, Austria — [3]Helmholtz-Zentrum Dresden-Rossendorf, Germany

A decade-long search to pin down nucleosynthesis events in our stellar neighborhood could be propelled by measuring the abundance patterns of live ^{182}Hf ($T_{1/2}$ = 8.9 Myr) together with ^{60}Fe and ^{244}Pu, which were incorporated in terrestrial archives.

At the Vienna Environmental Research Accelerator (VERA), we developed an ion-laser interaction mass spectrometry (ILIAMS) setup to suppress challenging medium-mass isobars. It uses a radio-frequency quadrupole ion-guide filled with a reactive buffer-gas (He and O_2), where an intense laser beam overlaps with the ion beam. Less-strongly bound unwanted isobar species ($^{182}WF_5^-$) are removed, while wanted species ($^{182}HfF_5^-$) remain unaffected.

Ion optical simulations on injection and transport through the ILIAMS setup resulted in a new ion-guide design. It will allow acceptance of large emittance ion beams and will feature a UV-laser to destroy and/or neutralize WF_5^-. Additional challenges for ^{182}Hf detection are (a) the chemical preparation of HfF_4 AMS targets from large amounts of deep-sea MnFe crusts and (b) fabrication of reliable low-level (^{182}Hf/Hf $\simeq 10^{-13}$) reference materials.

MS 6.3 Thu 15:00 F128

Measurement of Interstellar Radionuclides as Fingerprints of Recent r-Process Events — •Sebastian Zwickel[1,2], Sebastian Fichter[1], Dominik Koll[1], Johannes Lachner[1], Georg Rugel[1], Konstanze Stuebner[1], Carlos Vivo Vilches[1], Stephan Winkler[1], and Anton Wallner[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Technical University Dresden, Dresden, Germany

Interstellar radionuclides deposited in our solar system can give information about recent nucleosynthesis events in the solar neighbourhood. The detection of ^{60}Fe with Accelerator Mass Spectrometry (AMS) in various geological and lunar samples yields evidence for two nearby supernovae (SNe) in the last 10 My. Measuring pure r-process ^{244}Pu in the same samples can relate SN nucleosynthesis with r-process signatures; either as a concomitant production or deposition. Its first detection in a deep sea manganese crust demonstrates the recent deposition of interstellar r-process nuclides in terrestrial archives, but is suffering from poor time resolution due to the rarity of ^{244}Pu.

This talk discusses the motivation and chemical sample preparation towards the search for ^{244}Pu as well as other radionuclides in lunar soil. The absence of geological activity allows for a longer search into the past than is possible with terrestrial material.

MS 6.4 Thu 15:15 F128

Improved ^{60}Fe measurements at CologneAMS — Susan Herb, Gereon Hackenberg, Markus Schiffer, Timm Pabst, Elisa Chopan, Alfred Dewald, and •Dennis Mücher — Institut für Kernphysik, Universität zu Köln

Since the first indication of Supernovae (SN) deposited signals in terrestrial reservoirs, the key isotope ^{60}Fe became an appealing isotope for astrophysical applications. Furthermore, ^{60}Fe produced in iron meteorites by galactic cosmic rays via spallation on ^{62}Ni and ^{64}Ni gives pivotal insight into the structure and history of our solar system. AMS is by far the most sensitive method to detect ^{60}Fe, with currently only a single laboratory offering ^{60}Fe AMS measurements, worldwide. This is partly due to the high beam energies required to suppress and separate the highly abundant isobar ^{60}Ni. In this work we present recent improvements of the 10MV AMS system at the University of Cologne which have significantly improved the efficiency and stability of the ^{60}Fe measurements using a gas-filled magnet. The fully digital setup now allows to tune the system and conduct the ^{60}Fe measurements fully automatically, further improving the overall efficiency of the AMS measurements. The currently achieved background level of ^{60}Fe/Fe of about $5 \cdot 10^{-15}$ allows for a routine measurement of iron meterotites. Future ideas to further improve the detection limit and efficiency of the setup will be discussed.

MS 6.5 Thu 15:30 F128

Cosmogenic ^{10}Be Dating of a Ferromanganese Crust Into the Early Miocene — •Dominik Koll[1,2], Anton Wallner[1], Johannes Lachner[1], Sebastian Fichter[1], Georg Rugel[1], Konstanze Stuebner[1], Carlos Vivo-Vilches[1], Stephan Winkler[1], Rene Ziegenruecker[1], and Sebastian Zwickel[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]The Australian National University, Canberra, Australia

Deep-sea ferromanganese crusts are slow-growing geological archives on seamounts without sediment coverage and are found in all major oceans. Their growth by precipitation with growth-rates of 1-10 mm/Myr records the oceanic inventory of radionuclides over several million years. The dating of ferromanganese crusts is typically achieved by following the decrease of cosmogenic ^{10}Be concentration in a depth-profile as a result of its radioactive decay.

In preparation for the search for the interstellar radionuclides ^{60}Fe and ^{244}Pu, the ferromanganese crust VA13/2-237KD was analyzed by optical and X-ray scans, stable element analysis and accelerator mass spectrometry for cosmogenic ^{10}Be until the end of the early Miocene. In this contribution, the characterization of the crust is presented with results from the cosmogenic ^{10}Be dating at the DREAMS facility of HZDR including an unexpected anomaly during the late Miocene.

MS 6.6 Thu 15:45 F128

Lowering the background levels of ^{14}C AMS measurements at CologneAMS — •Tom Sittig, Martina Gwozdz, Stefan Heinze, Markus Schiffer, Elisa Chopan, Gereon Hackenberg, Timm Pabst, and Dennis Mücher — Institute for Nuclear Physics, University of Cologne, Germany

AMS CO_2 gas measurements are useful as they allow for ultra small sample sizes to be analysed. A low background is important to achieve reliable and reproducible ^{14}C/^{12}C ratios. Because previously these background levels were higher than expected at CologneAMS when performing blank measurements, a source of contamination was investigated. As the result a new preparation routine has been implemented at the 6MV AMS system of CologneAMS.

By including the target holders alongside the CO_2-targets during heating for an extended period of time, followed by cooling both to room temperature under an argon atmosphere, we were able to decrease the background level by 60%. The new blank ratios are consistent with the machine blank level at $3.7 \cdot 10^{-15} \pm 18\%$. The stability of background levels is also improved and consistent with statistical expectations.

This increased stability allows us to investigate the sources of memory effects observed in cases where samples with low ^{14}C contents were preceded by samples with high ^{14}C content, optimising our setup even further in the future.

MS 6.7 Thu 16:00 F128

Exploring analysis of ^{99}Tc at environmental levels — •Stephanie Adler[1], Karin Hain[1], Fadime Gülce[1], Martin Martschini[1], Stefan Pavetich[2], Stephen G. Tims[2], L. Keith Fifield[2], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics - Isotope Physics, Vienna, Austria — [2]Australian National University, Canberra, Australia

Determination of absolute concentrations of the anthropogenic radionuclide ^{99}Tc ($t_{1/2}$=2.1×10^5 yr) in environmental samples by AMS requires suppression of the stable isobaric background of ^{99}Ru and a reliable normalization method. At the Vienna Environmental Research Accaelerator (VERA) it was shown that RuF_5^- can be suppressed by a factor of up to 10^5 using a laser, making extraction of $^{99}TcF_5^-$ a viable option for Ion Laser InterAction MS (ILIAMS). However, none of the methods for the extraction of TcF_5^- provided a reproducibility better than 50%. Without ILIAMS, the separation of ^{99}Ru from ^{99}Tc is currently only possible at the AMS facility at the Australian National University (ANU), using a 14 MV tandem accelerator. There, ^{99}Ru and ^{99}Tc are separated in an 8-anode ionization chamber owing to minute differences in their energy loss characteristics, observable only at high ion energies. Experiments at the meanwhile shutdown Munich AMS-facility using TcO^- and normalization to the ^{93}Nb-current extracted from the sputter matrix showed a precision of 30%. Using this approach at the ANU, a ^{99}Tc dilution series of 10^{10}-10^7 at/sample was measured in preparation for the measurement of environmental samples, achieving R^2=0.993 and a blank level of ~2×10^6 at/sample.

MS 6.8 Thu 16:15 F128

Sample preparation for accelerator mass spectrometry (AMS) – Approach to identify potential ^{10}Be contamination sources — •Silke Merchel[1,2], Johannes Lachner[1,2], Oscar Marchhart[1], Georg Rugel[2], and Alexander Wieser[1] — [1]University of Vienna, Faculty of Physics, Isotope Physics, Austria — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany

In the last decades, AMS has largely improved in the direction of lower detection limits, especially for applications of ^{10}Be/^{9}Be in Earth and environmental sciences. However, potential sources of ^{10}Be contamination while chemical sample preparation are often known but rarely identified in detail and quantified, which would be the first step to reduce these unwanted contributions. Thus, we have aimed at investigating ^{10}Be in (a) deionised/subboiled water, (b) commercial ^{27}Al carrier solutions, (c) ^{9}Be minerals and (d) cation exchange materials differently precleaned before first use. For better quantification, we have e.g., varied ^{27}Al amounts and used ^{27}Al carriers from different companies. Though, it was partially hard to distinguish in-between "single" ^{10}Be sources and between other sources like laboratory "dust" and cross-contamination (in lab and ion source) at the <4x10^{-15} level.

To conclude, our general recommendation is to minimize the amounts of water, ion exchange materials and ^{27}Al carrier. For ultra-low-level ^{10}Be/^{26}Al dating, subboiled water and customised Al carriers from minerals might be advantageous. The good news, cross-contamination in an AMS chemistry lab in use for >12 years – for samples orders of magnitude different in ^{10}Be/^{9}Be – is negligible.

MS 7: Poster

Time: Thursday 16:30–19:00 Location: Empore Lichthof

MS 7.1 Thu 16:30 Empore Lichthof

Doppler- and sympathetic cooling for the investigation of short-lived radionuclides — •Franziska Maria Maier[1,2] and Simon Sels[1] — [1]ISOLDE/CERN — [2]Universität Greifswald

For the MIRACLS collaboration.

Ever since its introduction in the mid 1970s, laser cooling has become a fundamental technique to prepare and control ions and atoms for a wide range of precision experiments. Nevertheless, because of its simplicity and element-universality, buffer-gas cooling in a linear, room-temperature Paul trap is more commonly used at contemporary radioactive ion beam (RIB) facilities. Recent advances in experimental RIB techniques, especially in laser spectroscopy and mass spectrometry, would however strongly benefit from ion beams at much lower beam temperature as in principle attainable by laser cooling.

Within the MIRACLS low-energy apparatus, we demonstrate that laser cooling is compatible with the timescale imposed by short-lived radionuclides as well as with existing instrumentation at RIB facilities[1]. Despite an initial kinetic energy of the externally-produced hot ions of several eV at the trap's entrance, temporal widths of the extracted ion bunches corresponding to an ion-beam temperature of around 6 K are obtained within a cooling time of 200 ms.

I will present the experimental results of our laser cooling studies, including the improvement of mass resolving power of an MR-ToF device (electrostatic ion beam trap), and give an outlook to future opportunities for high-precision measurements at RIB facilities.

[1] S. Sels, F.M.Maier et al, Phys.Rev.Res. 4, 033229 (2022).

MS 7.2 Thu 16:30 Empore Lichthof

Atomic Vapor Laser Isotope Separation of ^{48}Ca — •Dominik Studer[1,2,3], Tom Kieck[1,2], Sebastian Raeder[1,2], Michael Block[1,2,4], Christoph E. Düllmann[1,2,4], and Klaus Wendt[3] — [1]Helmholtz-Institut Mainz — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Institut für Physik, JGU Mainz — [4]Department Chemie - Standort TRIGA, JGU Mainz

Due to its high neutron excess, ^{48}Ca is a highly favorable nuclide for accelerator-based production of superheavy elements (SHE) in fusion-evaporation reactions. Elements with atomic numbers >113 can exclusively be produced with this projectile. Consequently, the SHE programme at, e.g., GSI Darmstadt depends critically on the availability of gram amounts of this isotope. Since ^{48}Ca has a low abundance of 0.187% in natural calcium, an isotope enrichment process is mandatory. In order to assess local production capabilities, a tabletop Atomic Vapor Laser Isotope Separation (AVLIS) setup is being tested at JGU Mainz. A highly collimated atomic beam of calcium is produced from an array of heated microcapillaries and ^{48}Ca is selectively ionized in a three-step photoionization process by pulsed laser radiation. Ions are separated by an electric field and collected on a metal plate. The efficiency, selectivity and scalability of this setup is studied. The present status is presented in this contribution.

MS 7.3 Thu 16:30 Empore Lichthof

Towards deterministic ionization and loading of molecules for quantum logic spectroscopy — •René Nardi, Stefan Walser, Brandon Furey, Zhenlin Wu, Guanqun Mu, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck

Our group studies the complex rovibrational structure of trapped molecular ions. These states are inaccessible to standard quantum information readout methods, but can be explored by co-trapping them with an atomic ion for which a convenient cooling and qubit level scheme exists. The molecular states can then be coupled to an electronic state of the atomic ion via quantum logic spectroscopy. To prepare and load arbitrary molecular species, we are developing a system where a molecular gas is leaked in, photoionized, and then accelerated towards a linear Paul ion trap. Ion optics are then used to steer the molecules through a differentially pumped region and into our UHV chamber. Molecules can be injected into the trapping region by adjusting the accelerating voltage and aligning the molecular beam through an aperture in the trap end cap. Here they can interact with an atomic ion crystal, cooling the molecules and resulting in their entrapment. We are building a setup to test this approach and we use time-of-flight mass spectrometry to map out the molecular ion species produced from photoionization of various gasses.

MS 7.4 Thu 16:30 Empore Lichthof

A Faraday cup for absolute ion beam current determination at the RISIKO mass separator — •Raphael Hasse[1], Sebastian Berndt[1], Vadim Gadelshin[1], Christoph E. Düllmann[1,2,3], Tom Kieck[2,3], Nina Kneip[4], and Klaus Wendt[1] — [1]Johannes Gutenberg-Universität Mainz — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Helmholtz-Institut Mainz — [4]Leibniz Universität Hannover

Faraday cups are commonly used for ion beam current measurements. They provide an easy and robust way to quantitatively determine ion currents for different applications in mass spectrometry, accelerator operation and others. Based on comparative measurements using γ spectroscopy, which indicated a systematic underestimation of the ion beam current in earlier measurements, a new Faraday cup was developed and characterized at the RISIKO mass separator of the Johannes Gutenberg-University Mainz. During this work several target shapes and repeller configurations were investigated in simulations, optimized to compensate and minimize errors due to the loss of charged secondary particles, i. e., secondary electrons and sputtered secondary ions. Calibration measurements with ^{165}Ho using resonance ionization mass spectrometry confirm an absolute quantification of ion beams in the range of 100 pA to 100 nA with a precision of better than 5%.

MS 7.5 Thu 16:30 Empore Lichthof

Fe-55 ion implantation by resonance ionization mass spectrometry for the PrimA-LTD project — •Thorben Niemeyer[1], Sebastian Berndt[1], Holger Dorrer[1], Nina Kneip[2], Dennis Renisch[1,3], Dominik Studer[1,3,4], Christoph E. Düllmann[1,3,4], and Klaus Wendt[1] — [1]Johannes Gutenberg Universität Mainz, 55099 Mainz — [2]Leibniz Universität Hannover, 30060 Hannover — [3]Helmholtz-Institut Mainz, 55090 Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt

New activity standardisation techniques for radionuclide metrology are developed within the scope of the the PrimA-LTD project. Low temperature micro calorimeters will be implanted with 100 Bq Fe-55 to measure its fractional electron-capture probabilities in the K-, L- and M-shell with high precision. This will allow experimental assessment of high-precision theoretical calculations.

The implantation of Fe-55 into the absorbers of the microcalorimeters is underway at the RISIKO mass separator at Mainz University. The resonance ionisation mass spectrometry method will be used due to its outstanding element selectivity and efficiency. Fully-automated pulsed Ti:Sa lasers are used to probe the atomic spectrum below and above the ionization potential. Measurements of Rydberg series allow the verification of the known ionization potential while strong auto-ionizing states will be used for the identification of a new element-selective two-step ionization scheme later to be used for the implantation. Laser spectroscopy and efficiency measurements of RISIKO are performed with stable Fe-56.

MS 7.6 Thu 16:30 Empore Lichthof

MOCCA: a 4k-pixel molecule camera for the position and energy resolved detection of neutral molecule fragments — •Daniel Kreuzberger[1], Christian Enss[1], Andreas Fleischmann[1], Lisa Gamer[2], Loredana Gastaldo[1], Christopher Jakob[2], Ansgar Lowack[1], Oldřich Novotný[2], Andreas Reifenberger[1], Dennis Schulz[1], and Andreas Wolf[2] — [1]Heidelberg University — [2]Max Planck Institute for Nuclear Physics, Heidelberg

The MOCCA detector is a 4k-pixel high-resolution molecule camera based on metallic magnetic calorimeters and read out with SQUIDs that is able to detect neutral molecule fragments with keV kinetic energies. It will be deployed at the Cryogenic Storage Ring CSR at the Max Planck Institute for Nuclear Physics in Heidelberg, a storage ring built to prepare and store molecular ions in their rotational and vibrational ground states, enabling studies on electron-ion interactions. To reconstruct the reaction kinematics, MOCCA measures the energy and position of incident particles on the detector, even with multiple particles hitting the detector simultaneously.

We present a new read-out scheme which uses only 32 SQUID channels for the 4096 pixels of the detector as well as some new fabrication details including copper-filled through-wafer vias to heat-sink the detector to the wafer backside. In addition we present the results of first characterization measurements.

MS 7.7 Thu 16:30 Empore Lichthof

Novel use of Actinide Resin® for multi-actinide analysis with AMS — •Thomas Roth[1], Francesca Quinto[1], Markus Plaschke[1], Karin Hain[2], Peter Steier[2], and Horst Geckeis[1] — [1]Institute for Nuclear Waste Disposal (INE), Karlsruhe Institute of Technology (KIT), Germany — [2]Faculty of Physics, University of Vienna, Austria

$Fe(OH)_3$ co-precipitation and conversion to an Fe_2O_3 specimen is an effective procedure for group separation (without subsequent column separation) and concurrent determination of actinides in aqueous environmental samples using AMS. However, matrix elements like Al and Si can also be precipitated in the process and thus increase the AMS specimen′s mass. As previously observed, the overall detection efficiency of the actinides decreases with increasing matrix content of the AMS specimen, partly due to a dilution effect. A novel procedure employing Actinide Resin® has been tested and compared to the $Fe(OH)_3$ co-precipitation for preparation of two sets of six Rhine River water samples (each 2 L volume) collected near the French Fessenheim NPP. Preliminary results for separation efficiency indicate that the use of Actinide Resin® reduces the Al and Si content of the AMS specimen by ca. 80%. Such a result is supported by a similar reduction of the specimen mass. The results obtained with the two preparation methods were consistent with each other, indicating global fallout as origin with concentrations of ca. 10^7 atoms/L for ^{237}Np, ca. 10^7 atoms/L for ^{236}U and Pu at background level.

MS 7.8 Thu 16:30 Empore Lichthof

Super-SIMS - from the idea to first measurements — •René Ziegenrücker[1], Georg Rugel[1], Dominik Koll[1], Johannes Lachner[1], Axel D. Renno[1], Carlos Vivo Vilches[1], Anton Wallner[1], and Michael Wiedenbeck[2] — [1]Helmholtz- Zentrum Dresden-Rossendorf, Dresden — [2]Deutsches GeoForschungsZentrum GFZ, Potsdam

The Dresden Super-SIMS is a combination of the DREAMS facility and a CAMECA IMS7f-auto as the ion source, and combines the advantages of both worlds: on one hand the suppression of molecular isobaric background with a 6 MV tandem accelerator and on the other the special and depth resolved information about the origin of the measured signals in the sample. This is possible without the samples undergoing any chemical treatment, and a polished surface (< a few nm) is sufficient for the measurement. While former attempts were intended to analyse semiconductor samples, the primary aim of Super-SIMS is the measurement of geological samples.

Nevertheless, first experiments were done with silicon to characterise the system and compare it with former attempts. Several samples with known content of phosphorus, including the blank, from the former URI-Project (Ultra clean injector) at the Technical University of Munich were measured. The sample with highest P content was used as internal reference material and the measurements showed a good agreement between measured concentrations by Super-SIMS and URI.

MS 7.9 Thu 16:30 Empore Lichthof

ISOLTRAP's new Mini-RFQ buncher for beam purification — •Daniel Lange on behalf of the ISOLTRAP collaboration — Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany

High-precision mass measurements of radioactive ions are used to determine nuclear binding energies, which reflect all forces in the nucleus and are used to study among others nuclear structure, nuclear astrophysics and weak interaction. Far away from stability, production cross-sections drop and beams are contaminated with isobars and molecules, impeding precision measurements.
For this, the ISOLTRAP mass spectrometer at ISOLDE/CERN [1] uses various ion traps, including a tandem Penning-trap system and multi-reflection time-of-flight mass spectrometer (MR-ToF MS). The latter is suitable of both mass separation and fast, precise mass measurements. These two different modes of operation can be used in succession to enable measurements of extremely contaminated beams when a re-trapping system is used [2].
The new Mini-RFQ behind the MR-ToF MS should not only recapture the ions of interest, but also re-bunch them. Additionally, a cryogenic approach is pursued to further improve the precision of the mass measurement with the MR-ToF MS. The current setup of the ISOLTRAP experiment is presented together with the future re-bunching design. For this purpose, the experimental test-setup with initial simulations will be outlined in more detail.

[1] Lunney D. et al., J. Phys. G: Nucl. Part. Phys. 44 (2017) 064008
[2] Dickel T. et al., J. Am. Soc. Mass Spectrom., 28 (6) (2017)

MS 7.10 Thu 16:30 Empore Lichthof

Design of a tandem mass spectrometer with ion trap to study particle nucleation under multicollisional conditions. — •Anastasiya Khramchenkova, Yihui Yan, and Jozef Lengyel — TUM School of Natural Sciences, Technical University of Munich, Garching, Germany

The goal of our research is to describe the essential molecular factors of one of the most critical atmospheric processes - the first steps of new particle formation. During aerosol formation, small clusters can grow and dissociate at any time, but only few reach the critical size at which further growth of the particle becomes spontaneous. However, the size and chemical composition of such critical nuclei have yet to be characterized, as there is currently no suitable analytical method. To this end, we are developing a tandem mass spectrometer for investigating particle nucleation at close to ambient pressures, combining precise control over cluster size with in situ real-time monitoring of complex kinetic analysis. The hydrated particles are generated by electrospray ionization, mass selected in a quadrupole mass filter, subsequently stored and exposed to precursor molecules in a ring electrode ion trap. After a variable storage time, an ion packet is extracted and focused into a perpendicularly mounted TOF MS, where the spectra are recorded with an MCP detector. Herein, we will discuss the instrumentation - design and implementation of each component. We will describe the characteristics of different RF ion guides, including stacked ring ion guides and multipoles, supplemented by ion trajectory simulations probed by the software package SIMION.

MS 7.11 Thu 16:30 Empore Lichthof

Spatially resolved trace analysis of radionuclides with laser ionization mass spectrometry — •Paul Hanemann[1], Tobias Weissenborn[1], Nina Kneip[1], Laura Leifermann[1], Darcy van Eerten[1], Manuel Raiwa[1], Felix Berg[2], and Clemens Walther[1] — [1]Institute of Radioecology and Radiation Protection, Leibniz University Hannover — [2]Institute of Nuclear Chemistry, University Mainz

Resonant laser secondary neutral mass spectrometry (rL-SNMS) combines the high spatial resolution of traditional time of flight secondary ion mass spectrometry (ToF-SIMS) with the advantage of element selectivity. Multiple grating-tuned Ti:Sa lasers allow access to a range of resonant ionization schemes. Combined with mass spectrometry, the method can detect actinides in single radioactive particles from the environment, down to 10^7 atoms of a single isotope [1]. In micrometer-sized particles from the Chornobyl exclusion zone, the relative ^{238}Pu content can be determined by suppressing the dominant ^{238}U in spent fuel. This is achieved quasi non-destructively without chemical preparation of the sample. The current capabilities of the rL-SNMS system are presented in this poster, with an outlook on further developments of the method and application to ultra-trace analysis.[1] DOI:10.1126/sciabv.abj1175

MS 7.12 Thu 16:30 Empore Lichthof

Assessment of anthropogenic actinide background levels on the ground of the new 1-MV compact AMS system HAMSTER at HZDR — •Sebastian Fichter[1], Anton Wallner[1], Karin Hain[2], and Michael Hotchkis[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany — [2]University of Vienna, Faculty of Physics, Isotope Physics, Vienna, Austria — [3]Australian Nuclear Science and Technology Organisation, Lucas Heights, Australia.

The new multi-purpose 1-MV AMS facility HAMSTER (*Helmholtz Accelerator Mass Spectrometer for Tracing Environmental Radionuclides*) is built within the HZDR research campus in Dresden-Rossendorf starting in 2022. The new machine is especially dedicated to the analysis of ultra-trace levels of actinides in environmental samples. Therefore, eventual contamination of the site where the new accelerator building is being constructed should be avoided and clarified. Hence, several soil samples close to the construction site of the new accelerator building have been analyzed to assess the content and isotopic ratios of the actinides U, Np and Pu. The samples have been processed in the existing chemistry labs of HZDR's 6-MV DREAMS facility showing low background levels. Overall, the samples show expected signatures of global fallout in Pu concentrations and ^{A}Pu/^{239}Pu ratios. However, in some samples increased ^{236}U concentrations and relatively low ^{233}U/^{236}U atomic ratios have been detected pointing to an additional source of ^{236}U. Additional analysis is currently ongoing.

MS 7.13 Thu 16:30 Empore Lichthof

Preparation of a Pa-233 tracer for accelerator mass spectrometry of Pa-231 in environmental samples — •Janis Wolf, Astrid Barkleit, Sebastian Fichter, Robin Steudtner, and Anton Wallner — Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

The measurement of Pa-231 ($t_{1/2}$ = 3.28·10^4 a) by accelerator mass spectrometry (AMS) has many applications including nuclear forensics, U/Pa dating and radiological risk assessment of the U-235 decay chain. The measurement requires the addition of an isotopic spike and as Pa-231 is the only long-lived Pa isotope, the short-lived isotope Pa-233 ($t_{1/2}$ = 26.98 days) is used. This enables the measurement of the isotopic ratio Pa-231/Pa-233 and monitoring of the efficiency of the sample preparation and measurement procedure.

The Pa-233 spike is typically separated from a solution of its long-lived mother nuclide Np-237 using an ion-exchange resin. Due to the tendency of Pa to attach to surfaces, different procedures for this separation are tested with the aim to find a procedure with high Pa-233 yields that can be performed quickly and without additional safety precautions during AMS sample preparation.

MS 8: Accelerator Mass Spectrometry III

Time: Friday 11:00–12:45 Location: F128

Invited Talk MS 8.1 Fri 11:00 F128

Two color resonant laser SNMS for isotope micro imaging of nuclear fuel debris — •Tetsuo Sakamoto — Kogakuin University, Tokyo, Japan

Tetsuo Sakamoto

Great East Japan Earthquake occurred in 2011. Effect of the earthquake was very large. Fukushima Daiichi (1F) nuclear accident is one of the serious disasters. The decommissioning of 1F is now in progress. There are many problems to be solved. One of those is the method for taking out nuclear fuel debris safely.

For that reason, there is a strong need for analysis methods of debris precisely. The most important thing in the debris analysis is isotope ratio of a certain elements, because the ratio is closely related to both the accident progress and the state of debris. Secondary ion mass spectrometry (SIMS) is a candidate for the analysis. However, isobaric interferences often make it difficult to analyze precise isotope ratio analysis.

The author has been developed a resonance ionization sputtered neutral mass spectrometer (R-SNMS) for element-selective ionization and detection by using a set of newly developed tunable Ti:Sapphire lasers. It consists of two lasers independently tunable at a repetition rate of 10 kHz.

MS 8.2 Fri 11:30 F128

Isobar separation in the actinide range with ILIAMS — •Andreas Wiederin[1,2], Karin Hain[1], Martin Martschini[1], Aya Sakaguchi[3], Peter Steier[1], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics - Isotope Physics, Austria — [2]University of Vienna, Vienna Doctoral School in Physics, Austria — [3]University of Tsukuba, Faculty of Pure and Applied Science, Japan

Isobaric background is among the main obstacles to the development of new AMS applications. By combining ILIAMS (Ion Laser InterAction Mass Spectrometry) with the actinide beamline of VERA (Vienna Environmental Research Accelerator), instrumental isobar separation in the mass range of the actinides has become available for the first time in AMS. ILIAMS combines an RFQ ion guide with high-powered lasers or reactive gases for isobar separation of anions at thermal energies.

The first application for ILIAMS in this mass range is the characterization of a recently produced ^{236}Np spike material intended for normalizing environmental ^{237}Np measurements. ILIAMS is used to monitor potential isobaric interference from ^{236}U or ^{236}Pu co-produced alongside the desired ^{236}Np and even suppresses ^{236}U by several orders of magnitude.

The isotopic ratios ^{238}Pu/^{239}Pu, ^{241}Pu/^{241}Pu, and ^{238}Pu/^{241}Pu are used as fingerprints for nuclear emission sources but partially require extensive chemical separation procedures and tedious radiochemical analysis. First results indicate that ILIAMS will also enable unambiguous mass-spectrometric access to ^{238,241}Pu usually superimposed by isobaric background from ^{238}U and ^{241}Am, respectively.

MS 8.3 Fri 11:45 F128

A new setup to characterise the tritium content of reactor graphite at Cologne-AMS — •Timm-Florian Pabst, Markus Schiffer, Gereon Hackenberg, Stefan Heinze, Martina Gwozdz, Alfred Dewald, and Dennis Mücher — Institute for Nuclear Physics, University of Cologne, Germany

There is approximately one kiloton of activated reactor graphite in Germany, mainly originating from research reactors and waiting for characterization and disposal. For storage in repositories like the mine Konrad, activity limits have to be considered. Reactor graphite has a complex radio nuclide vector with ^{3}H and ^{14}C as its main components.

We are aiming for a small AMS system dedicated for ^{3}H measurement, by which gas is extracted from the reactor graphite and directly injected into a sputter ion source. Such a set-up is well suited for automated measurements and a high sample throughput. As a first step we expanded our ion source test bench at Cologne-AMS by a 100 kV tandem accelerator with a carbon stripper foil and a 90° analysing magnet followed by a multi-Faraday cup unit. The gas analyte is provided by heating the reactor graphite to approximately 1000°C, enhancing the diffusion of ^{3}H. Isobar molecules are suppressed by the tandem accelerator stage. A dedicated control system based on Siemens S7 programmable logic controllers and a LabVIEW based control software allows complete remote operation of all components of the setup.

In this contribution we will present the system layout as well as results of first test measurements with an H-beam regarding sample preparation, system transmission and molecular dissociation.

MS 8.4 Fri 12:00 F128

Anthropogenic Actinides as Potential Markers for the Anthropocene — •Janis Wolf[1,2], Andreas Maier[3], Maria Meszar[4], Michael Strasser[5], Michael Wagreich[4], and Karin Hain[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]University of Vienna, Faculty of Physics, Vienna, Austria — [3]University of Vienna, Department of Geography and Regional Research, Vienna, Austria — [4]University of Vienna, Department of Geology, Vienna, Austria — [5]University of Innsbruck, Department of Geology, Innsbruck, Austria

To establish the Anthropocene as a new geological epoch, a reference point for the base of this epoch has to be defined using stratigraphic markers. Long-lived anthropogenic actinides released by atmospheric nuclear weapons testing may be suitable markers.

Thus, anthropogenic actinides U-233,236, Np-237 and Pu-239,240,241 were analyzed in a peat bog core taken from the Pürgschachen mire, using Accelerator Mass Spectrometry (AMS). The distribution of the actinides in the peat bog is compared to their distribution in other environmental reservoirs including a lake sediment core and urban sediments. This presentation will discuss the measurement results and interpret the isotope ratios in terms of emission source identification and their suitability as geological markers for the Anthropocene.

MS 8.5 Fri 12:15 F128

Characterisation of Reactor Graphite with AMS Ion Beam Techniques — Martina Gwozdz[1], Markus Schiffer[1], •Stefan Heinze[1], Klaus Eberhardt[2], Gereon Hackenberg[1], Susan Herb[1], Timm- Florian Pabst[1], Max Stefan[1], Alexander Stolz[1], Erik Strub[3], Alfred Dewald[1], and Dennis Mücher[1] — [1]Institut für Kernphysik, Universität zu Köln — [2]Institut für Kernchemie, Johannes Gutenberg Universität, Mainz — [3]Institut für Kernchemie, Universität zu Köln

Activated graphite, e.g. from graphite moderated reactors contains several radioactive isotopes like ^{14}C, ^{36}Cl, or ^{3}H. For the final disposal of such material a quantitative characterization is demanded. We are aiming for a system which enables automated measurements using the AMS technique with gaseous samples for the above mentioned isotopes. The aimed system should provide a high sample throughput as well as the possibility of sample dilution in cases of high activity. At CologneAMS, a new gas-interface was built and tested for ^{14}C measurements which uses a syringe for the transport of the sample gas into the ion source and a separate reservoir which can be used for high dilution. An advantage over the already established procedure using Liquid Scintillation Counting (LSC) is that the setup at the CologenAMS does not need elaborate chemical sample preparation and has a sensitivity down to $3 \cdot 10^{-9}$Bq/g. In this contribution we will present the layout of our systems as well as the stage of realisation. Supported by BMBF under contract number 15S9410B.

MS 8.6 Fri 12:30 F128

Super-SIMS at HZDR: Status and Future — •Georg Rugel[1], René Ziegenrücker[1], Axel D. Renno[1], Dominik Koll[1], Johannes Lachner[1], Pavol Noga[2], Carlos Vivo-Vilches[1], Anton Wallner[1], and Michael Wiedenbeck[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Slovak University of Technology in Bratislava, Trnava, Slovakia — [3]Deutsches GeoForschungsZentrum GFZ, Potsdam, Germany

The status and the future setup of the Super-SIMS at HZDR, Dresden will be outlined. The instrument is the combination of a commercial **S**econdary **I**on **M**ass **S**pectrometry instrument (CAMECA IMS 7f-auto) with DREAMS (DREsden AMS). While the SIMS provides micron-scale lateral resolution, AMS ensures high selectivity through highly effective molecule suppression by the stripping process. High transmission for major element ions including silicon, fluorine and iodine has been demonstrated in initial tests (see ref. [1]). The high energies from our 6-MV tandem were not actually required for our background suppression needs. Our new compact 1-MV AMS system will be used in the future for Super-SIMS.

[1] Rugel et al. NIMB 532 (2022) 52-57.

MS 9: Penning traps, highest precision, neutrino physics, storage rings, new facilities and approaches

Time: Friday 14:30–16:30 Location: F128

Invited Talk MS 9.1 Fri 14:30 F128

Developments to improve antiproton and other mass measurements — •Christian Smorra on behalf of the BASE collaboration — Johannes Gutenberg Universität Mainz — RIKEN Fundamental Symmetries Laboratory — Max-Planck Insititute for Nuclear Physics

Precision mass measurements in Penning traps have been performed on a wide variety of charged particles, and provide important input parameters for testing the fundamental interactions. For example, the most recent precision comparison of the proton and antiproton masses with 16 parts per trillion uncertainty provides the most stringent test of CPT invariance in the baryon sector and an antiparticle test of the weak equivalence principle with unprecedented resolution.

Common limitations to all mass measurements are uncertainties imposed by magnetic field fluctuations and finite particle temperatures. I will present the current efforts by the BASE collaboration to improve on these limitations for the antiproton mass measurements. This comprises the development of the transportable antiproton trap BASE-STEP that provides the possibility to relocate measurements of accelerator-produced particles away from the magnetic noise environment at the production site. Further, I will present the sympathetic cooling method for a single proton in a two-trap system using a cloud of laser-cooled beryllium ions. Here, we exchange energy by image currents between the traps in a coupled oscillator system. Presently, we cool the proton to a fraction of 1 K and plan to extend the cooling range down to the temperature of laser-cooled ions.

MS 9.2 Fri 15:00 F128

Preparations for ^{163}Ho implantation into 3-inch wafers for ECHo — •Sebastian Berndt[1], Nikolas Bittner[1], Holger Dorrer[1], Christoph E. Düllmann[1,2,3], Raphael Hasse[1], Tom Kieck[2,3], Nina Kneip[4], and Klaus Wendt[1] for the ECHo-Collaboration — [1]Johannes Gutenberg University Mainz — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Helmholtz Institute Mainz — [4]Leibniz University Hannover

The "Electron Capture in ^{163}Ho" (ECHo) experiment aims at measuring the electron neutrino mass in the sub-eV range by the analysis of the calorimetrically measured energy spectrum following the electron capture process of ^{163}Ho. The radioisotope ^{163}Ho is produced from enriched ^{162}Er in the high-flux nuclear reactor at Institut Laue-Langevin (ILL) Grenoble in France. This production process is followed by chemical separation to remove all elements other than Ho and by mass spectrometric separation for removal of remaining trace amounts of ^{166m}Ho. The ^{163}Ho is finally implanted into the absorbers of the ECHo Metallic Magnetic Calorimeters with high purity. Mass separation and implantation is performed in a single step at the RISIKO mass separator at University Mainz. For the scalability of the ^{163}Ho implantation from a single ECHo-100k chip with 64 absorbers to a 3-inch wafer with 40 ECHo-100k chips, the implantation region at RISIKO had to be adapted. A x-y stage and a Mapping Aperture Detector (MAD) were installed in the implantation chamber. The MAD is a wire detector with 8 wires that are read out individually to constantly monitor the size and position of the ion beam.

MS 9.3 Fri 15:15 F128

Towards a Parts-per-trillion Atomic Mass Measurement of the ^{3}He Nucleus — •Olesia Bezrodnova[1], Sangeetha Sasidharan[1,2], Sascha Rau[1], Wolfgang Quint[2], Sven Sturm[1], and Klaus Blaum[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]GSI Helmholtzzentrum, Darmstadt, Germany

Masses of light nuclei provide a network of essential parameters used for the fundamental nature description. For example, the mass difference of T and ^{3}He is used as a consistency check for the model of systematics in the KATRIN experiment, aiming to set a limit on the $\bar{\nu}_e$ mass [1].

The most precise mass measurements of the lightest nuclei, including ^{3}He, revealed considerable inconsistencies between the values reported by different experiments [2]. In order to provide an independent cross-check, the multi-Penning-trap mass spectrometer LIONTRAP has obtained the masses of the proton [3], the deuteron and the HD^{+} molecular ion [4].

Present activities of the experiment are directed at the atomic mass measurement of the ^{3}He nucleus with a relative uncertainty lower than 10 ppt. This contribution presents the status of the ongoing measurement campaign.

[1] M. Aker *et al.*, Nat. Phys. **18**, 160-166 (2022)
[2] S. Hamzeloui *et al.*, Phys. Rev. A **96**, 060501(R) (2017)
[3] F. Heiße *et al.*, Phys. Rev. A **100**, 022518 (2019)
[4] S. Rau *et al.*, Nature **585**, 43-47 (2020)

MS 9.4 Fri 15:30 F128

A novel transportable PI-ICR Penning-trap mass spectrometer — •Daniel Lange, Menno Door, Sergey Eliseev, Pavel Filianin, Jost Herkenhoff, Kathrin Kromer, Alexander Rischka, Chistoph Schweiger, and Klaus Blaum — Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany

The new, transportable PILOT (Phase-Imaging Located in One Transportable) - trap experiment aims to measure masses of short-lived nuclides with low production rates and half-lives down to 100 ms with relative uncertainties of about 10^{-8}. This should be realised with a Penning-trap based modified buffer-gas cooling and PI-ICR technique [1]. In order to deal with the low production rates of some isotopes a modified dynamic buffer-gas cooling technique is used in only a single measurement trap. Therefore a fast piezo valve has been developed, which enables a fast and precisely timed helium injection into the Penning-trap, followed by a fast helium release to be directly able to measure in the same trap. This increases the overall efficiency by also avoiding the transport of ions between the traps. The setup is situated in the warm bore of a 6 T superconducting coldhead-cooled magnet which ensures transportability to different radioactive beam facilities. Here, mass measurements of e.g. rare superheavy nuclides become possible contributing to nuclear physics and the search for the island of stability, see e.g. [2]. The current status as well as the developed dynamic cooling method of this experiment are presented.

[1] Eliseev, S. et al., Phys. Rev. Lett. 110, 082501 (2013).
[2] Block, M. et al., Nature 463, 785-788 (2010).

MS 9.5 Fri 15:45 F128

MOCCA - A 4k-pixel microcalorimeter detector for the Cryogenic Storage Ring CSR — •Christopher Alexander Jakob[1], Lisa Gamer[1], Klaus Blaum[1], Christian Enss[2], Andreas Fleischmann[2], Oded Heber[3], Daniel Kreuzberger[2], Ansgar Lowack[2], Michael Rappaport[3], Andreas Reifenberger[2], Dennis Schulz[2], Abhishek Shahi[3], Yoni Toker[4], Andreas Wolf[1], and Oldřich Novotný[1] — [1]MPIK Heidelberg — [2]KIP Heidelberg University — [3]Weizmann Institute of Science, Rehovot, Israel — [4]Bar-Ilan University, Ramat Gan, Israel

The low temperatures and low gas densities in cold interstellar clouds allow the present molecules to relax into their vibrational and rotational ground states. At the Max Planck Institute for Nuclear Physics in Heidelberg, these conditions can be reproduced in the Cryogenic Storage Ring CSR, where heavy molecular ions can cool down while stored for thousands of seconds and electron-ion recombination can be investigated. To reconstruct the full kinematics of these processes, position- and energy-sensitive coincident detection of multiple neutral reaction products is required. For this purpose, MOCCA, a 4k-pixel molecule camera based on metallic magnetic calorimeters with a detection area of 45 mm×45 mm, was developed at the Kirchhoff Institute for Physics in Heidelberg. We present the detector readout scheme, characterization measurements, and the implementation of MOCCA into the CSR-independent MOCCA standalone setup, that will be used to study photon- and collision-induced ion fragmentation processes before MOCCA will be integrated into CSR.

MS 9.6 Fri 16:00 F128

Nuclear two-photon decay of ^{72m}Ge with an isochronous heavy-ion storage ring — •David Freire-Fernández for the E143-Collaboration — MPIK, Heidelberg, Germany — Heidelberg University, Heidelberg, Germany

The nuclear two-photon (2γ) decay is a rare decay mode in atomic nuclei whereby a nucleus in an excited state emits two gamma rays simultaneously. First order processes usually dominate the decay, however two-photon emission may become significant when first order processes are forbidden or strongly suppressed, which can be achieved at the experimental storage ring ESR (GSI/FAIR). Within this work we will present the implemented methodology and the obtained results of a beam time performed in 2021, when for the first time the isochronous mode of the ESR alongside two non-destructive Schottky detectors were operated for the study of short-lived isomers. We investigated specifically the isotope ^{72}Ge, as it is the most easily accessible nucleus having a first excited 0^{+} state below the pair creation threshold paramount for the study of 2γ decay without competition of first order decays.

Preliminary results point out that its half-life is considerably shorter than expected from the extrapolation of previously studied $0^{+} \rightarrow 0^{+}$ transitions. Therefore, new theoretical investigations are required which, in combination with our experimental measurements, will allow us to determine the transition nuclear polarizabilities. In addition, the most precise mass measurements obtained by isochronous mass spectrometry will be presented.

MS 9.7 Fri 16:15 F128

Plan of collinear fast beam laser spectroscopy on neutron rich La isotopes to explore the onset and evolution of triaxiality in nuclear ground states using RAON CLS system — •Jung-Bog Kim[1], Jens Lassen[2], Rouhong Ki[2], Hans A. Schuessler[3], SeongGi Jo[4], Sinbee Choi[1], Sung Jong Park[4], A Takamine[5], M Wada[5], H Limura[6], and Duck-Hee Kwon[7] — [1]Korea National University of Education, Cheongju, Rep. Korea — [2]TRIUMF Canada Particle Accelerator Laboratory, Vancouver BC, V6T2A3, Canada — [3]Dept. of Physics & Astronomy, Texas A&M University, College Station TX, 77843-4242, USA — [4]Institute of Basic Science, RISP, Daeheon, Rep. Korea — [5]Atomic Physics Laboratory, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan — [6]Japan Atomic Energy Agency, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan — [7]Korea Atomic Energy Research Institute, Daejeon, Rep. Korea

The RAON radioactive ion beam facility with resonant ionization laser ion source and a dedicated collinear fast beam laser spectroscopy facility will be the ideal place to carry out challenging, state-of-the-art experiments. One such experiment is to investigate nuclear structure beyond quadrupolar deformation. The neutron-deficient La isotopes are in the mass region where an axially asymmetric shape of nuclei is predicted theoretically. To clarify the deformation of 129La and even more neutron-deficient La isotopes, we are now planning to extend the laser spectroscopy to these nuclides.

Quantum Optics and Photonics Division
Fachverband Quantenoptik und Photonik (Q)

Christiane Koch
Freie Universität Berlin
Fachbereich Physik
Arnimallee 14
14195 Berlin
christiane.koch@fu-berlin.de

Overview of Invited Talks and Sessions

(Lecture halls A320, E001, E214, F342, and F442; Poster Empore Lichthof)

Invited Talks

Q 2.1	Mon	11:00–11:30	E001	**Interferometry with Bose-Einstein Condensates for inertial sensing** — •Sven Abend, Christian Schubert, Matthias Gersemann, Ernst M. Rasel, QUANTUS-QGYRO Teams
Q 9.1	Mon	17:00–17:30	A320	**Compressibility and the equation of state of an optical quantum gas in a box** — •Julian Schmitt
Q 10.1	Mon	17:00–17:30	E001	**Maiman's ruby laser reborn as diode pumped cw laser** — •Walter Luhs, Bernd Wellegehausen
Q 17.1	Tue	11:00–11:30	E001	**Thin-film lithium niobate waveguides for integrated quantum photonic technologies** — •Francesco Lenzini, Emma Lomonte, Wolfram Pernice
Q 18.1	Tue	11:00–11:30	E214	**Atoms coupled to nanofibers: from topological phases to correlated photon emission** — •Beatriz Olmos
Q 36.1	Wed	14:30–15:00	E214	**BMBF-Förderprogramm: Wissenschaftliche Vorprojekte** — •Bernhard Ihrig, Johannes Mund
Q 47.1	Thu	11:00–11:30	E001	**Quantum metrology with non-classical states of light** — •Michèle Heurs
Q 48.1	Thu	11:00–11:30	E214	**Using optomechanical systems to test gravitational theory – possibilities and limitations** — •Dennis Rätzel
Q 52.1	Thu	14:30–15:00	E001	**Nonperturbative Floquet engineering and Floquet-dissipative state preparation** — •Francesco Petiziol
Q 53.1	Thu	14:30–15:00	E214	**Quantum information with atomic quantum metasurfaces and integrated nanophotonics** — •Rivka Bekenstein
Q 61.1	Fri	11:00–11:30	E001	**Quantum Imaging With Nonlinear Interferometers** — •Markus Gräfe

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2023

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Prize Talks of the joint Awards Symposium

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich
SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt

SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Invited Talks of the joint Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit

See SYCC for the full program of the symposium.

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Invited Talks of the joint Symposium Quantum Optics and Quantum Information with Rigid Rotors

See SYQR for the full program of the symposium.

SYQR 1.1	Fri	11:00–11:30	E415	**Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets** — •Henrik Stapelfeldt
SYQR 1.2	Fri	11:30–12:00	E415	**Quantum toolbox for molecular state spaces** — Eric Kubischta, Shubham Jain, Ian Teixeira, Eric R. Hudson, Wesley C. Campbell, Mikhail Lemeshko, •Victor V. Albert
SYQR 1.3	Fri	12:00–12:30	E415	**Coherent rotational state control of chiral molecules** — •Sandra Eibenberger-Arias
SYQR 1.4	Fri	12:30–13:00	E415	**Optically levitated rotors: potential control and optimal measurement** — •Martin Frimmer
SYQR 2.1	Fri	14:30–15:00	E415	**Rotational optomechanics with levitated nanodumbbells** — •Tongcang Li
SYQR 2.2	Fri	15:00–15:30	E415	**Quantum rotations of nanoparticles** — •Benjamin A. Stickler
SYQR 2.3	Fri	15:30–16:00	E415	**Quantum control of trapped molecular ions** — •Stefan Willitsch
SYQR 2.4	Fri	16:00–16:30	E415	**Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables** — •Monika Leibscher

Sessions

Q 1.1–1.8	Mon	11:00–13:00	A320	**Quantum Technologies (joint session Q/A/QI)**
Q 2.1–2.7	Mon	11:00–13:00	E001	**Matter Wave Optics**
Q 3.1–3.8	Mon	11:00–13:00	E214	**Quantum Computing and Simulation (joint session Q/QI)**
Q 4.1–4.8	Mon	11:00–13:00	F102	**Cold Molecules (joint session MO/Q)**
Q 5.1–5.8	Mon	11:00–13:00	F342	**Quantum Optics: Open Quantum Systems**
Q 6.1–6.8	Mon	11:00–13:00	F442	**Quantum Effects (QED) (joint session Q/A)**
Q 7.1–7.32	Mon	16:30–19:00	Empore Lichthof	**Poster I**
Q 8.1–8.49	Mon	16:30–19:00	Empore Lichthof	**QI Poster I (joint session QI/Q)**
Q 9.1–9.7	Mon	17:00–19:00	A320	**Quantum Gases: Bosons I**
Q 10.1–10.7	Mon	17:00–19:00	E001	**Photonics I**
Q 11.1–11.8	Mon	17:00–19:00	E214	**Precision Measurements: Gravity I**
Q 12.1–12.6	Mon	17:00–18:45	F107	**Precision Spectroscopy of Atoms and Ions I (joint session A/Q)**
Q 13.1–13.7	Mon	17:00–19:00	F303	**Ultra-cold Atoms, Ions and BEC I (joint session A/Q)**
Q 14.1–14.8	Mon	17:00–19:00	F342	**Quantum Technologies: Color Centers I (joint session Q/A/QI)**
Q 15.1–15.8	Mon	17:00–19:00	F442	**Quantum Communication (joint session Q/QI)**
Q 16.1–16.8	Tue	11:00–13:00	A320	**Photonic Quantum Technologies (joint session Q/QI)**

Q 17.1–17.7	Tue	11:00–13:00	E001	**Integrated Photonics I (joint session Q/QI)**
Q 18.1–18.7	Tue	11:00–13:00	E214	**Quantum Optics: Cavity and Waveguide QED I**
Q 19.1–19.7	Tue	11:00–12:45	F303	**Precision Spectroscopy of Atoms and Ions II (joint session A/Q)**
Q 20.1–20.8	Tue	11:00–13:00	F342	**Quantum Gases: Bosons II**
Q 21.1–21.8	Tue	11:00–13:00	F442	**Quantum Technologies: Color Centers II (joint session Q/QI)**
Q 22.1–22.86	Tue	16:30–19:00	Empore Lichthof	**Poster II**
Q 23.1–23.7	Wed	11:00–12:45	A320	**Optomechanics I & Optovibronics**
Q 24.1–24.6	Wed	11:00–12:45	B305	**Quantum Networks I (joint session QI/Q)**
Q 25.1–25.8	Wed	11:00–13:00	E001	**Solid State Quantum Optics**
Q 26.1–26.8	Wed	11:00–13:00	E214	**Quantum Gases: Bosons III**
Q 27.1–27.7	Wed	11:00–13:00	F303	**Ultra-cold Atoms, Ions and BEC II (joint session A/Q)**
Q 28.1–28.8	Wed	11:00–13:00	F342	**Quantum Technologies: Trapped Ions (joint session Q/QI)**
Q 29.1–29.7	Wed	11:00–13:00	F428	**Implementations: Ions and Atoms (joint session QI/Q)**
Q 30.1–30.8	Wed	11:00–13:00	F442	**Nano-optics**
Q 31.1–31.8	Wed	11:00–13:00	F102	**Precision Measurements: Atom Interferometry I (joint session Q/A)**
Q 32	Wed	13:00–14:00	F342	**Members' Assembly**
Q 33.1–33.8	Wed	14:30–16:30	A320	**Quantum Gases: Bosons IV**
Q 34.1–34.7	Wed	14:30–16:30	B305	**Quantum Communication (joint session QI/Q)**
Q 35.1–35.8	Wed	14:30–16:30	E001	**Quantum Optics: Cavity and Waveguide QED II**
Q 36.1–36.7	Wed	14:30–16:30	E214	**Quantum Technologies (joint session Q/MO/QI)**
Q 37.1–37.7	Wed	14:30–16:15	F142	**Collisions (with Q) (joint session MO/Q)**
Q 38.1–38.8	Wed	14:30–16:30	F303	**Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)**
Q 39.1–39.8	Wed	14:30–16:30	F342	**Quantum Optics & Nano-Optics**
Q 40.1–40.8	Wed	14:30–16:30	F442	**Photonics II**
Q 41.1–41.6	Wed	14:30–16:00	F428	**Ultra-cold Atoms, Ions and BEC III (joint session A/Q)**
Q 42.1–42.36	Wed	16:30–19:00	Empore Lichthof	**Poster III**
Q 43.1–43.65	Wed	16:30–19:00	Empore Lichthof	**QI Poster II (joint session QI/Q)**
Q 44.1–44.8	Wed	17:00–19:00	A320	**Integrated Photonics II (joint session Q/QI)**
Q 45.1–45.8	Thu	11:00–13:00	A320	**Photonics III**
Q 46.1–46.7	Thu	11:00–13:00	B305	**Quantum Control (joint session QI/Q)**
Q 47.1–47.7	Thu	11:00–13:00	E001	**Precision Measurements with Optical Clocks (joint session Q/QI)**
Q 48.1–48.7	Thu	11:00–13:00	E214	**Optomechanics II**
Q 49.1–49.7	Thu	11:00–13:00	F303	**Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)**
Q 50.1–50.8	Thu	11:00–13:00	F342	**Quantum Gases: Fermions I**
Q 51.1–51.8	Thu	14:30–16:30	A320	**Precision Measurements**
Q 52.1–52.7	Thu	14:30–16:30	E001	**Floquet Engineering and Topology**
Q 53.1–53.7	Thu	14:30–16:30	E214	**Single Quantum Emitters (joint session Q/QI)**
Q 54.1–54.8	Thu	14:30–16:30	F102	**Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)**
Q 55.1–55.7	Thu	14:30–16:30	F303	**Precision Spectroscopy of Atoms and Ions III (joint session A/Q)**
Q 56.1–56.8	Thu	14:30–16:30	F342	**Quantum Gases: Fermions II**
Q 57.1–57.8	Thu	14:30–16:30	F428	**Quantum Networks II (joint session QI/Q)**
Q 58.1–58.8	Thu	14:30–16:30	F442	**Quantum Optics with Photons I**
Q 59.1–59.80	Thu	16:30–19:00	Empore Lichthof	**Poster IV**
Q 60.1–60.7	Fri	11:00–12:45	A320	**Photonics IV**
Q 61.1–61.7	Fri	11:00–13:00	E001	**Quantum Optics with Photons II**
Q 62.1–62.8	Fri	11:00–13:00	E214	**Precision Measurements: Gravity II**
Q 63.1–63.6	Fri	11:00–12:45	F107	**Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)**
Q 64.1–64.6	Fri	11:00–12:45	F303	**Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)**
Q 65.1–65.8	Fri	11:00–13:00	F342	**Many-body Physics**
Q 66.1–66.8	Fri	11:00–13:00	F428	**Quantum Metrology (joint session QI/Q)**
Q 67.1–67.8	Fri	11:00–13:00	F442	**Optomechanics III**
Q 68.1–68.7	Fri	14:30–16:15	B305	**Quantum Gases: Bosons V**
Q 69.1–69.7	Fri	14:30–16:30	F303	**Ultra-cold Atoms, Ions and BEC V (joint session A/Q)**
Q 70.1–70.8	Fri	14:30–16:30	F342	**Precision Measurements: Atom Interferometry II (joint session Q/A)**
Q 71.1–71.4	Fri	14:30–15:30	F442	**Quantum Optics: Cavity and Waveguide QED III**
Q 72.1–72.6	Fri	14:30–16:00	B302	**Precision Spectroscopy of Atoms and Ions V (joint session A/Q)**

Members' Assembly of the Quantum Optics and Photonics Division

Wednesday 13:00–14:00 F342

Sessions

– Invited Talks, Contributed Talks, and Posters –

Q 1: Quantum Technologies (joint session Q/A/QI)

Time: Monday 11:00–13:00 Location: A320

Q 1.1 Mon 11:00 A320

Holography with single photons — •Hrvoje Skenderovic and Denis Abramovic — Institute of Physics, Bijenicka cesta 46, 10000 Zagreb, Croatia

Holography relies on interference between two beams, reference and object. Although single photon can not be divided, holograms with heralded single-photon source in a classical holographic setup were recorded, due to indistinguishable paths. The amplitude and phase reconstructions show quantum enhancement for heralded over non-heralded channel. Non-classical nature of heralded photons is verified by continuous measurement of g2(0) of the light source during hologram acquisition.

Q 1.2 Mon 11:15 A320

Three-Dimensional Imaging of Single Atoms in an Optical Lattice via Helical Point-Spread-Function Engineering — •Tangi Legrand[1], Falk-Richard Winkelmann[1], Wolfgang Alt[1], Dieter Meschede[1], Andrea Alberti[1], and Carrie Weidner[2] — [1]Institut für Angewandte Physik, Universität Bonn, Germany — [2]Quantum Engineering Technology Laboratories, H. H. Wills Physics Laboratory and Department of Electrical and Electronic Engineering, University of Bristol, United Kingdom

Quantum gas microscopes can resolve atoms trapped in a 3D optical lattice down to the single site in the horizontal plane. Along the line of sight, however, a much lower resolution is achieved if the position is inferred from the defocus alone, although tomographic methods have been applied to extract this information [1]. However, phase-front engineering can be used to localize emitters in 3D with sub-micrometer resolution from a single experimental image [2]. The technique consists of shaping the imaging system's point spread function (PSF) such that it results in an axially rotating azimuthally asymmetric distribution. By means of a spatial light modulator, we create a double-helix PSF consisting of two lobes whose relative angle encodes an atom's axial position. We demonstrate 3D localization at the level of single lattice sites in a quantum gas microscope. As we show, the technique also features an increased depth of field. This method can find applications in other quantum gas experiments to extend the domain of quantum simulation from 2D to 3D. [1] O. Elíasson *et al.* Phys. Rev. A **102**, 053311 (2020), [2] S.R.P. Pavani *et al.* PNAS **106**, 2995 (2009).

Q 1.3 Mon 11:30 A320

Tomography of distant single Atoms — •Florian Fertig[1,2], Yiru Zhou[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Tim van Leent[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Entanglement of distant quantum memories forms the building block of quantum networks. Neutral atoms with long coherence times are possible candidates for such a quantum network link and can be entangled via the entanglement swapping protocol. Our experiment consists of two nodes, currently 400 m apart, employing single optically trapped Rubidium-87 atoms as quantum memories. A new collection setup allows for an increased entanglement event rate of 1/6 Hz allowing a state analysis and reconstruction of the entangled state.

Here, we use quantum state tomography for the first time on atom-atom entanglement and evaluate the influence of different kind of experimental improvements on the fidelity of the entangled state. We introduce time-filtering, a method to increase the atom-atom entanglement fidelity. At the cost of events we reach a fidelity > 90% well suited for demanding tasks like device-independent QKD.

Q 1.4 Mon 11:45 A320

Mid-Infrared Quantum Scanning Microscopy with Visible Light — •Josué R. León-Torres[1,2], Jorge Fuenzalida[1], Marta Gilaberte Basset[1], Sebastian Töpfer[1], and Markus Gräfe[1,2,3] — [1]Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, D-07745 Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Max-Wien-Platz 1, D-07745 Jena, Germany — [3]Technische Universität Darmstadt, Institute of Applied Physics, Hochschulstraße 6, D-64289 Darmstadt, Germany

Abstract: Laser scanning microscopy (LSM) is known to be the workhorse for modern life-science, it allows to get new insights into a variety of biological processes. LSM together with illumination in the mid infrared region (Mid-IR) permits to map the chemical composition of samples to a space frame. However, low-light observations in the Mid-IR spectrum are still challenging and a limiting factor for a faster development. A label-free quantum imaging system is presented here, capable of performing the detection in the visible regime, while illuminating the sample with undetected light in the Mid-IR region. Our quantum imaging with undetected light implementation aims to retrieve amplitude and phase images of biological samples containing a variety of functional groups that are present in the Mid-IR region. Due to the momentum correlations shared by the entangled photon-pair the illumination can take place in the Mid-IR spectrum and the detection can be carried out with silicon-based technology in the VIS spectrum.

Q 1.5 Mon 12:00 A320

GHz bandwidth four-wave mixing in a thermal rubidium vapor — •Max Mäusezahl[1], Felix Moumtsilis[1], Moritz Seltenreich[1], Jan Reuter[2,3], Hadiseh Alaeian[4], Harald Kübler[1], Matthias Müller[2], Charles Stuart Adams[5], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Forschungszentrum Jülich GmbH, PGI-8, Germany — [3]Universität zu Köln, Germany — [4]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, USA — [5]Department of Physics, Joint Quantum Centre (JQC), Durham University, UK

Fast coherent control of Rydberg excitations is essential for quantum logic gates and on-demand single-photon sources based on the Rydberg blockade as demonstrated for room-temperature rubidium atoms in a micro-cell. During our ongoing development of the next generation of this single-photon source we employ state-of-the-art 1010 nm pulsed fiber amplifiers to drive a Rydberg excitation via the 6P intermediate state.

Here we report on time resolved observations of nanosecond pulsed four-wave mixing and GHz Rabi cycling involving the 32S Rydberg state. Our results show oscillating dynamics of the mixed photons on the final transition of the FWM cycle. The MHz repetition rates and significantly higher photon yields allow us to study and optimize the antibuching through elaborate pulse shaping motivated by numerical simulations. Such excitation timescales also pave the way towards fast optimal control methods for high fidelity Rydberg logic gates.

Q 1.6 Mon 12:15 A320

Absorption sensing mode in radio frequency electrometry using Rydberg atoms in hot vapors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Chang Liu[1], Harald Kübler[2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 6R1, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffendwaldring 57, 70569 Stuttgart

We present theoretical work on atom-based RF E-field sensing using Rydberg atoms in hot vapors. There are two distinct strategies to detect the electric field strength of the RF wave, namely the Autler-Townes limit, where the splitting of the dressed states is proportional to the incident RF electric field strength and the amplitude regime, where we determine the electric field by measuring the difference of transmission in the presence of the RF electromagnetic field. We present theoretical calculations for the amplitude regime, using a two photon excitation scheme, that show how the scattering of the probed transition changes in the presence of the RF electromagnetic field. We find an analytical expression in the thermal limit with finite wave vector mismatch that yields an accurate approximation compared to full density matrix calculation in the strong coupling limit. Our work extends the understanding of the detection of weak RF E-fields with Rydberg-atom based RF sensors.

Q 1.7 Mon 12:30 A320

Light Filtration With Hot Atomic Vapor Cells — •Denis Uhland, Yijun Wang, Helena Dillmann, and Ilja Gerhardt — Institute of Solid State Physics, Light and Matter Group, Leibniz University Hannover

The interaction of light and atoms is one of the cornerstones to study quantum effects. Atomic vapor cells offer a convenient and robust framework to such studies. Not only can fundamental quantum effects be studied, but their robustness and ease of handling is beneficial for a vast array of applications in quantum technology. Examples are magnetometers, electrometers, atomic clocks, or laser frequency stabilization. We probe hot vapor cells with lasers and external magnetic fields to enable spectral narrow filtering and show their potential to improve confocal and wide-field imaging in microscopy [1]. Not only does this method efficiently suppress the undesired laser leakage of scattered excitation light, but it also enhances the detection efficiency by 15% compared to one of the best commercially available long-pass filters. Another flavor of such filters utilizes magnetic fields and founds on the Macaluso-Corbino effect. This allows to enable GHz-wide band-pass filters in a Faraday configuration.

[1] Uhland, D., Rendler, T., Widmann, M. et al. Single molecule DNA detection with an atomic vapor notch filter. EPJ Quantum Technol. 2, 20 (2015). https://doi.org/10.1140/epjqt/s40507-015-0033-1

Q 1.8 Mon 12:45 A320

Optimization and readout-noise analysis of a hot vapor EIT memory on the Cs D1 line — •Luisa Esguerra[1,2], Leon Messner[1,3], Elizabeth Robertson[1,2], Norman Vincenz Ewald[1], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany.

Efficient, noise-free quantum memories are indispensable components of quantum repeaters, which will be crucial for the realization of a global quantum communication network [1, 2]. We have realized a technologically simple, in principle satellite-suited quantum memory in Cesium vapor, based on electromagnetically induced transparency (EIT) on the ground states of the Cs D1 line [3]. We simultaneously optimize the end-to-end efficiency and the signal-to-noise level in the memory, and have achieved light storage at the single-photon level with end-to-end efficiencies up to 13(2)% at a minimal noise level corresponding to $\bar{\mu}_1 = 0.07(2)$ signal photons. From varying the control laser power at different detunings we gain profound understanding of the physical origin of the readout noise, and thus determine strategies for further minimization.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] J. Wallnöfer et al., Commun Phys 5, 169 (2022)
[3] L. Esguerra, et al., arXiv:2203.06151 (2022)

Q 2: Matter Wave Optics

Time: Monday 11:00–13:00 Location: E001

Invited Talk Q 2.1 Mon 11:00 E001

Interferometry with Bose-Einstein Condensates for inertial sensing — •Sven Abend[1], Christian Schubert[2], Matthias Gersemann[1], Ernst M. Rasel[1], and QUANTUS-QGYRO Teams[1] — [1]Institut für Quantenoptik, LU Hannover — [2]DLR-SI, Hannover

Matter-wave interferometers show great a potential for improving inertial sensing. The absence of drifts recommends them for a variety of applications in geodesy, navigation, or fundamental physics. Bose-Einstein condensates (BECs) provide the means to achieve the lowest expansion energies of few picokelvin.

Such ensembles, bring in reach extremely accurate gravimeters, accelerometers and gyroscopes. An atom interferometer with scalable area may be formed in a twin lattice combined with a relaunch mechanism to obtain multi loops as well. Due to this scalability, it offers the perspective of reaching unprecedented sensitivities for rotations in comparably compact sensor head setups.

Moreover, atom-chip technologies offer the possibility to generate a BEC, paving the way for field-deployable miniaturized atomic devices. The extremely low expansion energies of BECs open up to extend the time atoms spend in the interferometer to tens of seconds. This brings in reach unprecedented sensitivities in space-borne applications.

Q 2.2 Mon 11:30 E001

Wave-packet evolution during laser pulses driving an atomic clock transition — •Nadja Augst and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

Single-photon optical transitions enable novel applications of atom interferometry to dark-matter and gravitational-wave detection [1–3]. This work investigates the wave-packet evolution for an atom's center of mass during a laser pulse driving such a transition. Particular attention is paid to the effects of finite pulse duration on the central trajectory of the atomic wave packets and the phase that they acquire in the diffraction process. While the resulting deviations of the central trajectories are typically quite small, they can have a significant impact on the interferometric phase shift in high-precision measurements and a detailed analysis is therefore important. Our approach relies on a description of the matter-wave propagation in terms of central trajectories and centered wave packets [4].

[1] Y. A. El-Neaj et al., *EPJ Quantum Technol.* **7**, 6 (2020).
[2] M. Abe et al., *Quantum Sci. Technol.* **6**, 044003 (2021).
[3] L. Badurina et al., *J. Cosmol. Astropart. Phys.* **05** (2020) 011.
[4] A. Roura, *Phys. Rev. X* **10**, 021014 (2020).

Q 2.3 Mon 11:45 E001

Transverse motion of diffraction wavelets in a matter-wave beam-splitter — •Oleksandr Marchukov and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, D-64289, Darmstadt, Germany

Matter-wave interferometry with Bose-Einstein condensates (BECs) is a rapidly developing tool for precision measurements [1]. A crucial element of matter-wave interferometers is a beam-splitter that employs the interaction of atoms with laser beams and creates superposition of macroscopically occupied momentum states.

We consider the Bragg beam-splitting of an off-axis BEC with three-dimensional Gaussian laser beams [2]. The transverse position offset leads to the inseparability of the longitudinal and transverse motion during the pulse. Experimentally, this manifests as transverse momentum kicks. In order to describe both the Bragg oscillations between the momenta components and the motion of the BEC, we model the wavefunction of the condensate via a superposition of squeezed coherent states, initially separated by even multiples of laser photon momentum. We construct a Lagrangian field theory using the variational ansatz [3] that leads to a system of coupled Bragg-Schrödinger equations and Newtonian equations for the Bragg fragments. We compare our results with the (3+1)D numerical simulations, using realistic experimental parameters, and find a good agreement.

[1] D. Becker, et al., Nature 562, 3910395 (2018)
[2] A. Neumann, et al., Phys. Rev. A 103, 043306 (2021)
[3] R. Walser, et al. New J. Phys., 10(4), 045020 (2008)

Q 2.4 Mon 12:00 E001

Four-Wave Mixing Neurons — •Kai Niklas Hansmann and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4a, D-64289 Darmstadt, Germany

Artificial neural networks, and especially deep learning, are a rapidly increasing field and have found numerous applications in research and industry over recent years [1]. We propose to implement such a network in a physical system, utilizing the non-linearity of interacting ultracold quantum gases.

For this, we study the four-wave mixing process in bosonic matter waves [2, 3]. Given a superposition of three waves, the four-wave mixing process generates a fourth signal wave. We identify the three initial waves as input and the signal wave as output of an artificial neuron. We show, that the constructed system fulfills all requirements for neuron activity and responds to the input in a non-linear fashion. We perform benchmark calculations to determine the performance of the neuron.

Considering a homogeneous Bose-Einstein condensate in three dimensions with present plane matter waves, we find Josephson-like oscillations beyond the undepleted pump approximation. These can be expressed analytically and agree with numerical Gross-Pitaevskii simulations.

[1] O. Abiodun et al., *Heliyon* **4**, e00938 (2018).
[2] L. Deng et al., *Nature* **398**, 218-220 (1999).
[3] J.M. Vogels et al., *Phys. Rev. Lett.* **89**, 020401 (2002).

Q 2.5 Mon 12:15 E001

Multipole analysis for matter-wave optics — •Jan Teske and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

In 1934 Frits Zernike introduced his orthogonal "Kreisflächenpolynome" to describe wavefront aberrations in optics. Nowadays, technical matter-wave optics requires [1] high precision modeling as interferometry with Bose-Einstein condensates [2] is paving the way to a new era of quantum technologies.

In this contribution, we present a (3+1)D multipole expansion adapting Zernike's for a consistent and efficient description for matter-wave optics with BECs. For this purpose, we are characterizing external potentials obtained by magnetic chip traps and Laguerre-Gaussian beams used for trapping, guiding and delta-kick collimation. Afterwards, we demonstrate an efficient approximation scheme for different density distributions. Further, we discuss density and phase perturbations that we analyze in terms of our partial wave expansion. Finally, we discuss phase aberrations caused during delta-kick collimation and the resulting density distortions after long expansion times.

[1] C. Deppner et al., PRL 127 (2021)
[2] M. Lachmann et al., Nature Communications 12, 1317 (2021)

Q 2.6 Mon 12:30 E001

A reflective atom interferometer — •Johannes Fiedler and Bodil Holst — University of Bergen, Bergen, Norway

The field of atom interferometry has expanded enormously over the last few decades. Atom interferometers are used in various applications, from measuring fundamental physics constants to atomic clocks. Detailed planning is ongoing for using atom interferometers as dark matter and gravitational wave detectors. Most applications use cold atoms or BEC and split the wave function via laser pulses. Transmission interferometer with thermal atoms uses dielectric objects [1] or a standing laser field [2] to split the beam. Via these techniques, the matter wave can only be separated over a few mrad [3]. A reflected atom interferometer can dramatically enhance the beam splitting to a rad. In this talk, we will present a scheme for a reflective atom interferometer using the surface diffraction of two parallel plates to achieve the large-angle separation of the wave function [4]. We will show a realisable interferometer setup and demonstrate the expected interference patterns.

[1] N. Gack et al. Phys. Rev. Lett. 125, 050401 (2020). [2] S. Eibenberger et al. Phys. Rev. Lett. 112, 250402 (2014). [3] C. Brand et al. Nature Nanotechnology 10, 845 (2015). [4] J. Fiedler et al. in preparation.

Q 2.7 Mon 12:45 E001

QUANTUS-2: Double Bragg atom interferometry in microgravity on long time scales — •Laura Pätzold[1], Merle Cornelius[1], Dorthe Leopoldt[2], Julia Pahl[3], Anurag Bhadane[4], Waldemar Herr[2,5], Patrick Windpassinger[4], Christian Schubert[5], Markus Krutzik[3,6], Sven Herrmann[1], Ernst M. Rasel[2], and The QUANTUS Team[1,2,3,4,7,8] — [1]U Bremen — [2]LU Hannover — [3]HU Berlin — [4]JGU Mainz — [5]DLR SI — [6]FBH Berlin — [7]U Ulm — [8]TU Darmstadt

Matter wave interferometry allows for quantum sensors with a wide range of applications, e.g. in geodesy or tests of fundamental physics. As a pathfinder for future space missions, QUANTUS-2 is a high-flux Rb-87 Bose-Einstein condensate (BEC) experiment operating in microgravity at the ZARM drop tower in Bremen. By applying a magnetic lens, we are able to reduce the total internal kinetic energy of the BEC to $\frac{3}{2}k_B \cdot 38\,\mathrm{pK}$ in three dimensions [1]. This is required to enhance the atomic signal for interferometry on time scales in the order of seconds as envisioned for future space based precision experiments. Via a retro-reflex interferometry setup, QUANTUS-2 is performing atom interferometry based on double Bragg diffraction in free fall. In this talk, we present our latest results on the performance of open Mach-Zehnder type interferometers on extended time scales.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers DLR 50WM1952-1957.

[1] C. Deppner et al., Phys. Rev. Lett. **127**, 100401 (2021)

Q 3: Quantum Computing and Simulation (joint session Q/QI)

Time: Monday 11:00–13:00 Location: E214

Q 3.1 Mon 11:00 E214

An energy estimation benchmark for quantum computers — •Andreas J C Woitzik[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany

While quantum-mechanical measurements yield intrinsically stochastic outcomes, the fluctuations in the output of current noisy intermediate-scale quantum (NISQ) devices are caused, for the large part, by imperfections in the hardware components and operations. We propose a simple energy estimation benchmark and use it to gauge noise-induced fluctuations in the output of IBM Quantum System One in Ehningen. We find that the errors we measure in our benchmark correlate only weakly with the reported calibration data of the machine. Moreover, a time-resolved analysis of the benchmark measure reveals periodic oscillations and unpredictable outliers that cannot be mildened by measurement error mitigation. We conclude that we cannot rely on single realizations of circuit outcomes, but rather on appropriately sampled ensembles.

Q 3.2 Mon 11:15 E214

Effects of particle losses in two photon quantum walks — •Federico Pegoraro, Philip Held, Sonja Barkhofen, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS) Warburger Str. 100, 33098, Paderborn, Germany

In real photonic quantum systems losses are an unavoidable factor limiting the scalability to many modes and particles, restraining their application in fields as quantum information and communication. A considerable amount of engineering effort has been taken in order to improve the quality of particle sources and system components. At the same time, data analysis and collection methods based on post-selection have been used to mitigate the effect of particle losses. This has allowed for investigating experimentally multi-particle evolutions where the observer lacks knowledge about the system's intermediate propagation states. Nonetheless, the fundamental question how losses affect the behaviour of the surviving subset of a multi-particle system has not been investigated so far. For this reason, with this contribution we study the impact of particle losses in a quantum walk of two photons reconstructing the output probability distributions for one photon conditioned on the loss of the other in a known mode and temporal step of our evolution network. We present the underlying theoretical model that we have devised in order to model controlled particle losses, we describe a platform capable of implementing our theory and in the end we show how localized particle losses change the output distributions without altering their asymptotic spreading properties.

Q 3.3 Mon 11:30 E214

Realization of a photonic ultra-fast free space discrete-time quantum walk. — •Jonas Lammers, Syamsundar De, Nidhin Prasannan, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Recent developments in quantum systems based on time-multiplexed techniques have shown high potential for quantum communication and information processing protocols. The time-multiplexed architecture has already been used in experiments demonstrating exponential increase in GHZ state generation and quantum advantage based on Gaussian boson sampling. Here we demonstrate an ultra-fast free space discrete-time quantum walk. With the newest generation of SNSPDs enabling higher than ever timing resolutions, we were able to overcome the need for long optical delay paths - typically optical fibers - in time-multiplexed systems. The resulting free space architecture enables us to increase measurement repetition rates by multiple orders of magnitude and promises increased stability. Furthermore, we can expect an increase in efficiency which would lead to an exponential increase in observable step numbers. We performed a full polarization resolved quantum walk characterization using coherent light and heralded single photons, observing up to twenty quantum walk steps with high similarity to theory. The demonstrated ultra-fast quantum walk is a promising platform for quantum simulations and opens up a path for large-scale quantum photonic networks utilizing time-multiplexing.

Q 3.4 Mon 11:45 E214

Multiphoton entangled graph states from a single atom — •Philip Thomas, Leonardo Ruscio, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching

Optical photons interact very weakly with their environment, making them robust qubit carriers suitable for numerous protocols in quantum information science. Many experiments on photonic entanglement that were carried out over the last decades relied on the well-established toolbox of non-linear optics. However, the underlying process is intrinsically probabilistic and thus poses a practical limit on the size of entangled states one can generate. In order to avoid this obstacle, we use a single Rubidium atom in an optical cavity as an efficient photon source [1]. Single photons are emitted sequentially while the atomic spin qubit mediates entanglement between them. We show that by tailored single-qubit operations on the atomic state we generate Greenberger-Horne-Zeilinger (GHZ) states of up to 14 photons and linear cluster states of up to 12 photons. A combined source-to-detection efficiency of 43% leads to coincidence rates orders of magnitude higher than the previous state-of-the-art [2]. Our work represents a step towards scalable measurement-based quantum computing and communication.

[1] P. Thomas *et al.*, Nature **608**, 677-681 (2022).
[2] H.-S. Zhong *et al.*, Phys. Rev. Lett. **121**, 250505 (2018).

Q 3.5 Mon 12:00 E214

Multi-photon coherence and interference — •Sholeh Razavian[1,2], Klaus Mølmer[3], Jasmin Meinecke[1,2], and Harald Weinfurter[1,2] — [1]Department fur Physik, Ludwig-Maximilians-Universitat, Munich, Germany — [2]Max-Planck-Institute for quantum optics, Garching, Germany — [3]Niels Bohr Institute, Copenhagen, Denmark

The Hong-Ou-Mandel(HOM) effect is a prime example of photon interference in quantum optics and forms the basis for many quantum applications. While HOM interference is a two-photon effect, we are lifting it to the general case, considering multi-photon interference including decoherence effects.

Here we are analyzing polarized photons propagating in integrated waveguide arrays with polarization dependent coupling. With two observables, one for path and one for polarization. The output is a superposition of all the different configurations in a possibly non-classical state.

We analyze multiphoton coincidence measurements and samples from the probability distribution in order to investigate polarization-dependent decoherence of the total quantum state.

Q 3.6 Mon 12:15 E214

Physical computing with a superfluid — Maurus Hans[1], •Elinor Kath[1], Marius Sparn[1], Nikolas Liebster[1], Felix Draxler[2], Helmut Strobel[1], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [2]Interdisziplinäres Zentrum für Wissenschaftliches Rechnen, Universität Heidelberg, Germany

We report on the implementation of a hybrid neural network with a physical system. As a proof-of-concept we implement the regression and interpolation of a non-linear, one-dimensional function. A digital micromirror device is used to prepare an elongated atomic cloud and encode input values by imprinting a phase profile onto the superfluid. Its non-linear response is detected by the observation of the density distribution, from which the output value is generated by a trained linear layer. We compare the performance of this hybrid neural network for different parameters and give an outlook for further directions.

Q 3.7 Mon 12:30 E214

A novel quantum simulation platform for ultracold ytterbium atoms using hybrid optical potentials — •Etienne Staub[1,2], Tim O. Höhn[1,2], Guillaume Brochier[1,3], Clara Z. Bachorz[1,2,4], David Gröters[1,2], Bharath Hebbe Madhusudhana[1,2,5], Nelson Darkwah Oppong[1,2,6], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]École normale supérieure de Lyon, Lyon, France — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany — [5]Los Alamos National Laboratory, Los Alamos, USA — [6]JILA, University of Colorado at Boulder, Boulder, USA

We report on our recent progress constructing a novel experimental platform for ytterbium atoms. Our approach combines optical lattices and optical tweezers, providing a versatile, robust and scalable environment for both analog and digital quantum simulation. A central ingredient of our implementation are optical potentials at the magic and tune-out wavelengths for the ground and meta-stable clock state of ytterbium. Leveraging high-resolution optical clock spectroscopy, we present preliminary results from our efforts to experimentally determine two new magic wavelengths and the ground-state tune-out wavelength near the narrow cooling transition at 556nm. Furthermore, we demonstrate loading, cooling and imaging of individual atoms in our tweezer array. Possible avenues of research include the simulation of lattice gauge theories and the implementation of quantum computing schemes by means of collisional gates.

Q 3.8 Mon 12:45 E214

Robust localization effects in dipolar systems with positional disorder — •Adrian Braemer and Martin Gärttner — University Heidelberg, Germany

We study a Heisenberg XXZ model with disordered couplings arising from power-law interactions between randomly positioned sites. This type of system is realized naturally in a large range of quantum simulation platforms. We numerically find indications of a localization transition and derive a simple, effective model for the local integrals of motion based on strongly interacting pairs. By systematically taking into account higher order resonances, we find a strong renormalization flow towards a pure Ising model. This might explain the numerically observed robustness of the localization transition, which in this system does not drift towards strong disorder strength as the system size is increased. One may even conjecture that the localized phase could be stable in this type of systems.

Q 4: Cold Molecules (joint session MO/Q)

Time: Monday 11:00–13:00 Location: F102

See MO 1 for details of this session.

Q 5: Quantum Optics: Open Quantum Systems

Time: Monday 11:00–13:00 Location: F342

Q 5.1 Mon 11:00 F342

Certifying multi-mode light-matter interactions in lossy resonators — •Dominik Lentrodt[1,2], Oliver Diekmann[2], Christoph H. Keitel[2], Stefan Rotter[3], and Jörg Evers[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [3]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

Few-mode models - such as the Jaynes-Cummings model and its generalisations - have been an indispensable tool in studying the quantum dynamics of light-matter interactions in optical resonators. Recently, however, novel regimes featuring strong coupling in combination with large losses have attracted attention in various experimental platforms. In this context, central assumptions of these canonical quantum optical models have to be revisited. In this talk, we will discuss recent extensions of Jaynes-Cummings type few-mode models and an associated class of loss-induced multi-mode effects. In particular, we will introduce an exact basis transformation to derive few-mode theory from first principles and a simple classification criterion for the appearance of multi-mode effects in lossy resonators. We will further discuss open problems, the relation to alternative approaches, and implications for recent experiments in x-ray cavity QED with Mössbauer nuclei — an emerging platform at the high-energy frontier of quantum optics, featuring lossy resonators doped with ultra-low decoherence emitters.

Q 5.2 Mon 11:15 F342

Noise-induced networks — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We analyze a transport problem on a graph with multiple constraints and in the presence of noise and determine the network topologies to which the dynamics converges. The dynamics results from the interplay of a nonlinear interaction function and Gaussian, additive noise. The deterministic model is based on an optimization algorithm that has been designed starting from biologically-inspired models and reproduces essential elements of a neural network. The amplitude of the noise is a variable that simulates the temperature of an external bath. We show that different network topologies emerge as a function of the noise amplitude and are generally multi-stable. Remarkably, the system converges to the most robust configuration at finite noise amplitudes thereby exhibiting a resonant-like behavior. Interestingly, this configuration is not found by the deterministic dynamics and is reached with the maximal convergence. Our results suggest that stochastic dynamics can boost transport on a nonlinear network.

Q 5.3 Mon 11:30 F342

Loss-induced topological protection — •Vinzenz Zimmermann[1], Konrad Tschernig[2], Kurt Busch[1,3], and Armando Perez-Leija[2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Berlin, Germany — [2]CREOL/College of Optics, University of Central Florida, Orlando, Florida, USA — [3]Max-Born-Institut, Berlin, Germany

Arrays of evanescently coupled waveguides have become a veritable platform with especially promising prospects in topologically protected photonics [1]. By employing topologically protected states in specifically engineered arrays of waveguides, precise manipulations and robust propagation of classical and quantum states of light can be realized in entirely passive systems [2]. These topological effects have been shown to exist beyond Hermitian quantum-optical systems [3]. We explore the possibility to synthesize topologically protected steady states in dissipative waveguide arrays realizing non-Hermitian effective Hamiltonians. The Su-Schrieffer-Heeger (SSH) model implementing one dimensional dimer chains is studied in the framework of the tight binding model [4]. From an open quantum system perspective, the existence of zero modes in the spectrum of the corresponding Liouville superoperator is considered. The efficiency of the procedure regarding different initial excitations and system parameters is discussed.

[1] Laser Photonics Reviews 9, 363-384 (2015)
[2] Optica 3, 925 (2016)
[3] Phys. Rev. Research 2, 013387 (2020)
[4] Phys. Rev. Lett. 42, 1698 (1979)

Q 5.4 Mon 11:45 F342

Laser operation based on Floquet-assisted superradiance — •Lukas Broers[1] and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany.

We demonstrate the feasibility of utilizing the non-equilibrium Floquet-assisted superradiant phase (FSP) in the dissipative Rabi-Dicke model for laser operation. We relate this phase to the population inversion of Floquet states of the driven two-level systems in the cavity. This inversion is depleted near Floquet energies that are resonant with the cavity frequency to sustain a coherent light-field. We show the robustness of this state against key imperfections. We consider the effect of a finite linewidth of the driving field and find that the linewidth of the light field in the cavity narrows drastically across the FSP transition, reminiscent of a line narrowing at the laser transition. We find that the FSP is robust against inhomogeneous broadening and that the depleted population inversion of near-resonant Floquet states leads to hole burning in the inhomogeneously broadened Floquet spectra. Finally, the FSP is robust against dissipation processes, with coefficients up to values that are experimentally available.

[1] L. Broers et al., Floquet engineering of non-equilibrium superradiance, arXiv:2203.07434 (2022)

[2] L. Broers et al., Laser operation based on Floquet-assisted superradiance, arXiv:2211.01320 (2022)

Q 5.5 Mon 12:00 F342

Exact treatment of strongly damped quantum dynamics with a continuous degree of freedom — •Stefanie Eileen Bränzel — Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

Current experiments show an increasing need for an exact description of the system dynamics because of its strong interaction with an environment. For instance in the field of optomechanics, there are many setups where a quantum system couples to an oscillating cantilever, e.g. gravimetry or an optical cavity with an oscillating mirror. However, for such systems the analytical solutions are generally infeasible. Thus, numerical methods are needed.

We apply the Hierarchy of Pure States (HOPS) formalism to strongly-damped open quantum systems with a continuous degree of freedom. This approach provides a non-perturbative description for the interaction between a quantum particle trapped in an arbitrary position-dependent potential with an environment. As an example, we demonstrate the accuracy of this HOPS method written in position space for a harmonic potential where the analytical solution is known for a Lorentzian environment. We furthermore visualize the stochastic dynamics by means of the Wigner representation. We recognize that our approach yields accurate results and plan on applying it to systems with an anharmonic potential, e.g. the Morse potential. We are convinced that the HOPS formalism will allow us to thoroughly investigate optomechanical systems, strongly damped cantilever and much more.

Q 5.6 Mon 12:15 F342

Nested Open Quantum Systems description of Photonic Bose–Einstein Condensate in a Planar Cavity — •Andris Erglis[1] and Stefan Yoshi Buhmann[2] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany

The photonic Bose–Einstein Condensate (BEC) is a macroscopic state of light forming in thermal equilibrium with a sharply peaked ground mode occupation. A prevalent way to achieve it is through a photon-dye interaction in a cavity with high-reflectance mirrors.

Here we present a rigorous derivation of the dynamics of a photon BEC employing a nested open quantum systems approach [1]. We describe dye molecules using the polaron Hamiltonian and model photon–molecule interactions using macroscopic quantum electrodynamics. We obtain rates of the condensation process via Green's tensor, allowing us to describe the photon BEC in arbitrary geometries.

We apply our formalism to a simple geometry – a finite-size planar cavity. Through numerical simulations, we demonstrate that condensation occurs in a two-dimensional untrapped gas, where each cavity mode is characterised by the transverse wave vector of the photons. We analytically study the behaviour of the photonic BEC in the limit of the size of the mirrors becoming very large or the mode spacing going to zero.

[1] ”Nested Open Quantum Systems Approach to Photonic Bose–Einstein Condensation”, Andris Erglis and Stefan Yoshi Buhmann, arXiv:2203.11039 (2022).

Q 5.7 Mon 12:30 F342

Quantum Master Equations for finite system-bath coupling — •Tobias Becker[1], Lingna Wu[1], Alexander Schnell[1], Juzar Thingna[2] und André Eckardt[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Department of Physics and Applied Physics, University of Massachusetts, Lowell, MA 01854, USA

For open quantum systems that are coupled to their environment an effective description for the reduced dynamics of the system is of great interest. For ultraweak coupling between system and bath Lindblad master equations yield an adequate approximation. However for finite coupling or for non-Markovian dynamics approaches beyond Lindblad are required. A good candidate is the Redfield equation, which is obtained in second order of the system bath coupling. However it is well known to violate positivity in certain parameter regimes. To overcome this problem we derive an alternative Lindbladian approximation to the Redfield equation, which is valid beyond the ultraweak coupling regime. Moreover we propose yet another quantum master equation, which corrects Redfield by drawing inspiration from the statistical mean-force Gibbs state.

Q 5.8 Mon 12:45 F342

Superradiance in 1D chains of multilvel atoms — •Aleksei V. Konovalov, Tom Schmit, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We analyse the properties of the light coherently scattered by a periodic array of atoms when the distance between neighbouring atoms is comparable with the wavelength. We specifically focus on superradiant scattering and analyse it as a function of the array periodicity. We also account for the multilevel atomic structure, where several dipole transitions of the same atom couple to the incident light and can mutually interfere. Starting from the full quantum master equation [1], we determine the properties of the light by means of the coherent-dipole approximation [2]. We then determine the collective Lamb-shift for chains of Na^{23} and Rb^{87} atoms in experimentally relevant geometries.

[1] Aleksei Konovalov and Giovanna Morigi. "Master equation for multilevel interference in a superradiant medium." *Physical Review A* 102.1 (2020), p. 013724.
[2] Bihui Zhu, John Cooper, Jun Ye, and Ana Maria Rey. "Light scattering from dense cold atomic media." *Physical Review A* 94.2 (2016), p. 023612.

Q 6: Quantum Effects (QED) (joint session Q/A)

Time: Monday 11:00–13:00 Location: F442

Q 6.1 Mon 11:00 F442

In the eye of the beholder: Interference in multi-atom dynamics — •Stefan Yoshi Buhmann[1] and Janine Franz[1,2] — [1]University of Kassel, Germany — [2]University of Freiburg, Germany

The Casimir–Polder force between an excited with a ground-state atom had been subject to an old controversy: Does its distance dependence exhibit oscillations due to interference [1] or not [2]? A time-dependent analysis of this scenario has revealed that the correct answer is a matter of perspective: the force on the excited atom does oscillate while that on the ground-state atom does not [3].

We complete this picture by studying the rate with which the excitation of the atom gets lost or is transferred to the ground-state atom, considering a range of channels: environment-assisted spontaneous decay, resonance energy transfer, and Auger decay. Again, we find that the correct answer depends on the perspective and hence the specific process considered.

[1] L. Gomberoff, R. R. McLone, E. A. Power, J. Chem. Phys. **44**, 4148 (1966).
[2] E. A. Power, T. Thirunamachandran, Phys. Rev. A **47**, 2539 (1993).
[3] P. Barcellona, R. Passante, L. Rizzuto, S. Y. Buhmann, Phys. Rev. A **94**, 012705 (2016).

Q 6.2 Mon 11:15 F442

Quantum friction near nonreciprocal media and chiral media — •Omar Jesús Franca Santiago and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We investigate how the quantum friction experienced by a polarisable charged particle moving with constant velocity parallel to a planar interface is modified when the latter consists of a chiral media or nonreciprocal media, with special focus on topological insulators. We use macroscopic quantum electrodynamics to obtain the Casimir-Polder frequency shift and decay rate. These results are a generalization of the respective quantities to matter with time-reversal symmetry breaking which violates the Lorentz reciprocity principle. We illustrate our findings by examining the nonretarded and retarded limits for five examples: a perfectly conducting mirror, a perfectly reflecting nonreciprocal mirror, a three-dimensional topological insulator, a perfectly reflecting chiral mirror and an isotropic chiral medium.

[1] S.Y. Buhmann, D.T. Butcher, S. Scheel. NJP 14, 083034 (2012).
[2] S. Fuchs, J.A. Crosse, S.Y. Buhmann. Phys. Rev. A 95, 023805 (2017).
[3] D.T. Butcher, S.Y. Buhmann, S. Scheel, NJP 14, 113013 (2012).

Q 6.3 Mon 11:30 F442

Casimir free energy of two bi-isotropic spheres in the plane-wave approach — •Tanja Schoger[1], Benjamin Spreng[2], Gert-Ludwig Ingold[1], and Paulo A. Maia Neto[3] — [1]Universität Augsburg, Augsburg, Germany — [2]University of California, Davis, USA — [3]Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

The Casimir interaction between two bi-isotropic spheres, where polarization mixing upon reflection at each sphere occurs, is studied in the plane-wave approach. We demonstrate that an asymptotic expansion of the Casimir force for large spheres, compared to the surface-to-surface distance, leads to the proximity force approximation (PFA) of the Casimir interaction [1].

A special case of bi-isotropic spheres are perfect electromagnetic conductors (PEMC) interpolating between the spheres with infinite permittivity and infinite permeability for which we present results for vanishing as well as non-zero temperatures [1, 2]. Apart from the PFA results, we also determine the leading PFA corrections and the results for large distances which reveal that the transition from an attractive force to a repulsive force depends on the temperature and the distance between the spheres.

[1] T. Schoger, B. Spreng, G.-L. Ingold, P. A. Maia Neto, Int. J. of Mod. Phys. A 37, 2241009 (2022)
[2] S. Rode, R. Bennett, S. Y. Buhmann, New J. Phys. 20, 043024 (2018)

Q 6.4 Mon 11:45 F442

Heat transport using nonreciprocal media — •Nico Strauss, Stefan Yoshi Buhmann, and Omar Jesús Franca Santiago — Institute of Physics, University of Kassel, Germany

The second law of thermodynamics dictates that heat flows from warm to cold objects, thereby providing a direction of time [1]. In the optics of nonreciprocal media [2], an arrow of time is alternatively provided by the observation that optical paths cannot be reversed. How are these two notions compatible of the level of quantum electrodynamics? In order to answer this question, we calculate the nanoscale heat transfer between the surfaces of two nonreciprocal media, namely axionic topological insulators which exhibit a temperature difference $\Delta T = T_1 - T_2$. We investigate the impact of the nonreciprocal properties of the plates on the heat transfer and investigate their interplay with the second law in the near field.

[1] Volokitin, A. I.; Persson, B. N. J. Rev. Mod. Phys. **4**, 79 (2007)
[2] S. Y. Buhmann et al., New J. Phys. **14**, 083034 (2012).

Q 6.5 Mon 12:00 F442

The Casimir-Polder force near an elliptical nanowire — •Bettina Beverungen[1], Kurt Busch[1,2], and Francesco Intravaia[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Max-Born-Str. 2 A, 12489 Berlin, Germany

Quantum and thermal fluctations of the electromagnetic field lead to many highly interesting and nontrivial effects such as the emergence of forces between neutral objects. These persist even in the limit of zero temperature due to the irreducible nature of the quantum fluctuations. While these interactions typically fall off rapidly with distance, they play a significant role at short separations relevant for modern nanotechnological applications. It is therefore important to understand how they depend on the geometry and material properties of the objects involved.

A prominent example is the Casimir-Polder force, which describes the interaction between a neutral atom or nanoparticle and a macroscopic object. Here, we investigate this interaction for an atom near a metallic nanowire of elliptical cross section. To verify the validity of our results, we show that they reduce to the case of a circular nanowire for low ellipticities. As a way to gain additional insight into the problem, we analyze the asymptotic behavior of the interaction energy with a particular focus on the distance regime where the effect of curvature is most pronounced.

Q 6.6 Mon 12:15 F442

Constraints on Beyond-Standard-Model Particles from the Muon's Anomalous Magnetic Moment — •Clive Reese and Stefan Yoshi Buhmann — University of Kassel, Germany

While the Standard Model is incredibly successful in predicting the anomalous magnetic moment of the electron, the same theory fails at predicting the anomalous magnetic moment of the muon a_μ. Recent experimental results by Fermilab reinforce the discrepancy, displaying a deviation of 4.2 σ [1]. Particles Beyond Standard Model (BSM) can contribute to a_μ due to one-loop corrections and thus explain the anomaly.

In our work we assume one fermion and one (pseudo-)scalar particle in the interaction, where either one of the particles or both can be BSM particles. We calculate the contribution to a_μ in dependence of the masses, coupling constants and electric charges. Considering experimental and theoretical limits it turns out that chiral couplings constitute good candidates, while uncharged fermions like neutrinos cannot explain the anomaly. A scalar in PeV-Scale is too heavy to be detected, but an theoretically explain the anomaly.

[1] B. Abi et al.: 'Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm', Phys. Rev. Lett. **126**, 141801 (2021)

Q 6.7 Mon 12:30 F442

Influence of quantum vacuum fluctuations on the causality of field correlations within nonlinear crystals — •Cristofero Oglialoro[1], Frieder Lindel[2], Fabian Spallek[1], and Stefan Yoshi Buhmann[1] — [1]University of Kassel, Germany — [2]University of Freiburg, Germany

A major consequence of Heisenberg's uncertainty principle is that, even though the expectation value of a quantum field vanishes, its ground state exhibits so-called quantum vacuum fluctuations. In recent years, experimental progress has made it possible to study the ground state fluctuations through electro-optic sampling by measuring changes in the polarisation of a laser pulse passing through a nonlinear crystal. The rotation of the polarisation can be attributed to the interaction of the pulse with the quantum vacuum. Macroscopic QED allows to describe the changes in this vacuum structure induced by the interaction with dielectric macroscopic bodies and provides a theoretical framework to survey its physical signatures. Studies of the correlation of the field of two laser pulses in a nonlinear crystal have even shown that points causally disconnected according to special relativity can exhibit a nonvanishing correlation function due to the interaction with the vacuum fluctuations [1]. We want to further investigate the influence of the quantum vacuum on the causality of correlations within dielectric macroscopic bodies and the possibility to explore the space-time structure of vacuum correlations in the altered metric provided by a nonlinear crystal in analogy to the behaviour in curved space-time.

[1] F. F. Settembrini, et al., Nat. Commun. 13, 3383 (2022).

Q 6.8 Mon 12:45 F442

Dispersive and dissipative dielectrics with 'scalar-field' type environments — •Sascha Lang[1,2,3], Stefan Yoshi Buhmann[1], Ralf Schützhold[2,4,3], and William G. Unruh[5,6] — [1]University of Kassel, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Universität Duisburg-Essen, Germany — [4]Technische Universität Dresden, Germany — [5]University of British Columbia, Canada — [6]Texas A&M University, United States

Macroscopic quantum electrodynamics provides a powerful framework for studying a large variety of dispersive and dissipative media [1]. To account for quantum fluctuations, a noise polarisation is manually incorporated into the formalism. This phenomenological approach is inspired by microscopic derivations (based on, e.g., the famous Huttner-Barnett model [2]) which explicitly describe damping via interactions with baths of harmonic oscillators. Unfortunately, models with harmonic-bath type environments are usually quite involved and facilitate straightforward solutions only for time independent systems and in the case of relatively simple position dependences.

We present an alternative approach and model dissipation via a scalar field that may carry energy and information away from the medium [3,4]. This model is much simpler than established microscopic descriptions and still holds for explicitly time-dependent systems.

[1] Scheel & Buhmann, Acta Phys. Slov. **58**, 675 (2008)
[2] Huttner & Barnett, PRA **46**, 4306 (1992)
[3] Lang, Schützhold & Unruh, PRD **102**, 125020 (2020)
[4] Lang, Sauerbrey, Schützhold & Unruh, PRR **4**, 033074 (2022)

Q 7: Poster I

Time: Monday 16:30–19:00 Location: Empore Lichthof

Q 7.1 Mon 16:30 Empore Lichthof

Power scaling of an Yb-doped diode-pumped mode-locked laser — •Thomas Konrad[1], Andy Steinmann[1], Tobias Steinle[1], Monika Ubl[1], Matthias Seibold[2], Gabriele Untereiner[3], Mario Hentschel[1], Philipp Flad[1], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]IHFG, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [3]1st Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Today's high power solid-state lasers are often constructed as thin-disk lasers. They require complex and expensive pumping systems. An easier and cheaper way is using solid-state lasers with conventional bulk crystals. They cannot reach the power levels of thin-disk lasers, but can still provide sufficient peak power for many applications such as nonlinear frequency conversion, yet being cheaper than disk lasers. In this work we follow different approaches to increase the average power of a femtosecond mode-locked Yb:KGW laser with a dual crystal cavity design. One important aspect is improving the crystal cooling to overcome thermal limitations. This can be realized by soldering the crystal to the heat sink to improve the thermal contact. Other aspects include optimizing crystal dimensions, doping concentrations, as well as pump and mode sizes.

Q 7.2 Mon 16:30 Empore Lichthof

5 W high power femtosecond laser at 2060 nm from a stabilized doubly resonant optical parametric oscillator — •han rao[1,2], Christian markus dietrich[1,2], José ricardo cardoso de andrade[3], robin mevert[1,2], fridolin jakob geesmann[1], ayhan demicran[1,2], ihar babushkin[1,2,3], and uwe morgner[1,2] — [1]Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Cluster of Excellence PhoenixD, Hannover, Germany — [3]Max Born Institute, Berlin, Germany

A high power 2 μm femtosecond laser source is demonstrated by a degenerate doubly resonant optical parametric oscillator (DROPO), which is synchronously-pumped by a home-built Yb:YAG Kerr-lens mode-locked thin-disk laser, emitting pulses at wavelength of 1030 nm with a pulse duration of 270 fs, 25 W output power and 32.5 MHz repetition rate. By using a dither-free scheme which utilizes a "parasitic" sum-frequency generation (SFG) of the signal and pump intracavity as error signal, we stabilize our degenerate DROPO. A stable output power of 4.9 W at degeneracy is observed with a pump power of 18.7 W, which results in a conversion efficiency of 26%. The long-term stability measurement of the power over 40 minutes showed a root mean square (RMS) power noise of 1.1%.

Q 7.3 Mon 16:30 Empore Lichthof

Towards generation of high power 2 μm pulses in the few cycle regime — •Jon Morten Drees[1], David Zuber[1,2], Ihar Babushkin[1,2,3], and Uwe Morgner[1,2,4] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines) 30167 Hannover, Germany — [3]Max Born Institute, Max-Born-Straße 2a, 10117 Berlin, Germany — [4]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

Ultrashort pulses in the short-wavelength infrared (SWIR) can be used for various applications such as high harmonic generation or an all-optical Attoclock. Most of the systems that provide such radiation are built with laser materials based on thulium or Cr:ZnSe. While such Systems can achieve high output powers they usually have relatively long pulse durations and require additional pulse compression to reach the few cycle regime. Due to this disadvantage we wanted to go another way to create 2 μm radiation. A regenerative amplifier, providing 750 μJ pulses at 1030 nm with a repetition rate of 100 kHz, is used to generate white-light at 700 nm, which is amplified in a non-collinear optical parametric amplifier (NOPA). By difference frequency generation with the 1030 nm pump a 2 μm seed can be generated efficiently. With two additional NOPA stages the SWIR pulse can then be amplified to achieve high pulse energies. This approach will allow us to achieve pulse durations of approximately 20 fs with pulse energies of up to 100 μJ.

Q 7.4 Mon 16:30 Empore Lichthof

Compression of Laser Pulses by Nonlinear Multipass Cells — •Peer Biesterfeld[1], David Zuber[1,2], Jose Mapa[1], and Uwe Morgner[1,2,3] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines) 30167 Hannover, Germany — [3]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

Due to the high efficiency, good scalability to high pulse energies and compactness multipass cells (MPCs) for post compression of laser pulses, are currently of high interest. In particular, gas-filled MPCs enable the compression of pulses with high pulse energies and simultaneously high average powers with efficiencies higher than 90%.

The compression of picosecond pulses to the few cycle regime is beyond the limits of a single MPC. To find the best way simulations based on the unidirectional pulse propagation equation (UPPE) in cylindrical coordinates are performed, leading to a two stage setup. In the first cell, a high compression ratio is achieved in order to exploit the high reflectivity of broadband dielectric mirrors. The high compression factor is achieved by using molecular gases as a nonlinear medium at comparatively low gas pressure and low cost. Gires-Tournois Interferometers (GTIs) are being used to compress the pulse before the second cell, which is operated in an atomic noble gas using silver mirrors.

To verify the functionality of the cell, the spectral, temporal and spatial characteristics of the output are measured and compared with the simulation results.

Q 7.5 Mon 16:30 Empore Lichthof

Low order harmonic generation in laser induced borosilicate glass plasma and CdTe quantum dots — •Victor Kärcher[1], Tobias Reika[1], Pedro F. G. M. da Costa[2], Andrea S.S. de Camargo[2], and Helmut Zacharias[1] — [1]Center for Soft Nanoscience, Busso-Peus Str. 10, 48149 Münster — [2]Sao Carlos Institute of Physics, University of Sao Paulo, Brazil

An investigation of the size dependent influence of CdTe quantum dots on the generation of low order harmonics up to the fifth order in laser induced plasma (LIP) of borosilicate glass for a fundamental wavelength of $\lambda=1030$\,nm and a pulse duration of $\tau=40$\,fs is presented. The aqueous soluble CdTe quantum dots are generated by seed-mediated growth approach. The CdTe nano particles are spin coated with different thicknesses on the surface. Laser intensities above ionization threshold are used to generate the plasma by laser induced optical breakdown. Electrons are accelerated in the electric field emitting harmonics after subsequent recombination. The resulting third harmonic is characterized by blue shifts originating from Raman and phonon lines of the targets. Applying CdTe quantum dots on the targets surface spectral shaping with different sizes and different coating thicknesses is observed. Peak amplification factors between 10 an 17 for small and large particles respectively are reached for the third harmonic while no size dependency of the power density is observed. The fifth harmonic is unaffected by Raman and phonon lines and no spectral shaping is observed as for the third. Amplification factors between 25 and 20 for small and large particle sizes respectively are observed.

Q 7.6 Mon 16:30 Empore Lichthof

Light-field control of electrons in graphene heterojunctions — •Tobias Boolakee[1], Christian Heide[1], Antonio Garzón-Ramírez[2], Heiko B. Weber[1], Ignacio Franco[2,3], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department of Chemistry, University of Rochester, Rochester, New York, USA — [3]Department of Physics, University of Rochester, Rochester, New York, USA

Ultrashort and intense laser pulses enable the observation and control of electronic processes in a wide variety of systems ranging from atomic and molecular processes to the microscopic motion of electrons inside solids. The time scale of this motion is set by the oscillation period of light, i.e., a few femtoseconds, and thus limits a potential bandwidth of emerging electric currents up to the petahertz range. Here we discuss strong-field physics in graphene, an electric conductor, and therefore, an ideal platform to drive and probe currents induced by the shape of the laser electric field. We can distinguish and take advantage of two types of charge carriers: Real carriers, persisting after their excitation, and virtual carriers, existing during the light-matter interaction only. We show that in a gold-graphene-gold heterostructure, the two types of carriers can be disentangled in their photocurrent response, as they are susceptible to the carrier-envelope phase of incident few-cycle laser pulses. These insights now enable us to design and demonstrate a proof-of-concept of an ultrafast logic gate.

Q 7.7 Mon 16:30 Empore Lichthof

Design and construction of a multi-hit-capable electron spectrometer for ultrafast photoemission experiments — •Jonathan Pölloth, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen.

The investigation of electron photoemission from metallic needle tips by femtosecond laser pulses allows to gain insights into ultrafast light-matter interaction processes. An important observable is the energy spectrum of the emitted electrons. Two typical features of such strong field spectra are the multiphoton peaks and the plateau due to rescattering. So far, mostly one-electron spectra have been considered, only recently first experiments on multi-electron emission were realised [1,2]. The energy-resolved simultaneous detection of more than one electron from one laser pulse is challenging. Here, we demonstrate a multi-hit-capable electron spectrometer for measuring electron energy spectra emitted from a tungsten needle tip. We use an electrostatic cylindrical deflector analyser that provides spatial separation of different electron energies. The spectrometer is designed and optimized using a commercial finite element solver. Our simulations show that an energy resolution below 0.25 eV at a central electron energy of 100 eV is feasible. This resolution not only allows us to observe strong field effects in the spectrum, but also to distinguish between different multiphoton order peaks.

[1] S. Meier, J. Heimerl and P. Hommelhoff, arXiv:2209.11806 (2022)
[2] R. Haindl et al., arXiv:2209.12300, (2022)

Q 7.8 Mon 16:30 Empore Lichthof

Guided acceleration in dielectric laser accelerators — •Leon Brückner, Tomás Chlouba, Johannes Illmer, Stefanie Kraus, Julian Litzel, Roy Shiloh, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Dielectric laser accelerators (DLA) are a highly promising technology that could enable the miniaturiziation of accelerators to tabletop or even microchip size. A DLA consists of a silicon nanostructure that is illuminated with a pulsed laser.

This creates an evanescent near-field that accelerates electrons entering the channel of the structure. To reach high energies, it is necessary to extend this interaction from micrometer length to millimeters or more. This is challenging as the electrons also experience deflecting forces and are eventually lost. To counteract this, we have employed an alternating phase focusing scheme: the electrons experience alternating transversal focusing and defocusing forces, guiding them through the structure. We could guide a 28.4 keV electron beam through the 225 nm wide channel of a 77 μm long nanostructure [1]. To accelerate with this scheme, it is also necessary to continuously change the grating periodicity (tapering) to conserve phase-matching between the particles and the accelerating field. We have developed and fabricated structures with lengths of several hundred micrometers that combine particle guiding with tapering. These structures will enable acceleration over much longer distances than previously possible. We will report the current state of the experiment. [1] R. Shiloh et al., Nature 597, 498-502 (2021)

Q 7.9 Mon 16:30 Empore Lichthof

Selective intracavity control of interlaced femtosecond soliton combs — •Julia A. Lang[1], Luca Nimmesgern[1], Sarah R. Hutter[2], Alfred Leitenstorfer[2], and Georg Herink[1] — [1]Universität Bayreuth, Deutschland — [2]Universität Konstanz, Deutschland

Complex sequences of multiple solitons are observed in almost all ultrafast mode-locked laser, but their dynamics remain difficult to access, control, or eventually apply. In this contribution, we present deterministic control of relative soliton motion between two interlaced harmonic mode-locked frequency combs. We implement intra-cavity control by acousto-optic modulation allowing us to selectively address pulses in a 40 MHz Er:fiber laser. The soliton trajectories following the external stimulus are rapid, tuneable and deterministic. As shown in [1], intracavity feedback plays an important role in the formation of stable soliton molecules. In this work, we experimentally resolve and analyse the dynamics in the frame of soliton interaction with an effective binding potential. As a proof-of-concept, we demonstrate first steps towards the use of tuneable intracavity soliton motions for ultrafast pump-probe spectroscopy.

[1] Nimmesgern, Luca et al. Soliton molecules in femtosecond fiber lasers: universal binding mechanism and direct electronic control. Optica 8, 10 (2021).

Q 7.10 Mon 16:30 Empore Lichthof

Bi-chromatic current excitation in 2D-materials with complex laser fields — •Simon Wittigschlager[1], Tobias Boolakee[1], Christian Heide[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen (FAU), Erlangen-Nürnberg, Germany — [2]Stanford PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, California, USA

We present a highly versatile and stable scheme to drive ultrafast light field-induced currents in solids using bi-chromatic laser fields (1550 nm and 775 nm) with full control over the polarisation states of both colours to form complex sum fields. We use these laser fields to steer electrons inside 2D-materials on trajectories, tailored to probe specific characteristics of their underlying band structure. In particular, if the field waveform is asymmetric with respect to time inversion, a momentum imbalance of excited electrons may occur, resulting in a measurable photocurrent. Importantly, while such schemes are usually realized as a Michelson interferometer with both colours separated spatially, our collinear approach grants superior stability with 2.99 mrad long-term phase jitter without the use of active stabilization techniques. We expect this highly stable setup to form the basis for probing electronic phenomena in solids, such as spin polarisation, Berry curvature and topological states, with unprecedented resolution at ultrafast timescales.

Q 7.11 Mon 16:30 Empore Lichthof

Pseudo Thermal Light Source in the XUV for Diffraction Imaging — •Jonas Musall[1], Chris Sträche[1], Philip Mosel[1], Sven Fröhlich[1], David Theidel[2], Hamed Merdji[2], Uwe Morgner[1], and Milutin Kovacev[1] — [1]Institute of Quantum Optics, Cluster of Excellecnce PhoenixD and Quantum Frontiers, Leibniz University Hanover, Welfengarten 1, 30167 Hanover, Germany — [2]LOA, ENSTA ParisTech, CNRS, Ecole Polytechnique, UMR 7639, 828 Boulevard des Maréchaux, 91120 Palaiseau, France

Coherent diffraction imaging (CDI) is a widely-used approach for nanoscale imaging. Besides its frequent use at synchrotron facilities, developments in laser-driven high harmonic sources have made it available on a smaller scale. A less explored possibility is the use of incoherent radiation for diffraction imaging as presented just recently [1]. This would allow a large number of compact sources in the X-ray range to be used for diffraction imaging. We are developing a method to control the degree of coherence in harmonics at 13 nm to investigate the transfer from coherent to incoherent imaging. To achieve this, the harmonic beam is scattered on different densities and sizes of nanoparticles. Additionally, the generated incoherent light can yield useful information on the initial coherent light source, such as the spot size and temporal pulse width [2].

[1] Classen, Anton et al. in: Physical Review Letters 119 (2017), Issue 5 [2] Tamasaku, Kenji et al. in: Journal of Synchrotron Radiation 26 (2019), No. 6

Q 7.12 Mon 16:30 Empore Lichthof

Potential Hazards and Mitigation of X-Ray Radiation Generated by Laser-Induced Plasma from Research-Grade Laser Systems — •Philip Mosel[1], Sven Fröhlich[1], Jose Mapa[1], Sven Kleinert[1], David Zuber[1], Jan Düsing[2], Thomas Püster[2], Günther Dittmar[3], Uwe Morgner[1], and Milutin Kovacev[1] — [1]Institute of Quantum Optics, Cluster of Excellence PhoenixD and Quantum Frontiers, Leibniz Universität Hannover, Hannover, 30167 — [2]Laser Zentrum Hannover e.V., Hannover, 30419 — [3]Ingenieur-Büro Prof. Dr.-Ing. G. Dittmar, Aalen, 73433

Ultra-short pulses and high laser intensities are used in a variety of laser-matter applications in laboratories and industry. Such processes can lead to unwanted generation of X-rays, which are a dangerous radiation factor [1]. We present an analysis of the radiation dose rate and the emitted X-ray spectrum during ablation of a rotating copper cylinder as a function of different laser parameters [2]. Furthermore, we studied the X-ray emission from commonly used metals, alloys and ceramics for ultrafast laser processing [3]. The results show that focused sub-picosecond pulses with intensity higher than 10^{13} W/cm^2 can exceed the annual irradiation limit even in one hour, making adequate shielding a necessity for researchers' safety.

[1] Legall, Herbert, et al., Applied Physics A 125.8 (2019): 1-8.
[2] Mosel, Philip, et al., Optics Express 30.20 (2022): 37038-37050.
[3] Mosel, Philip, et al., Materials 14.16 (2021): 4397.

Q 7.13 Mon 16:30 Empore Lichthof

Coherent imaging using a high-harmonic source — •Chris Sträche, Jonas Musall, Philip Mosel, Sven Fröhlich, Uwe Morgner, and Milutin Kovacev — Leibniz Universität Hannover, Deutschland, Welfengarten 1, 30167 Hanover

With increasingly smaller structures in the semiconductor industry and biological samples in the nanometer range imaging is becoming a challenging task. According to recently published results a resolution around 16 nm can be achieved using coherent diffraction imaging (CDI) [1]. To enhance the resolution limit higher photon energies, scanning the sample with a well-defined beam and overlapping probe positions (Ptychography) can be used. Here we present diffraction imaging using 13 nm based on high-harmonic generation in a semiinfinite gas cell. A variety of samples ranging from basic resolution targets up to biological samples and electronic circuits are to be characterized. With this setup a resolution below 50 nm is expected to be achieved. Keywords: lensless imaging, high-harmonic generation, coherent diffraction imaging, Pytchography Quellen: [1] Eschen, Wilhelm, et al. "Material-specific high-resolution table-top extreme ultraviolet microscopy." Light: Science & Applications 11.1 (2022): 1-10.

Q 7.14 Mon 16:30 Empore Lichthof

Pulse Characterization by Frequency-Resolved Optical Gating (FROG) for Extreme-Ultraviolet (XUV) Frequency Comb Generation — •Fiona Sieber[1], Lennart Guth[1], Jan-Hendrik Oelmann[1], Tobias Heldt[1], Simon Angstenberger[1], Stepan Kokh[1], Janko Nauta[1,2], Nick Lackmann[1], Nele Griesbach[1], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut for Nuclear Physics, Heidelberg, Germany — [2]Department of Physics, Swansea University, Singleton Park, SA2, United Kingdom

The characterization of femtosecond pulses, which play a major role in precision spectroscopy, is challenging due to the lack of an accurate time reference on the ultrafast scale. Therefore the pulse has to be referenced by itself. In the scope of transferring a near-infrared frequency comb with 100 MHz repetition rate to the XUV-regime via high harmonic generation (HHG), 80 W femtosecond pulses are characterized in the time and frequency domain before the HHG stage using a FROG set-up. [1] The pulse is overlapped with a delayed copy of itself in a nonlinear crystal and the generated second harmonic is detected by a Czerny-Turner spectrometer. The shape, duration and power spectral density of the laser pulse are retrieved from the recorded FROG traces (intensities dependent of frequency and delay) using a noise removal protocol and the ePIE algorithm [2].

[1] J. Nauta et al., Optics Express, Vol. 29, No. 2, 2624 (2018)
[2] P. Sidorenko et al., Optica, Vol. 3, No. 12, 1320 (2016)

Q 7.15 Mon 16:30 Empore Lichthof

A hard X-Ray Split-and-Delay Unit for the HED Instrument at the European XFEL — •Dennis Eckermann[1], Sebastian Roling[1], Matthias Rollnik[1], Peter Gawlitza[2], Karen Appel[3], Liuba Samoylova[3], Harald Sinn[3], Frank Siewert[4], Thomas Tschentscher[3], Frank Wahlert[1], Ulf Zastrau[3] und Helmut Zacharias[1] — [1]Westfälische Wilhelms Universität, Münster, Deutschland — [2]Frauenhofer Institut IWS, Dresden, Deutschland — [3]European XFEL GmbH, Hamburg, Deutschland — [4]HZB, Berlin, Deutschland

A concept of a Split-and-Delay Unit which is capable of doing hard X-Ray pump-probe Experiments.

Q 7.16 Mon 16:30 Empore Lichthof

Simulations of magnetic field amplification and electric field suppression in ultrashort optical laser pulses — •Lorenz Grünewald[1,2], Rodrigo Martín-Hernández[3], Elizaveta Gangrskaia[4], Valentina Shumakova[4], Carlos Hernández-García[3], and Sebastian Mai[1] — [1]Institute for Theoretical Chemistry, Faculty of Chemistry, University of Vienna, Währinger Str. 17, 1090 Vienna, Austria — [2]Vienna Doctoral School in Chemistry (DoSChem), University of Vienna, Währinger Str. 42, 1090 Vienna, Austria — [3]Grupo de Investigación en Aplicaciones del Láser y Fotónica (ALF-USAL), Dpt. Fisica Aplicada, Universidad de Salamanca, Pl. La Merced sn., E37008 Salamanca, Spain — [4]Institute for Photonics, Faculty of Electrical Engineering and Information Technology, TU Wien, Gußhausstr. 27-29, 1040 Vienna, Austria

We present particle-in-cell simulations of the electromagnetic fields of an ultrashort azimuthally polarized laser beam (APB), and demonstrate that they exhibit a region close to the beam axis with strong oscillating magnetic field and vanishing electric field. Upon focusing the APB on a small metal iris, a so-called aperture, fast oscillating ring currents are induced around the aperture circumference, which in turn generates an additional magnetic field (MF) contribution that strongly increases the MF strength at the beam center [3]. Improved experimental setups with different aperture geometries, which yield further enhancements, are suggested, enabling a MF-only spectroscopy. [1] DOI: 10.1016/j.ccr.2015.02.015, [2] DOI: 10.1364/JOSAB.32.000345, [3] DOI: 10.1021/acsphotonics.8b01312

Q 7.17 Mon 16:30 Empore Lichthof

Transportable Laser System Employing Fourier Limited Picosecond Pulses for Laser Cooling of Relativistic Ion Beams — •Benedikt Langfeld[1,2], Sebastian Klammes[3], and Thomas Walther[1,2] — [1]Technische Universität Darmstadt — [2]HFHF Darmstadt — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH

Laser cooling of relativistic ion beams has been shown to be a promising technique to generate cold ion beams with a small velocity distribution. To strongly reduce intrabeam scattering, a well-known problematic effect for high-intensity ion beams which broadens the velocity distribution, pulsed laser systems with broad bandwidths can be employed.

In this work, we present our tunable high repetition rate UV laser system. We have developed a transportable master-oscillator-power-amplifier system, supplying Fourier transform limited pulses with a continuously adjustable pulse length between 50 and 735 ps and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257 nm with up to 4 W average power can be achieved. The combination of the tunable seed laser (3 nm @ IR seed wavelength) and the large Doppler shift allows to easily match the output wavelength to the cooling transition of the ions.

Q 7.18 Mon 16:30 Empore Lichthof

Coherent beam recombination of intense femtosecond beams/pulses after controllable beam break-up and spectral broadening by using optical vortex lattices — •Lyubomir Stoyanov[1,2], Alexander Dreischuh[2], and Gerhard Paulus[1,3] — [1]Institute of Optics and Quantum Electronics, Friedrich Schiller University, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Department of Quantum Electronics, Faculty of Physics, Sofia University, 5 J. Bourchier Blvd., 1164 Sofia, Bulgaria — [3]Helmholtz Institute Jena, Helmholtzweg 4, 07743 Jena, Germany

Ultra-short laser pulse generation, as well as extreme nonlinear processes like high-harmonic generation, are extensively studied and still actively developing fields of modern photonics. Ever since their discovery, researchers are dealing with problems like spectral broadening, filamentation, pulse/beam diagnostics, pulse amplification, and coherent beam recombination. On the other hand, singular optics is another rapidly developing field in which subject of interest is the sculpting of a laser beam by nesting phase singularities in it.

At high beam/pulse intensities, the beams are prone to instabilities, which could be suppressed by controllable splitting of the beam into sub-beams. This makes sense only if there is a reliable way to coherently recombine the sub-beams after their spectral broadening for pulse compression prior entering the laser-matter interaction zone. Some novel approaches towards these unsolved problems in nonlinear optics, based on previous studies on laser beams carrying phase singularities, will be presented and discussed.

Q 7.19 Mon 16:30 Empore Lichthof

Higher-order mean-field theory of chiral waveguide QED — •Kasper Jan Kusmierek[1], Sahand Mahmoodian[1,2], Martin Cordier[3], Jakob Hinney[4], Arno Rauschenbeutel[3,4], Max Schemmer[3], Philipp Schneeweiss[3,4], Jürgen Volz[3,4], and Klemens Hammerer[1] — [1]Institut für theoretische Phyisk, Leiniz University Hannover, Hannover, Germany — [2]Centre for Engineered Quantum Systems, School of Physics, University of Sydney, Sydney, Australia — [3]Departement of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [4]Vienna Center for QuantumScience and Technology, Vienna, Austria

Waveguide QED with cold atoms provides a potent platform for the study of non-equi-librium, many-body, and open-system quantum dynamics. Here we apply an improved mean-field theory based on higher-order cumulant expansions to describe the experimentally relevant, but theoretically elusive, regime of weak coupling and strong driving of large ensembles. We determine the transmitted power, squeezing spectra and the degree of second-order coherence, and systematically check the convergence of the results by comparing expansions that truncate cumulants of few-particle correlations at increasing order. This reveals the important role of many-body and long-range correlations between atoms in steady state. Our approach allows to quantify the trade-off between anti-bunching and output power in previously inaccessible parameter regimes. Calculated squeezing spectra show good agreement with measured data, as we present here.

Q 7.20 Mon 16:30 Empore Lichthof

Collective radiative effects in nanofiber-coupled atomic ensembles: From timed Dicke states to full inversion — •Christian Liedl, Felix Tebbenjohanns, Constanze Bach, Sebastian Pucher, Arno Rauschenbeutel, and Philipp Schneeweiss — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Dicke superradiance is a hallmark effect in quantum optics. There, an ensemble of initially excited atoms can emit a burst of light due to spontaneous phase locking of the atomic dipoles during their decay. In order to observe this phenomenon, the atoms are typically placed in close vicinity of each other. In contrast, here, we study superradiance using macroscopically separated atoms. Each atom is almost unidirectionally coupled to the nanofiber-guided mode, allowing us to describe the dynamics using a cascaded interaction model. In our experiment, we coherently invert up to 1000 atoms and study their decay dynamics. We analyze the role of coherent forward scattering over the whole parameter regime, from weak excitation to almost full inversion. We observe superradiant burst dynamics and find a characteristic threshold behavior. Finally, we find that the superradiant burst has a random phase with respect to the excitation laser. This confirms that the build-up of coherence during the decay indeed stems from spontaneous phase locking of the atoms, which lies at the heart of superradiant.

Q 7.21 Mon 16:30 Empore Lichthof

Ultrafast excitation exchange in multimode cavities — •Oliver Diekmann, Dmitry O. Krimer, and Stefan Rotter — Institute for Theoretical Physics, Vienna University of Technology (TU Wien), Vienna A-1040, Austria

The single-mode Jaynes-Cummings model has been of paramount importance in the development of quantum optics. Recently, also the strong coupling to more than a single mode of an electromagnetic resonator has drawn considerable interest. We investigate how this *superstrong* coupling regime can be harnessed to coherently control quantum systems. In particular, we show that elliptical cavities and Maxwell-Fish-Eye lenses can be used to implement a pulsed excitation-exchange between two quantum emitters. This periodic exchange is mediated by single photon pulses and can be extended to a photon-exchange between two atomic ensembles, for which the coupling strength is enhanced collectively. Our study illustrates how ideas from classical optics can be used in the realm of multimode strong coupling for applications in quantum technology.

Q 7.22 Mon 16:30 Empore Lichthof

Properties of few level atomic systems possessing a permanent dipole moment. — •Alexandra Mirzac — Insitute of Applied Physics, Academiei str.5, MD-2028, Chisinau, Moldova

The quantum optical properties of two- and three-level atomic systems interacting with electromagnetic field is an area of research directed to solve applied problems emerging in laser science, fluorescent spectroscopy, nano-imaging and quantum information theory.

Dipolar two-level atomic systems are widely researched to detect novel multiphoton features and terahertz emission properties. Three level atomic systems with permanent dipole moment include both the properties of a two- and three-level system simultaneously. One can switch between these properties as function of tunable Rabi frequency. Also, three-level system exhibit many coherent interference effects, which can serve as application for testing quantum protocols and information storage. For this reason, few level atomic dipolar systems are perspective setups for generation of tunable electromagnetic waves such as terahertz domain. Consequently, detection of effective terahertz radiation is an emerging task both for applied and theoretical quantum optics. Additionally, non-resonant multiphoton conversion from optical to microwave region is a feasible quantum technology, where few level dipolar systems can be used for solution development.

Thus, the permanent non-zero dipole moment improves the quantum optical properties of few level atomic system in comparison to the similar ones yet in the absence of the permanent dipole moment.

Q 7.23 Mon 16:30 Empore Lichthof

Cavity-enhanced spectroscopy of molecular quantum emitters — •Evgenij Vasilenko, Weizhe Li, Senthil Kuppusamy, Mario Ruben, and David Hunger — Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology (KIT)

Rare earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also rare earth ion-based molecular complexes have shown excellent optical coherence properties [1]. Due to the long optical lifetime of the optical transition $^5D_0$-$^7F_0$, an efficient spin-photon interface for quantum information processing requires the coupling of single ions to a microcavity. Open-access Fabry-Pérot fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [2]. Since the used molecular quantum emitters require a cryogenic environment, the demands on mechanical stability of the cavity setup have a high priority. To tackle these challenges, we report on the development of a monolithic type of cavity assembly, sacrificing some lateral scanning ability for the purpose of significantly increasing the passive stability. We integrate molecules into the cavity in the form of a crystalline thin film on a macroscopic mirror and identify a sub-nanometer local surface roughness, sufficient to avoid excessive scattering loss. We report on first studies of cavity-enhanced emission spectroscopy.

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Hunger et al., New J. Phys 12, 065038 (2010)

Q 7.24 Mon 16:30 Empore Lichthof

Spectral Theory of Non-Markovian Dissipative Phase Transitions — •Baptiste Debecker, John Martin, and Francois Damanet — Universite de Liege, Liege, Belgique

The generation of phase transitions in quantum systems by coupling to engineered reservoirs provides a powerful way of accessing otherwise inaccessible non-equilibrium properties. However, until now, the theory of dissipative phase transitions (DPTs) has only been well established for quantum systems coupled to idealised Markovian environments, where Liouvillian gap closing is a hallmark. Here we extend the well-known Markovian formalism to general non-Markovian quantum systems. Furthermore, we illustrate our approach by showing how it can be used to reveal DPTs in standard quantum optical models, where the Lindblad description fails to capture them.

Our theory paves the way for exploring the dissipative control of phase transitions beyond the limiting Markovian regime, which is particularly important for understanding real materials or various other experimental platforms such as in the solid state, cold atoms, or cavity and circuit QED.

Q 7.25 Mon 16:30 Empore Lichthof

Optical Microcavity with Coupled Single SiV$^-$ Centers in a Nanodiamond for a Quantum Repeater Platform — •Selene Sachero[1], Robert Berghaus[1], Gregor Bayer[1], Andrea B Filipovski[1], Lukas Antoniuk[1], Niklas Lettner[1], Richard Waltrich[1], Marco Klotz[1], Patrick Maier[1], and Viatcheslav Agafonov[2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Tours University, France

A quantum repeater node requires a long-lived memory that can be addressed coherently. Additionally, efficient writing and reading of quantum states with high rates are crucial. optical cavities can be used as spin-photon platforms to accomplish such requirements. By coupling silicon vacancy defect centers (SiV$^-$) in a nanodiamond to an open Fabry-Pérot cavity, our work paves the way for a light-matter interface with efficient coherent control. Our fully tunable cavity formed by two Bragg mirrors allows short cavity lengths down to $\approx 1\mu$m, and provides efficient coupling of the quantum emitter at liquid helium temperatures.

Here, we perform photoluminescence measurements of SiV$^-$ centers and power-dependent photoluminescence excitation of single SiV$^-$ centers by collecting the cavity modulated sideband. We observe spectrally stable emitters and measure a linewidth close to the Fourier limit below $\Delta\nu$ = 200 MHz. With the Purcell-enhanced cavity signal we demonstrate coherent optical driving and access the electron spin all-optical in a strong external magnetic field.

Q 7.26 Mon 16:30 Empore Lichthof

Enhanced photon emission from hBN defects centers inside a tunable fiber-cavity — •Florian Feuchtmayr[1], Gregor Bayer[1], Stefan Häussler[1,2], Richard Waltrich[1], Noah Mendelson[3], Chi Li[3], David Hunger[4], Igor Aharonovich[3,5], and Alexander Kubanek[1,2] — [1]Inst. f. Quantenoptik, Uni Ulm, D — [2]Center f. Integ. Q. Science and Techn. (IQst), D — [3]School of Math./ Phys. Sciences, Univ. of Tech. Sydney, AUS — [4]Phys. Institut, Karlsruhe Inst. of Tech., D — [5]ARC Centre of Exc. f. Transf. Meta-Optical Systems, Univ. of Tech. Sydney, AUS

Coupling single quantum emitters to the mode of optical resonators is essential for the realization of quantum photonic devices. We present a hybrid system consisting of defect centers in a few-layer hexagonal boron nitride (hBN) sheet and a fiber-based Fabry-Pérot cavity. The smooth surface of the chemical vapor deposition grown hBN layers enables efficient integration into the cavity. This hybrid platform is operated over a broad spectral range of more than 30 nm. Owing to cavity funneling, large cavity-assisted signal enhancement up to 50-fold and strongly narrowed linewidths are demonstrated, a record for hBN-cavity systems. On top, we implement an excitation and readout scheme for resonant excitation, allowing to establish cavity-assisted photoluminescence excitation spectroscopy. In total, we reach a milestone for the deployment of 2D materials to fiber-based cavities in practical quantum technologies.

Q 7.27 Mon 16:30 Empore Lichthof

Onset of atomic selforganization in optical cavities: from quantum to thermal momentum distributions — •Tarek Moussa, Simon B. Jäger, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, D-67663, Kaiserslautern, Germany

We theoretically study the dynamics of transversally driven atoms coupled to a single-mode optical cavity. The atoms spontaneously form a structured pattern above a critical driving strength. This pattern formation is known as atomic selforganization and results in a Bragg grating of the atoms which supports constructive interference of scattered laser photons. We study this threshold using a mean-field treatment and as a function of the initial temperature of the atomic cloud. Below threshold, we analyze the response of the atomic gas which we find to be fundamentally different in the low and high temperature regimes. For thermal energies much lower than the photon recoil energy we find long-lived coherent oscillations. Instead, for thermal energies well above the recoil energy we find that all fluctuations are strongly damped. Using this insight, we explore the importance of thermal fluctuations regarding resonant parametric amplification realized by a time-periodic modulation of the driving strength.

Q 7.28 Mon 16:30 Empore Lichthof

Coupling and dissipation in a system of Yb atoms interacting with a cavity on a narrow line — •Dmitriy Sholokhov, Saran Shaju, Ke Li, and Jürgen Eschner — University of Saarland, Saarbrücken, Germany

^{174}Yb atoms are trapped in a MOT, using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, residing inside a high-finesse cavity (length 5 cm, finesse 45 000). The trap light also acts as side-pump creating strong atom-cavity interaction. We present a comprehensive investigation of the cavity output spectra for variable trap/pump light detuning, cavity detuning, and atom number. We compare the properties of the cavity light with free-space scattered light (fluorescence) in order to identify the coupling mechanisms and dissipation channels of the coupled system.

Q 7.29 Mon 16:30 Empore Lichthof

Collective atom-cavity coupling and non-linear dynamics with atoms with multilevel ground states — •Elmer Suarez[1], Federico Carollo[2], Igor Lesanovsky[2,3], Beatriz Olmos[2,3], Philippe W. Courteille[4], and Sebastian Slama[1] — [1]Center for Quantum Science and Physikalisches Institut, Eberhard-Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [3]3School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [4]Instituto de Física de São Carlos, Centro de pesquisa em óptica é fotônica, Universidade de São Paulo, Brazil

We investigate experimentally and theoretically the collective coupling between atoms with multilevel ground state manifolds and an optical cavity mode. The ensuing dynamics can be conveniently described by means of an effective dynamical atom-cavity coupling strength that depends on the occupation of the individual states and their coupling strengths with the cavity mode. This leads to a dynamical backaction of the atomic populations on the atom-cavity coupling strength. Our results show that the multilevel structure of electronic ground states can significantly alter the relaxation behavior in atom-cavity settings as compared to ensembles of two-level atoms.

Q 7.30 Mon 16:30 Empore Lichthof

Quantum entanglement of atoms in presence of dipole-dipole interaction — •Sergiu Bazgan, Nicolae Enaki, and Tatiana Paslari — Institute of Applied Physics, State University of Moldova, Chisinau, Moldova, Republic of

It is studied the interaction between the single-mode cavity field and the pair of indistinguishable two-level atoms. The proposed model takes into account the dipole-dipole interaction between two-level atoms. In good cavity limits, the analytical solution for the Schrodinger equation, in the presence of detuning between the cavity field and the atomic transition was obtained. With the help of this solution, the quantum-statistical properties of the system are investigated. Much attention is devoted to the entanglement between atoms. The influence of dipole-dipole interaction and detuning on the resonance on the formation of entanglement is investigated.

Q 7.31 Mon 16:30 Empore Lichthof

Bath Induced synchronization — •Sayan Roy and Giovanna Morigi — Universität des Saarlandes

Synchronization is a collective phenomenon observed in nature at various scales[1]. An important question is what are the basic ingredients leading to synchronization in the microscopic domain[2,3]. In this work, we analyze the dynamics of two qubits coupled to a chain of linear oscillators acting as a reservoir. This model is amenable to an analytical treatment, which allows us to identify the conditions when the interaction with the phononic bath induces self-sustained oscillations of the two qubits. We then discuss when these dynamics can be understood as quantum synchronization.

[1]. A. Pikovsky, M. Rosenblum, and J. Kurths, Synchronization: A Universal Concept in Nonlinear Sciences (Cambridge University Press, Cambridge, 2001).
[2]. B. Buča, J. Tindall, and D. Jaksch, Nat Commun 10, 1730 (2019).
[3]. B. Bellomo, G. L. Giorgi, G. M. Palma, and R. Zambrini, Phys. Rev. A 95, 043807 (2017).

Q 7.32 Mon 16:30 Empore Lichthof

Network self-organization: the role of the activation function — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

The interplay of nonlinear dynamics and noise is at the basis of coherent phenomena, such as stochastic resonance, synchronization, and noise-induced phase transitions. In a recent work we analysed network dynamics in the presence of Gaussian noise when the activation function, governing the dynamics of the network connections, is a sigmoidal (Hill) function. In these settings we demonstrated the onset of network topologies that maximize the transport efficiency and behave as noise-induced resonances. In this work we systematically analyse this behavior for different classes of activation functions. We identify the activation function that yields the most robust network configuration at the the maximal convergence speed. We then discuss possible applications to neural networks in the quantum domain.

Q 8: QI Poster I (joint session QI/Q)

Time: Monday 16:30–19:00 Location: Empore Lichthof

See QI 6 for details of this session.

Q 9: Quantum Gases: Bosons I

Time: Monday 17:00–19:00 Location: A320

Invited Talk Q 9.1 Mon 17:00 A320

Compressibility and the equation of state of an optical quantum gas in a box — •Julian Schmitt — University of Bonn, Germany

Quantum gases of atoms, exciton-polaritons, and photons provide a test bed for many-body physics under both in- and out-of-equilibrium settings. Experimental control over their dimensionality, potential energy landscapes, or the coupling to reservoirs offers wide possibilities to explore phases of matter, for example, by probing susceptibilities, as the compressibility. For gases of material particles, such studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases; for optical quantum gases, they have so far remained elusive. In my talk, I will discuss experimental work demonstrating a measurement of the compressibility of a two-dimensional quantum gas of photons in a box potential, from which we obtain the equation of state for the optical medium. The experiment is carried out in a nanostructured dye-filled optical microcavity. We observe signatures of Bose-Einstein condensation at large phase-space densities in the finite-size system. Upon entering the quantum degenerate regime, the density response to an external force sharply increases, hinting at the peculiar prediction of a highly compressible Bose gas. In other recent work, we have demonstrated a non-Hermitian phase transition of an open photon Bose-Einstein condensate, which is revealed by an exceptional point in the fluctuation dynamics.

Q 9.2 Mon 17:30 A320

Realization of a fractional quantum Hall state with ultracold atoms — •Julian Léonard[1,2], Sooshin Kim[1], Joyce Kwan[1], Perrin Segura[1], Fabian Grusdt[3,4], Cécile Repellin[5], Nathan Goldman[6], and Markus Greiner[1] — [1]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [3]Department of Physics and ASC, LMU München, Theresienstr. 37, München D-80333, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [5]Univ. Grenoble Alpes, CNRS, LPMMC, 38000 Grenoble, France — [6]CENOLI, Université Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium

Fractional quantum Hall states embody emblematic instances of strongly correlated topological matter, where the interplay of magnetic fields and interactions gives rise to exotic properties including fractionally charged quasi-particles, long-ranged entanglement, and anyonic exchange statistics. Here, we report on the realization of a fractional quantum Hall (FQH) state with ultra-cold atoms in an optical lattice. The state is a lattice version of a bosonic $\nu = 1/2$ Laughlin state with two particles on sixteen sites. We observe a suppression of two-body interactions, we find a distinctive vortex structure in the density correlations, and we measure a fractional Hall conductivity of $\sigma H/\sigma 0 = 0.6(2)$ via the bulk response to a magnetic perturbation. Our work provides a starting point for exploring highly entangled topological matter with ultracold atoms.

Q 9.3 Mon 17:45 A320

Observation of a continous time crystal — •Hans Kessler[1], Phatthamon Kongkhambut[1], Jim Skulte[1], Evgenii Gadylshin[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

Time crystals are classified as discrete or continuous depending on whether they spontaneously break discrete or continuous time translation symmetry. While discrete time crystals have been extensively studied in periodically driven systems since their recent discovery, the experimental realisation of a continuous time crystal [1] is still pending. We report the observation of a limit cycle phase in a continuously pumped dissipative atom-cavity system [2], which is characterized by emergent oscillations in the intracavity photon number. We observe that the phase of this oscillation is random for different realisations, and hence this dynamical many-body state breaks continuous time translation symmetry spontaneously. The observed robustness of the limit cycles against temporal perturbations confirms the realisation of a continuous time crystal.

[1] H. Keßler et al., Emergent limit cycles and time crystal dynamics in an atom-cavity system, PRA, 99(5), 053605 (2019)
[2] P. Kongkhambut et al., Observation of a continuous time crystal, Science 307, 6606, 670-673 (2022)

Q 9.4 Mon 18:00 A320

Dynamics of Stripe Patterns in Supersolid Spin–Orbit-Coupled Bose Gases — •Kevin T. Geier[1,2], Giovanni I. Martone[3], Philipp Hauke[1,2], Wolfgang Ketterle[4,5], and Sandro Stringari[1] — [1]Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Università di Trento, I-38123 Trento, Italy — [2]INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, Trento, Italy — [3]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France; 4 Place Jussieu, 75005 Paris, France — [4]MIT-Harvard Center for Ultracold Atoms, Cambridge, Massachusetts 02138, USA — [5]Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

The supersolid phase of matter combines superfluid properties with a crystalline spatial structure, arising as a consequence of the spontaneous breaking of both phase and translational symmetry. In spin–orbit-coupled Bose–Einstein condensates, supersolidity has been predicted and observed in the form of stripes in the density profile, but up to now it has been unclear whether the stripe pattern features the typical excitations of a crystal. In this talk, I will explain based on analytical and numerical results how spin perturbations can induce the translational, compressional, as well as rotational motion of the stripes. Our findings expose the rich hybridization of density and spin degrees of freedom and show that this system is indeed a paradigmatic supersolid with a fully dynamic crystalline structure.

Q 9.5 Mon 18:15 A320

Observation of many-body scarring in a Bose-Hubbard quantum simulator — Guo-Xian Su[1], Hui Sun[1], •Ana Hudomal[2], Jean-Yves Desaules[3], Zhao-Yu Zhou[1], Bing Yang[4], Jad C. Halimeh[5], Zhen-Sheng Yuan[6], Zlatko Papić[3], and Jian-Wei Pan[6] — [1]Heidelberg University, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]University of Leeds, UK — [4]Southern University of Science and Technology, China — [5]LMU Munich, Germany — [6]University of Science and Technology of China

Quantum many-body scarring has recently opened a window into novel mechanisms for delaying the onset of thermalization by preparing the system in special initial states, such as the $\mathbb{Z}_2$ state in a Rydberg atom system. Here we realize many-body scarring in a Bose-Hubbard quantum simulator from previously unknown initial conditions such as the unit-filling state [1]. Our measurements of entanglement entropy illustrate that scarring traps the many-body system in a low-entropy subspace. Further, we develop a quantum interference protocol to probe unequal-time correlations, and demonstrate the system's return to the vicinity of the initial state by measuring single-site fidelity. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments.

[1] G.-X. Su et al., arXiv:2201.00821 (2022).

Q 9.6 Mon 18:30 A320

Quantum Gas Microscopy of Cesium Atoms in Optical Superlattices — Julian Wienand[1,2,3], Alexander Impertro[1,2,3], Simon Karch[1,2,3], Hendrik von Raven[1,2,3], •Scott Hubele[1,2,3], Sophie Häfele[1,2,3], Ignacio Pérez[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Schellingstr. 4, D-80799 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80333 Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany

Ultracold cesium atoms provide a promising experimental platform for quantum simulation of interacting quantum many-body phases. This is due to a convenient control of the scattering length via a broad low-field Feshbach resonance and the possibility to engineer state-dependent lattices with minimal heating. In this talk we present recent progress on our cesium quantum gas microscope, where we have implemented 2d optical superlattices, a digital mirror device (DMD) for potential shaping, and an active magnetic field stabilization. This paves the way for quantum simulation of a large variety of different Hamiltonians ranging from tunable spin models to topological lattices. In order to enhance the nearest-neighbor tunnel coupling, we work with rather short-spaced optical lattices prohibiting the direct resolution of neighboring lattice sites. To overcome this challenge we have developed a novel deep-learning assisted single-site reconstruction algorithm, which provides access to local observables.

Q 9.7 Mon 18:45 A320

Phase Diagram Detection via Gaussian Fitting of Number Probability Distribution — Daniele Contessi[1,2,3], Alessio Recati[1], and •Matteo Rizzi[2,3] — [1]Università di Trento & INO-CNR Pitaevskii BEC Center, Povo, Italy — [2]Peter-Grünberg-Institut 8, FZ Jülich, Germany — [3]Institute for Theoretical Physics, University of Cologne, Germany

In recent years, methods for automatic recognition of phase diagrams of quantum systems have gained large interest in the community: Among others, machine learning analysis of the entanglement spectrum has proven to be a promising route. Here, we discuss the possibility of using an experimentally readily accessible proxy, namely the number probability distribution that characterizes sub-portions of a quantum many-body system with globally conserved number of particles. We put forward a linear fitting protocol capable of mapping out the ground-state phase diagram of the rich one-dimensional extended Bose-Hubbard model: The results are quantitatively comparable with more sophisticated traditional numerical and machine learning techniques. We argue that the studied quantity should be considered among the most informative and accessible bipartite properties.

D. Contessi, A. Recati, M. Rizzi, https://arxiv.org/abs/2207.01478

Q 10: Photonics I

Time: Monday 17:00–19:00 Location: E001

Invited Talk Q 10.1 Mon 17:00 E001

Maiman's ruby laser reborn as diode pumped cw laser — •Walter Luhs[1] and Bernd Wellegehausen[2] — [1]Photonic Engineering Office, Herbert-Hellmann-Allee 57, 79189 Bad Krozingen, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

In ninety sixty Theodore Maiman realized the first laser, a flashlamp pumped Ruby laser, which was the onset of a tremendous ongoing development of optics and quantum optics.

In the growing family of lasers, the Ruby laser however remained exotic, needing a population inversion with respect to the ground state. Although possible, cw operation was extremely difficult to achieve, and so the Ruby laser only found applications as a powerful pulsed system.

In 2019, we could first demonstrate cw laser oscillation of ruby in linear and ring resonators, pumped with 1 W 405 nm laser diodes, and achieve with Ruby crystals of 5 mm length stunningly low thresholds of below 100 mW and output powers up to 80 mW. Some of the ruby crystals used in this work can be traced back to the original material from Theodore Maiman, handed by himself to Herbert Welling, the German laser pioneer, for first experiments and then remained for more than 50 years in the basement of the institute.

Meanwhile, we realized ultra-compact and stable laser systems with resonators below 3 mm length, yielding narrowband tunable single frequency emission. Features of these systems are presented, and possible applications will be discussed.

Q 10.2 Mon 17:30 E001

Generation of ultrashort VUV pulses by frequency-tripling compressed high-energy pulses centered around 400 nm — •Nora Schmitt, Armin Azima, Marek Wieland, Mark Prandolini, and Markus Drescher — University of Hamburg, Institute for Experimental Physics, 22761 Hamburg, Germany

Generating ultrashort laser pulses in the vacuum ultraviolet spectral region (VUV, ~100 to 200 nm) is key to studying an abundance of atomic and molecular transitions. Pump-probe experiments utilizing intense ultrashort laser pulses in this spectral region have successfully been realized and used to study the dynamics of several systems. However, the most widely used source in the VUV is the 5th harmonic of a Ti:Sa laser, which is centered around 160 nm, limiting the number of accessible transitions. In order to drive nonlinear transitions in this wavelength regime, alternative VUV generation schemes should provide pulse energies approaching μJ levels . In a novel approach, we generate pulses around 133 nm by frequency-tripling in a gas cell. The fundamental pulses, centered at 400 nm, are spectrally broadened in a stretched hollow core capillary fiber filled with helium and temporally compressed by a slightly detuned 4f-setup. For the 400 nm pulses, we obtain a pulse duration of 10 fs (FWHM) at 800 μJ pulse energy, evaluated by fringe resolved interferometric autocorrelation (FRIAC) measurements. Our simulations suggest that tripling these pulses in our geometry will yield a conversion efficiency in the order of 10^{-3}.

Q 10.3 Mon 17:45 E001

Tailored transverse field distributions in an enhancement resonator for high harmonic generation — •Tamila Rozibakieva[1], Stephan H. Wissenberg[2], Hans-Dieter Hoffmann[2], Constantin L. Häfner[2,3], Peter G. Thirolf[1], and Johannes Weitenberg[2,4] — [1]Ludwig-Maximilians-Universität München LMU — [2]Fraunhofer Institute for Laser Technology ILT — [3]Chair for Laser Technology LLT, RWTH Aachen University — [4]Max-Planck Institute of Quantum Optics MPQ

An enhancement resonator is a passive optical resonator, which is used for resonant enhancement of an optical power or intensity. Enhancement resonators are used in nonlinear processes such as high-harmonic generation (HHG), which requires high intensity (>10^13 W/cm^2) even at large repetition rates (>10 MHz). At Fraunhofer ILT, a VUV frequency comb is being set up for the excitation of the low-energy isomeric nuclear transition of 229-Thorium at LMU Munich as part of an ERC synergy project. The spectrum in the VUV frequency comb can be achieved via HHG in a Xe gas jet, in our case as the 7th harmonic of a driving laser at 1050 nm. A key challenge with enhancement resonators for HHG is the coupling of the harmonics out of the resonator. The talk will focus on an analysis of transverse modes that can be used to geometrically couple out high harmonics through a slit in a resonator mirror, for example the GH[1,0]-mode, the slit mode or a non-collinear resonator. It will be presented how a large spatial overlap with impinging Gaussian beam can be achieved for these modes. Funding: ERC Synergy project, Grant Agreement No. 856415.

Q 10.4 Mon 18:00 E001

Femtosecond Fast Tunable Ultraviolet Radiation through Non-collinear Sum-frequency Mixing in a Visible NOPO — •Fridolin Geesmann[1], Robin Mevert[1,2], David Zuber[1,2], Han Rao[1,2], and Uwe Morgner[1,2,3] — [1]Institute of Quantum Optics, Leibniz Universität Hannover, Hannover, Germany — [2]Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines), Hannover, Germany — [3]Laser Zentrum Hannover e.V., Hannover, Germany

We report on a rapidly tunable non-collinear optical parametric oscillator (NOPO), which simultaneously delivers femtosecond pulses in the visible and ultraviolet wavelength range. The system is pumped by the third harmonic of a Yb based MOFA system, which is focused into a BBO crystal to generate the visible pulses via a DFG process. A KDP crystal is placed in a second focus of the NOPOs ring cavity for further frequency conversion. Thereby, ultraviolet wavelengths were reached through non-collinear sum-frequency mixing of the visible pulses with residual infrared pump radiation. With this approach, two synchronized outputs were realized, delivering fast tunable pulses from 449-690 nm and 340-413 nm with output powers up to 232 mW and 59 mW, respectively. By replacing the visible output coupler with an HR mirror, even higher power in the UV of up to 90 mW was achieved. In addition, the quick tuning of the two outputs was shown over their entire wavelength range with a frequency of 43.9 Hz. Even higher tuning speeds can be expected by using a different piezoelectric actuator, as this has been the limiting factor so far.

Q 10.5 Mon 18:15 E001

Towards intracavity optical parametric amplification of a Ti:sapphire laser oscillator — •Robin Mevert[1,2], Jintao Fan[1,2], Fridolin Jakob Geesmann[1,2], Han Rao[1,2], David Zuber[1,2], Tino Lang[3], and Uwe Morgner[1,2,4] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Leibniz Universität Hannover, Cluster of Excellence PhoenixD (Photonics, Optics, and Engineering-Innovation Across Disciplines), Hannover, Germany — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germ — [4]Laser Zentrum Hannover e.V., Hannover, Germany

Nowadays, Ti:sapphire oscillators still play a major role as a typical work horse for the generation of femtosecond laser pulses in the near-infrared since its broadband emission range can support pulse durations in the sub-10fs range. Unfortunately, power scaling of Ti:sapphire lasers is limited by the thermal lensing effect inside the Ti:sapphire crystal as well as the additional gain-narrowing effects. On the other hand, synchronously-pumped femtosecond optical parametric oscillators (OPOs) in the near-infrared are easily power scalable since there are only nonlinear absorption effects inside the gain material. This fact is utilized nowadays in optical parametric amplifiers which are often used to amplify the output power of a Ti:Sapphire laser. However, the main drawback is the drastic decrease in repetition rate towards the kHz range which causes additional obstacles for later applications such as high-harmonic generation. In this work, we investigate the possibility to use the parametric gain of a BBO-crystal to amplify the Ti:sapphire laser inside a single cavity.

Q 10.6 Mon 18:30 E001

Jitter comparison of gain-switched diodes — •Simon Angstenberger, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

Gain-switched diodes are a cost-efficient and widely used approach to seed flexible amplifier chains. However, the timing jitter of the gain-switching process limits the implementation in applications with critical timing on the tens of picosecond scale. We compare different diode concepts, namely a Fabry-Perot (FP) laser diode and a distributed feedback (DFB) laser diode. We find that the timing jitter for the FP diode is significantly lower, when driven with the same electronic driver. Furthermore, we investigate the influence of optical feedback by means of a fiber Bragg grating (FBG) on the jitter performance. Eventually, a comparison is made of the obtained values to a fiber laser for reference.

Q 10.7 Mon 18:45 E001

Optimization of photonic multilayer structures to increase upconversion efficiency — •Fabian Spallek[1,2], Stefan Yoshi Buhmann[2], Thomas Wellens[1], and Andreas Buchleitner[1,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Institut für Physik, Universität Kassel — [3]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg

The efficiency of solar silicon solar cells can be substantially improved by widening the spectral operating window by means of upconversion materials [1]. These convert two low-energy photons into one photon with higher energy [1]. Embedding the upconverter material in photonic dielectric nanostructures allows to influence the interplay of absorption and emission rates, energy transfer processes, local irradiance and local density of (photonic) states which in turn determines the overall efficiency.

We utilize methods from macroscopic quantum electrodynamics to calculate the influence of multilayer nanostructures on spontaneous emission and absorption rates in the upconverter. This allows us to propose specific designs optimized for upconversion efficiency [2]. Lastly, we take into account manufacturing errors and compare indicators for the achievable upconversion luminescence and quantum yield of our optimized design to existing, experimentally implemented Bragg structures.

[1] C. L. M. Hofmann et al., Nat. Commun. **12**, 14895 (2021)
[2] F. Spallek et al., J. Phys. B: At. Mol. Opt. Phys. **50**, 214005 (2017)

Q 11: Precision Measurements: Gravity I

Time: Monday 17:00–19:00 Location: E214

Q 11.1 Mon 17:00 E214

a testbed for Tilt-To-Length coupling and Differential-Wavefront-Sensing performance in LISA — •Alvise Pizzella, Miguel Dovale, and Gerhard Heinzel — AEI Hannover, Germany

The LISA mission aims at measuring gravitational waves (GWs) in the sub-Hz band using inter-spacecraft interferometry. It consists in a constellation of three satellites in triangle formation with 2.5 Gm-long arms following an Earth-like heliocentric orbit. The target sensitivity of pm/Hz^1/2 presents unprecedented technical challenges; such as minimal detected power levels, causing shot noise, and the coupling of the angular jitter of the spacecraft and test masses to the interferometrically-measured longitudinal displacement (Tilt-To-Length (TTL) coupling). TTL is forecasted to be the second highest noise entry in LISA. In order to readout from the heterodyne interference beatnote the length and angular signals, necessary for respectively GWs detection and maintaining the interferometer*s alignment, LISA implements Differential-Wavefront-Sensing (DWS), combining the individual phase readouts from the four segments of a Quadrature PhotoDiode (QPD). An ultra stable interferometer testbed representative of the Optical Bench (OB) of a LISA spacecraft has been developed in order to validate the critical interferometric techniques for LISA. The testbed features steering mirrors that can induce synthetic tilts between the beams to simulate spacecraft or test mass motion. This experiment has been used to demonstrate optical reduction of TTL by using imaging. Current work is focusing on developing a new method to readout the DWS and achieving nrad DWS noise levels.

Q 11.2 Mon 17:15 E214

Dual balanced readout for scattered light noise suppression in gravitational wave detection — •André Lohde, Daniel Voigt, and Oliver Gerberding — Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

Gravitational wave interferometers are highly sensitive to scattered light noise. This is due to the interfering character of straylight back-scattered into the interferometer that is potentially modulated at moving surfaces. Today's interferometers, such as LIGO, Virgo and KAGRA are already limited by scattered light noise in the low frequency domain. Future detectors, however, such as the Einstein Telescope, depend upon advanced scattered light mitigation to fulfill design requirements.

Here, I present the technique of implementing two balanced homodyne detectors for the readout of a Michelson interferometer. This technique promises to allow partial subtraction of scattered light noise by simple arithmetic operations and thus improval of the sensitivity of gravitational wave detectors.

Q 11.3 Mon 17:30 E214

A Free-Beam Backlink for the Space-Based Gravitational Wave Detector LISA — •Daniel Jestrabek[1,2], Lea Bischof[1,2], Melanie Ast[1,2], Jiang Ji Ho Zhang[1,2], and Gerhard Heinzel[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Hannover, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The Laser Interferometer Space Antenna (LISA) will be the first Gravitational Wave Detector in space, consisting of three satellites forming an equilateral triangle of 2.5 million kilometers distance. The challenge introduced by the relative movements of the satellites can be overcome by the implementation of steerable optical benches to compensate for these changes. This makes an optical connection necessary that links the moving benches so that the gravitational wave signal can be extracted in post-processing. One possible solution for such an optical connection (also called "Backlink") is the use of mirrors that guide the light in free space between the benches. The mirrors must be actively steered to keep this Free-Beam Backlink stable. Control electronics were developed, tested, and implemented for the Free-Beam Backlink within a LISA-like test bed, the Three-Backlink Experiment. This test bed consists of two separate, rotatable benches in between which light is exchanged through three optical connections: the free-beam link and two fiber-based solutions.

We present here the working principle of the Free-Beam Backlink and its optimization, enabling stable heterodyne interference over separated optical benches with a low noise contribution.

Q 11.4 Mon 17:45 E214

Compact Laser Interferometer for Testmass Readout in Gravitational Wave Detectors — •Wanda Vossius, Meenakshi Mahesh, Tobias Eckhardt, Leander Göbbels, and Oliver Gerberding — Institut für Experimentalphysik, Geb. 68 Z. 21-21c, Luruper Chaussee 149, 22761 Hamburg, Deutschland

In order to realise the sensitivity required for future gravitational wave detectors, there is a need for an increase of three orders of magnitude for the precision of the testmass readout. This would decrease the noise at frequencies below 10Hz and allow for the detection of gravitational waves of lower amplitude. Local displacement sensors in gravitational wave detectors have to be both compact and stable without the need for readjustment while the detector is running.

We present the plan and current status on a compact readout sensor in the form of an interferometer. This interferometer is only 3 cm long with an armlength of about 5 cm. It contains a single quasimonolithic optic which results in an unequal armlength Michelson interferometer with a dual port readout. In order to reduce the coupling of electronic noise and ghostbeams into the readout, we plan to use a Deep Frequency Modulation on the laser. To ensure the stability criteria, the optical components will be glued onto a titanium carrier.

Q 11.5 Mon 18:00 E214

Postprocessing subtraction of tilt-to-length noise in LISA — •Sarah Paczkowski[1,2], Roberta Giusteri[1,2], Martin Hewitson[1,2], Nikolaos Karnesis[3], Ewan Fitzsimons[4], Gudrun Wanner[1,2], and Gerhard Heinzel[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany — [3]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece — [4]The UK Astronomy Technology Centre, Royal Observatory, Edinburgh, Blackford Hill, Edinburgh EH9 3HJ, United Kingdom

The space mission LISA aims to observe gravitational waves over a frequency range from 0.1 mHz to 1 Hz. LISA is characterised by its three satellites which form a nearly equilateral triangle with a 2.5 million km arm length. Laser interferometers will measure the distance between free-falling test masses hosted in each satellite with picometer precision down to mHz frequencies. To reach this performance, several noise sources have to be kept under control.

One of these is the coupling of an angular jitter into the interferometric phase readout, called TTL coupling. This cross-coupling arises, for example, from misalignments within the optical system. Unless mitigated, this noise source is expected to affect the scientific performance of LISA. In this talk, I will present a method to calibrate and subtract TTL noise that has no impact on LISA science operations. Selected proof-of-principle simulation results will demonstrate the performance based on the current design configuration of LISA.

Q 11.6 Mon 18:15 E214

Status of the AEI 10m Prototype: a gravitational wave detector prototyping facility — Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[1,2], Juliane von Wrangel[1,2], Janis Wöhler[1,2], and •David S. Wu[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany

The current status will be presented on the Albert Einstein Institute (AEI) 10 m Prototype facility in Hannover, where new technologies and techniques for full scale gravitational wave detectors (GWDs) are developed and tested. A particular area of focus is the investigation of techniques to surpass the standard quantum limit (SQL) of interferometry by providing a test bed interferometer to experimentally test these techniques in a low noise GWD-like environment. Current activities are focussed on getting the Sub-SQL Interferometer online and commissioned to it's designed sensitivity. These activities range from new motion sensors, seismic isolation techniques, precision optics, and scattered light mitigation.

Q 11.7 Mon 18:30 E214

Toward testing LISA post-processing pipeline under realistic circumstances with experimental data. — •Narjiss Messied — Max-Planck Institut für Gravitationsphysik (Albert-Einstein Institut), Callinstraße 38, Hannover, Germany

Laser Interferometer Space Antenna (LISA) is a space-based mission that aims to detect gravitational waves in the mHz range with heterodyne interferometry. Gravitational wave signals encoded in a beam phase are extracted by a phasemeter. Raw phase data from this core device is dominated by various noise sources, for example, laser frequency noise, clock noise, etc. Hence, LISA requires the initial noise reduction pipeline (INReP), a set of complex data post-processing algorithms, in order to dig up gravitational wave signals from such noise-dominant data. Any research on this pipeline has relied on synthetic data produced by numerical LISA simulators so far, which can not cover all realistic features of actual phasemeter outputs during the mission. In this talk, we present the latest efforts toward the verification of this pipeline with experimental data from our on-ground testbed called the Hexagon, which acts as a miniature-scale LISA with three beam sources and three independent phasemeters.

Q 11.8 Mon 18:45 E214

The Three-Backlink Experiment for the first space-based gravitational wave detector LISA — •Jiang Ji Ho Zhang[1,2], Lea Bischof[1,2], Daniel Jestrabek[1,2], Melanie Ast[1,2], Michael Born[1,2], Katharina-Sophie Isleif[3], Stefan Ast[4], Nicole Knust[1,2], Daniel Penkert[1,2], and Gerhard Heinzel[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Hannover, Germany — [2]Leibniz Universität Hannover, Hannover, Germany — [3]Deutsches Elektronen-Synchroton (DESY) Zeuthen, Hamburg, Germany — [4]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

The Laser Interferometer Space Antenna (LISA) will be the first gravitational wave detector in space, aiming to use laser interferometry to detect gravitational wave signals in the 0.1 mHz to 1 Hz band. It consists of three satellites forming a near-equilateral triangle with 2.5 million km arms. Due to the orbital mechanics, the inter-satellite distances and angles vary by about 1% and 1.5% per year, respectively. Each satellite features two moving optical sub-assemblies (MOSAs) that compensate for the angular dynamics. They both carry one optical bench, which in turn are connected via a flexible optical link. This is the so-called Backlink. The noise of the optical pathlength difference between two counter propagating beams along the Backlink is required to reach 1 pm/sqrt(Hz) stability. The Three-Backlink Experiment is a trade-off study between different designs of the Backlink: two fiber-based and one free beam. Here, we report on the design and technical aspects of the experiment, the current status and the ongoing work.

Q 12: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

Time: Monday 17:00–18:45 Location: F107

See A 6 for details of this session.

Q 13: Ultra-cold Atoms, Ions and BEC I (joint session A/Q)

Time: Monday 17:00–19:00 Location: F303

See A 7 for details of this session.

Q 14: Quantum Technologies: Color Centers I (joint session Q/A/QI)

Time: Monday 17:00–19:00 Location: F342

Q 14.1 Mon 17:00 F342

NMR-fingerprinting of biomolecules on the picoliter level — •Nico Striegler, Thomas Unden, Jochen Scharpf, Stephan Knecht, Christophoros Vassiliou, Jochen Scheuer, Michael Keim, John Blanchard, Martin Gierse, Mohammad Usman Qureshi, Ilai Schwartz, and Philipp Neumann — NVision Imaging Technologies GmbH

A standard method for diagnostics and analytics is nuclear magnetic resonance (NMR). Conventional NMR only function well for large enough samples and is inherently limited by the low thermal spin polarisation. The combination of nuclear spin hyperpolarisation with a microscale quantum sensor enables study of metabolism on the single-cell level. This can be used for evaluating the treatment effectiveness from tumor biopsies using only a few cells. In this study the combination of a Nitrogen-Vacancy-based quantum sensor and a hyperpolarized Fumarate solution enables heteronuclear magnetic resonance spectroscopy of liqudis in picoliter volumes. The NMR probe is based on an ensemble of negatively charged Nitrogen-Vacancy (NV) centers in a ten micrometer thick diamond layer. Hyperpolarization of the solution is based on parahydrogen induced polarization (PHIP) methods, which is done in house and then transferred to the detection volume of the quantum sensor. Microwave pulse sequences brings the NV electron spins into adjustable frequencies for detection of AC magnetic fields generated by the nuclear spins of interest.

Q 14.2 Mon 17:15 F342

Impact of Charge Conversion on NV-Center Relaxometry — •Isabel Barbosa, Jonas Gutsche, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany

Relaxometry schemes employing nitrogen-vacancy (NV) centers in diamonds are essential in biology and physics to detect a reduction of the color centers' characteristic spin relaxation (T_1) time caused by, e.g., paramagnetic molecules in proximity. However, while only the negatively-charged NV center is to be probed in these pulsed-laser measurements, an inevitable consequence of the laser excitation is the conversion to the neutrally-charged NV state, interfering with the result for the negatively-charged NV centers' T_1 time or even dominating the response signal. In this work, we perform relaxometry measurements on an NV ensemble in nanodiamond combining a 520 nm excitation laser and microwave excitation while simultaneously recording the fluorescence signals of both charge states via independent beam paths. Correlating the fluorescence intensity ratios to the fluorescence spectra at each laser power, we monitor the ratios of both charge states during the T_1 measurement and systematically disclose the excitation-power-dependent charge conversion. Even at laser intensities below saturation, we observe charge conversion, while at higher intensities, charge conversion outweighs spin relaxation. These results underline the necessity of fluorescence normalization during the measurement to accurately determine the T_1 time and characterize paramagnetic species close to the sensing diamond.

Q 14.3 Mon 17:30 F342

SiV center in nanodiamonds as a potential source for a hybrid quantum network node — •Marco Klotz[1], Richard Waltrich[1], Niklas Lettner[1], Lukas Antoniuk[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm — [2]Universite Francois Rabelais de Tours

Combining conventional photonic systems with the good optical and spin properties of group IV defects in diamond puts a platform for quantum technologies into reach. Here, we present measurements of characteristic properties of SiV centers in nanodiamond in comparison with bulk diamond. This reveals key benefits of a nanostructured defect host for future integration into photonic-enhancing structures, e.g. cavities.

Q 14.4 Mon 17:45 F342

Vector Magnetometry Based on Polarimetric Optically Detected Magnetic Resonance — Philipp Reuschel[1], Mario Agio[1,2], and •Assegid M. Flatae[1] — [1]Laboratory of Nano-Optics, University of Siegen, Siegen (Germany) — [2]National Institute of Optics (INO), National Research Council (CNR), Sesto Fiorentino (Italy)

Vector magnetometry has various applications in navigation systems, spintronics and life sciences. So far, different sensitive magnetic field sensors exist, for example, superconducting quantum interference devices and alkali vapor cells magnetometers. However, they suffer from high technical complexity and low spatial resolution. Recently, negatively charged nitrogen-vacancy (NV-) color centers in diamond have been developed as sensitive magnetic field sensors based on the optically detected magnetic resonance (ODMR). However, these approaches require knowledge of the crystal axes and need an external magnetic bias field or they rely on the use of single NV- centers. Recently, by combining ODMRs of ensembles of NV- color centers with polarimetry, we have been able to determine the magnitude and direction of an unknown magnetic field [1]. A longitudinal laser polarization component enables the unequivocal distinction of the four crystal axes containing NV- centers, allowing high sensitivity and robust vector magnetometry without a bias field. Our approach is general for other spin-1 color centers with C3v symmetry, and it is compatible with standard microscopy methods. Reference [1] P. Reuschel, M. Agio, A. M. Flatae, Adv. Quantum Technol. 2200077 (2022).

Q 14.5 Mon 18:00 F342

Coherent optical spectroscopy on ensembles of Silicon-vacancy color centers in diamond — •Anna Fuchs and Christoph Becher — Universität des Saarlandes, Saarbrücken 66123, Germany

Spectral hole burning (SHB) and coherent population trapping (CPT) are important techniques both in spectroscopy to characterize an ensemble of emitters in terms of their coherence times and in coherent control experiments to realize e.g. quantum memories or sensors. Single negatively charged silicon-vacancy (SiV^-) color centers in diamond are of the leading candidates for qubit systems in quantum communication [1] based on their long spin coherence and narrow optical emission lines. In addition, ensembles of SiV centers show strong coherent light-matter interaction [2], enabling applications as Raman-based optical quantum memories or for realizing single photon nonlinearities. However, the spin coherence of SiV ensembles so far remains unexplored.
In this talk, we report our results of SHB and CPT measurements on two different SiV^- - ensembles in an external magnetic field. The SHB measurements reveal in both samples an additional narrow resonance of a few MHz linewidth, which we attribute to coherent population oscillations (CPO) due to the beat frequency between the two independent input laser fields. The CPT measurements allow us to determine the Zeeman splittings not resolvable in excitation or emission spectroscopy due to inhomogeneous line broadening.

[1] Stas et al., Science 378, 557 (2022)
[2] Weinzetl et al., Phys. Rev. Lett. 122, 063601 (2019)

Q 14.6 Mon 18:15 F342

Probing the Orbital Coherence of a Tin-Vacancy Center in a Diamond Nanopillar via Coherent Population Trapping — •Cem Güney Torun[1], Joseph H. D. Munns[1], Franziska M. Herrmann[1], Gregor Pieplow[1], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Tin-vacancy color center in diamond (SnV) has gained much attention in recent years as a promising spin-photon interface. This is mainly due to its excellent optical properties resulting from the inhibited first-order coupling to external electric fields via DC Stark Shifts [1] and millisecond spin coherence through decreased phononic coupling by the large ground state splitting of 850 GHz [2]. Here, we analyze the coherence properties of the ground state orbital levels under zero magnetic field. This is implemented via a coherent population trapping experiment where two optical transitions in a lambda scheme are simultaneously driven and a reduction in the fluorescence signal is observed. Working in the spectral domain enables the extraction of a rapid 5 ps phononic decay time after analyzing the data; showing that the orbital degree of freedom is not particularly suitable for most quantum information processing applications. Finally, implications of orbital coherence times on the spin levels are considered. These experiments lay the basis for the coherent control of SnV spin states.

[1] J. Görlitz, et al. *npj Quan. Inf.* 8.1 (2022): 1-9.
[2] R. Debroux, et al. *Phy. Rev. X* 11.4 (2021): 041041.

Q 14.7 Mon 18:30 F342

Optical Microcavity with Coupled Single SiV- Centers in a Nanodiamond for a Quantum Repeater Platform — •Robert Berghaus[1], Gregor Bayer[1], Selene Sachero[1], Andrea B Filipovski[1], Lukas Antoniuk[1], Niklas Lettner[1], Richard Waltrich[1], Marco Klotz[1], Patrick Maier[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Tours University, France

A quantum repeater node requires a long-lived memory that can be addressed coherently. Additionally, efficient writing and reading of quantum states with high rates are crucial. Optical cavities can be used as spin-photon platforms to accomplish such requirements. By coupling silicon vacancy defect centers (SiV-) in a nanodiamond to an open Fabry-Pérot cavity, our work paves the way for a light-matter interface with efficient coherent control. Our fully tunable cavity formed by two Bragg mirrors allows short cavity lengths down to $\approx 1\mu$m and provides efficient coupling of the quantum emitter at liquid helium temperatures. Here, we perform photoluminescence measurements of SiV- centers and power-dependent photoluminescence excitation of single SiV centers by collecting the cavity modulated sideband. We observe spectrally stable emitters and measure a linewidth close to the Fourier limit below $\Delta\nu = 200$ MHz. With the Purcell-enhanced cavity signal we demonstrate coherent optical driving and access the electron spin all-optical in a strong external magnetic field. The electron spin can be initialized within 67 ns and a lifetime of 350 ns is reached.

Q 14.8 Mon 18:45 F342

Entanglement in a disordered chain of coupled qubits — •Alexander Michael Minke[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg, Germany

Nitrogen-Vacancy (NV) centers in diamond are promising candidates for quantum computation due to their long coherence times. However, the robust implementation of scalable quantum registers composed of suitably coupled NV centers remains a challenge, due to limited control of their assembly. We therefore investigate the entanglement properties of arrays of dipole-coupled NV centers, the robustness of these properties against positional disorder and the dependence of the registers' resilience on their size. We find that, for chains with an even number of components, some manifolds of eigenstates show resilient entanglement properties when scaling up the system.

Q 15: Quantum Communication (joint session Q/QI)

Time: Monday 17:00–19:00 Location: F442

Q 15.1 Mon 17:00 F442

Eavesdropper location inside quantum channel using nonlinear optics — •Alexandra Popp[1,2], Birgit Stiller[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light (MPL), Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nürnberg (FAU), Erlangen, Germany.

Secure communictation is highly important in today's information age. Quantum key distribution uses the laws of quantum mechanics to offer secure key exchange between two parties. A key feature of this is the notice of eavesdropping through changes to the quantum bit error rate or excess noise of the quantum channel. Once the eavesdropper is detected, it however needs to be localized and removed from the communication channel. In a quantum channel, this can be especially challenging. We present a novel idea for localizing eavesdroppers on the cm level within quantum as well as classical communication channels using localized acoustic waves created by a correlation-based technique. Amongst other interception techniques, we show that our setup is capable of detecting interception by evanescent outcoupling with as low as 1% outcoupling.

Q 15.2 Mon 17:15 F442

Hacking QKD Sender Electronics Using Deep Learning — •Adomas Baliuka[1,2], Markus Stöcker[1,2], Michael Auer[1,2,3], Peter Freiwang[1,2], Harald Weinfurter[1,2,4], and Lukas Knips[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München — [2]Munich Center for Quantum Science and Technology, 80799 München — [3]Universität der Bundeswehr, 85577 Neubiberg — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching

Quantum key distribution (QKD) promises provably secure communication. However, the proofs make assumptions which have to be met carefully in practical implementations. Violations of the assumptions open up *side channels*, which enable an eavesdropper to obtain secret information. For a QKD sender, imperfections in quantum state preparation can lead to *quantum side channels* by encoding secret information in degrees of freedom (e.g., frequency, spatial mode) not protected by the QKD protocol. On the other hand, information can also leak via *classical side channels*, such as acoustic vibrations or classical electromagnetic emissions.

We analyze electromagnetic emissions from the electronics of our home-built BB84 QKD sender at a distance of a few centimeters. We are able to extract virtually all information about the secret key using a neural network and even observe traces of electromagnetic radiation at distances of up to a few meters. We discuss countermeasures and evaluate a revised electronics design, showing a significant reduction of emissions and attack performance.

Q 15.3 Mon 17:30 F442

Atomic arrays based on optical tweezers at the center of an optical cavity — •Lukas Hartung, Matthias Seubert, Stephan Welte, Emanuele Distante, and Gerhard Rempe — Max-Planck Institut für Quantenoptik, Hans-Kopfermann-Str.1, 85748 Garching

Future quantum networks require multi-qubit network nodes that are capable to manipulate and process quantum information locally and distribute entanglement over the entire network. Therefore, a variety of fundamental qubit-operations and quantum gates are necessary and were already demonstrated, e.g. single qubit-rotations, local [1] and remote qubit-gates [2] and efficient atom-photon entanglement [3]. However, scaling up to many qubits at one node remains an outstanding challenge.

In this talk, we present the generation of arrays of rubidium 87 atoms in an optical cavity. The atoms are loaded and trapped in an optical lattice probabilistically and are then rearranged within the lattice with the help of optical tweezers. In this way, we increase the rate of generation of atomic arrays by orders of magnitudes and, in principle, preserve the capabilities already demonstrated in the past.

[1] Welte, Stephan, et al., Photon-Mediated Quantum Gate between Two Neutral Atoms in an Optical Cavity, Phys. Rev. X 8, 011018 (2018)

[2] Daiss, Severin, et al., A quantum-logic gate between distant quantum-network modules, Science 371, 614 (2021)

[3] Thomas, Philip, et al., Efficient generation of entangled multiphoton graph states from a single atom, Nature 608, 677-681 (2022)

Q 15.4 Mon 17:45 F442

Quantum communication protocols over a 14 km urban fiber link — •Stephan Kucera, Elena Arenskötter, Christian Haen, Jonas Meiers, Tobias Bauer, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The application of existing telecom-fiber infrastructure for quantum communication protocols enables efficient development of quantum networks [1]. It also entails multiple challenges, since existing infrastructure in an urban region is often underground, or paired with the electrical overhead power line.

We report on the implementation of entanglement distribution and quantum-state teleportation over a 14 km polarization-stabilized urban dark-fiber link, which is partially underground, partially overhead, and patched in several stations. Using a type-II cavity-enhanced SPDC photon-pair source, a $^{40}Ca^{+}$ single-ion quantum memory whose transition matches the source, and quantum frequency conversion to the telecom C-band of one photon of a pair [2], we demonstrate photon-photon entanglement, ion-photon entanglement, and teleportation of a qubit state from the ion onto the remote telecom photon, all realized over the urban fiber link.

[1] H. Kimble, Nature 453, 1023*1030 (2008)

[2] E. Arenskötter et al., arXiv:2211.08841 (2022)

Q 15.5 Mon 18:00 F442

Free-space continuous-variable quantum key distribution using discrete modulation — •Kevin Jaksch[1,2], Thomas Dirmeier[1,2], Yannick Weiser[1,2], Stefan Richter[1,2], Ömer Bayraktar[1,2], Bastian Hacker[1,2], Conrad Rössler[1,2], Imran Khan[1,2], Andrej Krzic[3], Teresa Kopf[3], René Berlich[3], Matthias Goy[3], Daniel Rieländer[3], Fabian Steinlechner[3], Florian Kanitschar[4,5], Stefan Petscharning[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Twesh Upadhyaya[5], Jie Lin[5], Norbert Lütkenhaus[5], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [4]AIT Austrian Institute of Technology, Center for Digital Safety&Security, Vienna, Austria — [5]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Canada

In future metropolitan quantum key distribution (QKD) networks, point-to-point free-space links will allow to secure the communication beyond the existing but inflexible fiber backbone. For this purpose, we investigate a continuous-variable QKD system using a discrete modulation pattern in the polarization degree of freedom. We present our results obtained in an experiment over an urban 300m free-space link between the Federal Ministry of Education and Research (BMBF) and the Federal Office for Information Security (BSI) in Bonn.

Q 15.6 Mon 18:15 F442

Atom-Photon Entanglement over 101 km Telecom Fiber — •Yiru Zhou[1,2], Pooja Malik[1,2], Florian Fertig[1,2], Matthias Bock[3], Tim van Leent[1,2], Wei Zhang[1,2], Christoph Becher[3], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Fachrichtung Physik, Universität des Saarlandes, Saarbrücken, Germany — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany

The crucial task for future quantum networks is to share entanglement over large distances. For that, quantum systems are required which provide an efficient light-matter interface, long coherence times and the possibility to connect to low-loss quantum channels.

Here we present the distribution of entanglement between an atom and a photon. Spontaneous emission of a photon at 780 nm from a single, trapped Rb-87 atom is employed to obtain entanglement between the polarization of the photon and the respective Zeeman state of the atom. Raman state transfer is used to change the encoding of the atomic qubit in a combination of F=1 & F=2 hyperfine states [1]. The reduced sensitivity to magnetic fields enables one to increase the coherence time to 7 ms. Together with efficient polarization-preserving quantum frequency conversion to telecom wavelengths minimizing the photon loss [2], we demonstrate the distribution of atom-photon entanglement over 101 km telecom fiber with a fidelity ≥70.8%.

[1] M. Körber et al., Nat. Photonics 12, 18 (2018)

[2] T. van Leent et al., Nature 607, 69-73 (2022)

Q 15.7 Mon 18:30 F442

A 3km free-space link in the munich quantum network — •Michael Auer[1,2,3], Adomas Baliuka[1,2], Fabian Farina[3], Peter Freiwang[1,2], Swantje Kastrup[3], Hedwig Körfgen[3], Hanns Zimmermann[3], Nils gentschen Felde[3], Lukas Knips[1,2,4], Udo Helmbrecht[3], and Harald Weinfurter[1,2,4] — [1]Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Universität der Bundeswehr München, Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany

Quantum key distribution (QKD) enables secure key exchange, based on fundamental laws of quantum mechanics. Widespread commercial use of this technology requires robust and scalable QKD modules paired with underlying infrastructure and proper key management.

The MuQuaNet aims to build, test and operate a secure quantum communication network with multiple nodes by employing a heterogeneous framework using various manufacturers and provide this network as a transparent service to other institutes, authorities and offices.

Here, we focus on a 3km optical free-space link using a small-size, low-power, FPGA-controlled decoy-state BB84 QKD sender operating at 850nm and 100MHz. With a modulated 1550nm beacon laser, active beam stabilization using two fast steering mirrors, synchronization as well as classical communication is achieved. This will show how to integrate individual QKD links into a network or key management solution and will yield insights to long-term effects and maintainability of QKD devices outside a well controlled environment.

Q 15.8 Mon 18:45 F442

Development and characterization of a high-rate receiver for satellite-based QKD — •Conrad Rössler[1,2], Kevin Günthner[1,2], Bastian Hacker[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudstr. 7/A3, 91058 Erlangen, Germany

Since the famous BB84 protocol was proposed in 1984, QKD has evolved to a very mature and promising quantum technology. While classical communication is being threatened by the approach of quantum computers, QKD offers an information theoretical secure way to share a key between two parties. Our high-rate receiver is designed and tested for phase-encoded satellite-based QKD. We present the corresponding discrete variable QKD protocol as well as the concept and characterization of our photon-detection-based phase locking and time synchronization of sender and receiver.

Q 16: Photonic Quantum Technologies (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: A320

Q 16.1 Tue 11:00 A320

Fluorescence Excitation of Quantum Dots by Entangled Two-Photon Absorption — •Tobias B. Gäbler[1,2], Patrick Hendra[1,2], Nitish Jain[1], Erik Prenzel[1], and Markus Gräfe[1,2,3] — [1]Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, D-07745 Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Max-Wien-Platz 1, D-07745 Jena, Germany — [3]Technische Universität Darmstadt, Institute of Applied Physics, Hochschulstraße 6, D-64289 Darmstadt, Germany

Fluorescence excited by absorption of entangled light becomes a prominent candidate to tackle the challenges in the state-of-the-art two-photon imaging techniques, such as the requirement of bright excitation light and fast photobleaching. However, due to the low brightness of entangled photon pair sources used in most studies, fluorescence measurements were not feasible.

Our work addresses this issue by optimization of several experimental parts. Initially, a setup of an efficient entangled photon pair source based on nonlinear waveguides was assembled. Secondly, quantum dots were used to maximize the absorption cross sections and thus the probability to detect fluorescence photons. Additionally, we performed coherence measurements to observe influences of single-photon effects.

Our measurements of fluorescence demonstrate that obstacles like disruptive single-photon effects or insufficient photon pair rates can be handled. These results represent the next step towards an experimental realization of entangled light fluorescence microscopy.

Q 16.2 Tue 11:15 A320

Nonclassical states of light via high harmonic generation in semiconductors — •René Sondenheimer[1], Ivan Gonoskov[2], Christian Hünecke[2], Daniil Kartashov[3], Ulf Peschel[4], and Stefanie Gräfe[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Strasse 7, 07745 Jena, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University Jena, Helmholtzweg 4, 07743 Jena, Germany — [3]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [4]Institute of Solid State Theory and Optics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

I will discuss the generation of higher-order harmonics from a quantum optics perspective via the interaction of a semiconductor with a coherent pump field focusing on the regime where strong-field intraband excitations dominate. While the fundamental mode undergoes intricate but sufficiently mild modifications due to nonlinear interactions, the harmonic modes can be described by coherent displacements depending on the position quadrature component of the driving laser field within our approximations. Similar to high-harmonic generation in atoms, all radiation field modes are entangled, allowing for potential novel protocols for quantum information processing with high photon numbers over a large range of frequencies.

Q 16.3 Tue 11:30 A320

Interfacing a quantum memory based on warm atomic vapour with single photons from a semiconductor quantum dot — •Benjamin Maass[1,2,3], Avijit Barua[3], Norman Vincenz Ewald[2], Leon Messner[1,2,3], Jin-Dong Song[4], Stephan Reitzenstein[3], and Janik Wolters[2,3] — [1]Optische Systeme, Humboldt Universität zu Berlin, Germany — [2]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin, Germany — [3]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [4]Center for Opto-Electronic Materials and Devices, Korea Institute of Science and Technology, Korea

The complexity of modern quantum applications demands for heterogeneous technological solutions. In particular, the excellent controllability and robustness of atomic quantum memories and the effectiveness of single photon generation with solid state emitters can serve as a cornerstone for future applications in quantum optics, e.g. synchronization and buffering of optical networks.

We present prospects of using a warm caesium vapour as storage medium for single photons at the caesium D1 line (894nm). Our quantum memory is based on electromagnetically induced transparency (EIT) in a ladder-type configuration and allows for on-demand storage and retrieval of few-photon light pulses with 20 MHz repetition rate. We achieve 1/e storage times of 20 ns and an end-to-end efficiency of 1%. The high storage bandwidth of the memory and the low read-out noise promise compatibility with single photons from deterministically fabricated quantum light sources based on InGaAs quantum dots.

Q 16.4 Tue 11:45 A320

Room-temperature quantum memory: Interfacing atomic vapours and semiconductor quantum dots — •Esteban Gómez-López[1], Quirin Buchinger[2], Tobias Huber[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, 12489 Berlin — [2]University of Würzburg, 97074 Würzburg

Quantum repeaters are a key element for scalable quantum networks, where quantum memories can substantially increase the efficiency of long-distance communications [1]. Quantum memories based on warm atomic ensembles constitute an attractive platform as they can store high-bandwidth photons [2] up to the second range [3]. Here we show an Electromagnetically Induced Transparency (EIT) quantum memory hosted in warm cesium vapour. Storage of faint coherent light pulses shows high readout efficiency. A measured bandwidth in the order of 200 MHz makes the memory compatible with the Fourier-limited emission of semiconductor Quantum Dots (QD) embedded in micropillar cavities [4]. We also present the first attempts to interface the emission from a QD-micropillar with our quantum memory by fine-tuning the emission wavelength of the emitters to the hyperfine transitions of the Cs D1 line, where the EIT memory takes place. This work sets the base for a hybrid quantum memory for single photons from a semiconductor single-photon source based on warm atomic ensembles. [1] P. van Loock et al., Adv. Quantum Technol. 3, 1900141 (2020). [2] N. Sangouard et al., Rev. Mod. Phys. 83, 33 (2011). [3] O. Katz and O. Firstenberg, Nat. Commun. 9, 2074 (2018). [4] H. Wang et al., Phys. Rev. Lett. 116, 213601 (2016).

Q 16.5 Tue 12:00 A320

Raman control for ultrahigh fidelity spin gates for the generation of large entangled photonic states with group-IV vacancies — •Gregor Pieplow[1], Joseph H. D. Munns[2], Mariano I. Monsalve[1], and Tim Schröder[1,3] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Psi Quantum, 94304 California Palo Alto, USA — [3]Ferdinand-Braun-Institut, 12489 Berlin, Germany

Large photonic entangled states such as multiphoton Greenberger-Horne-Zeilinger (GHZ) states or cluster states (CS) play a crucial role as a resource in two key photonic quantum information applications: measurement-based quantum computing, and one-way quantum repeaters. Here, we focus on theoretically investigating the deterministic generation of photonic resource states by employing a promising class of optically active spin defects in diamond: group-IV color centers. Specifically, we investigate the generation of linear cluster states and GHZ states. Because the generation of a large entangled photonic state comprised of single photons requires many iterations of the same coherent operations on a quantum emitter, they have to be of ultra high fidelity or otherwise the quality of the state degrades exponentially. This work provides a highly detailed investigation of the optical coherent control that facilitates single and two qubit gates, which are used for the deterministic generation of highly entangled states. We also introduce an original GHZ and CS quality measure, which will underline the importance of ultrafast and high fidelity control techniques for creating large time-bin entangled photonic qubit states.

Q 16.6 Tue 12:15 A320

Ideal Single Photon Sources at Telecom Wavelengths — •Jonas Grammel[1], Julian Maisch[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Univer- sität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency.

Q 16.7 Tue 12:30 A320

Spatially and spectraly indistinguishable single mode photons from domain-engineered crystal — •Baghdasar Baghdasaryan[1,2], Fabian Steinlechner[3,4], and Stephan Fritzsche[1,2,4] — [1]Theoretisch-Physikalisches Institut, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [4]Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Pure single-photon sources are currently one of the most important goals of photonic quantum technologies. A heralded single photon from spontaneous parametric down-conversion (SPDC) is a good candidate for a pure single-photon source. However, the photons from SPDC occur in pairs, that are highly correlated in space and frequency. This correlation reduces the purity of the heralded photons. Domain-engineered crystals with a Gaussian nonlinear response have been successfully used to minimize spectral correlations and enhance spectral purity in SPDC. However, a general approach, which minimizes both, spectral and spatial correlations, is still lacking. We go beyond the ansatz of the Gaussian nonlinear response and find a general nonlinear response that maximizes both the spatial and spectral purity of the SPDC emission.

Q 16.8 Tue 12:45 A320

Towards time-multiplexed pseudo-on-demand generation of single-photons in the C-band based on SPDC — •Xavier Barcons Planas[1,2,3], Leon Messner[1,2,3], Helen Chrzanowski[2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institute of Optical Sensor Systems, German Aerospace Center (DLR), Berlin, Germany — [3]Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

The deterministic generation of single photons is crucial for photonic quantum technology applications. Spontaneous parametric down-conversion (SPDC) is one of the most prominent processes for the generation of single-photons, where a classical pump beam can spontaneously convert into (entangled) pairs of signal and idler photons. Despite significant advantages in the versatility and the possibility of room-temperature operation, photon-pairs are emitted probabilistically because of the spontaneous nature of the process. We present first results of our efforts to overcome this limitation through temporal multiplexing [1]. We herald the presence of the signal photon from a monolithic cavity SPDC source [2] by detecting the corresponding idler, and store the signal in a highly-efficient storage loop [3]. The synchronization of the source with the memory provides a pseudo-on-demand single-photon source.

[1] E. Meyer-Scott *et al.*, Rev. Sci. Instrum. **91**, 041101 (2020).
[2] R. Mottola *et al.*, Opt. Express **28**, 3159 (2020).
[3] T. Pittman *et al.*, Phys. Rev. A **66**, 042303 (2002).

Q 17: Integrated Photonics I (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: E001

Invited Talk Q 17.1 Tue 11:00 E001

Thin-film lithium niobate waveguides for integrated quantum photonic technologies — •Francesco Lenzini[1], Emma Lomonte[1], and Wolfram Pernice[1,2] — [1]University of Muenster, 48149 Muenster, Germany — [2]Heidelberg University, 69120 Heidelberg, Germany

Lithium-Niobate-On-Insulator (LNOI) has emerged in recent years as a promising platform for integrated quantum photonic technologies because of its high-index contrast, enabling the realization of waveguides with a compact footprint, large second-order optical nonlinearity, and high electro-optic coefficient. In the first part of my talk I will give a general overview about our fabrication process for the realization of low-loss LNOI waveguide circuits, with a special focus on the development of efficient fiber-to-chip interconnects based on the use of grating couplers with a metal back-reflector. In the second part of my talk, I will instead discuss some applications in integrated quantum photonic technologies of the developed LNOI circuits. Specifically, I will present the first demonstration of an electro-optically tunable LNOI waveguide network integrated on-chip with superconducting nanowire single-photon detectors (SNSPDs), as well as the realization of high-speed programmable circuits specially designed for operation with single photons emitted by a Quantum Dot source.

Q 17.2 Tue 11:30 E001

Duty cycle errors in periodically poled $LiNbO_3$ waveguides — •Sebastian Brauner, Christof Eigner, Harald Herrmann, Lara Padberg, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics,Institute for Photonic Quantum Systems (PhoQS), Warburgerstr. 100, 33098 Paderborn, Germany

Photon pair generation and quantum frequency conversion are fundamental in quantum communication. Waveguides and specifically tailored quasi-phase matching have shown an amazing potential for future quantum communication technologies, which established material platforms as $LiNbO_3$ are about to explore. However, one often observes deviations from the expected performance, i.e. a low efficiency and distorted spectral phase-matching curves. We attribute these distortions to imperfections of the period poling. To gather a profound understanding, how such imperfections impact on the device performance, we conduct theoretical and experimental studies how duty cycle errors affect the conversion characteristic.

Q 17.3 Tue 11:45 E001

Ultrabright and narrowband intra-fiber biphoton source at ultralow pump power — •Alexander Bruns[1], Chia-Yu Hsu[1,3], Sergiy Stryzhenko[1,2], Enno Giese[1], Leonid Yatsenko[2], Ite Yu[3,4], Thomas Halfmann[1], and Thorsten Peters[1] — [1]TU Darmstadt, Germany — [2]National Academy of Science of Ukraine, Kyiv, Ukraine — [3]National Tsing Hua University, Hsinchu, Taiwan — [4]Center for Quantum Technology, Hsinchu, Taiwan

Nonclassical photon sources of high brightness are key components of quantum communication technologies. We here demonstrate the generation of narrowband, nonclassical photon pairs by employing spontaneous four-wave mixing in an optically-dense ensemble of cold atoms within a hollow-core fiber.

The brightness of our source approaches the limit of achievable generated spectral brightness at which successive photon pairs start to overlap in time. For a generated spectral brightness per pump power of up to 2×10^9 pairs/(s MHz mW) we observe nonclassical correlations at pump powers below 100 nW and a narrow bandwidth of $2\pi \times 6.5$ MHz. In this regime we demonstrate that our source can be used as a heralded single-photon source. By further increasing the brightness we enter the regime where successive photon pairs start to overlap in time and the cross-correlation approaches a limit corresponding to thermal statistics.

Our approach of combining the advantages of atomic ensembles and waveguide environments is an important step toward photonic quantum networks of ensemble-based elements.

Q 17.4 Tue 12:00 E001

Realisation of an integrated source for Gaussian boson sampling — Laura Padberg, •Simone Atzeni, Michael Stefszky, Kai Hong Luo, Harald Herrmann, Benjamin Brecht, Christof Eigner, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Photonic quantum computing based on Gaussian Boson Sampling (GBS) is a quickly emerging research field, whose first implementations have demonstrated the role of single-mode squeezed states at telecom wavelength as key resources. Generally, the generation of these states relies on the process of parametric down-conversion in a nonlinear crystal, where care has to be taken to ensure that spectral correlations in the source do not lead to the generation of undesired multi-mode squeezed states. Due to its unique dispersion properties, bulk potassium titanyl phosphate (KTP) is typically employed for the generation of single-spectral-mode squeezed states at telecom wavelength. However, the performance of KTP sources will benefit from the enhanced light-matter interaction of a waveguide approach.

Here, we present the modelling, characterisation, and fabrication of a waveguide in periodically poled rubidium-doped KTP (ppRb:KTP). This system can act as a high-quality integrated source of single-mode squeezed states at telecom wavelength and can be readily employed in a GBS photonic processor.

Q 17.5 Tue 12:15 E001

Development of micro-integrated optical systems for atom-based quantum sensors — •Conrad Zimmermann, Marc Christ, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Berlin, Germany

Compact and mobile quantum sensors enable a broad range of applications in e.g. navigation and field-sensing with high sensitivity. The size and weight requirements derived from these applications place high demands on the degree of miniaturization, integration and robustness of all subsystems of such a device. Working on the physics package, we develop and qualify necessary integration technologies to realize miniaturized, ultra-stable optical systems and increase their functionality. Using these techniques, we set up a micro-integrated optical distribution system with a volume of ~25 ml to generate a crossed beam optical dipole trap. The two high-power laser beams precisely overlap in their focal points (ω_0 = 32 μm), and the system exhibits a high mechanical and thermal alignment stability. We present initial results from its operation in a cold atom experiment.

One approach to further reduce the overall size of a cold-atom based quantum sensor is to integrate optical setups within the vacuum system. We show development and qualification efforts for future in-UHV optical systems for atom trapping and manipulation.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1978 and 50WM1949.

Q 17.6 Tue 12:30 E001

Design and Simulation of Photonic Integrated Ion Traps — •Guochun Du[1], Elena Jordan[1], Carl-Frederik Grimpe[1], Anastasiia Sorokina[2,3], Steffen Sauer[2,3], Pascal Gehrmann[2,3], Stefanie Kroker[2,3], and Tanja E. Mehlstäubler[1,4,5] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

Ion traps are a promising platform for realizing high-performance quantum computers and atomic clocks. To make these systems scalable, integrated photonic components for guiding and manipulating laser light on a chip scale are important. We will report on finite element simulations of our integrated ion traps. In the simulations, we examined the distortion of the potential at the position of the ion due to the openings in the electrodes for the outcouplers. Our simulations indicate that a transparent conductive coating can help to smoothen the potential. Further, we study how our traps can benefit from grating outcouplers designed with shallow angles.

Q 17.7 Tue 12:45 E001

Integrated photonics for the ATIQ quantum computer demonstrator — •Carl-Frederik Grimpe[1], Guochun Du[1], Anastasiia Sorokina[2,3], Pascal Gehrmann[2,3], Steffen Sauer[2,3], Elena Jordan[1], Tunahan Gök[4,5], Radhakant Singh[4,5], Maxim Lipkin[4,5], Pragya Sah[4,5], Stephan Suckow[4], Babita Negi[5], Stefanie Kroker[1,2,3], and Tanja E. Mehlstäubler[1,6,7] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [3]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [4]AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany — [5]Chair of Electronic Devices, RWTH Aachen University, Aachen, Germany — [6]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [7]Laboratorium für Nano- und Quantenengineering, Hannover, Germany

The BMBF project "ATIQ" aims to develop reliable trapped-ion quantum computer demonstrators with more than 40 qubits and with multi-qubit gate fidelities larger than 99.5%. To make the trapped ion systems scalable, we are developing integrated photonic systems for guiding and manipulating the laser light at the chip level. In this talk, we will discuss some design considerations to make when integrating photonics in surface ion traps. Furthermore, we will discuss the characterization of the photonic elements and benchmarking of the ion trap performance.

Q 18: Quantum Optics: Cavity and Waveguide QED I

Time: Tuesday 11:00–13:00 Location: E214

Invited Talk Q 18.1 Tue 11:00 E214

Atoms coupled to nanofibers: from topological phases to correlated photon emission — •Beatriz Olmos — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

An ensemble of emitters coupled to a common environment displays collective behaviour. This includes the enhanced and inhibited emission of photons from the ensemble (so-called super and subradiance, respectively), and the emergence of induced dipole-dipole interactions among the emitters. Among these structures, so-called nanophotonic waveguides such as single mode optical nanofibers particularly stand out, since the translationally invariant nature of the nanofiber-guided modes gives rise to infinitely ranged couplings between the emitters. In this talk, I will summarize some of the latest theoretical results in my group, where we have shown how these all-to-all interactions can facilitate the study of non-trivial topology, the emergence of phase transitions, and correlated photon emission, among other phenomena.

Q 18.2 Tue 11:30 E214

Effective mode theory for open quantum systems — •Lucas Weitzel Dutra Souto, Felix Riesterer, Dominik Lentrodt, and Andreas Buchleitner — University of Freiburg, Germany

In the frequently employed theoretical approaches for open resonator QED systems, one usually considers a quantum emitter - such as an atom - in a cavity which interacts with a few discrete electromagnetic cavity modes. Losses and leakage from the cavity are modelled via a (weak) interaction with the environment. Models that employ this treatment, as is the case for the seminal Jaynes-Cummings model and its generalizations, have been tremendously successful in describing experiments. However, these models are intrinsically phenomenological and it is not known if they hold in all situations, as the underlying approximations are still unclear. For instance, in the case of strongly leaking systems, such as plasmonic cavities, this approach is not valid anymore and various theoretical assumptions need to be reassessed. We hence try to answer the following question: Is it possible to construct from first principles a few-mode description for leaky cavities in the spirit of the Jaynes-Cummings model? This will extend our theoretical understanding of more general systems or, in the case of a negative answer, lead to a no-go theorem.

Q 18.3 Tue 11:45 E214

Crafting the dynamical structure of synchronization by harnessing bosonic multi-level cavity QED — •Riccardo J. Valencia-Tortora[1], Shane P. Kelly[1], Tobias Donner[2], Giovanna Morigi[3], Rosario Fazio[4,5], and Jamir Marino[1] — [1]JGU Mainz, Mainz, Germany — [2]ETH Zürich, Zürich, Switzerland — [3]Saarland University, Saarbrücken, Germany — [4]ICTP, Trieste, Italy — [5]Università di Napoli Federico II, Napoli, Italy

Recently, the theoretical and experimental investigation of multi-level cavity systems has gathered increasing attention. Yet, the rich diversity of dynamical responses they can host is still widely unexplored, and the few individual results call for a unifying picture both for theoretical and experimental purposes. We present a framework which could serve this scope based on a dynamical reduction hypothesis, which in summary states that the dynamics of collective observables can be described by a few-body effective Hamiltonian. Using this conjecture as a guiding principle, we intuitively explain and craft the dynamical response of an exchange model for SU(N) spins mediated by cavity photons after a quench. In this regard, we unveil the susceptibility of the dynamical response of multi-level systems to quantum fluctuations and intra-levels entanglement, observing among the others the onset of a chaotic phase characterized by exponential sensitivity to the initial conditions. To conclude, we discuss possible extensions to other spin-exchange quantum simulators and a universal conjecture for the dynamical reduction of non-integrable all-to-all interacting systems.

Q 18.4 Tue 12:00 E214

Cascaded photon emission of a single three-level ladder atom into two cavities — •Gianvito Chiarella, Tobias Frank, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics, Garching bei München, Germany

Crossed Fiber Cavities coupled to single 87Rb atoms have proven to be a potentially useful resource for quantum communication applications [1,2]. Their main feature lies in the capability to couple two distinct light modes to two atomic transitions simultaneously with high cooperativity. This property makes them a good candidate for the investigation of fundamental phenomena in quantum optics which manifest in the presence of two vacuum fields strongly interacting with the atom. We explore the scenario where the cavities couple to two electrical-dipole transitions of a three-level ladder atom. In certain parameters regimes, we predict an effect for which the atom relaxes down the ladder states into its ground state emitting two resonant photons without populating the intermediate state. In this talk, I will present the theoretical simulation of such a model and discuss its experimental implementation.

Q 18.5 Tue 12:15 E214

Light-matter interaction at the transition between cavity and waveguide QED — •Daniel Lechner, Riccardo Pennetta, Martin Blaha, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Humboldt Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin

The interaction between a light field and an ensemble of quantum emitters is usually described in the framework of cavity quantum electrodynamics (QED) or waveguide QED. The choice depends on whether the emitters interact with a single-mode light field confined in a resonator or a propagating one, for which a continuum of frequency modes is allowed. These two branches of quantum optics share the common goal of harnessing light-matter coupling. However, they often use very different experimental set-ups and theoretical descriptions. Here, we experimentally and theoretically explore the transition from cavity to waveguide QED with an ensemble of cold atoms that is coupled to a fiber-ring resonator containing a nanofiber section. By changing the length of the resonator from a few meters up to several tens of meters, we tailor the spectral density of modes of the resonator without affecting the system's cooperativity parameter. We demonstrate that for progressively longer resonators, the paradigmatic Rabi oscillations of cavity QED gradually vanish while signatures of the dynamics typical for waveguide QED appear.

Q 18.6 Tue 12:30 E214

Relativistic formulation of quantum electrodynamical density functional theory for cavities — •Valeriia Kosheleva[1], Lukas Konecny[1], Heiko Appel[1], Angel Rubio[1,2], and Michael Ruggenthaler[1] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Center for Computational Quantum Physics (CCQ), The Flatiron Institute, 162 Fifth Avenue, New York, New York 10010, USA

Recent advances in cavity QED, particularly in polaritonic chemistry, necessitate the development of theoretical methods for describing many-electron systems strongly coupled to photons. One of the most popular ab initio approaches for modeling realistic materials is density functional theory (DFT). Recently, this theory was generalized for cavity systems [1,2] and is referred as quantum electrodynamical density functional theory (QEDFT). The matter part in QEDFT is usually treated within non-relativistic formalism which is a good approximation for light element-containing systems. However, as soon as heavier atoms are involved relativistic effects become essential for understanding the physical and chemical properties of atoms and molecules. In the present work, we introduce relativistic reformulation of cavity QEDFT. As an example, we consider the application of our formalism to study the the effect of strong coupling on absorption spectra of molecules containing heavy atoms.

[1] I. V. Tokatly, Phys. Rev. Lett. 110, 233001 (2013).
[2] M. Ruggenthaler et al., Phys. Rev. A 90, 012508 (2014).

Q 18.7 Tue 12:45 E214

Quantum Theory for Self-organization in Many-body Cavity QED — •Tom Schmit[1], Simon Jäger[2], Tobias Donner[3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [3]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

Ensembles of atoms strongly coupled with the electric field of an optical cavity offer a formidable laboratory for studying the out-of-equilibrium dynamics of long-range systems in the quantum regime. In this work, we derive by means of the formalism developed in Ref. [1] a quantum master equation describing the dynamics of atoms which interact with a multimode high-finesse cavity. We then derive the BBGKY hierarchy and analyse the predictions in several relevant limits. Our theory reproduces the results of the experiment of Ref. [2] and provides a powerful tool for singling out the individual contributions to the onset of metastability in quantum globally-interacting systems.

[1] S. B. Jäger, T. Schmit, G. Morigi, M. J. Holland, and R. Betzholz, Phys. Rev. Lett. **129**, 063601 (2022).
[2] A. Morales, P. Zupancic, J. Léonard, T. Esslinger, and T. Donner, Nature Materials **17**, 686 - 690 (2018).

Q 19: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

Time: Tuesday 11:00–12:45 Location: F303

See A 11 for details of this session.

Q 20: Quantum Gases: Bosons II

Time: Tuesday 11:00–13:00 Location: F342

Q 20.1 Tue 11:00 F342

Bose-Einstein Condensation of Photons in a Four-Site Lattice Potential — •Niels Wolf, Andreas Redmann, Christian Kurtscheid, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Deutschland

Bose-Einstein condensation can be observed with ultracold atomic gases, polaritons, and since about a decade ago also with low-dimensional photon gases. Cold atomic gases in lattice potentials are usually prepared following the creation of a condensate by transferring it into the periodic potential, while in recent work with photon gases direct condensation into a coherently split state of light has been realized [1]. Here we report on experimental work directed at realizing thermalized photon gases in periodic potentials of increased complexibility, i.e. beyond a double well.

Our experiments use a controlled mirror surface delamination technique to imprint variable potentials for light in a dye-filled optical microcavity environment. Photons thermalize by repeated absorption re-emission processes on the dye molecules in a four-site lattice potential superimposed by a weak harmonic trapping potential. We observe Bose-Einstein condensation of photons in the four-fold split coherent superposition of the localized microsites wave function representing the system ground state in the microcavity.

[1] C. Kurtscheid et al., Science 366, 894 (2019)

Q 20.2 Tue 11:15 F342

Many-body interference at the onset of chaos — •Eric Brunner[1,2], Lukas Pausch[1,2,3], Edoardo G. Carnio[1,2], Gabriel Dufour[1,2], Alberto Rodríguez[4], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104, Freiburg, Germany — [3]CESAM Research Unit, University of Liège, 4000 Liège, Belgium — [4]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

We unveil the signature of many-body interference across dynamical regimes of the Bose-Hubbard model. Increasing the particles' indistinguishability enhances the temporal fluctuations of few-body observables, with a dramatic amplification at the onset of quantum chaos. By resolving the exchange symmetries of partially distinguishable particles, we explain this amplification as the fingerprint of the initial state's coherences in the energy eigenbasis. In the domain of fully developed quantum chaos, ergodic delocalisation of the eigenstates suppresses this fingerprint.

Q 20.3 Tue 11:30 F342

Dynamical characterization of the chaotic phase in the Bose-Hubbard model — David Peña Murillo and •Alberto Rodríguez — Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

We study the dynamical manifestation of the Bose-Hubbard model's chaotic phase [1] by analysing the temporal behaviour of connected two-point density correlations on experimentally accessible time scales up to a few hundred tunneling times. The time evolution of initial Mott states with unit density in systems including up to 17 bosons (Hilbert space dimension ≈ 10^9) reveals that the chaotic phase can be unambiguously identified from the early time fluctuations of the considered observable around its equilibrium value [2]. The emergence of the chaotic phase is also seen to leave an imprint in the initial growth of the time signals. The possibility to discern specific features of this many-body chaotic phase, on top of the universal prediction of random-matrix theory, from these experimentally accessible measures is explored.

[1] L. Pausch *et al.*, Phys. Rev. Lett. 126, 150601 (2021)
[2] D. Peña Murillo, MSc Thesis, Universidad de Salamanca (2022)

Q 20.4 Tue 11:45 F342

Orbital dynamics of bosons in the second Bloch band of an optical lattice — •José Vargas[1,2], Marlon Nuske[1], Raphael Eichberger[1], Carl Hippler[1], Ludwig Mathey[1,2], and Andreas Hemmerich[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany — [2]The hamburg center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We explore Josephson-like oscillations of a Bose-Einstein condensate populating the second Bloch band of a bipartite optical square lattice, which provides a double well structure with two inequivalent, degenerate energy minima. An oscillation of the relative population difference between the two energy minima of the second band is observed. The oscillation frequency depends on the ratio of two distinct collisions processes: the on-site collision term of atoms in either of the three local orbitals in shallow and deep wells of the lattice, and a flavour changing collision. The observations are compared to the predictions given by a full quantum model limited to only two single-particle modes neglecting dissipation, which reproduces the measured oscillations and show the correct dependency of the oscillation frequency on the ratio among the strength of the aforementioned collision terms.

Q 20.5 Tue 12:00 F342

Stability of vortices in dipolar droplets — Milan Radonjić[1,2], •Antun Balaž[2], and Axel Pelster[3] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Vortices in dipolar Bose-Einstein condensates have been studied theoretically and numerically for a long time, but have proved to be elusive and were experimentally observed only very recently [1]. Based on variational calculations, it was suggested [2] that vortices may also exist in dipolar droplets [3], exotic quantum states that emerge due to quantum fluctuations [4]. Here we investigate if self-bound dipolar droplets can support vortices using numerical approach based on the extended Gross-Pitaevskii equation, which includes quantum depletion and finite-size corrections. We also study dynamical stability of such vortex states for experimentally relevant values of system parameters.

[1] L. Klaus et al., In press, Nat. Phys. (2022).
[2] A. Cidrim et al., Phys. Rev. A **98**, 023618 (2018).
[3] H. Kadau et al., Nature **530**, 194 (2016).
[4] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); Phys. Rev. A **86**, 063609 (2012).

Q 20.6 Tue 12:15 F342

Optimal route to quantum chaos in the Bose-Hubbard Hamiltonian — •Lukas Pausch[1,2], Edoardo G. Carnio[2,3], Alberto Rodríguez[4], and Andreas Buchleitner[2,3] — [1]Département de Physique, Université de Liège, Belgium — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [3]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Germany — [4]Departamento de Física Fundamental, Universidad de Salamanca, Spain

The dependence of the chaotic phase of the Bose-Hubbard Hamiltonian [1,2] on particle number, system size and particle density is investigated in terms of spectral and eigenstate features. Within the energy and parameter range where chaos fully unfolds, the expectation value and the eigenstate-to-eigenstate fluctuations of the fractal dimensions of Bose-Hubbard eigenstates show clear signatures of ergodicity and are well described by random-matrix theory (RMT) [1,2]. As the limit of infinite Hilbert space dimension is approached along different directions, the fastest convergence to the random-matrix predictions is achieved at fixed particle density ≲ 1 [3]. Despite the agreement on the level of low-order statistical moments, the model is ever more distinguishable from RMT in terms of its full fractal dimension distributions as Hilbert space grows. These results provide evidence of a way to discriminate among different many-body Hamiltonians in the chaotic regime.

[1] L. Pausch et al., Phys. Rev. Lett. 126, 150601 (2021)
[2] L. Pausch et al., New J. Phys. 23, 123036 (2021)
[3] L. Pausch et al., J. Phys. A 55, 324002 (2022)

Q 20.7 Tue 12:30 F342

Full quantum simulations of Bose gases with the complex Langevin method — •Philipp Heinen and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

While path integrals can be straightforwardly evaluated by standard Monte Carlo methods in the case of a real action, these are not applicable for a complex action because the interpretation of the integrand as a probability density is lost in this case, a fact that is commonly known as sign problem. This hinders ab initio simulations of the interacting Bose gas in the field-theoretic framework, since the purely imaginary Berry phase term in its action causes a sign problem even in thermal equilibrium. The complex Langevin (CL) algorithm is a generic, model-independent approach to tackle the sign problem by recasting the path integral into a stochastic Langevin equation and by complexifying the originally real degrees of freedom of the problem. While it has a long-standing history in high energy physics, its application to ultracold atoms is rather recent. In my talk I want to demonstrate that CL is able to simulate interacting bosons from first principles and show applications to the BKT transition and the physics of dipolar Bose gases.

Q 20.8 Tue 12:45 F342

An Atomic Mode Parametric Amplifier Mediated by Cavity Photons — •Fabian Finger, Rodrigo Rosa-Medina, Nicola Reiter, Panagiotis Christodoulou, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Parametric amplification is a fundamental concept of nonlinear dynamics, occurring in fields so diverse as mechanics, electronics, and atomic physics. In the past, ultracold quantum gases exhibiting short-range contact interactions have been used to demonstrate parametric amplification of atomic modes. Here, we make use of global-range interactions in an optical cavity to realize a fast parametric amplifier producing atomic pairs in specific spin and momentum modes. Our implementation relies on Raman scattering between spin levels in a spinor Bose-Einstein condensate, induced by the interplay of a running-wave transverse laser and the vacuum field of the cavity. Detuned from Raman resonance, a four-photon process gives rise to effective spin-mixing dynamics. We observe pair production of signal and idler atoms in tens of microseconds and demonstrate its nonlinear character by varying the number of atoms in the pump reservoir. We extend our results to a regime exhibiting two concurring pair production channels and observe correlated momenta between the highly fluctuating signal and idler modes, verifying the phase matching condition of the parametric amplifier. Our results demonstrate a new experimental platform for fast atomic parametric amplification and provide prospects for matter-wave interferometry using entangled motional states.

Q 21: Quantum Technologies: Color Centers II (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: F442

Q 21.1 Tue 11:00 F442

Purcell-Enhanced Emission from Individual SiV$^-$ Center coupled to a Photonic Crystal Cavity — •Niklas Lettner[1,2], Lukas Antoniuk[1], Konstantin Fehler[1,2], Anna P. Ovvyan[3], Nico Gruhler[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France

The combination of classical integrated photonic structures with color centers in diamond, like the Silicon Vacancy (SiV$^-$) Center, offer a promising platform for on-chip quantum optics experiments. We functionalize classical silicon nitride photonic crystal cavities with SiV$^-$ color centers in nanodiamonds in a hybrid approach. We show the experimental results coupling SiV$^-$ centers efficiently to a photonic crystal cavity mode and the Purcell enhanced emission of individual SiV$^-$ transitions [1]. By utilizing two mode coupling we achieved lifetimes of 460 ps [2].

[1] Fehler, Konstantin G., et al. Nanophotonics 9.11 (2020): 3655-3662.
[2] Fehler, Konstantin G., et al. ACS Photonics 8.9 (2021): 2635-2641.

Q 21.2 Tue 11:15 F442

Fabrication and characterization of μm-thin color center enriched diamonds for an open microcavity quantum network node — •Colin Sauerzapf[1,2], Julia Brevoord[1], Julius Fischer[1], Yanik Herrmann[1], Leonardo Wienhoven[1], Matteo Pasini[1], Laurens Feije[1], Matthew Weaver[1], Maximilian Ruf[1], Jörg Wrachtrup[2], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Quantum network nodes are an essential building block to realize a Quantum Internet [1]. Color centers in diamond, like the established Nitrogen-Vacancy (NV) with its long spin coherence and spin register capabilities or the emerging Tin-Vacancy (SnV) centers, are promising candidates to realize such quantum nodes [2]. Integrating the color center into an open microcavity and therefore boosting the emission of coherent photons via the Purcell effect can significantly improve the entanglement rate of the system [3, 4]. Here we present a fabrication method for the required μm-thin color center enriched diamond platelets bonded to a Bragg mirror as well as the characterization of those samples in terms of emitter properties and performance in an open microcavity [5].

[1] S. Wehner et al., Science 362, 6412 (2018) [2] M. Ruf et al., J. Appl. Phys. 130, 070901 (2021) [3] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021) [4] E. Janitz et al., Optica 7, 1232-1252 (2020) [5] M. Ruf et al., Nano Lett. 19, 6, 3987*3992 (2019)

Q 21.3 Tue 11:30 F442

Overcoming spectral diffusion of NV defect centers in diamond nanostructures for enhanced entanglement generation — •Laura Orphal-Kobin[1], Kilian Unterguggenberger[1], Tommaso Pregnolato[1,2], Natalia Kemf[2], Mathias Matalla[2], Ralph-Stephan Unger[2], Ina Ostermay[2], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

In large-distance quantum networks, quantum nodes are entangled by single photons. Using NV defect centers in diamond, network entanglement protocols were demonstrated in bulk-like microstructured samples. Performances could be significantly improved by coupling NVs to nanostructures, which increases the photon collection efficiency into a particular optical mode. However, ionization of surface defects leads to spectral diffusion of the NV zero-phonon-line resonance.

We demonstrate NVs in nanostructures that exhibit spectrally stable emission suited for entanglement generation [1]. Choosing a substrate with a high density of bulk nitrogen defects incorporates natural NVs and seems to screen fluctuating electric fields from the surface. Moreover, long ionization times allow for resonant control sequences in which high energy pulses can be circumvented for many entanglement attempt repetitions (optical π-pulses). By suppressing spectral diffusion, we propose spin-photon entanglement rates on the order of hundreds of kHz using NVs in nanostructures.

[1] L. Orphal-Kobin et al., arXiv:2203.05605 (2022).

Q 21.4 Tue 11:45 F442

High-precision localization of color centers in diamond for deterministic coupling to quantum photonic nanostructures — •Maarten H. van der Hoeven[1], Julian M. Bopp[1], Maximilian Kähler[1], Tommaso Pregnolato[1,2], Marco Stucki[1,2], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Quantum photonic circuits are fundamental building blocks for quantum information applications, like secure communication or quantum computing. In the past decades, it has been demonstrated that color centers in diamond have excellent properties to serve as qubits in such systems [1]. To create an efficient spin-photon interface, the color centers have to be coupled to quantum photonic nanostructures. The scalable fabrication of such devices with high yield and optimal performance requires deterministic alignment techniques [2]. This is achieved with high-precision localization of color centers in bulk diamond with uncertainties of a few tens of nanometers. Our approach is to determine the color center positions relative to alignment markers etched into the diamond's surface and subsequently fabricate nanostructures around them [3]. This technique allows for a pre-selection of the emitters and only the ones with the most suitable properties are chosen and integrated into a photonic device.

[1] M. Ruf et al., *Journal of Applied Physics* 130, 070901 (2021)

[2] S. Rodt et al., *J. Phys.: Condens. Matter* 32, 153003 (2020)

[3] T. Pregnolato et al., *APL Photon.* 5, 086101 (2020)

Q 21.5 Tue 12:00 F442

A novel open microcavity setup for an efficient spin-photon interface with diamond color centers — •Julius Fischer[1], Yanik Herrmann[1], Julia Brevoord[1], Colin Sauerzapf[1,2], Leonardo Wienhoven[1], Matteo Pasini[1], Laurens Feije[1], Matthew Weaver[1], Maximilian Ruf[1], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Open microcavities are capable of equipping color centers in diamond with an efficient spin-photon interface [1,2] enabling their use as quantum nodes for quantum internet applications [3]. The well-established Nitrogen-Vacancy (NV) center with its long spin coherence times and spin register capabilities as well as the emerging Tin-Vacancy (SnV) center are two promising candidates. We recently showed Purcell enhancement under resonant excitation of NV centers in open microcavities [4]. However, the performance was limited by cavity length variations due to vibrations [4]. Here we present a new cryogenic low-vibration open microcavity setup including first measurements on defect center enriched μm-thin diamond samples.

[1] M. Ruf et al., Journal of Applied Physics 130, 070901 (2021) [2] E. Janitz et al., Optica 7, 1232-1252 (2020) [3] S. Wehner et al., Science 362, 6412 (2018) [4] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021)

Q 21.6 Tue 12:15 F442

Advances in Nanoscale Nuclear Magnetic Resonance with NV centers in diamond — •Marcel Martin[1], Nicolas Palazzo[2,3], Erik Knall[2], Daniel Kim[2,3], Nadine Meister[2], Ryan Gelly[2,3], Ryan Cimmino[2], Bartholomeus Machielse[2], Elana Urbach[2], Mikhail Lukin[2], Hongkun Park[2,3], and Nabeel Aslam[1] — [1]Institute of Condensed Matter Physics, Technische Universität Braunschweig, Braunschweig, Germany — [2]Department of Physics, Harvard University, Cambridge, USA — [3]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, USA

Limitations of traditional nuclear magnetic resonance (NMR) can be overcome by using Nitrogen vacancy (NV) centers in diamond as local NMR probes which rely on statistical rather than thermal polarisation.

Proof-of-concept NMR measurements with NV centers have successfully been demonstrated in the past but revealed new challenges. One of them being the fast diffusion of molecules in liquids out of the detection volume, prohibiting NMR sensing by the NV centers. This can be solved by confining liquids in close proximity to the NV sensor. We realized this by structuring the diamond surface with nanowells, which function as traps for zeptoliter scale samples. In addition we demonstrated the controlled creation of NV centers underneath these nanostructures. We present NMR data measured with NV centers in such devices.

The promising technique of nanoscale NMR using NV centers is not restricted to liquids though but can be applied to a wide variety of materials. We will discuss a selection of potential applications.

Q 21.7 Tue 12:30 F442

Highly-efficient extraction of single photons from silicon vacancy in diamond using plasmonic nanoantenna — Ilya Fradkin[1], Mario Agio[2], and •Dmitry Fedyanin[1] — [1]Dolgopudny, Moscow, Russia — [2]University of Siegen, Siegen, Germany

Color centers in diamond and related wide-bandgap semiconductors are considered as one of the most promising quantum optoelectronic systems for single-photon sources and spin qubits. However, one of the major obstacles towards their practical exploitation is the high refractive index of diamond, which limits the maximum photon extraction efficiency to only a few percent for a horizontally oriented dipolar emitter, while for a vertically oriented emitter, the collection efficiency is even lower. At the same time, for practical applications, the efficiency of photon extraction of higher than 70% is typically required even at 100% quantum efficiency of the emitter. In this work, we develop a plasmonic nanoantenna that not only dramatically enhances the quantum efficiency of the silicon-vacancy (SiV) center in diamond but also improves the collection efficiency of the vertically oriented emitter by more than two orders of magnitude. We numerically demonstrate that the proposed nanoantenna allows to achieve the collection efficiency of more than 85%. Even more remarkable result is that the collection efficiency almost does not depend on the distance from the SiV center to the nanoantenna at distances from 10 to 100 nm and exceeds 80%, which is particularly beneficial for practical applications.

Q 21.8 Tue 12:45 F442

Fabrication of suspended "Sawfish" photonic crystal cavities in diamond — •Tommaso Pregnolato[1,2], Marco Stucki[1,2], Julian Bopp[1,2], Maarten van der Hoeven[2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut gGmbH, Berlin, Germany — [2]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany

Color centers in diamond are a promising candidate for the development of quantum photonic applications: for example, their long spin-coherence times make them the optimal choice for building spin-based quantum networks [1]. Such networks will be formed by many nodes containing color centers that are all interconnected by photonic channels. An efficient interface between spin and photon is key for the success of such a system, as it enables the transfer of information from the stationary qubits (i.e. the spins) to the flying qubits (i.e. the propagating photons). Such interface can be achieved by coupling a defect center to a photonic crystal cavity [2]. Here, we report on our progress of fabricating such photonic crystal cavities, based on our recently proposed "sawfish" cavity design [3]. Our design is optimized for enhancing the interaction between tin-vacancy centers in diamonds and single-mode light fields. We present our fabrication procedure to obtain such suspended devices, our investigations on how different parameters affect the relevant etching rates and our first optical characterizations.

[1] M. Atatüre, et al., Nat. Rev. Mater. 3, 38-51 (2018) [2] T. Schröder, et al, J. Opt. Soc. Am. B 33, B65-B83 (2016) [3] J. Bopp, et al., arXiv:2210.04702 (2022)

Q 22: Poster II

Time: Tuesday 16:30–19:00 Location: Empore Lichthof

Q 22.1 Tue 16:30 Empore Lichthof

Conformal duality of Bose-Einstein condensates with two- and three-body interactions — •David Reinhardt[1], Matthias Meister[1], Dean Lee[2], and Wolfgang P. Schleich[3] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Michigan State University, Department of Physics and Astronomy, East Lansing, Michigan, USA — [3]Institute of Quantum Physics, Ulm University, Ulm, Germany

It is well known that the eigenstates of nonlinear quantum systems (e.g. Bose-Einstein condensates described by the Gross-Pitaevskii equation) differ from those of the linear Schrödinger equation [1]. For instance, solitons only occur in nonlinear systems. When additionally considering three-body interactions new solution types emerge [2]. By analyzing the different solution spaces, we find that there exists a conformal duality between systems with two- and three-body interactions. This allows to predict the properties in the three-body case by means of the two-body case. For example, irregular two-body solutions can become bound solutions when including three-body interactions.

[1] L. D. Carr et al., PRA 62, 063610 (2000).
[2] H. Schürmann, PRE 54, 4312 (1996).

Q 22.2 Tue 16:30 Empore Lichthof

Matter-wave lensing of shell-shaped Bose-Einstein condensates — •Patrick Boegel[1], Alexander Wolf[2], Matthias Meister[2], and Maxim Efremov[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89081 Ulm, Germany — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, D-89081 Ulm, Germany

Motivated by the recent experimental realization [1] of ultracold quantum gases in shell topology, we propose a straightforward implementation of matter-wave lensing techniques for shell-shaped Bose-Einstein condensates. This approach allows to significantly extend the observation time of the condensate shell during its free expansion and enables the study of novel quantum many-body effects on curved geometries. With both analytical and numerical methods, we derive optimal parameters for realistic lensing schemes to conserve the shell shape of the condensate for times up to hundreds of milliseconds [2].

This project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under Grants Nos. 50WM1862 and 50WM2245B.

[1] Nature 606, pages 281-286 (2022)
[2] P Boegel, et. al, arXiv:2209.04672

Q 22.3 Tue 16:30 Empore Lichthof

Understanding the dynamics of quantum mixtures for dual species atom interferometry in space — •Priyanka Guggilam.L[1], Jonas Böhm[1], Baptist Piest[1], Ernst Rasel.M[1], and the MAIUS team[1,2,3,4,5,6] — [1]Instiut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]FBH Berlin — [4]DLR Instiut für Raumfahrtsysteme, Bremen — [5]Instiut für Physik, HU Berlin — [6]Instiut für Quantenoptik, Universität Mainz

The MAIUS (Matter wave interferometry under microgravity) project aims to demonstrate atom interferometry in space as a promising tool for precision measurements, e.g., of Einstein's equivalence principle (EEP), with accuracies that couldn't be achieved with classical tests. With the launch of MAIUS-1, it was possible to create the first BECs in space using Rb-87 atoms and performing interference experiments with these macroscopic quantum objects. In the MAIUS-2/3 missions, we concentrate on the understanding of the dynamics of K-41 and Rb-87 quantum mixtures in microgravity and to utilize them as sources for dual species atom interferometry in space. This contribution focuses on the mission goals, simulation results of quantum mixture density profiles, transport of mixtures considering gravitational effects and preparation of mixtures using delta-kick cooling for further reduction of the momentum spread. These techniques are important prerequisites to perform EEP tests with BECs created on an atom chip under microgravity. The MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

Q 22.4 Tue 16:30 Empore Lichthof

Non-equilibrium steady states of driven dissipative quantum gases beyond ultraweak coupling — •Adrian Köhler, André Eckardt, and Alexander Schnell — TU Berlin, Berlin, Deutschland

The microscopic description of ideal quantum gases in presence of a finite coupling to a heat bath poses a theoretical challenge. Even though the system itself is non-interacting, the system-bath coupling is cubic in the field operators making the problem interacting. As a first step, we study the mean-field dynamics of the single-particle density matrix under the Redfield quantum master equation. We find that typical steady-state solvers converge only in a very limited parameter regime, forcing one to rely on numerically more costly time-integration. We also discuss approaches to overcome this problem using perturbation theory in the coupling strength. We apply our approach to a Bose gas coupled to two baths of different temperature, for which in the regime of ultraweak coupling Bose condensation is predicted also in cases, where both bath temperatures lie well above the equilibrium crtitical temperature [PRL 119, 140602]. In the regime of finite coupling, we find that steady-state solutions of the Redfield quantum master equation form a condensate in the ground state.

Q 22.5 Tue 16:30 Empore Lichthof

Compressibility and the equation of state of an optical quantum gas in a box — •Leon Espert Miranda, Erik Busley, Andreas Redmann, Christian Kurtscheid, Kirankumar Karkihalli Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Germany

The compressibility of a medium, quantifying its response to mechanical perturbations, is a fundamental quantity determined by the equation of state. For gases of material particles, studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases. Here we demonstrate a measurement of the equation of state as well as the compressibility of a homogeneously trapped two-dimensional quantum gas of light inside a nanostructured dye-filled optical microcavity. Upon reaching quantum degeneracy we observe signatures of Bose-Einstein condensation in the finite-size system, causing a sharp increase of the density response to an external force, hinting at the infinite compressibility of the uniform two-dimensional Bose gas.

Q 22.6 Tue 16:30 Empore Lichthof

Bath engineering in atomic quantum gas mixtures — •Lorenz Wanckel, Alexander Schnell, and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, 10623 Berlin, Germany

Periodically driven isolated quantum systems usually heat up over time to the infinite temperature state via resonant excitation. For open driven systems, which are allowed to dissipate energy into a thermal bath, there is a non-equilibrium steady state, which is determined by the details of driving and dissipation. Appropriate engineering of the system and bath parameters can lead to interesting system states. We investigate theoretically a one-dimensional ideal Bose gas, which is locally driven and globally coupled to a three dimensional thermal bath, given by a second species of atoms. We explore the spectral densities for various baths, fermionic and bosonic, and show that the interplay of driving and dissipation can induce Bose condensation in the ground state or some excited state at bath temperatures well above the crossover temperature, at which Bose condensation would occur as a finite size effect in the system. Our analysis, which is based on a microscopic model that is solved using Floquet-Born-Markov theory, can be used to probe the results in a realistic experiment.

Q 22.7 Tue 16:30 Empore Lichthof

Vortex Motion and Annihilation in Holographic Superfluids — Paul Wittmer[1,2], Christian-Marcel Schmied[2,3], •Martin Zboron[3], Thomas Gasenzer[1,2,3], and Carlo Ewerz[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

Gauge-gravity duality establishes a connection between strongly correlated quantum systems and higher-dimensional gravitational theories at weak coupling. In general, finding the quantitative parameters of the quantum system thus described is challenging. We numerically simulate dynamics of generic vortex configurations in the holographic superfluid in two and in three spatial dimensions and match to these the corresponding dynamics resulting from the dissipative Gross-Pitaevskii equation. Excellent agreement between the vortex core profiles and their trajectories in both frameworks is found, both in two and three dimensions. Comparing our results to phenomenological equations for point- and line-like vortices allows us to extract friction parameters of the holographic superfluid. The parameter values suggest the applicability of two-dimensional holographic vortex dynamics to strongly coupled Bose gases or Helium at temperatures in the Kelvin range, effectively enabling experimental tests of holographic far-from-equilibrium dynamics.

Q 22.8 Tue 16:30 Empore Lichthof

Dynamical phases in an atom-cavity system: From time crystals to dark states — •Jim Skulte[1,2], Phatthamon Kongkhambut[1], Richelle J.L. Tuquero[3], Hans Kessler[1], Jayson G. Cosme[3], Andreas Hemmerich[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

Ultracold atoms placed inside a high finesse optical cavity, which are continuously pumped or periodically driven display very rich phase diagrams. We specifically discover non-equilibrium phases called time crystals emerging in this platform. Time crystals are classified as discrete or continuous depending on whether they spontaneously break discrete or continuous time translation symmetry. First, we study an emergent limit cycle phase for a blue-detuned pump and show that this state can be classified as a continuous time crystal [1]. On the other hand, phase shaking of the pump beam can be used to map the system onto a parametrically driven dissipative three-level Dicke model [2]. For weak driving this leads an incommensurate time crystal, while for strong driving this state is only metastable and relaxes into a dark state [3]. [1] P. Kongkhambut et al., Science 377, 6606 (2022)

[2] J. Skulte et al., PRA 127, 253601 (2021)

[3] J. Skulte et al., arXiv:2209.03342 (2022)

Q 22.9 Tue 16:30 Empore Lichthof

Dynamical light-matter phases in an atom-cavity platform — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Institut für Laser-Physik, Universität Hamburg — [2]National Institute of Physics, University of the Philippines

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the very small field decay rate ($\kappa/2\pi$ = 3.5 kHz), which is in the order of the recoil frequency ($\omega_{rec}/2\pi$ = 3.6 kHz). This leads to a unique situation where cavity field evolves with the same time scale as the atomic density distribution. Pumping the system with a steady state light field, red detuned with respect to the atomic resonance, the Dicke model is implemented including the self-organisation phase transition. Starting in the self-ordered superradinat phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry-broken states [1]. Modulation of the phase of the pump field give rise to an incommensurate time crystalline behaviour [2]. For a blue-detuned pump light with respect to the atomic resonance, we observe limit cycles. Since the used pump protocol is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry[3]. [1] H. Keßler et al., PRL 127, 043602 (2021), [2] P. Kongkhambut et al., PRL 127, 253601 (2021), [3] P. Kongkhambut et al., Science 377, 6606 (2022).

Q 22.10 Tue 16:30 Empore Lichthof

Vortex splitting, not stirring — •Lars Arne Schäfer — Institut für angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, D-64289 Darmstadt

We examine Bose-Hubbard ring systems in two dimensional configurable arrays of dipole potentials [1]. This is an example for an atomtronics device [2]. Here, an individual small ring with few sites and few particles acts like an artificial atom with a clearly resolved spectrum. We analyze the single-particle spectrum in terms of eigenfunctions of the Hamiltonian operator as well as the discrete translational symmetry of the 1-D lattice. Coupling two or more of such systems creates a quantum network.

It is experimentally feasible to create controllable time-dependent on-site optical potentials by means of electronic wavefront manipulation (DMD, SLD) and microlens arrays. In contrast to phase imprinting, we study two counter-propagating lattice potentials to create persistent currents or vortices of few bosons. This is in analogy to Bragg matter-wave splitters for linear momentum states [3]. Finally, we study the efficiency for pulsed splitting of many-body states into vortex-anti-vortex pairs.

[1] M. R. Sturm et al., Phys. Rev. A, **95**, 063625 (2017)

[2] R. Dumke et al., J. Opt., **18**, 093001 (2016)

[3] A. Neumann, M. Gebbe, and R. Walser, Phys. Rev. A, **103**, 043306 (2021)

Q 22.11 Tue 16:30 Empore Lichthof

Constructing a matter-wave microscope for lithium atoms featuring a highly tunable optical lattice — •Mathis Fischer, Nora Bidzinski, Justus Brüggenjürgen, Luca Asteria, Henrik Zahn, Marcel Kosch, Klaus Sengstock, and Christof Weitenberg — Institut für Laserphysik, Universität Hamburg, Germany

Imaging is crucial for gaining insight into physical systems. In the case of ultracold atoms in optical lattices, quantum gas microscopes have revolutionized the access to quantum many-body systems by detecting single particles. However they are limited to investigating 2D systems and are technically demanding. We have developed the novel technique of matter-wave microscopy that allows for a magnification of an atomic sample that can then be imaged using standard absorption imaging techniques. This enables sub-lattice resolution of single lattice-sites and imaging of coherence properties in 3D systems even with rather low-resolution imaging setups. In addition, we have introduced a novel lattice setup with a highly stable and dynamically controllable lattice geometry. The interference of three laser beams is suppressed by detuning their frequencies and then pairwisely reestablished by imprinting sidebands onto each beam. This setup allows us to use the same beams as a dipole trap, which we can employ as a confining potential during matter-wave optics and for creating BECs. We are currently upgrading our lithium machine to combine these developments with the precise control over the interaction strength using Feshbach resonances. In the future, we plan to implement single particle sensitive imaging to study intriguing many-body systems.

Q 22.12 Tue 16:30 Empore Lichthof

Towards a K39 Quantum gas microscope — •Ruben Erlenstedt[1], Scott Hubele[1,2], Martin Schlederer[1,2], Alexandra Mozdzen[1,2], Guillaume Salomon[1,2], and Henning Moritz[1,2] — [1]Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland — [2]Cluster of Excellence: CUI - Advanced Imaging of Matter

Ultracold atoms offer unique opportunities for studying quantum magnetism due to the tunability of the interaction strength as well as the tunneling parameters in optical lattices. In recent years, we have built a setup able to cool 39K atoms to Bose-Einstein condensation and to image them with a high resolution (NA=0.7) using an in-vacuo objective. Together with a brief overview of the machine, I will present the progress of my master's thesis towards realising the 'science' optical lattices that will be used for the realization of Hubbard models as well as near resonant 'pinning' optical lattices that will be used for single atom sensitive imaging.

Q 22.13 Tue 16:30 Empore Lichthof

A functional renormalization group approach to non-thermal fixed points in an ultracold Bose gas — •Aleksandr N. Mikheev[1,2], Jan M. Pawlowski[2,3], and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]ExtreMe Matter Institute EMMI, GSI, Planckstraße 1, 64291 Darmstadt, Germany

Classification and understanding of scaling solutions in closed quantum systems far from thermal equilibrium, known as non-thermal fixed points, is one of the open problems in non-equilibrium quantum many-body theory. The usual method involves searching for possible self-similar solutions to a (non-perturbative) evolution equation, e.g., Boltzmann or Kadanoff-Baym, starting from a far-from-equilibrium initial condition. We outline an alternative approach based on the correspondence between scaling and fixed points of the renormalization group. Using an ultracold Bose gas as an example we show how possible far-from-equilibrium scaling solutions can be systematically obtained by solving fixed-point renormalization-group equations.

Q 22.14 Tue 16:30 Empore Lichthof

Non-thermal fixed points of universal sine-Gordon coarsening dynamics — Philipp Heinen[1], Aleksandr N. Mikheev[1,2], Christian-Marcel Schmied[1], and •Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

We examine coarsening of field-excitation patterns of the sine-Gordon (SG) model, in two and three spatial dimensions, identifying it as universal dynamics near non-thermal fixed points. The focus is set on the non-relativistic limit, governed by a Schrödinger-type equation with Bessel-function nonlinearity. The results of our classical statistical simulations suggest that, in contrast to wave turbulent cascades, in which the transport is local in momentum space, the coarsening is dominated by rather non-local processes corresponding to a spatial containment in position space. The scaling analysis of a kinetic equation obtained with path-integral techniques corroborates this numerical observation and suggests that the non-locality is directly related to the slowness of the scaling in space and time. Our methods, which we expect to be applicable to more general types of models, could open a long-sought path to analytically describing universality classes behind domain coarsening and phase-ordering kinetics from first principles, which are usually modelled in a near-equilibrium setting by a phenomenological diffusion-type equation in combination with conservation laws.

Q 22.15 Tue 16:30 Empore Lichthof

A sodium potassium mixture experiment for simulating polaron physics — •Jan Kilinc, Lilo Höcker, Lorenz Hahn, Joris Hoffmann, Maurus Hans, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, Heidelberg, Deutschland

The motion of quantum impurities in a Bose-Einstein condensate (BEC) is an exemplary many-body phenomenon and a theoretical challenge especially in the regime of strong interactions between the impurities and the BEC. In the experiment such a Polaron problem can be studied using an atomic mixture, where one species realizes the impurity, while the BEC is realized with the other species. The interaction can be controlled by sizeable inter-species Feshbach resonances between sodium and potassium. In this poster, we present the current status of our sodium potassium experiment.

Q 22.16 Tue 16:30 Empore Lichthof

Non equilibrium dynamics of bosons populating higher bands of an optical lattice — •José Vargas[1,2], Car Hippler[1], and Andreas Hemmerich[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany — [2]The hamburg center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We experimentally and theoretically explore from single-particle to many-body dynamics of a Bose-Einstein condensate populating higher bands of an optical lattice. Topics such as Bloch-oscillations along different paths over each addressable Brillouin zone of the lattice, pair-tunneling phenomenon, and recondensation dynamics are investigated.

Q 22.17 Tue 16:30 Empore Lichthof

Effective Model of Phase Excitations in a 1D Spin-1 BEC Far from Equilibrium — Ido Siovitz, •Hannes Köper, Aleksandr Mikheev, Philipp Heinen, Stefan Lannig, Yannick Deller, Helmut Strobel, Markus Oberthaler, and Thomas Gasenzer — Kirchhof Institut für Physik, Universität Heidelberg, Heidelberg, Deutschland

The spin-1 Bose gas quenched far from equilibrium to the easy-plane shows a plethora of interesting phenomena, of which we discuss the universal spatio-temporal self-similar scaling on account of the system's vicinity to an hypothesized non-thermal fixed point. The appearance of topological excitations, such as instantons, in the transversal spin degree of freedom during the equilibration process of the condensate leads to a varying length scale, reflecting the self-similar scaling of correlations. Due to the multitude of degrees of freedom in the spin-1 BEC, the causes of the system's behavior far from equilibrium are difficult to investigate.

We present a low-energy effective field theory to describe the dynamics of the system and find the driving mechanism behind the production of such topological objects in the system. We show that the effective model presents the same self similar scaling behavior of the full spin-1 Bose gas quenched to the easy-plane phase.

Q 22.18 Tue 16:30 Empore Lichthof

Stability analysis of a periodically driven ultra-cold Bose gas — •Larissa Schwarz, Simon B. Jäger, Dimo Claude, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, D-67663, Kaiserslautern, Germany

We theoretically study the dynamics of a Bose-Einstein condensate under periodic driving of the s-wave scattering length. In this setup, we first determine the stability of the condensate using Bogoliubov theory with time-periodic modulation. We find an exponential gain in the resonant k-modes due to a parameteric amplification which leads to a rapid condensate depletion. These findings are compared with the simulation of the Gross-Pitaevskii equation which shows the formation of a density-wave pattern with the predicted k-wavevector. We extend the Bogoliubov theory by including non-linearities which result in an effective damping of the k-modes. This enables the creation of stable density-wave pattern below a critical driving strength. Moreover, above this critical driving strength we analyze simple non-quadratic models and find macroscopic and stable occupation of the resonant k-mode.

Q 22.19 Tue 16:30 Empore Lichthof

Study of a matter wave neural network — •Moritz Sträter, Niklas Käming, Klaus Sengstock, and Christof Weitenberg — Universität Hamburg (UHH), Hamburg, Deutschland

Machine learning and neural networks have proven a powerful tool for studying quantum many-body physics. Moreover, the search for new architectures and implementations of neural networks building on optical or quantum hardware is an ongoing research topic.

In this poster, we present the progress on the evaluation of a new concept of a matter-wave neural network based on the coherent coupling of momentum modes of a BEC. We study the effects of interactions on the capacity and performance of the network for example classification tasks.

In the future, we hope to find and quantify a possible advantage of coherence, non-linearities and quantum correlations for generic classification tasks, which are offered in such cold-atom hardware.

Q 22.20 Tue 16:30 Empore Lichthof

A Rydberg Atom in a BEC — •Aileen A. T. Durst and Matthew T. Eiles — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

A Rydberg atom immersed in a BEC has many extreme interaction features. While the interaction between one of the BEC particles and its neighbors is typically short-ranged compared to other length scales in the condensate, the range of the interaction of the enormous Rydberg impurity and the surrounding bath particles is comparable to or even larger than the mean interparticle distance in the gas. Furthermore, this interaction potential is highly oscillatory and can support multiple bound states. These properties complicate the theoretical description and analysis of the Rydberg impurity, whose interaction potential cannot be replaced in general by a contact pseudopotential. We relate the Rydberg impurity problem to other impurity problems by characterizing it by the number of bound states and, equivalently, the Rydberg-bath particle scattering length, and in this way investigate in which parameter regions the system exhibits quasiparticle character.

Q 22.21 Tue 16:30 Empore Lichthof

Pattern formation and symmetry breaking in a periodically driven 2D BEC — •Nikolas Liebster[1], Marius Sparn[1], Elinor Kath[1], Maurus Hans[1], Keisuke Fujii[2], Sarah Görlitz[2], Helmut Strobel[1], Tilman Enss[2], and Markus Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Heidelberg, Germany — [2]Institut für Theoretische Physik, Heidelberg, Germany

Dynamical pattern formation is a ubiquitous phenomenon in nature, and has relevance in many fields in physics. The emergence of these patterns, as well as how symmetries are broken, remains an open field of research in quantum physical systems. By periodically driving the scattering length in a 2D potassium-39 Bose-Einstein condensate, we use parametric resonance to non-linearly populate specific momentum modes of trapped condensates. We show the emergence of randomly oriented standing waves with D4 symmetry and investigate the effects of background density distributions on the formation of patterns on the condensate.

Q 22.22 Tue 16:30 Empore Lichthof

BKT Physics for Bose Gas in 2D Box — •Til Möhnen and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

For a two-dimensional Bose gas a Berezinskii-Kosterlitz-Thouless (BKT) transition from a superfluid phase of bound vortex-antivortex pairs to a normalfluid phase of unpaired vortices and antivortices occurs at a critical temperature, which is determined by the Nelson criterion. Here we analyze the finite-size effects of this phase transition by considering a Bose gas in a two-dimensional box. To this end we derive the underlying renomalization-group equations, which describe the screening of both the condensate and the superfluid density due to the presence of vortices and antivortices. Their solution for the parameters of the recent experiment [1] allows to quantify the impact of finite-size effects in terms of the condensate fraction. Furthermore, in the thermodynamic limit we obtain a vanishing condensate density in accordance with the Mermin-Wagner-Hohenberg theorem and we reproduce the universal BKT jump of the superfluid density at the critical temperature.

[1] P. Christodoulou et al., Nature **594**, 191 (2021)

Q 22.23 Tue 16:30 Empore Lichthof

Quantum many-body scars in a Bose-Hubbard quantum simulator — •Guoxian Su[1], Jean-Yves Desaules[2], Ana Hudomal[2,3], Aiden Daniel[2], Jad Halimeh[4], Zhen-Sheng Yuan[5], Jian-Wei Pan[5], and Zlatko Papic[2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, UK — [3]Institute of Physics Belgrade, University of Belgrade, 11080 Belgrade, Serbia — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, D-80799 München, Germany — [5]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Quantum many-body scarring is a phenomenon where a chaotic system prepared in special initial conditions exhibits long-lived oscillations. It presents a novel mechanism for delaying the onset of thermalization. We realize many-body scars in a Bose-Hubbard quantum simulator, which hosts an abundance of scar states. We show the slowed growth of entanglement entropy in scarred dynamics. And we investigate the ubiquity of scarring and its interaction with quantum criticality. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments and enables the study of such phenomena in fundamental physics such as lattice gauge theories.

Q 22.24 Tue 16:30 Empore Lichthof

Entropy extraction in spinor Bose gases — •Yannick Deller[1], Moritz Reh[1], Stefan Lannig[1], Alexander Schmutz[1], David Feiz[1], Helmut Strobel[1], Martin Gärttner[1,2,3], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Physikalisches Institut, Universität Heidelberg — [3]Institut für Theoretische Physik, Universität Heidelberg

The concept of entropy plays an important role for quantum informational properties of many-body systems. However, experimental extraction of entropies is in general a challenging task due to the rapid increase of the Hilbert space dimension with system size.

As our testbed we use a spin-1 Bose-Einstein condensate of rubidium in a tight optical trap, where we routinely generate non-classical spin states by quantum dynamics after a parameter quench. With a generalized POVM protocol [1], we are able to simultaneously measure two non-commuting spin observables. We extract an entropy using distributions of experimental repetitions with a statistical estimator, that avoids binning and coarse-graining of the data. We discuss how to extend these techniques to multiwell-systems with tunnel-coupling between the wells.

[1] Kunkel et. al., PRL 123, 063603 (2019)

Q 22.25 Tue 16:30 Empore Lichthof

Observation of edge states in topological Floquet systems — •Johannes Arceri[1,2], Christoph Braun[1,2,3], Alexander Hesse[1,2], Raphaël Saint-Jalm[1,2], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, München — [2]Munich Center for Quantum Science and Technology (MCQST), München — [3]Max-Planck-Institut für Quantenoptik, Garching

Floquet engineering, i.e., periodic modulation of a system's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. In particular, the so-called anomalous Floquet phase displays topological properties even if the Chern number of the bulk band vanishes. [1]

Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, including an anomalous phase. [2]

As the bulk-boundary correspondence relates the properties of the bulk bands to the number of topologically protected edge modes, special interest lies in studying the behavior of them. We are investigating the real-space evolution of a wavepacket close to the edge after the release from a tightly-focused optical tweezer. This way, we observe the chiral nature of the edge state, even in the anomalous Floquet phase, thereby directly revealing the topological nature of this phase.

[1] Rudner et al., Phys. Rev. X 3, 031005 (2013)
[2] Wintersperger et al., Nat. Phys. 16, 1058-1063 (2020)

Q 22.26 Tue 16:30 Empore Lichthof

Self-oscillating pump in a topological dissipative atom-cavity system — •Justyna Stefaniak, Davide Dreon, Alexander Baumgaertner, Simon Hertlein, Xiangliang Li, Tobias Donner, and Tilman Esslinger — ETH Zurich

Pumps are transport mechanisms in which direct currents result from a cyclic evolution of the potential. As Thouless showed, the pumping process can have topological origins, when considering the motion of quantum particles in spatially and temporally periodic potentials. However, the periodic evolution that drives these pumps has always been assumed to be imparted from outside, as has been the case in the experimental systems studied so far. Here we report on an emergent mechanism for pumping in a quantum gas coupled to an optical resonator, where we observe a particle current without applying a periodic drive. The pumping potential experienced by the atoms is formed by the self-consistent cavity field interfering with the static laser field driving the atoms. Owing to dissipation, the cavity field evolves between its two quadratures, each corresponding to a different centrosymmetric crystal configuration. This self-oscillation results in a time-periodic potential analogous to that describing the transport of electrons in topological tight-binding models, such as the paradigmatic Rice*Mele pump. In the experiment, we directly follow the evolution by measuring the phase winding of the cavity field with respect to the driving field and observing the atomic motion in situ. The observed mechanism combines the dynamics of topological and open systems, and features characteristics of continuous dissipative time crystals.

Q 22.27 Tue 16:30 Empore Lichthof

Stability and vulnerability of quantum gases along the BEC-BCS crossover with quenched disorder — •Felix Lang, Jennifer Koch, Sian Barbosa, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Quantum fluids in the so-called BEC-BCS crossover show very different microscopic pairs underlying the superfluid. This changing pairing might also change the response to perturbations of the system. We investigate the response of a molecular BEC and of a resonantly interacting Fermi gas to quenches into and out of an optical disorder potential. We monitor the response of the in-situ density distribution as well as the ability for hydrodynamic expansion, which we interpret as a measure of long-range phase coherence. Concerning the latter, we find that the BEC recovers hydrodynamic expansion after disorder quenches on time scales which can be related to energy scales in the system, whereas the unitary Fermi gas permanently loses its ability for hydrodynamics. We attribute this observation to an efficient breaking of Fermi pairs in the BEC-BCS crossover. Our work sheds light on the mechanisms underlying the superfluid pairing in interacting Fermi gases.

Q 22.28 Tue 16:30 Empore Lichthof

Report on an Erbium-Lithium machine — Florian Kiesel and •Alexandre De Martino — Eberhard Karls Universität Tübingen, Physikalisches Institut AG Groß, Auf der Morgenstelle 14, 72076 Tübingen

Ultracold Fermions cannot be cooled below about 10% of the Fermi temperature with conventional methods. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Here we report on the construction and implementation of first cooling stages of a two species apparatus for the optimized symp. cooling of fermionic Li with bosonic Er. This mixture has several promising features, that have not yet been utilized for symp. cooling in any other mixture. Pushing the temperature limit is essential for the quantum simulation of strongly correlated phenomena, in particular in optical lattice.

Q 22.29 Tue 16:30 Empore Lichthof

Towards quantum simulation with strontium atoms — •Thies Plassmann[1,2], Meny Menashes[1], Leon Schaefer[1], and Guillaume Salomon[1,2] — [1]Institute of Laserphysics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg, Germany

Individually controlled ultracold atoms in programmable potential landscapes have emerged as powerful systems to explore exotic states of matter in highly-correlated quantum many-body systems.

We are currently building a new quantum simulation platform based on strontium atoms. We will report on the building of our experimental apparatus designed for short cycle times and quantum gas microscopy with single particle as well as single spin resolution. By combining optical lattices with programmable optical tweezers, we aim to study the Fermi-Hubbard model and frustrated quantum magnetism with atoms trapped in tunable 3D potentials and excited to Rydberg states.

Q 22.30 Tue 16:30 Empore Lichthof

Pair correlations in a strongly interacting two-component Fermi gas — •Manuel Jäger and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Deutschland

We study pair correlations in a two-component fermionic system. In particular we investigate the crossover from a Bardeen-Cooper-Schrieffer (BCS) superfluid of loosely bound Cooper pairs to a Bose-Einstein condensate (BEC) of tightly bound dimers.

For studying this system experimentally, we use a spin-balanced mixture of the two lowest ^{6}Li Zeeman states and set their interaction strength by means of the Feshbach resonance at 832 G. We then perform photoexcitation of the pairs at various temperatures and interaction strengths. The photoexcitation induces a two-body loss in our system. From analyzing the loss rate we obtain Tan's contact.

Our measurements of the two-body contact extend previously reported measurements and calculations carried out at low temperatures and at unitarity. Moreover, we find that our results above 0.5 T_F can be well described by the second order quantum virial expansion in the whole BCS-BEC crossover.

Q 22.31 Tue 16:30 Empore Lichthof

Solving the Floquet matrix for driven optical lattices — •Anna Lena Hauschild, Niklas Köming, Corinna Menz, Christof Weitenberg, and Klaus Sengstock — Institute for Laser Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Ultra cold atoms in optical lattices are a highly-tunable system for quantum emulation of many body physics in solid state systems. By changing the setup of a driven lattice system, different band structure can be studied. In our project we want to build a numerical simulation of driven lattice systems.

Here we implement the Floquet matrix method, which gives a time independent matrix working with modified copies of the base Hamiltonian. In comparison to other relevant methods such as direct time evolution of tight-binding models, the computational effort of this method is higher, but due to less approximation it is in certain cases more accurate.

For the Floquet matrix method the resulting bands will not be ordered correctly: For intersecting bands we investigate the eigenstates and their properties around the point of intersection for the correct assignment. With this project we want so be able to find topological properties of the system and a preparation for experimental implementation.

Q 22.32 Tue 16:30 Empore Lichthof

Observation of Chiral Edge Current Suppression for Strongly Interacting Fermions in Hall Ladder Systems — •Marcel Diem[1], Tobias Petersen[1], Nejira Pintul[1], Benjamin Abeln[1], Koen Sponselee[1], Oscar Murzewitz[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institute for Laserphysics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg

Ultracold quantum gases of neutral atoms are an excellent platform for quantum simulation of Hall physics due to their ability to implement artificial gauge fields and, thus, to mimic the physics of charged particles in strong magnetic fields.

Here, we present the experimental realization of 2D Hall ladder systems in one real and one synthetic dimension and study edge currents for two ultracold fermionic ytterbium isotopes to access the role of interactions in topologically non-trivial systems. One isotope, ^{171}Yb, is non-interacting, whereas the isotope ^{173}Yb interacts repulsively. We use Raman beams to couple states with different m_F quantum number and momentum. This coupling gives rise to a strong artificial magnetic field, which is essential for the quantum Hall effect.

We observe a significant suppression of chiral edge currents for strongly interacting fermions in direct comparison to non-interacting fermions. Our work paves the way towards a better understanding of interaction effects in Hall systems.

Q 22.33 Tue 16:30 Empore Lichthof

Heidelberg Quantum Architecture: Fast and modular quantum simulation — •Tobias Hammel, Maximilian Kaiser, Vivienne Leidel, Micha Bunjes, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Heidelberg, Germany

More is always better. This is especially true when talking about the amount of data a Quantum Simulator can produce in a given time. The reason why is multilayered, ranging from the achievable signal-to-noise ratios in data demanding experiments, over the requirements on stability during an experimental run, to aspects of ease of use and debuggability.

This experiment aims at cycle rates of up to 10 cycles per second, possibly bridging the gap to programmable, on-demand quantum simulation. The key bottlenecks that are addressed in this newly build Lithium-6 machine are a reduction of MOT loading times and a high speed thermalization into an optical dipole trap.

Modularly exchangeable optical setups including an accordion lattice, a DMD and a dark ODT paired with various characterization modules enable the simulation of a variety of physical systems. Initially, the main focus will be on the fast preparation of few-fermion systems with high fidelities.

Q 22.34 Tue 16:30 Empore Lichthof

Ultracold Fermi Gases in Box Potentials — •Rene Henke, Hauke Biss, Cesar Cabrera, Lennart Sobirey, Niclas Luick, and Henning Moritz — Institute of Laserphysics, University of Hamburg, Hamburg, Germany

In the past years, our group has managed to create homogeneous ultracold Fermi gases of ^{6}Li atoms, both in 2D and 3D trap geometries. Using Bragg spectroscopy, we measured the excitation spectrum in a momentum resolved fashion. This allowed us to observe superfluidity in the BEC-BCS crossover, to extract the superfluid gap and to compare 2D and 3D systems directly.

This poster will review some of these results and present our progress towards creating spin imbalanced mixtures in two dimensions. For these, many questions still remain unanswered, especially concerning the nature of a potential spin-polarized superfluid. One of the key questions in these systems is, whether the theoretically predicted but elusive FFLO phase exists. In this phase, fermions are theorized to form Cooper pairs with finite total momentum, due to the different Fermi momenta of spin majority and minority. More accessible open questions are whether a partially polarized superfluid can be observed in general, how stable it is and whether the transition between fully paired superfluid and partially polarized Fermi gas is of first or higher order.

Q 22.35 Tue 16:30 Empore Lichthof

Engineering of lattice models with local control in fermionic quantum gas microscopes — •Si Wang[1,2], Sarah Hirthe[1,2], Dominik Bourgund[1,2], Petar Bojovic[1,2], Thomas Chalopin[1,2], Immanuel Bloch[1,2,3], and Timon Hilker[1,2] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Ludwig Maximilian University of Munich, Munich, Germany

Quantum simulation of ultracold atoms is a powerful tool for investigating long-standing problems in condensed matter physics. Our quantum gas microscope allows us to study the exotic phases of the Fermi-Hubbard model with single-site density and spin resolution. Furthermore, our recently implemented bichromatic superlattices, together with digital micromirror devices (DMDs) in real and Fourier space, open the possibility for the realization of collisional gates with individual site control.

Q 22.36 Tue 16:30 Empore Lichthof

Towards fast, deterministic preparation of few-fermion states — •Vivienne Leidel, Tobias Hammel, Maximilian Kaiser, Micha Bunjes, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

Heidelberg Quantum Architecture is a new experiment using ultracold Lithium-6 atoms aiming to achieve rapid cycle times of under one second. Among others, our approach is to speed up the MOT loading with more available laser power enabling the use of a high flux 2D MOT as well as a modular design with micrometer reproducibility.

In particular I will present setting up a laser lock to the Lithium-6 D2 transition using a modulation transfer scheme to ensure minimal drifts in frequency. An AOM Doublepass module enabling high stability and quick setup times is presented.

Physics in lower dimension often exhibits peculiar properties. Hence, we want to fine tune the dimentionality of the system using a miniaturized accordion lattice setup. It consists of two laser beams intersecting at a tunable angle. In this way controlling the spacing between the interference fringes, and therefore the strength of the confinement of our atoms.

Q 22.37 Tue 16:30 Empore Lichthof

Emergence of collective excitations in few Fermion systems — •Johannes Reiter, Philipp Lunt, Paul Hill, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Deutschland

The emergence of collective behaviour in strongly-interacting mesoscopic systems has been a long-standing question in nuclear and cold atom physics [1,2]. Our previously established technique to deterministically prepare few Fermion systems [3] in combination with the tunability of interactions in ultracold gases allows us to address this question. However, to observe clear signatures of elementary excitations in a strongly interacting few Fermion system precise control of the optical potential is required.

We present a refined version of phase shift interferometry [5] to detect wavefront aberrations on the atoms and compensate for them using a spatial light modulator.

Building on this, we study the quadrupole mode across the BEC-BCS crossover by means of spectroscopic probes. Tuning of the inter-particle interactions via a broad Feshbach resonance allows us to observe the transition from single-particle to collective excitations and varying the atom number enables us to observe the emergence of collective behaviour atom by atom.

[1] B. Mottelson *Science* 193 (4250), 287-294 (1976) [2] S. Giorgini et al. *Rev.Mod.Phys.* 80, 125 (2008) [3] F. Serwane et al. *Science* 332 (6027), 336-338 (2011) [4] L. Bayha et al. *Nature* 587.7835, 583-587 (2020) [5] P. Zupancic et al. *Optics express* 24.13, 13881-13893 (2016)

Q 22.38 Tue 16:30 Empore Lichthof

High-Resolution Optics for Modular Quantum Simulation — •Micha Bunjes[1], Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany) — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Heidelberg Quantum Architecture (HQA) is a new modular quantum simulator built to study the emergence of quantum phenomena in few to many-body systems.

At the heart of the custom-designed mounting structure lies a high-resolution objective acting as a fixed optical reference. To verify the performance enabled by the high numerical aperture, a modular test bench and a sub-resolution nanopore device are used to scan the point spread function of this objective across the entire field of view. In addition, the angle between the mechanical and optical axis is measured. Characterizing this system in detail enables an improved performance and counteract aberrations.

A crucial goal of HQA is an increased cycle rate, up to 10 cycles per second. To this end, a new proposal aims to accelerate the preparation of few-particle systems using a blue-detuned ring trap to increase local density and thermal scattering rate. After evaporation in this trap, the thermalization of atoms into a tight optical tweezer could be optimized. Two experimental solutions using axicons and Moiré lenses are explored.

Q 22.39 Tue 16:30 Empore Lichthof

Feshbach molecules in an orbital optical lattice — •Max Hachmann, Yann Kiefer, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We experimentally study strongly interacting degenerate Fermi gases exposed to an optical lattice. As a first benchmark, Kapitza-Dirac scattering at a 1D-optical standing wave is used to probe coherence properties of different atomic samples, including a strongly interacting Fermi gas spanning the whole BEC-BCS crossover regime. Adjusting the magnetic field in the vicinity of a Feshbach resonance allowed to create bosonic dimers formed by two fermionic 40K atoms, which are also studied in the optical lattice. Using a bipartite optical square lattice ultimately resulted in the successful selective population of higher Bloch bands, which are then analysed by means of a method resembling mass spectrometry. Binding energies and lifetimes in the second (first) Bloch band were extensively studied, where the longest lifetimes are observed at the onset of unitarity with values around 100ms(300ms). Our work prepares the stage for orbital BEC-BCS crossover physics.

Q 22.40 Tue 16:30 Empore Lichthof

Cavity-based Quantum Processor: Engineering Entanglement with Programmable Connectivity — •Marvin Holten, Stephan Roschinski, Johannes Schabbauer, Davide Natale, Giacomo Hvaring, Iris Haubold, Nicole Heider, Alexander Heiss, and Julian Leonard — Atominstiut, TU Wien, Austria

Entanglement is the fundamental resource for applications like quantum computation and communication beyond the possibilities of classical machines. Many current devices are limited to a small number of qubits if full connectivity between any two qubits independent of their spatial separation is required. Our goal is to investigate an alternative platform for quantum simulation and information processing with qubit full connectivity. The idea is to trap an array of individually addressable atoms inside an optical cavity. The photon-mediated interactions of the atoms in the cavity will enable us to introduce non-local couplings and entangling operations between any two atoms or qbits in the system. We will implement a non-destructive readout scheme that relies on injecting a few-photon field into the cavity. We plan to investigate in what ways the all-to-all connectivity of our quantum processor enables us to efficiently create highly entangled many-body ensembles, like GHZ states. Finally, we want to use the quantum processor to address longstanding questions about the thermalisation of closed quantum systems and information scrambling. With its scalability and fully programmable connectivity, our architecture has the potential to open up new pathways for a wide range of fields like quantum optimization, communication and simulation.

Q 22.41 Tue 16:30 Empore Lichthof

Preparation for the Integration of the BECCAL Laser System — •Marc Kitzmann[1], Victoria Henderson[1,2], Tim Kroh[1,2], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hrudya Thaivalappil Sunilkumar[1], Hamish Beck[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Achim Peters[1,2], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hannover — [5]DLR-SI, Hannover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR, Braunschweig

BECCAL (Bose-Einstein Condensate and Cold Atom Laboratory) is a cold atom experiment designed for operation on the ISS. It is a DLR and NASA collaboration, built on a heritage of sounding rocket and drop tower experiments, and NASA's CAL. This multi-user facility enables the exploration of fundamental physics with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales. In contrast to lab-based cold atom experiments, BECCAL must be operable without interference for three years on the ISS. To reach that goal and match the complexity of this space-based system to the stringent size, weight, and power limitations, we have to fulfill strict product assurance requirements for the laser system including higher cleanliness facilities and ESD protection. In this context, the planning and implementation of the specific lab setup and the first essential integration tests, using mock-ups, will be presented. This work is supported by the DLR with funds provided by the BMWK under grant numbers DLR 50WP1702, and 50WP2102.

Q 22.42 Tue 16:30 Empore Lichthof

A narrow linewidth and high power lasersystem for dual-species atom interferometry — •Wei Liu, Alexander Herbst, Henning Albers, Ashwin Rajagopalan, Knut Stolzenberg, Sebastian Bode, Ernst.M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The universality of free fall is one of the foundations of general relativity, which can be tested by observing the free falling of different test masses. The development of atom optics has allowed performing of quantum tests with dual-species atom interferometers. However trapping and cooling of different atomic species require lasers with different wavelengths, resulting in large and complex laser systems.

We present a new laser system capable of trapping and cooling ^{39}K, ^{41}K and ^{87}Rb. The system features high power and low maintenance by using frequency doubled C-band fiber lasers. We replace 11 external-cavity diode lasers and 8 tapered amplifiers with only 6 fiber lasers, remove all optical active components except acousto- and electro- optic modulators, and therefore simplify the laser system. On this poster we will describe the optical set up, characterisation measurements and the scheme of frequency stabilisation.

Q 22.43 Tue 16:30 Empore Lichthof

Rapid generation and number-resolved detection of spinor Rubidium Bose-Einstein condensates — Cebrail Pür[1], Mareike Hetzel[1], •Martin Quensen[1], Andreas Hüper[1,4], Jiao Geng[2,3], Wolfgang Ertmer[1,4], and Carsten Klempt[1,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]Key Laboratory of 3D Micro/Nano Fabrication and Characterization, School of Engineering, Westlake University, Zhejiang Province, China — [3]Institute of Advanced Technology, Westlake Institute for Advanced Study, Zhejiang Province, China — [4]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik (DLR-SI), Callinstraße 30b, D-30167 Hannover, Germany

High data acquisition rates and low-noise detection of ultracold neutral atoms present important challenges for high-precision atom interferometers that exploit the excellent mode quality of Bose-Einstein condensates. Here, we present a high-flux source of Rb-87 Bose-Einstein condensates combined with a number-resolving detection.

For the high-fidelity tomography of many-body quantum states in the spin degree of freedom, it is desirable to select a single mode for a number-resolving detection. We demonstrate the low-noise selection of subsamples with average atom numbers of up to 35 and their subsequent detection via accurate atom counting. The presented techniques offer an exciting path towards the creation and analysis of mesoscopic quantum states with unprecedented fidelities, and their exploitation for fundamental and metrological applications.

Q 22.44 Tue 16:30 Empore Lichthof

Light-induced correlations in ultracold dipolar atoms — •Ishan Varma, Marvin Proske, Dimitra Cristea, Nivedith Anil, and Patrick Windpassinger — Institute of Physics, JGU Mainz

Dysprosium is a fascinating candidate for studying cooperative and collective effects in dense ultra-cold media. With the largest ground-state magnetic moment of all elements in the periodic table (10 Bohr-magnetons), it offers a platform to study the effect on scattering of light due to competition between magnetic dipole-dipole interactions (DDI) and light induced correlations. In a sufficiently dense regime, the strong magnetic DDI significantly influence the propagation of light within the atomic sample. In particular, we want to look at signatures of collective light scattering phenomena like Super-radiance and Sub-radiance.

This poster reports on the progress made in generating dense samples of ultracold dysprosium atoms. We plan to optically transport atoms into a home-built science cell with high optical access. A high NA custom objective, designed and assembled in-house, will then be used to create dense atomic samples inside this cell. We evaluate the performance and discuss the installation of the custom objective in our experimental system. Further, an outlook is given on future measurements exploring collective and cooperative effects in the generated sample.

Q 22.45 Tue 16:30 Empore Lichthof

Two-dimensional grating magneto-optical trap — •Aaditya Mishra[1], Hendrik Heine[1], Joseph Muchovo[1], Julian Lemburg[1], Kai Bruns[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, D-30167 Hannover, Germany

Ultracold atoms provide exciting opportunities for precision measurements and testing fundamental physics. Two-dimensional(2D) magneto-optical traps(MOT) are advantageous in faster loading to 3D-MOTs and cooling more atoms. However, compact and power-efficient setups are essential in performing transportable experiments. In this poster, we will present a design of a two-dimensional grating magneto-optical trap (2D gMOT) requiring only a single input cooling beam. The cold atomic beam from the 2D gMOT will load atoms in a 3D gMOT implemented on an atom chip for efficient generation of BECs. This will lead to a robust, compact and efficient source of ultracold atoms that can be used in ground and space experiments.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate protection (BMWK) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II), DLR 50RK1978 (QCHIP) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 22.46 Tue 16:30 Empore Lichthof

Chip-Scale Quantum Gravimeter — •Julian Lemburg[1], Hendrik Heine[1], Joseph Muchovo[1], Aaditya Mishra[1], Kai Bruns[1], Ernst M. Rasel[1], Waldemar Herr[1,2], and Christian Schubert[1,2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, DLR-SI

Interferometers with Bose-Einstein condensates (BECs) enable a very precise measurement of inertial forces like gravity. Potential applications can be in ground and space-borne geodesy. A lower size, weight, and power consumption of these sensors can be realized by using atom chips. The latter enables the

creation of a high flux of delta-kick collimated BECs bringing in reach an unprecendented, low measurement uncertainty.
In this poster, we will present a concept to further reduce the sensor head to about shoe-box size. With a novel atom chip combined with the implementation of a relaunch scheme, an innovative single-beam quantum gravimeter is envisaged. The further miniaturization and reduction of complexity of the sensor head are the key features to improve the transportability and ease the in-field operation of the quantum gravimeter.
This work is funded by the German Research Foundation (DFG) in the CRC 1464 "TerraQ" (Project A03) and under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 22.47 Tue 16:30 Empore Lichthof

Realization of an optical accordion for ultracold atoms — •Carole Peiffer, Felix Lang, Sian Barbosa, Jennifer Koch, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

Optical lattices, created by the interference of two or more coherent and often far-detuned laser beams, are among the most established tools used to manipulate quantum gases. One special realization, the so-called optical 'accordion', promises enhanced flexibility: when changing the angle of the two interfering beams, the lattice constant changes, allowing control over the lattice spacings over a large range of values. We aim at realizing such an accordion setup using a beamsplitter, consisting of two custom Dove-prisms, glued together by a special UV-curing epoxy, in combination with a large focusing lens. When a single beam passes through the prism pair, it is split into two parallel rays, and their distance depends on the incidental beam's. After focussing by the lens onto the atom's position , interference creates the lattice potential. I will report the planning, construction and ex-situ characterization of an optical accordion which will be used to access lower dimensions in our setup with ultracold lithium-6 atoms.

Q 22.48 Tue 16:30 Empore Lichthof

A compact and robust fiber-based laser system for cold atom experiments in microgravity — •Janina Hamann[1], Jan Simon Haase[1], Jens Kruse[2], and Carsten Klempt[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, 30167 Hannover

Operating atom interferometers in space opens up the possibility of a further improved phase sensitivity due to prolonged interrogation times. Especially Bose-Einstein condensates (BEC) are suitable for zero-gravity interferometry due to their well-controlled spatial mode and slow expansion rate. To prepare cold atom experiments for space operation, microgravity facilities such as the Einstein-Elevator are used for ground testing. The generation and detection of a ^{87}Rb BEC in the Einstein-Elevator requires a laser system with a high frequency stability and robustness to 5 g accelerations and vibrations. We design a fiber-based laser system with a tuneable offset frequency stabilization that uses telecom components to ensure robustness. The rugged fiber-based setup is housed in a 19" crate, where fiber-based modulators generate an adjustable offset for the 780 nm laser and additional sidebands at several GHz. An atomic reference module is used for modulation transfer spectroscopy (MTS) on ^{85}Rb. We achieve a tuneable frequency stabilization with a frequency stability of 90 kHz that can perform frequency ramps of 300 MHz in milliseconds.

Q 22.49 Tue 16:30 Empore Lichthof

Laser systems for photoassociation spectroscopy of cold Hg-atoms — •Rudolf Homm and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Cold Hg-atoms in a magneto-optical trap offer opportunities for various experiments. The two stable fermionic isotopes are interesting with regard to a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. All stable isotopes can be used to form ultra-cold Hg-dimers through photoassociation in connection with vibrational cooling by applying a specific excitation scheme.

We will present our laser systems for photoassociation spectroscopy of cold Hg-atoms. The Hg-isotopes are preselected via a 2D-MOT and cooled in a 3D-MOT, while both are driven by the cooling laser system. It consists of a MOFA-Setup at 1014.8 nm followed by two consecutive frequency-doubling stages. The output power is over 900 mW at 253.7 nm without a sign of degradation in the BBO-crystal used in the second frequency-doubling stage, due to a cavity with elliptical focus in the crystal [1].

The setting of the spectroscopy laser system is quite similar to the cooling laser, while the aims are different. The output power needs to be only several dozen mW at the target wavelength of 254.1 nm, but the frequency tuning range of the system has to be much higher. We will report on the status of the experiments.

[1] Preißler, D., *et al.*, *Applied Physics B* **125** (2019): 220

Q 22.50 Tue 16:30 Empore Lichthof

Ultracold Bose gases in temporally and spatially modulated Potentials — •Marco Decker, Erik Bernhart, Marvin Röhrle, and Herwig Ott — Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau

We investigate Bose-Einstein condensates in spatially and temporally modulated potentials. This allows us to study quantum transport phenomena and quantum scattering problems.

To extend discrete models to continuum physics, we shift from lattice potentials to localized potentials in an optical trap. The potentials are projected onto the atoms with an objective inside the vacuum chamber, which is also used for absorption imaging. The atomic cloud can additionally be imaged via an electron column with high spatial resolution. Additionally, implementing two blue-detuned light sheets, we can furthermore change the trap geometry from 3D to quasi 2D.

Future studies will include time-dependent barriers and local dissipation via the electron column.

Q 22.51 Tue 16:30 Empore Lichthof

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2], Daniel Vadlejch[2], Tanja Mehlstäubler[2], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2,30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100,308116 Braunschweig, Germany

Crystals of ultracold trapped ions reach sizes of hundreds of individual particles and require high level of control over their motional temperature to account for the second-order Doppler shift in clocks and implement high-fidelity quantum gates in quantum computers. The existing thermometry tools fail to provide an accurate temperature estimation for large ground-state cooled crystals, either focusing only on the symmetric c.o.m. mode of motion or neglecting the involved spin-spin correlations between the ions.

To resolve the thermometry large-N bottleneck, we consider crystal many-body dynamics arising when motional sideband transitions are driven in a near ground-state regime, which is a widely used approach in thermometry of a single ion. To gain some valuable insights on the sideband thermometry method, we also address the single ion case and study it from the Fisher Information prospective.

Extending the approach further, we account for entanglement created between the ions in a crystal to derive a new reliable temperature estimator, insensitive to the number of ions, and field-test in experiments with 4- and 19-ion crystals done by colleagues from PTB and Innsbruck.

Q 22.52 Tue 16:30 Empore Lichthof

Invisible flat bands on a topological chiral edge — •Youjiang Xu, Irakli Titvinidze, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany

We prove that invisible bands associated with zeros of the single-particle Green*s function exist ubiquitously at topological interfaces of 2D Chern insulators, dual to the chiral edge/domain-wall modes. We verify this statement in a repulsive Hubbard model with a topological flat band, using real-space dynamical mean-field theory to study the domain walls of its ferromagnetic ground state. Moreover, our numerical results show that the chiral modes are split into branches due to the interaction, and that the branches are connected by invisible flat bands. Our work provides deeper insight into interacting topological systems. (preprint: arXiv:2204.11946)

Q 22.53 Tue 16:30 Empore Lichthof

Optical simulations for highly sensitive atom interferometry — •Gabriel Müller, Stefan Seckmeyer, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Using atom interferometers as highly sensitive quantum sensors requires both precise understanding and control of their main building block: atom light interactions. To properly describe the atom light interactions we need an accurate description of the laser-driven light fields. Distortions of ideal Gaussian beams on their path to the atoms can cause several disturbing effects. For example, the occurrence of asymmetric optical dipole forces acting on the atoms can cause a loss of contrast. Here, we build an optical simulation tool using Fast-Fourier-transform beam propagation methods to take into account arbitrarily shaped obstacles. We compare these results, on small scales, to solutions of Maxwell's equations finding good agreement. Finally, we apply our optical simulations to guide the design of the next unit of NASA's Earth-orbiting Cold Atom Lab and DESIRE, a microgravity experiment searching for Dark Energy.

This work is supported by DLR funds from the BMWi (50WM2245A-CAL-II and 50WM2253A-(AI)^2).

Q 22.54 Tue 16:30 Empore Lichthof

Green's functions formulation of Floquet topological invariants — •Marcus Meschede, Helena Drüeke, and Dieter Bauer — University of Rostock

Floquet topological insulators (FTIs) allow for topological protection through their time evolution as opposed to static topological insulators, which are only protected by their band topology. FTIs have become ubiquitous in the pursuit of realizing new phases of matter. In general, the momentum-dependent quasi-energy spectrum of single-particle time evolution operators or, equivalently, Floquet Hamiltonians is used to classify the band topology. In the presence of many-particle interactions, this single-particle picture breaks down. In order to overcome this issue, topological invariants of static systems have been formulated through their single-particle Green's functions. [1,2] We expand on this work by calculating Floquet topological invariants through their Floquet Green's function. As there is much experimental work on realizing FTIs, we hope to provide another tool to determine the topological properties of these systems through their bulk spectral function.

[1] Gurarie, V. "Single-Particle Green*s Functions and Interacting Topological Insulators." Physical Review B 83, 085426 (2011).

[2] He, Yuan-Yao, Han-Qing Wu, Zi Yang Meng, and Zhong-Yi Lu. "Topological Invariants for Interacting Topological Insulators. I. Ef-ficient Numerical Evaluation Scheme and Implementations." Physical Review B 93, 195163 (2016)

Q 22.55 Tue 16:30 Empore Lichthof

Light-induced correlations in cold dysprosium atoms — •Nivedith Anil, Marvin Proske, Ishan Varma, Dimitra Cristea, and Patrick Windpassinger — Institut für Physik, JGU Mainz

We intend to study light-matter interactions to explore the effect of magnet dipole-dipole interactions in highly dense samples of atoms exhibiting large permanent magnetic dipole moments. When the average interatomic distances are smaller than the wavelength of the scattering light, strong electric and magnetic dipole-dipole interactions give rise to collective light-scattering phenomena in the spectral and temporal domains. With the largest ground-state magnetic moment in the periodic table (10 Bohr-magneton), dysprosium is the perfect candidate for these experiments.

This poster reports on our progress in generating extremely dense ultracold atomic dysprosium clouds. We present our method to optically transport the atoms into a home-built science cell using a high-precision air-bearing translation stage. A custom-built high NA objective will re-trap the transported atoms in a tightly focussed microscopic optical dipole trap. Further, we discuss the design of a magnetic field system, which allows for highly precise magnetic field control and the ability to tune the contact interactions between the dysprosium atoms.

Q 22.56 Tue 16:30 Empore Lichthof

Borromean states in a one-dimensional three-body system — •Tobias Schnurrenberger[1], Lucas Happ[2], and Maxim Efremov[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany — [2]RIKEN Nishina Center, Strangeness Nuclear Physics Laboratory, Wako 351-0198, Japan

We explore the Borromean states of a one-dimensional quantum three-body system composed of two identical heavy particles and a different particle of smaller mass. There is no heavy-heavy interaction potential and no bound state supported by the heavy-light one. To determine the parameters of the heavy-light potential for which the Borromean states may exist, we apply and compare two approaches: (i) the Born-Oppenheimer approximation, being usually valid for a large mass ratio between heavy and light particles, and (ii) the Faddeev equations, being exact for any mass ratio.

Q 22.57 Tue 16:30 Empore Lichthof

Snapshot-based detection of hidden off-diagonal long-range order on lattices — Fabian Pauw[1], •Felix A. Palm[1], Annabelle Bohrdt[2], Sebastian Paeckel[1], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]Harvard University & ITAMP, Cambridge (MA), USA

Revealing the existence of hidden off-diagonal long range order is believed to be a promising avenue towards identifying and characterizing topological order. In continuum fractional quantum Hall systems this can be accomplished by attaching gauge flux tubes onto the particles. Following the recent advances of cold atom experiments in optical lattices, probing this hidden, non-local order parameter with Fock-basis snapshots for lattice analogs is now within reach. Here, we demonstrate the existence of hidden off-diagonal long range order in quasi two-dimensional lattices in the $\nu = 1/2$-groundstate of the experimentally realistic isotropic Hofstadter-Bose-Hubbard model. To this end, we provide a MPS-driven, hybrid one and two-site snapshot procedure to sample the one-particle reduced density matrix and all particle positions simultaneously, emulating an experimentally feasible protocol. We present strong numerical indications for the emergence of an algebraic decay and discuss the resolution achievable using only few snapshots.

Q 22.58 Tue 16:30 Empore Lichthof

Few fermions in an arbitrary potential — •Jonas Herkel, Sandra Brandstetter, Carl Heintze, Keerthan Subramanian, and Selim Jochim — Physikalisches Institut, University Heidelberg, Germany

Fermionic quantum systems with a tuneable atom number have proven to be a viable platform for exploring the emergence of many-body phenomena. In our experiment we are able to prepare a fermionic few-body system of 6Li atoms by spilling a two dimensional trap.

We use two different matter wave optic techniques to achieve single atom resolution. Combined with our spin resolved imaging technique, this allows for the examination of correlations between atoms in different spin states. A non interacting expansion maps the initial momenta to real space. For real space imaging we use a technique similar to (1), which combines the evolution in two harmonic potentials with different trapping frequencies, to magnify the spatial distribution. These imaging techniques allows us to explore hydrodynamic behavior of the few body limit.

We plan to setup a digital-micro-mirror-device (DMD) in a compact and modular way. The DMD will allow us to form nearly arbitrary uniform potentials, with a blue detuned laser. One possible application is a double box to explore the transport physics of a small number of atoms. The fast dynamics of the DMD additionaly allows for dynamic potentials, which could be utilized to explore collectivity of few atoms.

(1) Asteria et al. Nature 599, 571*575 (2021).
https://doi.org/10.1038/s41586-021-04011-2

Q 22.59 Tue 16:30 Empore Lichthof

Commercial Off-The-Shelf Replicate of the BECCAL Laser System for Cold Atom Experiments on the ISS — •Hamish Beck[1], Victoria Henderson[1,2], Tim Kroh[1,2], Jakob Pohl[1,2], Matthias Schoch[1], Christoph Weise[1], Hrudya Thaivalappil Sunilkumar[1], Marc Kitzmann[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Achim Peters[1,2], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hannover — [5]DLR-SI, Hannover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR, Braunschweig

BECCAL (Bose-Einstein Condensate–Cold Atom Laboratory) is a cold atom experiment designed for operation on-board the ISS. This DLR and NASA collaboration builds upon the heritage of sounding rocket and drop tower experiments as well as NASA's CAL. Fundamental physics with Rb and K BECs and ultra-cold atoms will be explored in this multi-user facility in microgravity, providing prolonged timescales and ultra-low energy scales compared to those achievable on earth. A ground-based replicate of the apparatus must also be built to support the operation of the flying experiment. The size, weight, and power constraints of such a Ground-based Test Bed (GTB) are relaxed, and so the laser system may be made from Commercial Off-The-Shelf (COTS) components. The design of this GTB laser system will be presented alongside the design of the flight hardware for a direct comparison.

This work is supported by the DLR with funds provided by the BMWK under grant numbers DLR 50WP1702, and 50WP2102.

Q 22.60 Tue 16:30 Empore Lichthof

Cryogenic system for Rydberg quantum optics — •Cedric Wind, Julia Gamper, Valerie Mauth, Florian Pausewang, Tore Homeyer, Hannes Busche, and Sebastian Hofferberth — Institute of Applied Physics, Bonn, Germany

Thanks to their strong interactions, Rydberg atoms are a key to neutral atom quantum simulation and computing or to implement nonlinear single photon devices such as single photon sources, optical transistors or photon-photon gates based on Rydberg quantum optics. Rydberg atoms also offer electric transitions over a wide range of the electromagnetic spectrum ranging from optical transitions close to the ground state to strong microwave transitions between Rydberg states. These properties make them an attractive ingredient to implement hybrid quantum systems interfacing optical and microwave frequencies.

Here, we present our design and construction of a cryogenic setup producing ultracold atoms in a 4K-environment to implement hybrid systems including Rydberg atoms. The system combines a closed-cycle cryostat with vibration isolation and an ultracold-atom production setup starting with a room-temperature magneto-optical trap and a magnetic transport into the cryo-region. In particular, the whole system is designed to enable fast exchange and cooling of samples in the experiment region to 4 K which can include electromechanical oscillators, superconducting circuits, or integrated photonic circuits. The cryostat promises a strong suppression of black-body induced Rydberg decay and improved vacuum conditions thanks to cryo-pumping that eliminates the need to bake the system when changing samples.

Q 22.61 Tue 16:30 Empore Lichthof

Rydberg superatoms for waveguide QED — •Nina Stiesdal[1], Lukas Ahlheit[1], Anna Spier[1], Jan de Haan[1], Kevin Kleinbeck[2], Jan Kumlin[3], Hans-Peter Büchler[2], and Sebastian Hofferbert[1] — [1]IAP, University of Bonn — [2]ITP3, University of Stuttgart — [3]CCQ, Aarhus University

Waveguide-systems where quantum emitters are strongly coupled to a single propagating light mode offer an interesting platform for quantum nonlinear optics. We work towards realizing a cascaded system in free space by using Rydberg superatoms - single Rydberg excitations in individual atomic ensembles smaller than the Rydberg blockade-volume - as directional effective two-level systems.

On this poster we show our setup implementing a one-dimensional chain of Rydberg superatoms with low internal dephasing. We employ a double magic-wavelength optical lattice to pin atoms during optical experiments using Rydberg states and thus reduce motional dephasing of the collective excitation. We further show our interferometer setup for obtaining phase information about the photons to perform full state tomography of outgoing multi-photon pulses to characterize the effective photon-photon interaction mediated by the superatom chain.

Q 22.62 Tue 16:30 Empore Lichthof

Rydberg quantum optics in ultracold Ytterbium gases — •Thilina Muthuarachchige[1], Xin Wang[1], Jonas Ceislick[1], Katherina Gillen[2], and Sebastian Hofferberth[1] — [1]Institute for Applied Physics, University of Bonn, Germany — [2]California Polytechnic State University, San Luis Obispo, USA

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far exclusively employed ultracold alkali atoms. Two-valence electron species, such as ytterbium, offer unique novel features such as narrow-linewidth laser-cooling, optical detection and ionization or long-lived nuclear-spin memory states.

On this poster, we present our ultracold ytterbium setup designed for few-photon Rydberg quantum optics experiments. The system is optimized for fast production of large, thermal ytterbium samples to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. Specifically, we discuss our two-chamber 2d/3d two-color MOT setup, our implementation of narrowline SWAP MOT techniques and Rydberg excitation of optically trapped Ytterbium atoms.

Q 22.63 Tue 16:30 Empore Lichthof

Level statistics and entanglement entropy of Rydberg dressed bosons in a triple-well potential — •Tianyi Yan[1], Matthew Collins[1], Rejish Nath[2], and Weibin Li[1] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [2]Department of Physics, Indian Institute of Science Education and Research, Dr. Homi Bhabha Road, Pune-411008, Maharashtra, India

We study signatures of quantum chaos of Rydberg dressed bosonic atoms in a three-well potential. Dynamics of the atoms are governed by an extended Bose-Hubbard model (EBHM) where long-range nearest-neighbor and next-nearest-neighbor interactions are induced by laser coupling the ground state to Rydberg state. We analyze level statistics of the EBHM with N atoms through numerical diagonalization. In the presence of a tilting potential, the level statistics is a Poissonian distribution when the dressed interaction is weak. It becomes a Wigner-Dyson distribution by increasing the interaction strength, signifying the emergence of quantum chaos. A hybrid distribution is obtained when the dressed interaction is much stronger than the hopping rate. Using Fock basis, we further calculate dynamical evolution of the entanglement entropy. The maximal value (upper bound) of the entanglement entropy is found to be $\ln(N+1)$. The maximum of the time-averaged entanglement entropy appears when the chaos is strong. The location of the maximum as a function of the dressed interaction and tilting potential is independent of N when N is large.

Q 22.64 Tue 16:30 Empore Lichthof

Chiral Rydberg State in cold atoms for chiral sensing. — Stefan Aull[1], Steffen Giesen[2], •Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Institut für Physik, Experimentalphysik I , Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]2Fb. 15 - Chemie, Hans- Meerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

It has been shown theoretically [1] that by combining a superposition of Hydrogenic wavefunctions in combination with appropriately adjusted phases, the resulting electronic state can show chiral properties. We are proposing a protocol for experimentally creating those states in a ultra-cold cloud of Rubidium atoms by exciting into a circular Rydberg state and subsequently generating a superposition of different states of almost maximum ℓ and m_ℓ. The results are aimed to be used for chiral discrimination [2] of molecules. Optimized parameters will be determined to maximize the chiral sensitivity.

[1] A. Ordonez, O. Smirnova. Propensity rules in photoelectron circular dichroism in chiral molecules. I. Chiral hydrogen, Phys. Rev. A 99, 043416 (2019)

[2] S Y Buhmann et al, Quantum sensing protocol for motionally chiral Rydberg atoms, New J. Phys. 23, 083040 (2021)

Q 22.65 Tue 16:30 Empore Lichthof

RF spectroscopy of ultracold Rydberg atoms and molecules — Edward Treu-Painter, Martin Trautmann, and •Johannes Deiglmayr — Universität Leipzig, Germany

RF Spectroscopy of Rydberg atoms is an established tool to determine the hyperfine structure [1] and quantum defects [2] of Rydberg atoms. We have recently extended this to the spectroscopy of long-range Rydberg molecules [3].

Here we present recent results on the characterization of the n^2D_J Rydberg series of Cesium using RF spectroscopy that yielded a new set of quantum defect parameters for the two fine-structure components with highly improved precision and accuracy. We will also present experimental and theoretical results on long-range Rydberg molecules correlated to n^2D_J Rydberg states that we probe by RF spectroscopy.

[1] H. Saßmannshausen, F. Merkt, and J. Deiglmayr, *High-resolution spectroscopy of Rydberg states in an ultracold cesium gas*, Phys. Rev. A **87(3)**, 032519 (2013) [2] J. Deiglmayr *et al.*, *Precision measurement of the ionization energy of Cs I*, Phys. Rev. A **93(1)**, 013424 (2016); M. Peper *et al*, *Precision measurement of the ionization energy and quantum defects of ^{39}K I*, Phys. Rev. A **100(1)**, 012501 (2019) [3] M. Peper and J. Deiglmayr, *Photodissociation of long-range Rydberg molecules*, Phys. Rev. A **102(6)**, 062819 (2020); M. Peper, and J. Deiglmayr, *Heteronuclear Long-Range Rydberg Molecules*, Phys. Rev. Lett. **126(1)**, 013001 (2021)

Q 22.66 Tue 16:30 Empore Lichthof

Stability of quantum degenerate fermionic polar molecules with and without microwave shielding — •Antun Balaž[1] and Axel Pelster[2] — [1]Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Department of Physics, Technical University of Kaiserslautern, Germany

A stabilization of a fermionic molecular gas towards collapse in attractive head-to-tail collisions and its evaporative cooling below the Fermi temperature has so far been achieved in two ways. Either a strong dc electric field is applied to confine the molecular motion to 2D [1] or inelastic collisions in 3D are strongly suppressed by applying a circularly polarized microwave field [2]. Here we use a Hartree-Fock mean-field theory [3,4] in order to determine the 3D properties of quantum degenerate fermionic molecules. In particular, we compare the stability diagrams occurring with and without microwave shielding, where a dipole-dipole interaction with negative and positive sign is present. In case when the orientation of the electric dipoles with respect to the trap axes is unknown, we outline how to reconstruct it from time-of-flight absorption measurements.

[1] G. Valtolina et al., Nature **588**, 239 (2020).
[2] A. Schindewolf et al., Nature **607**, 677 (2022).
[3] V. Veljić et al., New J. Phys. **20**, 093016 (2018).
[4] V. Veljić et al., Phys. Rev. Research **1**, 012009(R) (2019).

Q 22.67 Tue 16:30 Empore Lichthof

Creating auto-ponderomotive potentials for electron beam manipulation — •Franz Schmidt-Kaler, Michael Seidling, Robert Zimmermann, Nils Bode, and Peter Hommelhoff — Friedrich Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Advances in complex free electron beam manipulation are shown to be possible based on planar chips using electrostatic fields. In the co-moving frame of the electrons these static fields transform into alternating forces creating an engineered auto-ponderomotive potential. This confining pseudopotential resembles the one of a radiofrequency-driven Paul trap. Well-designed electrode layouts enable electron beam splitting and curved guiding, which we demonstrated. The applied electron energies range from a few eV to 1.7 keV (splitting) and 9.5 keV (guiding) permitting integration into standard scanning electron microscopes to allow entirely new electron control. Furthermore, we measured the first a-q stable parameter space demonstrating the similarity of our APE design's to Paul trap's potentials.

Q 22.68 Tue 16:30 Empore Lichthof

Coulomb effects in ultrashort few electron pulses — •Stefan Meier, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Most electron-based microscopy methods benefit from a high spatial coherence of the electron beam used. The smaller the electron source, the higher the spatial coherence, allowing, for example, particularly small foci in the electron microscope. Tungsten needle tips represent such highly coherent electron sources, with effective source sizes in the subnanometer range. Moreover, electron emission can be triggered by femtosecond short laser pulses, providing a source of ultrashort electron pulses. In this contribution, we investigate the transverse coherence properties of such a pulsed source as a function of the emitted current [1]. We show that the effective source size grows due to Coulomb effects already for one emitted electron per pulse on average. In a next step, we consider by post-selection only the electron pulses in which two electrons have been emitted. In this case we observe strong energy anticorrelation between both electrons due to the extreme spatial and temporal confinement of the electrons during emission. We report on the current status of these measurements and the implications that arise from them.

[1] S. Meier and P. Hommelhoff, ACS Photonics **9**, 3083 (2022)

Q 22.69 Tue 16:30 Empore Lichthof

Coherent Light-Electron Interaction in an SEM — •Maxim Sirotin, Tomáš Chlouba, Roy Shiloh, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen- Nürnberg (FAU), 91058 Erlangen

The coherent interaction of light and free electrons was experimentally demonstrated over a decade ago in a transmission electron microscope (TEM) in the form of photon-induced near-field electron microscopy (PINEM). Until today, it has found many fundamental scientific applications such as attosecond quantum coherent control, free electron quantum state generation and photon statistics reconstruction. So far, all PINEM experiments used ultrafast TEMs rather than scanning electron microscopes (SEM), mainly because the required high-resolution spectrometer is not commercially available. However, SEMs allow access to the yet unexplored subrelativistic energy range from ~0.5 to 30 keV which provides potentially higher electron-light coupling efficiency. Also, SEMs offer spacious and easily-configurable experimental chambers for extended optical setups, potentially boasting thousands of photon-electron interaction sites. We built a compact magnetic high-resolution electron spectrometer and experimentally demonstrated the quantum coherent coupling between electrons and optical nearfields in an SEM at unprecedentedly low, sub-relativistic energies [1]. This demonstration of PINEM in an SEM opens a new avenue to fundamental research in electron-photon quantum interactions.

[1] R. Shiloh, T. Chlouba, and P. Hommelhoff, Physical Review Letters **128**, 235301 (2022)

Q 22.70 Tue 16:30 Empore Lichthof

Simulation of expanding BECs and matter-wave lensing — •Nico Schwersenz and Albert Roura — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm

The extended microgravity conditions afforded by cold-atom experiments in space enable free-evolution times of many seconds, which can be exploited in high-precision measurements based on atom interferometry. However, in order to reach such long evolution times, it is necessary to employ ultracold atoms combined with matter-wave lensing techniques, and a detailed modeling is required. Here we present the results of 3D numerical simulations of BECs freely expanding for tens of seconds. As an application, we investigate the long-time behaviour of a BEC whose expansion has been collimated through matter-wave lensing. In particular, we examine the role played by the repulsive mean-field interaction and by quantum effects due to Heisenberg's uncertainty principle and the finite size of the BEC. Their relative importance is compared under different conditions.

Q 22.71 Tue 16:30 Empore Lichthof

High-order harmonic generation in gases with μJ laser pulses — •Matthias Meier[1], Philip Dienstbier[1], Yuya Morimoto[2], Francesco Tani[3], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]RIKEN Cluster for Pioneering Research (CPR), RIKEN Center for Advanced Photonics (RAP), Japan — [3]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Pump-probe schemes involving strong few-cycle driving pulses in the infrared in combination with attosecond probe pulses in the extreme ultraviolet are a powerful spectroscopic tool to investigate the ultrafast dynamics of electrons inside materials. For many spectroscopic schemes, it is desirable or even necessary to provide pump and probe pulses at high repetition rates for sufficient statistics and signal-to-noise ratios in the detection. Here, we present a laser system delivering infrared near infrared 8 fs pulses with 18 μJ energy and repetition rates up to 1 MHz. The few-cycle pulses are obtained by shortening 210 fs pulses from an Ytterbium laser amplifier with stable carrier-envelope phase. For this we use a two-stage compressor based on two argon-filled hollow-core photonic crystal fibers. The pulses are then delivered to a vacuum chamber which is set up for generating and characterizing isolated attosecond pulses.

Q 22.72 Tue 16:30 Empore Lichthof

The Parity Interferometer — •Freyja Ullinger[1,2] and Matthias Zimmermann[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89081 Ulm, Germany

The quantum-mechanical parity operator enables the reconstruction of the phase space representation of a quantum state [1,2,3,4]. However, the implementation of the parity operation is a subtle issue.

In this poster, we reveal the intrinsic relation between the parity operator and the quantum-mechanical harmonic oscillator. In particular, we present two methods for its realization: (i) we rely on a continuous time evolution in a harmonic potential, and (ii) we employ a combination of pulsed harmonic potentials and free propagation.

By exploiting these methods, we construct a novel parity interferometer. The output of our device measures the parity of a given initial state.

[1] A. Royer, Phys. Rev. A **15**, 449 (1977)

[2] S. Haroche, M. Brune, and J. M. Raimond, J. Mod. Opt. **54**, 2101 (2007)

[3] R. J. Birrittella, P. M. Alsing and C. C. Gerry, AVS Quantum Sci. **3**, 014701 (2021)

[4] S. Kleinert, 'Relativity, States and Quantum Evolutions in Atom Interferometry', Ph.D. thesis (Ulm University, Ulm, 2018)

Q 22.73 Tue 16:30 Empore Lichthof

Dynamics of quantum gases mixtures in space experiments — •Annie Pichery[1,2], Matthias Meister[3], Eric Charron[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. Space provides an environment where these clouds can float for extended times of several seconds, thus boosting the precision of these sensors. It also enables the operation of Bose-Einstein Condensate (BEC) mixtures for dual interferometers in miscibility conditions not possible on ground.

Simulating such dynamics of interacting dual species BEC mixtures presents however computational challenges due to the long expansion times. In this contribution, scaling techniques to overcome these limits are presented and illustrated in the case of space experiments on the ISS and aboard sounding rockets.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. CAL-II 50WM2245A/B.

Q 22.74 Tue 16:30 Empore Lichthof

Deep Learning Accelerated FDFD Simulations in Context of Inverse-Design Algorithms — •Lukas Schulte, Marco Butz, and Carsten Schuck — Center for Soft Nanoscience, Münster, Germany

Deep learning (DL) methods have shown tremendous success in various disciplines related to the design of photonic integrated circuit components. Likewise various fields of simulation, such as fluid dynamics, DL might be used to accelerate electromagnetic first-order simulations, as well.

To numerically access the photonic properties of metamaterials, efficient electromagnetic simulation algorithms are obligatory. In order to simulate the propagation of light through nanophotonic devices, various numerical methods, such as the finite-difference frequency-domain method (FDFD), have been developed. Requiring to solve large sparse linear systems iteratively, these methods come at the cost of being computationally expensive processes.

Here, we show how DL can be employed to decrease the computational effort of consecutive FDFD simulations, for example, encountered in inverse-design algorithms. Leveraged by the U-Net architecture our method is capable of predicting the electromagnetic response of a nanophotonic device. We use this prediction as a starting point for iterative refinement using FDFD, thus decreasing the required iteration and computation time drastically. Hereby, we minimize the overall time required by inverse-design algorithms to reach convergence and thus enable more sophisticated device layouts.

Q 22.75 Tue 16:30 Empore Lichthof

Stability of bound states in the continuum in one-dimensional resonator — •Ekaterina Maslova, Mikhail Rybin, Andrey Bogdanov, and Zarina Sadrieva — Saint-Petersburg, Russia

Bound states in the continuum (BIC) are resonances with infinite radiative quality (Q) factor. Although infinite Q factor is a mathematical abstraction, high-Q supercavity modes whose origin corresponds to genuine BIC can be excited in real samples. We consider Q-factor of BIC in one-dimensional resonators consisting of dielectric blocks. We investigate the dependence of the Q-factor on the structural disorder in symmetric and asymmetric structures. Symmetric structure unit cell consists of two similar blocks, while in asymmetric case there are two types of blocks with different size parameters. We studied electromagnetic waves in a finite array of blocks, which were calculated using the numerical simulation by finite difference method. The results show that in an asymmetric system the Q-factor is resistant to the introduction of structural disorder.

Q 22.76 Tue 16:30 Empore Lichthof

Deep Learning Accelerated FDFD Simulations in Context of Inverse-Design Algorithms — •Lukas Schulte[1,2,3], Marco Butz[1,2,3], and Carsten Schuck[1,2,3] — [1]Center for Soft Nanoscience, Münster, Germany — [2]Center for Nanotechnology, Münster, Germany — [3]Institute of Physics, University of Münster

Deep learning (DL) methods have shown tremendous success in various disciplines related to the design of photonic integrated circuit components. Similarly, DL may be used to accelerate electromagnetic first-order simulations. To numerically access the photonic properties of metamaterials requires efficient electromagnetic simulation algorithms. In order to simulate the propagation of light through nanophotonic devices, various numerical methods, such as the finite-difference frequency-domain method (FDFD), have been developed. Requiring to solve large sparse linear systems iteratively, these methods come at the cost of being computationally expensive processes. Here, we show how DL can be employed to decrease the computational effort of consecutive FDFD simulations, for example, encountered in inverse-design algorithms. Leveraging the U-Net architecture our method is capable of predicting the electromagnetic response of a nanophotonic device. We use this prediction as a starting point for iterative refinement using FDFD simulation, thus decreasing the required iteration and computation time drastically. Hereby, we minimize the overall time required by inverse-design algorithms to reach convergence and thus enable more efficient and compact device layouts.

Q 22.77 Tue 16:30 Empore Lichthof

Inverse design of dielectric laser accelerators and Smith-Purcell radiators — •Manuel Konrad, Michael Seidling, Urs Haeusler, Roy Shiloh, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Computational design and especially the inverse design approach are powerful tools for the design of nanophotonic structures. In inverse design, the structure is optimized according to an objective function, using an arbitrarily large number of parameters. The great advantage of inverse design over other schemes lies in the independence of the computational effort from the number of parameters, meaning one can efficiently explore a large parameter space. This often results in complex structures, which differ drastically from designs based on human intuition. With this design tool, various applications have already been demonstrated, such as highly efficient waveguides, complex optical demultiplexers, and different kinds of optical circuitry [1], but also for quantum correlations [2] and highly efficient light coupling to photonic nanostructures, used in dielectric laser acceleration of electrons [3]. We apply inverse design to the dielectric laser acceleration of electrons and Smith-Purcell radiation [4], while staying within the well-tested confines of silicon photonics. Our aim is to improve the performance of the current generation of structures with this novel technique.

[1] Molesky et al. Nature Photon 12, 659 (2018) [2] Dahan et al. Science 373, eabj7128 (2021) [3] Sapra et al. Science 367, 79 (2020) [4] Haeusler et al. ACS Photonics, 9, 2, 664 (2022)

Q 22.78 Tue 16:30 Empore Lichthof

Suppression of soliton-fission by a Zeno-like effect — •Niklas Bahr, Stephanie Willms, Ihar Babushkin, Uwe Morgner, Oliver Melchert, and Ayhan Demircan — Leibniz University Hannover, Cluster of Excellence PhoenixD, Hannover, Germany

The quantum mechanical Zeno-effect states that the spontaneous decay of an unstable quantum system can be inhibited by continuous measurements. We consider pulse propagation in nonlinear waveguides in terms of a generalized nonlinear Schrödinger equation, wherein linear loss assumes the role of continuous measurements within the quantum context. Under presence of perturbations, e.g. third order dispersion, a higher order soliton tends to decay in fundamental solitons. The reason for this is a process called soliton fission where, due to the spectral expansion of the soliton, energy is transferred to a phase matched resonant frequency. In this work, we show that upon tailoring the absorption characteristics so that the resonant frequency experiences loss, the breakup of higher-order solitons can be slowed down or even suppressed. We further show that this approach also applies to modulation instability induced soliton fission.

Q 22.79 Tue 16:30 Empore Lichthof

Bandwidth Optimization of SNSPDs Cryogenic Readout for Low-Jitter — •Roland Jaha[1,2], Wolfram Pernice[3], and Simone Ferrari[3] — [1]Institute of Physics, Münster 48149, Germany — [2]Center for Soft Nanoscience, Münster 48149, Germany — [3]Kirchhoff-Institute of Physics, Heidelberg 69120, Germany

High temporal resolution is a crucial performance metric of superconducting nanowire single-photon detectors (SNSPDs), as it would allow for increased rates in quantum key distribution (QKD) and optical sampling scopes with superior bandwidth. In recent years, considerable effort was made to improve the timing precision and sub-5 ps jitter has been demonstrated in the near-infrared. However, achieving this high temporal resolution goes in most cases at the cost of other performance metrics, such as detection efficiency. Therefore, while the community has been mainly invested in improving the detector geometry or material composition, we shift our focus towards the optimization of the electrical readout. We believe that in this way we can obtain low jitter while leaving other specifications relatively untouched. For our experiments, we design and fabricate cryogenic low-noise amplifiers (C-LNAs) with different readout bandwidths. The cryogenic operation allows for a significant reduction of the voltage noise, which is one of the main contributors to the timing jitter. Moreover, by tuning the amplifier bandwidth we are able to further improve the temporal resolution of the detector. We demonstrate that enhancing the low-frequency cutoff of the amplifier from 1 MHz to 200 MHz it is possible to reduce the timing jitter by more than 15 ps.

Q 22.80 Tue 16:30 Empore Lichthof

Integrated optical waveguides for the near-ultraviolet to blue visible spectral range for chip-based trapped-ion quantum computers — •Pascal Gehrmann[1,2], Anastasiia Sorokina[1,2], Carl-Frederik Grimpe[3], Guochun Du[3], Tunahan Gök[6,7], Radhakant Singh[6,7], Pragya Sah[6,7], Babita Negi[7], Maxim Lipkin[6,7], Stephan Suckow[6], Elena Jordan[3], Steffen Sauer[1,2], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Hannover, Germany — [6]AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany — [7]Chair of Electronic Devices, RWTH Aachen University, Aachen, Germany

Photonic integrated circuits (PICs) for on-chip light manipulation can be employed in scalable chip-based trapped-ion quantum computers. Trapped ions are used as qubits and are controlled by multiple wavelengths ranging from the near-ultraviolet (NUV) up to the near-infrared (NIR). The design of UV-PICs is a challenging task, since smaller dimensions and higher propagation losses are inevitable. This contribution covers the design of single-mode integrated optical waveguides on different material platforms for selected NUV and VIS wavelengths of an Yb^{+} ion. To improve the scalability, multi-wavelength operation is investigated.

Q 22.81 Tue 16:30 Empore Lichthof

Anisotropic properties of light-propelled microswimmers — •Elena Vinnemeier[1], Matthias Rüschenbaum[1], Cornelia Denz[1,2], and Jörg Imbrock[1] — [1]Institut für Angewandte Physik, Münster, Deutschland — [2]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Deutschland

Self-propelled particles enable versatile applications in various fields like in colloidal systems or in biomedicine. Utilizing light as an energy source is advantageous, since a fuel-free and highly controllable motion is possible. We demonstrate a novel propulsion mechanism relying solely on refraction of light, while an asymmetric particle shape and a symmetry-broken refractive index profile lead to a directional propulsion force. For fabrication of microswimmers direct laser writing by two-photon polymerization is employed. We compare the performance of these light-propelled particles with respect to velocity and directionality for different geometries and refractive index gradients.

Q 22.82 Tue 16:30 Empore Lichthof

Photonic integrated receiver concept for quantum communication — •Marco Dietrich[1,2], Bastian Hacker[1], Jonas Pudelko[1,2], Ömer Bayraktar[1,2], Francesco Morichetti[3], and Christoph Marquardt[1,2] — [1]Max Planck Institut für die Physik des Lichts, Staudstr. 2, 91058 Erlangen — [2]Institut für Optik, Information und Photonik, FAU Erlangen-Nürnberg, Staudstr. 7, 91058 Erlangen — [3]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Milan, Italy

Quantum Key Distribution (QKD) in free space requires the efficient reception of distorted optical modes. We investigate an interferometer mesh on a Photonic Integrated Chip (PIC) with the goal to correct the individual optical phases of several spatial input regions and coherently combine an arbitrary incident wavefront into a single fiber mode. Active elements allow for dynamical adaption to a changing input mode. This approach provides good passive stability and offers high scalability. We study this concept in the context of quantum communication with a realistic cubesat payload.

Q 22.83 Tue 16:30 Empore Lichthof

Ultra-low-loss non-reciprocal devices based on acousto-optic interaction in fiber null-couplers — •Riccardo Pennetta, Martin Blaha, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 12489 Berlin, Germany

The introduction of low-loss optical fibers probably represents the single most important advance in the growth of our telecommunication system. To meet our needs for secure communications, it is likely that our classical network will soon be operating alongside what is known as a quantum network. The latter is very sensitive to loss and thus poses new constraints to the performance of current fiber components. In particular, recent quantum network prototypes underlined the surprising absence of low-loss non-reciprocal fiber-based devices. Here, we present a solution to this issue by the proof-of-principle demonstration of ultra-low-loss (<0.1 dB) non-reciprocal devices (both isolators and circulators) based on so-called fiber null-couplers. The splitting ratio of these couplers can be controlled via acousto-optic interaction of the propagating light field with flexural acoustic waves that one launches along the coupling region. Fabricated from standard single-mode fibers, these devices are compatible with existing optical networks and could represent one important ingredient for the transmission and processing of optically encoded quantum information.

Q 22.84 Tue 16:30 Empore Lichthof

Fabrication of Computer-Generated Nanophotonic Devices — •David Lemli, Marco Butz, and Carsten Schuck — Institute of Physics, University of Münster, Germany

The increasingly sophisticated functionalities and performance requirements of photonic integrated circuit components produced by modern inverse design algorithms are practically difficult to achieve due to limitations of state-of-the-art nanofabrication processes. The main challenge consists in producing irregular computer-generated structures with 10s of nanometer resolution and high aspect ratios. In this work, we address this challenge with a holistic approach that combines electron-beam lithography and focused-ion-beam milling techniques with biasing deep-learning-based design algorithms to account for arbitrary fabrication constraints while minimizing the impact on individual device performance. We employ our methods for fabricating a wide range of pixel-discrete inversely designed nanophotonic structures and compare the measured performances with simulation based predictions. Our findings pave the way for fast and exact prototyping of novel and challenging nanophotonic devices for applications in information and communication technology, including photonic quantum technology.

Q 22.85 Tue 16:30 Empore Lichthof

Optical reservoir computing with incoherent optical memory — •Mingwei Yang[1,2], Elizabeth Robertson[1,2], Leon Messner[1,3], Norman Vincenz Ewald[1], Luisa Esguerra[1,2], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt, Institute of Optical Sensor Systems, Rutherfordstraße 2, Berlin, Germany. — [2]Technische Universität Berlin, Berlin, Germany. — [3]Humboldt-Universität zu Berlin, Berlin, Germany.

Reservoir computing is a machine learning method that is particularly suited for dynamic data processing. A fixed reservoir projects the input information to a high-dimensional feature space, and only the readout weights need to be trained, allowing fast data processing with low energy consumption [1]. In this work, we demonstrate an optical reservoir computing using incoherent memory in a cesium vapor cell to predict time-series data. The information is stored in the reservoir by controlling the pump and probe process on the Cs D2 transitions. The coupling between the reservoir and both the input and output data is realized by acousto-optic modulators. [1] G. Tanaka, T. Yamane, J. B. Héroux, R. Nakane, N. Kanazawa, S. Takeda, H. Numata, D. Nakano, and A. Hirose, *Recent advances in physical reservoir computing: A review,* Neural Networks 115, 100*123 (2019). [2] L. Jaurigue, E. Robertson, J. Wolters, and K. Lüdge, *Photonic reservoir computing with non-linear memory cells: interplay between topology, delay and delayed input,* in Emerging Topics in Artificial Intelligence (ETAI) 2022, vol. 12204 (SPIE, 2022), pp. 61*67.

Q 22.86 Tue 16:30 Empore Lichthof

Structuring hydrogels by two-photon lithography inside microfluidic channels for cell migration experiments — •Elena Bekker[1], Dustin Dzikonski[1], Riccardo Zamboni[1], Jörg Imbrock[1], and Cornelia Denz[1,2] — [1]Insitute of Applied Physics, University of Münster, Corrensstraße 2-4, 48149 Münster, Germany — [2]Physikalisch-Technische Bundesanstalt, Budesallee 100, 38116 Braunschweig, Germany

Hydrogels are highly swellable polymers which generally possess excellent biocompatibility and tissue-like properties. They can be structured via direct laser writing by two-photon lithography (2PL), enabling the fabrication of three-dimensional arbitrary structures with high resolution and spatial complexity. Using this technique, the microenvironment of cells can be mimicked with a high degree of control and reproducibility, whilst allowing variation in the physical properties of the structured gels. We perform 2PL fabrication inside channel systems of microfluidic devices, which provide a three-dimensional culture chamber for cells and allow the generation of chemical gradients to stimulate directed migration towards chemoattractant species. In this way, we investigate cell migration in confined three-dimensional environments.

Q 23: Optomechanics I & Optovibronics

Time: Wednesday 11:00–12:45 Location: A320

Q 23.1 Wed 11:00 A320

Quantum optomechanics with a levitated nanoparticle and an on-chip photonic crystal cavity — •Seyed Khalil Alavi[1,2], Jin Chang[3], Danial Davoudi[1], Marion Hagel[4], Simon Gröblacher[3], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, DE — [3]Kavli Institute of Nanoscience, Department of Quantum Nanoscience, Delft University of Technology, Delft, The Netherlands — [4]Max Planck Institute for Solid State Research, Stuttgart, DE

A levitated dielectric nanoparticle coupled to an optical cavity is a promising platform for quantum optomechanics. Recent progress includes cooling the particle's motion to the ground state achieved with a conventional optical cavity. A photonic crystal nanocavity (PCN) is an attractive alternative offering enhanced optomechanical coupling. The optomechanical coupling up to 10 kHz has been previously demonstrated with a stand-alone PCN. However, the system's fragility to optical absorption and mechanical perturbation prevented further advancement toward the quantum regime. In this talk, we present a new platform based on an on-chip PCN that can achieve the goal. The new PCN architecture ensures significantly improved mechanical and thermo-optic stability, allowing experiments at a high vacuum and with a large number of intracavity photons. We discuss our recent progress toward obtaining the quantum cooperativity above one.

Q 23.2 Wed 11:15 A320

Optoacoustic active phonon cooling in waveguides — •Laura Blázquez Martínez[1], Philipp Wiedemann[1], Andreas Geilen[1], Changlong Zhu[1], and Birgit Stiller[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058, Erlangen, Germany — [2]Physics department office, FAU Erlangen-Nürnberg, Staudtstr. 7 / B2, 91058, Erlangen, Germany

Optomechanical cooling is usually observed in resonator-based setups. In waveguides, active cooling via optomechanical or optoacoustic interactions is still largely unexplored. Here, we demonstrate experimentally active optoacoustic phonon cooling using the nonlinear effect of Brillouin-Mandelstam scattering in a chalcogenide glass photonic crystal fibre (PCF). The regime of height saturation for the anti-Stokes peak is demonstrated experimentally. Based on the Brillouin resonance behaviour, we show cooling by a temperature difference of $\Delta T \approx 190$ K from room temperature at 7.53 GHz, exceeding 3 times previously reported values.

Q 23.3 Wed 11:30 A320

Coherent control of Brillouin optomechanics in waveguides — •Changlong Zhu[1], Junyin Zhang[1], Christian Wolff[2], and Lijun Qiu[1] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Centre for Nano Optics, University of Southern Denmark, Campusvej 55, DK-5230, Odense M, Denmark

Brillouin optomechanics in waveguides allows a triply-resonant interaction between an optical, scattered light, and an acoustic wave. Here, we present a formalism to describe backward Brillouin optomechanics in waveguides in the dynamic regime with a pulsed pump. This formalism reveals the connection between waveguide Brillouin optomechanics and cavity optomechanics. By utilizing this theoretical framework, we show a closed solution for the coupled-mode equation of Brillouin optomechanics under the undepleted assumption, which can be used to investigate the coherent control of waveguide optomechanics in the quantum regime, such as coherent photon-phonon transfer, phonon cooling, and photon-phonon entanglement.

In addition, we propose a dynamic Brillouin cooling scheme in Brillouin-active integrated waveguides, where the optical dissipation exceeds the mechanical dissipation which is the common case in optical waveguides. By modulating the coupling intensity of the backward Brillouin anti-Stokes interaction via a pulsed pump, a phonon cooling factor with several orders of magnitude can be achieved.

Q 23.4 Wed 11:45 A320

Quantum optics approach to non-adiabatic phenomena in molecules — •Michael Reitz[1], Jacopo Fregoni[2], Raphael Holzinger[3], Agnes Vibok[4], and Claudiu Genes[1,5] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Madrid, Spain — [3]Institut für Theoretische Physik, University of Innsbruck, Innsbruck, Austria — [4]Department of Theoretical Physics, University of Debrecen, Debrecen, Hungary — [5]Physics Department, Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany

We propose an open quantum system approach to non-adiabatic phenomena in molecules, especially relevant during or after photo-excitation. In particular, we provide analytical approaches that qualitatively describe processes such as nonradiative transitions, internal conversion and intersystem crossing. The main overarching aspect of this theory is the derived unidirectionality of transfer between higher energy electronic states to lower energy states mediated by non-adiabatic couplings followed by quick vibrational relaxation, i.e., the often invoked Kasha's rule.

Q 23.5 Wed 12:00 A320

Nonlinear opto-vibronics in molecular systems — Quansheng Zhang[1], •Micheal Reitz[1], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, Erlangen, Germany

Opto-vibrational interactions in molecular systems occur in a hybrid fashion as light couples to electronic transitions, which in turn are modified by the vibrations of the nuclei. In standard approaches, under the Born-Oppenheimer approximation, the vibronic coupling is a spin-boson interaction modeled by a Holstein Hamiltonian, i.e., an electronic transition between two copies of the same harmonic potential landscape is slightly shifted. However, the potential landscapes for the excited and ground electric states may be different, with two different frequencies for the two harmonic curves. In such a case, the polaron transformation is modified by an operation involving a conditional squeezing operator.

We present here an analytical treatment based on a set of quantum Langevin equations for elective spin operators dressed by oscillations. These equations can be solved under some approximations to obtain information on emission and absorption spectra. Moreover, we propose to exploit the intrinsic nonlinear vibronic interaction to map light states to nuclear vibrations and viceversa. Our results are also applicable to quadratic optomechanics, such as in the membrane-in-the-middle scenario.

Q 23.6 Wed 12:15 A320

Interaction-Induced Directional Transport on Driven Coupled Chains — •Helena Drüeke and Dieter Bauer — Universität Rostock

We examine whether interaction between particles may introduce (topologically protected) directional transport in a driven two-particle quantum system. As a simple example, we consider two one-dimensional chains of equal length, each with one particle. The two particles interact but stay on their respective chain. The particles move alternatingly and without a preferred direction.

Without interaction between the particles, they each diffuse along their chains. Interaction between them suppresses this diffusion. With the proper timing of their alternating movement, the particles form a bound doublon state. Depending on their starting positions, this doublon either remains stationary or moves along the chain. The motion of the doublon consists of alternating, leapfrogging motion of the two particles.

Q 23.7 Wed 12:30 A320

Teaching Quantum Optics and Quantum Cryptography with Augmented Reality Enhanced Experiments — •Adrian Abazi[1], Paul Schlummer[2], Jonas Lauströer[3], Jochen Stuhrmann[3], Rasmus Borkamp[3], Wolfram Pernice[1], Reinhard Schulz-Schaeffer[3], Stefan Heusler[2], Daniel Laumann[2], and Carsten Schuck[1] — [1]Center for Nanotechnology, WWU Münster — [2]Institut für Didaktik der Physik, WWU Münster — [3]Department Design, HAW Hamburg

Recently, the Nobel Prize in physics was awarded for experiments with entangled photons, pioneering quantum technologies. To meet the growing demand of this field by furthering scientific comprehension of quantum physics and quenching misconception, especially about entanglement, new teaching approaches are required. Addressing this, we present a mixed reality quantum learning environment, by integrating commercially available AR-Headsets with a quantum optics setup for photon-pair generation and bell measurements. Students measure Bells inequality and conduct a version of the Ekert 91 quantum key distribution protocol. Simultaneously, visualizations of the underlying models and measurement results are rendered as holograms on appropriate locations of the optics setup. Dedicated actions, such as choosing a measurement basis, are reflected in the visualizations in real time. The learning environment has been implemented and is tested in undergraduate lab-courses. The components and software of the environment have been chosen to ease modifications and transfer.

Q 24: Quantum Networks I (joint session QI/Q)

Time: Wednesday 11:00–12:45 Location: B305

See QI 17 for details of this session.

Q 25: Solid State Quantum Optics

Time: Wednesday 11:00–13:00 Location: E001

Q 25.1 Wed 11:00 E001

Temperature annealing of hBN single-photon emitters in a nitrogen-rich atmosphere — •Nora Bahrami[1,2], Pablo Tieben[1,2], Janosch Stutenbaeumer[1], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany

Single-photon emitters (SPEs) are becoming increasingly important due to their diverse use in quantum photonics, such as quantum communication and metrology. Especially hexagonal boron nitride (hBN), a two-dimensional semiconductor material, has recently gained interest because of its remarkable optical properties, such as bright emission at room temperature across the visible and near infrared spectral range owing to the large bandgap of 6 eV. Nevertheless the nature of this emission, i.e., its atomic origin, is still undefined and fluorescence bleaching is an unfortunate occurrence for integrated applications, where stable emission is significant for further research. Therefore we evaluate a recipe to enhance the spectral characteristics in hBN flakes by high temperature annealing in a nitrogen-rich atmosphere. Individual emitters were characterized and compared on certain areas via photoluminescence mapping and by the analysis of g(2) -, saturation- and lifetime measurements as well as emission spectra before and after annealing. Our research opens up another step towards improving the optical properties of hBN.

Q 25.2 Wed 11:15 E001

Enhanced photon emission from hBN defects centers inside a tunable fiber-cavity — •Gregor Bayer[1], Florian Feuchtmayr[1], Stefan Häussler[1,2], Richard Waltrich[1], Noah Mendelson[3], Chi Li[3], David Hunger[4], Igor Aharonovich[3,5], and Alexander Kubanek[1,2] — [1]Inst. f. Quantenoptik, Uni Ulm, D — [2]Center f. Integ. Q. Science and Techn. (IQst), D — [3]School of Math./ Phys. Sciences, Univ. of Tech. Sydney, AUS — [4]Phys. Institut, Karlsruhe Inst. of Tech., D — [5]ARC Centre of Exc. f. Transf. Meta-Optical Systems, Univ. of Tech. Sydney, AUS

Coupling single quantum emitters to the mode of optical resonators is essential for the realization of quantum photonic devices. We present a hybrid system consisting of defect centers in a few-layer hexagonal boron nitride (hBN) sheet and a fiber-based Fabry-Pérot cavity. The smooth surface of the chemical vapor deposition grown hBN layers enables efficient integration into the cavity. This hybrid platform is operated over a broad spectral range of more than 30 nm. Owing to cavity funneling, large cavity-assisted signal enhancement up to 50-fold and strongly narrowed linewidths are demonstrated, a record for hBN-cavity systems. On top, we implement an excitation and readout scheme for resonant excitation, allowing to establish cavity-assisted photoluminescence excitation spectroscopy. In total, we reach a milestone for the deployment of 2D materials to fiber-based cavities in practical quantum technologies.

Q 25.3 Wed 11:30 E001

Mechanically Isolated Quantum Emitters in Hexagonal Boron Nitride. — •Patrick Maier[1], Andreas Tangemann[1], Michael Koch[1], Michael Höse[1], Igor Aharonovich[2], T.T. Tran[2], Niklas Lettner[1], Lukas Antoniuk[1], and Alexander Kubanek[1] — [1]University of Ulm, Germany — [2]University of Technology Sydney

Single Photon emitters are a crucial resource for novel photonic quantum technologies. Quantum emitters hosted in two-dimensional hexagonal Boron Nitride (hBN) are a promising candidate for the integration into hybrid quantum systems. One type of emitters hosted in hBN has shown the remarkable property of Fourier limited linewidths from cryogenic up to room temperatures. This property can be attributed to mechanically isolated orbitals of the defect centers, which do not couple to in-plane phonon modes. Here, we present our recent results towards identifying the origin of this mechanical decoupling, which could be caused by out-of-plane emitters. We also present quantum random number generations using the symmetric dipole emission profile of these emitters.

Q 25.4 Wed 11:45 E001

Super-Poissonian Light Statistics from Individual Silicon Vacancy Centers Coupled to a Laser-Written Diamond Waveguide — •Michael K. Koch[1,2], Michael Hoese[1], Vibhav Bharadwaj[1,3], Johannes Lang[1], John P. Hadden[4], Roberta Ramponi[3], Fedor Jelezko[1,2], Shane M. Eaton[3], and Alexander Kubanek[1,2] — [1]Ulm University, D-89081 Ulm, Germany — [2]IQst, Ulm University, D-89081 Ulm, Germany — [3]Institute for Photonics and Nanotechnologies (IFN) - CNR, Milano 20133, Italy — [4]School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, United Kingdom

Light field engineering on the single photon level is a key challenge for future quantum technology. Ideally, it will be realized with integrated quantum photonics to ensure robustness and scalability. Here we present a system that combines single silicon vacancy centers (SiVs) with laser-written type II waveguides [1] in diamond. Typically, these waveguides exhibit low cooperativity at the single photon level due to their large mode volume. To overcome this limitation, we use a novel operational technique of waveguide-assisted detection and high numerical aperture excitation of SiV centers to achieve a strong non-linearity at the single photon level. We demonstrate single-emitter extinction measurements with a cooperativity of 0.0050 and a relative beta factor of 13% [2].

[1] M. Hoese et al., Phys. Rev. Applied 15, 054059 (2021)
[2] M. K. Koch et al., ACS Photonics 9, 3366-3373 (2022)

Q 25.5 Wed 12:00 E001

Cavity-enhanced extinction measurements of nanoscale structures — •Ines Amersdorffer[2,1], Florian Sigger[3], Thomas Hümmer[2,1], Jonathan Noé[2,1], Alexander Högele[1], Christoph Kastl[3], and David Hunger[4] — [1]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Qlibri GmbH, Munich, Germany — [3]Walter Schottky Institute and Physics Department, Technical University of Munich, Germany — [4]Physikalisches Institut, Karlsruhe Institute of Technology, Germany

Measurements of the marginal absorption of nanomaterials are challenging. One way to address this issue is the use of an optical resonator in which the light passes the sample multiple times and thereby enhances the absorption of nanoscale objects to a measurable amount. We demonstrate how a high-finesse microcavity can be utilised in order to measure the extinction of defects in monolayer MoS_2. Such atomistic defects embedded in nanomaterials are a promising candidate for single-photon sources. However, to make them optically accessible, it is beneficial to know their absorption properties. To this end, we performed wavelength-dependent extinction measurements. The absolute values of extinction were recorded with a detection limit of down to 0.01 % and agree with theoretical predictions. Furthermore, we show first insights from applying this novel microscopy technique to perovskite nanocubes. Spectroscopy on single perovskite crystals helps to pick and engineer them for suitable applications, e.g. LEDs. The results show advances towards routine hyperspectral absorption measurements on the nanoscale.

Q 25.6 Wed 12:15 E001

Simulation of waveguide coupled single and double layer graphene electro-optic modulators — •Pawan Kumar Dubey[1], Ashraful Islam Raju[1], Rasuole Lukose[1], Christian Wenger[1,2], and Mindaugas Lukosius[1] — [1]IHP-Leibniz Institut für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]BTU Cottbus Senftenberg, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany

On-chip integrated, graphene-based optical modulator has the advantages of a small device footprint, low power consumption and low drive voltage, enabling it to be used in micrometer-scale optical interconnect. One of the very first single-layer graphene modulator was experimentally demonstrated in 2011 by Liu et al.[1], with a modulation depth of 0.1db/μm and a 3dB bandwidth of 1.2 GHz. Over the decade, there have been improvements in the performance with the double-layer design, in which a dielectric layer between the two successive graphene layers was introduced. It has the potential to significantly improve modulation depth, modulation efficiency and bandwidth of the operation. In this study, we present simulated results about, ridge and buried waveguide coupled double layer graphene modulators along with the effect of material and thickness of spacer layer between two graphene layers. Our simulation demonstrates a modulation depth of, 0.17db/μm, which is 70% higher than the single-layer design. We also demonstrate a 3dB bandwidth of 40 GHz and power consumption less than 1Pj/bit.

Q 25.7 Wed 12:30 E001

Contactless sheet resistance measurements of thin III-V semiconductors by far-field terahertz reflectometry — •Konstantin Wenzel, Steffen Breuer, Robert B. Kohlhaas, and Lars Liebermeister — Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany

Measuring the electrical properties of thin semiconductor layers is crucial for the development of semiconductor devices. 4-point measurements, such as van-der-Pauw and Hall, determine these properties very accurately. However, since this method requires electrical contacts, the measurement location becomes unusable for further processing. At the same time, areas of the sample used for processing are not measured. Here, we present far-field terahertz (THz) reflectometry measurements as a contactless alternative for determining the sheet resistance with spatial resolution. We investigate various doped indium gallium arsenide samples epitaxially grown on indium phosphide substrates using THz time-domain spectrometry. We compare these measurements to standard 4-point measurements and discuss the limitations of our technique. The presented THz reflectometry allows non-contact and spatially resolved characterization of a broad spectrum of thin semiconductors, paving the way towards a new measurement technique for full-wafer characterization.

Q 25.8 Wed 12:45 E001

Valley polarization in pristine graphene with linearly polarised laser pulses — •Arkajyoti Maity, Ulf Saalmann, and Jan M. Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38,01187 Dresden

Information processing using preferential excitation of one of the two energy degenerate valleys in inversion symmetry broken graphene-like systems has been achieved by circularly polarized pulses. These pulses couple differentially to the valleys which have opposite orbital angular momentum, depending on their polarization[1]. Recent studies have, however, shown that linearly polarised light pulses can generate appreciable valley polarization, even in pristine graphene, without breaking inversion symmetry at the Hamiltonian level[2]. In our presentation, we will shed some light on the general mechanisms of this process of valley polarization with ultrashort laser pulses. We also show results for the terahertz regime, in which graphene shows strong non-linear behavior, and discuss the role of electronic decoherences for such longer pulses.

[1]Di Xiao, Wang Yao, and Qian Niu. Valley-contrasting physics in graphene:Magnetic moment and topological transport. Phys. Rev. Lett., 99:236809,Dec 2007 [2]Hamed Koochaki Kelardeh, Ulf Saalmann, and Jan M. Rost. Ultrashortlaser-driven dynamics of massless dirac electrons generating valley polarization in graphene. Phys.Rev.Research, 4:L022014, Apr 2022

Q 26: Quantum Gases: Bosons III

Time: Wednesday 11:00–13:00 Location: E214

Q 26.1 Wed 11:00 E214

Emergence of damped-localized excitations in the Mott phase due to disorder — Renan Souza[1,2], •Axel Pelster[1], and Francisco dos Santos[2] — [1]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil

A key aspect of ultracold bosonic quantum gases in deep optical lattice potential wells is the realization of the strongly interacting Mott insulating phase. Many characteristics of this phase are well understood, however little is known about the effects of a random external potential on its gapped quasiparticle and quasi-hole low-energy excitations. In the present study we investigate the effect of disorder upon the excitations of the Mott insulating state at zero temperature described by the Bose-Hubbard model. Using a field-theoretical approach we obtain a resummed expression for the disorder ensemble average of the spectral function. Its analysis shows that disorder leads to an increase of the effective mass of both quasiparticle and quasihole excitations. Furthermore, it yields the emergence of damped states, which exponentially decay during propagation in space and dominate the whole band when disorder becomes comparable to interactions. We argue that such damped-localized states correspond to excitations of the Bose-glass phase.

Q 26.2 Wed 11:15 E214

Quantum Critical Behavior of Entanglement in Lattice Bosons with Cavity-Mediated Long-Range Interactions — •Simon B. Jäger[1,2], Shraddha Sharma[2,3], Rebecca Kraus[2], Tommaso Roscilde[4], and Giovanna Morigi[2] — [1]Physics Department, Technische Universität Kaiserslautern — [2]Theoretische Physik, Saarland University — [3]ICTP-The Abdus Salam International Center for Theoretical Physics — [4]Univ. Lyon, Ens de Lyon, CNRS, Laboratoire de Physique

We analyze the ground-state entanglement entropy of the extended Bose-Hubbard model with infinite-range interactions. This model describes the low-energy dynamics of ultracold bosons tightly bound to an optical lattice and dispersively coupled to a cavity mode. The competition between on-site repulsion and global cavity-induced interactions leads to a rich phase diagram, which exhibits superfluid, supersolid, and insulating phases. We use a slave-boson treatment of harmonic quantum fluctuations around the mean-field solution and calculate the entanglement entropy across the phase transitions. At commensurate filling, the insulator-superfluid transition is signaled by a singularity in the area-law scaling coefficient of the entanglement entropy, which is similar to the one reported for the standard Bose-Hubbard model. Remarkably, at the continuous $\mathbb{Z}_2$ superfluid-to-supersolid transition we find a critical logarithmic term, regardless of the filling. This behavior originates from the appearance of a roton mode in the excitation and entanglement spectrum, becoming gapless at the critical point, and it is characteristic of collective models.

Q 26.3 Wed 11:30 E214

Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder — •Milan Radonjić[1,2], Rodrigo P. A. Lima[3,4], and Axel Pelster[4] — [1]I. Institute of Theoretical Physics, University of Hamburg, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]GISC and GFTC, Instituto de Física, Universidade Federal de Alagoas, Maceió AL, Brazil — [4]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Germany

We investigate theoretically how the superfluid and the condensate deformation of a weakly interacting ultracold Bose gas evolve during the ramping up of an external weak disorder potential. Both resulting deformations turn out to consist of two distinct contributions, namely a reversible equilibrium one [1,2], as well

as a non-equilibrium dynamical one, whose magnitude depends on the details of the ramping protocol [3]. For the specific case of the exponential ramping up protocol, we are able to derive analytic time-dependent expressions for the aforementioned quantities. After sufficiently long time, the steady state emerges that is generically out of equilibrium. We make the first step in examining its properties by studying the relaxation dynamics into it. Also, we investigate the two-time correlation function and elucidate its relation to the equilibrium and the dynamical part of the condensate deformation. [1] K. Huang and H.-F. Meng, Phys. Rev. Lett. 69, 644 (1992). [2] B. Nagler, M. Radonjić, S. Barbosa, J. Koch, A. Pelster, and A. Widera, New J. Phys. 22, 033021 (2020). [3] M. Radonjić and A. Pelster, SciPost Phys. 10, 008 (2021)

Q 26.4 Wed 11:45 E214

Quantum phase transitions of excited states in spinor BECs — •Bernd Meyer-Hoppe[1], Fabian Anders[1], Polina Feldmann[2,3], Luis Santos[2], and Carsten Klempt[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]Leibniz Universität Hannover, Institut für Theoretische Physik, Appelstraße 2, 30167 Hannover, Germany — [3]Stewart Blusson Quantum Matter Institute, The University of British Columbia, 2355 East Mall, Vancouver BC V6T 1Z4, Canada

Depending on external control parameters, the physically realized states of a given system can be grouped into phases that are defined by a measurable order parameter. For ultracold systems, where quantum fluctuations dominate thermal ones, quantum phases arise, which are separated by quantum phase transitions (QPTs) with a vanishing energy gap between the ground state and the first excited state. Today, ultracold quantum many-body systems can also be prepared at non-zero energy without thermalization. For such systems, it is possible to define excited-state quantum phase transitions (ESQPTs) by an analogous divergence of the density of states.

Here we present the experimental determination of a quantum phase diagram in a spinor BEC, where the energy of the system is one of the control parameters. The quantum phases are detected by the measurement of an interferometric order parameter that abruptly changes at the ESQPTs. We identify three quantum phases and their transitions by varying two control parameters: the effective magnetic field and the excitation energy.

Q 26.5 Wed 12:00 E214

Hartree-Fock Analogue Theory for Thermo-Optic Interaction — •Enrico Stein und Axel Pelster — Physics Department and Research Centre OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger-Straße 46, 67663 Kaiserslautern

Photon Bose-Einstein condensates are created in a microcavity filled with a dye solution in which photons are trapped. The dye continually absorbs and re-emits these photons causing the photon gas to thermalise at room temperature and finally to form a Bose-Einstein condensate. Because of a non-ideal quantum efficiency, these cycles heat the dye solution, creating a medium in which effective photon-photon interaction takes place. However, a full Hamiltonian formulation of this process has yet to be derived.

In this talk, we focus on a Hamiltonian description of the effective photon-photon interaction that includes the thermal cloud and, thus, resembles a Hartree-Fock analogue theory for this kind of interaction. Using an exact diagonalisation approach, we work out how the effective photon-photon interaction modifies the spectrum of the photon gas and how it affects the condensate width. As a second case study, we apply our theory to the dimensional crossover from 2D to 1D. In this scenario, we focus on a comparison with a plain variational approach based on the Gross-Pitaevskii equation and explicitly work out the contribution of the thermal cloud.

Q 26.6 Wed 12:15 E214

Condensate formation in a dark state of a driven atom-cavity system — •Jim Skulte[1,2], Phatthamon Kongkhambut[1], Hans Kessler[1], Jayson G. Cosme[3], Andreas Hemmerich[1,2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany. — [3]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

An intriguing class of quantum states in light-matter systems are the so-called dark states. We demonstrate condensate formation in a dark state in an ultracold quantum gas coupled to a high-finesse cavity and pumped by a shaken optical lattice [1]. We show experimentally and theoretically that the atoms in the dark state display a strong suppression of the coupling to the cavity. On the theory side, this is supported by solving the dynamics of a minimal three-level model [2] and of the full atom-cavity system. The symmetry of the condensate wave function is anti-symmetric with respect to the potential minima of the pump lattice, and displays a staggered sign along the cavity direction. This symmetry decouples the dark state from the cavity, and is preserved when the pump intensity is switched off.

[1] J. Skulte et al., Condensate formation in a dark state of a driven atom-cavity system, arXiv:2209.03342 (2022)

[2] J. Skulte et al., Parametrically driven dissipative three-level Dicke model, PRA 127, 253601 (2021)

Q 26.7 Wed 12:30 E214

Real-Time Instantons and Self-Similar Scaling in a 1D Spin-1 Bose Gas Far from Equilibrium — •Ido Siovitz, Stefan Lannig, Yannick Deller, Helmut Storbel, Markus Oberthaler, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

A system driven far from equilibrium via a parameter quench can show universal dynamics, characterized by self-similar spatio-temporal scaling, associated with the approach to a non-thermal fixed point. The study of such universality classes may assist in a thorough investigation of many systems ranging from the post-inflationary evolution of the universe to low-energy dynamics in cold gases.

Topological excitations in the system are considered to be one of the driving mechanisms of coarsening dynamics in the system and are, as such, a point of interest in the study of far from equilibrium physics. We will discuss the infrared scaling phenomena of a one-dimensional spin-1 Bose gas quenched from the polar phase to the easy-plane phase and provide evidence of the existence of real-time instantons, appearing as vortices in space and time. The latter's contribution to the coarsening dynamics of the system will be shown, and an effective theory describing the mechanism of their appearance will be presented.

Q 26.8 Wed 12:45 E214

Condensation and Thermalization of an Easy-Plane Ferromagnet in a Spinor Bose Gas — Maximilian Prüfer[2], Daniel Spitz[3], •Stefan Lannig[1], Helmut Strobel[1], Jürgen Berges[3], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institute for Physics, Heidelberg, Germany — [2]Vienna Center for Quantum Science and Technology, Vienna, Austria — [3]Institute for Theoretical Physics, Heidelberg, Germany

Bose-Einstein condensates are ideally suited to investigate dynamical phenomena emerging in the many-body limit, such as the build-up of long-range coherence, superfluidity or spontaneous symmetry breaking. We study the thermalization dynamics of an easy-plane ferromagnet in a homogeneous one-dimensional spinor Bose gas of ^{87}Rb. This is demonstrated by the dynamic emergence of effective long-range coherence of the spin field. For a thermalized state we verify spin-superfluidity by experimentally testing Landau's criterion and reveal the structure of one massive and two massless modes, which are a consequence of explicit and spontaneous symmetry breaking, respectively. Our experiments allow us to observe the thermalization of an easy-plane ferromagnetic Bose gas. The relevant momentum-resolved observables are in agreement with a thermal prediction obtained from a microscopic model in the Bogoliubov approximation.

Prüfer et al., Nature Physics (2022), DOI: 10.1038/s41567-022-01779-6

Q 27: Ultra-cold Atoms, Ions and BEC II (joint session A/Q)

Time: Wednesday 11:00–13:00 Location: F303

See A 14 for details of this session.

Q 28: Quantum Technologies: Trapped Ions (joint session Q/QI)

Time: Wednesday 11:00–13:00 Location: F342

Q 28.1 Wed 11:00 F342

Non-commuting dynamics in light-ion-interactions on an ion-trap system — •Sebastian Saner[1], Oana Bazavan[1], Donovan Webb[1], Gabriel Araneda[1], Mariella Minder[1], David Lucas[1], Raghavendra Srinivas[1], and Chris Ballance[1,2] — [1]University of Oxford, Oxford, UK — [2]Oxford Ionics, Oxford, UK

The interaction Hamiltonian that governs the dynamics between trapped ions and laser light [1] is well studied and understood in the limit of low laser powers, leading to simple dynamics. However, at high powers, off-resonant coupling to multiple carrier and motional transitions is not negligible, leading to more complex and richer dynamics, with Hamiltonians exhibiting non-commuting terms.

In quantum computing with trapped ions, fast and versatile interactions that require high laser powers are important. It is of interest to either suppress those off-resonant terms or harness them in a controlled way. In this talk, we present our experimental work on utilising non-commuting terms to create two-qubit entanglement [2]. Furthermore, we evaluate how to apply this idea in the context of hybrid spin-motion systems. Secondly, we will show how we employ a phase stable optical lattice to coherently suppress a non-commuting error source that appears in the conventional Molmer-Sorensen interaction. This approach has the potential to allow for fast and high-fidelity entangling gates which are not limited by scattering errors.

[1]: Wineland et al., J. Res. Natl. Inst. Stand. Technol. 103(3), 259-328, 1998
[2]: Bazavan, Saner et al., arXiv:2207.11193, 2022

Q 28.2 Wed 11:15 F342

Optimization methods for RF junctions in register-based surface-electrode ion traps — •Florian Ungerechts[1], Rodrigo Munoz[1], Axel Hoffmann[1,2], Brigitte Kaune[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Register-based ion traps are among the leading approaches for scalable quantum processors. A fundamental component of these are RF junctions that allow the ions to move between the specialized zones of the quantum processor via ion transport. We discuss the design choices and optimization methods of such a junction and present an optimized symmetric RF X-junction feasible for through-junction ion transport of single $^{9}Be^{+}$ ions and multilayer microfabrication.

Q 28.3 Wed 11:30 F342

Simultaneous super- and subradiant light emission of two stored ion in free space — •Stefan Richter[1], Sebastian Wolf[2], Joachim vom Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

Modification of spontaneous decay in space and time is a central topic of quantum physics. It has been predominantly investigated in cavity quantum electrodynamic systems. Altered spontaneous decay may equally result from correlations among the emitters in free space, as observed in super- and subradiance. Yet, preparation of an entangled quantum state and the resulting modified emission pattern has not been observed so far due to the lack of ultra-fast multi-pixelated cameras. Using two trapped ions in free space, we prepare their state via projective measurements and observe their corresponding collective photon emission. Depending on the direction of detection of the first photon, we record fundamentally different emission patterns, including super- and subradiance [1]. Our results demonstrate that the detection of a single photon may fundamentally determine the subsequent collective emission pattern of an atomic array, here represented by its most elementary building block of two atoms stored in an ion trap.

[1] arXiv:2202.13678

Q 28.4 Wed 11:45 F342

Quantum repeater node with two $^{40}Ca^{+}$ ions — •Max Bergerhoff, Omar Elshehy, Stephan Kucera, Matthias Kreis, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The quantum repeater cell according to [1] is a fundamental building block for large distance quantum networks. It serves for overcoming the exponential scaling of fiber transmission, by the division of a transmission fiber in two asynchronously driven segments and the use of quantum memories. Recent realizations with single atoms [2] in a cavity and ions in a large cavity [3] already demonstrate the advantage of this protocol. Here we report on the implementation of a free-space quantum repeater cell with two $^{40}Ca^{+}$ ions in the same trap that act as memories.

We demonstrate ion-photon entanglement according to [4] by controlled emission of single photons from the individually addressed ions. The entanglement is swapped onto the photons via the Mølmer-Sørensen gate [5]. We discuss the rate scaling due to the asynchronous sequence and the fidelity of the final photon-photon state.

[1] D. Luong et al., Appl. Phys. B 122, 96 (2016)
[2] S. Langenfeld et al., Phys. Rev. Lett. 126, 30506 (2021)
[3] V. Krutyanskiy et al. arXiv preprint arXiv:2210.05418 (2022)
[4] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[5] K. Mølmer and A. Sørensen, Phys. Rev. Lett 82, 1835-8 (1999)

Q 28.5 Wed 12:00 F342

Spin-dependent coherent light scattering from linear ion crystal — •Maurizio Verde[1], Benjamin Zenz[1], Stefan Richter[2], Zyad Shehata[2], Ferdinand Schmidt-Kaler[1], and Joachim von Zanthier[2] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Institut für Optik, Information und Photonik, Universität Erlangen, Erlangen, Germany

Linear crystals of ultracold ions are emerging platforms for quantum simulator thanks to their unique properties of long coherence times and high-fidelity optical manipulation. In this perspective, the development of new detection techniques based on photo-correlation measurements is of central interest in order to access structural and dynamical information. Following the ideas reported in [1] on light-crystal coherent scattering, we explored extensions of these phenomena and here we report on a new detection scheme to unveil the spin texture for linear chains of $^{40}Ca^{+}$ ions. First, we initialize the crystal in the desired spin configuration, then we use the narrow transitions at 729nm and 854nm to perform spin-dependent coherent scattering and measure the background-free $g^{(1)}$ photo-correlation function by recording light near 393nm in the far field. The laser beam geometry is chosen to minimize the single-ion recoil and therefore the corresponding Debye-Waller factor. We use a high spatio-temporal resolution MCP camera and reveal from the spatial interference pattern the spin texture of the crystal. We discuss the efficiency of our new method for detecting magnetic phases and phase transitions.

[1]Wolf et al., Phys. Rev. Lett. 116, 183002 (2016)

Q 28.6 Wed 12:15 F342

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2], Daniel Vadlejch[2], Tanja Mehlstäubler[2], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2,30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100,308116 Braunschweig, Germany

Crystals of ultracold trapped ions reach sizes of hundreds of individual particles and require high level of control over their motional temperature to account for the second-order Doppler shift in clocks and implement high-fidelity quantum gates in quantum computers. The existing thermometry tools fail to provide an accurate temperature estimation for large ground-state cooled crystals, either focusing only on the symmetric c.o.m. mode of motion or neglecting the involved spin-spin correlations between the ions.

To resolve the thermometry large-N bottleneck, we consider crystal many-body dynamics arising when motional sideband transitions are driven in a near ground-state regime, which is a widely used approach in thermometry of a single ion. To gain some valuable insights on the sideband thermometry method, we also address the single ion case and study it from the Fisher Information prospective.

Extending the approach further, we account for entanglement created between the ions in a crystal to derive a new reliable temperature estimator, insensitive to the number of ions, and field-test in experiments with 4- and 19-ion crystals done by colleagues from PTB and Innsbruck.

Q 28.7 Wed 12:30 F342

Mixed qubit types in registers of trapped barium ions — •Fabian Pokorny, Andres Vazquez-Brennan, Jamie Leppard, Ana Sotirova, and Chris Ballance — Department of Physics, University of Oxford, United Kingdom

Registers of mixed qubit types are a promising approach for scaling trapped-ion quantum computers. The insensitivity of one qubit type to the others' light fields eliminates scattering errors and enables advanced qubit control schemes.

Barium-ion qubits are uniquely suited for realising this approach. Their long-lived metastable states allow for the implementation of different qubit types using just one atomic species, which, combined with atomic transitions in the visible range, significantly reduces experimental complexity [1]. In our experiment we use $^{137}Ba^{+}$, whose nuclear spin of 3/2 provides magnetic-field insensitive 'clock' qubits in both the stable ground-state manifold and the long-lived metastable $5D_{5/2}$ manifold. The ground and metastable level qubits are connected via a pair of 'clock' transitions, and both qubit types can be driven using a two-photon Raman process with 532 nm light and low scattering error.

We show an all-fiber Raman system capable of single-ion addressing in a large qubit register and further demonstrate simultaneous manipulation of ground-state and metastable-state qubits. These are prerequisites for working with long registers of mixed qubit types and for realising partial projective measurements and mid-circuit measurements.

[1] D. Allcock et al., Applied Physics Letters, vol. 119, 2021.

Q 28.8 Wed 12:45 F342

Introducing a surface ion trap with integrated photonics for Yb+ ions — •Markus Kromrey[1], Elena Jordan[1], Guochun Du[1], Carl-Frederik Grimpe[1], Gillenhaal Beck[2], Karan Metha[5], and Tanja Mehlstäubler[1,3,4] — [1]Physikalisch Technische Bundesanstalt, Braunschweig, Deutschland — [2]Eidgenössische Technische Hochschule Zürich, Zürich, Schweiz — [3]Laboratorium für Nano- und Quantenengineering, Hannover, Deutschland — [4]Leibniz Universität Hannover, Hannover, Deutschland — [5]Cornell University, Ithaca, USA

One of the main obstacles to the scalability of ion trap applications such as quantum computing and quantum sensing is the miniaturization and scalability of the optics required to provide the trapped ions with the light necessary to manipulate them. In this talk, we will present a surface ion trap with integrated optics that requires much less space than classical setups. Integrated optics also offer routes to eliminating important technical noise sources present in conventional setups. The integrated optics deliver all the lasers required for a Yb 172 clock experiment to the ion. One of the main features of the trap is a grating coupler that provides the ion with light in a Hermite-Gaussian mode to excite the narrow Yb 172 octupole transition.

Q 29: Implementations: Ions and Atoms (joint session QI/Q)

Time: Wednesday 11:00–13:00 Location: F428

See QI 19 for details of this session.

Q 30: Nano-optics

Time: Wednesday 11:00–13:00 Location: F442

Q 30.1 Wed 11:00 F442

A Novel Approach to Nanophotonic Black-Box Optimization Through Reinforcement Learning — •Marco Butz[1], Alexander Leifhelm[1], Marlon Becker[2], Benjamin Risse[2], and Carsten Schuck[1] — [1]Center for Soft Nanoscience, Münster, Germany — [2]Institute for Geoinformatics, University of Münster, Germany

After the use of Photonic integrated circuits (PICs) has led to a significant increase in the performance of devices employed in classical telecommunication schemes in the last years, complex quantum optics experiments have recently undergone a similar transition from free space setups to PICs. This development poses challenging requirements on the PICs' individual components in both footprint and performance and even raises the need for novel functionalities that are not accessible by conventional design methods. Recently, various design algorithms addressing this problem have been demonstrated. However, they all suffer from various drawbacks such as reliance on convex optimization methods in non-convex environments or the presence of gradient fields, which cannot always be accessed easily. Here, we show a novel inverse-design method based on reinforcement learning capable of producing pixel-discrete nanophotonic devices with arbitrary functionality and small footprints. Freely configurable design constraints can be realized through multiple interfaces enabling manipulation of the internal data flow. To demonstrate the capabilities of our method we show the fully automated design of a silicon-on-insulator waveguide-mode converter with > 95% conversion efficiency from scratch.

Q 30.2 Wed 11:15 F442

Reentrant delocalization transition in one-dimensional photonic quasicrystals — Sachin Vaidya[1], •Christina Jörg[1,2], Kyle Linn[2], Megan Goh[3], and Mikael C. Rechtsman[1] — [1]Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA — [2]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, D- 67663 Kaiserslautern, Germany — [3]Department of Physics, Amherst College, Amherst, MA 01002, USA

Over the past few years, there has been significant interest in exploring the localization of waves propagating in disordered media, also known as Anderson localization. We experimentally demonstrate that the localization transition in certain one-dimensional photonic quasicrystals (PhQC) is followed by a surprising second delocalization transition upon further increasing quasiperiodic disorder strength - an example of a reentrant transition. We measure this localization and reentrant delocalization via the inhibition and complete recovery of transmission through an Aubry-André type PhQC for increasing quasiperiodic modulation. To further shed light on the observed reentrant transition, we also develop a tight-binding model inspired by the PhQCs that captures the essential localization physics of our system.

Q 30.3 Wed 11:30 F442

Nonlocal Soft Plasmonics: Ionic plasmon effects in planar homogeneous multi-layered systems — •Preethi Ramesh Narayan and Christin David — Institute of Condensed Matter Theory and Optics (IFTO), Abbe Center of Photonics, Friedrich-Schiller-University Jena (FSU Jena), Jena, Germany

Plasmonics is the study of resonant interactions between free electrons present in the conduction band of metals and incident electromagnetic radiation. These resonant interactions result in surface plasmon waves that propagate along the surface at the metal-dielectric interface. Apart from metals, such charge oscillations can also be found in soft matter as a charged ionic fluid in an impermeable lipid membrane. Such a system can be studied analogously from the behavior of metal nanosystems, with lower resonance frequencies in larger ionic systems. We study the ionic plasmon interactions in planar electrolyte systems. We also consider the nonlocal interactions between the charge carriers that happen due to strong spatial confinement on the microscale. The optical response of free positive and negative ions in an electrolyte is explained using a hydrodynamic, two-fluid model under the scope of nonlocality. These ions oscillate with different bulk plasmon frequencies based on their respective charge, mass, and concentration. This allows analyzing the nonlocal plasmonic effects through highly tunable system parameters. We develop this system further with the aim to understand energy transfer in nerve cells and electrolyte-solid interactions for photocatalysis.

Q 30.4 Wed 11:45 F442

Nonlinear response in nanostructured multilayers — •Navid Daryakar[1] and Christin David[2] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

We studied the nonlinear optical response of composite nanostructured layers in terms of a self-phase-modulated, third-order Kerr nonlinearity. Theoretical modeling is considered through effective medium theories (Maxwell-Garnett, Bruggeman) to identify the behavior of the composite nanostructures in linear and nonlinear regimes. The optical response is modified and the dependence on various system parameters such as fill fraction, layer thickness and width, diffraction orders and laser intensity is studied. We thus show at which intensity transitioning to the nonlinear regime occurs, and how material response changes can be conveniently used as a signature of the transition. Our finding is general, and the method can be applied to any material mixture of thin films. As such, we expect our results to enable future studies aimed at predicting nonlinear optical response of composite nanostructures on the nanoscale. Nonlinear effective medium theory is used to describe low densities of gold nanoparticles embedded in an equally nonlinear host material. The fill fraction strongly influences the effective nonlinear susceptibility of the materials increasing it by orders of magnitude in case of gold due to localized surface plasmonic resonances.

Q 30.5 Wed 12:00 F442

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn, •Nicholas Jobbitt, and David Hunger — Karlsruher Institut für Technologie

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of rare-earth ion spin qubits in a solid state host. We study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) as a coherent qubit material and work towards efficient single ion detection by coupling their emission to a high-finesse fiber-based Fabry-Pérot microcavity. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble at temperatures below 10 K makes it possible to spectrally address and readout single ions. The coherent control of the single ion $^5D_0$ - $^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between ions within the same nanocrystal permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. We observed fluorescence signals from small ensembles of Europium ions at cryogenic temperatures and measured cavity-enhanced optical lifetimes of half the free-space lifetime resulting in effective Purcell-factors of one. Considering the low branching ratio into the desired transition this amounts to a two-level Purcell-factor of 100. We will report on the progress towards single ion readout and control.

Q 30.6 Wed 12:15 F442

Improvements of the Timing Resolution of SNSPDs Using Enhanced Light Intensity — Roland Jaha[1,2], Wolfram Pernice[3], and •Simone Ferrari[3] — [1]Institute of Physics, Münster 48149, Germany — [2]Center for Soft Nanoscience, Münster 48149, Germany — [3]Kirchhoff-Institute of Physics, Heidelberg 69120, Germany

Superconducting nanowire single-photon detectors enable single-photon detection with low dark counts, count rates up to a few Gcps, and almost unitary detection efficiency which makes them a key element in many quantum and faint light experiments. During the last few years, much effort has been spent on the development of detectors with high temporal resolution. Such devices would allow for high-speed quantum communication and the realization of optical sampling with superior bandwidth.

Typical free-space coupled low-jitter detectors suffer from low detection efficiency because of their small active region. Our nanowires instead are placed on top of a photonic waveguide where photons can be absorbed along the detector length. Using this approach, we are able to probe the detector within a confined space thereby enhancing the temporal resolution without sacrificing its detection efficiency. By adopting NbN SNSPDs atop SiN waveguides, we investigate the dependence of the temporal resolution and latency time on the photon illumination. At high photon flux, we observe an enhancement of the slew rate of the nanowire voltage response, leading to a sub-3 ps timing jitter and a reduction of the latency time of more than 100 ps compared to the single-photon level.

Q 30.7 Wed 12:30 F442

Extinction of plasmonic ellipsoidal core-shell nanoparticles — •Mathis Noell and Carsten Henkel — Institut für Physik und Astronomie, Potsdam, Germany

Plasmonic nanostructures provide an interesting platform for localized heating and field enhancement. If a nanoparticle is covert with a thin absorbing layer, theory predicts a resonance that is not seen in experimental extinction spectra. To understand this issue, we analyze the distribution of electric fields and energy dissipation in and around an ellipsoidal nanoparticle. Calculations are done for gold Nano particles covered with a few nm thick absorbing layer. At the spurious resonance the field is highly localized in this layer, suggesting that strong coupling to the molecular exciton is possible at the few-photon level. Treating the interface between the absorbing layer and the surrounding medium as a sharp interface is an assumption which is most likely not true. As a first step towards a model without a sharp layer-medium interface we modeled the layer as an effective medium (mixture of layer material and medium). Using the effective medium approach, we observe that the spurious resonance is suppressed for sufficiently diluted shells. Using a inhomogeneous but continuous permittivity profile one can formulate a model with no sharp layer-medium interface. We analyze the effective medium and continuous permittivity approaches and compare them with experimental data.

Q 30.8 Wed 12:45 F442

Tailoring Near-Field*Mediated Photon Electron Interactions with Light Polarization — •Fatemeh chahshouri and Nahid Talebi — Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany

Inelastic interaction of free-electrons with optical near fields has recently attracted attention for manipulating and shaping free-electron wavepackets. Understanding the nature and the dependence of the inelastic cross section on the polarization of the optical near-field is important for both fundamental aspects and the development of new applications in quantum-sensitive measurements. Here, we investigate the effect of the polarization and the spatial profile of plasmonic near-field distributions on shaping free-electrons and controlling the energy transfer mechanisms, but also tailoring the electron recoil. We particularly show that polarization of the exciting light can be used as a control knop for disseminating the acceleration and deceleration path ways via the experienced electron recoil. We also demonstrate the possibility of tailoring the shape of the localized plasmons by incorporating specific arrangements of nanorods to enhance or hamper the transversal and longitudinal recoils of free-electrons. Our findings open up a route towards plasmonic near-fields-engineering for the coherent manipulation and control of slow electron beams for creating desired shapes of electron wavepackets.

Q 31: Precision Measurements: Atom Interferometry I (joint session Q/A)

Time: Wednesday 11:00–13:00 Location: F102

Q 31.1 Wed 11:00 F102

Ultracold matter trapped by light singularities and quantum noise. — •Alexey Okulov — Moscow, Russia

Superfluids within helical boundaries are interesting from the point of view of low dimensional physics, phase transitions and inertial sensors. The sensitivity to the ultraslow motions of reference frame is limited by an unavoidable zero-point fluctuations. The basic uncertainty relations induce the phase uncertainty by corresponding fluctuations of the particles amount in ultracold ensemble. Hopefully there exists an opportunity to reduce the phase uncertainty by means of the proper structuring of the boundaries geometry. Our aim is to present the convincing arguments in favour of usage the helical laser traps formed by the counterpropagating Laguerre-Gaussian optical vortices to reduce the restrictions on phase deviations. The evaluation of the phase uncertainty with multimode coherent states approach leads to the optimistic result that phase measurement accuracy may be improved by a factor containing 2ℓ, where ℓ is the topological charge of LG vortices, compared to the conventional nontwisted trap geometries. Recent advances in development of highly charged optical vortices with $\ell = 10^3-10^4$ open the opportunity to improve the sensitivity to reference frame slow motions by several orders of magnitude.

Q 31.2 Wed 11:15 F102

Simulating space-borne atom interferometers for Earth Observation and tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional performance to test the postulates of General Relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented sensitivity beyond current limits.

In this contribution, we present a simulator for satellite-based atom interferometry and demonstrate its functionality in designing the STE-QUEST mission scenario, a satellite test of the UFF with ultra-cold atoms to 10^-17 as proposed to the ESA Medium mission frame [https://arxiv.org/abs/2211.15412]. Moreover, we will highlight the possibility of this simulator to design Earth Observation missions going beyond state of the art such as the CARIOQA concept [https://arxiv.org/abs/2211.01215].

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 31.3 Wed 11:30 F102

Multi-Axis sensing utilising guided atom interferometry — •Knut Stolzenberg, Sebastian Bode, Alexander Herbst, Wei Liu, Henning Albers, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Inertial sensors based on atom interferometry are a superior alternative to classical sensors regarding accuracy and long-term stability. Particularly in the field of autonomous navigation quantum sensors can become a viable addition to GNSS and classical IMUs. Yet the simultaneous measurement of accelerations and rotations is challenging to present experiments.

In our setup a 1064 nm crossed optical dipole trap (ODT) is used for the evaporation to quantum degeneracy. By using acousto-optical deflectors in both ODT beam paths, we add versatile control over the trapping potentials with respect to position and trap depth. This allows for the creation of one or more BECs amounting to a total number of up to 250×10^3 ultracold ^{87}Rb atoms prepared in the magnetic insensitive state $\left|F = 1, m_F = 0\right\rangle$. After preparation the ensembles are loaded into 1D-optical waveguides to counteract gravity and ensure radial confinement. Subsequently we span Mach-Zehnder atom interferometers utilising double-Bragg diffraction. In addition to measuring accelerations, we discuss future perspectives enabling sensitivity to gradients and rotation rates.

Q 31.4 Wed 11:45 F102

Principal Component Analysis for Image processing in Atom Interferometry — •Stefan Seckmeyer[1], Holger Ahlers[1,2], Sven Abend[1], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) Institut für Satellitengeodäsie und Inertialsensorik,, Hannover, Germany

Image analysis plays an important role in several current state-of-the-art atom interferometry experiments. We investigate the extraction of physical quantities from absorption images of atom interferometers using principal component analysis (PCA).

As a starting point we take a simple mathematical model for the images of the output ports of a two-port atom interferometer which is using a Bose-Einstein condensate as an atom source.

We show an analytic prediction of the PCA results for a subset of parameters which allows us to ascribe physical quantities to the output of a PCA analysis. Using this method we are not only able to extract the interferometer phase for each image but also a spatial phase aberration map shared by all images, here introduced at the final beam splitter.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. 50WM2253A.

Q 31.5 Wed 12:00 F102

Systematic description of matter wave interferometers using elastic scattering in weakly curved spacetimes — •Michael Werner and Klemens Hammerer — Institut für Theoretische Physik and Institut für Gravitationsphysik (Albert-Einstein-Institut), Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We present a systematic approach to calculate all relativistic phase shift effects in Bragg-type light-pulse matter wave interferometer (MWI) experiments up to (and including) order $\mathcal{O}(c^{-2})$, placed in a weak gravitational field. The whole analysis is derived from first principles and even admits test of General Relativity (GR) apart from the usual Einstein Equivalence Principle (EEP) tests, consisting of universality of free fall (UFF) and local position invariance (LPI) deviations, by using the more general „parameterized post-Newtonian“ (PPN) formalism. We collect general phase shift formulas for a variety of well-known MWI schemes and present how modern experimental setups could measure PPN induced deviations from GR without the use of macroscopic test masses. This procedure should be seen as a way to easily calculate certain phase contributions, without having to redo all relativistic calculations in new MWI setups and come up with possibly new measurement strategies.

Q 31.6 Wed 12:15 F102

3D simulations of guided BEC interferometers — •Rui Li, Stefan Seckmeyer, and Naceur Gaaloul — 1Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany

Atom interferometry (AI) has grown into a successful tool for precision measurements, inertial sensing and search for physics beyond standard model. Such high precision measurements are achieved either by large momentum transfer (LMT) or long interrogation times. Recently, the former technique has led to a state-of-the-art separation of more than 400 hbark [1]. In this experiment, Bose-Einstein Condensates (BECs) are used to further enhance precision atom interferometry due to their intrinsically strong coherence and narrow momentum width.*However, simulations of dynamics of BEC interacting with light in a generic 3D setup are limited by computation power and system sizes. In this talk, we present a newly developed numerical toolbox to solve the time-dependent Gross-Pitaevskii equation in 3D. To demonstrate its capability, we study BEC interferometers realized in both free-fall and guided geometry and compare our results with experimental data.*We specifically investigate the double-Bragg diffraction (DBD) of a BEC in a guide by two retro-reflected laser beams in a real-time evolution. Finally, we present a phase scan of a fully guided Mach-Zehnder interferometer based on DBDs combined with Bloch oscillations for LMT.

[1] Gebbe, M., Siemß, JN., Gersemann, M. et al., Nat Comm., 12, (2021) 2544.

Q 31.7 Wed 12:30 F102

A thermal noise interferometer for the characterization of optical coatings — •Janis Wöhler[1,2], Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[2,1], Juliane von Wrangel[1,2], and David S. Wu[2,1] — [1]Max Planck Institute for Gravitational Physics, Hannover — [2]Institut für Gravitationsphysik, Leibniz Universität Hannover

The peak sensitivity band of ground-based gravitational wave (GW) detectors are currently limited by a combination of quantum noise and coating thermal noise (CTN). The latter is a result of the intrinsic properties, such as the mechanical loss and Young's modulus, of the high reflective mirror coatings used in GW interferometers. We report on a 10 cm hemispherical Fabry-Perot cavity with suspended mirrors capable of directly measuring CTN on a test mirror. All other noise sources were suppressed below CTN by installing it in the 10m Prototype facility in Hannover to leverage the ultra low noise environment and laser source. The calibration of the interferometer readout was achieved with a photon calibrator. This thermal noise interferometer will be an invaluable tool for characterization as part of the current global research efforts to find suitable new coating materials for future GW detectors.

Q 31.8 Wed 12:45 F102

Analysis of polarization states in polarization maintaining optical fibers — •Johannes Bäuerlein[1,2], Jonathan Joseph Carter[1,2], and Sina Maria Koehlenbeck[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstraße 38, 30167 Hannover, Germany — [2]Institut für Gravitationsphysik der Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Optical fibers proved to be a powerful tool for several applications in the field of laser optics. Here, we contemplate the use of polarization maintaining fibers in interferometric displacement sensors as a tool to minimize the difference of the optical paths of two signals. In an interferometer, a probe and a reference signal is required. Any disturbance that is not common will couple directly into the detected signal of the interferometer. It is therefore advantageous to minimize the difference in the optical path of the signals, we achieve this by sending the signals through the same fiber. To suppress interference between the signals before it is desired, the polarization of the signals must be orthogonal. Therefore, we will study the crosstalk between the two polarization states inside the fiber and its coupling to induced phase noise. We present an optical setup that allows us to measure the strength of the noise due to the crosstalk of polarization states in a fiber. The phase fluctuations will be compared in real time before and after coupling to the fiber, and the differential measurement serves as a monitor of induced noise by the fiber.

Q 32: Members' Assembly

Time: Wednesday 13:00–14:00 Location: F342

All members of the Quantum Optics and Photonics Division are invited to participate.

Q 33: Quantum Gases: Bosons IV

Time: Wednesday 14:30–16:30 Location: A320

Q 33.1 Wed 14:30 A320

Tomography of a number-resolving detector by reconstruction of an atomic many-body quantum state — •Mareike Hetzel[1], Luca Pezzè[2], Cebrail Pür[1], Martin Quensen[2], Andreas Hüper[1,5], Jiao Geng[3,4], Jens Kruse[1,5], Luis Santos[6], Wolfgang Ertmer[1,5], Augusto Smerzi[2], and Carsten Klempt[1,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]QSTAR and INO-CNR and LENS, Firenze, Italy — [3]Key Laboratory of 3D Micro/Nano Fabrication and Characterization of Zhejiang Province, Westlake University, Hangzhou, China — [4]Institute of Advanced Technology, Westlake Institute for Advanced Study, Hangzhou, China — [5]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), DLR-SI, Hannover, Germany — [6]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

The high-fidelity analysis of many-body quantum states of indistinguishable atoms requires the accurate counting of atoms. Here we report the tomographic reconstruction of an atom-number-resolving detector. The tomography is performed with an ultracold rubidium ensemble that is prepared in a coherent spin state by driving a Rabi coupling between the two hyperfine clock levels. The coupling is followed by counting the occupation number in one level. We characterize the fidelity of our detector and show that a negative-valued Wigner function is associated with it. Our results offer an exciting perspective for the high-fidelity reconstruction of entangled states and can be applied for a future demonstration of Heisenberg-limited atom interferometry.

Q 33.2 Wed 14:45 A320

Bose-Einstein condensation for hard-core bosons: Universal upper bound and Bogoliubov theory — •Martina Jung, Sophie Brass, Julia Liebert, Sebastian Paeckel, and Christian Schilling — Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München

Hard-core bosons (HCBs), subjected to an artificial Pauli principle with respect to the lattice site basis, are not only of broad physical relevance due to their close relation to Spin-1/2 operators, but their theoretical description has recently revealed some intriguing conceptual features: the mixed commutation relations of HCB creation and annihilation operators give rise to a universal upper bound on the number of HCBs that can condense in the maximally delocalized state.

In this talk, we explain when and how this universal bound on the maximally possible degree of condensation - given by $f = 1-\nu$, where ν is the filling factor - is saturated and dictates the physical behaviour of HCBs. In particular, we show by exact numerical means that this novel exclusion principle lies at the heart of the quantum phase transition in the one-dimensional lattice gas model. Based on this observation we then propose and work out a Bogoliubov theory specifically for HCBs in the regime of almost maximal condensation $f \approx 1-\nu$.

Q 33.3 Wed 15:00 A320

Optimal preparation of spin squeezed states with one-dimensional Bose-Einstein Condensates — •Tiantian Zhang, Mira Maiwöger, Filippo Borselli, Yevhenii Kuriatnikov, Jörg Schmiedmayer, and Maximilian Prüfer — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien.

Rubidium Bose-Einstein Condensates (BECs) in double wells is spin squeezed in their ground state. However, direct preparation of two condensates is limited by thermal noise in the relative degree of freedom. We circumvent this on our experiment by spatially split a single one-dimensional condensate into two using radio-frequency dressing along the transverse direction of the trap with an Atom Chip. Our single-atom-sensitive fluorescence imaging system makes the sub-shot-noise detection of the number imbalance possible. We present a simple yet effective short-cut to adiabatic splitting. It exploits tunnelling dynamics in the Bosonic Josephson Junction. We have not only observed experimentally an overall enhanced number squeezing compared to direct splitting to a decoupled trap, but also directly measured the oscillation of the number squeezing. The oscillation frequencies scale with the plasma frequencies and have been measured across two orders of magnitude. We can further improve the efficiency by implementing a splitting quench. This enforces squeezing with the trap frequency which is a few times above the experimentally accessible plasma frequencies.

Q 33.4 Wed 15:15 A320

Engineering Correlated Spin-Momentum Pairs in a Quantum Gas Coupled to an Optical Cavity — Fabian Finger, Rodrigo Rosa-Medina, •Nicola Reiter, Panagiotis Christodoulou, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Quantum correlations among the constituents of many-body systems determine their fundamental properties. Quantum gases with their pristine control over external and internal degrees of freedom offer a versatile platform to manipulate and detect such correlations at a microscopic level. Here, we report on the observation of correlated atomic pairs in specific spin and momentum modes. Our implementation relies on Raman scattering between different spin levels of a spinor Bose-Einstein condensate, which is induced by the interplay of a running-wave transverse laser and the vacuum field of an optical cavity. Far-detuned from Raman resonance, a four-photon process gives rise to collectively-enhanced spin-mixing dynamics. We investigate the statistics of the produced pairs and explore their non-classical character through noise correlations in momentum space. Our results demonstrate a new platform for fast generation of correlated pairs in a quantum gas and provide prospects for matter-wave interferometry using entangled motional states.

Q 33.5 Wed 15:30 A320

Interference of two composite bosons — Mama Kabir Njoya Mforifoum, Andreas Buchleitner, and •Gabriel Dufour — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

We study the Hong-Ou-Mandel interference of two identical composite bosons, each formed of two bosonic or fermionic constituents, as they scatter against a potential barrier in a one-dimensional lattice. For tightly bound composites, we show that the combination of their constituents' mutual interactions and exchange symmetry gives rise to an effective interaction between the composites, which induces a reduction of the interference contrast.

Q 33.6 Wed 15:45 A320

A dipolar quantum gas microscope — •Ralf Klemt[1], Kevin Ng[1], Jens Hertkorn[1], Paul Uerlings[1], Akshay Shankar[2], Lucas Lavoine[1], Tim Langen[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Indian Institute of Science Education and Research, Mohali

In this talk, we present experimental and theoretical efforts towards studying dipolar Bose- and Fermi-Hubbard models using ultracold dipolar quantum gases in optical lattices. In addition to Hubbard models which only incorporate short-range interaction, the anisotropic dipolar interactions found in dysprosium, allow us to introduce (next-) nearest neighbor interactions. This opens up the possibility to explore a wide range of problems ranging from quantum magnetism and lattice spin models to topological matter. We will discuss examples of quantum phases both with local and non-local order and lay out a path towards realizing and observing them experimentally.

We will present our new setup, which is designed to combine the single-site resolution of a quantum gas microscope with the long-range and anisotropic interactions found in lanthanides. We will use fermionic and bosonic isotopes of dysprosium trapped in an UV optical lattice with a lattice spacing of 180 nm. The short lattice spacing will significantly enhance the dipolar nearest neighbor coupling to be about 200 Hz (10 nK). We will combine this setup with a single-particle, spin- and energy resolved super-resolution imaging technique, in order to be able to extract almost arbitrary density correlation functions.

Q 33.7 Wed 16:00 A320

Towards coupling atomic tweezers to an optical cavity — •Stephan Roschinski, Johannes Schabbauer, Davide Natale, Giacomo Hvaring, Iris Haubold, Nicole Heider, Alexander Heiss, Marvin Holten, and Julian Léonard — Atominstitut, TU Wien, Austria

A central goal of current research is to efficiently create entangled states among an increasing number of qubits. While atomic platforms provide great scalability, they mostly rely on local interactions, for instance, collisional or Rydberg interactions. We describe the progress to build a novel platform to entangle atoms with non-local operations using photon-mediated interactions. The atoms will be trapped within individual optical tweezers which are coupled to the field of an optical cavity. Large optical access through a high-resolution microscope objective will enable us to individually address each atom and control its coupling with all-to-all connectivity. Further advantages of this platform include partial non-destructive readout and efficient multi-qubit entanglement operations. In the long term, the proposed platform provides a scalable path to studying many-body systems with programmable connectivity, as well as an efficient atom-photon interface for quantum communication applications.

Q 33.8 Wed 16:15 A320

Floquet analysis of quantum dynamics in periodically driven optical lattices — •Usman Ali[1], Martin Holthaus[2], and Torsten Meier[1] — [1]Paderborn University, Department of Physics, Warburger Strasse 100, D-33098 Paderborn, Germany — [2]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany

Ultracold atoms in optical lattices exhibit very rich dynamics in response to time-periodic driving. With amplitude and frequency of the driving field being the main control parameters, it is shown that the initial phase of the drive induces significantly and qualitatively different dynamics. We discuss how the role of the phase can be understood within Floquet formalism. An approach that is based on the quantum pendulum approximation, allows to analytically obtain the quasi-energy spectrum and the Floquet states. This approximation is well justified for resonant driving conditions, yet our interpretations provide a general understanding of the dynamics. We evaluate our approach for an experimentally relevant example.

Q 34: Quantum Communication (joint session QI/Q)

Time: Wednesday 14:30–16:30 Location: B305

See QI 21 for details of this session.

Q 35: Quantum Optics: Cavity and Waveguide QED II

Time: Wednesday 14:30–16:30 Location: E001

Q 35.1 Wed 14:30 E001

Observation of superradiant bursts in waveguide QED — Christian Liedl, Felix Tebbenjohanns, •Constanze Bach, Sebastian Pucher, Arno Rauschenbeutel, and Philipp Schneeweiss — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Dicke superradiance describes the collective decay dynamics of a fully inverted ensemble of two-level atoms. There, the atoms emit light in the form of a short, intense burst due to a spontaneous synchronization of the atomic dipoles. Typically, to observe this phenomenon, the atoms must be placed in close vicinity of each other. In contrast, here we experimentally observe superradiant burst dynamics with a one-dimensional ensemble of atoms that extends over thousands of optical wavelengths. This is enabled by coupling the atoms to a nanophotonic waveguide, which mediates long-range dipole-dipole interactions between the emitters. The burst occurs above a threshold atom number, and its peak power scales faster with the number of atoms than in the case of standard Dicke superradiance. Moreover, we study the coherence properties of the burst and observe a sharp transition between two regimes: in the first, the phase coherence between the atoms is seeded by the excitation laser. In the second, it is seeded by vacuum fluctuations. Our results shed light on the collective radiative dynamics of spatially extended ensembles of quantum emitters and may turn out useful for generating multi-photon Fock states as a resource for quantum technologies.

Q 35.2 Wed 14:45 E001

Applications of cooperative subwavelength quantum emitter arrays — •Nico Bassler[1,2], Michael Reitz[1], Kai Phillip Schmidt[2], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University, Erlangen, Germany

Abstract: We describe applications of subwavelength quantum emitter arrays as optical elements and in the context of chiral hybrid cavity design. A single two-dimensional array can act as an optical atom-thick metasurface with a narrow reflectivity window [1]. For normal illumination, the cooperative optical response, stemming from emitter-emitter dipole exchanges, can be augmented via externally tunable magnetic fields to control the state of polarization in transmission [2]. This is particularly interesting for the case of circularly polarized light, where the array can act as a chiral mirror, thus allowing the design of strongly frequency dependent, hybrid [3], chiral cavities. We then consider the application of such chiral cavities to the sensitive detection of chirality in enantiomers.

[1] J. Rui, D. Wei, A. Rubio-Abadal, S. Hollerith, J. Zeiher, D. M. Stamper-Kurn, C. Gross, and I. Bloch, *A subradiant optical mirror formed by a single structured atomic layer,* Nature 583, 369 (2020). [2] N. S. Bassler, M. Reitz, K. P. Schmidt, C. Genes, Linear optical elements based on cooperative subwavelength emitter arrays, arXiv:2209.03204 (2022). [3] O. Cernotik, A. Dantan and C. Genes, Cavity quantum electrodynamics with frequency-dependent reflectors, Phys. Rev. Lett. 122, 243601 (2019).

Q 35.3 Wed 15:00 E001

Waveguide-coupled superconducting nanowire single-photon detectors enhanced by subwavelength grating metamaterials — •Alejandro Sánchez-Postigo, Connor Graham-Scott, and Carsten Schuck — Institute of Physics, University of Münster, Heisenbergstraße 11, 48149 Münster, Germany

Waveguide-coupled superconducting nanowire single-photon detectors (SNSPDs) have developed into one of the most attractive single-photon detector technologies for integrated quantum photonics. Embedding ultra-short, transversally oriented superconducting nanowires within optical cavities have enabled waveguide-coupled SNSPDs with ultra-fast reset times and low timing jitter. However, actual devices exhibit on-chip detection efficiencies (OCDE) as low as 30%, mainly due to scattering loss in the crossing between the waveguide and the slab that supports the nanowire.

Subwavelength grating (SWG) metamaterials are periodic structures that, patterned at a scale that is smaller than the operating wavelength, allow for synthesizing artificial materials with tailored refractive index. In the last years, SWG structures have enabled many silicon photonics devices with unprecedented performance, including waveguides, fiber-chip couplers and filters. These promising metamaterials hold great potential for engineering the integration of SNSPDs with nanophotonic waveguides and tailoring the detector performance.

Here we show our progress on integrating, for the first time, SNSPDs with SWG structures, with the aim of reducing the scattering loss of the former and hence increasing their OCDE.

Q 35.4 Wed 15:15 E001

Inverse design approach to x-ray quantum optics with Mössbauer nuclei in cavities — Oliver Diekmann[1,2], Dominik Lentrodt[1,3], and •Jörg Evers[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Institute for Theoretical Physics, Vienna University of Technology, Austria — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Nanometer-sized thin-film cavities containing ensembles of Mössbauer nuclei have been demonstrated to be a rich platform for x-ray quantum optics [1]. At low excitation, these systems allow one to implement tunable artificial quantum systems at hard x-ray energies. However, until recently, the inverse problem of determining a cavity structure which realizes a desired level scheme remained unsolved. In this talk, I will introduce the inverse design and develop a comprehensive optimization which allows one to determine optimum cavity systems realizing few-level schemes with desired properties [2,3]. Using this approach, the accessible parameter spaces of artificial multi-level systems can be characterized. Further, I will discuss a number of qualitative insights into x-ray photonic environments for nuclei that will likely impact the design of future x-ray cavities and thereby improve their performance.

[1] R. Röhlsberger and J. Evers, in: Yoshida and Langouche (eds.), Modern Mössbauer Spectroscopy, Springer Vol. 137, p. 105 (2021).
[2] O. Diekmann, D. Lentrodt and J. Evers, Phys. Rev. A 105, 013715 (2022).
[3] O. Diekmann, D. Lentrodt and J. Evers, Phys. Rev. A 106, 053701 (2022).

Q 35.5 Wed 15:30 E001

Spectral dynamics of a strongly coupled system of Yb atoms in a high-finesse cavity — Dmitriy Sholokhov, •Saran Shaju, Ke Li, and Jürgen Eschner — University of Saarland, Saarbrücken, Germany

We trap ^{174}Yb atoms in a MOT using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, thereby creating a considerably colder and denser atomic cloud as compared to the case of MOT trapping on the dipole-allowed, 28 MHz wide $^1S_0$ - $^1P_1$ line at 399 nm [1]. The cloud resides in a 5 cm long, ~45 000 finesse optical cavity resonant with the 556 nm transition. We observe strong nonlinear interaction between cavity and atoms which, together with the time-dependent atom number inside the cavity mode, leads to complex dynamics of the system. In this contribution we characterize and analyze time-dependent and spectral properties of the light emitted into cavity and free space.

[1] H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, J. Eschner, Phys. Rev. A 99, 013415 (2019)

Q 35.6 Wed 15:45 E001

Controlling the spontaneous emission of trapped ions for quantum applications — •Giovanni Cerchiari, Yannick Weiser, Lorenz Panzl, and Rainer Blatt — Universität Innsbruck, Technikerstrasse 25/4, A-6020 Innsbruck, Austria

Trapped atomic ions are one of the most prominent platforms for bridging the gap between fundamental quantum physics research and quantum technology applications. In ions, laser excitation is used to encode quantum information into the electronic excited states, which, however, are unstable and can spontaneously relax by photon emission. The spontaneous emission of photon is recognized as one of the key constraints for the long-term storage of information and for the encoding process. In this contribution, I will explain why we believe that spontaneous emission is not a fundamental limit, but rather a phenomenon that may be controlled and suppressed to enhance quantum technology.

Q 35.7 Wed 16:00 E001

Subradiant States in Cavity QED — •Tom Schmit[1], Alexander Baumgärtner[2], Simon Hertlein[2], Carlos Máximo[2], Davide Dreon[2], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

We analyse theoretically self-organization of transversally pumped atoms that strongly couple to two cavity modes in the dispersive regime by means of the quantum master equation of Ref. [1]. We determine the stationary state and discuss the emerging phase diagram as a function of the experimental control parameters. We argue that, when the atomic detuning from the pump is on the blue, the atoms selforganize in patterns that exhibit the characteristics of subradiance. We then analyse the stability of these subradiant states by means of a quantum Euler equation, which we derive from the master equation in an appropriate limit. We compare our predictions with experimental measurements in the corresponding regime and find qualitative and quantitative agreement. ~\\ $[1]$ S. B. J{\"a}ger, T. Schmit, G. Morigi, M. J. Holland, and R. Betzholz, Phys. Rev. Lett. \textbf{129}, 063601 (2022).\\ $[2]$ P. Zupancic, D. Dreon, X. Li, A. Baumgärtner, A. Morals, W. Zheng, N. R. Cooper, T. Esslinger, and T. Donner, Phys. Rev. Lett. \textbf{123}, 233601 (2019).

Q 35.8 Wed 16:15 E001

Waveguide QED with Rydberg superatoms — •Nina Stiesdal[1], Lukas Ahlheit[1], Kevin Kleinbeck[2], Jan Kumlin[3], Anna Spier[1], Jan de Haan[1], Hans-Peter Büchler[2], and Sebastian Hofferberth[1] — [1]IAP, University of Bonn — [2]ITP3, University of Stuttgart — [3]CCQ, Aarhus University

The field of Waveguide QED investigates how light in a single mode propagates through a system of localized quantum emitters. If the coupling between individual photons and emitters is sufficiently strong, the photons can mediate an effective interaction between the emitters, creating a many-body system. The cascaded interaction with saturated emitters can be interpreted as a photon-photon interaction.

We realize effective two-level emitters by exploiting the Rydberg blockade effect. By confining $N{\sim}10.000$ atoms to a single blockaded volume, the ensemble only supports a single excitation creating a so-called Rydberg superatom. Due to the collective nature of the excitation, the superatom effectively represents a single emitter coupling strongly to single photons. The directional emission of the superatom into the initial probe mode realizes a waveguide-like system in free-space without any actual light-guiding elements.

This talk will discuss how we scale this system from one to few strongly coupled superatoms to study how the propagation of quantized light fields through a small emitter chain results in photon-photon correlations and entanglement between the emitters. We also show how we use controlled dephasing of the collective excitation into collective dark states to subtract exact photon numbers from an incoming pulse.

Q 36: Quantum Technologies (joint session Q/MO/QI)

Time: Wednesday 14:30–16:30 Location: E214

Invited Talk Q 36.1 Wed 14:30 E214

BMBF-Förderprogramm: Wissenschaftliche Vorprojekte — •Bernhard Ihrig und Johannes Mund — VDI Technologiezentrum GmbH

Die zweite Quantenrevolution und die schnell voranschreitenden Entwicklungen in der Photonik bieten großes Potenzial für Anwendungen in Ökonomie, Ökologie und Gesellschaft. Zugleich sind neue Erkenntnisse aus der Grundlagenforschung in einem frühen Stadium hinsichtlich der Herausforderungen und Risiken bei der Umsetzung oftmals kaum zu beurteilen. Daher müssen wissenschaftlich-technische Vorarbeiten eine Grundlage schaffen, die es ermöglicht, das Potenzial einer neuen Erfindung bzw. der neuen wissenschaftlichen Erkenntnis zu bewerten.

Das Bundesministerium für Bildung und Forschung (BMBF) beabsichtigt daher, sogenannte Wissenschaftliche Vorprojekte (WiVoPro) im Bereich der Photonik und der Quantentechnologien auf Grundlage des Forschungsprogramms Quantensysteme zu fördern. Das Ziel dieser Vorprojekte besteht darin, wissenschaftliche Fragestellungen im Hinblick auf zukünftige industrielle Anwendungen in den Quantentechnologien und der Photonik zu untersuchen. Sie sollen die bestehende Forschungsförderung ergänzen und eine Brücke zwischen Grundlagenforschung und industriegeführter Verbundförderung schlagen.

Wir als Projektträger VDI Technologiezentrum GmbH möchten die Maßnahme in diesem Rahmen vorstellen, bewerben und Ihre Fragen für eine mögliche Förderung beantworten.

Q 36.2 Wed 15:00 E214

Mikrofabrikation von Ionenfallen für einen skalierbaren Quantencomputer — •Eike Iseke[1,2], Friederike Giebel[1,2], Nila Krishnakumar[1,2], Konstantin Thronberens[1,2], Jacob Stupp[1,2], Amado Bautista-Salvador[1,2] und Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Hannover, Deutschlad — [2]Physikalisch Technische Bundesanstalt, Braunschweig, Deutschland

Die Ionenfallentechnologie ist eine vielversprechende Option auf dem Weg zur Entwicklung eines skalierbaren Quantencomputers. Eine mögliche Realisierung stellt die Multilagen-Ionenfalle dar [1]. Durch multiple Lagen wird die Integrationsdichte entscheidend erhöht und es können neuartige Ionenfallendesigns realisiert werden.

Die zunehmende Komplexität der Fallen stellt neue Anforderungen an die Mikrofabrikationsmethoden. Forschung und Entwicklung in diesem Feld fokussieren sich unter anderem auf die Interposer-Technologie, das Thermokompressionsbonden und die Substratdurchkontaktierung mittels TSVs (through silicon vias).

Diese fortschrittlichen Fabrikationsmethoden ermöglichen die Skalierung der Plattform sowohl durch die Möglichkeit die Anzahl der geführten Signale zu erhöhen, als auch durch die gesteigerte Zuverlässigkeit der Verbindungstechnologie.

Q 36.3 Wed 15:15 E214

Squeezed States of Light for Future Gravitational Wave Detectors at a Wavelength of 1550 nm — •Fabian Meylahn[1,2], Benno Willke[1,2], and Henning Vahlbruch[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — [2]Leibniz Universität Hannover, D-30167 Hannover, Germany

The generation of strongly squeezed vacuum states of light is a key technology for future ground-based gravitational wave detectors (GWDs) to reach sensitivities beyond their quantum noise limit. For some proposed observatory designs, an operating laser wavelength of 1550 nm or around 2 μm is required to enable the use of cryogenically cooled silicon test masses for thermal noise reduction. Here, we present the first the direct measurement of up to 11.5 dB squeezing at 1550 nm over the complete detection bandwidth of future ground-based GWDs ranging from 10 kHz down to below 1 Hz. Furthermore, we directly observe a quantum shot-noise reduction of up to 13.5 dB at megahertz frequencies. This allows us to derive a precise constraint on the absolute quantum efficiency of the photodiode used for balanced homodyne detection. These results hold important insight regarding the quantum noise reduction efficiency in future GWDs, as well as for quantum information and cryptography, where low decoherence of nonclassical states of light is also of high relevance.

Q 36.4 Wed 15:30 E214

A single-photon source based on hot Rydberg atoms — •Jan Reuter[1,2], Max Mäusezahl[3], Felix Moumtsilis[3], Tilman Pfau[3], Tommaso Calarco[1,2], Robert Löw[3], and Matthias Müller[1] — [1]Forschungszentrum Jülich GmbH — [2]Universität zu Köln — [3]Universität Stuttgart

The leading effects of a single-photon source based on Rydberg atoms are the strong van-der-Waals interaction between the atoms as well as the collective decay of the atom ensemble. Our setup is a vapor cell filled with Rubidium atoms which we excite via three different laser pulses. The decay of this excitation will then lead to the emission of a single photon. To ensure robustness, we investigated the behavior of moving Rydberg atoms and optimized the laser pulse sequence. For that, we simulated the transitions of Rubidium atoms from the ground state over the Rydberg state up to the singly-excited collective states. We can show that the collective decay of the single excitations leads to a fast and directed photon emission, while double excitations show no or only weak collective properties.

Q 36.5 Wed 15:45 E214

Resolving photon numbers using ultra-high-resolution timing single-channel electronic readout of a conventional superconducting nanowire single photon detector — •Gregor Sauer[1,2], Mirco Kolarczik[3], Rodrigo Gomez[1,2], Helmut Fedder[3], and Fabian Steinlechner[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [3]Swabian Instruments GmbH, 70435 Stuttgart, Germany

Photon-number-resolving (PNR) detectors are indispensable building blocks for applications in quantum communications, computing, and sensing. PNR is commonly achieved by multiplexing onto several superconducting nanowire single-photon detectors (SNSPD) or using transition-edge sensors with energy- and photon-number resolution. This comes at the cost of resource overhead (for multiplexing) or long recovery times (for transition-edge sensors).

Here, we show how ultra-high-resolution timing measurements of the rising and falling edge of electrical pulses generated from the SNSPDs enable to distinguish photon numbers of up to 5 in a single-shot measurement. This provides a practical and comparably low-cost PNR detector, offering high detection efficiency and operational repetition rate. We present the implementation of such a PNR detector system (in the telecom C-band) and its characterization by measuring the photon-number statistics of a 300fs-pulsed coherent input source with tunable average photon number and repetition rate.

Q 36.6 Wed 16:00 E214

N00N-states for super-resolving quantum imaging and sensing — •Gil Zimmermann[1] and Fabian Steinlechner[1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany

Quantum measurement techniques can serve to improve precision imaging and sensing through entanglement. Employing N00N-states, i.e., maximally path-entangled photon-number states of two modes, the Heisenberg limit 1/N with N photons can be reached in precision phase measurements, thus overcoming the shot-noise limit. Furthermore, the Rayleigh diffraction limit can be overcome by a factor N. Therefore, the goal is to efficiently generate high N00N-states with N>2 to improve current sensing schemes achieving super-resolution and super-sensitivity. High-N00N states with N=5 photons have already been generated experimentally with high fidelity, as shown by Afek et al. This talk will focus on schemes with relatively low complexity to generate high N00N-states. In addition, applications of high-N00N states, e.g., in the context of quantum-enhanced lidar systems or quantum microscopy, are discussed, taking into account their high fragility due to interactions with the environment.

Q 36.7 Wed 16:15 E214

Non-destructive measurement of phonon number states using the Autler-Townes effect — •Marion Mallweger[1], Murilo de Oliveira[2], Robin Thomm[1], Harry Parke[1], Natalia Kuk[1], Gerard Higgins[1,3], Romain Bachelard[2,4], Celso Villas-Boas[2], and Markus Hennrich[1] — [1]Department of Physics, Stockholm University, Sweden — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil — [3]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Sweden — [4]Université Côte d'Azur, CNRS, Institut de Physique de Nice, France

Quantum technologies employing trapped ion qubits are currently some of the most advanced systems with regards to experimental methods in quantum computation, simulation and metrology. This is primarily due to the excellent control available over the ions' motional and electronic states. In this work we present a new method to measure the distribution of motional number states in a non-destructive manner. The technique can be applied to all platforms where a quantum harmonic oscillator is coupled to a three level system. We demonstrate the technique using a single trapped $^{88}Sr^{+}$ ion. The method relies on the Autler-Townes effect that arises when two levels are strongly coupled while being probed by a third level. If the two levels are coupled on a sideband transition, then the magnitude of the Autler-Townes splitting depends on the phonon number state. This new method provides a robust and efficient way of measuring motional states of quantum harmonic oscillators. It can even be applied to perform single shot measurements of phonon number states in a non-destructive way.

Q 37: Collisions (with Q) (joint session MO/Q)

Time: Wednesday 14:30–16:15 Location: F142

See MO 10 for details of this session.

Q 38: Ultra-cold Plasmas and Rydberg Systems I (joint session A/Q)

Time: Wednesday 14:30–16:30 Location: F303

See A 18 for details of this session.

Q 39: Quantum Optics & Nano-Optics

Time: Wednesday 14:30–16:30 Location: F342

Q 39.1 Wed 14:30 F342

Ultra-small superconducting Nb-based plasmonic perfect absorbers single mode fiber coupled photodetectors — •Philipp Karl[1], Sandra Mennle[1], Monika Ubl[1], Ksenia Weber[1], Pavel Ruchka[1], Mario Hentschel[1], Philipp Flad[1], Jing-Wei Yang[2,3], Tzu-Yu Peng[2,3], Yu-Jung Lu[2,3], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Research Center for Applied Sciences, Academia Sinica, Taipei 11529, Taiwan — [3]Department of Physics, National Taiwan University, Taipei 10617, Taiwan

Quantum technologies require high-quality and efficient photodetectors and the ability to detect single photons, which can be provided by superconducting nanowire single photon detectors.

In this work, we present a superconducting niobium-based plasmonic perfect absorber detector and utilize the tunable plasmonic resonance to create a photodetector with near-100% absorption efficiency in the near-infrared spectral range. To reach the near-100% absorption, we take advantage of resonant plasmonic perfect absorber effects. This leads to an angle insensitivity and a high resonant absorption cross-section, which enable ultra-small active areas and short recovery times.

The ultra-small active areas are aided by a directly coupled single mode fiber in combination with high NA micro optics, which are printed onto the fiber.

Q 39.2 Wed 14:45 F342

Frequency Conversion in pressurized Hydrogen — •Alireza Aghababaei — Nussallee 12, 53115 Bonn, Deutschland

State-preserving frequency conversion in the optical domain is a necessary component in many configurations of quantum information processing and communication. Thus far, nonlinear crystals are used for this purpose. Here, we report on a new approach based on coherent anti-Stokes Raman scattering (CARS) in dense molecular hydrogen gas. This four-wave mixing process sidesteps the limitations imposed by crystal properties, it is intrinsically broadband and does not generate an undesired background. We demonstrate this method by converting photons from 434 nm to 370 nm and show that their polarization is preserved.

Q 39.3 Wed 15:00 F342

Low-noise quantum frequency conversion of single photons from silicon-vacancy centers in diamond to the telecom C-band — •Marlon Schäfer, Benjamin Kambs, Tobias Bauer, Dennis Herrmann, David Lindler, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

The vast majority of systems suitable as a quantum emitter for quantum communications show optical transitions in the visible or near infrared spectral region. Therefore, quantum frequency conversion (QFC) into low-loss telecom bands is the key enabling technology for long-range fiber-based quantum networks. Here, in addition to achieving high conversion efficiencies, the key issue is to minimize the conversion-induced noise photons in the target band. Especially conversion schemes that require a mixing wavelength in the vicinity of the target wavelength lead to high noise counts. A promising quantum emitter affected by this is the silicon-vacancy (SiV) center in diamond, where direct conversion to 1550 nm implies a mixing wavelength at 1405 nm, thus resulting in strong Raman and SPDC noise.

We present an efficient and low-noise QFC device converting SiV photons into telecom C-band. In a two-stage conversion process, the photons are first converted to an intermediate wavelength and then transduced to the target wavelength. This greatly increases the spectral distance between the mixing and the target wavelength, leading to very low noise rates of less than 1 photon/s/GHz. We discuss current limitations and applicability to other platforms such as SnV centers.

Q 39.4 Wed 15:15 F342

Towards interfacing a multiplexed warm vapor quantum memory with single photons from cavity enhanced spontaneous parametric down-conversion — •Leon Messner[1,2], Elizabeth Robertson[2,3], Luisa Esguerra[2,3], Helen Chrzanowski[2], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Berlin, Germany — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany

Recent investigation [1] shows that a significant speed-up in intercontinental quantum key distribution is achievable by having quantum memories with on the order of 10^3 randomly accessible storage modes. We present our latest results on a spatially multiplexed warm vapor EIT memory [2] with the ability to scale beyond this number, while having modest technological requirements. In future, this will allow isolated deployment away from laboratory infrastructure and facilitate remote operation on satellites and similarly insular locations. To gain a deeper understanding of the challenges presented by integrating these memories into quantum networks, we are planning to interface them with single photons generated by spontaneous parametric down-conversion inside a monolithic cavity [3,4].

[1] Wallnöfer, J. et al., Commun Phys **5**, 169 (2022)
[2] Esguerra, L. et al., arXiv:2203.06151 **[quant-ph]** (2022)
[3] Mottola, R. et al., Optics Express **28**, 3159-3170 (2020)
[4] Buser, G. et al., PRX Quantum **3**, 020349 (2022)

Q 39.5 Wed 15:30 F342

Two-Step Frequency Conversion from 637nm to telecom wavelengths in a PPLN waveguide — •Joscha Hanel — AG Nanooptik, Humboldt-Universität zu Berlin — AG Ding, ATMOS, Leibniz Universität Hannover

In the future, the reliable on-demand generation of single photons at telecommunication wavelengths will be an essential tool in mid- to long-range quantum communication networks. However, many known single photon sources operate at wavelengths in the visible or near-infrared, where transmission in telecommunication fibers is far from optimal. A promising technology to bridge this wavelength gap is quantum frequency conversion. In this talk, a novel device is presented that was designed to convert light from 637nm to telecommunication wavelengths using difference frequency generation (DFG). The heart of the device is a periodically poled LiNbO3 waveguide with two poling sections, allowing two consecutive DFG steps in a single waveguide using just one pump laser. While comparable one-step conversions have been performed in the past (e.g. Dréau et al., Phys. Rev. Applied 9, 064031 (2018)), this two-step approach promises a far better signal-to-noise ratio while keeping coupling losses minimal.

Q 39.6 Wed 15:45 F342

Quantum light source based on two-photon interferences — •Martin Cordier, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

The transmission of coherent light through an optically dense ensemble has wide applications ranging from biology to chemical spectroscopy. Since the 18th century it has been commonly described by Beer-Lambert's law. Recently, it has been shown that, the light transmitted through an ensemble of two-level emitters is violated due to incoherent scattering at the single emitter level [1]. Here, building on the work of [2,3], we realize an interferometer that allows us to tune the quantum phase between the transmitted coherent and incoherent light fields. By tuning this phase we show interference fringes in the photon coincidence rate. Beyond clarifying the fundamental nature of what is commonly termed incoherently scattered light, our study lends itself to developing applications in quantum technologies, such as novel quantum light sources.

[1] Veyron et al., Phys. Rev. Research 4, 033033 (2022).
[2] Mahmoodian, et al., Physical Review Letters 121, 143601 (2018).
[3] Prasad et al., Nature Photonics 1 (2020).

Q 39.7 Wed 16:00 F342

Optimized integration of quantum emitters on the Silicon platform — •Lida Shamsafar[1], Thomas Weiss[1,2], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute of Physics, University of Graz, and NAWI Graz, Graz, Austria

Stability and environmental control during operation is one of the necessary requirements desired for quantum-technological applications. The most promising way for such control of the surrounding is the direct integration of all required components on one chip. The most advanced and versatile platform for the implementation of highly complex and scalable photonic logic is the silicon platform. In this work, we utilize and optimize designs of photonic cavities in order to obtain high coupling efficiencies of quantum emitters to silicon waveguides. We will discuss how quantum emitter positioning will modify the light-matter interaction and how we can achieve best performance. Furthermore, radiation diagrams of TE and TM modes for the guided modes and free space modes are investigated in order to reduce radiative losses and maximize the coupling to the waveguides.

Q 39.8 Wed 16:15 F342

Single Mode Coupled Emission of Resonant Excited GaAs Quantum Dots — •Martin Kernbach[1,2], Julian Siller[1], Sophia Fuchs[1], and Andreas W. Schell[1,2] — [1]Leibniz Universität Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Quantum technologies like computing, QKD, or sensing demand for deterministic bright sources of single indistinguishable photons. In order to provide quantum light of isolated systems properly usable for quantum information science, an efficient excitation and extensive collection in a single mode is required. Single molecules and cavity confined quantum dots are convenient sources. The coupling to the excited state is maximized on resonance, but challenges the usability of the emitter due to the costs for the separation of the optical excitation mode from the mode of emission. A temporal, spacial, spectral, or combined method for separation is typically used. Here we present a realization of a single emitter under resonant excitation in a confocal setup coupled into a single mode fiber with the emission mode filtered by polarization. So far, a free beam is directed on the objective mounted with the scanning stages on a 1 m long stick in a liquid helium reservoir. For resonant cw excitation of GaAs semiconductor quantum dots a SNR of polarization suppression up to 100 and count rates of 280 kcps are archived by using a collecting lens with NA 0.68 only. Under this scheme further investigations regarding the blinking behavior are possible as well as probing alternative emitters like single molecules.

Q 40: Photonics II

Time: Wednesday 14:30–16:30 Location: F442

Q 40.1 Wed 14:30 F442

Bispectral High-Reflectivity Metamirrors — •Liam Shelling Neto[1], Johannes Dickmann[1], and Stefanie Kroker[1,2] — [1]TU Braunschweig, Institut für Halbleitertechnik, Braunschweig — [2]Physikalisch-Technische Bundesanstalt, Braunschweig

To manipulate electromagnetic waves in unique ways, metasurfaces, the two-dimensional variant of metamaterials, have opened up a whole new world of optical functionalities. From optical imaging to quantum optics, the full potential of metasurfaces depends heavily on their building blocks, i.e. metaatoms. To design metaatoms that meet tight requirements, as is the case in high-precision optical metrology, machine learning has shown promising results in the past years. Here we show preliminary results for implementing such a framework to design focusing metamirrors that provide high reflectivities for two different wavelengths. With high reflectivity and a tailored phase profile, such metamirrors could outperform conventional multilayer mirrors for high-precision optical interferometry due to their low thermal noise.

Q 40.2 Wed 14:45 F442

Light transport in designed symmetric multiple-scattering media — •Sudhir Saini[1], Kayleigh Start[1], Evangelos Marakis[2], and Pepijn Pinkse[1] — [1]MESA+ Institute for Nanotechnology, University of Twente, The Netherlands — [2]Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, Crete, Greece

The latest advancement in nanofabrication technology enables the exact synthesis of designed scattering media with features on the scale of the optical wavelength. To the best of our knowledge, random scattering media with global symmetries do not naturally occur. Here we use modern nanofabrication to study the effect on light propagation of mirror-symmetric disorder in a multiple-scattering medium. A commercial direct laser writing technique based on two-photon polymerization is used to fabricate the designed three-dimensional (3D) mirror-symmetric disordered samples. Light transport experiments combined with quantitative 3D modeling are used to study the effect of mirror symmetry on the medium's scattering properties. The optical characterization results establish polarization-dependent deviations at the symmetry plane from the bulk ensemble-averaged intensity distribution when pumped in an equally mirror-symmetric way. In the weak-scattering limit, Drexhage's theory for the emission properties of an emitter above a mirror predicts the experimentally observed intensity patterns well. We model our experiments with FE numerical methods in the multiple-scattering regime. Applications are envisioned in fundamental light propagation studies and anti-counterfeiting.

Q 40.3 Wed 15:00 F442

Nonlocal optical response of finite hyperbolic metamaterials — •Olga Kochanowska[1,2] and Christin David[1] — [1]Institute of Condensed Matter Theory and Optics, Abbe Center of Photonics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Faculty of Physics, University of Warsaw, Pasteura Street 5, 02-093 Warsaw, Poland

Metamaterials are artificial nano-engineered structures with properties beyond those encountered in nature. Especially interesting are hyperbolic metamaterials (HMMs), i.e. highly anisotropic media characterized by a hyperbolic dispersion relation. HMMs exhibit unusual properties, such as negative refraction of light, with applications in sub-diffraction imaging, refractometric sensing and photovoltaics. In our studies, a type II HMM (consisting of alternating metal and dielectric layers) was analyzed, using Finite-Difference Time-Domain (FDTD) and Fourier Modal Method (FMM) for numerical calculations. Initially, we assumed the local-response approximation (LRA), in which nonlocal effects are neglected. However, as in an HMM metal layers are of subwavelength thickness, the quantum nature of free electrons and their interactions in metals play a significant role and spatial dispersion effects are considered. Therefore, we implement the semi-classical hydrodynamic model into the FMM to account for nonlocal effects in hyperbolic gratings. Consequently, we compare the optical response of type II HMM in different geometries in the LRA and nonlocal case. We determine optimal parameters of the hyperbolic nanostructure at which nonlocal effects are relevant.

Q 40.4 Wed 15:15 F442

Low thermal noise meta-mirrors with 99.95 % reflectivity — •Johannes Dickmann[1], Steffen Sauer[1,2], Liam Shelling Neto[1], and Stefanie Kroker[1,2] — [1]Technische Universität Braunschweig, Institut für Halbleitertechnik, Langer Kamp 6a/b, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Many experiments in fundamental science are limited by the thermal noise of optical components, e.g. interferometric gravitational wave detectors, optical atomic clocks or cavity experiments on dark matter and general relativity. It has been found that, in addition to quantum noise, which can be reduced by using squeezed states of light, it is primarily Brownian noise of the mirror coatings that limit the sensitivity of the measurements. One way to reduce this noise is to use mirror layers with small mechanical losses, but these are difficult to find, especially at cryogenic temperatures. We present extensive investigations on microstructured mirror surfaces, i.e. meta-mirrors, for applications in high precision metrology. In particular, noise calculations and record-breaking experimental results of the reflectivities of these mirrors are presented.

Q 40.5 Wed 15:30 F442

Modeling beam imperfection using Hermite-Gauss modes for interferometric simulations — •Kevin Weber, Gudrun Wanner, and Gerhard Heinzel — Albert Einstein Institut, Hannover, Germany

Precision laser interferometry is a widespread technique used across many disciplines due to its high measurement accuracy. Using such a technique allows us to see the changes in earth*s gravitational potential, as in the GRACE-FO mission, or enables us to detect ripples in space-time itself, known as gravitational waves, as in LIGO or VIRGO. For future missions which deploy inter-spacecraft interferometers, the prior knowledge of all noise contributions is crucial for its success. Until now, most of our simulations use only perfectly Gaussian or tophat beam geometries. However, experimental beams never possess the mathematically perfect shape the models assume. In this talk, we will discuss possible sources of noise contributions from imperfect beam geometries. Also, we show possible means to predict those using a system of Hermite-Gaussian modes as mathematical beam descriptions.

Q 40.6 Wed 15:45 F442

Creation of Gauss-Bessel quasi-nondiffracting beams using Optical Vortices — •Maya Zhekova, Nikolay Dimitrov, and Alexander Dreischuh — Sofia University "St. Kliment Ohridski", Faculty of Physics

In recent years a way of creating Gauss-Bessel quasi-nondiffracting beams (GBBs) has been investigated, using optical vortices (OVs), which have been created and later annihilated. In and behind the focus of a thin lens, the resulting beam turns out to be such GBB. Different setups using spiral vortex plates (VPs) have been investigated, but their seemingly main weakness is the wavelength usage limited to the design wavelength of the VPs.

A novel scheme for laser beam shaping has been proposed and investigated, which is applicable in a wide range of wavelengths. The setup's key OV element is a single VP designed for 532 nm, which will be proven to transform beams at 445 nm, 532 nm, 633 nm and 800 nm into GBBs. We will show that this setup can transform beams into not only zeroth-order GB beams. In the case when a residual topological charge is left, the resulting beam will be a first-order Gauss-Bessel beam, again with a lack of spectral sensitivity.

Q 40.7 Wed 16:00 F442

Optical convolutional neural network with atomic nonlinearity — •Mingwei Yang[1,2], Elizabeth Robertson[1,2], Luisa Esguerra[1,2], Kurt Busch[3,4], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt, Institute of Optical Sensor Systems, Berlin, Germany. — [2]Technische Universität Berlin, Berlin, Germany. — [3]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Berlin, Germany. — [4]Max-Born-Institut, Berlin, Germany.

Due to their inherent parallelism, fast processing speeds and low energy consumption, free-space-optics implementations have been identified as an attractive possibility for analog computations of convolutions [1,2]. However, the efficient implementation of optical nonlinearities for such neural networks still remains challenging. In this work, we report on the realization and characterization of a three-layer optical convolutional neural network where the linear part is based on a 4f-imaging system and the optical nonlinearity is realized via the absorption profile of a cesium atomic vapor cell. This system classifies the handwritten digital dataset MNIST with 83.96% accuracy, which agrees well with corresponding simulations. [1] H. J. Caulfield and S. Dolev, *Why future supercomputing requires optics,* Nat. Photonics 4, 261*263 (2010). [2] M. Miscuglio, Z. Hu, S. Li, J. K. George, R. Capanna, H. Dalir, P. M. Bardet, P. Gupta, and V. J. Sorger, *Massively parallel amplitude-only fourier neural network,* Optica 7, 1812*1819 (2020).

Q 40.8 Wed 16:15 F442

Dispersion Interferometry for Relative Atmospheric Pressure Measurement — •Hugo Uittenbosch, Peter Mahnke, Raoul-Amadeus Lorbeer, and Oliver Kliebisch — Institute of Technical Physics, German Aerospace Center, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

Second harmonic interferometry is a common method in fusion research to measure dispersive phase shifts, i.e. for line-average electron densities [1]. Using this technique, a contact-less, relative barometer is implemented by measuring the pressure-dependent dispersive phase shift in air. This change in phase is converted into a change in pressure via the Ciddor equation [2]. In order to minimize the footprint of the experimental setup, a single crystal dispersion interferometer (SCDI) [3] is improved upon by generating a reference beam which contains both the fundamental and second harmonic beam coaxially, thereby reducing the system complexity. The device is used to measure changes in the dispersion of air in a pressurized chamber between 10^1 to 10^5 Pa and compared against a piezoresistive pressure transceiver. The deviation between both sensors was found to be less than 150 Pa.

[1] Drachev, V. P., et al. "Dispersion interferometer for controlled fusion devices." Rev. Sci. Instrum. **64**(4) (1993)

[2] Ciddor, Philip E. "Refractive index of air: new equations for the visible and near infrared." Appl. Opt. **35**(9) (1996)

[3] Lee, Dong-Geun, et al. "The new single crystal dispersion interferometer installed on KSTAR and its first measurement." Rev. Sci. Instrum. **92**(3) (2021)

Q 41: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

Time: Wednesday 14:30–16:00 Location: F428

See A 19 for details of this session.

Q 42: Poster III

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

Q 42.1 Wed 16:30 Empore Lichthof

Fermionic coherent state path integral for ultrashort laser pulses and transformation to a field theory of coset matrices — •Bernhard Mieck — keine Institution

A coherent state path integral of anti-commuting fields is considered for a two-band, semiconductor-related solid which is driven by a ultrashort, classical laser field. We describe the generation of exciton quasi-particles from the driving laser field as anomalous pairings of the fundamental, fermionic fields. This gives rise to Hubbard-Stratonovich transformations from the quartic, fermionic interaction to various Gaussian terms of self-energy matrices; the latter self-energy matrices are solely coupled to bilinear terms of anomalous-doubled, anti-commuting fields which are subsequently removed by integration and which create the determinant with the one-particle operator and the prevailing self-energy. We accomplish path integrals of even-valued self-energy matrices with Euclidean integration measure where three cases of increasing complexity are classified (scalar self-energy variable, density-related self-energy matrix and also a self-energy including anomalous doubled terms). According to the driving, anomalous-doubled Hamiltonian part, we also specify the case of a SSB with hinge-fields which factorizes the total self-energy matrix by a coset decomposition into density-related, block diagonal self-energy matrices of a background functional and into coset matrices with off-diagonal block generators for the anomalous pairings of fermions. This allows to derive a classical field theory for the self-energy matrices of exciton quasi-particles by gradient expansions of the determinant.

Q 42.2 Wed 16:30 Empore Lichthof

Hybrid platform for quantum optic experiments — •Simon Haugg[1], Niklas Lettner[1], Lukas Antoniuk[1], Konstantin Fehler[1,2], Anna P. Ovvyan[3], Nico Gruhler[3], Valery A. Davydov[4], Viatcheslav N. Agafonov[5], Wolfram H. P. Pernice[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Moscow, Russia — [5]Universite F. Rabelais, 37200 Tours, France

In a hybrid approach, we are utilizing and manipulating the interaction of solid state quantum emitters in nano-hosts, such as color-centers in nano-diamonds, with classical Si_3N_4-based photonic crystal cavities, in order to yield an efficient spin-photon interface. We present our efforts to realize this goal, which paves the way to a realization of integrated on-chip hybrid quantum systems.

Q 42.3 Wed 16:30 Empore Lichthof

Orbital angular momentum modes generated in the parametric down-conversion process with a non-Gaussian pump — •Lucas Gehse, Dennis Scharwald, and Polina Sharapova — Universität Paderborn, Paderborn, Germany

Electric fields can carry two types of angular momentum. The first is the spin angular momentum, which arises from the polarization of the light, and the second is the orbital angular momentum (OAM) which arises from the light phase distribution. OAM modes have an unlimited basis, which makes them very promising for fast and efficient quantum information and communication protocols [1]. It has recently been shown that a radially symmetric parametric down-conversion (PDC) process is a good source of photons with perfectly anti-correlated orbital numbers in both low- and high-gain regimes [2]. In this work, we investigate an SU(1,1) interferometer consisting of two PDC sources, which are two nonlinear crystals pumped by a Laguerre–Gaussian pump with different orbital and radial numbers. We consider various crystal lengths, pump widths and distances between the crystals, in order to find configurations with high-order OAM modes populated. We have found configurations in which up to 120 OAM modes can be generated using a pump with different orbital numbers. Mode shapes and intensity profiles for various configurations of the SU(1,1) interferometer in the low- and high-gain regimes were investigated and discussed.

[1] Manuel Erhard *et al.*, Light Sci Appl **7**, 17146 (2018)
[2] Lina Beltran *et al.*, J. Opt. **19**, 044005 (2017)

Q 42.4 Wed 16:30 Empore Lichthof

An Experimental Setup to Study Amplification Without Inversion in Mercury — •Daniel Preissler and Thomas Walther — TU Darmstadt, Institute for Applied Physics, Laser and Quantum Optics, Schlossgartenstr. 7, D-64289 Darmstadt

For conventional laser sources, the required power to achieve the necessary population inversion scales with at least the fourth power of the laser frequency. This severaly limits the generation of lasers at short ultraviolet wavelengths and below. To overcome this problem, the coherent reabsorption can be suppressed by carefully employing atomic coherence effects. This is called lasing without inversion (LWI).

In a recent publication Rein et al. (Phys Rev. A **105** (2022) 023722) showed an experimental setup to study an LWI scheme in atomic mercury vapor, consisting out of two driving lasers at 435.8nm and 546.1nm, a repumper at 404.7nm and a probe system which doubles as a pump source at 253.7nm. This allowed for the further refinement of a theoretical model and its comparison with experimental data.

Based on this model, critical parameters towards achieving amplification withouth inversion (AWI) - a prerequisite for LWI - could be identified through simulations. This includes the power and spectral width of the pump system and the power of the strong driving field at 435.8nm.

In this contribution the results of those simulations as well as the experimental steps taken to improve on those parameters will be presented. Additionally, measurements of the observed three photon coherence effect will be discussed.

Q 42.5 Wed 16:30 Empore Lichthof

Rydberg Dark States on an Atom Chain Interacting with a Chiral Waveguide — •Tom von Scheven[1], Anne V. Jeschke[1], Igor Lesanovsky[1,2], and Beatriz Olmos[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We consider a laser-driven chain of atoms coupled to a chiral waveguide and investigate the possibility of creating so-called dark states, i.e. eigenstates of the atomic chain where the photons become trapped. Beyond their fundamental interest, atomic systems that host such dark states are nowadays widely investigated due to their potential applications in quantum information processing, e.g., as quantum memories. It has been previously found that, under the right combination of atomic and laser parameters, product states of entangled pairs (so-called dimer states) can be excited in a chain of two-level systems coupled to a chiral waveguide. Here, we analytically and numerically demonstrate the existence of a new class of entangled dark states by exploiting the strong interactions present in a chain of Rydberg atoms close to a waveguide. Compared to the dimer states, the conditions on the laser parameters necessary to excite a dark state (e.g. detuning pattern) are less restrictive. Moreover, these Rydberg dark states possess entanglement that is shared among all atoms are more robust against external perturbations, such as dissipation into unguided modes. Our results demonstrate the potential of using Rydberg atoms in quantum optical many-body systems in order to create dark states.

Q 42.6 Wed 16:30 Empore Lichthof

Modified dipole-dipole interactions in the presence of a nanophotonic waveguide — •Mathias Bo Mjøen Svendsen[1] and Beatriz Olmos[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

When an emitter ensemble interacts with the electromagnetic field, dipole-dipole interactions are induced between the emitters. The magnitude and shape of these interactions are fully determined by the specific form of the electromagnetic field modes. If the emitters are placed in the vicinity of a nanophotonic waveguide, such as a cylindrical nanofiber, the complex functional form of these modes makes the analytical evaluation of the dipole-dipole interaction cumbersome and numerically costly. In this work, we provide a full detailed description of how to successfully calculate these interactions, outlining a method that can be easily extended to other environments and boundary conditions. Such exact evaluation is of importance as, due to the collective character of the interactions and dissipation in this kind of systems, any small modification of the interactions may lead to dramatic changes in experimental observables, particularly as the number of emitters increases. We illustrate this by calculating the transmission signal of the light guided by a cylindrical nanofiber in the presence of a nearby chain of emitters.

Q 42.7 Wed 16:30 Empore Lichthof

Organic dye molecules as possible candidates for spin-photon interfaces — •Max Masuhr and Daqing Wang — Institute of Physics, University Kassel, Heinrich-Plett-Straße 40, Kassel, Germany

Polycyclic hydrocarbon molecules are bright photon emitters, exhibiting high quantum efficiencies and narrow transition linewidths when embedded in matrices and cooled to liquid helium temperatures. The synthetic flexibility of molecules allows for tuning of their emission wavelengths and makes them promising candidates for linking with other quantum systems. Apart from the favorable photon emission properties between the singlet states, the long-lived triplet states in these molecules provide opportunities for quantum information storage. Here, we discuss lifetime measurements of the triplet states and investigate the feasibility of realizing a spin-photon interface based on the singlet-triplet transition in a single molecule.

Q 42.8 Wed 16:30 Empore Lichthof

Fiber-coupled plug-and-play heralded single photon source based on $Ti{:}LiNbO_3$ **and polymer technology** — •Christian Kiessler[1], Hauke Conradi[2], Moritz Kleinert[2], Viktor Quiring[1], Harald Herrmann[1], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn — [2]Fraunhofer HHI Berlin, Einsteinufer 37, 10587 Berlin

A reliable, but cost-effective generation of single-photon states is key for practical quantum communication systems. Requirements like affordability, stability, miniaturized design and fiber compatibility are essential for these sources.

Here, we present the first chip-size fully integrated fiber-coupled Heralded Single Photon Source (HSPS) module based on a hybrid integration of Lithium-Niobate into a polymer board. A spontaneous parametric down conversion (SPDC) process with a pump wavelength of 532 nm leads to signal and idler of 810 nm and 1550 nm. The module has a size of (2×1) cm^2 and is fully fibercoupled with one pump input fiber and two output fibers for separated signal and idler. We measure a heralded second-order correlation function of $g_h^{(2)} = 0.05$ with a heralding efficiency of $\eta_h = 4.5\,\%$ at low pump powers.

Q 42.9 Wed 16:30 Empore Lichthof

Purcell-Enhanced Emission from Individual Color Center in Diamond to Photonic Crystal Cavities — •Lukas Antoniuk[1], Konstantin Fehler[1,2], Niklas Lettner[1,2], Anna P. Ovvyan[3,5], Richard Waltrich[1], Nico Gruhler[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3,5], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France — [5]Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Classical photonic platforms combined with solid state quantum emitters, like the SiV^- center in diamond, enable for efficient quantum photonic devices. In a hybrid approach, we combine the SiV^- center in nanodiamonds with an efficient on-chip Photonic Crystal Cavity based on a Si_3N_4 photonic platform [1]. Utilizing an atomic force microscope, we developed a routine for placing and optimization of the emitter inside the mode of the cavity. For individual optical transitions of a single SiV^- center we achieved a Purcell enhancement of more than 4 as well as lifetimes as short as 450 ps [2].

[1] Fehler, Konstantin G., et al. ACS Nano 2019, 13, 6, 6891-6898. [2] Fehler, Konstantin G., et al. ACS Photonics 2021, 8, 9, 2635-2641.

Q 42.10 Wed 16:30 Empore Lichthof

Optical Characterization of InGan/Gan-based nanowires — •Mohsen Esmaeilzadeh[1,2], Pablo Tieben[1,2], Soumyadip Chatterjee[3], Apurba Laha[3], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Institute for Solid State Physics, Leibniz University Hannover, 30167 Hannover — [3]Department of Electrical Engineering, Indian Institute of Technology Bombay,400076 Mumbai

Recent progress has been achieved in using GaN-based nanostructures as LEDs. GaN as a semiconductor exhibits great thermal and chemical stability and the potential for tuning the band gap by alloying with indium over visible wavelengths.

Indium composition in growing InGaN is very sensitive to temperature. The compositional non-uniformity in InGaN impacts the emission wavelength of the InGaN nanostructures. We are specifically investigating the optical properties of single InGaN/GaN-based nanowires grown on Si (111) substrate using RIBER MBE C21 system equipped with a Veeco plasma cell.

A high resolution SEM microscope was used to investigate the morphology and structure of single nanowires. We used confocal fluorescence microscopy technique to determine the corresponding optical emission properties for a broad range of excitation wavelengths in the visible spectrum. Moreover, we studied the possible damage threshold of the nanowires by exposing them to high laser power for an extended period of time and observing the stability of the emission. Simultaneously, we monitored the corresponding fluorescence spectrum.

Q 42.11 Wed 16:30 Empore Lichthof

A quantum Rabi model with two interacting qubits — •Thomas J. Hamlyn[1,2] and Weibin Li[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham, Nottingham NG7 2RD, United Kingdom

We study a modified quantum Rabi model with a monochromatic bosonic mode and two qubits coupled via a spin-spin interaction. We focus on eigenstates of the model in two different regimes. Without qubit mixing, the Hilbert space can be divided into two symmetry sectors. It is found that the model can be reduced to the standard Rabi model, and therefore the eigenenergy can be obtained systematically through solving the so-called $\mathcal{G}$-function. With the qubit mixing, we study the superradiant phase transition with the mean field and direct diagonalization method, both giving consistent results. It is found that the symmetry of the ground state is broken. We explore the symmetry breaking by varying system parameters. Using a variety of methods, we show the dependence of the symmetry breaking on the qubit mixing

Q 42.12 Wed 16:30 Empore Lichthof

Optical properties of InGaN quantum dot embedded on GaN nanowire — •Hiren Dobariya[1], Pablo Tieben[1,2], Swagata Bhunia[3], Suddhasatta Mahapatra[3], Apurba Laha[3], and Andreas W. Schell[1,2] — [1]Institute for Solid State Physics, Gottfried Wilhelm Leibniz University, 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [3]Department of Electrical Engineering, Indian Institute of Technology Bombay, 400076 Mumbai

III-Nitride group-based materials, particularly Indium Gallium Nitride (InGaN) have emerged as one of the most critical materials for various applications, such as solid-state lighting, quantum technology, and scientific research. The unique nanostructure of GaN nanowires with quantum dots of InGaN embedded has been in focus for near-UV photonics research in general, as well as its room-temperature single photon generation. In this work, we present the detailed optical characterization of InGaN quantum dots embedded in GaN nanowires, grown by Plasma Assisted Molecular Beam Epitaxial (PAMBE) technique to realize sub-10 nm InGaN quantum dots exhibiting strong quantum confinement. We have carried out a detailed study on the optical characterizations of the InGaN quantum dots (QDs) in a home-built confocal microscope setup. The photoluminescence properties of the InGaN quantum dot at room temperature and cryogenic temperatures show strong emissions ranging from the green to red in the electromagnetic spectrum.

Q 42.13 Wed 16:30 Empore Lichthof

Machine-learning optimized entanglement in photonic topological insulators — •Saipavan Vengaladas[1,2], Armando Pérez-Leija[4], Kurt Busch[1,3], and Konrad Tschernig[4] — [1]Max-Born-Institut, 12489 Berlin, Germany — [2]Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany — [3]Humboldt-Universität zu Berlin, AG Theoretische Optik & Photonik, 12489 Berlin, Germany — [4]CREOL/College of Optics & Photonics, University of Central Florida, Orlando, 32816 FL, USA

Photonic Floquet topological insulators feature so-called edge states, and wavepackets built from edge states are topologically protected. As a result, they naturally resist the scrambling effects of disorder and retain their shape during propagation. This useful property gives rise to the intriguing possibility of protecting two-photon entangled states. While the necessary conditions to protect two-photon entanglement in topological insulators (TIs) have been well established[1], it is yet unclear how to construct optimally entangled two-photon states. This is no trivial task since the degree of entanglement, and the amount of bulk scattering are naturally competing properties inside TIs. In this work, we take a more general approach by defining a black-box optimization problem, which is tackled using a machine-learning based Latent Action Monte Carlo Tree Search (LA-MCTS) meta-algorithm[2]. We present the optimized states that we obtain by exploring the space of all possible states and discuss their properties. [1] K.Tschernig et al., Nat. Commun.12, 1974 (2021). [2] arxiv.org/abs/2007.00708

Q 42.14 Wed 16:30 Empore Lichthof

On-chip single-photon subtraction by individual silicon vacancy centers in a laser-written diamond waveguide — Michael Koch[1,2], •Vibhav Bharadwaj[1,3], Michael Höese[1], Johannes Lang[1], John P. Hadden[4], Roberta Ramponi[3], Fedor Jelezko[1,2], Shane M. Eaton[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]IQst, Ulm University, D-89081 Ulm, Germany — [3]Istituto di Fotonica e Nanotecnologie (IFN-CNR), Milan, Italy — [4]School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, UK

Apart from its perfect to application properties of hardness, transparency and thermal conductivity, diamond has created an interest in the quantum technologies community due to naturally occurring imperfection in the form of color centers such as Nitrogen vacancy (NV) and Silicon Vacancy (SiV). They have emerged as candidates for quantum computing and field sensing applications. Recently, Laser writing has allowed 3-d formation of photonic and microfluidic devices in diamond [1] with the ability to integrate waveguide with Ion implanted single SiV centers. In this poster, we show single-emitter extinction measurements from SiV coupled to a waveguide demonstrating single-photon subtraction from a quasi-coherent field resulting in super-Poissonian light statistics[2]. Our architecture enables light field engineering in an integrated design on the single quantum level.

[1] Bharadwaj V et al. Journal of Physics: Photonics (2019): 022001

[2] M. K. Koch et al., ACS Photonics 9, 3366-3373 (2022)

Q 42.15 Wed 16:30 Empore Lichthof

Sum-frequency generation in diced ridge waveguides in periodically poled $LiNbO_3$ — •Noel Heinen, Christian Kiessler, Michelle Kirsch, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

In order to make quantum technology commercially usable, it must be integrated into the existing optical C-band fiber network. However, there are devices based on nitrogen vacancies in diamonds with an operating wavelength of 639 nm, which therefore require a frequency converter interface. Here, we demonstrate a SFG process in titanium indiffused diced ridge waveguides in periodically poled $LiNbO_3$ for a conversion of 1550 nm and 1064 nm pump wavelengths to 630 nm. We performed simulations and mode field measurements to analyse the light guiding conditions of the waveguides and to find optimum fabrication parameters, since dicing of waveguides with a dicing saw is a new fabrication method in our group. We measure transmission losses below 0.8 $\frac{\text{dB}}{\text{cm}}$ and a normalized SFG conversion efficiency of $\eta_{\text{norm}} = 7.4\,\frac{\%}{\text{W}\cdot\text{cm}^2}$ at pump powers of a few milliwatts.

Q 42.16 Wed 16:30 Empore Lichthof

Open-system dynamics and fluctuation-dissipation relation in a photon Bose-Einstein condensate — •Aleksandr Sazhin[1], Göran Hellman[1], Fahri Emre Öztürk[1], Frank Vewinger[1], Johann Kroha[2], Vladimir Gladilin[3], Michiel Wouters[3], Martin Weitz[1], and Julian Schmitt[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]Physikalisches Institut, Universität Bonn, Nussallee 12, D-53115 Bonn — [3]TQC, Universiteit Antwerpen, Universiteitsplein 1, B-2610 Antwerpen

The tuneable openness of optical quantum gases, as photon or polariton condensates in optical microcavities, enables the exploration of new system states and phases, which would not be accessible under closed system conditions. Here, we experimentally demonstrate a non-Hermitian phase transition in a photon Bose-Einstein condensate in an open dye-filled optical microcavity. The transition separates a phase of biexponential photon number correlations from both lasing and an intermediate, oscillatory regime, as characterised by the second-order correlation dynamics of the BEC [1]. By studying the magnitude of the condensate number fluctuations and relating them to a response function, we verify a fluctuation-dissipation relation for the BEC coupled to a molecular reservoir [2]. In more recent work, we have extended these studies to the time domain, establishing a connection between the fluctuation dynamics and the response of the condensate population to an external pulse-like perturbation of the molecular reservoir. [1] F. E. Öztürk et al., Science 372, 88 (2021) [2] F. E. Öztürk et al., arXiv:2203.13255 (2022)

Q 42.17 Wed 16:30 Empore Lichthof

Integrated Photonics for Quantum Computing and Communication — •Jonas Zatsch[1,3], Jeldrik Huster[1,3], Simon Abdani[1,3], Christian Schweikert[2], and Stefanie Barz[1,3] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Institute of Electrical and Optical Communications Engineering, University of Stuttgart, 70569 Stuttgart, Germany — [3]Center for Integrated Quantum Science and Technology (IQST)

Future quantum information research aims at the realisation of computationally powerful quantum computers and the secure implementation of quantum communication protocols. This requires an increasing number of components with small footprint, high phase stability and low-loss connectivity. A promising scalable technology is integrated quantum photonics, allowing for a compact and robust manipulation of photonic quantum bits. We present an integrated photonic chip, based on the silicon-on-insulator platform, enabling photonic quantum information processing. We demonstrate the generation of photonic quantum states on chip using integrated beam splitters and phase shifters. We show the conversion of quantum information from one degree of freedom – path – to another – polarisation – and vice versa. Combining this conversion with efficient fibre coupling allows one to connect several chips and thus the implementation of networked protocols for quantum communication and quantum computing.

Q 42.18 Wed 16:30 Empore Lichthof

Generalized Description of the Spatio-Temporal Biphoton State in Spontaneous Parametric Down-Conversion — •Baghdasar Baghdasaryan[1,2], Carlos Sevilla-Gutiérrez[3], Fabian Steinlechner[3,4], and Stephan Fritzsche[1,2,4] — [1]Theoretisch-Physikalisches Institut, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [4]Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Spontaneous parametric down-conversion (SPDC) is a widely used source for photonic entanglement. Years of focused research have led to a solid understanding of the process, but a cohesive analytical description of the paraxial biphoton state has yet to be achieved. We present a simple-to-use closed expression for the biphoton state. The approach describes the full spectral and spatial properties of all interacting beams and applies to a wide range of experimental settings. The analytical treatment of the biphoton state decomposed into discrete Laguerre Gaussian (LG) modes also provides a deeper insight into the role of the Guoy phase in PDC. Especially, the coupling strength of spatial and spectral degrees of freedom (DOF) in PDC is fully controlled by the Gouy phase of pump, signal and idler beam. The control over the Gouy phase can be used to engineer entangled state separable in spatial and spectral DOF.

Q 42.19 Wed 16:30 Empore Lichthof

Generalized Ramsey Protocols — •Maja Scharnagl — Institute for theoretical physics, Leibniz University Hannover, Germany

We consider a variational class of generalized Ramsey protocols with two one-axis-twisting (OAT) operations, one before and one after the phase imprint, for which we optimize the direction of the signal imprint, the direction of the second OAT interaction and the measurement direction via a numerical routine for global optimization of constrained parameters. In doing so, we distinguish between protocols whose signal from spin projection measurements exhibits a symmetric or antisymmetric dependence on the phase to be measured. We find that the Quantum Fisher Information, which bounds the sensitivity achievable with a one-axis-twisted input state, can be saturated in our variational class of protocols for nearly all initial squeezing strengths. Therefore, the generalized Ramsey protocols considered here allow us to reduce quantum projection noise in comparison to the standard Ramsey protocol considerably.

Q 42.20 Wed 16:30 Empore Lichthof

Development of a stable, compact and cost-effective laser light source for resonant control of tin-vacancy color centres — •Franziska Marie Herrmann[1], Joseph Hugh Deakin Munns[1], Cem Güney Torun[1], and Tim Schröder[1,2] — [1]Integrated Quantum Photonics, Institut für Physik, Humboldt-Universität zu Berlin — [2]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Tin-vacancy colour centres in diamond are promising candidates for nodes in quantum networks, due to their suitable optical and spin properties. However, with a zero phonon line wavelength of 619 nm, resonant excitation cannot be achieved easily by commercially available and affordable laser systems. At 1238 nm however, narrowband lasers are commercially available and the targeted 619 nm can be reached by frequency doubling. Here we introduce a stable and cost-effective lasersystem relying on second harmonic generation for resonant quantum control of tin vacancy centres, describe the stabilization measures taken and demonstrate the functionality of the system by driving all-optical rabi oscillations.

Q 42.21 Wed 16:30 Empore Lichthof

Properties of SiV centers in nanodiamonds for quantum networks — •Richard Waltrich[1], Marco Klotz[1], Niklas Lettner[1], Lukas Antoniuk[1], Viatcheslav Agafonov[2], and Alexander Kubanek[1] — [1]Institut für Quantenoptik, Universität Ulm — [2]Universite Francois Rabelais de Tours

The realization of a quantum network is of major interest. Combining the good optical and spin properties of group IV defects in diamond with established technologies in photonic-structure production puts such a platform into reach. We present measurements of characteristic properties of SiV centers in nanodiamond in comparison with bulk diamond, showing key features for the realization of a quantum network node.

Q 42.22 Wed 16:30 Empore Lichthof

Characterization of an ultra broadband integrated MIR photon pair source — •Abira Gnanavel, Franz Roeder, Olga Brecht, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Broadband photon-pairs from parametric down-conversion (PDC) are of interest for spectroscopy at low light levels and applications such as entangled two-photon absorption.

Here, we present the design and characterization of periodically poled lithium niobate waveguides to generate ultra-broadband, non-degenerate photon pairs via type II PDC in the near-infrared and mid-infrared regime. We especially engineer the dispersion of those waveguides regarding the quasi-phase matching condition.

We present a condition where the signal and idler photons are group velocity matched and furthermore group velocity dispersion matched that is, they propagate at the same velocity but incur opposite amounts of chirp. The photons are generated in a periodically poled titanium-indiffused lithium niobate waveguide at wavelengths of 800nm and 2800nm, well suited for detection and MIR probing. We expect a spectral bandwidth exceeding 27 THz for this process when pumping with a low-cost cw laser diode. A higher bandwidth in the frequency domain results in tighter correlations in the time domain and thus an increased photon simultaneity, which is desirable for ultrafast spectroscopy applications because it enables better measurement precision.

Q 42.23 Wed 16:30 Empore Lichthof

Quantum Fluctuation Forces between Trapped Nanospheres — •Clemens Jakubec[1], Kanupriya Sinha[2], Uros Delic[1], and Pablo Solano[3] — [1]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [2]School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ 85287-5706, USA — [3]Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Concepción, Chile

We present an analysis of the quantum fluctuation forces between two dielectric nanospheres trapped via optical tweezers. We develop a full quantum description of the radiative forces between the two nanospheres considering their mutual interaction mediated via the classical trapping field and the quantum fluctuations of the electromagnetic field. An analysis of the three separate contributions to the total potential – the Casimir-Polder potential, the classical trap potential and the optical binding potential – is presented. The total potential is subsequently studied as a function of various parameters, such as the tweezer field intensity and phase, demonstrating that, for appropriate sets of parameters, there exists a mutual bound state of the two nanospheres which can be ~ 1000 K deep. Our results are pertinent to ongoing experiments with trapped nanospheres in the macroscopic quantum regime.

Q 42.24 Wed 16:30 Empore Lichthof

Characterization of an ultra-broadband integrated MIR photon pair source — •Abira Gnanavel, Franz Roeder, Olga Brecht, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

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Q 42.25 Wed 16:30 Empore Lichthof

Photon correlations of trapped calcium ion crystal — •Zyad Shehata, Stefan Richter, Manuel Bojer, and Joachim von Zanthier — FAU Erlangen-Nürnberg, Quantum Optics and Quantum Information, Staudtstr. 1, 91058 Erlangen, Germany

Trapped ions are an important resource for quantum information science. Here, we study the collective light emission of trapped calcium ion crystals, in particular the photon auto- and cross-correlations. Simultaneous photon bunching and anti-bunching emerge from such systems [1]. In this work, we focus on the first-, second-, and third-order correlation functions of two- and three-ion crystals taking into account concrete experimental conditions, in particular the contrast-reducing Debye-Waller factor. Various illumination schemes of the ions are discussed in the context of the trap geometry, getting analytical and numerical solutions for the second- and third-order correlation functions, including predictions for their signal-to-noise ratio.

[1] S. Wolf, S. Richter, J. von Zanthier, F. Schmidt-Kaler, Light of Two Atoms in Free Space: Bunching or Antibunching?, Phys . Rev, Lett. 124, 063603 (2020)."

Q 42.26 Wed 16:30 Empore Lichthof

Cryogenic ensemble spectroscopy of Europium molecular complexes — •Weizhe Li, Evgenij Vasilenko, Jannis Hessenauer, Senthil Kumar Kuppusamy, Mario Ruben, and David Hunger — Karlsruhe Institut für Technologie, Karlruhe, Germany

Rare Earth Ions (REI) doped into solid state crystals have long optical coherence time and even longer spin coherence time. This makes REI a promising candidate for spin qubits which are optically addressable. For integration into photonic structures, nano-scale materials are of particular interest. In Europium-doped nanocrystals (Eu^{3+}:Y_2O_3), an optical coherence time of 3.7 μs and spin coherence time of 3 ms were obtained [1, 2, 3]. More recently, crystallized molecular complexes hosting REI have shown excellent optical coherence lifetimes of more than 10 μs and long spin population lifetimes [4], evidencing a quiet local environment.

This opens up a promising direction to explore further. In our research, we investigate different Eu^{3+}-based molecules including the complex used in [4]. We perform cryogenic ensemble spectroscopy and spectral hole burning and consistently observe long-lived spin states and narrow homogeneous optical linewidths.

[1] J. Bartholomew et al. Nano letters 17.2(2017), pp. 778-787.
[2] A. Perrot et al. Physical review letters 111.20 (2013), p. 203601.
[3] D. Serrano et al. Nature communications 9.1 (2018), pp. 1-7.
[4] D. Serrano et al. Nature 603.7900 (2022), pp. 241-246.

Q 42.27 Wed 16:30 Empore Lichthof

Cryogenic characterization of Electrical circuits — •Anupam Kumar, Niklas Lamberty, Thomas Hummel, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Electrical components are typically optimized for operation near room temperature. Using these components for quantum photonics applications in the future will likely require operation at cryogenic temperatures since the measurement is often performed using superconducting detectors.

In this work, we characterize different electrical components made of various semiconductor platforms such as SiGe, GaAs, and InGaP. These commercial components are characterized at 4K and compared to each other for optimal performance. This allows the design of front-end electrical circuitry for SNSPDs, leading up to a single IC design.

Q 42.28 Wed 16:30 Empore Lichthof

Feed-forward for optical circuits with cryogenic electronics — •Niklas Lamberty, Thomas Hummel, Frederick Thiele, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Many quantum optical experiments require high purity single-photon states. For this purpose, we developed a cryogenic electronic feed-forward circuit for selection of single-photon states from a PDC source. The photon number is measured using a photon number resolving superconducting detector array operated at 1 K and evaluated by an amplifier and a logic circuit based on SiGe Heterojunction Bipolar Transistor and CMOS technology. The circuit is operated in a cryostat at 2.5 K.

A total signal delay of (59 ± 7) ns and a heatload of more than 5 mW was measured. The circuit achieved reliable selection of single photon detection events, when tested with a coherent state, and creates signals usable for a modulator driver.

Q 42.29 Wed 16:30 Empore Lichthof

Quantumness and speedup limit of a qubit under transition-frequency modulation — •Amin Rajabalinia[1], Mahshid Khazaei Shadfar[2,3], Farzam Nosrati[2,3], Ali Mortezapour[1], Roberto Morandotti[3], and Rosario Lo Franco[2] — [1]Department of Physics, University of Guilan, P. O. Box 41335-1914, Rasht, Iran — [2]Dipartimento di Ingegneria, Universit'a di Palermo, Viale delle Scienze, 90128 Palermo, Italy — [3]INRS-EMT, 1650 Boulevard Lionel-Boulet, Varennes, Quebec J3X 1S2, Canada

we investigate the ability of a frequency-modulated qubit embedded in a leaky cavity to maintain quantumness. To detect quantum coherence as the main distinguishing feature of the quantum world from the classical one, tomographic methods are used to reconstruct the density matrix of quantum systems. Although the implementation of such a strategy poses a technical challenge in terms of experimental measurement settings, Leggett-Garg inequality and quantum witness have been introduced as quantum indicators to quantify the nonclassicality of a system in order to overcome the complexity of detection in the experiment. The quantum witness is based on the classical no-signaling-in-time assumption, which states that a previous experiment has no effect on the statistical outcome of the subsequent experiment. We compare a standard quantum witness (SQW) and a recently introduced optimized quantum witness (OQW) as experimentally friendly figures of merit [Phys. Rev. A 101, 012331 (2020)]. The OQW successfully identifies quantum coherence protection via frequency modulation, whereas the SQW fails.

Q 42.30 Wed 16:30 Empore Lichthof

Towards the observation of collective radiance phenomena in a one-dimensional array of waveguide-coupled atoms with sub-$\lambda/2$ spacing — •Lucas Pache, Martin Cordier, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, Germany

Recently, it has been shown theoretically that the infidelity of photon storage and retrieval in quantum memories scales exponentially better with the number of emitters if one harnesses the collective response of closely spaced atomic arrays [1,2]. This improved scaling relies on the effect of selective radiance, i.e., destructive interference of scattering into undesired modes. This occurs when the mean distance in a periodic array of emitters is smaller than half of the atomic resonant wavelength ($d < \lambda/2$). In order to realize this situation, we trap and optically interface laser-cooled cesium atoms using a two-color nanofiber-based dipole trap which is composed of a blue-detuned partial standing wave and a red-detuned running wave light field. The resulting trapping potential consists of one-dimensional trapping sites which are spaced by $d \simeq 0.37\lambda$. We characterize this trapping configuration by measuring the trap frequencies as well as the lifetime and the total number of the trapped atoms.

[1] A. Asenjo-Garcia et al. PRX 7, 031024 (2017)
[2] M. Manzoni et al. NJP 20, 083048 (201

Q 42.31 Wed 16:30 Empore Lichthof

Multimode squeezed states in coherent optical time-frequency networks — •Patrick Folge, Matteo Santandrea, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Linear optical quantum networks are powerful tools in modern quantum applications and have gained a lot of attention due to their role in proving quantum computational advantages. Here, we present a resource efficient method for the implementation of linear optical quantum networks in a high-dimensional time-frequency encoding. We consider a multimode squeezing source based on type-0 parametric down-conversion (PDC) in the high gain regime as the quantum input of the system. To implement a linear optical network in the frequency bin basis we consider the use of a so-called quantum pulse gate (QPG), which allows for time-frequency mode selective frequency conversion. Here, the QPG is applied to coherently filter out input bins from the multimode squeezed state and superimpose them on the output ports of the QPG. This allows for the implementation of fully programmable linear quantum networks on the frequency bin basis. Here, we present our theoretical modeling of this system by applying it to the simple case of a frequency beam splitter. In this modelling we find that wider coherent filtering of the selected bins improves the performance of the network.

Q 42.32 Wed 16:30 Empore Lichthof

A few-MHz linewidth tunable optical filter based on a fibre-ring-resonator — •Gabriele Maron, Xinxin Hu, Luke Masters, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

We present a design for an ultra-narrowband, tunable optical filter, which is based on a fibre ring resonator. It consists of a fibre coupler with a variable splitting ratio, which allows us to set the filter linewidth and on-resonance transmission. At the same time, we set and actively stabilize the central frequency of the filter by means of actuators that change the optical round trip length of the fibre-ring. Operated in a notch-filter configuration, we recently used this device to isolate and investigate the incoherent emission from a single optically trapped atom, which was excited with near-resonant laser light [1]. The addition of a second variable fibre coupler into the fibre-ring extends the device's utility for filtering in an add-drop configuration. In this case, our characterisation reveals a resonator linewidth significantly narrower than the D_2 transition of ^{85}Rb, while maintaining a high transmission into the drop port. The tunability of the filter properties presents our device as a versatile platform for selective frequency filtering with a subnatural atomic linewidth resolution.

[1] L. Masters et al, arXiv:2209.02547 (2022)

Q 42.33 Wed 16:30 Empore Lichthof

Implementation of a sub 10 ps RMS jitter TDC for Hanbury Brown Twiss measurements in Astronomy — •Verena Leopold[1], Yury Prokazov[2], Evgeny Trubin[2], Stefan Richter[1], and Joachim von Zanthier[1] — [1]FAU, Erlangen, Germany — [2]Photonscore, Magdeburg, Germany

For Hanbury Brown Twiss measurements in Astronomy, it is crucial to detect photon arrival times very precisely from multiple detectors. Usually a TDC (Time-to-Digital- Converter) is used for recording this time stream. However, for these low contrast, long-running measurements, available TDCs show disadvantages. The main challenges are low quality analog inputs and non-linearities on short ps-timescales. We succesfully implemented a TDL (Tapped-Delay-Line) TDC inside an FPGA displaying a RMS jitter of (3.24 ± 0.03) ps with non-linearities on the order of 0.32%. As a next step the TDC will be tested in the lab before measuring a real star in Calern.

Q 42.34 Wed 16:30 Empore Lichthof

Manipulation of fluorescence emission as a tool for quantum optics experiments — •Yannick Weiser, Lorenz Panzl, Giovanni Cerchiari, and Rainer Blatt — University of Innsbruck, Technickerstraße 25, 6020 Innsbruck, Austria

We control the spontaneous emission of a trapped Ba^+ ion by back reflecting the fluorescence light of the ion onto itself via a mirror. Due to this retro reflection, the emitted photon interferes with itself, which enhances, or suppresses the emission rate, depending on the ion-mirror distance. We are working in two regimes. A static one, where the distance between the ion and the mirror is fixed and a dynamic one, where the optical path length is modulated. In both cases, applications in the field of quantum optics and quantum optomechanics are investigated.

In the static regime, we will alter the decay rate of the ion with a spherical mirror. This can suppress the fluorescence rate to 6% of its natural value. Using the spherical mirror, not only position measurements down to the quantum level are possible, but also the variance of the motional state becomes accessible. Since this scheme relies on the interaction of the fluorescence light with the emitter, no narrow internal transition is needed.

In the dynamic regime, the ion-mirror optical path will be modulated with a phase modulator. By driving the modulation with the motional frequency of the ion we can cool, or excite the ion's motion.

Q 42.35 Wed 16:30 Empore Lichthof

Second-order correlations of scattering electrons — •Florian Fleischmann[1], Mona Bukenberger[2], Raul Corrêa[3], Anton Classen[4], Simon Mährlein[1], Marc-Oliver Pleinert[1], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Department of Environmental Systems Science, ETH Zürich, 8092 Zürich, Switzerland — [3]Departamento de Física, Federal University of Minas Gerais, 31270-901 Belo Horizonte, Brazil — [4]Department of Soil and Crop Sciences, Texas A&M University, TX 77843 College Station, USA

We investigate the spatial second-order correlation function of two scattering electrons in the far field. First, we consider semi-classically the effects of the Pauli exclusion principle and Coulomb repulsion on the expected correlation pattern. This is followed by a full quantum-mechanical treatment of the problem. For this, we separate the system into center-of-mass and relative coordinates in analogy to the hydrogen atom ansatz. While the center-of-mass system is described as a free particle, we solve the Coulomb scattering problem in the relative system. We expand the respective initial state of the electrons in the eigenstates of the scattering problem. After incorporating the time evolution, the function is evaluated in the far field. We show the formal solution to the problem and discuss the current state of the numerical investigations.

Q 42.36 Wed 16:30 Empore Lichthof

Optimised single photon sources based on monolithic cavity-enhanced spontaneous parametric downconversion — •Helen Chrzanowski[1], Xavi Barcons Planas[1], and Janik Wolters[1,2] — [1]German Aerospace Center (DLR), Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany

Despite its limitations, spontaneous parametric downconversion (SPDC) remains the favoured platform for single photon generation in quantum information (QI) science. Exploiting developments in non-linear optics, recent years have ushered in increasingly sophisticated approaches to source engineering, including group velocity matching, waveguide geometries and bespoke poling techniques. Another approach of growing interest embeds the non-linear crystal within an optical cavity. Cavity-enhanced SPDC enjoys several advantages: firstly, it shifts accessible photon bandwidths from THz to GHz, enabling efficient interfacing with matter-based qubits. Such narrow spectral bandwidths also protect photon pairs from the deleterious effects of material dispersion. Secondly, the confinement of a cavity yields precise selectivity of spectral and spatial modes while also enhancing brightness - allowing high efficiencies and purities. Here, we theoretically investigate photon pair sources in resonant monolithic cavities utalising PPLN and PPKTP. We find design parameters that simultaneously optimise purity and (heralding) efficiency, while also allowing for spectral tunablity and requiring limited filtering. The development of highly pure and efficient narrowband photon pairs is a crucial tool to realise next generation of QI demonstrations.

Q 43: QI Poster II (joint session QI/Q)

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

See QI 23 for details of this session.

Q 44: Integrated Photonics II (joint session Q/QI)

Time: Wednesday 17:00–19:00 Location: A320

Q 44.1 Wed 17:00 A320

Integrated bright broadband PDC source for quantum metrology — •René Pollmann, Franz Roeder, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Broadband quantum light is a vital resource for quantum metrology applications such as quantum spectroscopy, quantum optical coherence tomography or entangled two photon absorption. For entangled two photon absorption especially very high brightness combined with high spectro temporal entanglement is crucial to observe a signal. So far these conditions could be met by using high power lasers driving bulk degenerate type 0 spontaneous parametric down conversion (SPDC) sources. This naturally limits the available wavelength ranges and precludes deterministic control over the output state. In this work we show an integrated two colour SPDC source utilising a group-velocity matched lithium niobate waveguide, reaching both high brightness ($> 6.7 \cdot 10^{11}$ pairs/Ws) and large bandwidth (> 6 THz) while using less than 5 mW of continuous wave pump power. Since the product of the measured correlation time of the photons $\Delta\tau \approx 80$ fs and the pump bandwidth of $\Delta\omega_p \ll 1$ MHz violates the classical Fourier limit, the source shows very strong time frequency entanglement. Furthermore our process can be adapted to a wide range of central wavelengths.

Q 44.2 Wed 17:15 A320

Diced ridge waveguides in titanium indiffused lithium niobate — •Michelle Kirsch, Christian Kiessler, Christof Eigner, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Lithium niobate (LN) is a widely used platform for integrated optical devices due to its optical properties, especially the high second order nonlinearity. Well-established titanium indiffused waveguides (Ti:LN) are limited in the ability of creating tightly confined fields due to the low index contrast. Another limitation in Ti:LN waveguide devices is the occurrence of intensity induced photorefractive damage inhibiting applications with high optical intensities in the waveguides. To counteract these challenges we use a ridge waveguide structure to achieve higher confinement in horizontal direction by precision diamond blade dicing in Ti:LN. We analysed the properties of the guided modes in dependence of the waveguide geometry for 1550 nm. Furthermore, we fabricated periodically poled ridge waveguides and characterized the second harmonic generation process by measuring the phase matching function at a pump wavelength of 1550 nm and the efficiency. Here we show an efficiency of 9.44 $\%W^{-1}cm^{-2}$. Moreover, we investigated the occurrence of photorefractive damage in the ridge waveguides by measuring the second harmonic power in dependence of the pump power. Here we show a high damage resistance up to a pump power of 500 mW.

Q 44.3 Wed 17:30 A320

Waveguide-Intergrated Superconducting Nanowire Avalanche Single-Photon Detectors — •Connor A. Graham-Scott[1,2,3], Matthias Häussler[1,2,3], Mikhail Yu. Mikhailov[4], and Carsten Schuck[1,2,3] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]Center for Soft Nanoscience (SoN), Busso-Peus-Straße 10, 48149 Münster, Germany — [4]B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, 61103 Kharkiv, Ukraine

Superconducting nanowire single-photon detectors (SNSPDs) are of great interest for applications in quantum communication, quantum information and quantum computing. A drawback of SNSPDs, however, is the low signal-to-noise ratio of their electrical output signals, resulting from operating at bias currents below the critical current of the ultra-thin superconducting nanowires.

High signal-to-noise ratio can be achieved by implementing a superconducting nanowire avalanche single photon detector (SNAP) architecture that connects several SNSPD elements in parallel, thus realising operation at high bias current and successive switching of elements upon photon absorption and current redistribution.

Here we show the design, fabrication and measurements of a successive-avalanche architecture SNAP with amorphous molybdenum silicide nanowires integrated with nanophotonic waveguides for on-chip single-photon counting with ultra-high signal-to-noise ratios.

Q 44.4 Wed 17:45 A320

Lithium-niobate microcombs for dual-comb spectroscopy — •Stephan Amann[1], Bingxin Xu[1], Yang He[2], Theodor W. Hänsch[1,3], Qiang Lin[2], Kerry Vahala[4], and Nathalie Picque[1] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Department of Electrical and Computer Engineering, University of Rochester, Rochester, New York 14627, USA — [3]Faculty of Physics, Ludwig-Maximilian University of Munich, Munich, Germany — [4]T.J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California 91125, USA

On-chip optical microresonators with a high Q-factor can generate soliton microcombs, broad spectra consisting of narrow lines with equal linespacing corresponding to the free spectral range of the resonator. Thin-film lithium niobate is a promising platform due to its large transparency window, strong second- and third-order nonlinearity and electro-optic effect. Here by driving a high-Q thin-film lithium niobate resonator with a picosecond electro-optic comb at 1.5 micron, we report stable soliton generation at a repetition rate locked by the electro-optic comb. Its high peak power grants an oscillation threshold at lower average powers than those necessary with continuous-wave pumping. The microcombs with a line spacing of 100GHz are well suited for spectroscopy in the condensed matter, where the linewidths of absorption features are often of the order of several hundreds of GHz. Dual-comb spectroscopy will leverage the time-domain interference of two microcombs to measure broad spectra within short measurement times.

Q 44.5 Wed 18:00 A320

Design of a satellite-based single photon source for quantum communication — •Najme Ahmadi for the QUICK3-Collaboration — Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Technologies of the so-called second quantum revolution have matured such they can now be used in space applications, e.g., long-distance quantum communication. Here we present the design of a compact true single photon source that can enhance the secure data rates in satellite-based quantum key distribution scenarios compared to conventional laser-based light sources. Our quantum light source is based on a fluorescent color center in hexagonal boron nitride. The emitter is off-resonantly excited by a diode laser and coupled to an integrated optics circuit that routes the photons to different experiments. These experiments either characterize the source directly by the second-order correlation function or test extended physical theories beyond the standard model. Our payload is currently being integrated into a 3U CubeSat and scheduled for launch in 2024 into the low Earth orbit. We can therefore evaluate the feasibility of true single photon sources in space and provide a promising route toward a high-speed quantum internet.

Q 44.6 Wed 18:15 A320

Influence of doping on the optical characteristics in lithium niobate — •Laura Bollmers, Laura Padberg, Christof Eigner, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Lithium niobate (LN) is a well-established material in integrated optics, and it is commonly used in nonlinear photonics. To make LN more versatile, material doping is crucial in improving the device's applicability. Depending on the doping material and concentration, different applications can be realised, e.g. Titanium doping can be used for waveguide fabrication, an essential part of integrated optics. Zinc doping can shift a bandgap to the UV region, enabling the material for UV/VIS application. Erbium doping enables applications for optical amplification, used for integrated laser sources, or quantum optical applications like memories.

Thus, doping LN can lead to a performance boost for optical applications. Especially in thin-film lithium niobate there are completely new application possibilities for doped substrate material. For optimisation, the interplay of experimental analysis and theoretical material modelling is crucial. So, we investigate the absorption spectra influenced by different dopants at different temperatures and show our latest results.

Q 44.7 Wed 18:30 A320

Towards Reconfigurable Lithium-Niobate-on-Insulator integrated non-von Neumann processors — •Julian Rasmus Bankwitz[1,2], Seongmin Jo[2], Francesco Lenzini[1], and Wolfram Pernice[2] — [1]Institute of Physics, University of Münster, Germany — [2]Kirchhoff Institute for Physics, University of Heidelberg, Germany

In recent years Artificial neural networks (ANNs) showed great advantages in a variety of fields like autonomous driving or language recognition. Fast and efficient efficient matrix-vector-multiplications (MVMs) are the building blocks of ANNs, as they represent the mathematical description of the interconnects of the ANN's neurons. With the exponentially increasing amount of data the world is generating every year, classical von-Neumann structured computers are facing their limits in computation speed and energy consumption. Overcoming those boundaries is a crucial task for modern computing, giving rise to alternative platforms like photonic integrated circuits (PICs). Lithium-Niobate-on-Insulator (LNOI) is an emerging material platform due to its broad optical bandwidth, low propagation loss and high second-order nonlinearity, enabling small footprint electro-optically reconfigurable circuits like adjustable ring resonators for non-classical light sources and Mach-Zehnder-Interferometers (MZIs) for electrically tunable optical switches. Here we demonstrate novel approaches of optical ANN matrices utilizing MZIs from LNOI for ultra-fast MVMs. From high precision fabrication engineering and modular PIC design we show high MZI extinction rations above 24 dB combined with GHz range modulation speed.

Q 44.8 Wed 18:45 A320

Light manipulation via integrated focusing grating couplers for quantum computing applications — •Anastasiia Sorokina[1,2], Guochun Du[3], Pascal Gehrmann[1,2], Carl- Frederik Grimpe[3], Steffen Sauer[1,2], Elena Jordan[3], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nanound Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

Downsizing optical components to control ion species in quantum computation is a vital turning point. Integrating routing and focusing elements into the chip architecture can substantially suppress environmental distortions and boost scalability. We investigated integrated waveguides and grating couplers to produce a linearly polarised Gaussian beam with a predefined emission angle, focus height and the size of the beam at this position. The studies were carried out using Lumerical FDTD simulation software and a subsequent post-processing routine. To address the different wavelengths required for the entire operation of the ion-based QCs, we have evaluated the capabilities and performance of our structures by taking advantage of the two most promising material platforms: Si3N4 and AlN. Our results can help overcome current limitations toward the multi-ion quantum system.

Q 45: Photonics III

Time: Thursday 11:00–13:00 Location: A320

Q 45.1 Thu 11:00 A320

Probing nonlinear optical processes with free electrons — •Jan-Wilke Henke[1,2], Yujia Yang[3,4], F. Jasmin Kappert[1,2], Arslan S. Raja[3,4], Germaine Arend[1,2], Guanhao Huang[3,4], Armin Feist[1,2], Zheru Qiu[3,4], Rui Ning Wang[3,4], Aleksandr Tusnin[3,4], Alexey Tikan[3,4], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany — [3]Institute of Physics, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland — [4]Center for Quantum Science and Engineering, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland

Integrated photonics has proven to facilitate the interaction of light with free electrons in electron microscopy by significantly boosting the coupling strength. This enables the exploration of quantum optics with free electrons as well as a probing of nonlinear optical effects inherent to integrated microresonators with electron spectroscopy.

Here, we harness the inelastic electron-light scattering to investigate the spatial and spectral properties of the electric field inside a high-Q silicon nitride microresonator. For increasing optical input powers, characteristic changes to the electron energy spectra that coincide with the formation of various nonlinear intracavity states including dissipative Kerr solitons are observed.

In the future, this enables new schemes in electron beam modulation and manipulation, while electron-based optical state probing may also be extended to different quantum states of light.

Q 45.2 Thu 11:15 A320

Incoherent diffractive imaging of (non)regular structures — •Sebastian Karl[1], Stefan Richter[1], Manuel Bojer[1], Fabian Trost[2], Kartik Ayyer[3], Henry Chapman[2], Ralf Röhlsberger[4], and Joachim von Zanthier[1] — [1]QOQI, FAU Erlangen Nürnberg, Germany — [2]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [3]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [4]Helmholtz-Institut Jena, Germany

X-ray crystallography relies on coherent scattering for high resolution structure determination. However, often the predominant scattering mechanism is an incoherent process like fluorescence, introducing severe background in the coherent diffractogram. Incoherent diffractive imaging (IDI) aims to use this incoherently scattered light for structure determination by measuring second order correlations in the far field [1]. While in theory single shot 3d imaging would be possible using IDI, careful theoretical examinations place thresholds on its feasibility [2,3]. IDI has been implemented at the European XFEL using metal foils. After evaluations for regular structures have been performed [4], we discuss the evaluation progress for non-regular structures and comment on the possibility of ab initio phasing using third order correlations on this dataset [5].

[1] A. Classen et al, PRL 119, 053401, 2017 [2] F. Trost et al., New J. Phys. 22, 083070, 2020 [3] L. M. Lohse et al., Acta Cryst. A 77, 480-496, 2021 [4] F. Trost et al., to be published [5] N. Peard et al., arXiv:2210.03793

Q 45.3 Thu 11:30 A320

Optical Ramsey Spectroscopy on a Single Organic Molecule — •Yijun Wang[1], Vladislav Bushmakin[2], Guilherme Stein[2], Andreas Schell[1,3], and Ilja Gerhardt[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany — [2]3. Physikalisches Institut, Universität Stuttgart and Stuttgart Research Center of Photonic Engineering (SCoPE), Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [3]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany

Single molecules are important players in quantum optics. Their coherence is of uttermost importance, since it influences the usage in quantum information processing, such as in quantum networking applications. We implement a pump-probe experiment in a Ramsey-type pulse sequence on a single 2.3,8.9-dibenzanthanthrene (DBATT) molecule to measure the optical coherence time and compare it with conventional methods [1]. The molecule is selected microscopically and spectroscopically at T=1.4 K. We also perform frequency-detuned excitation, gaining richer insights into the dephasing behavior of the molecule. The experiments exhibit that optical Ramsey spectroscopy is a promising tool for measuring the emitter's coherence properties.

[1] – Y. Wang, V. Bushmakin, G. Stein, A. Schell, and I. Gerhardt, *Optical Ramsey spectroscopy on a single molecule,* Optica **9**, 374-378 (2022).

Q 45.4 Thu 11:45 A320

Photoacoustic spectroscopy with a tunable narrowband infrared laser system — •Luca Schmid, Florent Kadriu, Sandro Kuppel, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

We report on a photoacoustic setup with a narrowband picosecond ultrafast tunable laser system in the mid-infrared. The fingerprints of various atmospheric species such as humid ambient air and carbon dioxide overtones at 5000 cm^{-1} at 2000 ppm have been detected. The entire molecular overtone is scanned within a few seconds with a linewidth-limited resolution of 2 cm^{-1}. We quantify the signal-to-noise ratio and compare these data with theoretically calculated spectra from the HITRAN database. Even extremely weak resonances can be resolved owing to the excellent brilliance of the laser source with several hundreds of mW output power.

Q 45.5 Thu 12:00 A320

Thermodynamic control of stimulated Brillouin-Mandelstam scattering in liquid-core optical fiber — •Andreas Geilen[1,2], Alexandra Popp[1,2], Debayan Das[1,3], Saher Junaid[4,5], Christopher G. Poulton[6], Mario Chemnitz[7], Christoph Marquardt[1,2], Markus A. Schmidt[4,5], and Birgit Stiller[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany — [3]Université Bourgogne Franche-Comté, 25030 Besançon, France — [4]Leibniz Institute of Photonic Technology, 07745 Jena, Germany — [5]Otto Schott Institute of Materials Research, 07743 Jena, Germany — [6]School of Mathematical and Physical Sciences, University of Technology, Sydney, NSW 2007, Australia — [7]Centre Énergie Matériaux Télécommunications, Québec, J3X 1S2, Canada

We present temperature and pressure dependent Brillouin-Mandelstam scattering measurements inside a fully sealed, CS_2-filled liquid-core optical fiber. The confinement of the liquid inside the micrometer-size silica capillary allows us to control and investigate the thermodynamic behavior. Tuning the temperature from 5 °C to 135 °C we reach high pressure values above 1000 bar as well as substantial absolute negative pressure values below -300 bar. With this, the Brillouin frequency shift (BFS) can be tuned by 40%. Our platform offers a rich source for fundamental optoacoustic investigation of liquids in different thermodynamic states, maintaining all-fiber convenience, while the low BFS (≈2.5 GHz) and a high temperature sensitivity of 7 MHz/°C are promising for sensing applications.

Q 45.6 Thu 12:15 A320

Optical solitons in curved spacetime — Felix Spengler[1], •Alessio Belenchia[1,2], Dennis Rätzel[3,4], and Daniel Braun[1] — [1]Institut für Theoretische Physik, Eberhard-Karls-Universität Tübingen, 72076 Tübingen, Germany — [2]Centre for Theoretical Atomic, Molecular, and Optical Physics, School of Mathematics and Physics, Queens University, Belfast BT7 1NN, United Kingdom — [3]ZARM, University of Bremen, Am Fallturm 2, 28359 Bremen, Germany — [4]Humboldt Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489 Berlin, Germany

From the seminal work of Plebanski in the '60s, we know that Maxwell equations in vacuum curved spacetime are equivalent to flat-spacetime Maxwell equations in the presence of a bi-anisotropic moving medium whose dielectric permittivity and magnetic permeability are determined entirely by the space-time metric. We will use this insight in order to describe light propagation in a nonlinear stationary medium in curved spacetime. We will focus on the case of a weak gravitational field and, via a non-linear Schrödinger equation, describe the propagation of an optical pulse in an effective, gradient-index medium in flat spacetime, which encodes both the material properties and curved spacetime effects. Furthermore, in analyzing the special case of propagation in a 1D optical fiber, we will also include the effect of mechanical deformations and show it to be the dominant effect for a fiber oriented in the radial direction in Schwarzschild spacetime.

Q 45.7 Thu 12:30 A320

Optical control of one-dimensional topological end states via soliton formation — •Christina Jörg[1,2], Marius Jürgensen[2], Sebabrata Mukherjee[3], and Mikael C. Rechtsman[2] — [1]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, D-67663 Kaiserslautern, Germany — [2]Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA — [3]Department of Physics, Indian Institute of Science, Bangalore 560012, India

Solitons are solutions of the nonlinear Schrödinger equation that maintain their shape during propagation. Here we show that soliton formation can be used to optically induce and control a linear topological end state in the bulk of a Su-Schrieffer-Heeger (SSH) lattice, using evanescently-coupled waveguide arrays. We observe an abrupt nonlinearly-induced transition above a certain power threshold due to an inversion symmetry-breaking nonlinear bifurcation of the soliton. We use a pump-probe framework such that the dynamics of the soliton is only coupled to the end state via the potential it induces, meaning that we may control the end state independently and all-optically. Specifically, we use orthogonal polarizations for the pump and probe: The pump induces the soliton and the probe experiences the potential induced by the soliton in which an end state appears as a result. In our case, the soliton acts as an all-optical switch to turn on and off the topological (linear) end state. Our results demonstrate all-optical active control of topological states.

Q 45.8 Thu 12:45 A320

From Berry phase to quantum skyrmions: a geometric loop tour in Physics — •Sinuhe Perea — Strand King's College London

In several physics systems the whole can be obtained as an exact copy of each of its parts, which facilitates the study of a complex system by looking carefully at its elements, separately. Reducionism offers simplified models which makes the problems easier, but "there's plenty of room...at the \emph{mesoscopic} scale". Here we present a tour for two of its representants: Berry phase and skyrmions, studying some of its basic definitions and properties, and two cases in which both arise together, to finish constraining the scale for our mesoscopic system in the quest of quantum skyrmions, discovering which properties are conserved and which others may be destroyed. In several classical physics systems the whole can be obtained as an exact copy of each of its parts, which facilitates the study of a complex system by looking carefully at its elements, separately. Reductionism offers simplified models which makes the problems easier, but "there's plenty of room...at the discrete scale". Here we present a tour for two of its representants: Constant section fiber bundles and skyrmions, studying some of its basic definitions and properties, and an example where both arise together via domain wall analogy. We will finish constraining the scale for our mesoscopic system in the quest of quantum and photonic skyrmions from above via Hamiltonian local minimisation and for below via novel graphic re-writing evolution, discovering which properties are conserved and which others may be destroyed.

Q 46: Quantum Control (joint session QI/Q)

Time: Thursday 11:00–13:00 Location: B305

See QI 26 for details of this session.

Q 47: Precision Measurements with Optical Clocks (joint session Q/QI)

Time: Thursday 11:00–13:00 Location: E001

Invited Talk Q 47.1 Thu 11:00 E001

Quantum metrology with non-classical states of light — •Michèle Heurs — Institute for Gravitational Physics, Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Nowadays, non-classical (fixed-quadrature "squeezed") light is routinely used in second-generation interferometric gravitational wave detectors such as aLIGO and AdVirgo to increase their detection sensitivity, leading to some of the most exciting astrophysical discoveries of the past years. Beyond this well-known application example, squeezing is a quantum technique that can benefit precision metrology in many other areas. It can be useful whenever the signal-to-noise ratio of the measurement is fundamentally limited by the quantum noise of the employed and technically already ultra-stabilised laser light.

This talk will highlight exemplary applications of squeezed light, ranging from interferometric gravitational wave detection to sub-shot-noise limited spectroscopy. The latter example makes use of high-frequency squeezed light sources, so-called *squeezing combs*, which will be introduced in this talk. These squeezing combs exhibit entanglement between the individual upper and lower squeezing sidebands which occur at the free spectral ranges of the squeezing cavity. This feature makes squeezing combs a promising resource for applications in quantum information.

Q 47.2 Thu 11:30 E001

A strontium optical clock based on Ramsey-Bordé spectroscopy — •Amir Mahdian[1], Oliver Fartmann[1], Ingmari C Tietje[1], Martin Jutisz[1], Conrad L Zimmermann[2], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We are developing an optical frequency reference based on Ramsey-Bordé interferometry using a thermal atomic beam. The $5s^2\ ^1S_0 \rightarrow 5s5p\ ^3P_1$ intercombination line in strontium is chosen as our clock transition, which should allow for an Allan deviation as low as 2×10^{-15} between 100 s and 1000 s.

After an overview of the current state of our atom interferometer, the latest developments in our laser systems and frequency stabilization will be presented. Moreover, I outline two methods for reading the population of the associated quantum states in the clock transition, along with the progress on spectroscopy on the $5s5p\ ^3P_1 \rightarrow 5p^2\ ^3P_0$ line at 483 nm.

This work is supported by the German Space Agency (DLR), with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR50WM1852, and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 47.3 Thu 11:45 E001

Instability investigation for a dual-wavelength coating frequency stabilization cavity — •Fabian Dawel[1,2], Alexander Wilzewski[1,2], Johannes Kramer[1,2], Lennart Pelzer[1,2], Marek Hild[1,2], Kai Dietze[1,2], Gayatri Sasidharan[1,2], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Optical resonators are a key tool for stabilizing lasers. For many experiments space is limited, so it is advantageous to lock multiple lasers to the same resonator. But so far, the correlation in noise contributions for two or more lasers on the same mirror pair has not been investigated. In this talk we present the stabilization of two lasers operating at 729 nm and 1069 nm on one mirror pair. We measure the effect of photo-thermal noise (PTN) and residual-amplitude modulation (RAM) on laser frequency instability. We find correlations between optical power and frequency. The wavelength coating stack next to the substrate shows PTN noise which is suppressed by coherent cancelation to a level of $3 \times 10^{-8}\ \frac{\mathrm{Hz}}{\mathrm{W}}$. The stack on top of this shows a PTN of $7 \times 10^{-7}\ \frac{\mathrm{Hz}}{\mathrm{W}}$. As expected, there is no significant cross-correlation between the lasers for noise induced by RAM. We measured relative frequency instabilities of less than 10^{-14} for both lasers, where the instability of one laser is limited by RAM. This work shows that dual-wavelength coatings can be used for highly stable laser applications, which makes it a viable tool for precision spectroscopy experiments.

Q 47.4 Thu 12:00 E001

The COMPASSO mission and its iodine clock — •Frederik Kuschewski[1], Thilo Schuldt[1], Martin Gohlke[2], Markus Oswald[1], Jonas Bischof[1], Jan Wüst[1,3], Alex Boac[1], Andre Bussmeier[1], Klaus Abich[1], Tasmim Alam[1], Tim Blomberg[1], and Claus Braxmeier[1,3] — [1]DLR Institute of Quantum Technologies — [2]DLR Institute of Space Systems — [3]Ulm University

High-precision clock technologies have a variety of applications both in lab environments and in space, such as research of geodesy, test of relativity theory and also navigation with the GNSS (global navigation satellite system) network. However, the established clock technologies in space (rubidium standards and masers) lack in precision and long-term stability, limiting the accuracy of space research and navigation. Optical clocks have the potential to improve the performance by orders of magnitude, hence offering unprecedented accuracy in numerous fields of research and high-precision navigation [1]. The DLR COMPASSO mission will demonstrate the first optical clock technology in orbit and its payload will be installed on the Bartolomeo platform of the ISS with a scheduled launch in 2025. In this contribution, we will present the mission architecture and highlight the features of the ruggedized clock technology [2], which utilizes modulation transfer spectroscopy in molecular iodine yielding a long-term fractional stability of up to 10^{-15}. [1] Schuldt, T. et al. GPS Solut. **25**, 83 (2021). [2] Schuldt, T. et al. Appl. Opt. **56**, 4, (2017).

Q 47.5 Thu 12:15 E001

Vibration isolation and frequency feedforward techniques in ultra-stable laser systems. — •Sofia Herbers[1], Jialiang Yu[1], Jan Kawohl[1], Mattias Misera[1], Thomas Legero[1], Uwe Sterr[1], Anders Wallin[2], Kalle Hanhijärvi[2], Thomas Lindvall[2], and Thomas Fordell[2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Germany — [2]VTT Technical Research Center of Finland Ldt., Finland

To improve the performance of metrology and precision measurements with optical clocks, ultra-stable lasers with extremely low frequency instability are required. Amongst others, accelerations acting on the laser systems' ultra-stable resonators limit the frequency stability even though the resonators' acceleration sensitivity is reduced by novel mounting designs and the best commercially available vibration isolation systems are used to reduce vibrations.

To overcome this limitation, we investigate adding additional feedback corrections to a commercial vibration isolation platform as well as applying feedforward corrections to the laser frequency. Additional seismometers and a tilt-meter are placed on the vibration isolation platform to detect its movement. The sensor outputs are used to generate correction signals that are either sent back to the actuators of the vibration isolation platform or sent forward to the laser frequency.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union*s Horizon 2020 Research and Innovation Programme.

Q 47.6 Thu 12:30 E001

E2-M1 polarisability of the strontium clock transition at the 813 nm lattice magic wavelength — •Joshua Klose, Sören Dörscher, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

To accurately determine the frequency shift of the clock transition caused by the optical lattice with fractional uncertainty of 10^{-17} or below, one must account for electric-quadrupole (E2) and magnetic-dipole (M1) interactions in a strontium lattice clock. However, the values of the E2-M1 polarisability difference of the clock states, $(5s^2)\,^1S_0$ and $(5s5p)\,^3P_0$, found in recent publications [1, 2] exhibit large discrepancies. We report on an independent experimental determination of the differential E2-M1 polarisability, $\Delta\alpha_{\mathrm{qm}}$, by measuring the differential light lattice shift between samples with different motional state distributions, leveraging the different dependence of the light shift terms on the atomic motional state. We find a value of $\Delta\alpha_{\mathrm{qm}} = -987^{+174}_{-223}\,\mu$Hz, which is in agreement with the value reported in Ref. [1] as well as the result of another recent investigation [3].

This project has been supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2123 QuantumFrontiers – Project-ID 390837967, SFB 1464 TerraQ – Project-ID 434617780 – within project A04, and SFB 1227 DQ-*mat* – Project-ID 274200144 – within project B02.

[1] I. Ushijima *et al.*, Phys. Rev. Lett. **121**, 263202 (2018)
[2] S. G. Porsev *et al.*, Phys. Rev. Lett. **120**, 063204 (2018)
[3] K. Kim *et al.*, arXiv:2210.16374 (2022)

Q 47.7 Thu 12:45 E001

An indium ion clock with a systematic uncertainty on the 10^{-18}-level — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Nishant Bhatt[1], Moritz von Boehn[1], Ingrid Maria Dippel[1], Jonas Keller[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Frequency is the most accurate physical property that can be measured by man-made machines. Nowadays, the best atomic clocks are based on optical transitions and reach systematic uncertainties around 1×10^{-18} surpassing the clocks that currently define the SI unit of time by a factor of 100 and more. Because of its intrinsically low sensitivities, $^{115}\mathrm{In}^+$ is a candidate for a clock with a systematic uncertainty on the 10^{-19}-level, not only for a single but also multiple indium ions. This so-called "multi-ion clock" allows for shorter averaging times to reach a given statistical uncertainty level [1,2].

In this talk, we will demonstrate clock operation with an $^{115}\mathrm{In}^+$ ion sympathetically cooled by three $^{172}\mathrm{Yb}^+$ ions in a segmented linear Paul trap. The systematic uncertainty is evaluated on the 10^{-18}-level. The setup is optimized for clock operation with multiple $^{115}\mathrm{In}^+$ ions allowing for a similar systematic uncertainty as a single-ion clock [1]. First clock operation with multiple indium ions featuring individual state readout on an EMCCD camera is shown and discussed.

[1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)

Q 48: Optomechanics II

Time: Thursday 11:00–13:00 Location: E214

Invited Talk Q 48.1 Thu 11:00 E214

Using optomechanical systems to test gravitational theory – possibilities and limitations — •Dennis Rätzel — ZARM, University of Bremen, 28359 Bremen, Germany — Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany

More than 100 years after the first development of a relativistic theory of gravity, there is an ever-increasing amount of predicted, yet untested, phenomena and unsolved scientific puzzles revolving around gravity. There are many proposals to apply quantum sensors to test for such phenomena or experimentally resolve some of the puzzles. In this talk, I will present my perspective on three proposals based on optomechanical systems: measurement of the gravitational field of light and relativistic particle beams, obtaining bounds on Chameleon-field dark energy models, and testing for quantum properties of the gravitational field. I will give a short introduction to the models involved and discuss fundamental constraints.

Q 48.2 Thu 11:30 E214

Force-Gradient Sensing and Entanglement via Feedback Cooling of Interacting Nanoparticles — •Henning Rudolph[1], Uros Delic[2], Markus Aspelmeyer[2,3], Klaus Hornberger[1], and Benjamin Stickler[1] — [1]University of Duisburg-Essen, Duisburg, Germany — [2]University of Vienna, Vienna, Austria — [3]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Vienna, Austria

The motion of levitated nanoparticles has recently been cooled into the quantum groundstate by electric feedback [1,2]. In this talk, we show theoretically that feedback-cooling of two levitated, interacting nanoparticles enables differential sensing of forces and the observation of stationary entanglement [3]. The feedback drives the particles into a stationary, non-thermal state which is susceptible to inhomogeneous force fields. We predict that force-gradient sensing at the zepto-Newton per micron range is feasible and that entanglement due to the interaction between charged particles is possible if the detection efficiency of the feedback loop exceeds the ratio of the mechanical normal mode frequencies.

[1] Magrini et al. "Real-time optimal quantum control of mechanical motion at room temperature." Nature (2021)
[2] Tebbenjohanns et al. "Quantum control of a nanoparticle optically levitated in cryogenic free space." Nature (2021)
[3] Rudolph et al. "Force-Gradient Sensing and Entanglement via Feedback Cooling of Interacting Nanoparticles." Physical Review Letters (2022)

Q 48.3 Thu 11:45 E214

A hybrid optomechanical system of an optically levitated nanoparticle and an optical microcavity in a resolved sideband regime — •Zijie Sheng[1,2], Seyed Khalil Alavi[1,2], Harald Giessen[3], Haneul Lee[4], Hansuek Lee[4], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, 70569 Stuttgart, DE — [2]Center for Integrated Quantum Science and Technology, Universität Stuttgart, 70569 Stuttgart, DE — [3]4th Physics Institute, Universität Stuttgart, 70569 Stuttgart, DE — [4]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon, 34141, Korea

An optically levitated dielectric nanoparticle coupled to an optical cavity has recently emerged as an optomechanical system with unique features that allow for quantum experiments at room temperature. The field has shown rapid progress in the past few years, including cooling of the particle's motion down to the ground state, achieved with a conventional Fabry-Pérot optical cavity in a resolved sideband regime. We present a new type of optomechanical system comprising a nanoparticle in an optical tweezer and a monolithic optical microcavity in a resolved sideband regime. We use a silica microtoroid as an optical cavity with a Q factor of up to 10^8. The optomechanical coupling is realized through the evanescent field when the particle is near the microtoroid. At a few hundred nanometers from the surface, the coupling of up to tens of kHz can be achieved, five orders of magnitude larger than the previous work with a bulk optical cavity. We discuss our progress toward attaining strong quantum cooperativity.

Q 48.4 Thu 12:00 E214

Phase locking of two levitated nanoparticles via non-reciprocal dipole-dipole coupling — •Manuel Reisenbauer[1], Livia Egyed[1], Murad Abuzarli[1], Anton Zasedatelev[1,2], Henning Rudolph[3], Klaus Hornberger[3], Aspelmeyer Markus[1,2], Benjamin A. Stickler[3], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]Austrian Academy of Sciences, A-1090 Vienna — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Arrays of optically levitated dielectric particles are a novel platform for exploring collective optomechanical dynamics. Recently, strong tunable dipole-dipole and electrostatic interaction have been demonstrated between several levitated particles.

We built an experiment based on an optical trap array of silica nanoparticles. Our platform enables independent control of particle dynamics and non-reciprocal dipole-dipole interactions together with a readout for individual particle motions. We employ a fully non-reciprocal coupling to drive the particles motion into self-sustained oscillations. We observe a phase transition into a collectively synchronized state of motion which we characterize via phase locking.

Our work has possible applications for sensing and metrology employing the reduction of phase noise below the thermomechanical limit of each individual oscillator. Finally, we will discuss the scalability of our system to large arrays of trapped particles.

Q 48.5 Thu 12:15 E214

Superconducting Quantum Magnetomechanics — •Christian M.F. Schneider[1,2,6,7], David Zöpfl[1,2], Mathieu L. Juan[3], Nicolas Diaz-Naufal[4], Lukas F. Deeg[1,2], Aleksei Sharafiev[1,2], Anja Metelmann[4,5], and Gerhard Kirchmair[1,2] — [1]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, 6020 Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, 6020 Innsbruck, Austria — [3]Institut Quantique and Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1, Canada — [4]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [5]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [6]Technical University of Munich, Physics Department, 85747 Garching, Germany — [7]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

Quantum control of massive mechanical resonators has come within reach in recent years. In this talk, I describe an experimental setup in which we couple magnetic cantilevers to a superconducting microwave resonator or a transmon. When cooled down to mK temperatures, we achieve high and tunable coupling strengths, and could demonstrate control over the mechanical system in form of feedback cooling to around 10 phonons. The intrinsic nonlinearity of the microwave circuit gives rise to a more power efficient cooling performance. For the ultimate goal of quantum control, we couple a transmon directly to the cantilever and show some first characterization measurements.

Q 48.6 Thu 12:30 E214

Nonclassical photon statistics in two-tone continuously driven optomechanics — •Kjetil Borkje[1], Francesco Massel[1], and Jack Harris[2,3] — [1]Department of Science and Industry Systems, University of South-Eastern Norway, PO Box 235, NO-3603 Kongsberg, Norway — [2]Department of Physics, Yale University, 217 Prospect Street, New Haven, Connecticut 06520, USA — [3]Department of Applied Physics, Yale University, 15 Prospect Street, New Haven, Connecticut 06520, USA

We present a study of a standard optomechanical system where the cavity mode is continuously driven at two different frequencies, and where sideband photons are detected by single photon detectors after frequency filtering the output from the cavity mode around its resonance frequency. We first derive the normalized second order coherence associated with the detected photons, and show that it contains signatures of the quantum nature of the mechanical mode which would be absent with only single-tone driving. To identify model-independent nonclassical features, we derive two inequalities for the sideband photon statistics that should be valid in any classical model of the system. We show that these inequalities are violated in the proposed setup. This is provided that the average phonon occupation number of the mechanical mode is sufficiently small, which in principle can be achieved through sideband cooling intrinsic to the setup. The proposed setup thus employs a mechanical oscillator in order to generate a steady-state source of nonclassical radiation.

[1] Børkje et al., Physical Review A, 104, 063507 (2021)

Q 48.7 Thu 12:45 E214

Dissipative cavity optomechanics with a suspended frequency-dependent mirror — Sushanth Kini Manjeshwar[1], Anastasiia Ciers[1], •Juliette Monsel[1], Cindy Peralle[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Göteborg, Sweden — [2]Department of Physics, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

Cavity optomechanics with a strongly frequency-dependent mirror, such as a photonic crystal mirror, offers novel capabilities in manipulating mechanical motion, such as the implementation of efficient cooling. Here, we build an input-output-based description of such an optomechanical system, generalizing Ref. [1] by including in our model a dissipative optomechanical coupling arising from the change in the loss rate of the cavity due to the mechanical motion. We then analyze the optomechanical properties of the system, in particular the mechanical frequency shift and optomechanical cooling. Finally, we show how our model matches our experimental measurements of a chip-based microcavity. Our setup consists of a suspended photonic crystal mirror [2] and a distributed Bragg reflector mirror, forming a free-space, Fabry-Pérot-type optomechanical microcavity with a length less than the optical wavelength and approaching the ultra-strong coupling regime.

[1] O. Černotík, A. Dantan, C. Genes, Phys. Rev. Lett. 122, 243601 (2019)
[2] S. Kini Manjeshwar, et al., Appl. Phys. Lett. 116, 264001 (2020)

Q 49: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Thursday 11:00–13:00 Location: F303

See A 23 for details of this session.

Q 50: Quantum Gases: Fermions I

Time: Thursday 11:00–13:00 Location: F342

Q 50.1 Thu 11:00 F342

Collective excitations in mesoscopic Fermi gases — •Philipp Lunt, Paul Hill, Johannes Reiter, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

Understanding the elementary excitations of strongly interacting many-body systems in terms of the independent motion of individual particles and their collective behaviour has been a central theme in many fields ranging from nuclear physics to cold atoms [1,2].

Here, we present a study of elementary excitations of a mesoscopic Fermi system across the BEC-BCS crossover by means of spectroscopic probes. Therefore, we use an established spilling technique [3] to prepare a balanced system of few fermionic atoms in a tightly confined tweezer. We excite the quadrupole mode by interference with a Laguerre-Gaussian mode. Tuning of the interparticle interactions via a broad Feshbach resonance allows us to observe the transition from single-particle to collective excitations. Furthermore, we investigate the breakdown of collectivity by reducing the atom number gradually.

[1] B. Mottelson Science 193 (4250), 287-294 (1976) [2] S. Giorgini et al. Rev.Mod.Phys. 80, 125 (2008) [3] F. Serwane et al. Science 332 (6027), 336-338 (2011)

Q 50.2 Thu 11:15 F342

Anomalous thermoelectric transport between fermionic superfluids — Philipp Fabritius, Jeffrey Mohan, Mohsen Talebi, Simon Wili, •Meng-Zi Huang, and Tilman Esslinger — Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Thermoelectric effects in superfluid systems have been far less explored than other superfluid transport both theoretically and experimentally. Landau's two-fluid model works well in conventional superconductors, yet studies beyond the two-fluid model are scarce. Here we study the Peltier and Seebeck effects together in a superfluid system, namely transport induced by a chemical potential bias and by a temperature bias, respectively. Our system is a mesoscopic channel connecting two superfluids of ultracold fermionic atoms, where the particle current in both the Peltier and the Seebeck configurations exhibits a strong non-Ohmic character. While non-Ohmic transport is associated with superfluid features, we observe a large entropy current concomitant with the particle current, incompatible with a simple two-fluid model. On the other hand, we engineer a controlled particle loss inside the mesoscopic channel to study its influence on thermoelectric response. Surprisingly, local dissipation can enhance the particle current in a Seebeck configuration (analogous to the fountain effect). This would imply a change in the reservoir response despite the dissipation being in the channel. We present possible explanations to the observations, including non-hydrodynamic transport.

Q 50.3 Thu 11:30 F342

Observation of Cooper pairs in a mesoscopic 2D Fermi gas — •Marvin Holten[1,2], Luca Bayha[1], Keerthan Subramanian[1], Sandra Brandstetter[1], Carl Heintze[1], Philipp Lunt[1], Philipp Preiss[1,3], and Selim Jochim[1] — [1]Physikalisches Institut, Heidelberg University, Germany — [2]Atominstiut, TU Wien, Austria — [3]Max Planck Institute of Quantum Optics, Garching, Germany

The formation of strongly correlated pairs is fundamental for the emergence of fermionic superfluidity and superconductivity. To understand the pairing mechanism is an ongoing challenge in the study of many strongly correlated fermionic systems. In this talk, I present the direct observation of Cooper pairs in our experiment. We have implemented a fluorescence imaging technique that allows us to extract the full in-situ momentum distribution with single particle and spin resolution. We apply it to a mesoscopic Fermi gas, prepared deterministically in the ground state of a two-dimensional harmonic oscillator. Our ultracold gas allows us to tune freely between a completely non-interacting unpaired system and weak attractions where we find Cooper pair correlations at the Fermi surface.

When increasing the interactions even further, the pair character is modified and the pairs gradually turn into tightly bound dimers. The collective behaviour that we discover in our mesoscopic system is closely related to observations in nuclear physics or metallic grains. Our method provides a new pathway to study many of the outstanding questions concerning fermionic pairing, for example in imbalanced systems or the normal phase.

Q 50.4 Thu 11:45 F342

Tunable diffusion properties of spin-polarized Fermi gases in time-dependent disorder — •Sian Barbosa, Max Kiefer-Emmanouilidis, Felix Lang, Michael Fleischhauer, and Artur Widera — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau, Germany

The transport of particles through disordered potential landscapes has been actively studied for the last decades. The vast majority of these studies, e.g. of Anderson localization, addressed the regime in which the disordered potential is static. However, it seems natural to investigate the influence of time-dependent disorder on transport properties. More specifically, a crossover from localization to diffusive, even hyper-ballistic, transport is expected to occur when the disorder varies in time. I will present the results of our experimental investigation of the dynamics of ultracold, spin-polarized fermionic lithium atoms when exposed to an optical speckle potential that can be frozen or continuously varying its random pattern in both space and time. We observe a strong dependence of the system's diffusion exponent on the so-called correlation time, a measure for the disorder's rate of change. We furthermore investigate new measures based on analysis of entropies to quantify the state of the system independent of specific models.

Q 50.5 Thu 12:00 F342

Competing antiferromagnetic and superfluid phases in the Feshbach-Hubbard model — •Victor Bezerra[1] and Axel Pelster[2] — [1]Friedrich-Engels-Gymnasium, Emmentalerstraße 67, 13407 Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Competing phases play an important role in strongly interacting systems, as for example in the case of superconductivity and antiferromagnetism. Alongside condensed matter-systems ultracold atoms loaded in optical lattices have shown to be quite promising to simulate and to understand the behavior of strongly correlated systems. In this work we study a two-dimensional model that contains both the usual repulsive Fermi-Hubbard Hamiltonian and a pairing term due Feshbach bosons, and study there the competition of antiferromagnetic order and conventional pairing order within a zero-temperature mean-field theory. With this we investigate, at first, the properties of the crossover from a Bose-Einstein condensate (BEC) phase to the Bardeen-Cooper-Schrieffer (BCS)-like phase, where a reentrant behavior occurs and band-insulator lobes are obtained analytically. Secondly, concerning the antiferromagnetic (AF) order, the well-known mean-field results are reproduced. And, finally, we obtain a quantum phase diagram, which reveals an intriguing interplay from a BEC-BCS crossover to an insulating AF order.

Q 50.6 Thu 12:15 F342

Report on an Erbium-Lithium machine — •Florian Kiesel and Alexandre De Martino — Eberhard Karls Universität Tübingen, Physikalisches Institut AG Groß, Auf der Morgenstelle 14, 72076 Tübingen

Ultracold Fermions cannot be cooled below about 10% of the Fermi temperature with conventional methods. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Here we report on the construction and implementation of first cooling stages of a two species apparatus for the optimized symp. cooling of fermionic Li with bosonic Er. This mixture has several promising features, that have not yet been utilized for symp. cooling in any other mixture. Pushing the temperature limit is essential for the quantum simulation of strongly correlated phenomena, in particular in optical lattice.

Q 50.7 Thu 12:30 F342

Excitation Spectrum and Superfluid Gap of an Ultracold Fermi gas — •Hauke Biss[1,2], Lennart Sobirey[1], René Henke[1], Cesar Cabrera[1,2], and Henning Moritz[1,2] — [1]Institute of Laser Physics, University of Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Hamburg, Germany

Ultracold Fermi gases with tunable interactions have allowed realizing the famous BEC-BCS crossover from a Bose-Einstein condensate (BEC) of molecules to a Bardeen-Cooper-Schrieffer (BCS) superfluid of weakly bound Cooper pairs. In this contribution, I will present how we use Bragg spectroscopy to measure the full momentum-resolved low-energy excitation spectrum of spin-balanced strongly interacting ultracold Fermi gases. This enables us to observe the smooth transformation from a bosonic to a fermionic superfluid in the BEC-BCS crossover. We use our spectra to determine the evolution of the superfluid gap and find excellent agreement with previous experiments and theory. As a next step, we reduce the dimensionality of the gas to probe the excitation spectrum of two-dimensional (2D) Fermi gases. This allows us to demonstrate superfluidity of 2D Fermi gases and to observe the influence of the reduced dimensionality on the stability of the superfluid phase. Finally, I will present our progress towards creating and probing spin-imbalanced mixtures in 2D.

Q 50.8 Thu 12:45 F342

Towards fast, deterministic preparation of few-fermion states — •Maximilian Kaiser[1], Tobias Hammel[1], Vivienne Leidel[1], Micha Bunjes[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut - University of Heidelberg, Heidelberg, Germany — [2]Max Planck Institute of Quantum Optics, Garching, Germany

Measurements of higher-order correlations in quantum systems, e.g. for the tomography of complex quantum states, require large data sets. This demand stands in contrast to typical cycle times of 10 seconds or more in traditional experiments with ultracold quantum gases.

We report on the ongoing development of a highly modular apparatus for fast, experimental quantum simulations using ultracold Lithium-6 with envisioned cycle times of well below 1 second. Within each run, few-fermion states are prepared in a sequence based upon [1].

The resulting high data output will especially be key for iteration-intensive research in the future, while the highly modular experimental interface allows a broad envelope of quantum systems to be realized and simulated.

[1] F.Serwane et Al., Science Vol. 332, p.336-338 (2011)

Q 51: Precision Measurements

Time: Thursday 14:30–16:30 Location: A320

Q 51.1 Thu 14:30 A320

Search of dark matter boson via isotope shift measurements in ytterbium ions — •Chih-Han Yeh[1], Laura S. Dreissen[1], Melina Filzinger[1], Nils Huntemann[1], Henning A. Fürst[1,2], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Astronomical observations support the existence of dark matter, but its origin and composition are unknown. A dark matter boson coupling neutrons and electrons in an atom could be observed with isotope shift measurements and a so-called King-plot analysis [1-3]. Here, known atomic and nuclear effects that dominate the isotope shift follow a linear scaling. We performed accurate isotope shift measurements in trapped ytterbium ions to search for these interactions via non-linearities in the King-plot. We determined the absolute frequencies of the $^2S_{1/2} \rightarrow {}^2D_{5/2}$ and $^2S_{1/2} \rightarrow {}^2F_{7/2}$ transitions in all 5 stable even isotopes of Yb^+ to the ~10 Hz level. We reproduce the non-linearities observed in Ref. [4], but reach a 10 to 100 fold higher accuracy. With these results we hope to shed light onto the source of the observed non-linearity and investigate a possible coupling from a new boson beyond the previously explored parameter range.

[1] C. Delaunay, et al., *Phys. Rev. D* **96**, 093001 (2017). [2] J. C. Berengut, et al., *Phys. Rev. Lett.* **120**, 091801 (2018). [3] W. H. King, *Isotope Shifts in Atomic Spectra* (Plenum Press, New York, 1984). [4] J. Hur, et al., *Phys. Rev. Lett.* **128**, 163201 (2022.)

Q 51.2 Thu 14:45 A320

Measuring Beam Deflections via Weak Value Amplification — •Elina Köster[1,2], Carlotta Versmold[1,2], Jan Dziewior[1,2], Florian Huber[1,2], Jasmin DA Meinecke[1,2], Lev Vaidman[1,2,3], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel

The technique of weak value amplification was already used to precisely measure small deflections of light. Yet, so far the interaction region was included in the measurement device, when e.g. measuring a tiny deflection of a light beam [1]. Here we introduce an interferometric weak measurement setup able to measure displacements and deflections of a light beam that occur outside of the measuring device. This is achieved by spatially separating the arms of a Sagnac interferometer and inserting a Dove prism in one of them.

Due to the mirroring of one of the arms the center of mass of the resulting interference pattern depends on the initial deflection of the beam. Amplified by the weak value of the system this allows a highly sensitive determination of the deflection or displacement.

[1] Dixon et al, "Ultrasensitive beam deflection measurement via interferometric weak value amplification.", Physical review letters, 102.17 (2009): 173601

Q 51.3 Thu 15:00 A320

The Photon-Per-Day Detection System of the ALPS II Experiment — •Daniel Brotherton for the ALPS II-Collaboration — University of Florida, Gainesville FL, U.S.

Axions and axion-like particles are a class of particles extending the Standard Model. The Any Light Particle Search II (ALPS II) will soon begin its first science run to probe their miniscule interaction with light. ALPS II follows the "light shining through a wall" approach. Laser light directed through a magnetic field towards a wall may convert into axions and cross unimpeded. On the opposite side, the axions may reconvert to light amidst another magnetic field and be detected. With respect to ALPS II's design parameters and target sensitivity, a detector is required capable of resolving on the order of a photon per day over a 20-day measurement run. In this talk, I will introduce ALPS II's heterodyne interferometric detection scheme. I will discuss the characterization of the detector scheme's noise background and the amount of stray light leaked into the reconversion region.

This work is supported by NSF grant PHY-2110705 and Heising Simons foundation grant 2020-1841.

Q 51.4 Thu 15:15 A320

Characterization of the Optical Systems in the ALPS II Experiment — •Todd Kozlowski for the ALPS II-Collaboration — DESY, Hamburg, Germany

The Any Light Particle Search II (ALPS II) is a "light-shining-through-the-wall" particle search experiment at DESY, currently in its final preparations for a science run. ALPS II will probe for axions and axion-like particles, a family of hypothetical particles outside of the Standard Model, to a sensitivity unparalleled by other model-independent, laboratory-based experiments and most other broadband experiments. ALPS II aims to detect light which has undergone photon-axion and subsequent axion-photon conversion in the presence of a magnetic field. In the initial design, a 60 W laser provides a constant flux of photons for conversion. Opposite a light-blocking shutter, a 122 meter long, high finesse 'regeneration cavity' increases the reconverted signal rate. The resulting ultra-weak signal field can then be detected using optical heterodyne interferometry. In this presentation, I will characterize our optical and control systems in the context of the requirements for the first science measurement. These results will include the performance of the very long storage-time regeneration cavity and the position and phase stability of the fields on the experiment's central optical breadboard.

This work is supported by NSF grant PHY-2110705 and Heising Simons foundation grant 2020-1841.

Q 51.5 Thu 15:30 A320

Indirect excitation mechanisms for the ^{229}Th isomer — •Tobias Kirschbaum[1], Nikolay Minkov[2], and Adriana Pálffy[1] — [1]Julius-Maximilians-Universität Würzburg, Germany — [2]Institute for Nuclear Research and Nuclear Engineering, Sofia, Bulgaria

Amongst all nuclei, the ^{229}Th nucleus presents the lowest first excited state at around 8 eV with an expected radiative lifetime of a few hours. Hence, this transition should be accessible with VUV light. In combination with its narrow linewidth, this renders ^{229}Th an ideal candidate for a nuclear clock with excellent accuracy and stability [1]. However, a hindrance towards its experimental realization is the relatively large uncertainty on the transition energy which makes direct laser excitation cumbersome.

Here, we investigate theoretically two different approaches to indirectly populate ^{229}Th's isomeric state. The first approach deals with quantum optical transfer schemes involving STIRAP and π-pulses via the second excited state at 29.19 keV at the Gamma Factory [2]. The second approach considers Electronic Bridge (EB) schemes in a VUV-transparent crystal environment doped with ^{229}Th [3]. Here, EB involves electronic defect states which appear in the band gap due to ^{229}Th doping. We present different EB schemes and the corresponding excitation rates for ^{229}Th:LiCAF.

[1] E. Peik *et al.*, Quantum Sci. Technol. **6**, 034002 (2021).
[2] T. Kirschbaum, N. Minkov and A. Pálffy, Phys. Rev. C **105**, 064313 (2022).
[3] B. S. Nickerson *et al.*, Phys. Rev. A **103**, 053120 (2021).

Q 51.6 Thu 15:45 A320

Recent Developments towards the Lifetime Measurement of the ^{229m}Th Nuclear Clock Isomer — •Kevin Scharl[1], Daniel Moritz[1], Mahmood Hussain[1], Sandro Kraemer[1,2], Lilli Löbell[1], Florian Zacherl[1], Shiqian Ding[3], Benedict Seiferle[1], and Peter G. Thirolf[1] — [1]LMU Munich — [2]KU Leuven, Belgium — [3]Tsinghua University, Beijing, China

The elusive thorium-229 isomer (^{229m}Th) with its unusually low-lying first excited state (8.338 ± 0.024 eV) represents the so far only candidate for the realization of an optical nuclear clock. Possible applications of a nuclear clock are not limited to highly precise time keeping, but reach into many other fields from geodesy to fundamental physics studies as dark matter research. Considerable progress was achieved in the past few years to characterize ^{229m}Th, from its first identification to recent observations of the long-searched radiative decay channel. While the determination of the nuclear resonance with laser-spectroscopic precision is still awaited, a measurement of the ionic lifetime of the isomer is being prepared by our group. There is experimental proof for the lifetime to last 10^3-10^4 s. To precisely target the quantity by hyperfine structure spectroscopy our experimental setup is based on a cryogenic Paul trap providing long enough storage of cooled ^{229m}Th. The talk will present the status of the experimental setup and first tests to characterize the cryogenic confinement of ^{229m}Th ions together with laser ablated $^{88}Sr^+$ ions, their sympathetic Doppler cooling and the spectroscopic readout of the trapped ion states. This work was supported by the European Research Council (ERC): Grant agreement No. 856415.

Q 51.7 Thu 16:00 A320

Towards VUV laser spectroscopy of the nuclear clock isomer 229mTh — •Mahmood Hussain[1], Johannes Weitenberg[2,3], Stephan H. Wissenberg[2], Tamila Rozibakieva[1], Hans-Dieter Hoffmann[2], Constantin L. Häfner[2,4], and Peter G. Thirolf[1] — [1]LMU Munich — [2]Fraunhofer ILT Aachen — [3]Max-Planck Institute of Quantum Optics, Garching — [4]RWTH Aachen University

The isotope 229-Thorium features a low-energy (approx. 8.3 eV) isomeric first nuclear excited state, the so-called thorium isomer. Its long coherence time and vacuum ultraviolet (VUV) transition energy make it the only nuclear transition that is accessible with current laser technology and therefore highly desirable for a clock operation. The small nuclear moments make the nuclear clock a unique quantum sensor to probe, e.g., dark matter or spatio-temporal fluctuations of fundamental constants. To drive the nuclear transition, we are developing a tabletop approx. 150 nm frequency comb that combines a high-power ultrastable frequency comb at 1050 nm, nonlinear pulse compression, and an enhancement resonator to produce VUV high power per comb mode (1 nW/mode) and a narrow comb linewidth (approx. 1 kHz) via high harmonic generation in Xe gas jet. Besides the VUV comb development, other challenges include, (i) coupling VUV pulses with trapped thorium ion(s) for coherent nuclear excitation and, (ii) orders of magnitude reduction in uncertainty of the transition frequency. The VUV comb's concept, the aforementioned challenges, and their prospective solutions will be discussed. Funding: European Research Council (ERC Synergy Grant, Agreement No. 856415).

Q 51.8 Thu 16:15 A320

Towards a Spaceborne Two-Photon Rubidium Frequency Reference — •Julien Kluge[1,2], Klaus Döringshoff[1,2], Daniel Emanuel Kohl[1,2], Moritz Eisebitt[2,3], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin — [3]II. Physikalisches Institut, RWTH Aachen University

Optical frequency standards based on two-photon spectroscopy using hot rubidium vapor are a promising candidate for realization of simple and compact optical clocks for application in next generation global navigation satellite systems.

In this presentation, we show the development of a two-photon frequency reference using FM spectroscopy at 778 nm for application in the CRONOS satellite mission. Recent results of our lab-based setups show a fractional instability below 3×10^{-13} per $\tau^{-1/2}$ for up to 1000 s. We present our design and first prototype of a spectroscopy module with a volume below 1/2 l, weight below one kilogramm and planned power budget of under 10 W for accommodation on a micro satellite. Additionally, reports on its performance and qualification for an in orbit verification mission are given. We further provide details on the architecture of the payload, the laser system for two-photon spectroscopy and the anticipated operation as part of an optical clock.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 52: Floquet Engineering and Topology

Time: Thursday 14:30–16:30 Location: E001

Invited Talk Q 52.1 Thu 14:30 E001

Nonperturbative Floquet engineering and Floquet-dissipative state preparation — •Francesco Petiziol — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

Time-periodic driving of quantum systems is a powerful tool for realizing effective Hamiltonians with desired properties (so-called "Floquet engineering") and, thus, for quantum simulation. Typical Floquet engineering techniques rely on perturbative approximations and can be categorized into "continuous" or "digital", depending whether they employ continuous time-dependent modulations, or stepwise evolutions with time-independent Hamiltonians. I will present a hybrid continuous-digital approach that allows one to engineer local coupling terms (such as three- and four-body couplings) in a nonperturbative and scalable fashion. This approach allows for the robust engineering of Kitaev's toric-code Hamiltonian, the paradigmatic model of a topological spin liquid, which involves purely four-spin interactions. I will, moreover, discuss how eigenstates of an effective Floquet-engineered Hamiltonian can be prepared and stabilized by coupling the system to artificial baths in superconducting circuits, by generalizing approaches of reservoir engineering. In particular, I will discuss the preparation of ground states of bosonic ladders with artificial magnetic flux.

Q 52.2 Thu 15:00 E001

Preparing and probing bosonic Chern-insulator analogs using Mott states or disorder — •Isaac Tesfaye[1], Botao Wang[2], and André Eckardt[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Université Libre de Bruxelles

Mimicking fermionic Chern insulators with bosons has drawn a lot of interest in experiments by using, for example, cold atoms [1,2] or photons [3]. Here we present a scheme to prepare and probe a bosonic Chern insulator analog by using (a) an ensemble of randomized bosonic states and (b) an initial Mott state configuration. By applying a staggered superlattice, we can identify the lowest band with individual lattice sites. The delocalization over this band in quasimomentum space is then achieved by introducing on-site disorder or local random phases (a). Switching off the interactions and adiabatically decreasing the superlattice then gives rise to a bosonic Chern insulator, whose topologically nontrivial property is further confirmed from the Laughlin-type quantized charge pumping. Adding to this, we propose a detection scheme allowing for the observation of the bosonic quantized charge pump using a feasible number of experimental snapshots. Our protocol provides a useful tool to realize and probe topological states of matter in quantum gases or photonic systems.

[1] M. Aidelsburger, M. Lohse, C. Schweizer, et al., Nature Physics 11, 162 (2015), [2] N. R. Cooper, J. Dalibard, and I. B. Spielman, Rev. Mod. Phys. 91, 015005 (2019), [3] T. Ozawa, H. M. Price, A. Amo, et al., Rev. Mod. Phys. 91, 015006 (2019).

Q 52.3 Thu 15:15 E001

Observation of a dissipative time crystal — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1], Ludwig Mathey[1], Jayson G. Cosme[2], and Andreas Hemmerich[1] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines.

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the small field decay rate ($\kappa/2\pi$ = 3.5 kHz), which is in the order of the recoil frequency ($\omega_{rec}/2\pi$ = 3.6 kHz). This leads to a unique situation where cavity field evolves with the same time scale as the atomic distribution. If the system is pumped transversally with a steady state light field, red detuned with respect to the atomic resonance, the Hepp-Lieb superradiant phase transition of the open Dicke is realized [1]. Starting in this self-ordered density wave phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry broken states [2].

[1] J. Klinder et al., PNAS 112, 3290-3295 (2015).
[2] H. Keßler et al., PRL 127, 043602 (2021).

Q 52.4 Thu 15:30 E001

Time-periodic Lindblad master equations for quantum systems with engineered interactions and dissipation — •Simon B. Jäger, Jan Mathis Giesen, Christoph Dauer, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, D-67663, Kaiserslautern, Germany

Floquet engineering enables the creation of exotic and correlated many-body quantum states by using time-periodic driving. However, driving usually generates heat in the quantum system which can eventually lead to thermalization and loss of coherence on long timescales. A pathway to circumvent these detrimental effects can be engineered dissipation that drains away part of the introduced energy and stabilizes the quantum system far away from equilibrium. One possibility to engineer dissipation and also interactions within the quantum system is by coupling it to bosonic modes. We will show how one can quite generally eliminate the bosonic modes in such a scenario and achieve a Lindblad master equation which includes the mediated interactions and dissipation. We apply this procedure to the time-periodic dissipative Dicke model, a workhorse for the recently observed dissipative time crystals, and confirm its validity. Our results pave the ways towards the theoretical description of many-body quantum systems with mediated interaction and dissipation in presence of periodic driving.

Q 52.5 Thu 15:45 E001

Unveiling heating suppression regimes in a periodic driving Bose gas using a spacetime mapping — •Etienne Wamba[1,2], Axel Pelster[1], and James Anglin[1] — [1]Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany — [2]Faculty of Engineering and Technology, University of Buea, Buea, Cameroon

We consider a Floquet-engineered model of many-body systems with rapid driving and map the evolutions of the model onto those of relatively slow processes. Such a mapping between rapid and slow evolutions allows us to investigate non-equilibrium many-body dynamics and examine how rapidly driven systems may avoid heating up, at least when mean-field theory is still valid. The fact that the fast time evolution of the system can be mapped exactly onto that of an almost static system suggests that rapid periodic driving does not automatically cause heating, because the system may have a kind of hidden adiabaticity.

Q 52.6 Thu 16:00 E001

Probing boundaries in interacting topological systems — •Marius Gächter, Zijie Zhu, Anne-Sophie Walter, Konrad Viebahn, and Tilman Esslinger — ETH, Zurich, Switzerland

Boundaries between topologically distinct materials give rise to gapless edge modes whose robustness against perturbations makes them promising candidates for technological applications. Therefore, it is crucial to gain a better understanding of topological edge states, especially regarding their response to interparticle interactions. In our experiment, we study quantised bulk Hall drifts of interacting ultracold fermions in the presence of a harmonic confinement. We discovered that quantised drifts halt and reverse in the opposite direction at the topological boundary which emerges due to the harmonic confinement. In the absence of interactions this reflection can be understood as a transfer of atoms between bands with opposite Chern numbers C = +1 and C = -1 via a gapless edge mode, in agreement with the bulk-edge correspondence. Interestingly, this reflection can be used to study the edge in an interacting system since a non-zero repulsive Hubbard U leads to the emergence of an additional edge in the system, which is purely interaction-induced.

Q 52.7 Thu 16:15 E001

Observation of edge states in topological Floquet systems — •Alexander Hesse[1,2], Christoph Braun[1,2,3], Raphaël Saint-Jalm[1,2], Johannes Arceri[1,2], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Floquet engineering, i.e., periodic modulation of a system's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. In particular, the so-called anomalous Floquet phase displays topological properties even if the Chern number of the bulk band vanishes. [1]

Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, including an anomalous phase. [2]

As the bulk-boundary correspondence relates the properties of the bulk bands to the number of topologically protected edge modes, special interest lies in studying the behavior of them. We are investigating the real-space evolution of a wavepacket close to the edge after the release from a tightly-focused optical tweezer. This way, we observe the chiral nature of the edge state, even in the anomalous Floquet phase, thereby directly revealing the topological nature of this phase.

[1] Rudner et al., Phys. Rev. X 3, 031005 (2013)
[2] Wintersperger et al., Nat. Phys. 16, 1058-1063 (2020)

Q 53: Single Quantum Emitters (joint session Q/QI)

Time: Thursday 14:30–16:30 Location: E214

Invited Talk Q 53.1 Thu 14:30 E214

Quantum information with atomic quantum metasurfaces and integrated nanophotonics — •Rivka Bekenstein for the SHIPTRAP-Collaboration — Hebrew University, Jerusalem, Israel

Quantum information processing with photonic qubits requires on-demand single photon sources, linear components, along with more advanced components such as quantum memories and deterministic nonlinearity to implement logic gates between photonic qubits. I will discuss two promising systems for generating and controlling photonic qubits. I will first present our fiber-coupled single-photon-source based on silicon-vacancy centers in nanophotonic cavity diamond. This source features high efficiency, purity, temporal control, and integrability. We have been able to demonstrate arbitrarily temporally shaped single photon pulses with high purity (g2(0) = 0.0168) and detection efficiency of 14.9. This achievement combined with previously demonstrated spin-photon gates and long-lived memory, enables on-demand generation of streams of correlated photons useful for one-way quantum computation. I will then present our quantum-metasurfaces-based quantum protocols for large-scale entanglement generation and quantum holography. These work build upon our recent analysis of quantum metasurfaces: two-dimensional atomic arrays which control light coherently by scattering.

Q 53.2 Thu 15:00 E214

Efficient High-Fidelity Flying Qubit Shaping — •Benedikt Tissot and Guido Burkard — Universität Konstanz

Single photon emission is the cornerstone of numerous quantum technologies, such as distributed quantum computing as well as several quantum internet and networking protocols. We find the upper limit for the photonic pulse emission efficiency for imperfect emitters and show a path forward to optimize the fidelity. The outlined theory for stimulated Raman emission is applicable to a wide range of physical systems including quantum dots, solid state defects, and trapped ions, as well as various parameter regimes in particular for any pulse duration. Furthermore, the mathematical idea to use input-output theory for pulses to absorb the dominant emission process into the coherent dynamics, followed by a quantum trajectory approach has great potential to study other physical systems.

Q 53.3 Thu 15:15 E214

Localized creation of yellow single photon emitting carbon complexes in hexagonal boron nitride — •Anand Kumar[1], Chanaprom Cholsuk[1], Askhan Zand[1], Mohammad Nasimuzzaman Mishuk[1], Tjorben Matthes[1], Falk Eilenberger[1], Sujin Suwanna[2], and Tobias Vogl[1] — [1]Abbe Center of Photonics, Institute of Applied Physics, Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Mahidol University, Bangkok 10400, Thailand

Single-photon emitters in solid-state systems have received a lot of attention as building blocks for numerous quantum technology applications. Defect-based single-photon emitters in hexagonal boron nitride (hBN) stand out due to their optical and physical properties, such as room temperature operation and high single photon luminosity. However, the localized fabrication of these emitters in the crystal lattice is still not very well understood and thus the integration with optical and electronic platforms remains challenging. In the present work, we demonstrate the localized fabrication of emitters by electron beam irradiation using a scanning electron microscope with sub-micron lateral precision. Density functional theory calculations, coupled with experimentally observed emission lines at 575 nm show that the emitters are related to the presence of carbon-based defects, which are activated by the electron beam interaction. We also present results on correlating crystal structure properties and polarization dynamics. Our results indicate that these emitters have a high fabrication yield of identical emitters, which is a crucial advantage for the realization of quantum integrated devices.

Q 53.4 Thu 15:30 E214

Fingerprinting color centers in hexagonal boron nitride — •Chanaprom Cholsuk[1], Sujin Suwanna[2], and Tobias Vogl[1] — [1]Abbe Center of Photonics, Institute of Applied Physics, Friedrich-Schiller-University, Albert-Einstein-Straße 15, 07745 Jena — [2]Optical and Quantum Physics Laboratory, Department of Physics, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand

Optical quantum technologies promise to revolutionize today's information processing and sensing. Crucial to many quantum applications are efficient sources of pure single photons. For a quantum emitter to be used in such application, or for coupling between different quantum systems, the optical emission wavelength of the quantum emitter needs to be tailored. Here, we use density functional theory (DFT) to calculate and manipulate the transition energy of fluorescent defects in the two-dimensional hexagonal boron nitride.

Our calculations feature the HSE06 functional which accurately predicts the electronic band structures of 267 different defects. Moreover, using strain-tuning we can tailor the optical transition energies of suitable quantum emitters to precisely match those of quantum technology applications. The complete photophysical properties of the emitters including spectrum profile, Huang-Rhys factor, radiative and non-radiative lifetime, quantum efficiency, and excitation and emission dipoles are also revealed. We thereby not only have a promising pathway for tailoring quantum emitters that can couple to other solid-state qubit systems but also get access to the complete fingerprint of the emitters for identifying the defect structure of the emitters.

Q 53.5 Thu 15:45 E214

Will a single two-level atom simultaneously scatter two photons? — •Luke Masters, Xinxin Hu, Martin Cordier, Gabriele Maron, Lucas Pache, Arno Rauschenbeutel, Max Schemmer, and Jürgen Volz — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

The interaction of light with a single two-level emitter is the most fundamental process in quantum optics, and is key to many quantum applications. As a distinctive feature, two photons are never detected simultaneously in the light scattered by the emitter. This is commonly interpreted by saying that a single two-level quantum emitter can only absorb and emit single photons. However, it has been theoretically proposed that the photon anti-correlations can be thought to arise from quantum interference between two possible two-photon scattering amplitudes, which one refers to as coherent and incoherent. This picture is in stark contrast to the aforementioned one, in that it assumes that the atom even has two different mechanisms at its disposal to scatter two photons at the same time. Here, we validate the interference picture by experimentally verifying the 40-year-old conjecture that, by spectrally rejecting only the coherent component of the fluorescence light of a single two-level atom, the remaining light consists of photon pairs that have been simultaneously scattered by the atom. Our results offer fundamental insights into the quantum-mechanical interaction between light and matter and open up novel approaches for the generation of highly non-classical light fields.

Q 53.6 Thu 16:00 E214

Multi-channel waveguide-integrated single photon sources — •Chaiyasit Nenbangkaeo, Alexander Eich, Tobias Spiekermann, and Carsten Schuck — Institute of Physics, University of Münster, Germany

Integrated quantum photonic technology requires large numbers of single quantum emitters. While single-emitter systems have successfully been embedded into nanophotonic waveguides [1], the integration of larger numbers of single-photon sources into complex photonic circuits has remained a challenge. Here we show a novel approach that allows for simultaneously coupling single-photons from several independent colloidal quantum dots into tantalum pentoxide waveguides (Ta2O5). We employ a lithographic technique that probabilistically inserts quantum dots into a waveguide array and then deterministically remove multi-emitter systems until only a single-emitter per waveguide channel remains, thus achieving high-yield integration of single-photon sources across multiple nanophotonic channels. We demonstrate the feasibility of our method with autocorrelation measurements, showing anti-bunching of quantum dot photoluminescence for each individual channel. Our work paves the way for deterministically equipping photonic integrated circuits with large numbers of single-photon sources benefitting a wide range of applications in quantum technology.

[1] Eich, Alexander, et al., ACS Photonics 2022 9 (2), 551-558

Q 53.7 Thu 16:15 E214

Photoluminescence Excitation Characteristics of Color Centers in hBN at Room Temperature — •Pablo Tieben[1,2], Hiren Dobariya[2], Nora Bahrami[1,2], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany

In the rapidly developing field of quantum technologies single photons play an important role for a number of applications. Optically active color centers in hexagonal boron nitride (hBN) are of particular interest as they exhibit bright single photon emission over a broad range as well as narrow linewidths at and even well above room temperature. Furthermore, as a solid-state single photon source, these emitters can be reliably integrated into photonic circuits and thus offer a large advantage in terms of scalability. A dependency of the fluorescence emission of single emitters on the excitation wavelength has been observed recently, implying a more complex level structure. Systematic measurements of this dependency could reveal more information about the underlying energy levels and thus atomic structure of these defects. Particularly interesting are patterns in the separation between excited states for a classification of different types of emitters. We perform spectroscopic measurements while varying the excitation wavelength over a large range to gain further insight into their characteristic properties and energy level schemes. By analysis of the excitation spectrum of individual defects, we are extracting information on the distribution of energetic transitions across a large number of emitters.

Q 54: Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)

Time: Thursday 14:30–16:30 Location: F102

See MO 17 for details of this session.

Q 55: Precision Spectroscopy of Atoms and Ions III (joint session A/Q)

Time: Thursday 14:30–16:30 Location: F303

See A 26 for details of this session.

Q 56: Quantum Gases: Fermions II

Time: Thursday 14:30–16:30 Location: F342

Q 56.1 Thu 14:30 F342

Hartree-Fock-Bogoliubov Variational Approach for BCS Superfluidity — •Nikolai Kaschewski and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

The established theory for the BCS-BEC crossover is based on formulating the underlying many-body problem with the functional integral and on performing a Hubbard-Stratonovich transformation in the Bogoliubov channel [1,2]. A saddle-point approximation reveals then that the whole BCS-BEC crossover can only be described once Gaussian fluctuations around the saddle point are taken into account, which turns out to be numerically quite demanding.

Here we tackle this many-body problem from another point of view. To this end we work out a variational approach for the underlying Hamilton operator in canonical field quantization, which includes not only the Bogoliubov but also the Hartree and the Fock channel. We determine the first beyond mean-field corrections and compare their results for the density profiles in the BCS regime with the corresponding ones of the functional integral theory.

[1] C. A. Sá de Melo, M. Randeria, and J. R. Engelbrecht, Phys. Rev. Lett. **71**, 3202 (1993).

[2] J. R. Engelbrecht, M. Randeria, and C. A. R. Sá de Melo, Phys. Rev. B **55**, 15153 (1997).

Q 56.2 Thu 14:45 F342

Correlations in ultracold few-fermion systems revealed by matterwave microscopy — •Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Marvin Holten, Philipp Lunt, Luca Bayha, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Germany

The ability to image individual quantum particles has provided unprecedented access to microscopic correlations in few and many-body ultracold quantum systems. Recent advances in momentum space microscopy of continuous systems have revealed how Pauli blocking leads to fermionic antibunching and formation of cooper pairs in mesoscopic 2D fermi gases in the vicinity of a phase transition precursor.

Microscopy is inherently limited by optical resolution and this prevents direct imaging in position space when interparticle spacing is smaller than the resolution limit. Here we circumvent this limit by magnifying the many-body wavefunction using matterwave techniques prior to imaging the system thereby giving us access to particle correlations in position space. We use this technique to probe correlations in two paradigmatic models consisting of an equal or unequal number of spin components. A spin-balanced system shows a tendency towards short distance correlations with increasing interaction strengths. The opposite limit of a strongly interacting single impurity in a Fermi gas is also explored which is prepared using radio frequency transfer with motional state resolution. As the interaction strength in the system is increased the impurity preferentially binds to one of the majority atoms as revealed by higher-order correlations.

Q 56.3 Thu 15:00 F342

A mesoscopic fluid of 10 fermions — •Sandra Brandstetter, Philipp Lunt, Carl Heintze, Jonas Herkel, Marvin Holten, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

A striking manifestation of collective behaviour is the emergence of hydrodynamics, the effective description of a system as a fluid. In addition to classical systems, hydrodynamic expansion has been observed in different many-body quantum systems, ranging from heavy ion collisions to ultracold quantum gases. However the emergence of hydrodynamics in the mesoscopic limit is still unexplored. Our cold atom experiment opens up new pathways starting from the smallest scales with deterministic control over the atom number and interaction strength. We observe the inversion of the initial aspect ratio after an interacting expansion - a signature of hydrodynamics - in a system comprised of only 10 particles.

We prepare few fermionic 6Li atoms in 2 different spin states in the ground state of an elliptical 2D trap. A sudden switch off of the confining potential in radial direction leads to an expansion in a 2D plane, which we perform at different interaction strengths. Our spin and single atom resolved imaging technique allows us to study correlations of any order between atoms. Two different matterwave magnification techniques provide access to momentum or real space at different times during the expansion, such that we can directly observe the inversion of the aspect ratio.

Q 56.4 Thu 15:15 F342

Full phase aberration correction - from the source to the atoms — •Paul Hill, Philipp Lunt, Johannes Reiter, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Heidelberg, Deutschland

Using light to engineer a broad class of potential landscapes for ultracold atoms has enabled numerous breakthroughs in the field of analog quantum simulation [1]. Especially, trapping and manipulation of individual particles requires light patterns of exquisite precision saturating the diffraction limit of high NA optics. Characterizing and eliminating wavefront errors in an optical setup is therefore a key factor for experimental success, but usually proves to be challenging or can only be done for parts of the setup.

Here, we present a method to measure the entirety of aberrations acquired in an optical setup with a Spatial Light Modulator (SLM), from the source plane to the atoms. This method relies on a type of Phase Shift Interferometry (PSI) [2] where we use a double well pattern sensitive to the phase aberrations present in the light path. Imaging the fluorescence signal of only 100 atoms trapped in this double well potential is sufficient to retrieve the relevant phase information, which is then used to cancel aberrations on the SLM. This allows critical components, including our vacuum window, to be mapped out that are usually inaccessible to aberration correction.

[1] W Hofstetter and T Qin 2018 J. Phys. B: At. Mol. Opt. Phys. 51 082001

[2] Philip Zupancic et al. Opt. Express 24, 13881-13893 (2016)

Q 56.5 Thu 15:30 F342

Dark state transport in a strongly interacting Fermi gas — Mohsen Talebi, •Simon Wili, Philipp Fabritius, Jeffrey Mohan, Meng-Zi Huang, and Tilman Esslinger — Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Laser-induced coherence of atomic states can dramatically alter the properties of an atomic medium. For example, a three-level system in a lambda configuration can be transparent to a resonant laser when another laser drives the other resonance. This is known as electromagnetically induced transparency (EIT). Another feature is the so-called dark state: The system driven by two lasers has an eigenstate which is a superposition of the two ground states. While the amplitudes of this superposition, described by a mixing angle, depend on the optical fields, the energy of this state does not, hence it is dark. EIT and dark states have various applications, such as slow light, stimulated rapid adiabatic passage (STIRAP), and photonic quantum memory. Here we study transport of a Fermi gas with two strongly-interacting spins, one of which is subject to an auxiliary lambda system. We create a particle current flowing through a one-dimensional channel connecting two superfluid reservoirs. A localized laser beam addressing a transition of the lambda system in the channel suppresses fast particle transport, while a second beam fulfilling the EIT condition can revive the fast transport. Hence we demonstrate a current that comprises a dark state for the first time in a strongly-interacting fermionic system. As in our system the pairing interaction depends on the mixing angle, this work paves the way for local and temporal engineering of fermionic pairing.

Q 56.6 Thu 15:45 F342

Exploring doped antiferromagnets with a Quantum Gas Microscope — Petar Bojovic[1,2], Sarah Hirthe[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Si Wang[1,2], Timon Hilker[1,2], and •Immanuel Bloch[1,2,3] — [1]Max Planck Institute of Quantum Optics — [2]Munich Center for Quantum Science and Technology — [3]Ludwig Maximilian University

We use our quantum gas microscope of fermionic ^{6}Li atoms loaded into the optical lattices to realize and study magnetic phases of the Fermi-Hubbard model with single-site spin and density resolution. In this talk, I will present our recent implementation of highly stable and tunable optical bichromatic superlattices, which provide the flexibility to test promising cooling protocol and reach novel phases of matter. I will furthermore discuss how we use a digital micromirror device (DMD) for potential shaping on individual sites and create tailored geometries [1, 2]. In such microscopically engineered systems, we can investigate interaction mechanisms in hole- or doublon- doped antiferromagnets and probe the formation of magnetically induced bound pairs among dopants.

[1] P. Sompet, S. Hirthe, D. Bourgund et al., Nature 606, 484-488 (2022)
[2] S. Hirthe et al., arXiv: 2203.10027 (2022)

Q 56.7 Thu 16:00 F342

Feshbach molecules in an optical orbital lattice — •Max Hachmann, Yann Kiefer, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We experimentally study strongly interacting degenerate Fermi gases exposed to an optical lattice. Previous studies focussed on the case, where only the lowest Bloch band is populated, such that the orbital degree of freedom is excluded. We report our experimental findings studying ultracold Feshbach molecules of fermionic 40K atoms selectively prepared in the second Bloch band of a bipartite optical square lattice, covering a wide range of interaction strengths including the regime of unitarity. Binding energies and band relaxation dynamics are measured by means of a method resembling mass spectrometry. The longest lifetimes arise for strongly interacting Feshbach molecules at the onset of unitarity with values around 300ms for the lowest band and 100ms for the second band. In the case of strong confinement in a deep lattice potential, we observe bound dimers also for negative values of the s-wave scattering length, extending previous findings for molecules in the lowest band. Our work prepares the stage for orbital BEC-BCS crossover physics.

Q 56.8 Thu 16:15 F342

Thermometry for trapped fermionic atoms in the BCS limit — •Sejung Yong, Sian Barbosa, Artur Widera, and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Measuring the temperature of an interacting fermionic cloud of atoms in the BCS limit represents a delicate task. In the literature temperature measurements have so far been only suggested in an indirect way, where one sweeps isentropically from the BCS to the BEC limit. Instead we suggest here a direct thermometry, which relies on measuring the column density and comparing the obtained data with a Hartree-Fock-Bogoliubov mean-field theory combined with a local density approximation. In case of an attractive interaction between two-components of ^{6}Li atoms trapped in a tri-axial harmonic confinement we show that minimizing the error within such an experiment-theory collaboration turns out to be a reasonable criterion for determining the temperature. The findings are discussed in view of various possible sources of errors.

Q 57: Quantum Networks II (joint session QI/Q)

Time: Thursday 14:30–16:30 Location: F428

See QI 33 for details of this session.

Q 58: Quantum Optics with Photons I

Time: Thursday 14:30–16:30 Location: F442

Q 58.1 Thu 14:30 F442

Improving the Phase Sensitivity of SU(1, 1) **Interferometers by Phase Matching Compensation** — •Dennis Scharwald and Polina Sharapova — Paderborn University, Department of Physics, Warburger Str. 100, D-33098 Paderborn, Germany

Improving the phase sensitivity of interferometers is a central challenge in quantum optics. Using coherent light, the lower limit for the sensitivity is given by the shot noise limit (SNL), while the quantum mechanical lower bound for this sensitivity is given by the Heisenberg limit. One way of surpassing the shot noise limit is using SU(1, 1) interferometers, which consist of two PDC sections. Between these sections pump, signal and idler photons experience some relative phase shift. [1]

In our work, we extend the approach of integro-differential equations for the description of the PDC process derived in Ref. [2] to a certain kind of configuration where the PDC radiation generated by a single crystal is focussed back into a PDC section after experiencing the phase shift. We show numerically that using this setup, the phase sensitivity of the interferometer can be improved below the shot noise limit easier than using an SU(1, 1) interferometer without such kind of compensation.

[1] M. Manceau *et al.*, New J. Phys. **19**, 013014 (2017)
[2] P. R. Sharapova *et al.*, Phys. Rev. Research **2**, 013371 (2020)

Q 58.2 Thu 14:45 F442

Quantum characterization of superconducting detectors — •Timon Schapeler and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Single-photon detectors, especially based on superconductivity are indispensable for most quantum applications, which makes characterizing them necessary to ensure proper operation. We show a characterization of superconducting nanowire single-photon detector arrays using quantum detector tomography. We quantify the photon-number-resolving ability through the purity of the detection outcomes. Additionally, we investigate the spectral response of a detector for possible spectroscopic applications.

Q 58.3 Thu 15:00 F442

Optical quantum tomography in the time domain — •Emanuel Hubenschmid[1], Thiago Guedes[2], and Guido Burkard[1] — [1]Universität Konstanz, 78467 Konstanz, Deutschland — [2]Forschungszentrum Jülich, 52428 Jülich, Deutschland

Electro-optic sampling presents a powerful tool to sample the waveform of a mid-infrared pulse in the time domain by measuring the effect a nonlinear interaction of the sampled mid-infrared pulse has on an ultrabroadband near-infrared pulse. Recent experiments applied this technique to sample the electric field fluctuation of the squeezed vacuum [Nature 541, 376 (2017)] on a sub-cycle scale. However, a full quantum tomography scheme in the time domain is still missing. Here we present a theoretical description of a possible electro-optic-based quantum tomography scheme with sub-cycle resolution. By combining novel theoretical tools to describe the interaction of the sampled pulse and an ultrabroadband near-infrared pump pulse in the nonlinear crystal [Phys. Rev. D 105, 056023 (2022)] and of quantum tomography with continuous wave-driven electro-optic sampling [Phys. Rev. A 106, 043713 (2022)], we calculate the probability distribution of our tomography schemes signal depending on the time delay between the sample and near-infrared pulse. Furthermore, we analyze the noise of the signal and describe how to reduce the contribution due to the broadness of the pump pulse. Combining these results, we describe how to reconstruct an arbitrary quantum state and its waveform, without any post-processing in the frequency domain and thereby paving the way towards quantum tomography in the time domain.

Q 58.4 Thu 15:15 F442

Measurement of two-point spectral correlation functions of pulsed quantum states of light — •Abhinandan Bhattacharjee, Patrick Folge, Laura Serino, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Coherence theory is an established research area for characterizing statistical randomness in an optical field. Typically, coherence is quantified through a two-point correlation function. This is routinely measured in spatial and temporal domains. One can also consider spectral coherence, however, the measurement of spectral two-point correlation function becomes challenging because interferometric techniques generally require high-intensity input fields and reconstruction algorithms do not work well for arbitrary spectral shapes.

Recently, the emergence of the quantum pulse gate (QPG), a frequency up-conversion process, has enabled the projection of an input field onto any desired spectral mode with high fidelity, including in the single photon regime. This device therefore overcomes the challenges of measuring spectral coherence. We propose an interferometric scheme that uses a QPG to project a classical or quantum state of light field onto a superposition of two spectral bins and obtains the two-point correlation function by measuring the intensity of the up-converted field as a function of the bin separation. In the context of parametric down-conversion, the spectral coherence measurement of only one of the arms certifies the spectral entanglement between two outputs.

Q 58.5 Thu 15:30 F442

Bi-photon correlation time measurements with a two-colour broadband SU(1,1) interferometer — •Franz Roeder, Michael Stefszky, René Pollmann, Kai Hong Luo, Matteo Santandrea, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

SU(1,1) interferometers have lately been used for several applications such as achieving super-sensitivity for quantum metrology or enabling spectroscopy and imaging with undetected photons. So far, most of the developed interferometers are based on parametric down-conversion (PDC) from bulk crystals, limiting the brightness of the sources as well as integrability. Furthermore, only spectral or temporal interferograms have been investigated so far.

Here, we demonstrate spectral and temporal interferometry using a SU(1,1) interferometer based on ultra-broadband, non-degenerate dispersion-engineered parametric down-conversion in nonlinear waveguides. These PDC sources exhibit strong frequency correlations and, simultaneously, sub-100 fs photon-photon correlation times. Measuring spectral and temporal interferograms simultaneously allows us to extract the ultra-short biphoton correlation time of our source, a task that has been challenging until now. Knowledge about this quantity is essential for further applications such as entangled two-photon absorption.

Q 58.6 Thu 15:45 F442

Terahertz sensing with undetected photons — •Mirco Kutas[1,2], Björn Haase[1,2], Jens Klier[1], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Fraunhofer Institute for Industrial Mathematicutes ITWM, Fraunhofer-Platz 1, 67663 Kaiserslarn — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

Today, terahertz applications are widely used in industry as well as scientific research. Although the used components have undergone a tremendous development in recent decades, detection of terahertz radiation is still subject of current investigation. By using a quantum-optical measurement concept, we demonstrate a novel approach to detect phase-sensitive terahertz information. With this concept, it is possible to transfer the terahertz photon properties after interaction with a sample to visible photons. As a result, detection can be realized by easily accessible and highly developed silicon-based detectors without the need of cooling or expensive equipment. We report on the demonstration of quantum sensing and spectroscopy in the terahertz frequency range by only detecting visible light.

Q 58.7 Thu 16:00 F442

Remote Imaging in a Three Atom System — •Manuel Bojer[1], Jörg Evers[2], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

We study a system consisting of three identical two-level atoms where two atoms are assumed to be close to each other such that they interact via the dipole-dipole interaction while the third atom is located at a distance $d \gg \lambda$, with λ the atomic transition wavelength. Although the distant third atom does not directly interact with the collective two-atom subsystem, it can be used to alter the total system's spontaneous emission properties via measurement-induced entanglement. We present a detection scheme for which Glauber's third-order photon correlation function displays an oscillatory behavior in time, with a frequency determined by the coherent coupling parameter of the dipole-dipole interaction between the first two atoms. This parameter crucially depends on the two-atom separation allowing to resolve the distance between the two adjacent atoms with sub-Abbe resolution.

Q 58.8 Thu 16:15 F442

Phase-quadrature quantum imaging with undetected light — •Björn Haase[1,2], Joshua Hennig[1,2], Mirco Kutas[1,2], Erik Waller[1], Julian Hering[2], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Fraunhofer Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

The use of nonlinear interferometers allows sensing with undetected photons. The corresponding experiments base on biphotons that are generated by spontaneous parametric down-conversion. They enable the transfer of spectral properties from one spectral range that is usually hard to investigate to photons from another spectral region easier to observe. By detecting these signal photons, the interaction of a sample with the idler light can be investigated. So far, the sample's information in terms of both phase and transmittance is received by measuring the corresponding interferogram, which is achieved by multiple recordings with phase changes in between. On this conference, I will present an alternative phase-quadrature approach with a nonlinear interferometer used for imaging with undetected light in the NIR range. With this development, in which we use wave plates and a polarizing beam splitter, we are able to obtain both the phase and visibility with one single image acquisition without the requirement to change optical paths or phases. Thus, with the reduced measurement duration it becomes possible to observe dynamic processes like the drying of an isopropanol film with this kind of nonlinear interferometer.

Q 59: Poster IV

Time: Thursday 16:30–19:00 Location: Empore Lichthof

Q 59.1 Thu 16:30 Empore Lichthof

State-dependent force spectroscopy for trapped ions — •Stefan Walser, Zhenlin Wu, René Nardi, Guanqun Mu, Brandon Furey, and Philipp Schindler — Institut für Experimentalphysik, Universität Innsbruck, Austria

Optical trapping and laser cooling are techniques that founded a revolution of quantum experiments in which atoms and molecules are manipulated using optical forces induced by laser light. A particularly useful technique are optical tweezers which are routinely used in many scientific disciplines. Certain trapped ions are an excellent basis for high precision spectroscopic experiments due to the available electronic structure for state preparation and read-out at the single atom level. Within this project we aim to combine state-dependent optical tweezers to manipulate the motional modes of an ion crystal with quantum logic spectroscopy. We plan to co-trap a well controllable $^{40}Ca^{+}$ logic ion with a molecular ion of interest which is inaccessible to the standard spectroscopic techniques in ion traps. Applying a state-dependent force on the molecular ion using an optical tweezer, the overall trapping potential is modified. This consequently changes the frequency of the ion's common motional mode. That frequency shift can be measured via the logic ion. Thereby we realize a quantum non-demolition measurement of the molecule's internal vibrational and rotational states. We hope that this project will facilitate the non-destructive state detection of molecules with the outlook of providing a basis for a compact spectrometer for atomic and molecular systems.

Q 59.2 Thu 16:30 Empore Lichthof

Decoherence of Rigid Rotors due to Emission of Thermal Radiation — •Jonas Schäfer, Benjamin A. Stickler, and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Duisburg

Recent advances in the control of levitated nanoparticles open the door for fundamental tests and sensing applications exploiting their rotational degrees of freedom [1]. This poster presents the quantum master equation of rotational and translational decoherence of internally hot dielectric particles of arbitrary size and shape emitting thermal radiation. We find that even highly symmetric objects, such as spheres, exhibit orientational decoherence since the internal excitations sourcing the emitted fields break the symmetry of the particle. We quantify the resulting decoherence rates for upcoming experiments with nanoscale to microscale objects.

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589-597 (2021)

Q 59.3 Thu 16:30 Empore Lichthof

Dynamics of superconducting microscale rotors — •Fynn Köller, Klaus Hornberger, and Benjamin A. Stickler — University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

The rotation dynamics of magnetizable objects can be affected strongly by spin-rotational coupling since their internal magnetization field contributes to their total angular momentum. Starting from the classical equations of motion, this poster will derive the Hamiltonian of a superconducting rotor of ellipsoidal shape levitated diamagnetically in a magnetostatic quadrupole field. We will discuss how signatures of strong spin-rotational coupling might become observable in upcoming experiments in the field of levitated nanomechanics and discuss the prospects for magnetic-field sensing.

Q 59.4 Thu 16:30 Empore Lichthof

Quantum interference of electrically trapped particles — •Eric van den Bosch, Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — University Duisburg-Essen, Duisburg, Germany

Orientational quantum revivals are a pronounced quantum interference effect caused by the fundamental quantization of angular momentum [1]. This poster will show how this quantum effect can be observed with electrically charged nanorotors suspended in the time-dependent fields of quadrupole ion traps. We will propose a concrete setup and discuss under what conditions coherence times on the order of a few seconds are realistically achievable.

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589 (2021)

Q 59.5 Thu 16:30 Empore Lichthof

Navigation via a Gimbal-Stabilized Quantum Accelerometer — •Mouine Abidi[1], Philipp Barbey[1], Yueyang Zou[1], Ann Sabu[1], Dennis Schlippert[1], Christian Schubert[2,1], Ernst. M Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Inertial navigation and positioning systems are the basis for controlling vehicles such as aircraft, ships, or satellites. However classical inertial sensors suffer from device-dependent drifts and require GNSS corrections.

Satellite navigation (GNSS) possesses inherent limitations. Its signals are prone to natural or human-made interference. Besides no GNSS signal in some areas.

Hybrid quantum navigation, based on the combination of classical Inertial Measurement Units with quantum sensors based on atom interferometry are a serious candidate for a new technology that meets today's requirements for inertial navigation.

We present our latest activities to transfer a complex laboratory-based device to a robust and compact measurement unit that can be used in a dynamic environment to subtract the drifts of classical devices. Using a new laser system design with the latest developed electronics along with the implementation of new optics schemes and commercial compact vacuum system.

Q 59.6 Thu 16:30 Empore Lichthof

T^4**-Atom Interferometer Sensitive to Angular Acceleration** — •Bernd Konrad and Maxim Efremov — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Nowadays, matter-wave interferometry has become a powerful technique for measuring acceleration, gravity gradient, and constant rotation with enormous precision [1]. Here, we explore atom interferometer which is highly sensitive to unknown constant angular acceleration $\dot{\Omega}$. By modeling rotation with fixed axis and constant angular acceleration with time-dependent angular velocity $\vec{\Omega}(t) = (\Omega_0 + \dot{\Omega}t)\vec{e}_\Omega$, where Ω_0 is its initial value, we employ atom-interferometric scheme based on a sequence $\pi/2 - \pi - \pi - \pi - \pi/2$ of five Raman laser pulses [2]. For a small enough Ω_0, we have found that the interferometer has a very high contrast, $C \approx 1$, more precisely it is reduced only by a correction scaling with the sixth order of Ω_0, that is $C = 1 + \mathcal{O}\left(\Omega_0^6\right)$. On the other hand, the leading term of the interferometer phase is linearly proportional to the angular acceleration $\dot{\Omega}$ and scales as T^4, namely $\varphi \propto \dot{\Omega}T^4 + \mathcal{O}\left(\Omega_0^3\right)$, where T is the total interferometer time. In addition, we have investigated the feasibility of the proposed scheme for the typical ground- and space-based configurations, such as a rotating platform on earth and satellites.

[1] G.M. Tino and M.A. Kasevich (Eds.), Atom Interferometry (IOS Press, Amsterdam, 2014)

[2] K.-P. Marzlin and J. Audretsch, Phys. Rev. A **53**, 312 (1996)

Q 59.7 Thu 16:30 Empore Lichthof

The Very Long Baseline Atom Interferometry facility for high precision gravity measurement — •Ali Lezeik[1], Mario Montero[1], Constantin Stojkovic[1], Klaus Zipfel[1], Dorothee Tell[1], Vishu Gupta[1], Henning Albers[1], Sebastian Bode[1], Jonas Klussmeyer[1], Ernst Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover- Insititut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

Matter-wave interferometry is a sequence of light pulses used to manipulate an ensemble of ultracold atoms and let them interfere. This interference pattern contains rich information about the intertial forces acting on the atoms like the gravitational acceleration, making atom interferometers useful devices for metrological applications and testing fundamental physics. Their sensitivity depends on several factors one of which being the freefall time. A second-long free fall of the atoms allows to reach acceleration sensitivities of 1 nm/s^2, comparable to the best classical gravimeters. In addition, excellent control over the environment and a high number of atoms in the ensemble is necessary to reduce systematic effects and enhance the signal to noise ratio. The 15 m high Very Long Baseline Atom Interferometry facility (VLBAI) aims for sub nm/s^2 gravity measurement sensitivities. We present the current status of the VLBAI and outline the distinguishing aspects of the facility that includes a dual source chamber of ytterbium and rubidium, a 10 m long UHV baseline magnetically shielded to below 1.5 nT/m, and a seismic attentuation system for intertial referencing.

Q 59.8 Thu 16:30 Empore Lichthof

Dark Energy search using atom interferometry in microgravity — •Sukhjovan S Gill[1], Magdalena Misslisch[1], Baptist Piest[1], Ioannis Papadakis[2], Vladimir Schkolnik[2], Sheng-wey Chiow[3], Nan Yu[3], and Ernst M Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany 30167 — [2]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany 12489 — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA 91109

The nature of Dark energy is one of the biggest quests of modern physics. It is needed to explain the accelerated expansion of the universe. In the chameleon theory, a hypothetical scalar field is proposed, which might affect small test masses like dilute atomic gases. In the vicinity of bulk masses, the chameleon field is hidden due to a screening effect making the model in concordance with observations. Dark Energy Search using Interferometry in the Einstein-Elevator(DESIRE) studies the chameleon field model for dark energy using Bose-Einstein Condensate of ^{87}Rb atoms as a source in a microgravity environment. Einstein-Elevator provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. This method suppresses the influence of vibrations, gravity gradients and rotations via common mode rejection. The specially designed test mass suppresses gravitational effects from self-mass and its environment. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

Q 59.9 Thu 16:30 Empore Lichthof

Experimental platform for multi-axis inertial quantum sensing — •Matthias Gersemann[1], Sven Abend[1], Mouine Abidi[1], Philipp Barbey[1], Mikhail Cheredinov[1], Ashwin Rajagopalan[1], Ann Sabu[1], Yueyang Zou[1], Christian Schubert[2], Ekim T. Hanimeli[3], Sven Herrmann[3], Simon Kanthak[4], Ernst M. Rasel[1], and the QUANTUS team[1,3,4,5,6,7] — [1]Institut für Quantenoptik, LU Hannover — [2]DLR-SI, Hannover — [3]ZARM, Uni Bremen — [4]Institut für Physik, HU zu Berlin — [5]Institut für Quantenphysik, Uni Ulm — [6]Institut für Angewandte Physik, TU Darmstadt — [7]Institut für Physik, JGU Mainz

In light pulse atom interferometry, ultracold atoms open the prospect of developing new techniques and concepts, in particular to increase the sensitivity of inertial measurements.

The possibility of precise motion control combined with large momentum transfer through double Bragg diffraction and Bloch oscillations contributed to the development of a new concept to create two simultaneous interferometers from a single BEC, as employed for the differentiation between rotations and accelerations. Thanks to the symmetry of this geometry, its extension can form the basis for a compact six-axis quantum inertial measurement unit based on atom-chip technology.

The underlying concepts, the system design used for this purpose, and the technical realization are presented in this contribution.

Q 59.10 Thu 16:30 Empore Lichthof

The Very Long Baseline Atom Interferometry facility for high precision gravity measurement — •Ali Lezeik[1], Mario Montero[1], Klaus Zipfel[1], Dorothee Tell[1], Vishu Gupta[1], Christian Meiners[1], Henning Albers[1], Sebastian Bode[1], Ernst Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover- Insititut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

Matter-wave interferometry is a sequence of light pulses used to manipulate an ensemble of ultracold atoms and let them interfere. This interference pattern provides information about the intertial forces acting on the atoms, making atom interferometers useful devices for metrological applications and testing fundamental physics. As their sensitivity scales quadratically with the freefall time, a second-long free fall of the atoms allows to reach acceleration sensitivities of 1 nm/s^2, comparable to the best classical gravimeters. Excellent control over the environment and a high number of atoms in the ensemble is also necessary to reduce systematic effects and enhance the signal to noise ratio. The 15 m high Very Long Baseline Atom Interferometry facility (VLBAI) aims for sub nm/s^2 gravity measurement sensitivities.

We present the current status of the VLBAI and outline the distinguishing aspects of the facility that includes a dual source chamber of ytterbium and rubidium, a 10 m long UHV baseline magnetically shielded to below 1.5 nT/m, and a seismic attentuation system for intertial referencing.

Q 59.11 Thu 16:30 Empore Lichthof

Absolute light-shift compensated laser system for a twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice atom interferometry is a method for forming symmetric interferometers with matter waves of large relative momentum by using two optical lattices propagating in opposite directions. A limiting factor is the loss of contrast associated with the AC Stark shift of far detuned light fields. This contribution presents the realization of a high power laser system for absolute light shift compensation and its potential for enhancing the interferometric contrast. The optical setup relies on two independent frequency doubling stages. One cavity produces the needed light fields for twin-lattice interferometry and another one produces one light field for AC Stark compensation.

Key features are the beam overlap on an interference filter with low power loss and coupling of high optical power in a photonic crystal fiber and further collimation of the output profile with flat-top beamshaper. The final beam contains the three linearly polarized light fields. Thanks to the flat-top shaped beam with more uniform intensity distribution it can be passed through our apertures with significantly less diffraction effects.

Q 59.12 Thu 16:30 Empore Lichthof

Multi-axis quantum gyroscope with multi-loop atomic Sagnac interferometry — •Ann Sabu[1], Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[1,2], Matthias Gersemann[1], Dennis Schlippert[1], Ernst Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Large area enclosed atom interferometers are potential devices for rotation measurements in inertial navigation. We aim at developing a compact and portable demonstrator capable of multi-axis inertial sensing, enabling precise measurement of rotations and accelerations. In future, an experimental realization of multi-loop atomic interferometry using such a portable gyrosope is also possible.

We present a brief theory of multi-loop atomic Sagnac interferometry, the current status of the preliminary system design of the demonstrator using the Bose-Einstein condensates (BECs) of ^{87}Rb atoms. We also present the design of the laser system for beamsplitter, cooling and detection sequence.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and through the CRC 1227 (DQ-mat), as well as support from DLR with funds provided by the BMWi under grant no. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

Q 59.13 Thu 16:30 Empore Lichthof

A state-of-the-art suppression of seismic noise. The Seismic attenuation for Very Long Baseline Atom Interferometry — •Jonas Klussmeyer, Sebastian Bode, Klaus Zipfel, Christian Schubert, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The increased separation time of atomic ensembles in a Very Long Baseline Atom Interferometer (VLBAI) allows one to scale up the sensitivity to inertial effects. Likewise, however this also increase the sensitivity to seismic noise introduced by the retro reflection mirror, which acts as an inertial reference. This noise source limits State-of-the-art atom interferometers (AI).

Here we present the VLBAI Seismic Attenuation System (SAS), which combines passive seismic attenuation in all degrees of freedom via an inverted pendulum hanging on geometric anti-springs with a vertical resonance frequency of 320 mHz. In order to suppress residual motion at the resonance, we aim for an active feedback utilizing various inertial sensors and actuators. The estimated instability using the SAS as an inertial reference has been calculated to around $10^{-6}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ per shot (drop: $2T = 0.8\,\mathrm{s}$, launch: $2T = 2.8\,\mathrm{s}$). Measuring the residual motion using an out-of-loop low-noise seismometer opens the path for either a direct feedback on the laser phase or a post-correction of the AI signal for reaching a $10^{-9}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ per shot instability, close to the shot noise limit for our 10^6 atoms.

Q 59.14 Thu 16:30 Empore Lichthof

Moving towards high precision classical sensor hybridization with atom interferometers — •Ashwin Rajagopalan, Ernst Rasel, Sven Abend, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Vibrational noise is one amongst the most dominant noise sources that hinders the measurement sensitivity of an atom interferometer. Although correlation with commercial accelerometers can be a solution, there are limitations in terms of compatibility, dimensions, sensitivity and correlation efficiency with the atom interferometer. The perspective is to measure the inertial reference mirror motion with utmost precision, which in turn enhances the measurement sensitivity of the atom interferometer. For this purpose, the accelerometer should be placed as close as possible to the mirror or even better if fully integrated with it. We have already demonstrated using a compact Opto-mechanical resonator directly on the inertial reference mirror to measure its motion and suppress the effects of vibrational noise on a T = 10 ms atom interferometer without any vibration isolation. The next step is to fully integrate the Opto-mechanical motion sensor with the inertial reference mirror such that the same test mass serves as the inertial reference mirror as well as one of the mirrors for the optical interferometer measuring motion. This eradicates the existence of a mechanical transfer function between the mirror and the motion sensor. Funded by the DFG EXC2123 QuantumFrontiers - 390837967 supported by the DLR with funds provided by BMWK under Grant No. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

Q 59.15 Thu 16:30 Empore Lichthof

Large-momentum-transfer atom interferometers with μrad-accuracy using Bragg diffraction — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Christian Schubert[2,3], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik

Large-momentum-transfer atom interferometers that employ elastic Bragg scattering from light waves are among the most precise quantum sensors available. To increase their accuracy from the mrad to the μrad regime, it is necessary to understand the rich phenomenology of Bragg interferometers, which can be quite different from that of a standard two-mode interferometer. We develop an analytic model for the interferometer signal and demonstrate its accuracy using extensive numerical simulations. Our analytic treatment enables the determination of the atomic projection noise limit of an LMT Bragg interferometer and provides the means to saturate this limit. It allows suppression of systematic phase errors by two orders of magnitude down to a few μrad using appropriate pulse parameters.

This work is supported through the DFG via QuantumFrontiers (EXC 2123), and DQ-mat (CRC1227) within Projects No. A05, No. B07, and No. B09.

Q 59.16 Thu 16:30 Empore Lichthof

Noise Description in Bragg Atom Interferometer Using Squeezed States — •Julian Günther[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperformthe standard quantum limit of $\frac{1}{\sqrt{N}}$ and approach the Heisenberg scaling of $\frac{1}{N}$ for the uncertainty inthe phase measurement $\Delta\phi$. We consider specifically the use of one-axis twisted, spin squeezed atomicstates in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty $\Delta\phi$ in the phasemeasurement taking into account the multi-port and multi-path nature of the Bragg Mach-Zehnderinterferometer, and determine optimally squeezed states for a given interferometer.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding origanisation DFG (project number 499225223).

Q 59.17 Thu 16:30 Empore Lichthof

Raman and Bragg diffractions in a combined system — •Ekim T. Hanimeli[1], Simon Kanthak[2,3], Matthias Gersemann[4], Mikhail Cheredinov[4], Sven Herrmann[1], Claus Lämmerzahl[1], Sven Abend[4], Ernst M. Rasel[4], and the QUANTUS team[1,2,3,4,5,6] — [1]ZARM, Universität Bremen — [2]Institut für Physik, HU Berlin — [3]Ferdinand-Braun-Institut, Berlin — [4]Institut für Quantenoptik, LU Hannover — [5]Universität Ulm — [6]Technische Universität Darmstadt

Combining Bragg and Raman processes allow for manipulation of both internal and external states of atoms in matter-wave interferometry. This enables novel interferometry topologies with the inclusion of techniques such as blow-away pulses, and clock interferometry. In order to investigate the possibilities arising from their combined use, we have realized a system capable of implementing both interrogation techniques, as well as single, double or higher order diffractions in a single setup. Here, we present some preliminary results from the implementation of this system for BEC interferometry.

The project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR 50WM2250C (QUANTUS+).

Q 59.18 Thu 16:30 Empore Lichthof

Momentum entanglement for atom interferometry — •Christophe Cassens[1], Fabian Anders[1], Alexander Idel[1], Polina Feldman[2], Dmitry Bondarenko[2], Sina Loriani[1], Karsten Lange[1], Jan Peise[1], Mathias Gersemann[1], Bernd Meyer-Hoppe[1], Sven Abend[1], Naceur Gaaloul[1], Christian Schubert[1,3], Dennis Schlippert[1], Luis Santos[2], Ernst Rasel[1], and Carsten Klempt[1,3] — [1]Institut für Quantenoptik, Leibniz Universität

Hannover, 30167 Hannover, Deutschland — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Deutschland — [3]Deutsches Zentrum fur Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, 30167 Hannover

Compared to light interferometers, the flux in cold-atom interferometers is low and the shot noise large. Sensitivities beyond this limitation require the preparation of entangled atoms in different momentum modes.

Here entangled twin-Fock states are deterministically created in the internal spin-degree of freedom of a Bose-Einstein condensate. Hereupon, the entanglement is transferred to distinct momentum-modes using two-photon Raman transitions and verified by measurement of a squeezing parameter.

The observed mode quality and the residual expansion demonstrate that this entangled source is well-suited to the application in light-pulse atom interferometers and opens up a path towards gravimetry beyond the standard quantum limit.

Q 59.19 Thu 16:30 Empore Lichthof

BECCAL - The Bose-Einstein Condensate and Cold Atom Laboratory — •Christian Deppner[1], Holger Ahlers[1], Patrick Brunssen[2], Marcel Eichelmann[1], Kai Frye-Arndt[1,3], Caroline Lösch[2], Arne Wacker[1], Meike List[2], Ernst M. Rasel[3], Waldemar Herr[1], Christian Schubert[1], and The BECCAL Team[1,2,3,4,5,6,7,8,9,10] — [1]DLR-SI, Callinstr. 30B 30167 Hannover, Germany — [2]DLR-SI, Am Fallturm 9, 28359 Bremen, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [4]DLR-QT — [5]DLR-SC — [6]Inst. für Quantenphysik, UUlm — [7]Inst. für Physik, JGU — [8]Inst. für Physik, HUB — [9]ZARM, Bremen — [10]FBH, Berlin

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is a NASA-DLR collaboration which will be a facility for conducting experiments with ultra-cold atoms and Bose-Einstein Condensates (BECs) aboard the International Space Station (ISS). BECCAL will enable the development of future quantum sensors based on matter-wave interferometry. The long term microgravity conditions on the ISS offer a unique environment for precision measurements as well as for fundamental research. We report on experimental opportunities and possible measurements with BECCAL. A detailed insight into the physics-package, where the ultra-cold atomic ensembles will be created and manipulated to perform these measurements will be given. Additionally, we show the microgravity and space heritage BECCAL is based on.

Q 59.20 Thu 16:30 Empore Lichthof

Utilizing Bose-Einstein condensates for atom interferometry in the transportable Quantum Gravimeter QG-1 — •Pablo Nuñez von Voigt[1], Nina Heine[1], Waldemar Herr[2], Christian Schubert[2], Ludger Timmen[3], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 is designed to determine local gravity to the low nm/s^2 level of uncertainty. It relies on the interferometric interrogation of magnetically collimated Bose-Einstein condensates (BEC) in a transportable setup. An atom-chip plays a major role in creating the BEC, allowing high controllability of the atomic cloud. In connection with the absorption detection a better characterization of uncertainties of the motional degrees of freedom is possible. For our current setup, we also discuss methods for operating the gravimeter in seismically noisy environments.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 59.21 Thu 16:30 Empore Lichthof

A compact setup for optically guided BEC interferometry at a single wavelength — •Simon Kanthak[1,2], Ekim Hanimeli[3], Matthias Gersemann[4], Mikhail Cheredinov[4], Sven Abend[4], Ernst M. Rasel[4], Markus Krutzik[1,2], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Quantenoptik, LU Hannover — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Quantenphysik, Universität Ulm

Precision sensing with Bose-Einstein condensates (BECs) has been achieved in macroscopic free-space atom interferometers with underlying large scale enclosed space-time areas. As an alternative approach, trapped atom systems offer the opportunity for BEC sensors in more compact packages. For this purpose, atoms can be Bose condensed, delta-kick collimated, guided, split and recombined in optical potentials, which requires an optical guide, crossed beams and beam splitters usually at different wavelengths.

We report on our design and results with a linear setup for optically guided BEC interferometry at a single wavelength. Here, an atom chip serves to initially generate and delta-kick collimate a BEC inside a horizontally aligned atomic waveguide. A far-detuned focused beam in a retro-reflector configuration provides both tools to levitate and symmetrically split the wave packets via double Bragg diffraction.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Climate Action (BMWK) under Grant No. 50WM2250B (QUANTUS+).

Q 59.22 Thu 16:30 Empore Lichthof

Designing high precision electronics for atom interferometers in space applications — •Alexandros Papakonstantinou, Isabell Imwalle, Christian Reichelt, Matthias Koch, Thijs Wendrich, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

Atom interferometers are a powerful tool for precision measurements. Their sensitivity scales with the free fall time, which on ground is limited by the size of the vacuum chamber. In microgravity this limitation disappears, enabling higher sensitivities. However, typical microgravity platforms like sounding rockets or the ISS have restrictions on size, weight and power. Also, the apparatus needs to be robust enough to survive the trip into space. In addition it should be fully remote controlled with a high degree of automation. For our microgravity experiments QUANTUS-1/-2 (drop tower), MAIUS-1/-2 (sounding rocket) and BECCAL (ISS), we have developed such components, including laser current drivers, atom-chip current drivers, RF and microwave generators, photodiode and temperature monitoring, power supplies and many more. This poster will show the progress and latest results of our developments.

Q 59.23 Thu 16:30 Empore Lichthof

Atom interferometry in microgravity on long time scales — •Dorthe Leopoldt[1], Anurag Bhadane[2], Merle Cornelius[3], Laura Pätzold[3], Julia Pahl[4], Ernst Rasel[1], and Quantus Team[1,2,3,4,5,6] — [1]LU Hannover — [2]JGU Mainz — [3]U Bremen — [4]HU Berlin — [5]U Ulm — [6]TU Darmstadt

Atom interferometry allows for precise quantum sensors, which can e.g. be used to perform a quantum test of Einstein's equivalence principle. The QUANTUS-2 experiment enables rapid BEC production of Rb-87 with over 1e5 atoms and performs atom interferometry under extended free fall at the ZARM drop tower in Bremen. With that it serves as a testbed for future space-based missions. By applying a quadrupole mode enhanced magnetic lens, we are able to reduce the total kinetic energy of the BEC down to 3/2*k_B*38 pK in three dimensions in order to increase the ensemble's density. Here, we present the latest results on single species atom interferometry in QUANTUS-2 and our next steps, including the implementation of potassium.

The QUANTUS project is supported by the DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50WM1952-1957.

Q 59.24 Thu 16:30 Empore Lichthof

Matter-Wave optics with time-averaged potentials and tunable interactions — •Henning Albers[1], Alexander Herbst[1], Wei Liu[1], Dorothee Tell[1], Ernst M. Rasel[1], Dennis Schlippert[1], and The PRIMUS-Team[2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]ZARM, Universität Bremen

The performance of matter-wave sensors highly depends on the center-of-mass motion and the expansion rate of the atomic ensemble. Time-averaged optical dipole traps give rise to nearly arbitrary dynamic potentials. Alongside with magnetic traps, such as those used in atom chip traps, they can provide fast Bose-Einstein condensate production. Here time-averaged potentials overcome the limitations of typical dipole traps by conserving the trap frequencies during evaporative cooling. The all-optical approach additionally allows to tune the atomic interactions by means of magnetic Feshbach resonances.

We discuss our latest results of combining dynamic optical potentials with tunable interactions when performing evaporative cooling [1] as well as applying all-optical matter-wave lenses [2].

[1] A. Herbst et al., PRA (2022): Rapid generation of all-optical ^{39}K Bose-Einstein condensates using a low-field Feshbach resonance

[2] H. Albers et al., CommPhys (2022): All-optical matter-wave lens using time-averaged potentials

Q 59.25 Thu 16:30 Empore Lichthof

Effective theory for Bloch-oscillation-based LMT atom interferometry — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Light-pulse atom interferometers are quantum sensors that enable a wide range of high-precision measurements such as the determination of inertial and electromagnetic forces or the fine-structure constant. Increased sensitivities can be achieved by implementing large momentum transfer (LMT) techniques. A well-known method to increase the momentum of the arms of an interferometer are sequential Bloch oscillations.

We present an accurate description for Bloch pulses based on Wannier-Stark states [Glück et al., Physics Reports 366, 6 (2002)] and the adiabatic theorem for non-hermitian Hamiltonians and verify our model by comparing to an exact numerical integration of the Schrödinger equation [Fitzek et al., Sci Rep 10, 22120 (2020)]. Based on this model, we characterize losses as well as phase uncertainties induced by lattice depth fluctuations in the context of LMT atom interferometry.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 59.26 Thu 16:30 Empore Lichthof

Quantum-clock interferometry — •Mario Montero[1], Ali Lezeik[1], Klaus Zipfel[1], Ernst M. Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover- Insititut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

Universality of Gravitational Redshift (UGR) states that the time dilation measured by two objects in a gravitational field is independent of their composition. Testing the validity of UGR can be achieved through Quantum-Clock Interferometry (QCI), where a sequence of light pulses is used to split, redirected and recombined wave packets and drive transitions between internal states of the atom to measure a phase shift between the interferometer arms. However only certain space-time geometries are sensitive to gravitational time dilation effects [1].

We discuss proposals for QCI geometries that are sensitive to the gravitational redshift, and our approach for an experimental implementation in the Very Long Baseline Atom Interferometry (VLBAI) facility in Hannover [2]. Due to its long lived clock state, ytterbium (Yb) is an appealing candidate to measure differences in proper time. We present the current status of our high-flux source of laser-cooled Yb-174 atoms [3].

[1] C. Ufrecht et al, Phys. Rev. Research 2, 043240 (2020).
[2] D. Schlippert et al, arXiv:1909.08524 (2019).
[3] E. Wodey et al, J. Phys. B: At. Mol. Opt. Phys. 54 035301 (2021).

Q 59.27 Thu 16:30 Empore Lichthof

Principal Component Analysis for Image processing in Atom Interferometry — •Stefan Seckmeyer[1], Holger Ahlers[1,2], Sven Abend[1], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) Institut für Satellitengeodäsie und Inertialsensorik,, Hannover, Germany

Image analysis plays an important role in several current state-of-the-art atom interferometry experiments. We investigate the extraction of physical quantities from absorption images of atom interferometers using principal component analysis (PCA).

As a starting point we take a simple mathematical model for the images of the output ports of a two-port atom interferometer which is using a Bose-Einstein condensate as an atom source.

We show an analytic prediction of the PCA results for a subset of parameters which allows us to ascribe physical quantities to the output of a PCA analysis. Using this method we are not only able to extract the interferometer phase for each image but also a spatial phase aberration map shared by all images, here introduced at the final beam splitter.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. 50WM2253A.

Q 59.28 Thu 16:30 Empore Lichthof

Towards a three axes quantum hybrid inertial sensor for mobile applications — •David Latorre Bastidas[1], Dennis Knoop[2], André Wenzlawski[1], Jens Grosse[2], Sven Herrmann[2], and Patrick Windpassinger[1] — [1]Institute of Physics, JGU Mainz — [2]ZARM, University of Bremen

Quantum hybrid inertial sensors based on cold atoms have been proposed as an accurate acceleration tracking alternative to current classical accelerometers. Such hybrid sensors allow a higher repetition rate and dynamic range than pure quantum atom interferometers. In this project, we plan to build a combination of an atom interferometer based on stimulated Raman transitions in a Mach-Zehnder configuration using Rubidium-87 with opto-mechanical sensors. For applications such as navigation or missions in space, optimization of the sensor in terms of size, weight and power are necessary, making it inevitable to find the optimal operating parameters.

This poster will give an overview of the current design and of the simulations that were used to optimize the measurement sequence. Further, an outlook is given on future on-site measurements and intermediate goals of the project.

Q 59.29 Thu 16:30 Empore Lichthof

Simulating space-borne atom interferometers for Earth Observation and tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional performance to test the postulates of General Relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented sensitivity beyond current limits.

In this contribution, we present a simulator for satellite-based atom interferometry and demonstrate its functionality in designing the STE-QUEST mission scenario, a satellite test of the UFF with ultra-cold atoms to 10^-17 as proposed to the ESA Medium mission frame [https://arxiv.org/abs/2211.15412]. Moreover, we will highlight the possibility of this simulator to design Earth Observation missions going beyond state of the art such as the CARIOQA concept [https://arxiv.org/abs/2211.01215].

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 59.30 Thu 16:30 Empore Lichthof

The Hannover Torsion Balance - a test platform for novel inertial sensing concepts — •Carolin Cordes, Christoph Gentemann, Gerald Bergmann, Moritz Mehmet, Gerhard Heinzel, and Karsten Danzmann — AEI Hannover

Gravity satellite missions require sensors that are sensitive to extremely small displacement changes of macroscopic test masses down to the millihertz regime. For the development of such novel sensors an environment is needed that resembles the conditions in space. Torsion pendulums can be used to simulate free-falling test masses in at least one degree of freedom in the lab on earth. For this reason, they are suitable testbeds for low frequency motion sensors. At the Albert Einstein Institute, we develop and construct such a test facility: the Hannover Torsion Balance, in which four dummy test masses are suspended as a torsion pendulum. A precise readout and control of the test mass motion is essential. To this end, an optical lever readout system and a capacitive readout and control system are implemented. A first interferometric readout will improve the test mass readout and control. To this aim, a Michelson interferometer will be added to the Torsion Balance. It will furthermore be an integral step towards testing novel optical satellite motion sensor readout techniques, such as Deep Frequency Modulation Interferometry. The poster will present the current status of the Torsion Balance and the latest results of the interferometric readout.

Q 59.31 Thu 16:30 Empore Lichthof

GRACE Follow-On and the Laser Ranging Interferometer: Measuring Earth Gravity from Space — •Malte Misfeldt[1,2], Vitali Müller[1,2], and Gerhard Heinel[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover — [2]Max-Planck Institut für Gravitationsphysik

The GRACE (Gravity Recovery And Climate Experiment) Follow-On twin satellites were launched in mid 2018 for continuity of the Earth gravity field measurements from GRACE (2002-2017). Formerly, the ranging measurement was performed using microwave interference. However, GRACE-FO hosts the novel Laser Ranging Interferometer (LRI), a technology-demonstrator for proving the feasibility of laser interferometry for precise inter-satellite ranging. The LRI surpasses the accuracy of the conventional microwave by a factor of 500 at high frequencies, which possibly enables new analysis techniques and insights into hydrological processes on Earth's surface.

This presentation discusses the design and working principle of the LRI are discussed. Furthermore, an outlook toward the next generation of gravity missions with an improved version of the LRI as the primary ranging instrument is given.

Q 59.32 Thu 16:30 Empore Lichthof

Balanced homodyne detection design and application at the AEI 10m Prototype facility — •Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[1,2], Juliane von Wrangel[1,2], Janis Wöhler[1,2], and David S. Wu[1,2] — [1]Leibniz Universität Hannover, Hannover, DE — [2]Max Planck Institute for Gravitational Physics, Hannover, DE

Fundamental sources of quantum noise currently limit the performance of ground-based interferometric gravitational wave detectors (GWD), but ongoing technical improvements offer opportunities pushing past this limit. To further upgrade GWD sensitivity, as in the planned Einstein Telescope and Cosmic Explorer, the interferometer readout is planned to be a Balanced Homodyne Detection scheme (BHD) with suspended components to allow the interferometer to operate at a true dark fringe. This also allows the interferometer to be read out at arbitrary quadratures, which will be required by some advanced techniques to suppress quantum noise. The implementation of BHD involves overcoming a number of technical difficulties, including the creation of a very stable local oscillator (LO) and its active stabilisation. This poster focuses on an overview of the relevant issues and obstacles to implementing a BHD using the Albert Einstein Institute (AEI) 10m Prototype, an optimal facility to study novel technologies for reaching and surpassing the interferometric standard quantum limit (SQL).

A report will be made on the current progress in the application of BHD with the construction of one of the triple mirror suspensions required for the LO's path.

Q 59.33 Thu 16:30 Empore Lichthof

Compact Optical Test Mass Sensing — •Victor Huarcaya — Albert-Einstein-Institut Hannover / Max-Planck-Institut für Gravitationsphysik, Hannover, Germany

High-precision measurement of all six degrees of freedom of freely floating test masses is necessary for gravitational space missions like GRACE (Gravity Recovery and Climate Experiment), its follow-on mission GRACE-FO, and GOCE (Gravity Field and steady-state Ocean Circulation Explorer). When aiming for sensing multiple degrees of freedom, typically, capacitive sensing is used, which facilitates a compact setup but does not provide competitive precision. In opposition, laser interferometers have been established as one of the tools of choice for high-precision measurement schemes. However, these measurements were restricted to the length changes in one degree of freedom. Here, we report on Deep Frequency Modulation (DFM). This novel interferometric readout technique is a promising candidate for improving the sensitivity beyond capacitance readout systems and reducing the complexity of the setup. Initial experimental results show optical zero measurements performance levels better than 250 pm/$\sqrt{\text{Hz}}$ at 1 mHz and electronic readout noise levels below 1 pm/$\sqrt{\text{Hz}}$ at 1 mHz. Based on DFM, we also report a novel sensor topology, the self-referenced single-element dual-interferometer (SEDI) inertial sensor, which takes simplification one step further by accommodating two interferometers in one optic which makes the SEDI sensor a promising approach for applications in high precision inertial sensing for both next-generation space-based gravity missions.

Q 59.34 Thu 16:30 Empore Lichthof

Scaling a robust Lorentz Symmetry test to multiple Yb$^+$ ions — •Kai C. Grensemann[1], Chih-Han Yeh[1], Laura S. Dreissen[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We recently completed a test of local Lorentz invariance (LLI) in the electron-photon sector using a single trapped ^{172}Yb$^+$ ion [1]. With a novel approach based on composite pulse Ramsey spectroscopy [2] we fully exploited the ion's high sensitivity to Lorentz violation (LV) [3] and reached second long coherence times. We extracted improved bounds on LV coefficients in the 10^{-21} region. Scaling the used method to a linear Coulomb crystal of N ions would further increase the sensitivity by $\sqrt{N}$. Here, we report on our ongoing efforts to test LLI on a 10 ion crystal. We show that the composite pulse sequence is highly robust against inhomogeneities of the magnetic and interaction fields, enabling easy upscaling to a 100 μm ion crystal. We also report on the progress of coherent multi-ion octupole excitation for efficient population of the F-state. The AC-Stark shift of several 100 Hz compared to a linewidth of 10 Hz [4] demands intensity deviations below ±4%, which we achieve by shaping the beam with a holographic phaseplate.

[1] L.S. Dreissen et al., *Nat. Commun.* **13**, 7314 (2022). [2] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018). [3] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [4] H. A. Fürst et al., *Phys. Rev. Lett.* **125**, 163001 (2020).

Q 59.35 Thu 16:30 Empore Lichthof

Progress on PTB's transportable Al$^+$ ion clock — •Constantin Nauk[1], Benjamin Kraus[1,2], Joost Hinrichs[1,3], Simone Callegari[1], Stephan Hannig[1,2], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks achieve fractional systematic and statistical frequency uncertainties on the order of 10^{-18}. This enables novel applications, such as height measurements in relativistic geodesy with ∼ 1 cm resolution for earth monitoring. Towards this goal, we set up a transportable clock based on the ^{1}S$_0$ → ^{3}P$_0$ transition in ^{27}Al$^+$. A co-trapped ^{40}Ca$^+$ ion allows state detection and cooling via quantum logic spectroscopy and sympathetic cooling.

We present the design and the current status of the transportable apparatus, review the recent development of the laser systems and show particularly the performance of the UV clock laser setup operating at 267.4 nm with a fractional frequency uncertainty of 10^{-16} at 1 second.

Q 59.36 Thu 16:30 Empore Lichthof

Compact rack-integrated UV laser system for a transportable Al$^+$ quantum logic optical clock — •Joost Hinrichs[1,2], Stephan Hannig[1,3], Benjamin Kraus[1,3], Constantin Nauk[1], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany

Optical atomic clocks currently provide the most precise frequency standards. For side-by-side comparisons or applications in relativistic geodesy, transportable and robust setups with lowest possible uncertainties are necessary. The feature of transportability requires a highly-stable, compact and automatized implementation.

For our transportable ^{27}Al$^+$ clock all components, including optics and the vacuum chamber, will be integrated into conventional 19 in-racks. As one part of the clock apparatus we present a compact design of the Al$^+$ logic laser emitting at 267 nm to drive the $^1S_0 \leftrightarrow {}^3P_1$ transition. The system consists of a fibre laser operating at 1068 nm and two frequency doubling cavities to generate the required UV output for the logic transition. The complete optical setup is housed in one rack-integrated aluminium drawer. We present the setup and characterize its efficiency and long-term stability.

Q 59.37 Thu 16:30 Empore Lichthof

Variational Clock Protocols — •Timm Kielinski — Institute for theoretical physics, Hannover, Germany

Enhancement of clock stability beyond the classical limit can be accomplished by introducing entanglement between the atoms. In particular, one-axis-twisting (OAT) interactions receive much attention since they give enhanced sensitivity by generating squeezed spin states or echo protocols and can be reliably implemented in several experimental setups. In local (frequentist) phase estimation, the sensitivity is characterized using tools as the Fisher information and is limited by the Cramér Rao bound. However, laser noise limits the clock stability and therefore frequency fluctuations during the clock operation have to be considered. To accomplish for the finite prior information, Bayesian phase estimation is applied representing the trade-off between reduction in quantum projection noise (QPN) and the coherence time limit (CTL) of the laser. This work aims to optimize the stability of ion clocks building on a variational class of Ramsey protocols. Theoretical predictions are validated by numerical simulations of the full feedback loop of an atomic clock. The main limitation is imposed by fringe hops, especially in the presence of dead time.

Q 59.38 Thu 16:30 Empore Lichthof

A compact strontium optical clock based on Ramsey-Bordé spectroscopy — •Oliver Fartmann[1], Ingmari C. Tietje[1], Amir Mahdian[1], Marc Christ[1,2], Conrad L. Zimmermann[2], Martin Jutisz[1], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Inst. f. Physik — [2]Ferdinand-Braun-Institut GmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We present the status of our optical clock based on Ramsey-Bordé spectroscopy using the ^{1}S$_0$ → ^{3}P$_1$ intercombination line at 689 nm in strontium. We give an overview of the underlying spectroscopy principle and a clock instability and uncertainty budget. Further, we present the current status in the laboratory including the design of a new compact and high-flux atomic oven and our work on the spectroscopy setup. Lastly, we show our progress towards micro-integrating the setup.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Climate Action (BMWK) under grant number DLR50WM1852 and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 59.39 Thu 16:30 Empore Lichthof

Development of Two Laboratory Two-Photon Frequency References — •Moritz Eisebitt[1,2], Julien Kluge[1,3], Daniel Emanuel Kohl[1,3], Klaus Döringshoff[1,3], and Markus Krutzik[1,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]II. Physikalisches Institut, RWTH Aachen University — [3]Ferdinand-Braun-Insitut, Leibniz-Institut für Höchstfrequenztechnik

We present two laboratory monochromatic two-photon frequency references operating on the $5S_{1/2} \rightarrow 5D_{5/2}$ transition in Rubidium utilising frequency modulation spectroscopy. Two-photon references with Rubidium have the benefit of a narrow linewidth and being inherently Doppler-free. The references have a combined fractional instability below $3 \cdot 10^{-13}/\sqrt{\tau}$ up to 1000s. Efforts to stabilise the residual amplitude modulation are discussed as well as the performance and limits of the frequency reference induced by environmental effects. Measurements of the dipole, quadrupole and octupole hyperfine structure constants of Rb $5D_{5/2}$ are presented which surpass the precision of the current state of art values by an order of magnitude.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK19711, 50WM2164.

Q 59.40 Thu 16:30 Empore Lichthof

Recent Progress of a miniaturized all diode laser based strontium lattice clock — •Max Schlösinger[1], Henri Zimmermann[1], Christoph Pyrlik[1], Vladimir Schkolnik[1], Ronald Holzwarth[2], Robert Jördens[3], Enrico Vogt[4], Andreas Wicht[5], and Markus Krutzik[1,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin — [2]Menlo Systems GmbH, Bunsenstr. 5, 82152 Martinsried — [3]QUARTIQ GmbH, Rudower Chaussee 29, 12489 Berlin — [4]Qubig GmbH, Balanstr. 57, 81541 München — [5]Ferdinand Braun Institut GmbH, Gustav-Kirchhoffstraße 4, 12489 Berlin

The joint SOLIS-1G project aims to develop a size weight and power (SWaP) optimized, all diode-laser based strontium lattice clock demonstrator, thereby exploring and enabling essential technologies for future space-borne optical lattice clocks.

We report on the current state of the SOLIS-1G subsystems with a focus on the physics package, micro-integrated laser systems and compact control electronics.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WM2151 and DLR50RP2190B.

Q 59.41 Thu 16:30 Empore Lichthof

A multi-ion indium clock — •Ingrid M. Dippel[1], Moritz von Boehn[1], H. Nimrod Hausser[1], Jonas Keller[1], Jan Kiethe[1], Tabea Nordmann[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Currently, single-ion optical clocks represent some of the most accurate experiments and are used in high-precision spectroscopy, metrology and geodesy [1]. Though very precise, the statistical uncertainty of these optical clocks is fundamentally limited by the low signal-to-noise ratios and require averaging times on the order of days to resolve frequencies at the limit of their systematic uncertainties at the 10^{-18} level. This motivates the approach to develop multi-ion systems, leading to reduced quantum projection noise (QPN) by a factor of $1/\sqrt{N_{\text{ion}}}$, which is limiting the statistical uncertainty of a clock. Thereby, the averaging times can be decreased by factor of N_{ion} for a given level of statistical uncertainty.

We present an experimental set-up based on $^{115}\text{In}^+$ ions sympathetically cooled by $^{172}\text{Yb}^+$ ions, aiming for multi-ion operation and at the same reaching frequency unertainties on the level of 10^{-19} [2]. Furthermore, we discuss future plans and methods for improving robustness, reducing systematic uncertainties and extending automation of basic lab routines and measurement processes.

[1] T. E. Mehlstäubler et al., *Rep. Prog. Phys.* **81**, 064401 (2018)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)

Q 59.42 Thu 16:30 Empore Lichthof

Development of a Miniaturized Two-photon Frequency Reference Towards Application on a Small Satellite Mission — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Moritz Eisebitt[2,3], Klaus Döringshoff[1,2], Sten Wenzel[2], Andrea Knigge[2], Andreas Wicht[2], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin — [3]II. Physikalisches Institut, RWTH Aachen University

Global navigation satellite systems require precise clocks with stringent constraints on size, weight and power budget. Two-photon spectroscopy of the rubidium 5S-5D transition in conjunction with optical frequency combs can provide compact, high precision clocks for next generation GNSS systems. We present a two-photon rubidium frequency reference set-up, achieving fractional frequency instabilities in the regime of $10^{-13}/\sqrt{\tau}$.

Furthermore, we present a prototype of a compact set-up, featuring a monolithically integrated extended cavity diode laser and a miniaturized, heated and magnetically shielded 1 cm long vapor cell. Details of the vapor cell assembly and the lasers system will be shown. This work, in combination with advanced micro-integration techniques, may lead to ultra-compact, low power but high performant optical frequency references.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971, 50WM2164.

Q 59.43 Thu 16:30 Empore Lichthof

A strontium lattice clock with 3×10^{-18} uncertainty — •Kilian Stahl, Joshua Klose, Roman Schwarz, Ingo Nosske, Uwe Sterr, Sören Dörscher, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present a strontium optical lattice clock, PTB-Sr3, that is equipped with in-vacuum heat shields providing a highly homogeneous thermal environment. Initial characterisation of systematic effects yields a fractional frequency uncertainty of about 3×10^{-18}. The clock has similar frequency instability as its predecessor, *i.e.*, below $2 \times 10^{-16}/\sqrt{\tau/\text{s}}$, and improved availability due to automated monitoring and recovery of laser frequency locks. We also report on a revisiting analysis of the atomic response to blackbody radiation (BBR), which reveals a previously unrecognised error in the dynamic correction coefficient corresponding to a 4×10^{-18} clock offset and improves the uncertainty of the atomic response near room temperature to about 1×10^{-18}. To improve the uncertainty of the BBR-induced frequency shift further, a closed-cycle cryocooler allows reducing the temperature of the heat shields to below 80 K. We discuss the prospects for improving the fractional frequency uncertainty of this clock into the 10^{-19} regime.

This project has been supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2123 QuantumFrontiers – Project-ID 390837967, SFB 1464 TerraQ – Project-ID 434617780 – within project A04, and SFB 1227 DQ-*mat* – Project-ID 274200144 – within project B02.

Q 59.44 Thu 16:30 Empore Lichthof

Towards a continuous wave superradiant Calcium Laser — •David Nak and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Hamburg, Deutschland

Superradiant Lasers are suitable as narrow light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1].

At present, the setup is being extended by an incoherent repumping mechanism, which will allow continuous wave operation.

[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

Q 59.45 Thu 16:30 Empore Lichthof

Improving frequency superresolution with a resonant quantum pulse gate — •Dana Echeverría-Oviedo, Michael Stefszky, Jano Gil-López, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS).

The application of temporal mode selective measurements for time-frequency quantum metrology has been shown to reach the ultimate precision limit imposed by quantum mechanics and therefore saturate the quantum Cramér-Rao lower bound. These measurements can be implemented with a quantum pulse gate (QPG), a dispersion engineered device based on sum frequency generation between shaped pulses. In practice, the QPG finite phasematching (PM) bandwidth (BW) limits the achievable resolution of such measurements. Increasing the QPG length reduces its PM BW. However, building longer QPGs is not a trivial task since nonlinear crystals cannot be arbitrarily long and longer samples are more sensitive to fabrication imperfections degrading its PM spectrum. To alleviate this limitation, it is of paramount importance to tailor narrower PM BW, pushing the QPG to its performance limit. We propose a resonant QPG, which is composed of two coupled waveguide cavities. One of them is a nonlinear cavity in which the interaction occurs, while the other acts as a coherent filter to obtain a single resonance mode. Our design reduces the PM BW by 3 orders of magnitude for the same nonlinear interaction length of the corresponding QPG, yielding a 5.9 better resolution in superresolved metrology measurements.

Q 59.46 Thu 16:30 Empore Lichthof

The role of frequency stability in measurements of the coefficient of thermal expansion — •Nina Meyer, Tobias Ohlendorf, Uwe Sterr, and Thomas Legero — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

Materials with small coefficients of thermal expansions (CTEs) of about 10^{-8} K^{-1} at room temperature are needed for extreme-ultraviolet lithography, in space and ground-based telescopes or ultra-stable resonators. Those small CTEs are usually accurately measured by two-beam Michelson interferometers [1] or by multiple-beam interference based on Fabry-Pérot resonators [2].

Our approach is based on a Fabry-Pérot resonator, consisting of the test material as spacer and two mirrors in a temperature-controlled vacuum chamber. To measure the small thermal expansion, we stabilize a transfer laser onto the TEM_{00} mode of the optical resonator and observe the beat frequency of the transfer laser and a frequency standard.

In this poster, we compare the stability of different types of transfer lasers to iodine-stabilized lasers and ultra-stable lasers via a frequency comb and discuss its influence on the CTE accuracy. We also provide an outlook to setups with lasers operating at 1.5 μm wavelength.

[1] R. Schödel, Meas. Sci. Technol. **19**, 084003 (2008).
[2] F. Riehle, Meas. Sci. Technol. **9**, 1042–1048 (1998).

Q 59.47 Thu 16:30 Empore Lichthof

En Route to hour long spin manipulation established via constantly driven Rabi nutation measurements — •Tianhao Liu, Jens Voigt, Silvia Knappe-Grüneberg, and Wolfgang Kilian — Physikalisch-Technische Bundesanstalt, 10587 Berlin, Germany

We describe a method for estimating the Larmor frequency of polarized nuclear spins by utilising Rabi nutation that is driven by an applied near-resonant magnetic field. Two data analysis methods for retrieving the Larmor frequency from the precession signals recorded by magnetometers on top of the cell are proposed and further verified with numerical simulations. Compared to the commonly used free decay method, the proposed method has distinct advantages on smaller polarisation loss and shorter measurement time. Main systematic sources on the estimated Lamour frequency by this method are identified and quantitively analysed with a forward analytic model. A series of experiments, where a cell of 3He polarised via spin-exchange optical pumping is placed under a SQUID system in a magnetically shielded room, have been performed to validate this method. A preliminary analysis shows that the relative uncertainty of less than 10-6 on the Lamour frequency could be achieved with data taken within few hundred seconds. This method could be used for traceable weak magnetic field measurements. Moreover, it provides a basis for coherently manipulating the nuclear spins for over an hour-long interval. To the end, we will present a slow Rabi nutation of 3He driven by near-resonance magnetic field over 1 hour.

Q 59.48 Thu 16:30 Empore Lichthof

Testing novel high-reflectivity mirror coatings from room temperature to 4 K — •Mona Kempkes, Jialiang Yu, Sofia Herbers, Thomas Legero, Uwe Sterr, and Daniele Nicolodi — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Brownian thermal noise of highly reflective mirror coatings is the fundamental limit to the performance of many precision laser experiments. Very high reflectivity mirrors with significantly lower mechanical losses than traditional Ta_2O_5/SiO_2 multilayers are needed to improve the stability of optical resonators. Few promising alternatives have been developed so far. However, direct coating noise measurements in representative setups are required to validate their performance, as demonstrated by our experiments with $Al_{0.92}Ga_{0.08}As/GaAs$ crystalline coatings [J. Yu et al., arXiv:2210.15671 (2022) and D. Kedar et al., arXiv:2210.14881 (2022)]. We will present our setup for the characterization of mirror coatings performance and direct Brownian thermal noise measurements from room-temperature to 4 K in a cryogenic optical resonator. This facility will be used to test novel mirror solutions as meta-mirrors and amorphous-Si based coatings.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union's Horizon 2020 Research and Innovation Programme and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC-2123 QuantumFrontiers, Project-ID 390837967.

Q 59.49 Thu 16:30 Empore Lichthof

Vacuum-integration of a double-tip fiber microscope — •Florian Giefer, Lukas Tenbrake, Sebastian Hofferberth, and Hannes Pfeifer — Institute of Applied Physics, University of Bonn, Germany

Multi-mode cavity optomechanical systems are a promising platform for investigating many body dynamics, for distributed sensing, and optomechanical circuits. A prominent implementation of optomechanical experiments is the membrane-in-the-middle setup, where a thin suspended film is placed inside of an optical fiber Fabry-Perot cavity. To extend this platform towards multiple mechanical resonators with tailored properties we envisage employing 3D direct laser written membrane structures that are placed on a DBR substrate and interfaced using multiple fiber-tip integrated mirrors. To reduce mechanical dampening by surrounding air, our structures need to be placed in a vacuum environment. Based on the concept of "scanning cavity microscopes" introduced by Mader et al., we develop an experimental setup capable of interfacing optomechanical structures on DBR substrates in vacuum using two fiber mirrors with complete position control. We present the design, implementation challenges and future prospects of our experimental setup.

Q 59.50 Thu 16:30 Empore Lichthof

Programmable trap array of optically levitated nanoparticles — •Livia Egyed[1], Manuel Reisenbauer[1], Iurie Coroli[1], Murad Abuzarli[1], Uroš Delić[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria

Arrays of coupled mechanical oscillators have been proposed for studies of collective effects such as non-reciprocal phonon transport, investigation of topological phases or multipartite entanglement. Existing experimental architectures are usually either based on fabricated structures or use an optical cavity to mediate the interaction between multiple mechanical modes, thereby limiting the maximal number of elements and the versatility of the created interaction, as well as prohibiting individual detection of the oscillators.

Here, we present a novel platform for studying collective dynamics based on a tunable trap array of levitated nanoparticles which allows for independent control and readout of the particles motions. In addition to standard cavity-mediated setups, we exploit the light-induced dipole-dipole interactions between the particles to introduce direct coupling between them. The ability to control non-reciprocal particle interaction paves the way towards exploring many particle phenomena with massive objects. We will present this platform as well as first results on the collective dynamics of two interacting particles.

Q 59.51 Thu 16:30 Empore Lichthof

Optimal Control of Quantum Squeezed States — •Anton Halaski, Matthias G. Krauss, Daniel Basilewitsch, and Christiane P. Koch — Freie Universität Berlin, Berlin, Germany

Squeezed states are interesting for various tasks, including applications in quantum sensing or quantum information processing. We demonstrate how a mechanical resonator in an optomechanical setup can be brought into a squeezed state using optimal control theory. Using Krotov's method [Reich et al. *J. Chem. Phys.* **136**, 104103 (2012)], we show how optimal control theory can reduce the time needed for squeezed state generation by several orders of magnitude compared to protocols with constant driving. Further, we derive a general protocol for acquiring squeezed states, which not only allows us to simplify the general pulse shapes but also to understand the physical processes during the time evolution of the system.

Q 59.52 Thu 16:30 Empore Lichthof

Quantum state tomography of a nanomechanical resonator in a pulsed measurement protocol — •Felix Klein[1], Jakob Butlewski[1], Alexander Schwarz[2], Klaus Sengstock[1], Roland Wiesendanger[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Pulsed optomechanical experiments have received growing interest in recent years as they promise a convenient path to full state tomography of quantum objects. Instantaneous snapshots and squeezing of one motional quadrature project the measurement induced noise into the perpendicular quadrature enabling quantum limited high precision measurements.

We realize high fidelity quantum state tomography of a nanomechanical SiN trampoline resonator in a fiber fabry pérot cavity achieving a position uncertainty of 2 pm using light pulses much shorter than the resonators oscillation period.

Here we give an overview of the current experimental setup and discuss ongoing modifications that will allow resolving the resonators zero-point motion.

Q 59.53 Thu 16:30 Empore Lichthof

Levitated nanoparticles in microgravity — •Govindarajan Prakash, Vincent Hock, Marian Woltmann, Sven Hermann, Claus Lämmerzahl, and Christian Vogt — University of Bremen, ZARM (Centre for Applied Space Technology and Microgravity)

Optomechanical levitation of nanoparticles provides a promising platform to perform tests with macroscopic particles on the interface between quantum and classical regimes. Schemes of such tests involve optical trapping, feedback cooling, and release and retrapping of nanoparticles. Here, we aim to discuss how this allows us to perform force sensing of the order of attonewtons in microgravity conditions at the drop towers of ZARM in Bremen using silica nanoparticles. We present the progress thus far in our preliminary aim of building a force sensor that might be suitable for usage in space-based environments for dark matter searches and the like

Q 59.54 Thu 16:30 Empore Lichthof

Nonlinear Oscillator with a Single Trapped Ion — •Moritz Göb, Bo Deng, Max Masuhr, Kilian Singer, and Daqing Wang — Experimentalphysik I, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel

Nonlinear oscillators are interesting test systems for realizing thermal machines in the quantum regime. In our experiment, we investigate a single, laser-cooled $^{40}Ca^{+}$ ion confined in a funnel-shaped Paul trap. This trap geometry leads to an interaction of the axial and radial phonons, which resembles the optomechanical interaction described by the radiation pressure Hamiltonian. Based on this system, we measure and characterize this nonlinear interaction and the resulted mechanical bistability. In this poster, I will detail the technical implementation of this experiment.

Q 59.55 Thu 16:30 Empore Lichthof

Ultrastrong coupling in levitated optomechanics — •Iurie Coroli[1], Kahan Dare[1,2], Jannek Hansen[1], Aisling Johnson[1], Markus Aspelmeyer[1,2], and Uros Delic[1] — [1]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI) Vienna, Austrian Academy of Sciences, A-1090 Vienna, Austria

Levitated nanoparticles have long been heralded as an excellent platform for quantum sensing. Recent proposals have sought to utilize instability due to ultrastrong coupling via coherent scattering but this regime has been out of reach to experimental systems. We report the first levitated optomechanical system to operate in the ultrastrong coupling regime, reaching a maximum coupling of $gx/\Omega x = 0.5$ operating in the resolved sideband regime. We demonstrate future extensions to this system which can dramatically improve the optomechanical cooperativity and further boost the coupling rates, which opens up quantum experiments in the ultrastrong coupling or even deep strong coupling regime to simple table-top systems.

Q 59.56 Thu 16:30 Empore Lichthof

Studying exceptional points in an optical fiber — •Quentin Levoy[1], Flore K. Kunst[1], and Birgit Stiller[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität, Erlangen, Germany

Exceptional points (EPs) are physical features appearing in non-Hermitian systems, which are typically systems subjected to loss and gains. At these EPs, the eigenvectors of the system coalesce and unique physical phenomena are displayed, such as an unusual dispersion and higher sensitivity to perturbations. EPs are the object of both theoretical and experimental studies. Even though they are associated to ubiquitious properties such as gain and loss and open system behaviour, it is not always straightforward to identify a physical platform that provides the right parameters to reach these EPs and to experimentally study them. Recently, it was proposed to use nonlinear optics and more specifically optoacoustics to finely tune gain and loss in an experimental setup, for instance an optical fiber. Here, we explore in detail how the interaction of optical and acoustic waves can provide an interesting framework to explore the properties of EPs and non-Hermitian physics. Observing this interaction in an optical fiber is one possible way to experimentally observe and study EPs of different orders, using only an optical fiber and a few laser beams.

Q 59.57 Thu 16:30 Empore Lichthof

A nanofabricated solid immersion lens for bright and high-purity single-photon emission from a germanium-vacancy center in diamond — •Justus Christinck[1,2], Franziska Hirt[1,2], Helmuth Hofer[1], Markus Etzkorn[2,3], Zhe Liu[2,3], Toni Dunatov[4], Milko Jakšić[4], Jacopo Forneris[5,6,7], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Braunschweig, Germany — [3]Technische Universität Braunschweig, Braunschweig, Germany — [4]Ruder Bošković Institute, Zagreb, Croatia — [5]University of Torino, Torino, Italy — [6]Istituto Nazionale di Fisica Nucleare (INFN), Torino, Italy — [7]Istituto Nazionale di Ricerca Metrologica (INRiM)

The group IV-vacancy color centers in diamond, such as the germanium-vacancy (GeV) center, are potential candidates for quantum metrology applications at room temperature. We report on the fabrication of a GeV center doped diamond sample by implantation of Ge-ions and subsequent high-temperature vacuum annealing. To enhance the photon-extraction from the diamond, solid immersion lenses were fabricated into the diamond surface in a focused ion beam scanning electron microscope (FIB-SEM) setup. A bright GeV center in a solid-immersion lens was examined in terms of its saturation behavior and its single-photon purity through the measurement of the $g^{(2)}(\tau)$ function. A saturation count rate at the detector of (833 ± 9) kcps was reached. A simultaneous count rate of 580 kcps and $g^{(2)}(0) = (0.12 \pm 0.06)$ were measured in the experiment.

Q 59.58 Thu 16:30 Empore Lichthof

Mechanically Isolated Quantum Emitters in Hexagonal Boron Nitride — •Andreas Tangemann[1], Patrick Maier[1], Michael Hoese[1], Prithvi Reddy[2], Andreas Dietrich[1], Michael K. Koch[1], Konstantin G. Fehler[1], Marcus W. Doherty[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany. — [2]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Australian Capital Territory 2601, Australia.

Single Photon emitters are a crucial resource for novel photonic quantum technologies. Quantum emitters hosted in two-dimensional hexagonal Boron Nitride (hBN) are a promising candidate for the integration into hybrid quantum systems. One type of emitters hosted in hBN has shown the remarkable property of Fourier limited linewidths from cryogenic up to room temperatures. This property can be attributed to mechanically isolated orbitals of the defect centers, which do not couple to in-plane phonon modes. Here, we present our recent results towards identifying the origin of this mechanical decoupling, which could be caused by out-of-plane emitters. We also present quantum random number generation using the symmetric dipole emission profile of these emitters.

Q 59.59 Thu 16:30 Empore Lichthof

Insights into the photophysics of the SnV center in diamond — •Philipp Fuchs[1], Johannes Görlitz[1], Michael Kieschnick[2], Jan Meijer[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken, Germany — [2]Universität Leipzig, Angewandte Quantensysteme, Linnéstraße 5, 04103 Leipzig, Germany

The negatively charged tin vacancy center (SnV^-) in diamond has been shown to be a versatile system that can be used as a quantum sensor, long-lived qubit, and single photon source. However, exploiting these properties requires active stabilization of the charge state, as the SnV^- can be easily ionized to its double negative charge state (SnV^{2-}) upon laser illumination, which is optically inactive [1].

In this work, we propose a simple rate equation model that includes this ionization process. We apply the model to an extensive set of measurements on different SnV centers, along with a thorough characterization of the efficiency of our measurement setup. We conclude that a charge-stabilized SnV^- center is a nearly ideal single photon source in terms of quantum efficiency, since we can describe any reduced photon rate by ionization to the optically inactive SnV^{2-} charge state without assuming other non-radiative decay channels.

[1] J. Görlitz et al., npj Quantum Inf 8, 45 (2022)

Q 59.60 Thu 16:30 Empore Lichthof

Optical investigations of evaporated dibenzoterrylene layers in a C60-fullerene matrix — •Franziska Hirt[1,2], Justus Christinck[1,2], Helmuth Hofer[2], Gunilla Harm[2,3], Andreas Reutter[2,3], Mike Stummvoll[2,3], Neda Noei[3], Uta Schlickum[2,3], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Laboratory for Emerging Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig — [3]Technische Universität Braunschweig, Universitätsplatz 2, 38106 Braunschweig

Polycyclic aromatic hydrocarbons are suitable to be used in a single-photon source at cryogenic and room temperatures, respectively. One prerequisite is their embedment in a stabilizing solid matrix protecting them from oxygen and thermal induced bleaching effects. We report a method based on a high temperature and high vacuum deposition procedure allowing for a controllable growth of single layers of dibenzoterrylene (DBT) molecules. They are placed between several monolayers of C60-fullerenes, which are forming the protection against the environmental conditions. An absorption spectrum of this composite was measured, revealing a linear superposition. Raman spectroscopy measurements proved that the DBT molecules were still intact after being deposited. First experiments in a self-built confocal laser scanning microscope did not show any emission at all, indicating a quenching behavior of the molecule after being evaporated. Thermal annealing could cancel out these quenching and an emission of DBT layers was detected. Further investigations will be presented at the conference.

Q 59.61 Thu 16:30 Empore Lichthof

Optimizing silicon vacancies in silicon carbide through nanophotonic integration — •Di Liu[1], Öney Soykal[2], Jawad Ul-Hassan[3], Florian Kaiser[4], Petr Siyushev[1], and Jörg Wrachtrup[1] — [1]University of Stuttgart and IQST, Germany — [2]Booz Allen Hamilton, USA — [3]Linköping University, Sweden — [4]LIST, Luxembourg

The silicon vacancy (V_{Si}) in silicon carbide (SiC) is an emerging spin qubit for quantum computing and quantum network applications, due to its excellent spin-optical properties and progressive nanophotonic integration. A fully scalable application requires a complete understanding of the system's internal spin dynamics in order to further engineer cavity-emitter coupling. In this work, we unravel relevant radiative and non-radiative transition rates of V_{Si} in 4H-SiC. They allow evaluation of several crucial parameters such as the quantum efficiency for estimation of the desired Purcell enhancement factor or the radiative transition cyclicity defining the maximally achievable emission rate.

We also show our latest results on integrating V_{Si} centers in nanophotonic waveguides, including direct waveguide-to-fiber coupling in cryogenic environment. This technique allows us to boost the platform efficiency towards relevant applications in quantum communication and computation.

Q 59.62 Thu 16:30 Empore Lichthof

3D Printed Optical Waveguide Structures with Microdiamonds containing NV Centers — •Marina Peters[1,2], Adrian Abazi[2], Daniel Wendland[2], Tim Buskasper[2], Lara Lindloge[1], Markus Gregor[1], and Carsten Schuck[2] — [1]Department of Engineering Physics, FH Münster, Germany — [2]Department for Quantum Technology, University of Münster, Germany

Quantum technology holds great potential for novel communication, computation and sensing concepts, however, current approaches do not easily scale to large system size. Integrated photonics offers possibilities to address such scaling challenges by leveraging modern nanofabrication processes for implementing complex nanophotonic circuitry. Here we show how nitrogen vacancy centers in diamond, as a prototypical quantum system, can be embedded into optical waveguides that allow for optical excitation and fluorescence collection. We achieve this by employing a lithographic positioning technique for microdiamonds on a silicon chip, which are subsequently integrated into polymer waveguides, produced in 3D direct laser writing. Our method allows for producing hundreds of devices with waveguide-integrated quantum systems on a chip, which can be addressed and read out via optical fiber arrays.

Q 59.63 Thu 16:30 Empore Lichthof

Integration and coupling of quantum emitters in 2D materials to laser-written waveguides — •Josefine Krause[1], Simone Piacentini[2], Mostafa Abasifard[1], Roberto Osellame[2], Giacomo Corrielli[2], and Tobias Vogl[1,3] — [1]Institute of Applied Physics, Albert-Einstein-Str. 15, 07745 Jena, Germany — [2]Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), Piazza Leonardo da Vinci 32, 20133 Milano, Italy — [3]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

The practical application of quantum optics, for example in satellite-based quantum communication, requires the miniaturization of optical components into small devices. A hybrid solution is to integrate quantum emitters hosted in layered two-dimensional (2D) materials onto a photonic chip containing femtosecond laser-written waveguides. Emitters in 2D materials, such as hexagonal boron nitride, are suitable photon sources because of their high photon extraction efficiency due to the material's thinness. We demonstrate a deterministic transfer of an exfoliated tungsten disulfide emitter, employed as a test material for its bright fluorescence at room temperature, onto the front face of a waveguide through a viscoelastic stamping technique. The spectral emission properties of the integrated flake were maintained after the integration and coupling through the waveguide. Furthermore, with the goal of space-based applications, we successfully qualified different miniaturized photonic chips in their mechanical robustness during vibration and shock exposure imitating a rocket launch.

Q 59.64 Thu 16:30 Empore Lichthof

Green's function calculations for two-dimensional arrays of molecular emitters — •Davide Torriglia, Daniel M. Reich, and Christiane P. Koch — Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

Collective excitations of atomic or molecular arrays have recently attracted a lot of interest in quantum optics as a tool to control the propagation, scattering and storage of light fields.

In this project, we aim to describe the coupling of a two-dimensional molecular array with a quantized light mode and investigate the effect of a graphene substrate on the collective state of the molecules.

As a first step towards this, we calculate the dyadic Green's function for various geometries to describe the propagation of the electromagnetic field classically according to Maxwell's equations.

Employing the resulting Green's functions in quantum mechanical simulations, we aim to directly account for the field-propagation effects on molecular arrays in complex geometries, such as those used in the generation of polaritons in modern experiments.

Q 59.65 Thu 16:30 Empore Lichthof

Influence of nonlocal and dispersive material response on fields of metallic plasmons — •Gino Wegner[1,2], Dan-Nha Huynh[1], Bill Antonio Bernhardt[1], Francesco Intravaia[1], and Kurt Busch[1,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, AG Theoretische Optik & Photonik, 12489 Berlin, Germany — [2]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max- Wien-Platz 1, 07743 Jena, Germany — [3]Max-Born-Institut, 12489 Berlin, Germany

Based on the insight that using (noble) metallic nanostructures or -features as subtrates for molecules, can significantly boost the Raman signal of nearby molecules due to plasmonic resonances, we investigate the fields of the latter in the vicinity of the metal surface. Based on established material models for the conduction-electronic response to light, we perform analytical Mie calculations as well as numerical simulations employing the Discontinuous Galerkin Time Domain method. The role of nonlocal and dispersive response is critically examined always keeping in mind the intertwining with geometrical features of the subtrates. For a selection of geometries, this study sheds light on pecularities, that have to be kept in mind, when designing metallic substrates for Surface Enhanced Raman Scattering/Spectroscopy.

Q 59.66 Thu 16:30 Empore Lichthof

Design of metasurface for carbon dioxide reduction photocatalysis — •Ning Lyu[1,2], Zelio Fusco[2], Fiona Beck[2], and Christin David[1] — [1]Institute of Condensed Matter Theory and Optics, Abbe Center of Photonics, Friedrich Schiller University of Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]School of Engineering, Australian National University, Acton ACT 2601, Australia

As artificial photosynthesis, the photocatalytic reduction of CO_2 addresses the emission of greenhouse gases by converting them back to organic fuels with solar energy. These redox reactions include multiple electron transfer processes and various products were generated vas separated reaction pathways simultaneously, such as formic acid, formaldehyde, methanol, methane, and some higher hydrocarbons products. Therefore, it is challenging to have a highly efficient, stable conversion of a selected single product. Metasurface with a large surface-to-volume ratio promote the concentration of hot electrons in the active site on surface and have a great potential in photocatalysis and co-catalysis applications.

We investigate how TiO_2 metasurfaces with nanopillars (NPs) and hollow nanotubes (NTs) affect selected pathways of CO_2 reductions in their optical properties with the Finite Element Method (FEM). Polarization- and angle-sensitive resonances were designed to overlap with selected reaction pathways using asymmetric pitches. By changing the polarization, the absorption efficiency for selected pathways remained at approximately 90% under the solar spectrum, while other pathways varied from about 96% to only 48%.

Q 59.67 Thu 16:30 Empore Lichthof

An Automated Setup for Single-Photon Fluorescence Microscopy Measurements — •Raphael V. Wichary, Matthias Nuss, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

We present a setup with automated beampath selection to perform ultrafast nonlinear fluorescence microscopy at the single-photon level in a diffraction-limited focus. Pneumatically movable mirrors built into an optical cage system enable quick and reliable changes in the beam path with accurate position reproducibility. The setup includes motorized waveplates for full excitation polarization control with a laser spectrum ranging from 675 nm to 810 nm. Incorporation of a TWINS interferometer [1] enables spectrally resolved measurements of single quantum emitters. Detection is handled either by avalanche photodiodes or by a superconducting nanowire single-photon detector (SNSPD). A Hanbury-Brown–Twiss Interferometer enables verification of anti-bunched photon statistics.

[1] D. Brida et al., Opt. Lett., 37, 3027-3029 (2012)

Q 59.68 Thu 16:30 Empore Lichthof

Quantum coherent interactions between electron vortices and chiral optical near-fields — •Neli Streshkova and Martin Kozák — Department of Chemical Physics and Optics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, CZ-121 16 Prague, Czech Republic

In the recent years new possibilities of shaping free electron beams into the so-called vortex beams have emerged. They hold the promise for many applications in electron microscopy. Specifically, electron vortex beams could be used as a sensitive probe for monitoring the optical near-fields, which emerge around chiral nanostructures under laser light illumination, with near nanometer precision. Here we present numerical simulations of the inelastic interaction between electron vortex beams and chiral optical near-fields. Initially, the electron wavefunction is modulated via inelastic ponderomotive scattering induced by the interference of two optical waves, one of which is an optical vortex wave carrying orbital angular momentum (OAM). The OAM is transferred to the electron beam, which then interacts with a chiral optical near-field of a golden nanosphere excited by circularly polarized optical field. This interaction leads to changes in the electron spectrum in dependence on the amplitude of the near-field, phase relation between the near-field and the modulating fields and the interplay between the helicity of the beam and the near-field itself. Such interaction scheme will in future allow full reconstruction of the optical and plasmonic near-field distribution of various nanostructures including both the amplitude and the phase.

Q 59.69 Thu 16:30 Empore Lichthof

Scattering of free electrons by optical fields and all-optical method for electron pulse characterization — •Kamila Moriová and Martin Kozák — Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague 2, Czech Republic

Free electrons can scatter of a standing light wave formed by two counter-propagating optical beams of identical frequency in vacuum. The coherent reflection of electron wave at periodic ponderomotive potential of the optical standing wave was first proposed by Kapitza and Dirac in 1933 [1] and it was experimentally demonstrated in 2001 [2]. The Kapitza-Dirac-like diffraction was also theoretically described for more general case with two counterpropagating light waves at different frequencies [3]. In this contribution we discuss different regimes of the interaction between electrons and light fields. Further we study the application of the classical regime of electron scattering at an optical standing wave formed by pulsed laser fields for full characterization of femtosecond electron pulses in an electron microscope [4], which is crucial for ultrafast pump-probe experiments with electron probes. [1] Kapitza, P. L. and Dirac, P. A. M. Proc. Camb. Phil. Soc. 29, 297-300 (1933). [2] Freimund, D. L. et al. Nature 413, 142 (2001) [3] Smirnova, O. et al. Phys. Rev. Lett. 92, 223601 (2004) [4] Hebeisen, C. T. et al. Opt. Express 16, 3334-3341 (2008)

Q 59.70 Thu 16:30 Empore Lichthof

Rapid Dilution Mass Photometry — •Carla M. Brunner[1], Emanuel Pfitzner[2], and Philipp Kukura[2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Department of Chemistry, University of Oxford

Mass Photometry (MP) is an optical method based on interferometric scattering microscopy that enables label-free detection of single proteins in solution based on their scattering contrast. Multiple species in a heterogeneous solution can be differentiated by their molecular mass and consequently, binding affinities can be determined. The study of weak interactions calls for high sample concentrations on the order of μM whereas MP requires low concentrations in the nM range.

Developing a rapid dilution method, we explored how the application of MP can be extended beyond these current constraints. Using microcapillaries, we show that we can inject high concentration solutions of transferrin and the IgG antibody 17b into a buffer medium whereupon the sample is diluted by several orders of magnitude within seconds, maintaining the possibility of single-particle detection and the capability to reliably distinguish different species. Nevertheless, carrying out further experiments with a wider range of protein species revealed that some improvements to the setup are required in order to be able to use our methodology more broadly. Measurements performed with HspB1 showed that aggregation of proteins in the capillary tip inhibits the precise determination of mass distributions. A careful investigation of our findings allowed us to pin down current limitations and suggest necessary modifications.

Q 59.71 Thu 16:30 Empore Lichthof

The squeeze laser — •Axel Schönbeck, Jan Südbeck, Jascha Zander, Dieter Berz-Vöge, Pascal Gewecke, Malte Hagemann und Roman Schnabel — Institut für Laserphysik der Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

An increasing number of laser-based measurements in metrology are performed at the quantum-noise limit. Squeezed light helps to overcome this limit. For example, as of 2019, all gravitational-wave observatories (GWOs) worldwide use squeezed vacuum states of light.

"Squeeze laser" is a well-motivated name for what is often referred to as a "squeezed light source". Squeezed light is generated in a laser resonator by parametric down-conversion. The laser's output modes have a large coherence time and are in a near-perfect TEM00 mode. We are launching a spin-off from UHH that will offer these squeeze lasers. Which applications benefit from them?

The squeeze laser is a valuable tool for research laboratories. It is required for one-sided device-independent quantum key distribution (QKD) [Nature Commun. 6, 8795 (2015)] and enables a new technique for absolute calibration of photo sensors [Phys. Rev. Lett. 117, 110801 (2016)]. Measurement-based optical quantum computing requires squeezed states [Science 366, 369-372 (2019)]. The squeeze laser can improve industrial laser Doppler vibrometers in environments with low optical losses [Review of Scientific Instruments 87, 102503 (2016)] [Quantum Sci. Technol. 8, 01LT01 (2022)]. It is also beneficial in the detection and imaging of biological cells and macromolecules [Nature Photon. 7, 229-233 (2013)].

Q 59.72 Thu 16:30 Empore Lichthof

Simulations with IfoCAD for tilt-to-length coupling characterization in LISA — •Rodrigo García Álvarez, Megha Dave, Gerhard Heinzel, and Gudrun Wanner — Albert Einstein Institüt, Hannover, Germany

A major contributor of noise in LISA is the so-called tilt-to-length coupling (TTL). This is the path length signal noise induced by angular and lateral jitters in an interferometric setup. Various TTL noise simulations conducted using IfoCAD, an in-house interferometry analysis tool are presented. These simulations include TTL noise in the test mass interferometers and the inter-satellite interferometers, caused by the jitter of the transmitting and receiving spacecraft. The status of IfoCAD simulations using LISA's latest optical design is included.

Q 59.73 Thu 16:30 Empore Lichthof

Characterization of laser noise with an optical fiber interferometer composed of a 3x3 fiber coupler — •Robin Klöpfer[1,2], Francesca Celine Catalan[1], Ralf Albrecht[1], Annika Belz[2], Harald Kübler[2], Robert Löw[2], Gareth Lees[1], and Tilman Pfau[2] — [1]AP Sensing GmbH, Herrenberger Straße 130, 71034 Böblingen, Germany — [2]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Over the past few decades, fiber-based sensors have been widely deployed in different areas. Distributed acoustic sensing (DAS) in particular has been an important tool for infrastructure monitoring and seismic activity detection. A DAS device sends coherent light into an optical fiber and evaluates the Rayleigh backscattering to monitor strain and acoustic signals over long distances in real time. Because of the high sensitivity of DAS, it is important to ensure a stable optical architecture, starting with a low-noise light source.

Here we characterize the phase and frequency noise of narrow-linewidth lasers using a 120° phase difference unbalanced Michelson interferometer composed of a 3x3 optical fiber coupler. This Michelson interferometer is capable of direct as well as wavelength- and polarization-independent extraction of the differential phase of the incoming laser light, without the need for noise models.

In addition, laser noise measurements are complemented by DAS performance evaluation to identify the most suitable laser for future sensor performance improvements.

Q 59.74 Thu 16:30 Empore Lichthof

Bright Squeezed Light Generation and Quantum Correlation Measurements — •Jasper Venneberg, Henning Vahlbruch, and Benno Willke — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) und Institut für Gravitationsphysik, Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

State-of-the-art, high-precision metrology experiments like gravitational wave detectors require carefully stabilized laser sources with exceptionally low relative power noise (RPN). The RPN is fundamentally quantum noise limited by the relative shot noise (RSN) for classical states of light. As the RSN scales inversely with the square root of the optical power, it can be reduced by increasing the power, i.e., making the laser "brighter". However, this poses various technical challenges and cannot be scaled indefinitely. Thus, additionally "squeezed" states of light can be applied to reduce the RPN below the classical quantum noise limit. This project investigates methods to generate high-power, sub-relative-shot-noise (or "bright squeezed") light. Also, the quantum correlation measurement technique is investigated as an alternative to traditional power noise sensing by correlating two photodetector signals. As presented, this method is capable of sub-shot noise measurements and could serve as a bright squeezing sensor.

Q 59.75 Thu 16:30 Empore Lichthof

Development and characterization of a 2D THz-imaging system based on a 3D printed telecentric f-theta-lens — •Viola-Antonella Zeilberger[1], Konstantin Wenzel[1], Sarah Klein[2], Martin Traub[2], Robert B. Kohlhaas[1], and Lars Liebermeister[1] — [1]Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Fraunhofer Institute for Laser Technology ILT, Steinbachstraße 15, 52074 Aachen, Germany

In recent years, terahertz (THz) time-domain spectroscopy (TDS) has become an established tool for various applications, of which non-destructive layer thickness measurements and defect localization are of particular interest. These applications require rapid 2D imaging. Currently, 2D THz imaging is realized by translating either the single point sensor or the sample, which limits the measurement speed. In this work, we present a THz scanning system based on mechanical beam steering by a motorized gimbal mirror and a telecentric f-theta lens. This system contains a commercial THz-TDS system with a photoconductive THz transceiver as the sensor head. The lens fabricated by a 3D printer using a cyclic olefin copolymer (TOPAS) is designed to scan an area of 1.5 cm x 1.5 cm. We characterize this lens by investigating its focusing properties, the f-theta distortion, and scattering losses caused by the 3D printing process. We find that our scanning system offers diffraction-limited imaging up to 2 THz and satisfies the f-theta condition very well. Hence, this approach offers simple, cost-effective THz-imaging with the potential for high scanning rates.

Q 59.76 Thu 16:30 Empore Lichthof

Laser Power Stabilization via Radiation Pressure — •Graziano Pascale, Marina Trad Nery, and Benno Willke — Max Planck Institute for Gravitational Physics (AEI), Hannover

This work reports a new scheme for laser power stabilization in which the power fluctuations of a laser beam are detected via the radiation pressure they produce in a suspended mirror. The ultimate goal of this experiment is to demonstrate an improved technique for power stabilization that can be implemented in the future generations of Gravitational Wave Detectors (GWDs). Most of the current stabilization techniques rely on sensing a small fraction of the laser power by a photodetector. These techniques are fundamentally limited by the high relative shot noise in the photodetector, which couples as sensing noise in the feedback loop.

To overcome this limit, the technique presented on this poster consists on sensing the full beam power of the laser via radiation pressure in a highly reflective micro-oscillator mirror. A proof of principle experiment has been successfully demonstrated in the past years and now an upgraded version is being setup. A key component of the current experiment is a novel micro-oscillator mirror with a spring constant smaller than 10-5 N/m and that might withstand 4 W of power. With the experiment presented in this poster, we want to demonstrate a relative power noise below 10^(-9) Hz^(-(1/2)) at frequencies around 10 Hz, which might be required in future GWDs.

Q 59.77 Thu 16:30 Empore Lichthof

Influence of Temperature and Salinity on the Spectral Characteristics of Brillouin-Scattering in Water — •Daniel Koestel and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, 64289 Darmstadt, Germany

In our group we are developing a LiDAR-system for remote sensing the temperature and salinity in the ocean upper-mixed layer (~100m depth). We successfully demonstrated the functionality of this setup with a temperature resolution of up to 0.07°C and a depth resolution of up to 1m [1]. Both, spectral Brillouin shift and Brillouin linewidth (FWHM), depend on temperature and salinity. The spectral shift dependency of said parameters has already been studied extensively in the past [2,3]. This contribution aims to bring light to the less researched linewidth dependency on temperature and salinity [4]. For this purpose, we generated spontaneous Brillouin-scattering at 530nm in water in a laboratory environment at different temperatures and salinities. We will present our latest results and discuss further steps in the development. [1] A. Rudolf, Th. Walther, "Laboratory demonstration of a Brillouin lidar to remotely measure temperature profiles of the ocean", Opt. Eng. 53(5) (2014). [2] K. Schorstein, E. S. Fry, and Th. Walther, "Depth-resolved temperature measurements of water using the Brillouin lidar technique", Appl. Phys. B 97(4), 931-934 (2009). [3] E. S. Fry et al., "Remote sensing of the ocean: measurement of sound speed and temperature", Proc. SPIE (1998). [4] E. S. Fry et al., "Temperature dependence of the Brillouin linewidth in water", J. Modern Opt. 49(3-4), 411-418 (2002).

Q 59.78 Thu 16:30 Empore Lichthof

Novel tunable cw UV laser system for laser cooling of bunched relativistic ion beams — •Jens Gumm, Jonas Moos, and Thomas Walher — TU Darmstadt

Experiments with highly charged ions at relativistic energies are of great interest for many atomic and nuclear physics experiments at accelerator facilities. In order to decrease the longitudinal momentum spread and emittance, laser cooling has proven to be a powerful tool.

In this work, we present a cw UV laser system operating at 257.25 nm for ion beam cooling at the ESR at GSI. The laser system will be used to minimize the final ion beam momentum spread and, therefore, the ion bunch length.
The laser can be scanned mode-hop free, via two SHG stages, over 20 GHz with a 50 Hz scan rate. In our latest measurements, we achieve a power of 1.7 W in the UV regime employing a novel elliptical focussing cavity to reduce the degradation effect in BBO.

Q 59.79 Thu 16:30 Empore Lichthof

A pre-stabilized 1550 nm laser source for the ETpathfinder — •Nicole Knust, Fabian Meylahn, and Benno Willke — Leibniz Universität Hannover / Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstr. 38, 30167 Hannover, Germany

The ETpathfinder is a new facility for testing technologies for the future third-generation gravitational wave observatory called Einstein Telescope. Three of the six interferometers of the Einstein Telescope are proposed to use silicon mirrors at a cryogenic temperature of about 10 K to reduce thermal noise. For compatibility with the new mirror material silicon, a shift to longer wavelengths than the currently used 1064 nm is required. The ETpathfinder will support the investigation of the potential of longer wavelengths in combination with silicon mirrors and the cryogenic cooling of an interferometer. Here we present the frequency and power stabilized laser source for the ETpathfinder with a wavelength of 1550 nm. In our design, the beam of a low-noise, low-power external cavity diode laser is amplified to 10 W output power in two stages. To reduce the beam pointing and higher order mode content, the beam is filtered by an optical cavity. Active, multiple path, and high-bandwidth laser power and frequency stabilizations are implemented to achieve the laser stability needed for use in gravitational wave detectors.

Q 59.80 Thu 16:30 Empore Lichthof

Laser noise in interferometric gravitational wave detectors — •Robert Fabian Maciy — Callinstraße 38, 30167 Hannover — Prinz-Albrecht-Ring 40, 30657 Hannover

This poster presents simulations of laser noise requirements for the laser source of future interferometric gravitational wave detectors, especially for the Einstein Telescope. The Einstein Telescope is a third generation gravitational wave detector that is currently in the design phase and is anticipated to achieve higher sensitivity over a wider frequency range compared to second generation gravitational wave detectors like Advanced LIGO by using longer interferometer arms and advanced experimental techniques. An understanding of how laser frequency and power noise couples to the detector output is crucial to calculate the stringent requirements for the laser system and the optics as well as to possible optimize the interferometer and laser design.

On this poster we will show the results from analytical and numerical calculations of the transfer functions of laser noise propagating through individual optical subsystems and the complete interferometer. As the detector is a complex instrument we will present an intuitive description of noise coupling at different complexity levels. Finally a initial requirement for the stability of the laser source for the Einstein Telescope is shown and discussed.

Q 60: Photonics IV

Time: Friday 11:00–12:45 Location: A320

Q 60.1 Fri 11:00 A320

stimulated Brillouin scattering in chiral photonic crystal fibre — •Xinglin Zeng[1], Philip Russell[1], and Birgit Stiller[1,2] — [1]Max-Planck institute for the science of light — [2]Department of Physics, Friedrich-Alexander-Universität

Stimulated Brillouin scattering (SBS) in optical fibres, in which guided light is parametrically reflected by coherent acoustic phonons, provides a powerful and flexible mechanism for controlling light. The recent advent of chiral photonic crystal fibres (PCF) has been shown to robustly preserve optical modes carrying circular polarization states and optical vortices over long distances, allowing investigation of nonlinear processes in the presence of chirality. Here, we report the topology-selective SBS effect in chiral PCF, demonstrate an optical vortex Brillouin laser and a reconfigurable nonreciprocal vortex isolator based on this novel effect. This work opens up new perspectives in Brillouin scattering, with potential interest in many areas, for example, quantum information processing, optical tweezers and telecommunications.

Q 60.2 Fri 11:15 A320

Complex aspherical singlet and doublet microoptics by grayscale 3D printing — •Leander Siegle, Simon Ristok, and Harald Giessen — 4th Physics Institute, University of Stuttgart

We demonstrate grayscale 3D printed aspherical singlet and doublet microoptical components and characterize and evaluate their excellent shape accuracy and optical performance. The typical two-photon polymerization (2PP) 3D printing process creates steps in the structure which is undesired for optical surfaces. We utilize two-photon grayscale lithography (2GL) to create step-free lenses. To showcase the 2GL process, the focusing ability of a spherical and aspherical singlet lens are compared. The surface deviations of the aspherical lens are minimized by an iterative design process, and no distinct steps can be measured. We design, print and optimize an air-spaced doublet lens with a diameter of 300 μm. After optimization, the residual shape deviation is less than 100 nm and 20 nm for the two lenses, respectively. We examine the optical performance with an USAF 1951 resolution test chart to find a resolution of 645 lp/mm.

Q 60.3 Fri 11:30 A320

3D lithography for single-photon level spectroscopy with superconducting detectors — •Johanna Biendl, Maximilian Protte, Timon Schapeler, Thomas Hummel, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

Wavelength is a characteristic property of light, the study of which is a crucial technique in many areas of physics. However, measuring wavelength at the single-photon level is a challenging task. Superconducting detectors have shown excellent single photon counting capabilities, however they are typically broadband devices. We aim to combine the advantages of superconducting single-photon detectors with spectrally selective elements at the microscale under cryogenic operating conditions. Using 3D lithography, we fabricated an array of Fabry-Pérot etalons that encodes the spectral information of incident light by generating a unique transmission pattern. By measuring these transmission spectra with superconducting nanowire single-photon detectors, we demonstrated functionality at the single-photon level. The combination of the etalon array with superconducting detectors will therefore enable a reconstructive single-photon spectrometer that can be operated in the near-infrared wavelength range.

Q 60.4 Fri 11:45 A320

Noise characterization of crystalline AlGaAs coatings for ultra-stable optical resonators — •Chun Yu Ma[1], Jialiang Yu[1], Sofia Herbers[1], Thomas Legero[1], Daniele Nicolodi[1], Fritz Riehle[1], Steffen Sauer[2], Dhruv Kedar[3], John M. Robinson[3], Eric Oelker[4], Jun Ye[3], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Institut für Halbleitertechnik and LENA, Technische Universität Braunschweig, Germany — [3]JILA, NIST and University of Colorado, Boulder, Colorado, USA — [4]University of Glasgow, UK

Brownian thermal noise of highly reflective dielectric coatings fundamentally limits the frequency stability of state-of-the-art ultra-stable lasers. Crystalline AlGaAs mirror coating with low mechanical loss is a promising candidate to reduce this limit. However, our recent measurements at cryogenic temperatures have shown novel noise sources in AlGaAs mirrors beyond their thermal noise level [J. Yu et al., arXiv:2210.15671 (2022) and D. Kedar et al., arXiv:2210.14881 (2022)].

In this work, we present a new investigation on the novel noise sources in AlGaAs mirrors in a room temperature ultra-stable resonator and give an update on our measurement at cryogenic temperatures. Our work provides insight into the predicted and actual noise limits set by these coatings.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union's Horizon 2020 Research and Innovation Programme.

Q 60.5 Fri 12:00 A320

Spectral tailoring of quasi-phase-matched nonlinear processes in Ti:$LiNbO_3$ waveguides using microheaters — •Jonas Babai-Hemati, Felix vom Bruch, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Nonlinear optical conversion processes, such as second harmonic generation (SHG) or parametric down-conversion are at the heart of many quantum optic applications. Various efficient devices have been demonstrated using periodically poled Ti-indiffused waveguides in $LiNbO_3$ (PPLN). Their performance, however, is often limited by inhomogeneities induced by an imperfect fabrication. We demonstrate that this problem can be mitigated by counteracting the inhomogeneities by a distinct temperature profile along the waveguide. Here, we theoretically and experimentally investigate a cascade of microheaters, inducing specifically tailored temperature profiles to improve the performance of an SHG-process. With an optimized temperature profile, we could modify the phase-matching resulting from nonuniform domain inversion or varying waveguide cross-section towards ideal spectra. Furthermore, our method also opens new possibilities to tailor spectra of nonlinear optical processes, allowing for highly efficient and tuneable generation of single photons.

Q 60.6 Fri 12:15 A320

Cryogenic Integrated Nonlinear Optics in Lithium Niobate — •Nina Amelie Lange, Jan Philipp Höpker, Maximilian Protte, Dominik Kostiuk, and Tim J. Bartley — Institute for Photonic Quantum Systems, Paderborn University, Germany

We demonstrate the operation of a nonlinear waveguide at cryogenic temperatures. We investigate the cryogenic performance of Second Harmonic Generation (SHG) and Spontaneous Parametric Down-Conversion (SPDC) in a titanium-indiffused periodically poled lithium niobate waveguide. We show that the nonlinear performance behaves as expected and we can describe the temperature dependent changes very well. Although we change the operation temperature by nearly two orders of magnitude, the SHG process and the SPDC single-photon source remain fully functional.

While SHG and SPDC are typically investigated under ambient conditions, we show that our nonlinear waveguide is compatible with the demanding operation conditions of cryogenic integrated components. The realization of the cryogenic nonlinear processes paves the way for developing novel integrated quantum experiments, for example by combining SPDC sources together with superconducting detectors.

Q 60.7 Fri 12:30 A320

Tunable niobium-based plasmonic superconducting photodetectors for the near- and mid-IR — •Sandra Mennle, Philipp Karl, Monika Ubl, Ksenia Weber, Pavel Ruchka, Mario Hentschel, Philipp Flad, and Harald Giessen — 4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

In the last few years, photon-based applications such as quantum technologies have become a growing field of research. In particular, highly sensitive photodetectors in the near- and mid-IR spectral range are of high importance. Superconducting nanowire single photon detectors, utilizing the resistivity change during the transition from the superconducting to the normal conducting phase, have great potential due to their high efficiency and sensitivity.

To enhance the absorption at larger wavelengths in the IR spectral range, a plasmonic perfect absorber geometry can be used, which utilizes an impedance-matched plasmonic resonance in combination with a spacer layer and a reflector.

In this work we present detectors which reach an absorption of over 95% for wavelengths up to 4 μm. In contrast to cavities, our approach exhibits angle independence, thus high-NA optics can be used to decrease the spot size, resulting in even smaller detector areas and therefore faster response.

Another advantage of the plasmonic approach is the large bandwidth. Furthermore, with simple changes of the geometry the resonance can be easily tuned over a wide spectral range.

Q 61: Quantum Optics with Photons II

Time: Friday 11:00–13:00 Location: E001

Invited Talk Q 61.1 Fri 11:00 E001

Quantum Imaging With Nonlinear Interferometers — •Markus Gräfe — Institute of Applied Physics, Technical University of Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany — Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

Exploiting nonclassical state of light allows new imaging and sensing approaches. In particular, nonlinear interferometers enable quantum imaging with undetected light. Here, based on the effect of induced coherence, samples can be probed with light that is not detected at all. Instead, it quantum correlated partner light is is recorded and yields the information of the sample although it never interacted with it. The talk will outline the fundamental concept, recent progress and limits as well as perspectives for biomedical application.

Q 61.2 Fri 11:30 E001

Unfolding the Hong-Ou-Mandel interference between narrowband heralded states — •Kaisa Laiho[1], Thomas Dirmeier[2,3], Golnoush Shafiee[2,3], and Christoph Marquardt[2,3] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Wilhelm-Runge-Str. 10, 89081 Ulm — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen — [3]Friedrich-Alexander-Universität Erlangen-Nürnberg, Department of Physics, Staudtstr. 7/B2, 91058 Erlangen

The Hong-Ou-Mandel (HOM) interference is pivotal for many quantum information and communication applications. In order to drive such quantum optics hardware often spectrally narrowband photonic emitters are required. Lately, parametric down-conversion (PDC) that produces photons in pairs have become a versatile source of twin beams in order to reliably generate heralded states for these purposes.

At high count rates the PDC process produces multiphoton contributions, which are often disregarded in experiments leading to falsified interpretations. Here, we derive the temporal characteristics of the HOM interference between two independent narrowband heralded states emitted via PDC. We consider the effect of the PDC multiphoton contributions and other experimental imperfections such as optical losses and an unbalanced beam splitter ratio. We find out that the multiphoton background can significantly diminish the visibility of the HOM interference dip. Further, the signal-idler cross-correlation turns into a useful figure of merit for the calibration of the photon flux. Our results are important for reaching a high visibility in an experiment.

Q 61.3 Fri 11:45 E001

Interferometric measurement of the quadrature coherence scale using two replicas of a quantum optical state — •Célia Griffet[1], Matthieu Arnhem[1,2], Stephan De Bièvre[3], and Nicolas J. Cerf[1,4] — [1]Centre for Quantum Information and Communication, Ecole polytechnique de Bruxelles, CP 165, Université libre de Bruxelles, 1050 Brussels, Belgium — [2]Department of Optics, Palacký University, 17. listopadu 1192/12, 77146 Olomouc, Czech Republic — [3]Univ. Lille, CNRS, UMR 8524, INRIA - Laboratoire Paul Painlevé, F-59000 Lille, France — [4]James C. Wyant College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

Assessing whether a quantum state is nonclassical (i.e., incompatible with a mixture of coherent states) is a ubiquitous question in quantum optics, yet a nontrivial experimental task because many nonclassicality witnesses are nonlinear in the state. In particular, if we want to witness or measure the nonclassicality of a state by evaluating its quadrature coherence scale, this a priori requires full state tomography. Here, we provide an experimentally friendly procedure for directly accessing this quantity with a simple linear interferometer involving two replicas (independent and identical copies) of the state supplemented with photon number measurements. This finding, that we interpret as an extension of the Hong-Ou-Mandel effect, illustrates the wide applicability of the multicopy interferometric technique in order to circumvent state tomography in quantum optics.

Q 61.4 Fri 12:00 E001

Photon counting with click detection — •Fabian Schlue[1], Michael Stefszky[1], Vladyslav Dyachuk[1], Suchitra Krishnaswamy[2], Jan Sperling[2], Benjamin Brecht[1], and Christine Silberhorn[1] — [1]Institute for Photonic Quantum Systems (PhoQS), Integrated Quantum Optics (IQO), Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Theoretical Quantum Science, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Gaining knowledge about the photon-number distribution (PND) of an arbitrary input state is important for improving quantum technologies like quantum simulation and quantum key distribution. However, current photon number resolved (PNR) detectors (e.g. transition edge sensors) have very low response time and operate at millikelvin, compared to click detectors (e.g. superconducting nanowire single photon detectors), which are cheaper, faster and can operate at several kelvin. However, pseudo PNR can be added in a resource-efficient way to click detectors by using time multiplexed detection (TMD).

Here we present a TMD device, based on cascaded beam splitters, that provides a variable amount of pseudo PNR by changing the number of multiplexed time bins. This can be easily done by adding or removing extension modules with fiber connections. Depending on the experimental needs a trade off between lower measurement time or higher PNR can be made. We implement several detectors tailored to different experimental boundary conditions and investigate methods to retrieve the PND from the measured click statistics. In particular, how different approximations impact the reconstruction.

Q 61.5 Fri 12:15 E001

Studying nonclassical states of light generated by conditional measurements using click detectors — •Ananga Mohan Datta[1], Konrad Tschernig[2], Armando Pérez-Leija[2], and Kurt Busch[1,3] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, 12489 Berlin, Germany — [2]CREOL, The College of Optics and Photonics, University of Central Florida, Florida 32816, USA — [3]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Conditional measurements are a promising way to generate nonclassical states of light [1-2]. Here we use the statistics produced by click detectors [3] to study the quantum states of light generated via conditional measurements on a detuned waveguide coupler. We investigate the states when one input port is excited by a coherent state while a single-photon Fock state is fed into the other port. We then analyze the projected states when several detectors click in one of the output ports. We present the results of the binomial Q_B parameter [4] of the projected state as a measure for the degree of nonclassicality induced by conditional click detection.

[1] M. Dakna et al., *Phys. Rev. A* **55**, 3184 (1997).
[2] T. J. Bartley et al., *Phys. Rev. A* **86**, 043820 (2012).
[3] J. Sperling et al., *Phys. Rev. A* **85**, 023820 (2012).
[4] J. Sperling et al., *Phys. Rev. Lett.* **109**, 093601 (2012).

Q 61.6 Fri 12:30 E001

Interference and Entanglement Generation using Multiport Beam Splitters — •Shreya Kumar[1], Daniel Bhatti[1], Alex E Jones[2], and Stefanie Barz[1] — [1]Institute for Functional Matter and Quantum Technologies and IQST, University of Stuttgart, 70569 Stuttgart, Germany — [2]Quantum Engineering Technology Labs, H. H. Wills Physics Laboratory and Department of Electrical and Electronic Engineering, University of Bristol, Bristol BS8 1FD, UK

Multi-photon entanglement is an integral part of optical quantum technologies. The generation of multi-photon entangled states typically employs the fusion of entangled pairs of photons from several sources. However, each type of state requires a different configuration of the experimental setup and thus, switching between different states can be cumbersome. Here, we demonstrate a simple and versatile scheme to generate different types of genuine tripartite entangled states with one experimental setup. We send three independent photons through a triport beam splitter, known as a tritter, to generate tripartite W, G and GHZ states. Varying the internal input states, for example, polarization, of the photons and post-selecting output combinations with a certain photon number distribution results in the generation of entangled states. We obtain fidelities of 87.33%, 83.42% and 78.84% for the W, G and GHZ states, respectively, confirming successful generation of genuine tripartite entanglement. Our scheme may also be used as a quantum network server, providing resource states to multiple parties to execute quantum protocols.

Q 61.7 Fri 12:45 E001

Twisted N00N states and the quantum Gouy phase — Markus Hiekkamäki, Rafael F. Barros, Marco Ornigotti, and •Robert Fickler — Photonics Laboratory, Tampere University, Tampere, Finland

Shaping the transverse structure of quantum light has attracted a lot of attention in quantum photonics ranging from fundamental studies to quantum information applications. A powerful way to describe any spatial structure in the paraxial limit are orthogonal transverse spatial modes e.g. Laguerre-Gauss modes. Amongst many other things, such spatial structures serve as a versatile testbed for novel complex quantum states.

I will present advanced schemes of spatial-mode modulation and how they can be used to generate spatial-mode N00N states. The latter describes states where N photons are in an extremal superposition between two orthogonal spatial modes. Our results show that such states when realized with twisted photons, i.e. photons carrying OAM, they can be used to achieve super resolving angle measurements. In addition, we studied spatial mode N00N states in connection to a fundamental wave phenomenon, the so-called Gouy phase. It describes the anomalous phase delay of transversely confined waves when propagating through a focus. When probing it in quantum domain, i.e. when probing the quantum Gouy phase we find that it behaves different from classical light waves in terms of phase evolution as well as spatial mode order.

Q 62: Precision Measurements: Gravity II

Time: Friday 11:00–13:00 Location: E214

Q 62.1 Fri 11:00 E214

Optical Zerodur Bench Toolkit for the BECCAL Cold Atom Experiment — •Faruk Alexander Sellami[1], Jean Pierre Marburger[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Tim Kroh[3], Victoria Henderson[3], Patrick Windpassinger[1], and The MAIUS and BECCAL team[1,2,3,4,5,6,7,8,9,10,11] — [1]Institut für Physik, JGU, Mainz — [2]ILP, UHH, Hamburg — [3]Institut für Physik, HU Berlin, Berlin — [4]FBH, Berlin — [5]IQ & IMS, LUH, Hannover — [6]ZARM, Bremen — [7]Institut für Quantenoptik, Universität Ulm, Ulm — [8]DLR-SC, Braunschweig — [9]DLR-SI, Hannover — [10]DLR-QT, Ulm — [11]OHB-SE, Bremen

The NASA-DLR BECCAL experiment will be a facility for the study of BECs of rubidium and potassium atoms in the microgravity environment of the ISS. For the required laser light distribution and intensity control of several light fields to manipulate the atoms we use an optical bench toolkit based on the glass ceramic Zerodur, which has been already successfully operated in sounding rocket experiments. This material has a negligible coefficient of thermal expansion and can withstand the mechanical shocks during rocket launch as well as temperature and pressure fluctuations to guarantee a stable functionality during the multi-year duration aboard the ISS. Multiple tests of several prototypes are presented. Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WP 1703 and 50 WP 2103.

Q 62.2 Fri 11:15 E214

An optical dipole trap in a drop tower - the PRIMUS-project — •Marian Woltmann[1], Christian Vogt[1], Sven Herrmann[1], Claus Lämmerzahl[1], and PRIMUS Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), 28359 Bremen — [2]LU Hannover, Institute of Quantum Optics

The application of matter wave interferometry in a microgravity (μg) environment offers the potential of largely extended interferometer times and thereby highly increased sensitivities in precision measurements, e.g. of the universality of free fall. While most microgravity cold atom experiments use magnetic trapping with an atom chip, the PRIMUS-project develops an optical dipole trap as an alternative source of ultracold atoms in a drop tower experiment. Solely using optical potentials offers unique advantages like improved trap symmetry, trapping of all magnetic sub-levels and the accessibility of Feshbach resonances. We demonstrated Bose-Einstein condensation of Rubidium in a compact setup on ground while now focusing on a fast, efficient preparation in microgravity using time-averaged optical potentials. Within this talk we will give an overview of the experiment and report on the current status and latest results. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50 WM 2042.

Q 62.3 Fri 11:30 E214

Atom interferometry in the transportable Quantum Gravimeter QG-1 — •Nina Heine[1], Pablo Nuñez von Voigt[1], Ludger Timmen[3], Waldemar Herr[2], Christian Schubert[2], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 is based on the principle of atom interferometry with collimated Bose-Einstein condensates to determine the local gravitational acceleration aiming for an unprecedented level of accuracy $<3\,nm/s^2$. This talk elaborates on the design and implementation of the interferometry setup into the atom chip based experimental system. An introduction to the measurement concept and studies of the interferometer performance will be presented and put into perspective with perfomance estimates for given experimental parameters.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 62.4 Fri 11:45 E214

The Hannover Torsion Balance - a test platform for novel inertial sensing concepts — •Christoph Gentemann[1,2], Gerald Bergmann[2,1], Carolin Cordes[1,2], Gerhard Heinzel[2,1], Moritz Mehmet[2,1], and Karsten Danzmann[2,1] — [1]Leibniz Universität Hannover — [2]Max Planck Institute for Gravitational Physics

Current satellite geodesy missions such as GRACE Follow-On are limited at low frequencies by the noise of their accelerometers. These sensors measure non-gravitational accelerations with free-floating test masses in a capacitive housing through capacitance changes. To test new and more sensitive accelerometer designs a setup is desirable that simulates the force-free environment of space in the laboratory.

Suitably designed torsion pendulums can provide such a test bed, since their rotational motion can be designed to have a low resonance frequency and therefore behave approximately force-free in one dimension above said frequency.

In this talk I will present the Hannover Torsion Balance (HTB), which aims at providing a high precision test platform to investigate new optical readout techniques for test mass motion such as deep frequency modulation interferometry. The current status, including test mass sensing and control, will be discussed. In our laboratory these two things are currently based on electrostatic readout and feedback, to provide a sensible comparison with the space-based accelerometers.

Future upgrades to laser interferometric readout of the sensitive degree of freedom will also be discussed.

Q 62.5 Fri 12:00 E214

Deep Frequency Modulation Interferometry for test mass readout — •Stefano Gozzo — Albert Einstein Institute Hannover

The new generation of space-based experiments for gravitational wave detection and geodesy comes with a number of technological challenges. The design of future space-based interferometers will have to comply with sub-pm/*Hz sensitivity requirements at low frequencies while providing multi-fringe dynamic range and minimizing the complexity of the optical set up configuration.

The Deep Frequency Modulation Interferometry (DFMI) technique aims at simplifying the standard interferometric readout by replacing it with an exclusively digital phasemeter. An introduction to the DFMI technique will be given in this talk.

While DFMI allows to reduce the amount of optical component, space-based gravity field recovery missions usually require a two interferometer set up. The unequal length arm nature of space-based interferometers makes them sensitive to frequency noise, so that an additional interferometer for frequency stabilization purposes is needed. In order to minimize the complexity of such an optical set up, we developed a Single Element Double Interferometer (SEDI) design. A single piece optical element hosts an unequal armlength interferometer probing the position of a test mass and an internal reference interferometer.

The combination of a SEDI with a DFMI readout is a promising scheme to achieve minimal optical complexity while complying with the initial sensitivity goal, and its performances are currently being tested in the AEI Hannover laboratories.

Q 62.6 Fri 12:15 E214

Experimental Results on Cavity-Laser-Locking for Future Gravimetric Satellites — •Martin Weberpals, Vitali Müller, Malte Misfeldt, and Gerhard Heinzel — Max Planck Institute for Gravitational Physics, Hannover, Germany

The precise measurement of satellite distance variations in a low earth orbit can reveal the structure of Earth's gravity field, which is directly related to the mass distribution underneath the satellites.

The satellite pairs GRACE (2002-2017) and GRACE Follow-On (2018-) provided monthly maps of Earth's gravity field, which are extremely valuable for climate research and the understanding of mass redistribution processes on Earth. Future missions, in which laser interferometry will be the primary means of determining the inter-satellite range, are currently being prepared.

In this presentation, we give a short overview on the heterodyne laser instrument concept and address our experimental activities conducted so far in supporting European instrument development. We show our setup for achieving a classical Pound-Drever-Hall (PDH) lock, based on commercial RedPitaya devices as an initial stage. We also present the status of our work on an extension to the PDH lock, allowing us to read out the free spectral range of a cavity. This measurement can be used to calculate the absolute laser frequency, which is required to convert ranging phase data into biased inter-satellite distance. In the end, we show how these activities contribute to the development of European Instrument Control Electronics potentially to be used in future missions.

Q 62.7 Fri 12:30 E214

High-Power Laser Beam in Higher-Order Hermite-Gaussian Modes — •Benjamin von Behren[1], Joscha Heinze[2], Nina Bode[1], and Benno Willke[1] — [1]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Leibniz Universität Hannover, 30167 Hannover, Germany — [2]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

The sensitivities of current gravitational-wave detectors are limited around signal frequencies of 100Hz by mirror thermal noise. One proposed option to reduce this thermal noise is to operate the detectors in a higher-order spatial laser mode. This operation would require a high-power laser input beam in such a spatial mode. Here, we discuss the generation of the Hermite-Gaussian modes HG3,3, HG4,4 and HG5,5 using one water-cooled spatial light modulator (SLM) at a continuous-wave optical input power of up to 85W. We report unprecedented conversion efficiencies for a single SLM of about 43%, 42% and 41%, respectively, and demonstrate that the SLM operation is robust against the high laser power. This is an important step towards the implementation of higher-order laser modes in future gravitational-wave detectors.

Q 62.8 Fri 12:45 E214

Laser Welding the 100 g Mirrors for the AEI 10 m Prototype Suspensions with Micrometer Precision — •Juliane von Wrangel[1,2], Steffen Böhme[3], Matteo Carlassara[1,2], Gerd Harnisch[3], Firoz Khan[1,2], Philip Koch[1,2], Tobias Koch[3], Johannes Lehmann[1,2], Harald Lück[1,2], Janis Wöhler[1,2], and David S. Wu[1,2] — [1]Leibniz Universität Hannover — [2]Max-Planck-Institut für Gravitationsphysik, Hannover — [3]Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Jena

The 10 m Prototype facility of the Albert-Einstein-Institute Hannover will measure and surpass the Standard Quantum Limit (SQL) by constructing the Sub-SQL Interferometer in a gravitational wave detector (GWD) like configuration. Compared to a full scale GWD, the 100 g test mass mirrors are relatively lightweight to enhance the quantum radiation pressure noise. To isolate these mirrors seismically, they are designed as triple suspensions. The last pendulum stage is quasi-monolithic to suppress suspension thermal noise. This final stage consists of four 20 um thin glass fibers laser welded to each of the mirrors. The welding procedure needs to be done with micrometer precision due to the small dimensions of the layout to ensure the suspended mirrors to be straight within a pitch angle of < 10 mrad.

In cooperation with the Fraunhofer Institute for Applied Optics and Precision Engineering in Jena, a semi-automated fiber welding machine was designed. For this setup, a CO2 laser is used to cleave and weld the glass fibers with the desired precision. In the future, this technique will also be applicable to other mirror suspensions of similar dimensions.

Q 63: Ultra-cold Plasmas and Rydberg Systems II (joint session A/Q)

Time: Friday 11:00–12:45 Location: F107

See A 28 for details of this session.

Q 64: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Friday 11:00–12:45 Location: F303

See A 29 for details of this session.

Q 65: Many-body Physics

Time: Friday 11:00–13:00 Location: F342

Q 65.1 Fri 11:00 F342

Wave-particle duality of many-body quantum states — •Christoph Dittel[1,2,3], Gabriel Dufour[1,2], Gregor Weihs[4], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany — [4]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

We formulate a general theory of wave-particle duality for many-body quantum states, which quantifies how wavelike and particlelike properties balance each other. Much as in the well-understood single-particle case, which-way information – here, on the level of many-particle paths – lends particle character, while interference – here, due to coherent superpositions of many-particle amplitudes – indicates wavelike properties. We analyze how many-particle which-way information, continuously tunable by the level of distinguishability of fermionic or bosonic, identical and possibly interacting particles, constrains interference contributions to many-particle observables and thus controls the quantum-to-classical transition in many-particle quantum systems. The versatility of our theoretical framework is illustrated for Hong-Ou-Mandel-like and Bose-Hubbard-like exemplary settings.

Q 65.2 Fri 11:15 F342

Chiral edge dynamics of ultracold erbium atoms in a synthetic Hall system — Roberto Vittorio Röll, Arif Warsi Laskar, •Franz Richard Huybrechts, and Martin Weitz — Universität Bonn, Deutschland

The study of non-trivial topological phases of matter offers opportunities to produce platforms for interesting physics and plays an important role in the advancement of applications in the realm of quantum computing and information. Research on topologically protected edge states is currently being conducted due to their robustness with regards to smooth changes in the system's geometry. Here we report on the observation of chiral edge dynamics with an ultracold atomic erbium system in a synthetic 2D Hall ribbon, which is spanned by one internal and one external degree of freedom of the atoms. The topological nature of the system is confirmed by observing both closed and skipping orbits, and by determining the local Chern marker.

Q 65.3 Fri 11:30 F342

Ferromagnetism and Skyrmions in the Hofstadter-Fermi-Hubbard Model — •Felix A. Palm[1], Mert Kurttutan[2], Annabelle Bohrdt[3], Uli Schollwöck[1], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]Freie Universität Berlin, Germany — [3]Harvard University & ITAMP, Cambridge (MA), USA

Strongly interacting fermionic systems host a variety of interesting quantum many-body states with exotic excitations. For instance, the interplay of strong interactions and the Pauli exclusion principle can lead to Stoner ferromagnetism, but the fate of this state remains unclear when kinetic terms are added. While in many lattice models the fermions' dispersion results in delocalization and destabilization of the ferromagnet, flat bands can restore strong interaction effects and ferromagnetic correlations. To reveal this interplay, here we propose to study the Hofstadter-Fermi-Hubbard model using ultracold atoms. We demonstrate, by performing large-scale DMRG simulations, that this model exhibits a lattice analog of the quantum Hall ferromagnet at magnetic filling factor $\nu = 1$. We reveal the nature of the low energy spin-singlet states around $\nu \approx 1$ and find that they host quasi-particles and quasi-holes exhibiting spin-spin correlations reminiscent of skyrmions. Finally, we predict the breakdown of flat-band ferromagnetism at large fields. Our work paves the way towards experimental studies of lattice quantum Hall ferromagnetism, including prospects to study many-body states of interacting skyrmions and explore the relation to high-Tc superconductivity.

Q 65.4 Fri 11:45 F342

Many-particle interference in the tunneling dynamics of ultracold atoms experiencing dipole-dipole interactions — •Malte Henes[1,2], Andreas Buchleitner[1,2], and Christoph Dittel[1,2,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstraße 19, 79104 Freiburg, Germany

We study how dipole-dipole interactions affect many-particle interference in the tunneling dynamics of ultracold fermionic (^{87}Sr) (or bosonic ^{88}Sr) atoms, in a one-dimensional optical lattice or in an array of optical tweezers. The atoms' tunneling is considered as fully coherent, mediated by a Hubbard-like Hamiltonian, and dipole-dipole interactions, induced by the atoms' $^1S_0 \rightarrow {}^3P_0$ clock transition, are modelled through a master equation with a coherent, dispersive, and an incoherent, dissipative part. As a result of the interplay between dipole-dipole interactions and tunneling dynamics, we identify perfectly subradiant (dark) states for fermions, and find that the reduced visibility contrast in the particles' tunneling dynamics is indicative of the particles' partial distinguishability – induced by their dissipative interaction with the electromagnetic environment.

Q 65.5 Fri 12:00 F342

Aubry transition in chains of long-range interacting particles — •Raphaël Menu[1], Jorge Yago Malo[2], Maria Luisa Chiofalo[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universit *at des Saarlandes, D-66123 Saarbr *ucken, Germany — [2]Dipartimento di Fisica Enrico Fermi, Universita di Pisa and INFN, Largo B. Pontecorvo 3, I-56127 Pisa, Italy

The celebrated Frenkel-Kontorova model provides a framework for understanding the onset of structures emerging from the interaction of a periodic crystalline structure with an underlying substrate with competing characteristic lengths. By tuning the depth of the substrate potential, the crystal undergoes a transition from a frictionless sliding on the surface to a pinned state. This is the so-called Aubry transition. While the classical picture of this model is well-understood, its quantum nature is still largely unexplored. Experimental realizations, such as chains of laser cooled trapped ions interacting with a periodic potential, are characterized by repulsive long-range interactions, for which the paradigm of the Frenkel-Kontorova model is only partially applicable.

In this work we analyze theoretically the dynamics at the Aubry transition for a chain of trapped ions interacting via the long-range Coulomb interaction.

Q 65.6 Fri 12:15 F342

Charge pumping in the anomalous Floquet topological insulator with Falicov-Kimball interactions — •Arijit Dutta[1], Tao Qin[2], and Walter Hofstetter[1] — [1]Goethe-Universität Frankfurt, Institut für Theoretische Physik, Frankfurt, Germany — [2]School of Physics and Optoelectronics Engineering, Anhui University, Hefei, Anhui Province 230601, People's Republic of China

The anomalous Floquet topological insulator (AFTI) is a unique phase found in periodically driven systems which hosts topological edge states even when the Chern number of the bulk band is zero. This results in quantized charge pumping in a nanoribbon geometry. Using Floquet-Keldysh DMFT we evaluate the efficiency of pumping in the AFTI phase in presence of Falicov-Kimball (FK) interaction and compare it with the corresponding results in the nonanomalous Floquet topological insulator - the so-called Haldane phase. We further discuss heating issues and relevance to experiments.

Q 65.7 Fri 12:30 F342

Nonlinear Response of Coherently Driven Atomic Arrays in the Discrete Truncated Wigner Approximation — •Christopher Mink and Michael Fleischhauer — University of Kaiserslautern-Landau

We derive a semiclassical approximation for the collective spontaneous and stimulated emission of an ensemble of driven two-level systems based on the discrete truncated Wigner approximation. In the case of totally symmetrical decay ("Dicke model") our method accurately reproduces exact results including width and height of the superradiant burst and population trapping even at small ensemble sizes.

We then study the dynamics of square subwavelength atomic arrays of 14x14 atoms and the non-isotropic emission of photons of initially fully inverted arrays. Furthermore the nonlinear transmissivity and reflectivity in the presence of a classical driving field at varying intensities is determined.

Q 65.8 Fri 12:45 F342

Spin-Holstein Models in Trapped-Ion Systems — •Johannes Knörzer[1], Tao Shi[2], Eugene Demler[3], and Ignacio Cirac[4] — [1]Institute for Theoretical Studies, ETH Zurich, 8006 Zurich, Switzerland — [2]Chinese Academy of Sciences, Beijing 100190, China — [3]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [4]Max Planck Institute of Quantum Optics, 85748 Garching, Germany

In this work, we highlight how trapped-ion quantum systems can be used to study generalized Holstein models, and benchmark expensive numerical calculations. We study a particular spin-Holstein model that can be implemented with arrays of ions confined by individual microtraps, and that is closely related to the Holstein model of condensed matter physics, used to describe electron-phonon interactions. In contrast to earlier proposals, we focus on simulating many-electron systems and inspect the competition between charge-density wave order, fermion pairing, and phase separation. In our numerical study, we employ a combination of complementary approaches, based on non-Gaussian variational ansatz states and matrix product states, respectively. We demonstrate that this hybrid approach outperforms standard density-matrix renormalization group calculations. At the end of the talk, I will give a perspective of interesting applications in quantum simulation.

Q 66: Quantum Metrology (joint session QI/Q)

Time: Friday 11:00–13:00 Location: F428

See QI 36 for details of this session.

Q 67: Optomechanics III

Time: Friday 11:00–13:00 Location: F442

Q 67.1 Fri 11:00 F442

Direct laser-written optomechanical membranes in fiber Fabry-Perot cavities — •Lukas Tenbrake[1], Alexander Fassbender[2], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany

Cavity optomechanical experiments in micro- and nanophotonic systems have demonstrated record optomechanical coupling strenghts, but require elaborate techniques for interfacing. Their scaling towards larger systems including many mechanical and optical resonators is limited. Here, we demonstrate a directly fiber-coupled tunable and highly flexibile platform for cavity optomechanics based on 3D laser written polymer structures directly integrated into fiber Fabry-Perot cavities. Our experiments show vacuum coupling strengths of $\gtrsim$ 30 kHz at mechanical mode frequencies of $\gtrsim$ 3 MHz. This allows us to optomechanically tune the mechanical resonance frequency by tens of kHz exceeding the mechanical linewidth at cryogenic temperatures of ~ 6 kHz at 4 K. The ease of interfacing the system through the direct fiber coupling, its scaling capabilities to larger systems with coupled resonators, and the possible integration of electrodes makes it a promising platform for upcoming challenges in cavity optomechanics. Fiber-tip integrated accelerometers, directly fiber coupled systems for μ-wave to optics conversion or large systems of coupled mechanical resonators are in reach.

Q 67.2 Fri 11:15 F442

Hollow core photonic crystal fibers as sources for levitated nanoparticles in future quantum experiments — •Stefan Lindner, Yaakov Fein, Paul Juschitz, Jakob Rieser, Markus Aspelmeyer, and Nikolai Kiesel — University of Vienna, Faculty of Physics

Over the last decade several proposals using optically levitated nanoparticles as a platform to create macroscopic quantum states have been put forth. Yet as of today environmental decoherence still poses a substantial roadblock hindering the access to such experiments. Especially the interaction with background gas molecules has to be overcome by reducing the pressure these experiments are conducted in. The attainable vacuum for levitation experiments is directly related to the type of particle loading scheme in place. Here we present a novel method for loading nanoparticles via hollow core photonic crystal fibers, that allows direct loading of into pressures in the ultra high vacuum (UHV) regime.

By guiding two counter-propagating lasers of equal wavelength through a hollow core fiber one creates an “optical conveyor belt” that connects an UHV pressure main vacuum chamber to an ambient or low vacuum “loading” chamber. By detuning one of the two lasers with respect to the other, nanoparticles can be transported from the loading chamber, through the fiber, directly into the trap in the main vacuum chamber. This handover of particles has been demonstrated down to pressures of 10^{-8} mbar and is currently extended, targeting below 10^{-10} mbar, where gas collisions occur at sub-kHz timescales.

Q 67.3 Fri 11:30 F442

Tunable light-induced dipole-dipole interaction between optically levitated nanoparticles — •Jakob Rieser[1], Mario A. Ciampini[1], Henning Rudolph[2], Nikolai Kiesel[1], Klaus Hornberger[2], Benjamin A. Stickler[2], and Uroš Delić[1] — [1]Faculty of Physics, University of Vienna, Vienna, AUT — [2]Faculty of Physics, University of Duisburg-Essen, Duisburg, DEU

By coupling mechanical systems one can observe interesting collective effects, such as topological phonon transport or in the quantum case the possibility of entanglement. Current optomechanical experiments utilize an optical cavity mode to mediate interactions, which limits the tunability of the system. Here we are interested in directly coupling parties using scattered light in a finely controlled manner.

It has been known that optically levitated microparticles can interact through light – optically bind – and form self-organized patterns that resemble crystals. In my talk, I will present coherent, direct interaction between two dielectric nanoparticles levitated in a trap array. In contrast to previous optical binding studies, the interparticle coupling is inherently non-reciprocal. I will show how tuning the relative optical phase, laser powers, and the particle distance gives us full control of the optical interactions. Finally, I will demonstrate how we can suppress the optical coupling using the light polarization, in which case we can observe electrostatic interactions.

Q 67.4 Fri 11:45 F442

Co-trapping an atomic ion and a silica nanoparticle in a Paul trap — •Dmitry S. Bykov, Lorenzo Dania, Florian Goschin, and Tracy E. Northup — Institut für Experimentalphysik, Technikerstr. 25, Universität Innsbruck, Austria

In this work, we experimentally demonstrate the simultaneous trapping of two objects whose charge-to-mass ratio differs by six orders of magnitude in the same Paul trap. The first object is a calcium ion with a single elementary charge and a mass of 40 Da. The second object is a silica nanoparticle with 1000 elementary charges and a mass of 10^{10} Da. To achieve simultaneous trapping, we drive the trap electrodes with two radio-frequency tones: one to trap the nanoparticle and the other to trap the atomic ion. Such a dual-frequency drive allows us to circumvent the charge-to-mass selectivity of a Paul trap. This demonstration paves the way for building a hybrid ion-nanoparticle system under ultra-high vacuum. Such a system is a promising platform for advancing quantum control of particle motion and testing quantum mechanics at unprecedented levels.

Q 67.5 Fri 12:00 F442

Optomechanics with a torsional mode of an optical nanofiber — •Jihao Jia, Sebastian Pucher, Arno Rauschenbeutel, Philipp Schneeweiss, Felix Tebbenjohanns, and Jürgen Volz — Humboldt-Universität Berlin, Germany

Tapered optical fibers (TOFs) with a sub-wavelength-diameter waist, so-called optical nanofibers, have proven to be extremely versatile tools with applications ranging from telecommunication devices and sensors to trapping and optically interfacing laser-cooled atoms. Surprisingly, in the realm of optomechanics, the mechanical motion of the nanofiber waist of such TOFs is so far largely unexplored. Here we show experimentally that the torsional motion of the nanofiber waist of a TOF can be extremely well decoupled from the environment, reaching quality factors of up to 10 million. By analyzing the polarization fluctuations of a probe light field transmitted through the TOF, we measure the nanofiber's torsional motion in real time. Feeding back this signal to the nanofiber, we cool its fundamental torsional mode by several orders of magnitude to sub-Kelvin temperatures. Based on our observations, we discuss the prospects of ground-state cooling. Our results show that optical nanofibers represent a competitive optomechanical platform, which may enable new hybrid quantum systems, e.g., by coupling the torsional motion to cold atoms that are trapped in the evanescent field surrounding the nanofiber.

Q 67.6 Fri 12:15 F442

Strong Coulomb interaction between highly charged optically trapped submicron particles in vacuum — •Ayub Khodaee[1], Anton Zasedatelev[1], and Markus Aspelmeyer[1,2] — [1]Faculty of Physics, Boltzmanngasse 5, Vienna, Austria — [2]IQOQI - Vienna, Boltzmanngasse 3, Vienna, Austria

Optically levitated nano- and micro-particles, in which the motion of a mechanical degree of freedom is controlled via light-induced forces, comprise a new class of ultimately isolated macroscopic mechanical oscillators with high-quality factors exceeding 108 [Gonzalez-Ballestero, C., et al., Science 374.6564 (2021): eabg3027]. One of the central goals of levitated optomechanics nowadays is to prepare a particle wave packet in a sufficiently pure quantum state and generate entanglement between macroscopic mechanical oscillators [Gonzalez-Ballestero, C., et al., Science 374.6564 (2021): eabg3027]. Strong electrostatic interaction between highly charged levitated particles is one the most promising strategies to generate stationary entangled states. The preparation of a pair of highly charged optically levitated particles in the ultra-high vacuum (UHV) is an experimental challenge on the way to implement ground state cooling and quantum entanglement between optically trapped particles. Here we address this problem and present our experimental approach to load, charge, and control sub-micron particles in tunable optical traps in UHV.

Q 67.7 Fri 12:30 F442

Numerical analysis of a novel optical trap design based on optomechanical backactions — •Jose Manuel Monterrosas Romero[1,2], Ester Koistinen[1], Seyed Khalil Alavi[1,2], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart — [2]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart

Optical traps have proven to be an invaluable tool for many scientific applications. However, due to the nature of the traps, their spatial shapes are diffraction limited, and a trapped object often suffers from severe absorption heating, especially in a high vacuum. To mitigate these issues, we propose a new type of optical trap based on the use of dynamic optomechanical backactions between optical nanocavities and a dielectric particle. Our trap consists of two photonic crystal nanobeam cavities (PCNC) closely placed in parallel. Numerical simulations confirm that an extremely sharp potential can be created in the middle between the two PCNCs, which can trap a dielectric nanoparticle stably at room temperature. Furthermore, we find that the dynamic optomechanical forces allow for trapping the particle with significantly suppressed optical heating, therefore reducing heat-induced trap instability. We also present the possibility of creating more complex trapping potentials by adding a second beam with different frequencies for each cavity. All of these unique properties make our system a promising trapping platform for levitated optomechanics.

Q 67.8 Fri 12:45 F442

On a way to quantum entanglement via Coulomb interaction between optically trapped macroscopic particles — •Anton Zasedatelev[1], Ayub Khodaee[1], Klemens Winkler[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna — [2]The Institute for Quantum Optics and Quantum Information

The quantum superposition principle and entanglement are one of the most striking features of the microscopic world and the key resource behind emerging quantum technologies, including quantum telecommunication, computing, metrology etc. The quantum entanglement of macroscopic mechanical oscillators is a unique resource to examine fundamental principles of quantum mechanics at the interface with classical physics. Electromagnetically induced quantum entanglement of macroscopic objects is essential for understanding the role of electromagnetic radiation quantization and vacuum fluctuations in ensuring consistency of the macroscopic systems to the basic principles of quantum mechanics, e.g. causality and complementarity. Here we discuss experimental challenges towards generation of quantum entanglement between center-of-mass motions of two highly charged sub-micrometer dielectric particles optically levitated in an ultra-high vacuum. This work is in progress, and takes the following steps: (i) optical trapping of two closely located and highly charged particles (ii) ground state cooling of their mechanical normal modes, (iii) generation and measurement of entanglement through long-range Coulomb interaction.

Q 68: Quantum Gases: Bosons V

Time: Friday 14:30–16:15 Location: B305

Q 68.1 Fri 14:30 B305

Integrating physical intuition into neural networks for potential reconstruction in ultracold atoms — •Miriam Büttner and Axel U. J. Lode — Institute of Physics, Albert-Ludwig University of Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany

Ever since the rise of interest in Bose-Einstein Condesates (BECs), the research field of interacting ultracold indistinguishable particles has expanded, both in its experimental realizations as well as in its theoretical descriptions.In this work, we present a physically motivated neural network architecture for the extraction of quantum observables from single-shot measurements of ultracold atoms. The focus of the work is put on the inclusion of physical intuition into such a network architecture. Our proposed architecture utilizes extended pre-processing that exploits the stochastic nature of the measurement results, given that the so called single-shot images consist of samples of the N-body density. As we are extracting an external potential from samples of a density, our loss function takes inspiration from the constrained-search approach to density functional theory. We thus demonstrate, that in a way similar to inverse density functional methods, a Bose-Einstein condensate*s external potential can be reconstructed.

Q 68.2 Fri 14:45 B305

An unsupervised deep learning algorithm for single-site reconstruction in quantum gas microscopes with short-spaced optical lattices — •Alexander Impertro[1,2], Julian Wienand[1,2], Sophie Häfele[1,2], Hendrik von Raven[1,2], Scott Hubele[1,2], Till Klostermann[1,2], Cesar Cabrera[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Department of Physics, LMU München, and MCQST, 80799 Munich — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching

In quantum gas microscopy experiments, reconstructing the site-resolved lattice occupation with high fidelity is essential for the accurate extraction of physical observables. For short interatomic separations and limited signal-to-noise ratio, this task becomes exponentially more challenging. Previous methods use only limited a-priori knowledge about the system at hand and rapidly decline in performance as the lattice spacing is decreased below the imaging resolution. Here, we present a novel algorithm based on deep convolutional neural networks to reconstruct the site-resolved lattice occupation in a regime, where the lattice constant is half the imaging resolution, with high fidelity. The network can be directly trained with experimental fluorescence images in an unsupervised manner. It is able to capture density-dependent effects due to its inherent nonlinearity and allows a fast reconstruction of large images. Additionally, we demonstrate two methods to benchmark the experimental reconstruction fidelity with data from our cesium quantum gas microscope, where we find promising results across all fillings.

Q 68.3 Fri 15:00 B305

Spectroscopy of xenon-helium mixtures for Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Bose-Einstein condensation of visible spectral range photons is currently investigated in our and other groups using liquid dye solutions as thermalization media for photon gases in optical microcavities. We here propose an experimental approach to apply these principles for the construction of a coherent light source in the VUV (100 - 200nm), a wavelength regime for which it is difficult to construct lasers due to the high pump power needed to achieve population inversion in active media.

As dye solutions are not suitable for VUV operation, an alternative thermalization medium needs to be found, allowing for contact to the thermal environment by repeated absorption and re-emission of photons. Our candidate are dense heteronuclear xenon-helium mixtures with absorption and emission features around 147nm wavelength, provided by quasi-molecular states formed from the atomic xenon's $5p^6$ and $5p^5 6s$ states, respectively. We here report on recent spectroscopic investigations of such samples at high pressure, with particular emphasis on the spectral overlap between absorption and emission profiles. Further, results on the validity of the thermodynamic Kennard-Stepanov relation are presented, whose fulfillment is a prerequisite for the proposed approach.

Q 68.4 Fri 15:15 B305

How creating one additional well can generate Bose–Einstein condensation — •Mihály Máté[1,5], Örs Legeza[1], Rolf Schilling[2], Mason Yousif[3], and Christian Schilling[3,4] — [1]Wigner Research Centre for Physics, Budapest, Hungary — [2]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany — [3]Clarendon Laboratory, University of Oxford, Oxford, United Kingdom — [4]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität, München, Germany — [5]Department of Mathematics, Technical University of Munich, Germany

We propose and study a model for N hard-core bosons which allows for the interpolation between one- and high-dimensional behavior by variation of just a single external control parameter s/t. It consists of a ring-lattice of d sites with a hopping rate t and an extra site at its center. Increasing the hopping rate s between the central site and the ring sites induces a transition from the regime with a quasi-condensed number N_0 of bosons proportional to $\sqrt{N}$ to complete condensation with $N_0 \simeq N$. In the limit $s/t \to 0, d \to \infty$ the low-lying excitations follow from an effective ring-Hamiltonian. An excitation gap makes the condensate robust against thermal fluctuations at low temperatures. These findings are supported and extended by large scale density matrix renormalization group computations. We show that ultracold bosonic atoms in a Mexican-hat-like potential represent an experimental realization allowing one to observe the transition from quasi to complete condensation by creating a well at the hat's center.

Q 68.5 Fri 15:30 B305

Wilsonian Renormalization in the Symmetry-Broken Polar Phase of a Spin-1 Bose Gas — •Niklas Rasch[1], Aleksandr N. Mikheev[1,2], and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, Germany

Wilsonian renormalization group theory is applied in a 1-loop perturbative expansion to the spin-1 Bose gas both in the thermal and in the symmetry-broken polar phase. For the latter, the symmetry is broken explicitly and flow equations including the renormalization of the condensate density are computed. A scheme is established for investigating the flow equations in a cut-off independent manner at fixed particle density. We observe the emergence of anomalous scaling in the chemical potential which relates to a flow towards the quasi-relativistic phononic regime. To restore convergent flow equations, we explicitly include wave-function renormalization of the first order time derivative and adapt the rescaling scheme. This yields convergent, cut-off independent predictions for all couplings. We are able to qualitatively describe the gas close to criticality, e.g. the shift of the critical temperature, and quantitatively predict low-temperature observables, e.g. condensate depletion.

Q 68.6 Fri 15:45 B305

Quantum walk of two composite bosons — •Pedro Weiler, Mama Kabir Njoya Mforifoum, Gabriel Dufour, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg i.Br.

Many-body interference plays a key role in the dynamics of identical particles. In this contribution we discuss the quantum walk of two identical composite bosons on a 1D lattice. We consider composites made up of either two fermions or two bosons bound by contact interactions. Depending on the quantum statistics of the composite bosons' constituents, we observe different dynamical behaviours arising from an interplay of interaction and exchange processes.

Q 68.7 Fri 16:00 B305

Pairing of 2D electromagnetic bosons under spin-orbit coupling and transverse magnetic field — •Sergueï Andreev — Albert-Ludwigs-Universität Freiburg, D-79104 Freiburg

Exciton-polaritons in 2D semiconductors are electromagnetic bosons characterized by massive dispersion, polarization (spin) and pairwise interactions produced by the Coulomb forces between the constituent electrons and holes. Two bosons with opposite spins may form a bound state (biexciton). The bosons experience effective momentum-dependent magnetic fields due to the electron-hole exchange interaction and longitudinal-transverse splitting of the photon modes. These effective fields couple the spin-singlet biexciton to the continua in the triplet scattering channels. In this talk we shall discuss the ensuing phenomena for monolayer and bilayer semiconductors placed into an external transverse magnetic field (Faraday geometry). We predict biexcitonic halos possessing synthetic angular momenta $L_z = \pm 2\hbar$ [1] and dissociation of a biexciton Bose-Einstein condensate into a superfluid current of excitons upon increasing the density. We point out affinity of these phenomena to the polarized exciton superstripe emerging at zero transverse magnetic field in the equilibrium many-body phase diagram of dipolar excitons in bilayers at sufficiently large inter-layer distances, where the biexciton becomes weakly bound [2].

[1] S. V. Andreev, Phys. Rev. B 106, 155157 (2022)
[2] S. V. Andreev, Phys. Rev. B 103, 184503 (2021)

Q 69: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 14:30–16:30 Location: F303

See A 31 for details of this session.

Q 70: Precision Measurements: Atom Interferometry II (joint session Q/A)

Time: Friday 14:30–16:30 Location: F342

Q 70.1 Fri 14:30 F342

INTENTAS - Interferometry with entangled atoms in space — •Jan Simon Haase[1], Janina Hamann[1], Jens Kruse[2], and Carsten Klempt[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, 30167 Hannover

Atom interferometers are high-precision measurement devices for the sensing of inertial moments as accelerations and rotations. A zero-gravity environment enables prolonged interrogation time and consequently a higher resolution. Therefore, space-borne atom interferometers promise unprecedented resolution for a wide range of applications from geodesy to fundamental tests.

A fundamental limit for their precision is the Standard Quantum Limit (SQL), which determines a limit for the interferometric resolution. The SQL can only be surpassed by using entangled ensembles of atoms as a source for the interferometer.

The goal of the INTENTAS project (Interferometry with entangled atoms in space), which will be presented in this talk, is to demonstrate a compact source of entangled atoms in the Einstein-Elevator, a microgravity platform which allows zero-gravity tests for up to 4 s. The planned experiments will pave the way to employ entangled atomic sources for high-precision interferometry in space applications.

Q 70.2 Fri 14:45 F342

Generalized Ramsey Protocols — •Maja Scharnagl — Institute for theoretical physics, Leibniz University Hannover, Germany

We consider a variational class of generalized Ramsey protocols with two one-axis-twisting (OAT) operations, one before and one after the phase imprint, for which we optimize the direction of the signal imprint, the direction of the second OAT interaction and the measurement direction via a numerical routine for global optimization of constrained parameters. In doing so, we distinguish between protocols whose signal from spin projection measurements exhibits a symmetric or antisymmetric dependence on the phase to be measured. We find that the Quantum Fisher Information, which bounds the sensitivity achievable with a one-axis-twisted input state, can be saturated in our variational class of protocols for nearly all initial squeezing strengths. Therefore, the generalized Ramsey protocols considered here allow us to reduce quantum projection noise in comparison to the standard Ramsey protocol considerably.

Q 70.3 Fri 15:00 F342

Dynamics of quantum gases mixtures in space experiments — •Annie Pichery[1,2], Matthias Meister[3], Eric Charron[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. Space provides an environment where these clouds can float for extended times of several seconds, thus boosting the precision of these sensors. It also enables the operation of Bose-Einstein Condensate (BEC) mixtures for dual interferometers in miscibility conditions not possible on ground.

Simulating such dynamics of interacting dual species BEC mixtures presents however computational challenges due to the long expansion times. In this contribution, scaling techniques to overcome these limits are presented and illustrated in the case of space experiments on the ISS and aboard sounding rockets.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. CAL-II 50WM2245A/B.

Q 70.4 Fri 15:15 F342

Atom interferometry on the International Space Station — •Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], and the CUAS team[1,2,3,4] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz Research School, Hanover, Germany — [3]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [4]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany

Matter-wave interferometers based on Bose-Einstein condensates are exquisite tools for precision measurements, relativistic geodesy, and Earth observation. Employing this quantum technology in space further increases the sensitivity of the measurements due to the extended free fall times enabled by microgravity. Here we report on a series of experiments performed with NASA's Cold Atom Lab aboard the ISS demonstrating atom interferometers with different geometries in orbit. By comparing measurements with atoms in magnetic sensitive and insensitive states we have realized atomic magnetometers mapping the residual magnetic background in the apparatus. Our results pave the way towards future quantum sensing missions with cold atoms in space.

This work is supported by NASA/JPL through RSA No. 1616833 and the DLR Space Administration with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM1861-2 and 50WM2245-A/B.

Q 70.5 Fri 15:30 F342

Large-momentum-transfer atom interferometers with μrad-accuracy using Bragg diffraction — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Christian Schubert[2,3], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik

Large-momentum-transfer atom interferometers that employ elastic Bragg scattering from light waves are among the most precise quantum sensors available. To increase their accuracy from the mrad to the μrad regime, it is necessary to understand the rich phenomenology of Bragg interferometers, which can be quite different from that of a standard two-mode interferometer. We develop an analytic model for the interferometer signal and demonstrate its accuracy using extensive numerical simulations. Our analytic treatment enables the determination of the atomic projection noise limit of an LMT Bragg interferometer and provides the means to saturate this limit. It allows suppression of systematic phase errors by two orders of magnitude down to a few μrad using appropriate pulse parameters.

This work is supported through the DFG via QuantumFrontiers (EXC 2123), and DQ-mat (CRC1227) within Projects No. A05, No. B07, and No. B09.

Q 70.6 Fri 15:45 F342

Applications of tuneable interactions in atom interferometry sources — •Alexander Herbst, Henning Albers, Wei Liu, Knut Stolzenberg, Sebastian Bode, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Atom interferometers are powerful tools for precision measurements in fundamental physics or applications such as inertial sensing. Fundamentally, the sensitivity of these devices is limited by shot noise, thus motivating high-flux atomic sources. Furthermore, control over the ensemble's initial conditions and its expansion dynamics is key for systematic error mitigation.

To address these challenges we demonstrate a high flux source of ultra-cold ^{39}K with nearly Heisenberg limited expansion rates in the horizontal plane. Due to its broad Feshbach resonances at comparably low magnetic fields ^{39}K allows for changing its atomic interactions without the need for complex coil setups. By dynamically tuning its scattering length along the evaporation trajectory we achieve quantum degeneracy in below 200 ms evaporation time, maintaining a constant flux. Subsequently, changing the scattering length to a minimal positive value reduces the mean-field energy, thus offering a simple and robust way to decrease the expansion rate to an effective temperature equivalent of a few nanokelvin. Moreover, our method can also be applied to improve more complex techniques such as matter-wave lensing, allowing for effective temperatures in the sub-nK regime.

Q 70.7 Fri 16:00 F342

Optical simulations for highly sensitive atom interferometry — •Gabriel Müller, Stefan Seckmeyer, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Using atom interferometers as highly sensitive quantum sensors requires both precise understanding and control of their main building block: atom light interactions. To properly describe the atom light interactions we need an accurate description of the laser-driven light fields. Distortions of ideal Gaussian beams on their path to the atoms can cause several disturbing effects. For example, the occurrence of asymmetric optical dipole forces acting on the atoms can cause a loss of contrast. Here, we build an optical simulation tool using Fast-Fourier-transform beam propagation methods to take into account arbitrarily shaped obstacles. We compare these results, on small scales, to solutions of Maxwell's equations finding good agreement. Finally, we apply our optical simulations to guide the design of the next unit of NASA's Earth-orbiting Cold Atom Lab and DESIRE, a microgravity experiment searching for Dark Energy.

This work is supported by DLR funds from the BMWi (50WM2245A-CAL-II and 50WM2253A-(AI)^2).

Q 70.8 Fri 16:15 F342

BEC atom interferometry techniques for very long baselines — •Dorothee Tell[1], Vishu Gupta[1], Henning Albers[1], Klaus H. Zipfel[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

The Very Long Baseline Atom Interferometry (VLBAI) facility at the university of Hannover aims for high precision measurements of inertial quantities. Goals span from absolute gravimetry to fundamental physics at the interface between quantum mechanics and general relativity. To this end, the VLBAI facility will make use of ultracold atoms freely falling in a 10 m long vacuum tube with well-known bias forces. We will utilize Bragg atom optics to realize Mach-Zehnder-like geometries sensitive to acceleration.

Here we present the source of rubidium Bose-Einstein condensates ready to be installed at the bottom of the VLBAI baseline for interfer- ometry on fountain trajectories. We demonstrate the necessary meth- ods and schemes, such as matter-wave lenses, Bragg beam splitters and Bloch oscillations, in proof-of-principle experiments performed in the cm-scale baseline available in the source chamber. We discuss prospects and challenges of extending the free fall distance to 10 m.

This work is funded by the DFG as a major research equipment, via Project-ID 434617780 - SFB 1464 TerraQ and Project-ID 274200144 - SFB 1227 DQ-mat, and under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - Project-ID 39083796.

Q 71: Quantum Optics: Cavity and Waveguide QED III

Time: Friday 14:30–15:30 Location: F442

Q 71.1 Fri 14:30 F442

Waveguide QED with Mössbauer Nuclei — •Petar Andrejic[1], Leon Merten Lohse[2,3], and Adriana Palffy[4] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Deutsches Elektronen-Synchrotron — [3]Georg-August-Universität Göttingen — [4]Julius-Maximilians-Universität Würzburg

Grazing incidence X-ray waveguides have become a well established platform for X-ray quantum optics. In these systems the waveguide mediated collective coupling of the X-rays plays a significant role. Recently a formalism has been developed to describe the collective nuclear response using the classical electromagnetic Green's function for the waveguide [1,2]. However, so far these works have considered only translationally symmetric systems, and plane wave driving fields. We show that driving the waveguides at forward incidence instead allows for direct excitation of multiple guided modes, with centimetre scale attenuation lengths. In this regime, micro-patches of embedded Mössbauer nuclei absorb and emit collectively into a super-position of these modes, with the resultant radiation field displaying pronounced interference beats on a micrometre scale. By considering variations in the size and positions of the micro-patches, it is feasible to engineer the resultant inter-nuclear coupling, with potential for applications in quantum simulation and experimental exploration of mesoscopic quantum dynamics.

[1] X. Kong, D. E. Chang, and A. Pálffy, Phys. Rev. A 102, 033710 (2020)
[2] P. Andrejić and A. Pálffy, Phys. Rev. A 104, 033702 (2021)

Q 71.2 Fri 14:45 F442

Quantum State Preparation in a Micromaser — •Andreas J C Woitzik[1], Edoardo Carnio[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Federal Republic of Germany

Quantum algorithms process information encoded into quantum states via an appropriate unitary transformation. Their purpose is to deliver a sought-after target state that represents the solution of a predefined computational problem. From a physical perspective, this process can be interpreted as a quantum state control problem, where a given target state is to be prepared with an optimally tailored unitary transformation. In this talk we adopt the one-atom (or micro-) maser, i.e., a string of atoms interacting sequentially with a cavity mode, to study the transfer of quantum information in state space. We aim, in particular, for the relation between the cavity's convergence towards a given target state and the entanglement content of the injected atomic string.

Q 71.3 Fri 15:00 F442

Star-to-chain transformations for ultra-strong coupling — David D. Noachtar[1], Johannes Knörzer[1,2], and •Robert H. Jonsson[1,3] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]Institute for Theoretical Studies, ETH Zurich, Switzerland — [3]Nordita, Stockholm, Sweden

The ultra-strong coupling regime requires non-perturbative methods, for example, to calculate the radiation emitted from an atom. We show how star-to-chain transformations can be combined with methods based on matrix product state or Gaussian methods, respectively. Being well known in the study of open quantum systems, we demonstrate that the approach allows us to also treat field observables - both in vacuum states and thermal states of the field. As applications we consider giant atoms in the ultra-strong coupling regime [1], and the emission from a uniformly accelerated emitter in the Unruh effect [2].

[1] D. D. Noachtar, J. Knörzer, and R. H. Jonsson, "Nonperturbative treatment of giant atoms using chain transformations", Phys. Rev. A 013702, (2022).
[2] R. H. Jonsson, and J. Knörzer, "Star-to-chain transformations for relativistic matter-light interaction", in preparation.

Q 71.4 Fri 15:15 F442

Few-mode theory beyond the rotating-wave approximation — •Felix Riesterer, Lucas Weitzel, Dominik Lentrodt, and Andreas Buchleitner — Institute of Physics Albert-Ludwigs University of Freiburg Hermann-Herder-Str. 3 D-79104 Freiburg

For ideal cavities, the quantization of the electromagnetic field is rather simple. In real cavities with finite losses, however, the mode spectrum of the resonator becomes continuous, which makes the mathematical treatment numerically expensive and only possible with advanced techniques. It is then desirable to obtain a simplified description of the continuum, to model the field and quantum dynamics in open cavities. To overcome this problem, one uses projections to an equivalent system which is analog to the Jaynes-Cummings model coupled to an external heat bath, which can then be treated with the Lindblad formalism. In this process, the so-called rotating wave approximation has to be applied, where counter-rotating terms are omitted. In this work, we consider a generalized system-bath model by adding the counter-rotating terms to the commonly considered Hamiltonian. Our approach is aimed at understanding how these models can be applied or generalized for complex resonators with large losses, as they are encountered, e.g., in plasmonic cavities.

Q 72: Precision Spectroscopy of Atoms and Ions V (joint session A/Q)

Time: Friday 14:30–16:00 Location: B302

See A 33 for details of this session.

Quantum Information Division
Fachverband Quanteninformation (QI)

Otfried Gühne
Universität Siegen
Walter-Flex-Str. 3
57068 Siegen
otfried.guehne@uni-siegen.de

Guido Burkard
Universität Konstanz
Universitätsstraße 10
78464 Konstanz
guido.burkard@uni-konstanz.de

Overview of Invited Talks and Sessions

(Lecture halls B302, B305, and F428; Poster Empore Lichthof)

Invited Talks

QI 3.1	Mon	11:00–11:30	B305	**Characterising quantum device variability with machine learning** — •Natalia Ares
QI 5.1	Mon	11:00–11:30	F428	**Building Superconducting Quantum Hardware towards Error-Corrected Quantum Computing** — •Christopher Eichler
QI 10.1	Tue	11:00–11:30	B302	**Quantum information in minimal quantum thermal machines** — •Géraldine Haack
QI 11.1	Tue	11:00–11:30	B305	**Characterisation of multipartite entanglement beyond the single-copy paradigm** — •Nicolai Friis
QI 17.1	Wed	11:00–11:30	B305	**Self-testing with dishonest parties and entanglement certification in quantum networks** — •Gláucia Murta, Flavio Baccari
QI 19.1	Wed	11:00–11:30	F428	**Experimental quantum error correction with trapped ions** — •Philipp Schindler
QI 21.1	Wed	14:30–15:00	B305	**Qube and Qube-II – Towards Quantum Key Distribution with Small Satellites** — •Lukas Knips
QI 26.1	Thu	11:00–11:30	B305	**Quantum firmware: optimal control for quantum simulators** — •Tommaso Calarco
QI 28.1	Thu	11:00–11:30	F428	**Conveyor-mode single-electron shuttling in Si/SiGe for a scalable quantum computing architecture** — •Inga Seidler, Tom Struck, Ran Xue, Stefan Trellenkamp, Hendrik Bluhm, Lars R. Schreiber
QI 30.1	Thu	14:30–15:00	B305	**Adaptive constant-depth circuits for manipulating non-abelian anyons** — Sergey Bravyi, Isaac Kim, Alexander Kliesch, •Robert König

Invited Talks of the joint Symposium SAMOP Dissertation Prize 2023

See SYAD for the full program of the symposium.

SYAD 1.1	Mon	14:30–15:00	E415	**Quantum gas magnifier for sub-lattice resolved imaging of 3D quantum systems** — •Luca Asteria
SYAD 1.2	Mon	15:00–15:30	E415	**From femtoseconds to femtometers – controlling quantum dynamics in molecules with ultrafast lasers** — •Patrick Rupprecht
SYAD 1.3	Mon	15:30–16:00	E415	**Particle Delocalization in Many-Body Localized Phases** — •Maximilian Kiefer-Emmanouilidis
SYAD 1.4	Mon	16:00–16:30	E415	**Feshbach resonances in a hybrid atom-ion system** — •Pascal Weckesser

Prize Talks of the joint Awards Symposium

See SYAS for the full program of the symposium.

SYAS 1.1	Tue	14:35–15:05	E415	**The Reaction Microscope: A Bubble Chamber for AMOP** — •Joachim Ullrich
SYAS 1.2	Tue	15:05–15:35	E415	**Quantum Computation and Quantum Simulation with Strings of Trapped Ca+ Ions** — •Rainer Blatt
SYAS 1.3	Tue	15:35–16:05	E415	**Amplitude, Phase and Entanglement in Strong Field Ionization** — •Sebastian Eckart
SYAS 1.4	Tue	16:05–16:35	E415	**All-optical Nonlinear Noise Suppression in Mode-locked Lasers and Ultrafast Fiber Amplifiers** — •Marvin Edelmann

Invited Talks of the joint Symposium From Molecular Spectroscopy to Collision Control at the Quantum Limit

See SYCC for the full program of the symposium.

SYCC 1.1	Thu	11:00–11:30	E415	**The unity of physics: the beauty and power of spectroscopy** — •Paul Julienne
SYCC 1.2	Thu	11:30–12:00	E415	**Using high-resolution molecular spectroscopy to explore how chemical reactions work** — •Johannes Hecker Denschlag
SYCC 1.3	Thu	12:00–12:30	E415	**Monitoring ultracold collisions with laser light** — •Olivier Dulieu
SYCC 1.4	Thu	12:30–13:00	E415	**The birth of a degenerate Fermi gas of molecules** — •Jun Ye

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Invited Talks of the joint Symposium Quantum Optics and Quantum Information with Rigid Rotors

See SYQR for the full program of the symposium.

SYQR 1.1	Fri	11:00–11:30	E415	**Femtosecond timed imaging of rotation and vibration of alkali dimers on the surface of helium nanodroplets** — •Henrik Stapelfeldt
SYQR 1.2	Fri	11:30–12:00	E415	**Quantum toolbox for molecular state spaces** — Eric Kubischta, Shubham Jain, Ian Teixeira, Eric R. Hudson, Wesley C. Campbell, Mikhail Lemeshko, •Victor V. Albert
SYQR 1.3	Fri	12:00–12:30	E415	**Coherent rotational state control of chiral molecules** — •Sandra Eibenberger-Arias
SYQR 1.4	Fri	12:30–13:00	E415	**Optically levitated rotors: potential control and optimal measurement** — •Martin Frimmer
SYQR 2.1	Fri	14:30–15:00	E415	**Rotational optomechanics with levitated nanodumbbells** — •Tongcang Li
SYQR 2.2	Fri	15:00–15:30	E415	**Quantum rotations of nanoparticles** — •Benjamin A. Stickler
SYQR 2.3	Fri	15:30–16:00	E415	**Quantum control of trapped molecular ions** — •Stefan Willitsch
SYQR 2.4	Fri	16:00–16:30	E415	**Full control over randomly oriented quantum rotors: controllability analysis and application to chiral observables** — •Monika Leibscher

Sessions

QI 1.1–1.8	Mon	11:00–13:00	A320	**Quantum Technologies I (joint session Q/A/QI)**
QI 2.1–2.8	Mon	11:00–13:00	B302	**Quantum Foundations**
QI 3.1–3.7	Mon	11:00–13:00	B305	**Quantum Machine Learning**
QI 4.1–4.8	Mon	11:00–13:00	E214	**Quantum Computing and Simulation (joint session Q/QI)**
QI 5.1–5.5	Mon	11:00–12:30	F428	**Superconducting Qubits and Hybrid Systems**
QI 6.1–6.49	Mon	16:30–19:00	Empore Lichthof	**Poster I (joint session QI/Q)**
QI 7.1–7.8	Mon	17:00–19:00	F342	**Quantum Technologies: Color Centers I (joint session Q/A/QI)**
QI 8.1–8.8	Mon	17:00–19:00	F442	**Quantum Communication I (joint session Q/QI)**
QI 9.1–9.8	Tue	11:00–13:00	A320	**Photonic Quantum Technologies (joint session Q/QI)**
QI 10.1–10.7	Tue	11:00–13:00	B302	**Quantum Thermodynamics and Open Quantum Systems I**
QI 11.1–11.7	Tue	11:00–13:00	B305	**Quantum Entanglement I**
QI 12.1–12.7	Tue	11:00–13:00	E001	**Integrated Photonics I (joint session Q/QI)**
QI 13.1–13.8	Tue	11:00–13:00	F428	**Quantum Simulation**
QI 14.1–14.8	Tue	11:00–13:00	F442	**Quantum Technologies: Color Centers II (joint session Q/QI)**
QI 15	Tue	13:15–14:00	B305	**Members' Assembly**
QI 16.1–16.8	Wed	11:00–13:00	B302	**Concepts and Methods I**
QI 17.1–17.6	Wed	11:00–12:45	B305	**Quantum Networks I (joint session QI/Q)**
QI 18.1–18.8	Wed	11:00–13:00	F342	**Quantum Technologies: Trapped Ions (joint session Q/QI)**
QI 19.1–19.7	Wed	11:00–13:00	F428	**Implementations: Ions and Atoms (joint session QI/Q)**
QI 20.1–20.8	Wed	14:30–16:30	B302	**Concepts and Methods II**
QI 21.1–21.7	Wed	14:30–16:30	B305	**Quantum Communication II (joint session QI/Q)**

QI 22.1–22.7	Wed	14:30–16:30	E214	**Quantum Technologies II (joint session Q/MO/QI)**
QI 23.1–23.65	Wed	16:30–19:00	Empore Lichthof	**Poster II (joint session QI/Q)**
QI 24.1–24.8	Wed	17:00–19:00	A320	**Integrated Photonics II (joint session Q/QI)**
QI 25.1–25.8	Thu	11:00–13:00	B302	**Quantum Entanglement II**
QI 26.1–26.7	Thu	11:00–13:00	B305	**Quantum Control (joint session QI/Q)**
QI 27.1–27.7	Thu	11:00–13:00	E001	**Precision Measurements with Optical Clocks (joint session Q/QI)**
QI 28.1–28.7	Thu	11:00–13:00	F428	**Spin Qubits**
QI 29.1–29.8	Thu	14:30–16:30	B302	**Quantum Thermodynamics and Open Quantum Systems II**
QI 30.1–30.7	Thu	14:30–16:30	B305	**Quantum Algorithms**
QI 31.1–31.7	Thu	14:30–16:30	E214	**Single Quantum Emitters (joint session Q/QI)**
QI 32.1–32.8	Thu	14:30–16:30	F102	**Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)**
QI 33.1–33.8	Thu	14:30–16:30	F428	**Quantum Networks II (joint session QI/Q)**
QI 34.1–34.8	Fri	11:00–13:00	B302	**Concepts and Methods III**
QI 35.1–35.8	Fri	11:00–13:00	B305	**Quantum Computers: Algorithms and Benchmarking**
QI 36.1–36.8	Fri	11:00–13:00	F428	**Quantum Metrology (joint session QI/Q)**
QI 37.1–37.7	Fri	14:30–16:15	F428	**Quantum Many Body Systems**

Members' Assembly of the Quantum Information Division

Tuesday, 07/03/2023 13:15–14:00 B305

More information will be sent to the members of the division by e-mail.

Sessions

– Invited Talks, Contributed Talks, and Posters –

QI 1: Quantum Technologies I (joint session Q/A/QI)

Time: Monday 11:00–13:00 Location: A320

See Q 1 for details of this session.

QI 2: Quantum Foundations

Time: Monday 11:00–13:00 Location: B302

QI 2.1 Mon 11:00 B302

Uncertainty relations from graph theory — •Kiara Hansenne, Carlos de Gois, and Otfried Gühne — Universität Siegen, Siegen, Germany

Quantum measurements are inherently probabilistic and quantum theory often forbids to precisely predict the outcomes of simultaneous measurements. This phenomenon is captured and quantified through uncertainty relations. Although studied since the inception of quantum theory, the problem of determining the possible expectation values of a collection of quantum measurements remains, in general, unsolved. By constructing a close connection between observables and graph theory, we derive uncertainty relations valid for any set of dichotomic observables. These relations are, in many cases, tight, and related to the size of the maximum clique of the associated graph. As applications, our results can be straightforwardly used to formulate entropic uncertainty relations, separability criteria and entanglement witnesses.

QI 2.2 Mon 11:15 B302

Many-particle coherence and higher-order interference — •Marc-Oliver Pleinert[1], Eric Lutz[2], and Joachim von Zanthier[1] — [1]Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany — [2]Institute for Theoretical Physics I, University of Stuttgart, 70550 Stuttgart, Germany

Quantum mechanics is based on a set of only a few postulates, which can be separated into two parts: one part governing the 'inner' structure, i.e., the definition and dynamics of the state space, the wave function and the observables; and one part making the connection to experiments. The latter is known as Born's rule, which – simply put – relates detection probabilities to the modulus square of the wave function. The resulting structure of quantum theory permits interference of indistinguishable paths; but, at the same time, limits such interference to certain interference orders. In general, quantum mechanics allows for interference up to order $2M$ in M-particle correlations. Depending on the mutual coherence of the particles, however, the related interference hierarchy can terminate earlier. Here, we show that mutually coherent particles can exhibit interference of the highest orders allowed. We further demonstrate that interference of mutually incoherent particles truncates already at order $M+1$ although interference of the latter is principally more multifaceted. Finally, we demonstrate the disparate vanishing of such higher-order interference terms as a function of coherence in experiments with mutually coherent and incoherent sources.

QI 2.3 Mon 11:30 B302

What aspects of the phenomenology of interference witness nonclassicality? — •Lorenzo Catani[1], Matthew Leifer[2], Giovanni Scala[3], David Schmid[3], and Robert Spekkens[4] — [1]Technische Universitaet Berlin — [2]Chapman University — [3]University of Gdansk — [4]Perimeter Institute for Theoretical Physics

Interference phenomena are often claimed to resist classical explanation. However, such claims are undermined by the fact that the specific aspects of the phenomenology upon which they are based can in fact be reproduced in a noncontextual ontological model [Catani et al. arXiv:2111.13727]. This raises the question of what other aspects of the phenomenology of interference do in fact resist classical explanation. We answer this question by demonstrating that the most basic quantum wave-particle duality relation, which expresses the precise trade-off between path distinguishability and fringe visibility, cannot be reproduced in any noncontextual model. We do this by showing that it is a specific type of uncertainty relation, and then leveraging a recent result establishing that noncontextuality restricts the functional form of this uncertainty relation [Catani et al. arXiv:2207.11779]. Finally, we discuss what sorts of interferometric experiment can demonstrate contextuality via the wave-particle duality relation.

QI 2.4 Mon 11:45 B302

Contextuality as a precondition for entanglement — •Martin Plávala and Otfried Gühne — Universität Siegen, Siegen, Deutschland

Quantum theory features several phenomena which can be considered as resources for information processing tasks. Some of these effects, such as entanglement, arise in a non-local scenario, where a quantum state is distributed between different parties. Other phenomena, such as contextuality can be observed, if quantum states are prepared and then subjected to sequences of measurements. Here we provide an intimate connection between different resources by proving that entanglement in a non-local scenario can only arise if there is preparation & measurement contextuality in a sequential scenario derived from the non-local one by remote state preparation. Moreover, the robust absence of entanglement implies the absence of contextuality. As a direct consequence, our result allows to translate any inequality for testing preparation & measurement contextuality into an entanglement test; in addition, entanglement witnesses can be used to obtain novel contextuality inequalities.

QI 2.5 Mon 12:00 B302

Distribution of quantum incompatibility across subsets of multiple measurements — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, D-40225 Düsseldorf, Germany

The incompatibility of quantum measurements, i.e., the impossibility of measuring two or more observable quantities simultaneously, is one of the most fundamental properties of quantum physics. Not only are incompatible measurements necessary to reveal nonlocal effects, such as quantum steering and the violation of Bell inequalities, but they are also valuable resources that provide advantages in various information processing tasks. It is generally known that increasing the number of distinct measurements can also increase the incompatibility. However, it is yet unknown how much incompatibility can be gained from adding more measurements to an existing measurement scheme and on what this gain depends. Here, we show how the maximal incompatibility that can be gained by increasing the number of measurements can be upper bounded by functions of the incompatibility of respective subsets of the available measurements. More generally, we show how to bound the incompatibility of a set of measurements using the properties of its subsets, which reveals a new notion of measurement incompatibility. We prove the relevance of our bounds by providing tight examples using noisy measurements based on mutually unbiased bases. Finally, we discuss the direct consequences of our results for the nonlocality that could be gained by increasing the number of measurements in a Bell experiment.

QI 2.6 Mon 12:15 B302

Simulability of Sets of Continuous and Infinite-Dimensional POVMs — •Sophie Egelhaaf[1], Juha-Pekka Pellonpää[2], and Roope Uola[1] — [1]Département de Physique Appliquée, Université de Genève, CH-1205 Genève, Switzerland — [2]Department of Physics and Astronomy, University of Turku, FI-20014 Turun yliopisto, Finland

When considering quantum information tasks such as steering and Bell nonlocality, the statistics not only depend on the state(s) shared by the parties but also the set of POVMs available to them. A key feature for witnessing true quantum behaviour is the incompatibility of POVMs. If a set of POVMs is jointly measurable, i.e. not incompatible, it can be fully compressed. Hence Ioannou et al [1] use the compression dimension of a set of POVMs, named the simulability, to quantify the incompatibility of the set. However, so far many findings only apply to finite-dimensional and discrete POVMs. We are working on adapting these findings such that they also hold for infinite-dimensional and continuous POVMs. In this context we are interested in finding the most incompatible and least compressible pair of continuous and infinite-dimensional POVMs, examples potentially being position and momentum as well as number and phase.

[1] M. Ioannou et al. Simulability of high-dimensional quantum measurements. arXiv preprint arXiv:2202.12980 (2022)

QI 2.7 Mon 12:30 B302

Causality and signalling in a quantum information space-time — •Leonardo Silva Vieira Santos — Universitat Siegen, Siegen, Germany

In recent years, there has been a growing interest and effort in understanding causality in the quantum domain. Much of this is due to the tension between the two most successful scientific theories of modern physics: quantum mechanics and Einstein's general relativity. On the one hand, quantum mechanics is a probabilistic theory whose application typically takes place in contexts with a fixed and well-defined causal structure. General relativity, on the other hand, is deterministic but has a dynamical causal structure. We propose a framework to study space-time causal structures from the point of view of quantum information theory. In our approach, the causal constrains of a space-time determines the possible deterministic transformations between states of quantum systems called quantum causal probes. As a result, we demonstrate how well-known processes with indefinite causal order and indefinite time direction emerge from the formalism.

QI 2.8 Mon 12:45 B302

Bohmian Trajectories of Quantum Walks — •Florian Huber[1,2,3], Carlotta Versmold[1,2,3], Jan Dziewior[1,2,3], Lukas Knips[1,2,3], Eric Meyer[4], Harald Weinfurter[1,2,3], Alexander Szameit[4], and Jasmin Meinecke[1,2,3] — [1]Department für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [4]Institute of Physics, University of Rostock, Germany

Quantum walks are the quantum mechanical analogue of classical random walks. While in classical mechanics each particle follows a definite trajectory, in standard quantum mechanics (QM) no such description of the coherent propagation of the quantum walker is possible. However, certain interpretations of QM, as for example Bohmian mechanics, a non-local hidden variable theory, attribute definite positions and momenta to particles and therefore allow to visualize particle trajectories.

For photons these Bohmian trajectories correspond to energy flow lines given by the Poynting vector in classical electrodynamics and can be reconstructed from weak measurements. We report on the simulation and first measurement results of such energy flow lines of a quantum walk, realized in an integrated waveguide array written into fused silica substrate. By analyzing different time steps of the quantum walk evolution we are able to reconstruct the trajectories giving information about the energy flow in quantum walk structures.

QI 3: Quantum Machine Learning

Time: Monday 11:00–13:00 Location: B305

Invited Talk QI 3.1 Mon 11:00 B305

Characterising quantum device variability with machine learning — •Natalia Ares — University of Oxford

Machine learning is proving to be essential in the tuning and characterization of quantum devices. The search for operation conditions, which often requires navigating large and complex parameter spaces, can now be fully automated, with performances superior to those achieved by human experts. Now these machine learning approaches are not only enabling scalability by automating qubit control, but also by providing us with unprecedented insight into quantum device variability.

We can use machine learning algorithms for automatic tuning across different semiconductor platforms. This demonstrates not only the robustness of these algorithms against the differences in the characteristics of the material system and device architecture, but that they can provide a tool for their comparison and analysis. I will show that by using a physics-aware machine learning algorithm we are able to infer the disorder potential affecting the operation of quantum dot devices, revealing a hidden characteristic of such devices, and thus narrowing the gap between simulation and reality.

QI 3.2 Mon 11:30 B305

The application of quantum neural networks in function approximation — •David Kreplin and Marco Roth — Fraunhofer IPA, Nobelstraße 12, 70569 Stuttgart, Deutschland

Approximating functions by parameterized quantum circuits is a promising application for quantum computing, since the repetitive encoding of the input data can result in an exponentially growing complexity of the function. In the literature, this approach is often described as Quantum Neural Networks (QNNs), since it can be similarly utilized as classical artificial neural networks.

In this talk, we show how an efficient and general function approximation can be realized by a QNN. We discuss the construction, training, and the application of the QNN with the example of solving a differential equation based model of a hydrogen electrolyzer and benchmark the results against classical neural networks.

A particular focus in this talk will be on the unavoidable noise that results from the finite sampling of the quantum state. This so-called shot noise strongly degrades the training process and yields a noisy outcome of the QNN. We discuss how that shot noise can be strongly reduced during the training of the QNN by an additional regularization term. This not only reduces the noise in the final function but also simplifies the training process on shot based simulators or real devices. Finally, we present results from the real quantum computing hardware and we reflect on the obstacles that we currently face in training such QNNs on the real backends.

QI 3.3 Mon 11:45 B305

Parameterized quantum circuits for reinforcement learning of classical rare dynamics — Alissa Wilms[1,2], •Laura Ohff[2,3], Andrea Skolik[4,5], David A. Reiss[1], Sumeet Khatri[1], and Jens Eisert[1,6,7] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [2]Porsche Digital GmbH, Ludwigsburg, Germany — [3]Otto-Friedrich Universität Bamberg, Bamberg, Germany — [4]Leiden University, Leiden, The Netherlands — [5]Volkswagen Data:Lab, Munich, Germany — [6]Fraunhofer Heinrich Hertz Institute, Berlin, Germany — [7]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

In the study of non-equilibrium or industrial systems, rare events are crucial for understanding the systems' behavior. Since they are atypical, one requires specific methods for sampling and generating rare event statistics in an automated and statistically meaningful way. We propose two quantum reinforcement learning (QRL) approaches to study rare dynamics of time-dependent systems and investigate their benefits over classical approaches based on neural networks. We investigate how architectural choices influence the successful learning by QRL agents and demonstrate that a QRL agent is capable of learning the rare dynamics of a random walker with using just a single qubit. Furthermore, we are able to numerically demonstrate an improved environment exploration during learning and a better performance in coping with environment scaling by the quantum agents in comparison to their classical counterparts.

QI 3.4 Mon 12:00 B305

Optimal storage capacity of quantum Hopfield neural networks — •Lukas Bödeker[1,2], Eliana Fiorelli[1,2,3], and Markus Müller[1,2] — [1]Institute for Theoretical Nanoelectronics (PGI-2), Forschungszentrum Jülich, 52428 Jülich, Germany — [2]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [3]Instituto de Fisica Interdisciplinar y Sistemas Complejos (IFISC), CSIC UIB Campus, Palma de Mallorca, E-07122, Spain

Quantum neural networks form one pillar of the emergent field of quantum machine learning. Here, quantum generalisations of classical networks realizing associative memories - capable of retrieving patterns, or memories, from corrupted initial states - have been proposed. It is a challenging open problem to analyze quantum associative memories with an extensive number of patterns, and to determine the maximal number of patterns the quantum networks can reliably store, i.e. their storage capacity. In this work, we propose and explore a general method for evaluating the maximal storage capacity of quantum neural network models. As an example, we apply our method to an open-system quantum associative memory formed of interacting spin-1/2 particles realizing coupled artificial neurons. The system undergoes a Markovian time evolution resulting from a dissipative retrieval dynamics that competes with a coherent quantum dynamics. We map out the non-equilibrium phase diagram and study the effect of temperature and Hamiltonian dynamics on the storage capacity. Our method opens an avenue for a systematic characterization of the storage capacity of quantum associative memories.

QI 3.5 Mon 12:15 B305

Quantum kernel methods for regression — •Jan Schnabel — Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA, Center for Cyber Cognitive Intelligence (CCI), Stuttgart, Germany

It was shown in Refs. [1,2] that encoding data into a quantum state and interpreting the respective expectation value when measuring w.r.t. an observable as machine learning model, links quantum computing to the rich framework of classical kernel theory. Hence, these theoretical tools can now be used to understand quantum models. Here, the inherent structure of quantum kernel methods is particularly suited for NISQ applications. As a result, these facts caused constantly growing research activities in this field, where little attention has been hitherto paid to quantum kernel regression problems.

In this talk, I briefly introduce the core theoretical concepts of different approaches for computing quantum kernels before discussing associated challenges. The latter includes the role of classical data pre-processing and selection, data redundancies as well as the design of quantum feature maps. These aspects are discussed based on project-specific use cases from hydrogen production research. Beyond that, I attempt to provide a systematic comparison of different quantum kernel regression approaches and show results from real backend runs. This also incorporates demonstrating effects of proper error mitigation techniques.

[1] M. Schuld and N. Killoran. Phys. Rev. Lett. 122, 040504 (2019)
[2] M. Schuld, arXiv:2101.11020v2 (2021)

QI 3.6 Mon 12:30 B305

Renormalisation through the lens of QCNNs — •Nathan A. McMahon, Petr Zapletal, and Michael J. Hartmann — Friedrich-Alexander-Universität Erlangen- Nürnberg

The cluster-Ising model is an example of a quantum model with a symmetry protected topological (SPT) phase. For this model, the efficiency of performing phase recognition has recently been improved over measuring string order parameter (SOP) by the use of a particular quantum convolutional neural network (QCNN), which was motivated by renormalisation theory.

Unlike most neural networks, the function of the QCNN used here is relatively straightforward to explain. First, each layer of the QCNN performs a process analogous to both renormalisation/quantum error correction. Second, the remainder of the circuit simply determines if we are in the ground state of a stabiliser Hamiltonian. If the energy is sufficiently low we consider the input state to be in the target phase.

This QCNN also has a second feature, it is exactly equivalent to a constant depth quantum circuit + post-processing. Beyond just providing a cheaper circuit, this also points to the generalisation of phase recognising QCNNs beyond the cluster-Ising model. Combining these with the fidelity view of quantum phases, I will discuss the potential of QCNNs as a quantum information theory construction of renormalisation.

QI 3.7 Mon 12:45 B305

Quantum Gaussian Processes for Bayesian Optimization — •Frederic Rapp and Marco Roth — Fraunhofer IPA, Stuttgart 70569, Nobelstrasse 12

An important aspect of machine learning is finding the best possible hyperparameters for a given model. Bayesian optimization is one often used algorithm when tackling this task. It requires a surrogate model where Gaussian processes can be used. Gaussian processes are a method based on the evaluation of kernel matrices that serve as covariance functions. These matrices can be evaluated using a quantum computer by encoding the data into the quantum Hilbert space. We study Gaussian processes using quantum kernels based on parameterized quantum circuits, and their application to regression tasks, as well as their usage as a surrogate model for Bayesian optimization. We show that the method can solve a regression of a one-dimensional function under the influence of different quantum computing noise sources. We discuss the important aspects of the model and provide an example of the optimization of the method when solving a multi-dimensional regression task. Finally, we perform a hyperparameter tuning using Bayesian optimization based on quantum Gaussian process regression. We show that the quantum version of the algorithm is able to find suitable hyperparameter settings of a given problem that are comparable to applying the classical counterpart and even better than using a random search based algorithm.

QI 4: Quantum Computing and Simulation (joint session Q/QI)

Time: Monday 11:00–13:00 Location: E214

See Q 3 for details of this session.

QI 5: Superconducting Qubits and Hybrid Systems

Time: Monday 11:00–12:30 Location: F428

Invited Talk QI 5.1 Mon 11:00 F428

Building Superconducting Quantum Hardware towards Error-Corrected Quantum Computing — •Christopher Eichler — Department of Physics, FAU Erlangen, Germany

Quantum Computers will ultimately rely on near-perfect logical gates, implemented while correcting errors at the physical level. The need for developing quantum hardware optimized for performing fast, repeatable, and high-fidelity syndrome measurements in quantum error-correcting codes such as the surface code therefore becomes increasingly important. In my talk, I will present advances in performing qubit readout and two-qubit gates in multi-qubit superconducting quantum processors, which enabled the recent experimental demonstration of repeated quantum error correction in surfaces codes. I will show how quantum processors optimized for quantum error correction can also serve as a testbed to explore noisy intermediate-scale quantum algorithms. The talk will conclude with a discussion about open challenges and opportunities to advance the speed and fidelity of syndrome detection in scalable device architectures by exploiting tunable coupling elements.

QI 5.2 Mon 11:30 F428

Towards High-Fidelity Fluxonium Quantum Processors — •Florian Wallner[1,2], Johannes Schirk[1,2], Ivan Tsitsilin[1,2], Christian Schneider[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

To solve real-world problems on error-corrected quantum computers it is estimated that multiple hundreds to thousands of physical qubits have to be combined to build one logical qubit. This results in an impractical large overhead in the number of qubits and demands new types of qubits with orders of magnitude improvements in performance.

Here, we report on our recent advances to build superconducting fluxonium qubits that offer distinct advantages compared to the wide-spread transmons-type qubits. We show high coherence times and fast high-fidelity single qubit gates, realized through the flux bias line, which significantly reduces the control line overhead associated with flux qubits. Furthermore, we demonstrate a dispersive readout with assignment fidelity greater than 96%. Since these qubits have low transition frequencies a significant thermal population needs to be removed at the start of each experiment. We achieve this by employing an unconditional active reset and a conditional real-time feedback-assisted reset that can later enable dynamical circuits. In addition, we provide an outlook on our efforts to build multi-qubit devices and multi-qubit gates.

QI 5.3 Mon 11:45 F428

High-impedance resonators based on granular aluminum — •Mahya Khorramshahi[1], Martin Spiecker[1], Patrick Paluch[2], Thomas Reisinger[1], and Ioan Pop[1] — [1]Institute for Quantum Materials and Technology, Karlsruher Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [2]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Superconductors with characteristic impedance larger than the resistance quantum are a valuable resource in superconducting circuits. They enable the design of protected qubits such as Fluxoniums or 0-pi qubits and can improve the coupling to small-dipole-moment objects, which may be useful for interfacing with spin-qubits, donor spins, etc. Here we present compact resonators in the lower GHz regime with a high characteristic impedance given by a high-kinetic-inductance material, namely granular aluminum, with spurious modes above 10GHz. We fabricated the resonators with an electron-beam lithography lift-off process, and we coupled them using a 50 Ohm coplanar waveguide architecture. Measurements performed in a dilution cryostat reveal that the resonators maintain high-quality factors in the single photon regime, a valuable resource for future quantum hardware implementations

QI 5.4 Mon 12:00 F428

Rare earth ions in molecular crystals for quantum information application — •Jannis Hessenauer[1], Evgenij Vasilenko[1], Weizhe Li[1], Christina Ioannou[1], Kumar Senthil Kuppusamy[2], Mario Ruben[2], and David Hunger[1,2] — [1]Karlsruher Institut für Technologie (KIT), Physikalisches Institut — [2]Karlsruher Institut für Technologie (KIT), Institut für Quantenmaterialen

Rare-earth ions in solid state hosts are promising candidates for optically addressable spin qubits, owing to their long optical and spin coherence times in the solid state [1]. Recently, rare earth ions in organic molecules have demonstrated outstanding coherence properties, while also promising a large parameter space for optimization by chemically engineering of the host molecule [2]. We characterize the optical properties of novel rare earth ion based molecular materials at low temperature using techniques such as photoluminescence excitation spectroscopy, absorption spectroscopy and spectral hole burning. We observe narrow homogenous and inhomogeneous linewidths and long-lived spin polarization, confirming the great potential of molecular rare earth materials for quantum information applications.

[1] Kinos, Adam, et al. ”Roadmap for rare-earth quantum computing.” arXiv preprint arXiv:2103.15743 (2021).
[2] Serrano, Diana, et al. ”Ultra-narrow optical linewidths in rare-earth molecular crystals.” Nature 603.7900 (2022): 241-246.

QI 5.5 Mon 12:15 F428

Schrödinger cat states of a 16-microgram mechanical oscillator — •Marius Bild[1,2], Matteo Fadel[1,2], Yu Yang[1,2], Uwe von Lüpke[1,2], Phillip Martin[1,2], Alessandro Bruno[1,2], and Yiwen Chu[1,2] — [1]Department of Physics, ETH Zürich, 8093 Zürich, Switzerland — [2]Quantum Center, ETH Zürich, 8093 Zürich, Switzerland

While the principle of superposition in quantum physics is routinely validated for microscopic systems, it is still unclear why we do not observe macroscopic objects to be in superpositions of states that can be distinguished by some classical property. I will present our experiments, that harness the resonant Jaynes-Cummings interaction between a high overtone resonator mode of a bulk acoustic wave resonator and a superconducting qubit, to demonstrate the preparation of Schrödinger cat states of motion. In such a state, the constituent atoms oscillate in a superposition of two opposite phases with an effective oscillating mass of 16μg. Making use of the circuit quantum acoustodynamics toolbox we have developed, we furthermore show control over amplitudes and phases of the created Schrödinger cat states, and investigate their decoherence dynamics by observing the disappearance of Wigner negativities. Our results can find applications in continuous variable quantum information processing and in fundamental investigations of quantum mechanics in massive systems.

QI 6: Poster I (joint session QI/Q)

Time: Monday 16:30–19:00 Location: Empore Lichthof

QI 6.1 Mon 16:30 Empore Lichthof

Towards multi-photon tests of hyper-complex quantum mechanics — •Ece Ipek Saruhan, Marc-Oliver Pleinert, and Joachim von Zanthier — Quantum Optics and Quantum Information, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen, Germany

Axioms of quantum mechanics do not tell much about the structure of the Hilbert space such as, e.g., the number system, which could be real, complex, or hyper-complex. Probabilities are amplitude squares of wave functions, which are defined on a complex space in general. Can one consider the result of a dot product to be a hyper-complex number? Asher Peres proposed a way to test hyper-complex quantum mechanics with a single particle scattered from 3 different scatterers [1]. We adapt this test to a 3-slit interference setup and extend it to multi-slit and multi-particle scenarios. We construct Peres-like functions to see if the multitude of paths and particles show different sensitivity to, still hypothetical, hyper-complex phases.

[1] A. Peres, Phys. Rev. Lett. 42, 683 (1979).

QI 6.2 Mon 16:30 Empore Lichthof

An analysis on the almost quantum correlation set — •Vitor Sena and Rafael Rabelo — University of Campinas, Brazil

A good way to investigate the foundations of quantum theory is through the correlations it allows between results of measurements performed on spatially separated systems. These correlations may present some known nonclassical phenomena such as Bell nonlocality, but, interestingly, the set of nonlocal correlations allowed by quantum theory is quite specific and, in some sense, limited. There is a set of correlations slightly larger than this, known as the almost quantum correlations set, which presents similarities and differences with the set of quantum correlations. In this work, we study the relationship between these sets by numerically estimating their relative volumes in different scenarios. In doing so, we seek to understand the kind of correlations allowed by each one and how their differences can be shown quantitatively.

QI 6.3 Mon 16:30 Empore Lichthof

Reducing Bias in Quantum State Tomography — •Yien Liang[1,2] and Matthias Kleinmann[1] — [1]Universität Siegen, Walter-Flex-Straße 3, D-57068 Siegen, Germany — [2]Peking University, Beijing 100871, China

Quantum state tomography aims to estimate the quantum state of a system using quantum measurements. It is well known that such an estimate cannot be perfect, that is, the procedure may yield an operator with negative eigenvalues or the mean reconstructed state deviates from true state. This is the dilemma of having a nonphysical reconstruction or a biased estimator. It also has been shown that any unbiased estimator has to yield rather large negative eigenvalues. We ask the complementary question: What is the minimum bias of an estimator, even if one is willing to accept an increased variance of the estimator? We show that the bias can indeed be improved by orders of magnitude, but at the price of being rather pathological. We furthermore discuss the behavior of estimators with low bias compared to canonical estimators for large sample sizes and many qubits.

QI 6.4 Mon 16:30 Empore Lichthof

Witnessing non-Markovianity in quantum Brownian motion by quasi-probability distributions in phase-space — •Irene Ada Picatoste Fernández[1], Moritz Ferdinand Richter[1], and Heinz-Peter Breuer[1,2] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The theory of open quantum systems aims to describe the dynamics of a quantum system coupled to an environment using a limited number of degrees of freedom. The Caldeira-Leggett model of quantum Brownian motion represents a physically interesting example of such systems showing strong memory effects, i.e., non-Markovian dynamics, in certain parameter regimes. Recently, a witness for non-Markovianity has been developed which is based on the Kolmogorov distance between quasi-probability distributions of two states [1]. Additionally, for Gaussian dynamics, a new measure of non-Markovianity can be defined using exclusively the Glauber-Sudarshan P-function. Here, we apply this witness to the Caldeira-Leggett model and show the behaviour of the non-Markovianity measure in different scenarios, while studying where the witness works best.

[1] M. F. Richter, R. Wiedenmann and H.-P. Breuer, arXiv:2210.06058 [quant-ph].

QI 6.5 Mon 16:30 Empore Lichthof

Photon-number resolved model for multimode quantum opti- cal setups based on Gaussian states — •Florian Niederschuh, Erik Fitzke, and Thomas Walther — Institute for Applied Physics, TU Darmstadt, Darmstadt, Germany

Experiments in quantum optics and photonic quantum information protocols regularly employ multimode states with low photon numbers. While early setups used single photon avalanche diodes, recent advances aim at the realization of photon-number resolving detectors. Consequently, mathematical models for the prediction of photon-number resolved detection probabilities may provide valuable insight and aid in experimental design. Here, a formalism for simulating the photon statistics of Gaussian states is presented. It is based on the construction of suitable generating functions, which are further processed by software for automatic differentiation. This allows the extraction of various statistical quantities, e.g. the photon number distribution, cumulative probabilities and statistical moments. The model considers an array of experimental imperfections and agrees with recent measurement results of an entanglement-based phase-time coding setup for quantum key distribution [Fitzke et al. (2022). PRX Quantum, 3, 020341].

QI 6.6 Mon 16:30 Empore Lichthof

Entanglement classification schemes : comparison between Majorana representation and algebraic geometry approaches — •Tom Weelen[1], Naïm Zénaïdi[2], Pierre Mathonet[2], and Thierry Bastin[1] — [1]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, BE-4000 Liège, Belgium — [2]Département de Mathématique, Université de Liège, BE-4000 Liège, Belgium

Quantum entanglement can be of different kinds [1] and classifying the quantum states in this respect may represent a difficult challenge in general multipartite systems. In particular, entanglement classes that are inequivalent under stochastic local operations and classical communication (SLOCC) are of fundamental importance. For N-qubit systems with $N > 3$, there is an infinity of such SLOCC entanglement classes [1] and it makes sense to gather them into a finite number of families, as was done for symmetric states in Refs. [2,3] using two distinct approaches (Majorana representation and algebraic geometry tools, respectively). Here, we compare these two structures and identify whether they can be embedded into one another or not. To do so, we formulate the structure of Ref. [2] in terms of k-secants and k-tangents (k a positive integer) of the Veronese variety [3] and we prove that only the k-tangent structuration provides a coherent structure compatible with that of Ref. [3].

[1] W. Dür et al., Phys. Rev. A **62**, 062314 (2000). [2] T. Bastin et al., Phys. Rev. Lett. **103**, 070503 (2009). [3] M. Sanz et al., J. Phys. A: Math. Theor. **50**, 195303 (2017).

QI 6.7 Mon 16:30 Empore Lichthof

What channels can be implemented without a reference frame? — •Fynn Otto — University of Siegen, Germany

Quantum reference frames are needed for communication tasks for which the method of information encoding matters. In contrast to – for example – sending integers, reference frames are needed for communicating, e.g. quantum phases or directional information. Even if a classical communication link between two parties is established, it is not possible to send a *direction in space*.

Lacking a reference frame limits the set of operations that can be performed deterministically. Changing reference frames is equivalent to the passive evolution of a state under the unitary operator $U(g)$, representing the transformation g. The transformations between reference frames form a group G, and allowed frame-agnostic channels turn out to be G-covariant: the channel $\mathscr{E}$ must commute with every $U(g)$.

Here we investigate the reachable states for two important cases: lacking a phase reference (corresponding to the group $G = U(1)$) and lacking a Cartesian frame alignment ($G = SU(2)$). Examples of G-covariant state transformation are provided along with possible classification and interpretation of the reachability structure.

QI 6.8 Mon 16:30 Empore Lichthof

Leveraging noisy physical observables with machine learning. — •Adisorn Panasawatwong, Ulf Saalman, and Jan-Michael Rost — Max-Planck-Institute for the Physics of Complex Systems

A noisy light pulse containing many frequencies leads to deterministic electron dynamics in the illuminated target, whose response will also look noisy. At first glance, it cannot be distinguished from a random signal which results from fully chaotic dynamics. While the latter contains little information, the former contains valuable information about the target system, even more than its (linear) response to a Fourier-limited single-frequency pulse.

We are developing a machine learning-based approach which can distinguish the two kinds of noisy signals according to their actual information content: their complexity. Without using entropy, we show emergence of information by interpreting the result from auto-encoder.

Knowing the degree of complexity in the signal enables us to develop networks tailored to extract the amount of information about the target which is contained in the noisy observable due to its complexity.

QI 6.9 Mon 16:30 Empore Lichthof

Entanglement in free fermion systems — Lexin Ding[1,2], •Gesa Dünnweber[1,2], and Christian Schilling[1,2] — [1]Faculty of Physics, Arnold Sommerfeld Centre for Theoretical Physics (ASC), Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Entanglement is becoming an increasingly important resource for the realisation of quantum information tasks. Several measures of mode entanglement have been proposed for fermionic systems.

We consider a spinful free fermion chain under nearest neighbour hopping and determine an analytic measure of the resulting site-site entanglement. Including in particular the restrictions imposed by parity or particle number superselection rules, we study how various factors affect the accessible entanglement. This approach is extended to a model that includes an additional hopping term where we investigate the evolution of entanglement across a Lifshitz-type transition. Relating orbital entanglement to the concept of locality within a molecule, we present numerical results for a hydrogen chain.

Finally, we are interested in protocols for extracting entanglement from fermionic systems such as entanglement swapping, where superselection rules demand modifications to the established protocols for qubits.

QI 6.10 Mon 16:30 Empore Lichthof

Quantum Key Distribution from Bound Entanglement — •Zeynab Tavakoli[1] and Gláucia Murta[2] — [1]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany — [2]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

Quantum key distribution (QKD) aims to secure communication and establish a secret key between two honest parties. A secret key is a string of independent and random bits known to both parties. Key distillation in QKD is related to entanglement distillation; by distilling a maximally entangled state, one can get the key by measuring it. The belief was that achieving security is equivalent to distilling maximally entangled states. However, Authors of [Phys.Rev.Lett.80,5239,(2005)] show bound entangled states are usable to obtain key. Bound entangled states are quantum states that no maximally entangled states can be distilled from them using LOCC. Bound entangled states used in QKD have entanglement, which protects correlations from the environment. However, the entanglement is so twisted that it cannot be brought into a maximally entangled state. In this work, we studied known examples of bound entangled states useful for QKD. In particular, we investigate the noise tolerance of the corresponding QKD protocol, construct new bound entangled states around the original examples, and investigate their achievable key rates. Finally, we investigate if bound entangled states can be used in a simple QKD protocol where a single copy of the state is distributed and measured each round.

QI 6.11 Mon 16:30 Empore Lichthof

Randomness Certification for Multipartite Arbitrary Dimensional Systems — Yu Xiang[1,2], •Yi Li[1], and Qiongyi He[1,2,3] — [1]State Key Laboratory for Mesoscopic Physics, School of Physics, Frontiers Science Center for Nano-optoelectronics, and Collaborative Innovation Center of Quantum Matter, Peking University, Beijing 100871, China — [2]Collaborative Innovation Center of Extreme Optics, Shanxi University, Taiyuan, Shanxi 030006, China — [3]Peking University Yangtze Delta Institute of Optoelectronics, Nantong, Jiangsu 226010, China

We first present a method to certify the randomness generated in multipartite arbitrary dimensional systems, closely to the actual situation where some of the untrusted sides are measured locally. The proposed method also provides a hierarchy of upper and lower bounds of randomness with different assumptions. Comparing with the bipartite scenario, our result shows more randomness can be certified in this asymmetric network. Surprisingly, for some systems, we find that there exists nonzero certified randomness on the untrusted parties together, even though no randomness can be induced in either mode individually, which implies randomness in the multipartite network can be used for some security tasks in the future. The ease of our method is also demonstrated by adopting some existing experimental data. Finally, we prove that multipartite steering is necessary for generating randomness in the asymmetric network.

QI 6.12 Mon 16:30 Empore Lichthof

Markovian master equations beyond the adiabatic and inertial limit — •Josias Langbehn[1], Roie Dann[2], Raphael Menu[3], Giovanna Morigi[3], Ronnie Kosloff[2], and Christiane Koch[1] — [1]Freie Universität Berlin, Berlin — [2]Institute of Chemistry, Hebrew University, Jerusalem — [3]Universität des Saarlandes, Saarbrücken

Markovian master equations in Gorini-Kossakowski-Sudarshan-Lindblad (GKLS) form can accurately describe the dynamics of many open quantum systems ranging from optical to solid state systems. Adding a drive to the system complicates the derivation of any such master equation. The Markovian framework has been extended to drives in the adiabatic regime [1] and beyond that to inertial drives within the "non-adiabatic master equation" (NAME) [2]. The aim of this work is to extend this framework to drives that go even beyond the inertial limit by introducing a numerical scheme for finding an eigenoperator basis. In principle this allows for arbitrary drives, going as far as Markovian master equations in GKLS form remain valid. Moreover, the numerical scheme allows treating situations where no inertial solution can be found analytically. This opens the door for optimal control tasks where the time-dependency of the optimal drives may not be adiabatic/ inertial. We observe significant deviations between the NAME and the adiabatic/ inertial limit in multiple exemplary systems considered.

[1] Albash, T., Boixo, S., Lidar, D. A. & Zanardi, P. New J. Phys. 14, 123016 (2012). [2] Dann, R., Levy, A. & Kosloff, R. Phys. Rev. A 98, 052129 (2018).

QI 6.13 Mon 16:30 Empore Lichthof

Mimicking non-Markovian dynamics using the stochastic surrogate Hamiltonian — •Jonas Fischer and Christiane Koch — Freie Universität Berlin

Some control tasks, like qubit reset, demand interaction between the system and environment. In order to perform these tasks quickly, it is beneficial if this coupling is as strong as possible. Typically, this leads to non-Markovian dynamics, for which there is no unified propagation method so far.

One possible candidate is the surrogate Hamiltonian. The real environment is substituted by a collection of two-level systems that capture the influence of the real environment on the system. This allows for the propagation of the full Hilbert space, allowing for the description of non-Markovian dynamics.

Due to the truncation of the Hilbert-space, this method is limited to short timescales. At a certain point in time, the environmental modes will saturate and recurrences in the system dynamics will occur. The stochastic surrogate Hamiltonian is aiming to resolve this issue by randomly resetting the environmental modes into a thermal state. These resets should be performed in such a way that the recurrences get suppressed, but at the same time, they should destroy as few correlations as possible. We present a reset method that reproduces the correct reduced density matrices for both the reset mode and the other environmental modes.

QI 6.14 Mon 16:30 Empore Lichthof

Quantum transport in noisy networks of coupled harmonic oscillators — •Emma King, Raphael Menu, and Giovanna Morigi — Theoretische Physik, Universitat des Saarlandes, D-66123 Saarbruecken, Germany

In recent years rapid progress has been made towards the realisation of scalable quantum computers. While devices with an increasing number of qubits are being realised, the present size does not yet allow for the efficient implementation of error-correction schemes. This highlights the importance of understanding the role of an environment on the target quantum coherent dynamics. In this work we address the question as to which properties of an external environment are detrimental, and, in contrast, which properties can be used as resources for quantum transport. For this purpose we consider two chains of coupled harmonic oscillators with long range interactions that decay in a power law fashion. The one chain acts as the system while the other is the environment. In this setting we derive a quantum master equation starting from the Liouville-von Neumann equation and identify the requirements on the environment for which the master equation has the Lindblad form. We then analyse transport in the chain as a function of the environment characteristics, identifying the regime(s) in which it leads to faster propagation of information along the chain.

QI 6.15 Mon 16:30 Empore Lichthof

Engineering a heat engine purely driven by quantum coherence — •Stefan Aimet — Imperial College London, London, United Kingdom — FU Berlin, Berlin, Germany

The question of whether quantum coherence is a resource beneficial or detrimental to the performance of quantum heat engines has been thoroughly studied but remains undecided. To isolate the contribution of coherence, we analyse the performance of a purely coherence-driven quantum heat engine, a device that does not include any heat flow during the thermodynamic cycle. The engine is powered by the coherence of a multi-qubit system, where each qubit is charged via interaction with a coherence bath using the Jaynes-Cummings model. We demonstrate that optimal coherence charging and hence extractable work is achieved when the coherence bath has an intermediate degree of coherence. In our model, the exctractable work is maximised when four copies of the charged qubits are used. Meanwhile, the efficiency of the engine, given by the extractable work per input coherence flow, is optimised by avoiding coherence being stored in the system-bath correlations that is inaccessible to work. We numerically find that the highest efficiency is obtained for slightly lower temperatures and weaker system-bath coupling than those for optimal coherence charging.

QI 6.16 Mon 16:30 Empore Lichthof

Design of a 4-party active base choice phase-coding quantum key distribution multi-user hub — •Adrian Klute, Maximilian Tippmann, Lucas Bialowons, Erik Fitzke, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

In the developing field of secure quantum communication, several quantum key distribution (QKD) systems have been tested with various protocols. However, building scalable QKD systems with more than 2 parties is a challenging task. We recently presented a 4-party star-shaped quantum hub system, which is based on time-bin entanglement. The crucial part in this setup is the precise building of interferometers. Precise building methods with sufficient reliability are needed to exchange keys with low quantum bit error rate between all user pairs of the hub. Not only the building method but also a suitable design choice of the interferometer can reduce uncertainties in the building process. In that sense we are discussing the technological challenges of two known interferometer designs for an active phase-coding protocol, a Sagnac-Michelson and a Sagnac-Mach-Zehnder configuration. We present first results to assess the success of the building method that we used.

QI 6.17 Mon 16:30 Empore Lichthof

Towards a city-wide quantum key distribution network with a multi-user phase-time coding quantum key hub — •Maximilian Tippmann, Erik Fitzke, Till Dolejsky, Florian Niederschuh, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

Quantum key distribution (QKD) paves a way to make today's IT-infrastructure resilient against future attacks e.g. from quantum computers. Various QKD protocols and setups have been tested over the last decades. However, most experiments focus on two-user systems, thus not allowing an easy scaling to multiple users. Here, we report on a quantum key hub implementing the phase-time protocol with a central untrusted node for simultaneous pairwise key exchange, tested with four users, but readily scalable to more than 100 users. The central untrusted node consists of an entangled photon pair source, and provides high-flexibility, allowing plug-and-play reconfiguration of the connected parties. Furthermore, the setup has been tested with real-world deployed fiber demonstrating the practicability of our approach. Going towards a city-wide deployment, we look into setup specific issues, including post-processing and alignment of the setup, arising from the distribution of the communicating parties to a city-wide scale.

QI 6.18 Mon 16:30 Empore Lichthof

System Components for Single-Photon Quantum Key Distribution in the Telecom C-band — •Timm Gao, Mareike Lach, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

We report on the evaluation of system components for single-photon based quantum communication in the telecom C-band. We evaluate the performance of different hardware components for quantum key distribution. Special emphasis lies here on the receiver module, where free-space and fiber-based approaches are comparatively discussed.

QI 6.19 Mon 16:30 Empore Lichthof

Night Sky Background Measurement for Quantum Key Distribution — •Rengaraj Govindaraj[1,2], Michael Auer[1,2,3], Adomas Baliuka[1,2], Peter Freiwang[1,2], Lukas knips[1,2,4], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799, München, Germany — [2]Munich Center for Quantum Science and Technology, 80799, München, Germany — [3]Universität der Bundeswehr, 85577 Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Free-space satellite-to-ground quantum key distribution (QKD) enables two authenticated parties - potentially separated by global distances - to exchange a secret key that can be used for symmetric cryptography. However, the performance of free-space QKD crucially depends on the quantum bit error ratio (QBER) and hence on the contributions of background light sources such as light from natural sources as the sun or stars as well as from artificial light sources. As those noise contributions vary with time of day, season, weather and location, their study is important for estimating future QKD missions. We here present our experimental method to map the night sky background in terms of its brightness in the spectral bands around 850nm and 1550nm and discuss the implications for satellite-based QKD.

QI 6.20 Mon 16:30 Empore Lichthof

Designing versatile and performant DM-CV QKD systems for the QuNET initiative — •Stefan Richter[1,2], Ömer Bayraktar[1,2], Kevin Jaksch[1,2], Bastian Hacker[1,2], Imran Khan[1,2,5], Emanuel Eichhammer[1,5], Emmeran Sollner[1,5], Twesh Upadhyaya[3], Jie Lin[3], Norbert Lütkenhaus[3], Florian Kanitschar[4], Stefan Petscharnig[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Chair of Optical Quantum Technologies, Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany — [2]Quantum Information Processing Group, MPI for the Science of Light, Erlangen, Germany — [3]Institute for Quantum Computing, Dept. of Physics and Astronomy, University of Waterloo, Canada — [4]Security & Communication Technologies Unit, Austrian Institute of Technology, Vienna, Austria — [5]now with KEEQuant GmbH, Fürth, Germany

Continuous-variable quantum key distribution (CV-QKD) is a key technology for guarding critical communication links against the rapidly growing threat of large-scale quantum computers. We present our progress in implementing a versatile and performant CV-QKD system designed for metropolitan fiber optical networks. Important performance indicators estimated during a public technology demonstration in August 2021 and recent improvements will be discussed. We also highlight special design aspects and challenges of the implementation, in particular with regard to stability and error correction requirements.

QI 6.21 Mon 16:30 Empore Lichthof

Night Sky Background Measurement for Quantum Key Distribution — •Rengaraj Govindaraj[1,2], Michael Auer[1,2,3], Adomas Baliuka[1,2], Peter Freiwang[1,2], Lukas Knips[1,2,4], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799, München, Germany — [2]Munich Center for Quantum Science and Technology, 80799, München, Germany — [3]Universität der Bundeswehr, 85577 Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Free-space satellite-to-ground quantum key distribution (QKD) enables two authenticated parties - potentially separated by global distances - to exchange a secret key that can be used for symmetric cryptography. However, the performance of free-space QKD crucially depends on the quantum bit error ratio (QBER) and hence on the contributions of background light sources such as sun or stars as well as artificial light sources. As those noise contributions vary with time of day, season, weather and location, their study is important for planning the location and performance of ground station's future QKD missions. We here present our experimental method and device to map the night sky background in terms of its brightness in the spectral bands around 850nm and 1550nm and discuss the implications for satellite-based QKD.

QI 6.22 Mon 16:30 Empore Lichthof

Towards quantum communication over intercity optical fiber link — •Ali Hreibi, Ann-Kathrin Kniggendorf, Harald Schnatz, and Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

We report on the status of the PTB's work to establish a quantum communication test bed between Braunschweig and Hanover (the "Niedersachsen Quantum Link"). In this context, we present an overview of the quantum key distribution (QKD) system based on the BBM92 protocol set up at PTB and the test of quantum communication via optical fiber up to 90 km in length. The QKD system generates Polarization-entangled photon pairs using the nonlinear optical process of spontaneous parametric down-conversion, and transmits the entangled photon pairs (signal, and idler) to a local and a remote location through the optical fiber. Photons are detected on both sides and measurement data is processed by the system in order to generate a secure quantum encryption key. The Communications security relies on the laws of quantum mechanics and the noncloning theorem which prevents a quantum state from being copied or measured without disturbing it.

QI 6.23 Mon 16:30 Empore Lichthof

The Ideal Wavelength for Daylight Free-Space Quantum Key Distribution — •Mostafa Abasifard[1], Chanaprom Cholsuk[1], Roberto G. Pousa[2], Anand Kumar[1], Ashkan Zand[1], Daniel K. L. Oi[2], and Tobias Vogl[1,3] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Computational Nonlinear and Quantum Optics, SUPA Department of Physics, University of Strathclyde, Glasgow G4 0NG, United Kingdom — [3]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany

Quantum key distribution (QKD) has matured from proof-of-principle demonstrations in the lab to commercial systems. Intercontinental quantum communication distances have been bridged with satellites. Satellite-based quantum links can only operate during the night, as the sunlight would otherwise saturate the detectors used to measure the quantum states. For high data rates and continuous availability, operation during daylight is desirable.

We model a satellite-to-ground quantum channel for the BB84 protocol in order to determine the optimal wavelength for daytime free-space QKD. We look at the 400 nm to 1700 nm wavelength range and find extractable secret bits per signal for several light sources. As expected, the Fraunhofer lines appear as peaks in the spectrum of the secure data rate. For the ideal wavelength, we also propose a true single photon source, based on a resonator coupled color center in hexagonal boron nitride.

QI 6.24 Mon 16:30 Empore Lichthof

Dynamic Polarization State Preparation for Single-Photon Quantum Cryptography — •Koray Kaymazlar, Tim Gao, Daniel Vajner, Lucas Rickert, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Quantum key distribution (QKD) systems using polarization encoding require fast modulation of the polarization states of single-photon pulses. Here, we present a setup for preparing the polarization of single photons dynamically. The system consists of electronics based on a field programmable gate array (FPGA) and a digital to analog converter (DAC) driving a free space electro optic modulator (EOM) with 500 MHz bandwidth. We characterize and optimize the performance of this setup in terms of extinction ratio and repetition rate and discuss its suitability for applications in QKD experiments.

QI 6.25 Mon 16:30 Empore Lichthof

Investigation of the phase-space distribution of the BPSK-encoded optical coherent signal from a geostationary satellite — •Hüseyin Vural[1], Conrad Rössler[1], Andrew Reeves[2], Bastian Hacker[1], Thomas Dirmeier[1], Karen Saucke[3], and Christoph Marquardt[1] — [1]Max-Planck Institut für die Physik des Lichts (MPL) — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) - Institut für Kommunikation und Navigation — [3]Tesat Spacecom

Coherent optical communication between a satellite and a terrestrial ground station can facilitate classical as well as quantum-limited communication. In a recent paper, we demonstrated quantum limited signals from a geostationary satellite in a homodyning measurement, that indicate the viability of long-distance quantum key distribution (QKD) and global secure communication. Here, we investigate the phase-space distribution of the BPSK-encoded coherent signal from the same satellite, however at an optical ground station in an urban area and by heterodyning the quantum signal with a free running commercial laser. Our results indicate that scalable solutions for quantum-limited signals may be in reach.

QI 6.26 Mon 16:30 Empore Lichthof

Single atoms in optical cavities as source for multiphoton graph states — •Leonardo Ruscio, Philip Thomas, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Generating multiphoton entangled states is an essential step for the development of quantum information protocols such as measurement based quantum computation. Thanks to their weakly interacting nature, entangled photons are in fact ideal qubit carriers. So far, the most successful source of entangled photons has been spontaneous parametric down conversion, where scaling up is dramatically limited by its intrinsically probabilistic nature. We experimentally demonstrate the feasibility of a single Rubidium atom in an optical cavity as an efficient source of multiphoton graph states [1]. We use the atom as a memory mediating the entanglement generation between the photons and we efficiently grow GHZ states of up to 14 photons and linear cluster states of up to 12 photons. With an overall efficiency of 43%, our experiment opens a way towards scalable measurement-based quantum computation and communication, where this scheme could be for example extended to two atoms in a cavity to generate higher-dimensional cluster states.

[1] P.Thomas et al., Nature 608, 677-681 (2022)

QI 6.27 Mon 16:30 Empore Lichthof

Driven Gaussian Quantum Walks — •Philip Held[1], Melanie Engelkemeier[1], Syamsundar De[1], Sonja Barkhofen[1], Jan Sperling[2], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany — [2]Paderborn University, Theoretical Quantum Science, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Quantum walks function as essential means to implement quantum simulators, allowing one to study complex and often directly inaccessible quantum processes in controllable systems. In this contribution, the new notion of a driven Gaussian quantum walk is presented. Here, instead of a unitary operation, a nonlinear map is used to describe the operation of the quantum walk in optical settings. Including nonlinear elements as core components, this type of quantum walk introduces quantumness of the dynamic itself, regardless of the input state. A parametric down-conversion is chosen as the nonlinear operation, introducing new walkers and squeezing during the evolution. To characterize nonlinear, quantum, and quantum-nonlinear effects following from this evolution, a full framework for driven Gaussian quantum walks is developed. In particular, the generation and amplification of highly multimode entanglement, squeezing, and other quantum effects are studied over the duration of the nonlinear walk.

QI 6.28 Mon 16:30 Empore Lichthof

Quantum Simulation of Biased Open System Dynamics — •Marcel Cech[1], Federico Carollo[1], and Igor Lesanovsky[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We present a protocol for the generation of rare quantum jump trajectories on a digital quantum simulator. Our approach allows to bias open system dynamics with regard to any, even non-linear, function, e.g. it can increase or decrease the likelihood of trajectories with specific emission patterns and correlation properties. We derive the dynamical map of the corresponding biased process. Moreover, we show how the biased open systems dynamics can be implemented on an IBM quantum processor. Using as an example an open two-level system we discuss challenges and current limitations of this approach.

QI 6.29 Mon 16:30 Empore Lichthof

Preparing ground states of the Fermi-Hubbard model with shallow quantum circuits — •Tobias Schmale[1], Bence Temesi[1], Hamed Saberi[1], and Hendrik Weimer[2,1] — [1]Institut für Theoretische Physik, Hannover, Germany — [2]Institut für Theoretische Physik, TU Berlin, Germany

The 2D Fermi-Hubbard model is a paradigmatic model in condensed matter physics, potentially holding the key to understanding high-temperature superconductivity. We turn to digital quantum simulations of the model, as classical simulation methods remain prohibitively challenging. We investigate a strategy for adiabatic preparation of the ground state by shallow quantum circuits running in constant time on a highly parallelized architecture. Additionally, we consider a simplified architecture consisting of a single computing register in a trapped-ion architecture based on ion shuttling, where we find that a single auxiliary qubit is sufficient to implement the mapping from fermions to qubits. We show that these architectures naturally allow for the realization of extensions to the Hubbard model such as next-nearest-neighbor hopping, which might be crucial to stabilize d-wave superconductivity.

QI 6.30 Mon 16:30 Empore Lichthof

Quantum Simulations: Endeavours with trapped ions in a 2D array and a Linear Paul trap — •Apurba Das, Deviprasath Palani, Florian Hasse, Maharshi Pran Bora, Lucas Eisenhart, Tobias Spanke, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Freiburg, Deutschland

Individual ions, trapped in a customised trap architecture offer one of the most promising platforms for quantum simulations[1]. In our lab, applying suitable local and global control fields on the trapped ions, we set up and tune increasingly complex quantum systems with a high level of control in a 2D array on a Surface electrode radio frequency trap and in a linear Paul trap. In our 2D array, we realize the Floquet-engineered coupling of adjacent sites through local manipulation of trapping potentials[2] and tuning of the system in real-time and interference of coherent states over large amplitudes[3]. Here, we also demonstrate the relocation of ions in a deterministic manner. In the Linear Paul Trap, we show the preparation of two ions in a squeezed state of motion featuring entanglement of the ions' motional degrees. This leads to the realization of an experimental analogue of the particle pair creation during cosmic inflation in the early universe[4]. In addition, we move towards the transfer of entanglement of motional degrees of freedom to internal degree of freedom.

[1] T. Schaetz et al., New J. Phs. 15, 085009 (2013)
[2] P. Kiefer et al., PRL 123, 213605 (2019)
[3] F. Hakelberg et al., PRL 123, 100504 (2019)
[4] M. Wittemer et al., PRL 123, 180502 (2019)

QI 6.31 Mon 16:30 Empore Lichthof

Programmable cooling on noisy quantum computers: Implementation and error analysis — •Imane El Achchi[1], Anne Matthies[1], Achim Rosch[1], Mark Rudner[2], and Erez Berg[3] — [1]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany — [2]University of Washington, Seattle, WA 98195-1560, US — [3]Weizmann Institute of Science, Rehovot, 76100, Israel

Recent advances in quantum computing provide a vast playground for the application of quantum algorithms on noisy intermediate-scale quantum devices. Here, we test the performance of the programmable adiabatic demagnetization protocol proposed in Ref. [1] on IBM's quantum devices. The cooling protocol prepares low-energy states for any gapped Hamiltonian independently of the system's initial state. Half the qubits simulate the system, and the other a bath in a strong Zeeman field, initialized in the polarized state. Entropy is transferred from the system to the bath by slowly decreasing the Zeeman field. Finally, the bath spins are measured and reset to the polarized state. The process is repeated throughout the protocol until a low-energy state of the system is reached. Cooling protocols are generally stable against low noise, making them a promising application for near-term quantum computers. We experimentally observe a cooling effect for the available small system size and limited gate depth on the IBM quantum device using quantum optimal control. Furthermore, we analytically analyze the dynamics of the cooling protocol to find a dark state of the corresponding quantum channel.

[1] arxiv: 2210.17256

QI 6.32 Mon 16:30 Empore Lichthof

Treating finite system-bath coupling using the hierarchy-of-pure-states approach — •Johann Assmus, Tobias Becker, and André Eckardt — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany

Open quantum system dynamics can be described by master equations for the system's reduced density matrix, however, the derivation of these equations often requires some assumptions like the Born-Markov-approximation. The hierarchy-of-pure-states approach is an alternative to master equations where the system is described by a stochastic ensemble of pure states and additional auxiliary states [1]. Since the dynamics of these pure states can be derived without any approximations, this approach is numerically exact. However, an approximation is made, by allowing for a finite number of auxiliary states. We compare the solutions of this method with the exact dynamics of a damped harmonic oscillator to examine its behaviour in regards to the number of hierarchies and other parameters.

[1] D. Süß, A. Eisfeld, W.T. Strunz, Phys. Rev. Lett. 113, 150403 (2014)

QI 6.33 Mon 16:30 Empore Lichthof

Quantisation and breakdown of topological transport in the Hubbard-Thouless pump — •Marius Gächter, Zijie Zhu, Anne-Sophie Walter, Konrad Viebahn, Stephan Roschinski, Joaquín Minguzzi, Kilian Sandholzer, and Tilman Esslinger — ETH, Zurich, Switzerland

Predicting the fate of topologically protected transport in the strongly correlated regime represents a central challenge within condensed matter physics. On the one hand, free-fermion energy bands and their geometric properties give rise to quantised transport phenomena, such as the quantum Hall effect and its dynamic analogon, the Thouless pump. The quantisation in these systems is considered robust against perturbations that commute with a protecting symmetry. On the other hand, interparticle interactions support strongly correlated states of matter, which often preclude particle transport, exemplified by the Mott transition in the Hubbard model. Will topology prevail in the presence of strong correlations? Here, we systematically probe the response of a topological Thouless pump to Hubbard interactions in an ultracold-atom experiment. We identify three distinct regimes, that is, pair pumping for strongly attractive interactions, quantised pumping for weak and moderate interactions, as well as the breakdown of transport for strong repulsive Hubbard U. Our experiments pave the way for investigating edge effects in interacting topological insulators, as well as interaction-induced topological phases with no counterpart in free-fermion systems.

QI 6.34 Mon 16:30 Empore Lichthof

Switching Topological State via Ferroelectric Polarization Field — •Jiabao Yang and Niels B. M. Schröter — Max-Planck-Institute of Microstructure Physics, Weinberg 2, 06120 Halle(Saale), Germany

The quantum spin hall insulator (QSHI) has shown great potential in low-dissipation spintronics and topological quantum computing, most of which highly rely on the emergency of topological edge state. Two common achieving methods, electric gating and strain effect are both challenging though the former requires continuous energy consumption and the latter needs precise control of strain. Two-dimensional(2D) ferroelectric material (FE), a kind of material with spontaneous and switchable charging polarization, can bring out a controllable topological order of 2D heterostructure when stacked with a heavy-element trivial insulator. The built-in electric field leads to new band alignment of the heterostructure, and band inversion occurs at the conduction band minimum of 2D FE and valence band maximum of TI. With the help of the robust interlayer spin-orbit coupling effect, the band gap can be opened. α-In2Se3, a typical ferroelectric material with a quite large polarizing built-in electric field(1.35eV), is an ideal substrate for monolayer WTe2. What is expected is the new topological state occurs in the van der Waals heterostructure around the gamma point and new non-volatile control of topological states.

QI 6.35 Mon 16:30 Empore Lichthof

Noise-assisted adiabatic quantum search algorithm: a study via quantum trajectories — •Raphaël Menu[1], Christiane P. Koch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbr *ucken, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

Adiabatic quantum computing offers a precious alternative to quantum circuits for the implementation of quantum search algorithms. Indeed, while circuits require an oracle, namely a black box, to test whether the algorithm converged towards the target state, adiabatic quantum search algorithms performs the calculation via the adiabatic preparation of the ground state of a simple effective two-level system. Yet, such an approach is not flawless since it requires a large annealing time so that transitions out of the ground state are suppressed, and therefore one may reach time scales when the effects of the environment become relevant.

In this work, we study by the means of the framework of quantum trajectories (Monte Carlo wavefunction) the adiabatic implementation of the Grover search algorithm, and investigate how one can improve the performance of the search via the coupling of the computation qubit to an ancilla, leading to a shortest annealing time and a correction of the computational errors.

QI 6.36 Mon 16:30 Empore Lichthof

Microwave quantum memory based on rare earth doped crystal — •Jianpeng Chen[1,2,3], Ana Strinic[1,2,3], Achim Marx[1,2], Kirill G. Fedorov[1,2], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Quantum memory is essential in future quantum technologies, such as quantum computing circuits and quantum communication links. Specifically, Crystals doped with rare earth ions are promising competitive candidates due to their long coherence times [1] and potential multiplexing capability [2]. Here, we use a transmission line to couple microwave signals to rare earth ion dopants in yttrium orthosilicate crystals (Y2SiO5) at 10 mK. We present experimental results on storing coherent microwave states using the spin echo protocol. We will discuss the resulting coherence time and the impact of the transmission line design on the efficiency of the quantum information storage and its multimodality potential. We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036). [1] Zhong, M, Nature 517, 177*180 (2015). [2] Antonio Ortu et al.Quantum Sci. Technol. 7 035024 2022.

QI 6.37 Mon 16:30 Empore Lichthof

Towards on-chip microwave-to-telecom transduction based on erbium-doped silicon — •Daniele Lopriore[1,2] and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

The development of a device that converts microwave to optical photons at a telecommunication wavelength would be a key enabler for the communication between remote quantum computers. In this context, we are investigating erbium ensembles doped into nanophotonic silicon waveguides. This novel hardware platform features a unique combination of a small inhomogeneous broadening and an exceptional optical coherence even in nanostructured materials [1]. In an external magnetic field, the ground and excited states are split into doublets, which allows the erbium ensemble to act as the nonlinear medium mediating an efficient conversion process [2,3]. To this end, we plan to enhance both the microwave and the telecom transitions with resonators of high quality factor, fabricated on the same silicon chip. By optimizing the resonator geometries in order to maximize the overlap between the resonating fields and the erbium dopants, we aim to achieve transduction efficiencies approaching unity [3]. This would pave the way for the entanglement of superconducting qubits in remote cryostats.

[1] A. Gritsch, et al. Phys.Rev.X 12, 041009 (2022).
[2] L. Williamson, et al. Phys.Rev.Lett. 113, 203601 (2014).
[3] C. O'Brien, et al. Phys.Rev.Lett. 113, 063603 (2014).

QI 6.38 Mon 16:30 Empore Lichthof

Towards an efficient Quantum Network - Silicon Vacancy Color Centers in Diamond — •Donika Imeri[1,2], Tuncay Ulas[1], Sunil Kumar Mahato[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

Quantum networks combine a high level of security and the ability to scale up the qubit number which is crucial for quantum information processing. These networks contain nodes that store information. Quantum communication can be enabled by linking these nodes via entanglement. Silicon vacancy color centers in diamonds are promising components for optically connected quantum processors. The point defects establish an efficient optical interface and display a protective inversion symmetry. Therefore, the incorporation of nanophotonic structures, as well as coherent resonators, is possible. This can be used to generate entanglement between spin and photonic qubits. Long coherence times are a benefit, however, this includes the challenge of working in a cryogenic environment. Here, we present a platform to generate efficient and secure quantum communication by connecting multiple quantum processors.

QI 6.39 Mon 16:30 Empore Lichthof

Towards active stabilization of magnetic fields for trapped ions — •Lucas Eisenhart, Deviprasath Palani, Fabian Thielemann, Florian Hasse, Apurba Das, Ulrich Warring, Tobias Spanke, and Tobias Schaetz — Physikalisches Institut, Freiburg, Deutschland

When experimenting with trapped ions, it can be of great importance to generate magnetic fields that are highly stable, for example, when exploiting the electron degree of freedom in quantum applications. For this we characterize magnetic field sensors, with the help of which we may be able to adapt the coil current in our experiments to reduce field fluctuations. For magnetic field amplitudes in a range from 0.1G to 10^5G we use a Hall sensor with a sensitivity of 0.02mV/G and and a bandwidth that reaches up to 200kHz. For smaller magnetic field amplitudes in a range from 60μG to 10G we use a fluxgate sensor module that has a sensitivity of 1V/G and a bandwidth of up to 1kHz. We present our benchmark results of the hall- and fluxgate-sensor within our test environment.

QI 6.40 Mon 16:30 Empore Lichthof

High-order series expansions and crystalline structures for Rydberg atom arrays — •Duft Antonia, Jan Koziol, Matthias Mühlhauser, Patrick Adelhardt, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

We investigate a model of hardcore bosons on the links of a Kagome lattice subject to a long-range decaying van-der-Waals interaction. This model is known to be the relevant microscopic description of Rydberg atom arrays excited by a detuned laser field which has been realized in experiments recently. Particular interest lies on this system as it is an engineerable quantum platform which has been predicted to to host a topological phase. We investigate the quantum phase diagram for different limiting cases with a main focus on the low interaction-strength limit where we apply high-order linked cluster expansions.

QI 6.41 Mon 16:30 Empore Lichthof

Numerical investigation of the Ising model in a light-induced quantized transverse field — •Anja Langheld and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We investigate the Ising model in a light-induced quantized transverse field [1] with a particular focus on antiferromagnetic, potentially frustrated Ising interactions. Using exact diagonalization, we provide data for the antiferromagnetic chain in a longitudinal field that is inconsistent with earlier results coming from mean-field considerations [2]. In order to study the model on frustrated, two-dimensional lattice geometries, we extend the mean-field calculation and develop a quantum Monte Carlo update based on the recently introduced wormhole update [3], for which the photons are integrated out. By this means, the photons induce a retarded spin-spin interaction in imaginary time that is also non-local in space in contrast to the Ising interaction inherent to the model.

[1] J. Rohn et al., Phys. Rev. Research 2, 023131 (2020)
[2] Y. Zhang et al., Sci Rep 4, 4083 (2014)
[3] M. Weber et al., Phys. Rev. Lett. 119, 097401 (2017)

QI 6.42 Mon 16:30 Empore Lichthof

Luttinger's Theorem in the One-Dimensional tJ-model — •Annika Böhler[1,2], Henning Schlömer[1,2], and Fabian Grusdt[1,2] — [1]Ludwig-Maximilians University, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

The Hubbard model in one dimension is known to exhibit spin charge separation, which has recently been observed in settings of ultracold fermions in optical lattices. Another signature of spin-charge separation in a lattice, that has not been directly observed thus far, is constituted by a change of the Fermi momentum. Luttinger's theorem relates the volume of the Fermi surface - and therefore the Fermi momentum - to the underlying particle density of the system. Here we discuss a proof of the theorem [M. Oshikawa, Phys. Rev. Lett. 84 (2000), 3370] in the presence of spin charge separation and evaluate whether it provides a tool to distinguish between qualitatively distinct spin-1/2 liquids and spinless chargon liquids via their different Fermi momenta. We show that Friedel oscillations of the density at the edge of a system can be used to directly observe the change of Fermi momentum, reflecting a qualitative change in the nature of charge carriers which we associate with an emergent U(1) symmetry corresponding to the total number of holes in the large-U limit of the Hubbard model.

QI 6.43 Mon 16:30 Empore Lichthof

Guided variational quantum algorithm for time evolution in dynamical mean field theory — •Stefan Wolf[1], Michael J. Hartmann[1], and Martin Eckstein[2] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]I. Institute of Theoretical Physics, Department of Physics, University of Hamburg

Dynamical mean-field theory (DMFT) is a useful tool to treat models of strongly correlated fermions like the Hubbard model. The lattice of the model is replaced by a single-impurity site embedded in an effective bath. The resulting single impurity Anderson model (SIAM) can then be solved self-consistently with a quantum-classical hybrid algorithm. This procedure involves repeatedly preparing the ground state on a quantum computer and evolving it in time. We propose an approximation of the time evolution operator by a Hamiltonian variational ansatz. The parameters of the ansatz are obtained via a variational quantum algorithm that utilizes a small number of Trotter steps, given by the Suzuki-Trotter expansion of the time evolution operator, to guide the evolution of the parameters. The cost function is evaluated by measuring a single ancilla qubit using the Hadamard test, thus reducing the required number of measurements compared to other approaches. The resulting circuit for the time evolution is shallower than a comparable Suzuki-Trotter expansion. We show results for two-site DMFT with half-filling. We further looked into the possibility to extend the approach for the impurity model with more than one bath site and away from half-filling.

QI 6.44 Mon 16:30 Empore Lichthof

Measurement Induced State Preparation — •Daniel Alcalde Puente — PGI8, Wilhelm-Johnen-Straße 52428 Jülich

This work explores the protocol proposed in (Roy, Sthitadhi, et al. "Measurement-induced steering of quantum systems." Physical Review Research 2.3 (2020): 033347) for state preparation outside of the Lindblad limit. In this protocol, a system is coupled to ancillas with a time-independent Hamiltonian, with the ancillas being periodically reset. The protocol exploits the frustration-free nature of the parent Hamiltonian, enabling the writing of local operators that map from locally excited states to locally unexcited states. The full dynamics of this protocol are simulated using Matrix Product States and quantum trajectories, and the behavior of the protocol is analyzed for different measurement intervals. In particular, our study explores the case of preparing the spin-1 Affleck-Kennedy-Lieb-Tasaki state and discusses the protocol's resilience to errors. The results show that the dynamics of the protocol match the dynamics of the Lindblad limit for relatively large measurement intervals, that the optimal measurement interval is close to the expected ideal measurement interval, and that the protocol converges even for large measurement intervals, though only slowly.

QI 6.45 Mon 16:30 Empore Lichthof

Portfolio Optimization using a Quantum Computer — •Matthias Hüls and Daniel Braun — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Deutschland

Entering the era of Noisy Intermediate-Scale Quantum (NISQ) devices, hopes are raising to already make practical use of the existing quantum processors. While deep algorithms still fail on the error prone hardware, variational algorithms show error resilience to some extend. This makes them well suited for the NISQ technology. Therefore, popular candidates like the Quantum Approximate Optimization Algorithm (QAOA), designed to solve combinatorial optimization problems, attracted much attention in recent years. In a case study, we benchmark the performance of the QAOA for the portfolio optmimization problem. We focus on how the characteristics of a given problem instance influence the algorithms performance and deduce a criterion for distinguishing between 'easy' and 'hard' instances.

QI 6.46 Mon 16:30 Empore Lichthof

Performance of Grover's Algorithm on IBM Quantum Processors — •Yunos El Kaderi[1,2], Andreas Honecker[1], and Iryna Andriyanova[2] — [1]LPTM UMR CNRS 8089, CY Cergy Paris Université, France — [2]ETIS UMR CNRS 8051, CY Cergy Paris Université, France

This work tests the performance of Grover search circuits on the available IBM superconducting quantum devices that are accessible on the IBMQ cloud. Ideally, we expect to get a probability distribution that is clearly peaked at the targeted state. However, the quantum circuit executed on NISQ devices is vulnerable to noise which leads to fluctuations in the expected results. This depends on the quality of the device which is defined by a Quantum Volume parame-

ter and on the depth of the circuit. Some previous works reached results that are completely noisy with no useful information, see for example Ref. [1] for 4 qubits (16 elements). Here we show that suitable implementations on concurrent IBMQ devices can actually yield useful results and explore the limitations.
[1] Y. Wang, P.S. Krstic, Phys. Rev. A **102**, 042609 (2020)

QI 6.47 Mon 16:30 Empore Lichthof

QVLS Q1 supporting experiment for development of techniques for ion transport and sympathetic cooling — •Christian Joohs[1,2], Markus Duwe[1,2], Yannick Hermann[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

Within the ongoing development of the ion-based quantum computer Q1 carried out by QVLS (**Q**uantum **V**alley **L**ower **S**axony), a supporting experiment is being built and used for research and development of transport and cooling techniques. The trap is experimentally realised by a surface electrode Paul trap, which allows movement of trapped ions in a two-dimensional space above the trap. This possibility is used to realise the computer in a register-like fashion (termed QCCD architecture [1,2]) by having different zones on the trap chip that account for different tasks including storage, readout, and quantum logic gate application. A key aspect therefore is the development of ion transport techniques between said zones while maintaining a low heating rate and without interruption of the ion's electronic quantum state. Furthermore, we study the possibility to sympathetically cool two logic ions with a single cooling ion of significantly heavier mass. We report on previous progress and goals.

[1] D.J. Wineland *et al.*, J. Res. Natl. Inst. Stand. Technol. **103**, 259 (1998)
[2] D. Kielpinski, C. Monroe, and D. J. Wineland, Nature **417**, 709 (2002)

QI 6.48 Mon 16:30 Empore Lichthof

Towards a fault tolerant microwave-driven two qubit quantum processor — •Markus Duwe[1,2], Hardik Mendpara[1,2], Nicolas Pulido-Mateo[1,2], Ludwig Krinner[1,2], Giorgio Zarantonello[3], Amado Bautista-Salvador[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]National Institute of Standards and Technology, Boulder, USA

A universal quantum gate set can be realized by the combination of single-qubit gates and one entangling operation. In this work, we realize such a gate set using the microwave near field approach [1]. We trap two 9Be+ ions in a radio-frequency surface electrode trap and perform the quantum logic operations with embedded microwave conductors. The individual qubits are addressed by micromotion sidebands [2] and the entangling gate is performed via a Mølmer-Sørensen type interaction. We approach an infidelity of 10^{-4} with single qubit gates and 10^{-3} with entangling gates using partial tomography [3]. We report on challenges and solutions for further improving the gate fidelities and to characterize gate errors.

[1] C. Ospelkaus *et al.*, Phys. Rev. Lett. **9**, 090502 (2008)
[2] U. Warring *et al.*, Phys. Rev. Lett. **17**, 173002 (2013)
[3] M. Duwe *et al.*, Quantum Sci. Technol. **7**, 045005 (2022)

QI 6.49 Mon 16:30 Empore Lichthof

Next generation platform for implementing fast gates in ion trap quantum computation — •Donovan Webb, Sebastian Saner, Oana Bazavan, Mariella Minder, and Christopher Ballance — University of Oxford

Scalable trapped-ion quantum computation relies on the development of high-fidelity fast entangling gates in a many ion crystal. Conventional geometric phase gates either suffer from scattering errors or off-resonant carrier excitations. A potential route to achieve fast entanglement is creating a standing wave which can suppress the unwanted carrier coupling [Mundt 2003].

We present the roadmap to our next-generation platform tailored for fast gates in the ~1μs regime where gate speeds become comparable to the secular trap frequency. The quadrupole transitions between S1/2 and D5/2 levels in Calcium 40 will be driven to perform Molmer-Sorenson gates with a standing wave rather than a typical travelling wave. The off-resonant carrier excitation may be strongly suppressed by placing ions at the nodes of the optical lattice. This new platform has scope for a multi-ion chain and a corresponding array of optical lattices which each address a single ion. The lattice array is created by a set of counter-propagating beams which are tightly focused by a symmetric setup of high-NA lenses. Control of the optical phase at the ion site will be achieved by actively stabilising the counter-propagating beam interferometer and feedbacking on the ion signal.

QI 7: Quantum Technologies: Color Centers I (joint session Q/A/QI)

Time: Monday 17:00–19:00 Location: F342

See Q 14 for details of this session.

QI 8: Quantum Communication I (joint session Q/QI)

Time: Monday 17:00–19:00 Location: F442

See Q 15 for details of this session.

QI 9: Photonic Quantum Technologies (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: A320

See Q 16 for details of this session.

QI 10: Quantum Thermodynamics and Open Quantum Systems I

Time: Tuesday 11:00–13:00 Location: B302

Invited Talk QI 10.1 Tue 11:00 B302

Quantum information in minimal quantum thermal machines — •Géraldine Haack — University of Geneva, Switzerland

Minimal models for quantum thermal machines are central to understand energy exchanges at the quantum scale and the intimate connection between quantum thermodynamics and quantum information theory. In particular, one would like to determine whether quantum features, like entanglement, interactions and quantum statistics, can be beneficial to the efficiency of a thermal machine made of few quantum constituents. This research direction becomes even more fascinating in view of recent experimental progresses towards manipulating out-of-equilibrium multi-partite quantum systems, allowing for new designs and investigations of quantum thermal machines. In this talk, I will present some of our latest results concerning the advantages that open quantum systems can offer towards heat and quantum information management at the nanoscale, including storing energy, generation of quantum correlations and optimization of dissipative flows. References: Khandelwal et al., PRX Quantum 2, 040346 (2021) Seah et al., PRL 127, 100601 (2021) Brask et al., Quantum 6, 672 (2022)

QI 10.2 Tue 11:30 B302

Quantum optomechanical thermodynamics — •David Edward Bruschi — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Germany

Quantum Thermodynamics extends the notions from classical thermodynamics to the quantum regime. Novel features appear, and processes acquire intrinsic probabilistic nature, in the sense that classically forbidden processes can statistically occur at least in principle. Given the advances in quantum technologies, it remains an open question to develop and characterize quantum systems as potential quantum thermal machines.

We propose an extension of the concepts of quantum thermodynamics to optomechanical systems. We study their properties and characterize them as quantum thermal machines. Applications and extensions are discussed in light of quantum technological applications.

QI 10.3 Tue 11:45 B302

Catalytic Gaussian thermal operations — •Benjamin Yadin[1], Hyejung Jee[2], Carlo Sparaciari[2,3], Gerardo Adesso[4], and Alessio Serafini[3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]Department of Computing, Imperial College London, London SW7 2AZ, UK — [3]Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK — [4]School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, UK

We examine the problem of state transformations in the framework of Gaussian thermal resource theory in the presence of catalysts. To this end, we introduce an expedient parametrisation of covariance matrices in terms of principal mode temperatures and asymmetries, and consider both weak and strong catalytic scenarios. We show that strong catalysts (where final correlations with the system are forbidden) are useless for a single mode, in that they do not expand the set of states reachable from a given initial state. We then go on to prove that weak catalysts (where final correlations with the system are allowed) are capable of reaching more final system states, and determine exact conditions for state transformations of a single mode in their presence. Next, we derive necessary conditions for Gaussian thermal state transformations holding for any number of modes, for strong catalysts and approximate transformations, and for weak catalysts with and without the addition of a thermal bath. We discuss the implications of these results for devices operating with Gaussian elements.

QI 10.4 Tue 12:00 B302

Which Bath-Hamiltonians Matter for Thermal Operations? — •Frederik vom Ende — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

We explore the set of thermal operations from a mathematical and topological point of view. We introduce the concept of Hamiltonians with resonant spectrum with respect to some reference Hamiltonian, followed by proving that when defining thermal operations it suffices to only consider bath Hamiltonians which satisfy this resonance property. Moreover we find a semigroup representation of the (enhanced) thermal operations in two dimensions by characterizing any such operation via three real parameters, thus allowing for a visualization of this set. This allows us to specify all qubit thermal operations (without the closure). This talk is based on the article J. Math. Phys. 63, 112202 (2022)

QI 10.5 Tue 12:15 B302

Thermodynamics of a many-body three level maser — •Julia Boeyens, Benjamin Yadin, and Stefan Nimmrichter — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen 57068, Germany

Many-body systems that are invariant under permutation of particles display interesting effects like superradiance due to their collective dynamics. These effects are apparent even in systems of particles that are, in principle, distinguishable but are permutation invariant from the perspective of the bath. It was recently demonstrated that multi-level systems that are collectively coupled to a thermal environment have thermodynamic properties that are different from collective spin systems and collections of distinguishable particles [1]. The thermodynamic effects of interactions between the multi-level systems are, however, yet to be investigated. Interactions should heighten the differences observed between the non-thermal steady states obtained by multi-level systems and the already well studied spin systems. In this work we study a three level maser coupled collectively to two thermal reservoirs. The performance is compared to an equivalent engine that is made up of the same number of three level systems that are distinguishable from the perspective of the baths.

[1] B. Yadin, B. Morris, K. Brandner arXiv:2206.12639 (2022)

QI 10.6 Tue 12:30 B302

A Trapped Ion Anharmonic Oscillator — •Bo Deng, Moritz Göb, Max Masuhr, Daqing Wang, and Kilian Singer — Experimentalphysik I, Universität Kassel, Heinrich Plett Str. 40, 34132 Kassel, Germany

In a tapered trap used for the realization of a single ion heat engine, the coupling of radial and axial modes implements an anharmonic mechanical oscillator. In this talk, we show that this coupling can be approximately described by the radiation-pressure Hamiltonian in the context of optomechanics. We further characterize the nonlinearity of this oscillator and the resulting mechanical bistability. Finally, we will discuss possible applications for thermal machines in the quantum regime.

QI 10.7 Tue 12:45 B302

Probing coherent quantum thermodynamics using a trapped ion — •Oleksiy Onishchenko[1], Giacomo Guarnieri[2], Pablo Rosillo-Rodes[3], Daniël Pijn[1], Janine Hilder[1], Ulrich G. Poschinger[1], Martí Perarnau-Llobet[4], Jens Eisert[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, Mainz, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [3]Institute for Cross-Disciplinary Physics and Complex Systems, Campus Universitat de les Illes Balears, Palma, Spain — [4]Department of Applied Physics, University of Geneva, Geneva, Switzerland

We report an experimental measurement of the genuine quantum correction to the classical fluctuation-dissipation relation (FDR) [1] in a trapped ion platform. We employ a single qubit and perform thermalization and coherent drive via laser pulses to implement a quantum coherent work protocol [1]. Using the excellent degree of control of trapped ions, we find agreement with the theory of quantum FDR and violate any classical explanation by more than 10.9 standard deviations [2]. This work opens the path to further experimental exploration of quantum thermodynamics, in particular to measurements of non-Markovian evolution, where the state of the qubit would not be reset between single experiments.

[1] M. Scandi *et al.*, Phys. Rev. Research **2**, 023377 (2020).
[2] O. Onishchenko *et al.*, arXiv:2207.14325 (2022).

QI 11: Quantum Entanglement I

Time: Tuesday 11:00–13:00 Location: B305

Invited Talk QI 11.1 Tue 11:00 B305

Characterisation of multipartite entanglement beyond the single-copy paradigm — •Nicolai Friis — Institute of Atomic and Subatomic Physics - Atominstitut, TU Wien, Vienna, Austria

Scenarios with multiple parties such as one would imagine will be encountered in future large-scale quantum networks present complex challenges for the characterisation of entanglement. One of the most basic insights in the theory of multipartite entanglement is the fact that some mixed states can feature entanglement across every possible bipartition of a multipartite system, yet can be biseparable, i.e., can be produced as mixtures of partition-separable states. To distinguish biseparable states from those states that genuinely cannot be produced from mixing partition-separable states, the term genuine multipartite entanglement was coined. The premise for this distinction is that only a single copy of the state is distributed and locally acted upon. However, advances in quantum technologies prompt the question of how this picture changes when multiple copies of the same state become locally accessible. In this talk I will discuss recent work [Yamasaki et al., Quantum 6, 695 (2022), Palazuelos & de Vicente, Quantum 6, 735, (2022)] which demonstrates that multiple copies unlock genuine multipartite entanglement from partition-separable states, even from undistillable ensembles. These results show that a modern theory of entanglement in multipartite systems, which includes the potential to locally process multiple copies of distributed quantum states, exhibits a rich structure that goes beyond the convex structure of single copies.

QI 11.2 Tue 11:30 B305

Entanglement in quantum hypergraph states — •Jan Nöller[1] and Mariami Gachechiladze[2] — [1]Technische Universität Darmstadt — [2]Technische Universität Darmstadt

Hypergraph states are the natural generalization of well-known graph states, capturing multipartite entanglement between three or more parties.

We investigate how local Pauli stabilizers of symmetric hypergraph states can be used to quantify their geometric entanglement measures, and to explain exponentially increasing violation of local realism.

Specifically, we recover some known results for states with low hyperedge cardinalities and extend these further to infinitely many classes of hypergraph states.

Finally, we derive some results on robustness for the violation of separability inequalities against particle loss.

QI 11.3 Tue 11:45 B305

Bound Entanglement in Generalized Grid States — •Robin Krebs — Technical University Darmstadt, Germany

Quantum grid states are mixed quantum states introduced to study bound entanglement. They are defined by graphs on a regular grid, allowing for graph theoretical separability criteria.

Recently a generalization including hyperedges was proposed by Ghimire et al. In our work, we extend the graphical range and PPT criterion to allow treatment of hyperedges to deepen the understanding of entanglement in generalized grid states and study the behaviour of the Schmidt number under this generalization.

QI 11.4 Tue 12:00 B305

Quantifying electron entanglement faithfully — Lexin Ding[1,2], Zoltan Zimboras[3,4,5], and •Christian Schilling[1,2] — [1]Ludwig Maximilian University of Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Germany — [3]Theoretical Physics Department, Wigner Research Centre for Physics, Budapest, Hungary — [4]Algorithmiq Ltd., Helsinki, Finland — [5]Eötvös Lorán University, Budapest, Hungary

Entanglement is one of the most fascinating concepts of modern physics. In striking contrast to its abstract, mathematical foundation, its practical side is, however, remarkably underdeveloped. Even for systems of just two orbitals or sites no faithful entanglement measure is known yet. By exploiting the spin symmetries of realistic many-electron systems, we succeed in deriving a closed formula for the relative entropy of entanglement between electron orbitals. Its broad applicability in the quantum sciences is demonstrated: (i) in light of the second quantum revolution, it quantifies the true physical entanglement by incorporating the crucial fermionic superselection rule (ii) an analytic description of the long-distance entanglement in free electron chains is found, refining Kohn's locality principle (iii) the bond-order wave phase in the extended Hubbard model can be confirmed, and (iv) the quantum complexity of common molecular bonding structures could be marginalized through orbital transformations, thus rationalizing zero-seniority wave function ansatzes.

QI 11.5 Tue 12:15 B305

Constructing entanglement witnesses based on the Schmidt decomposition of operators — •Sophia Denker[1], Chengjie Zhang[2], Ali Asadian[3], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]School of Physical Science and Technology, Ningbo University, Ningbo, 315211, China — [3]Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Gava Zang, Zanjan 45137-66731, Iran

Characterizing entanglement is an important issue in quantum information, as entanglement is considered to be a resource for quantum key distribution or quantum metrology. One useful tool to detect and quantify entanglement are witness operators. A standard way to design entanglement witnesses for two or more particles is based on the fidelity of a pure quantum state; in mathematical terms this construction relies on the Schmidt decomposition of vectors. In this contribution, we present a method to build entanglement witnesses based on the Schmidt decomposition of operators. Our scheme works for the bipartite and the multipartite case and is found to be strictly stronger than the concept of fidelity-based witnesses. We discuss in detail how to improve known witnesses for genuine multipartite entanglement for various multipartite quantum states. Finally, we demonstrate that our approach can also be used to quantify quantum correlations as well as characterize the dimensionality of entanglement.

QI 11.6 Tue 12:30 B305

Maximally entangled symmetric states of two qubits — •Eduardo Serrano-Ensástiga[1,2] and John Martin[2] — [1]Centro de Nanociencias y Nanotecnología, Universidad Nacional Autónoma de México, Ensenada, Baja California, México — [2]Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, Liège, Belgium

The problem studied by Verstraete, Audenaert and De Moor [1] -about which global unitary operations maximize the entanglement of a bipartite qubit system- is revisited and solved when permutation symmetry between the qubits is taken into account. This condition appears naturally in bosonic systems or spin-1 systems [2]. Our results [3] allow us to characterize the set of symmetric absolutely separable states (SAS) for two qubits. In particular, we calculate the maximal radius of a ball of SAS states around the maximally mixed state in the symmetric sector, and the minimum radius of a ball that includes the set of SAS states. For symmetric 3-qubit systems, we deduce a necessary condition for absolute separability and bounds for the radii of similar balls studied in the two-qubit system.

[1] F. Verstraete, K. Audenaert, and B. De Moor, Phys. Rev. A, 64, 012316, (2001). [2] O. Giraud, P. Braun, and D. Braun, Phys. Rev. A, 78, 042112, (2008). [3] E. Serrano-Ensástiga, and J. Martin, ArXiv:2112.05102 (2021).

QI 11.7 Tue 12:45 B305

Geometry of the state space of two qubits — •Simon Morelli[1], Christopher Eltschka[2], Marcus Huber[3], and Jens Siewert[4,5] — [1]Basque Center for Applied Mathematics (BCAM), 48009 Bilbao, Spain — [2]Istitut für Theoretische Physik, Universität Regensburg, 93053 Regensburg, Germany — [3]Atominstitut, Technische Universität Wien, 1020 Vienna, Austria — [4]University of the Basque Country UPV/EHU, 48080 Bilbao, Spain — [5]IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, Spain

The quantum marginal problem and related questions have received considerable attention recently. We investigate an even simpler question for which there is no answer so far: Given the purities of the two local states of a bipartite system, what is the maximum purity the global state can achieve? We derive an exact solution for two qubits. Together with previous findings [1], this result gives rise for a new representation of the state space – the Bloch ball – of two qubits. We show that this visualization has various interesting properties regarding geometry, majorization, and entanglement.

[1] S. Morelli, C. Kloeckl, C. Eltschka, J. Siewert, and M. Huber, Lin. Alg. App. **584**, 294 (2020).

QI 12: Integrated Photonics I (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: E001

See Q 17 for details of this session.

QI 13: Quantum Simulation

Time: Tuesday 11:00–13:00 Location: F428

QI 13.1 Tue 11:00 F428

Quantum simulation of graph complexity problems — •Durga Dasari and Joerg Wrachtrup — 3. Physics Institute, ZAQUANT, University of Stuttgart, 70569,Stuttgart, Germany

Finding the perfect matchings that cover the entire graph is known to be a computationally hard (#*P*) problem in graph theory. A similar analogy exists for spin-lattices, where the coverings of lattice by dimers is a hard combinatorial problem. Dimer models are well studied in statistical physics and in many-body physics. We show here how to simulate such computationally complex problems using a simple model system comprising of a single quantum probe interacting with a rectangular spin-lattice. We identify different configurations for complete lattice filling using dimers through the quantum probe coherence, and use it further to obtain the pairing statistics, that confirm the previously known results for planar graphs. We highlight here the new role of quantum sensor that allows it to go beyond its conventional sensing applications towards resolving computational complexity in graph theory.

QI 13.2 Tue 11:15 F428

Quantum simulations of infinite spin transverse field Ising model using the variational quantum eigensolver algorithm — •Sumeet Sumeet, Max Hörmann, and Kai P. Schmidt — Institut für Theoretische Physik I Friedrich-Alexander-Universität Erlangen-Nürnberg

With the advancements in quantum technologies it has become inevitable to investigate the potential existence of quantum advantage for the paradigmatic models of quantum-many body physics. One of the very basic models is the transverse field Ising model that can be simulated on a quantum computer to compute properties such as the ground-state energy of a spin system. This problem, when tackled on a classical computer, leads to an exponential surge in the cost of computation with increasing system size. The advent of classical-quantum hybrid algorithms has shifted the focus to investigate the solution to this problem with algorithms such as the variational quantum eigensolver (VQE) which is considered reasonably good for obtaining the ground-state energies of quantum many-body systems in the NISQ era. In this work, we exploit the Hamiltonian variational ansatz for calculating the ground-state energy and fidelity of the transverse-field Ising model on one- and two-dimensional geometries. We devise strategies to compute the ground-state energy in the thermodynamic limit on quantum computers. In that regard, we apply numerical linked cluster expansions (NLCE) to VQE in order to simulate infinite spin systems using calculations on finite graphs. Further, we extend this approach to geometrically frustrated systems.

QI 13.3 Tue 11:30 F428

Toolbox for the digital twin of a Rydberg atom QPU — •Daniel Jaschke[1,2,3], Alice Pagano[1,2,3], Sebastian Weber[4], and Simone Montangero[1,2,3] — [1]Institute for Complex Quantum Systems, Ulm University — [2]Dipartimento di Fisica e Astronomia "G. Galilei" & Padua Quantum Technologies Research Center, Università degli Studi di Padova — [3]INFN, Sezione di Padova — [4]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart

The many-body simulation of a QPU at the level of the Hamiltonian and pulses requires the integration of different tools leading to a simulation that encompasses different aspects and their interplay. In the example of a Rydberg atom QPU, we demonstrate how tensor network simulations can be used to gain insight into the system. Therefore, we employ an integration of an effective description of strontium-88 atoms, optimal control methods, a dedicated compiler, and tree tensor networks. To show the power of this tool, we focus on how benefits from parallelization of a quantum algorithm scale with the system size.

QI 13.4 Tue 11:45 F428

Accessing entanglement phase transitions from fluctuations — •Teemu Ojanen, Ali Moghaddam, and Kim Pöyhönen — Physics Unit, Faculty of engineering and natural sciences, Tampere University, Tampere Finland

Entanglement phase transitions in driven unitary quantum circuits subject to projective measurements provides an example of new type of critical phenomena in quantum information platforms. While the random unitary two-qubit gates drive the system rapidly into a volume-law entangled phase, the projective measurements of a finite fraction of qubits after each cycle try to freeze the proliferation of entanglement and drive the system to an area-law entangled phase. At critical measurement rate, the system undergoes a phase transition between the volume and area law phases. I will show how this phenomenon can be accessed directly via fluctuations of conserved quantities, circumventing the need to measure entanglement entropies. Remarkably, this could exponentially reduce the required number of measurements to observe entanglement phase transitions in experiments.

QI 13.5 Tue 12:00 F428

Signatures of MBL in a dilute gas of ultracold polar molecules in a 2D optical lattice — •Timothy J. Harris[1,2,3], Andrew J. Groszek[1], Arghavan Safavi-Naini[4,5], and Matthew J. Davis[1] — [1]ARC CoE EQUS, University of Queensland, Brisbane, Australia — [2]LMU Munich, Munich, Germany — [3]MCQST, Munich, Germany — [4]QuSoft, Amsterdam, the Netherlands — [5]University of Amsterdam, Amsterdam, the Netherlands

We present our work exploring many-body localization (MBL) in systems of ultracold polar molecules in two-dimensional (2D) optical lattices. We characterize a novel ergodicity breaking mechanism that emerges in molecular quantum simulators when a fraction of the lattice sites are left unoccupied. We consider a system of diatomic polar molecules pinned in a deep 2D optical lattice with at most one molecule per site. The system is well described by a dipolar spin-1/2 Hamiltonian, with effective on-site disorder arising from the dilute, randomised configurations of molecules in the lattice. We perform extensive exact diagonalisation simulations to explore non-equilibrium dynamics and eigenstate properties for systems of up to 16 molecules at 50% lattice filling. We observe several essential signatures of MBL, including retention of initial state memory in the system's long-time dynamics, logarithmic growth of bipartite entanglement entropy, divergent entanglement fluctuations and a transition to Poissonian level-spacing statistics. Our results are realisable in current molecular quantum gas microscope experiments, and open exciting new avenues to explore non-equilibrium many-body physics with ultracold polar molecules.

QI 13.6 Tue 12:15 F428

Confinement and phase diagrams of one-dimensional $\mathbb{Z}_2$ lattice gauge theory — •Matjaž Kebrič[1,2], Jad C. Halimeh[1,2], Christian Reinmoser[1,2], Ulrich Schollwöck[1,2], Luca Barbiero[3], Annabelle Bohrdt[4,5], and Fabian Grusdt[1,2] — [1]Department of Physics and ASC, LMU München, Theresienstr. 37, München D-80333, Germany — [2]MCQST, Schellingstr. 4, D-80799 München, Germany — [3]DISAT, Politecnico di Torino, I-10129 Torino, Italy — [4]ITAMP, Cambridge, MA, USA — [5]Department of Physics, Harvard University, Cambridge, MA 02138, USA

We present our work on confinement in a one-dimensional $\mathbb{Z}_2$ lattice gauge theory (LGT), where dynamical matter is coupled to gauge fields. This results in a non-local confining potential among pairs of individual particles, which bind into mesons. This is a notoriously difficult problem to tackle when the density of matter is finite and dynamical. We solve the confinement problem in the 1D $\mathbb{Z}_2$ LGT, by relating confinement to translational symmetry breaking in a non-local basis. We study the mechanism and effect of confinement in a broad context. Our model is already within the reach of existing cold-atom experiments. We thus consider the manifestation of confinement in the context of quantum simulation experiments and study the effect of finite temperature. In addition, we map out phase diagrams at different fillings and uncover rich physic driven by the interplay of non-local confining potential and purely local interactions. Furthermore, we develop a mean-field description of the LGT and explore the possibility to use the LGT formalism to describe mixed dimensional spin systems.

QI 13.7 Tue 12:30 F428

Time Evolution of Matrix Product States Using Adaptive Subspace Expansion — •Tizian Blatz, Sebastian Paeckel, and Martin Grundner — Arnold Sommerfeld Center of Theoretical Physics, Department of Physics, University of Munich, Theresienstrasse 37, 80333 Munich, Germany

Today's advances in experimentally realizable ultracold-atom-based quantum simulators are tied to the evolution of computational methods ranging from phenomenological approaches to full quantum state descriptions. Matrix product states (MPS) are a prominent numerical state class that has gained popularity due to the success of density-matrix renormalization group (DMRG) algorithms for ground state search. Beyond the ground state, accessing dynamic quantities and finite-temperature states realized in experiments requires methods for a state's evolution in time. Here, we present recent advances in MPS time-evolution methods based on the time-dependent variational principle (TDVP) accompanied by a subspace expansion prescription. Compared to the current state of the art, this method excels in describing challenging initial conditions, global quenches, and long (effective) interaction ranges, which are common, in particular, in (quasi) two-dimensional ultracold-atom setups. We highlight both technical aspects of the method as well as prospective use cases in the cold-atom context.

QI 13.8 Tue 12:45 F428

Confinement in doped $\mathbb{Z}_2$ lattice gauge theories — •Simon Linsel[1,2], Lukas Homeier[1,2,3], Annabelle Bohrdt[3,4], and Fabian Grusdt[1,2] — [1]Ludwig-Maximilians-Universität München, Munich. Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Harvard University, Cambridge, MA, USA — [4]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA

In proof-of-principle experiments, ultracold atoms have demonstrated that $\mathbb{Z}_2$ lattice gauge theories with dynamical matter can be studied in quantum simulators, and realistic proposals for large-scale realizations exist. Here we study the deconfinement of charges in such models, with a strong focus on observables directly accessible from snapshots generated by quantum simulators. We demonstrate that in the $\hat{\tau}^x$-basis the confined phase is characterized by localized hole pairs connected by (short) strings while deconfinement implies a global net of strings spanning over the entire lattice: We probe deconfinement with Monte Carlo simulations using percolation-inspired order parameters. Moreover, we simulate a Hamiltonian in two dimensions that is experimentally realistic. For small doping, there is a thermal deconfinement phase transition. For large doping, charges are always confined in the thermodynamic limit. For a related three-dimensional model, a thermal deconfinement phase transition exists for arbitrary doping. We map out the phase diagram and calculate the critical exponents. We speculate whether the use of percolation-inspired order parameters can be extended to the Fradkin-Shenker model and related models.

QI 14: Quantum Technologies: Color Centers II (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: F442

See Q 21 for details of this session.

QI 15: Members' Assembly

Time: Tuesday 13:15–14:00 Location: B305

All members of the Quantum Information Division are invited to participate.

QI 16: Concepts and Methods I

Time: Wednesday 11:00–13:00 Location: B302

QI 16.1 Wed 11:00 B302

Taming the Rotating Wave Approximation — •Daniel Burgarth[1,2], Paolo Facchi[3], Robin Hillier[4], and Marilena Ligabo[3] — [1]Macquarie University — [2]FAU Erlangen — [3]Bari University — [4]Lancaster University

The Rotating Wave Approximation (RWA) is one of the oldest and most successful approximations in quantum mechanics. It is often used for describing weak interactions between matter and electromagnetic radiation. In the semi-classical case, where the radiation is treated classically, it was introduced by Rabi in 1938. For the full quantum description of light-matter interactions it was introduced by Jaynes and Cummings in 1963. Despite its success, its presentation in the literature is often somewhat handwavy, which makes it hard to handle both for teaching purposes and for controlling the actual error that one gets by performing the RWA. Bounding the error is becoming increasingly important. Recent experimental advances in achieving strong light matter couplings and high photon numbers often reach regimes where the RWA is not great. At the same time, quantum technology creates growing demand for high-fidelity quantum devices, where even errors of a single percent might render a technology useless for error-corrected scalable quantum computation. I will report a conceptually simple way of explaining it and show how to tame it by providing non-perturbative error bounds, both for the semi-classical case and the full quantum case.

QI 16.2 Wed 11:15 B302

On the validity of the rotating wave approximation for interacting harmonic oscillators — •Paul Lageyre[1], Alessandro Ferreri[1], G. S. Paraoanu[2], Frank K. Wilhelm[1,3], Andreas W. Schell[4,5], and David Edward Bruschi[1,3] — [1]Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Aalto University School of Science, FI-00076 AALTO, Finland — [3]Universität des Saarlandes, 66123 Saarbrücken, Germany — [4]Leibniz Universität Hannover, 30167 Hannover, Germany — [5]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

The rotating wave approximation (RWA) is widely used in the study of the dynamics of quantum systems. Within the interaction picture, terms in the Hamiltonian modelling two (or more) coupled quantum system acquire a phase factor. The RWA prescribes that terms rotating faster in phase with time tend to average out, and thus can be neglected in respect to slower rotating ones, which dominate the dynamics. The RWA is particularly easier to prove valid if the coupling is weak enough. Regardless of the success in applying this approximation, a deeper understanding of its domains of validity and the degree of error introduced otherwise would be greatly beneficial.

In this work we quantify the deviation from the full dynamics of coupled harmonic oscillators if the RWA is applied. We employ techniques from symplectic geometry and are able to directly relate the error introduced to the squeezing-like terms in the Hamiltonian that are dropped. We compute analytical expressions for the set of pure Gaussian states and discuss further applications.

QI 16.3 Wed 11:30 B302

Using beamsplitters as analogues for quantum mechanical joint spin measurements — •Hasan Ozgur Cildiroglu — Ankara University Dögol St. 06100 Ankara/Turkiye

Beamsplitters are optical and quantum mechanical components used to split incident light or particle beam at a designated ratio into two separate beams. The use of lossless beamsplitters with phase retarders reveals essential properties. In particular, they can be used as analogues to joint spin measurements in entangled quantum systems. In this study, after investigating this special property of beamsplitters, it will be tested in various hybrid gedanken experimental setups. Thus, a new method will be introduced for experimental testing of Bell-CHSH inequalities.

QI 16.4 Wed 11:45 B302

Quantum Correlations in Molecules: From quantum resourcing to chemical bonding — •Lexin Ding[1,2], Stefan Knecht[3,4], Zoltán Zimborás[3,5,6], and Christian Schilling[1,2] — [1]Ludwig Maximilian University of Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Germany — [3]Algorithmiq Ltd., Helsinki, Finland — [4]ETH Zurich, Switzerland — [5]Wigner Research Centre for Physics, Budapest, Hungary — [6]Eötvös Lorán University, Budapest, Hungary

The second quantum revolution is all about exploiting the quantum nature of atoms and molecules to execute quantum information processing tasks. To boost this growing endeavor and by anticipating the key role of quantum chemistry therein, our work establishes a framework for systematically exploring, quantifying and dissecting correlation effects in molecules. By utilizing the geometric picture of quantum states we compare – on a unified basis and in an operationally meaningful way – total, quantum and classical correlation and entanglement in molecular ground states. To unlock and maximize the quantum informational resourcefulness of molecules an orbital optimization scheme is developed, leading to a paradigm-shifting insight: A single covalent bond equates to the entanglement 2ln(2). This novel and more versatile perspective on electronic structure suggests a generalization of valence bond theory, overcoming deficiencies of modern chemical bonding theories.

QI 16.5 Wed 12:00 B302

Witnessing quantum non-Markovianity for high-entropy states using quasi-probability distributions — •Moritz Ferdinand Richter, Irene Ada Picatoste Fernández, and Heinz-Peter Breuer — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Memory effects in the dynamics of open quantum systems can be characterized by the flow of information between the open systems and its environment [1]. Quantum non-Markovian dynamics features a flow of information from the environment back to the open system. A commonly used measure quantifying this information backflow is based on the evaluation of the trace distance between two quantum states evolving in time according to a family of quantum dynamical maps. Yet, the computation of this measure becomes increasingly demanding in case of continuous variable systems with increasing entropy of the states at hand. We present a witness for quantum non-Markovianity which is based on the Kolmogorov distance between quasi-probability distributions [2]. Furthermore, we show that this witness is particularly efficient in high-entropy scenarios, and apply it to the determination of non-Markovianity in quantum Brownian motion [3].

[1] H.-P. Breuer, E.-M. Laine, J. Piilo and B. Vacchini, Rev. Mod. Phys. 88, 021002 (2016).
[2] M. F. Richter, R. Wiedenmann and H.-P. Breuer, arXiv:2210.06058 [quant-ph].
[3] S. Einsiedler, A. Ketterer and H.-P. Breuer, Phys. Rev. A 102, 022228 (2020).

QI 16.6 Wed 12:15 B302

Trajectory Representation of non-Markovian Quantum Dynamics — •Charlotte Bäcker, Konstantin Beyer, and Walter Strunz — Technische Universität Dresden, 01062 Dresden

The Markovian evolution of quantum systems can be described with the help of the well-known GKSL master equation. Quantum non-Markovianity is often associated with some backflow of information from the environment into the system. This backflow of information is closely related to the presence of memory effects and can result in negative decay rates in Lindblad-type master equations.

We address the question of whether such memory effects have to be quantum or if they can be modelled by classical memory only. We show how to obtain non-Markovian Lindblad-type master equations with time-dependent decay rates from trajectories described by consecutive classically conditioned measurements.

QI 16.7 Wed 12:30 B302

Optimizing the atom transport of neutral atoms between distant super-lattice sites — •Cristina Cicali[1,2], Robert Zeier[1], Felix Motzoi[1], and Tommaso Calarco[1,2] — [1]Forschungszentrum Jülich,Peter Grünberg Institute, Quantum Control (PGI-8), 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany

A variety of quantum platforms have demonstrated a capacity for efficiently manipulating quantum states to simulate macroscopic properties or to implement quantum gates. High-fidelity quantum operations rely on the precise control over the quantum system in order to minimize possible error sources such as decoherence. Within the BMBF project FermiQP, we are working together with the group of Christian Groß in Tübingen, on optimizing protocols to transport via optical tweezers the neutral atoms trapped in a two-dimensional super lattice. Optimized protocols aim at maximizing the transport velocity while considering error sources coming from excitation of the motional ground state of the atom, the non-deterministic imperfections in the optical apparatus, coming from aberrations and diffraction in the tweezers, as well as the presence of further atomic wells in the lattice. We present first numerically optimized example trajectories for the atom transport and discuss potential improvements to the protocols.

QI 16.8 Wed 12:45 B302

Optical cavities based on optical Tamm states for application in quantum optics — •Manuel Goncalves — Ulm University - Inst. of Experimental Physics, Ulm, Germany

Single optical Tamm states arise on junctions of one-dimensional binary photonic crystals of different Zak phase (a topological invariant). By stacking multiple crystals of alternating Zak phase multiple photonic modes arise in the band gap. Differently from Fabry-Perot cavities, structures based on multiple optical Tamm states exhibit more modes than the number of coupled cavities. An analysis of the optical properties of the modes is presented.

These cavities can achieve large quality factors, have small mode volume, due to the short cavity length (half-wavelength), and are tunable by varying the angle of incidence of external illumination. Due to these properties, they can be used in quantum optics applications and substitute the much larger Fabry-Perot cavities.

QI 17: Quantum Networks I (joint session QI/Q)

Time: Wednesday 11:00–12:45 Location: B305

Invited Talk QI 17.1 Wed 11:00 B305

Self-testing with dishonest parties and entanglement certification in quantum networks — •Gláucia Murta[1] and Flavio Baccari[2] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann- Straße 1, Garching 85748, Germany

Multipartite entanglement is a crucial resource for network cryptographic tasks, such as secret sharing and anonymous quantum communication. Here, we consider the task of entanglement verification in a quantum network. The goal is to certify entanglement of the distributed state even when some of the parties (an unknown subset of parties in the network) may act maliciously. Our main result is a device-independent verification protocol that can certify genuine multipartite entanglement in the presence of dishonest parties. Our protocol is based on the Svetlichny inequality, and we show that the maximal violation of the Svetlichny inequality can self-test the GHZ state even in the presence of dishonest parties.

QI 17.2 Wed 11:30 B305

Extracting maximal entanglement from linear cluster states — •Jarn de Jong[1], Frederik Hahn[1], Nikolay Tcholtchev[2], Manfred Hauswirth[2], and Anna Pappa[1,2] — [1]Electrical Engineering and Computer Science Department, Technische Universitaet Berlin, 10587 Berlin, Germany — [2]Fraunhofer Institute for Open Communication Systems - FOKUS, 10589 Berlin, Germany

Most quantum information processing architectures only allow for nearest-neighbour entanglement creation. In many cases, this prevents the direct generation of maximally entangled states, which are commonly used for many communication and computation tasks. Here we show how to obtain maximally entangled GHZ states between vertices initially connected by a minimum number of connections, which specifically allows them to share linear cluster states. We prove that the largest GHZ state that a linear cluster state on n qubits can be transformed into by means of local Clifford unitaries, local Pauli measurements and classical corrections, is of size $\lfloor (n+3)/2 \rfloor$. We demonstrate exactly which qubit selection patterns are possible below this threshold and which are not, and implement the transformation on the `IBMQ Montreal` quantum device for linear cluster states of up to $n = 19$ qubits.

QI 17.3 Wed 11:45 B305

Aging effects in multiplexed quantum networks — •Lisa T. Weinbrenner[1], Lina Vandré[1], Tim Coopmans[2], and Otfried Gühne[1] — [1]Universität Siegen, Germany — [2]Universiteit Leiden, Netherlands

Aging is a well known problem which effects humans as well as technical devices. It is described by the effect that the probability for a failure in a given time interval increases with the life time of the biological or technological object. Different types of objects (e.g. humans and technical devices) age according to qualitatively different failure rates. The difference can be understood if these objects are modeled as systems of redundant parts with possibly initial defects [1].

Multiplexed quantum networks are quantum networks with multiple connections between two nodes, i.e., with redundancy in the edges of the network [2]. The functionality of the entire network depends on the functionality of the technical devices used. This leads to the question how the failure rates of the single devices lead to aging effects in the entire network. In this contribution we will apply the theory of aging to the technical devices used in a multiplexed quantum network. Our results rely on the analytical treatment of the underlying stochastic process of failure of the devices, as well as numerical simulations for different network structures.

[1] L. A. Gavrilov and N. S. Gavrilova, J. Theor. Biol. 213, 527-545 (2001)
[2] O. A. Collins et al., Phys. Rev. Lett 98, 060502 (2007)

QI 17.4 Wed 12:00 B305

Cavity-Assisted Entanglement Generation between Spins and Photon Pulses — •Ferdinand Omlor, Benedikt Tissot, and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

The reliable entanglement generation between distant nodes of a quantum network is a core challenge for the realization of quantum communication. Spin qubits contained in optical cavities are promising systems which can be interconnected by photons using fiber optics. So far the focus of theoretical studies was on single modes. We present a way to study multimode signals, in particular pulses of finite duration. This multimode character needs to be taken into account to correctly calculate the fidelity of entanglement generation between a single photon pulse and a spin qubit. We specifically study this with the network architecture proposed by K. Nemoto et al., Phys. Rev. X 4, 031022 (2014) in mind.

QI 17.5 Wed 12:15 B305

A Graphical Formalism for Entanglement Purification — •Lina Vandré and Otfried Gühne — Universität Siegen, Germany

Hypergraph states form an interesting family of multi-qubit quantum states which are useful for quantum error correction, non-locality and measurement-based quantum computing. They are a generalisation of graph and cluster states. The states can be represented by hypergraphs, where the vertices and hyperedges represent qubits and entangling gates, respectively.

For quantum information processing, one needs high-fidelity entangled states, but in practice most states are noisy. Purification protocols address this problem and provide a method to transform a certain number of copies of a noisy state into single high-fidelity state. There exists a purification protocol for hypergraph states [1]. In my talk, I will first reformulate the purification protocol in a graphical manner, which makes it intuitively understandable. Based on this, I will propose systematic extensions, which naturally arise from the graphical formalism.

[1] T. Carle et al., Phys. Rev. A 87, 012328 (2013)

QI 17.6 Wed 12:30 B305

Generation of multidimensional entanglement in quantum optical systems — •Felix Twisden-Peareth, Jan Sperling, and Polina Sharapova — Paderborn University, Warburger Str. 100 | 33098 Paderborn

Multidimensional entanglement is a key source for many quantum applications, such as quantum computing, quantum communication and quantum simulation [1].

In this work, we investigate a four-channeled quantum optical system, which is driven by two spontaneous parametric down-conversion (SPDC) sources (each emitting two photons), in order to find configurations that generate maximal entanglement. The entanglement is quantified by the Schmidt number $K = \mathrm{Tr}[\rho_r^2]^{-1}$, which is applicable to both pure and mixed states [2]. In our system, to calculate the Schmidt number, we provide reductions regarding both frequencies and spatial channels. In order to affect the entanglement, the photons in the system are manipulated regarding their polarization and relative position by introducing a time delay. It was found that Schmidt numbers equal to the dimensionality of the system can be generated. For this, the generation of a coherent superposition of different polarizations is provided, which is followed by a temporal separation of its parts. All results are calculated for the material system $LiNbO_3$.

[1] J. Wang, et al., Multidimensional quantum entanglementwith large-scale integrated optics, Science **360**, 285*291 (2018).
[2] B. M. Terhal and P. Horodecki, Schmidt number for density matrices, Physical Review A **61**, 040301 (2000).

QI 18: Quantum Technologies: Trapped Ions (joint session Q/QI)

Time: Wednesday 11:00–13:00 Location: F342

See Q 28 for details of this session.

QI 19: Implementations: Ions and Atoms (joint session QI/Q)

Time: Wednesday 11:00–13:00 Location: F428

Invited Talk QI 19.1 Wed 11:00 F428

Experimental quantum error correction with trapped ions — •Philipp Schindler — University of Innsbruck

For large-scale quantum computing, effective quantum error correction will be mandatory. Current, small-scale experiments can be used to validate assumptions on the physical errors in the system that are required for fault-tolerant operation. I will report on our experimental efforts towards fault-tolerant quantum information processing in our trapped-ion platform. In particular, I will discuss the implementation of a fault tolerant universal set of logical operations. The results from these experiments are used to inform the development of large scale ion-trap quantum devices.

QI 19.2 Wed 11:30 F428

Towards an entangling gate between bosonic qubits in trapped ions — •Stephan Welte, Martin Wagener, Moritz Fontbote-Schmidt, Hendrik Timme, Luca Hermann, Ralf Berner, Edgar Brucke, Paul Röggla, Ivan Rojkov, Florentin Reiter, and Jonathan Home — ETH Zurich, Zurich, Switzerland

Encoding quantum information in a harmonic oscillator provides a resource-efficient platform for quantum error correction. A promising code is Gottesman-Kitaev-Preskill (GKP) encoding [1], which has been realized both in trapped ions [2, 3] and superconducting qubits [4]. State preparation, single qubits rotations, readout, and error correction have been realized in both architectures. However, a universal two-qubit gate has not yet been realized. We will describe our work on such an entangling gate between GKP qubits prepared in the motional modes of calcium ions in a Paul trap. The modes are coupled via the Coulomb interaction approximating a beam splitter interaction. Together with squeezing operations, this interaction can realize the desired universal gate. In theoretical work, we investigate this gate for experimentally realistic parameters and finite energy states. In parallel, we are developing an apparatus for an experimental implementation, including the fabrication of a novel ion trap and the implementation of individual addressing with tightly focused laser beams.

[1] D. Gottesman, A. Kitaev, and J. Preskill. PRA 64, 012310 (2001) [2] C. Flühmann et al. Nature 566, 513(2019) [3] B. de Neeve et al. Nat. Phys. 18, 296 (2022) [4] V. Sivak et al. arXiv 2211.09116 (2022)

QI 19.3 Wed 11:45 F428

A universal two-qubit computational register for trapped-ion quantum processors — •Nicolas Pulido-Mateo[1,2], Hardik Mendpara[1,2], Markus Duwe[1,2], Giorgio Zarantonello[1,2,3], Amado Bautista-Salvador[1,2], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA

Here we report on the realization of a two qubit universal computational register compatible with the QCCD architecture [1]. Single qubit gates are performed by addressing each ion individually via a micromotion sideband [2]. The entangling operation is implemented using an MS-type interaction, where we measure an infidelity that approaches 10^{-3} [3] when using partial state tomography. To characterize the single qubit gates we use a randomized benchmarking protocol [4] and obtain an infidelity of $3.8(4) \times 10^{-3}$. We perform a characterization of the register by means of the cycle benchmarking protocol [5] obtaining, as a preliminary result, a composite process fidelity of 96.6(4) %. Finally we use simulation software for quantum open systems to model possible error sources and calculate an error budget.

[1] D. Kielpinski *et al.*, Nature **417**, 709 (2002).
[2] U. Warring *et al.*, Phys. Rev. Lett. **17**, 173002 (2013)
[3] M. Duwe *et al.*, Quantum Sci. Technol. **7**, 045005 (2022)
[4] C. Piltz *et al.*, Nature Communications **5**, 4679 (2014).
[5] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)

QI 19.4 Wed 12:00 F428

Coherent Control of Trapped Ion Qubits with Localized Electric Fields — •Raghavendra Srinivas[1,2], Clemens Löschnauer[1], Maciej Malinowski[1], Amy Hughes[1], Rustin Nourshargh[1], Vlad Negnevitsky[1], David Allcock[1,3], Steven King[1], Clemens Matthiesen[1], Thomas Harty[1], and Chris Ballance[1,2] — [1]Oxford Ionics — [2]University of Oxford — [3]University of Oregon, Eugene

We present a new method for coherent control of trapped ion qubits in separate interaction regions of a multi-zone trap by simultaneously applying an electric field and a spin-dependent gradient. Both the phase and amplitude of the effective single-qubit rotation depend on the electric field, which can be localised to each zone. We demonstrate this interaction on a single ion using both laser-based and magnetic field gradients in a surface-electrode ion trap, and measure the localisation of the electric field.

[1] arXiv:2210.16129

QI 19.5 Wed 12:15 F428

Entangling scheme for Rydberg ion crystals using electric kicks in radial direction — •Han Bao[1], Jonas Vogel[1], Alexander Schulze-Makuch[1], Ulrich Poschinger[1], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

Due to the strong dipole interaction between Rydberg atoms, fast entangling gates have been achieved both in neutral atoms [1] and trapped ions [2]. A second unique feature of Rydberg states is their high electric polarizability. For trapped ions, Rydberg states electric polarizability may lead to a change of the secular frequency [3]. Such state dependent secular frequency can establish entanglement [4]. Here, we show that using electric kicks in the radial direction demands a 100 times lower voltage, thus much more feasible for an experimental realization. Accordingly, as lower motional are transiently excited only, the scheme becomes more robust. We also show scaling the method up for larger ions crystals, using a complex sequence of electric kicks, such that finally the motion state is recovered back.

We discuss the status of the experimental realization the electric kick entanglement generation.

[1]Levine et al., *Phys. Rev. Lett.* **123**, 170503 (2019)
[2]Zhang et al., *Nature* **580**, 345 (2020)
[3]Schmidt-Kaler et al., *New J. Phys.* **13**, 075014 (2011)
[4]Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019)

QI 19.6 Wed 12:30 F428

Coherent transfer of transverse optical momentum to the motion of a single trapped ion — •Felix Stopp[1], Maurizio Verde[1], Milton Katz[2], Martín Drechsler[2], Christian Schmiegelow[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]CONICET, Instituto de Física de Buenos Aires (IFIBA), Universidad de Buenos Aires, Buenos Aires, Argentina

A structured light beam is carrying orbital angular momentum and we demonstrate the excitation of the center of mass motion of a single atom in the transverse direction to the beam's propagation. This interaction is achieved with a vortex beam carrying one unit of orbital angular momentum and one unit of spin angular momentum. Using a singly charged $^{40}Ca^{+}$ ion, cooled near the ground state of motion in the three-dimensional harmonic potential of a Paul trap, we probe the sidebands of the $S_{1/2}$ to $D_{5/2}$ transition near 729 nm to quantify the momentum transfer. Exchange of quanta in the perpendicular direction to the beam's wave vector k is observed in case of centered a vortex shaped beam, while parasitic carrier excitation is reduced by a factor 40. This is in sharp contrast to the vanishing spin-motion coupling at the center of Gaussian beam. We characterize the coherent interaction by an effective transverse Lamb-Dicke factor $\eta_\perp^{\mathrm{exp}} = 0.0062(5)$ which is in agreement with our theoretical prediction $\eta_\perp^{\mathrm{theo}} = 0.0057(1)$ [1]. Finally we discuss the application of our finding for quantum information processing with trapped ion crystals.

[1] accepted Paper 22 November 2022: Phys. Rev. Lett.

QI 19.7 Wed 12:45 F428

Lasersystem for Control of Magnsium Atoms — •Tobias Spanke, Lennart Guth, Philip Kiefer, Lucas Eisenhart, Deviprasath Palani, Apurba Das, Florian Hasse, Jörn Denter, Mario Niebuhr, Ulrich Warring, and Tobias Schätz — Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg

Trapped ions present a promising platform for quantum simulations. Versatile and robust laser systems with narrow bandwidth and high power and intensity stability are required for reliable control of this platform. The latest systems for Mg^{+}, Be^{+} ions are based on vertical external cavity surface emitting lasers (VECSEL)[1] in the near-infrared. We are testing new compact cooling systems with impact on short-term frequency stability using commercially available PC parts. With the goal of measuring magnesium ions at a frequency stability of 200 kHz ($\lambda \approx 1120$ nm, P=2 W) with high accuracy. We aim at further development of the VECSEL into a compact, stable and user-friendly "turnkey" system.

[1]Burd, S. et al.(2016), VECSEL systems for generation and manipulation of trapped magnesium ions, Optica Vol. 3, Issue 12, pp. 1294-1299 (2016)

QI 20: Concepts and Methods II

Time: Wednesday 14:30–16:30 Location: B302

QI 20.1 Wed 14:30 B302

Entropy and catalysis — •Henrik Wilming — Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

I discuss the solution of the "catalytic entropy conjecture", showing that von Neumann entropy can be characterized in the following way: Non-decreasing entropy provides a necessary and sufficient condition to convert the state of a physical system into a different state by a reversible (unitary) transformation that acts on the system of interest and a further, finite-dimenaionsal, "catalyst" whose state has to remain invariant exactly under the unitary time-evolution.

QI 20.2 Wed 14:45 B302

Foundations of fermionic particle correlations — •Damiano Aliverti-Piuri, Kaustav Chatterjee, Lexin Ding, and Christian Schilling — LMU University, Faculty of Physics, Munich

Multipartite systems are an essential topic in Quantum information theory, and a comprehensive theory has been developed regarding the several kinds of correlations they can exhibit. Such correlations, especially entanglement, are both interesting on a theoretical level, and useful for quantum processing tasks. Our starting point is the well-established definitions of uncorrelated, classically correlated, and unentangled states of multipartite systems - for example, distinguishable particles. To these three sets of states correspond three correlation measures, based on geometric ideas: total correlation, quantum correlation, and relative entropy of entanglement. Inspired by recent work by other authors (Gigena and Rossignoli; Gottlieb and Mauser), we propose a systematic approach towards particle correlations in systems of *indistinguishable* particles, with an emphasis on fermions. We (i) give definitions of types of increasingly correlated fermionic states, and of the respective geometric correlation measures; (ii) motivate our definitions from the point of view of Resource theory; (iii) study some promising properties of these states and measures; (iv) obtain analytical formulas for 2-fermion systems and other simple cases.

QI 20.3 Wed 15:00 B302

Resource Theory of Fermionic Correlation — •Kaustav Chatterjee, Damiano Aliverti Piuri, Lexin Ding, and Christian Schilling — Faculty of Physics, Arnold Sommerfeld Centre for Theoretical Physics, Ludwig-Maximilian-University of Munich, Germany

Resource theories are a generic approach used to manage any valuable resource, such as entanglement, purity and asymmetry. Such settings provide a novel framework to discuss information theoretic tasks like quantum state transformations and characterizing the utility of quantum states with respect to some resource measure. Analogous to resource theories of correlations and entanglement for distinguishable parties, we establish a hierarchy of resource theories for indistinguishable fermionic systems where each theory corresponds to a specific resource involving fermionic total correlation, fermionic quantum correlation or fermionic entanglement. In our theory, easily implementable operations (the free operations) are related to the set of fermionic linear optics (FLO) operations and their extensions, which naturally selects out the subset of Gaussian states as a candidate for free states in particular case where the resource is fermionic total correlations. We also introduce monotones (based on quantum relative entropy) to quantify the hierarchy of resources and explore quantum state transformation properties under such theories. We further comment on efficient classical simulation of our free operations and reveal how non-free resource states can be connected to the idea of complexity of fermionic sampling

QI 20.4 Wed 15:15 B302

Continuity of robustness measures in quantum resource theories — Jonathan Schluck, Gláucia Murta, Hermann Kampermann, Dagmar Bruss, and •Nikolai Wyderka — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Robustness measures provide an intuitive and operational way to quantify resources in quantum resource theories, such as entanglement and coherence. Despite exhibiting useful mathematical properties like monotonicity, the use of robustness measures is hindered by the fact that some of their properties like continuity remain unclear, in particular when the set of resource-free states is nonconvex. To that end, we investigate continuity properties of different robustness measures by showing that their continuity depends on the shape of the set of free states. In particular, we show that in many cases star-convexity is sufficient for Lipschitz-continuity, and we provide specific examples of sets leading to noncontinuous robustness measures. Finally, we illustrate the applicability of our results by introducing the robustness of teleportation fidelity and by deriving bounds on the robustness of quantum discord.

QI 20.5 Wed 15:30 B302

Graph state preparation with noisy interactions — •Konrad Szymanski — Universität Siegen, Siegen, Germany

Graph states are regarded as a testing ground of various quantum information schemes – they are useful in analysis of e.g. cryptography, measurement-based quantum computation, error correction, and metrology. Their preparation relies on the interaction pattern provided by a graph – an Ising-like Hamiltonian $\hat{H}$ is built from it and the *graph state* is the result of evolution of the multiqubit $|+\rangle^{\otimes N}$ state under $\hat{H}$. Due to the simplicity, implementation is possible for a wide array of physical systems, including ion traps, nitrogen vacancies, and superconducting qubits.

However, such realizations invariably suffer from noise, which presents itself in a multitude of ways: the engineered interactions may have imperfect strengths, additional transitions may arise, and the systems rarely can be protected from coupling with the outside world.

All of these contribute to the reduced utility of the produced quantum states. Here, I investigate the effects of *preparation noise* in this context. In particular, imperfect interaction strengths effectively lead to an *ensemble* of graph states being prepared, which still possess some of the desirable qualities of the *perfectly prepared* state. Theoretical considerations are compared with real-world implementations of graph states.

QI 20.6 Wed 15:45 B302

Computational Complexity in Functional Theory — •Lukas Kienesberger, Julia Liebert, and Christian Schilling — University of Munich (LMU), Munich, Germany

Using tools from quantum information theory, we investigate the computational complexity of calculating the universal energy functional in functional theories. Firstly, we prove for the two-fermion Hubbard model that the space of density matrices constituting the functional's domain decomposes into exponentially many regions, separated by submanifolds where the functional fails to be analytic. As our second main result, we show that determining the functional itself on those cells is weakly np-complete. We demonstrate how these findings contradict the generally accepted assumption of a single analytic functional. Third, we analyze and quantify the relations between the number of subdomains and the spectrum of a generic interaction.

QI 20.7 Wed 16:00 B302

On a Matrix Ensemble for Arbitrary Complex Quantum Systems — William Salazar and •Javier Madroñero — Centre for Bioinformatics and Photonics (CIBioFi), Universidad del Valle, Cali, Colombia

We propose a specific system dependent matrix ensemble as an alternative to the unitary Haar one as a model for the study of the late time dynamics of correlation functions in arbitrary complex quantum systems. We show that for arbitrary systems this ensemble yields an unitary 1-design and for strongly chaotic systems it becomes an approximated 2-design. We are able to provide universal expressions for two- and four-point ensemble-averaged correlation functions. Additionally, we show that for small energy windows our ensemble reduces to the eigenstate thermalization hypothesis.

QI 20.8 Wed 16:15 B302

Exact Unification of Spacetime, Gravity and Quanta — •Hans-Otto Carmesin — Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

Quantum physics, QP, and its relation to general relativity, GR, provide an exciting problem of physics [1]. That problem is solved as follows [2]: Firstly, a quadruple of four basic principles, the spacetime quadruple, SQ, is identified: Gaussian gravity, special relativity, the equivalence principle and the physical reality of cosmological vacuum. In particular, we introduce a measurement of a gravitational parallax distance r by using a pair of hand leads. So, that distance is an element of physical reality. Secondly, the dynamics of cosmological vacuum, VD, is derived from the SQ. Thirdly, the postulates [3] of quantum physics and GR are derived from VD. Fourthly, solutions for the essential paradoxes of QP are provided. In particular, consequences for quantum information are discussed.

[1] Einstein, A. and Podolski, B. and Rosen, N. (1935): Can the quantum-mechanical description of physical reality be considered complete? Phys. Rev., 47, pp. 777-780.
[2] Carmesin, H.-O. (December 2022): Unification of Spacetime, Gravity and Quanta. Berlin: Verlag Dr. Köster.
[3] Ballentine, L. (1998): Quantum Mechanics. London - Singapore: World Scientific Publishing.

QI 21: Quantum Communication II (joint session QI/Q)

Time: Wednesday 14:30–16:30 Location: B305

Invited Talk QI 21.1 Wed 14:30 B305

Qube and Qube-II – Towards Quantum Key Distribution with Small Satellites — •Lukas Knips for the Qube/Qube-II-Collaboration — Ludwig Maximilian University (LMU), Schellingstr. 4, D-80799 Munich, Germany — Max Planck Institute of Quantum Optics (MPQ), Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 Munich, Germany

Quantum Key Distribution (QKD) is a provably secure method for distributing secret keys between two trusted parties over a quantum channel for symmetric cryptography. As demonstrated by the Chinese satellite MICIUS, exchange of a secure key between a satellite and an optical ground station is possible, thereby indeed enabling QKD on a global scale. While this large satellite demonstrated its feasibility, the QUBE missions are focussing on a more economic solution for global key exchange.

In this talk, I will start with an overview of the first QUBE satellite, a so-called CubeSat with a size of only $30 \times 10 \times 10\ \mathrm{cm}^3$ and consequently with severe limitations on available power and space. The satellite includes two different quantum state sources and a quantum random number generator and is now ready for launch. QUBE will test performance and space readiness of those components. QUBE-II, a second satellite, is currently being designed and will be able to exchange a key mainly thanks to a much larger optical telescope with an optical aperture of about 80 mm and to a full QKD post-processing over an optical data communication channel.

QI 21.2 Wed 15:00 B305

Security of Time-Frequency Quantum Key Distribution — •Federico Grasselli, Nikolai Wyderka, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf

One of the current drawbacks of Quantum key distribution (QKD) are the relatively low generation rates of secret keys, hindered by effects such as noise in the quantum channel and detector saturation. Such issues can be alleviated by increasing the dimension of the encoding space with time-frequency QKD, where log2(d) bits of information are encoded in 'd' time bins of a single photon, thereby increasing the efficiency of the communication.

We focus on a specific experimental implementation of time-frequency QKD that can be easily scaled to higher dimensions. For this setup, we discuss a method to prove its security by closing a critical loophole that has been often overlooked in QKD implementations based on the photons' temporal degree of freedom. Moreover, we provide preliminary experimental data demonstrating that our security method can be applied to practical time-frequency QKD setups.

QI 21.3 Wed 15:15 B305

Multipartite measurement device-independent quantum key distribution with quantum memories — •Julia Alina Kunzelmann, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf

Quantum repeaters build a useful tool to increase the communication distance in quantum networks. To achieve higher repeater rates, multiplexing between quantum memories can be used. We generalize the multiplexing scheme for quantum repeaters to N parties where the station performs GHZ measurements. This setup is used for measurement device-independent conference key agreement. In this work, we present a protocol that allows the distribution of a secret key in a multipartite star network via one central repeater station. We analyze the secret key rate of the protocol depending on various protocol parameters.

QI 21.4 Wed 15:30 B305

Easy-to-compute local Clifford invariants for graph states — •Frederik Hahn[1] and Adam Burchardt[2,3,4] — [1]Technische Universität Berlin, Berlin, Deutschland — [2]Universität Amsterdam, Amsterdam, Niederlande — [3]QuSoft, Amsterdam, Niederlande — [4]CWI, Amsterdam, Niederlande

In this work, we study easy-to-compute LC-invariants of graph states. Although previous studies have already led to finite sets of invariants that fully characterize the LC-equivalence classes of graph states, these invariants are computationally inefficient. Their computation requires knowledge of the given state's full stabilizer set, which is exponential in the number of its qubits n.

In this paper, without the need to calculate this entire stabilizer set, we instead present an easy-to-calculate LC-invariant of order O(n^3). It is closely related to the so-called foliage of a graph and has a simple graphical interpretation in terms of leaves, axils, and twins: For any graph, we define a partition of the set of its vertices based on a simple equivalence relation and call it the foliage partition of this graph. We further show that foliage partitions remain invariant under any local complementation of the corresponding graph. Foliage partitions then represent simple LC-invariants for graph states, since there is a one-to-one correspondence between LC-operations on a graph state and local complementations of its graph. Finally, we generalize foliage partitions from qubits to qudits and prove their invariance under the generalized local complementation operations.

QI 21.5 Wed 15:45 B305

Towards consumer-level quantum-secure cryptography - Entanglement based short-range Quantum Key Distribution — •Henning Mollenhauer[1], Daniel Tippel[1], Pius Gerisch[1], Donika Imeri[1,2], and Ralf Riedinger[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg

Many schemes for Quantum Key Distribution (QKD) have been proposed and realized over the years. A common challenge that arises in experimental implementations is the exponential loss of photons in quantum channels over long distances. Solutions to this challenge like purification protocols with quantum repeaters have not to date been efficiently implemented. A different approach to QKD is the key distribution over a short distance- and therefore low-loss- quantum channel. QKD over short distances can be used to exchange an information-theoretically secure root-of-trust that is safely stored on two end modules. Based on the root-of-trust, keys for encryption are generated in re-keying schemes on each end module. With this approach, it is possible to spatially separate the end modules and communicate classically over already existing communication infrastructure. Since no quantum channel is involved in the actual process of communication, encrypted messages can be sent between end modules over arbitrary distances. We here present an experimental setup that aims to realize short-distance QKD with end modules that in the future could be made compact enough to be implemented on small silicone-based chips.

QI 21.6 Wed 16:00 B305

A theoretical and experimental analysis of the single-photon advantage in quantum coin flipping — •Fenja Drauschke[1,2], Daniel A. Vajner[1], Tobias Heindel[1], and Anna Pappa[2] — [1]Institut für Festkörperphysik, TU Berlin — [2]Institut für Softwaretechnik und Theoretische Informatik, TU Berlin

Quantum coin flipping is a prominent cryptographic primitive within the framework of non-collaborative models, where two or more distrustful parties want to perform a fair coin flip. The parties are separated by a distance and wish to agree on a random bit. Quantum coin flipping has raised much interest recently, as it has various applications and holds enormous potential for improving the security of secure communications. At the same time, the use of single-photon sources for quantum communication setups is also attracting a lot of attention as it promises further security advantages compared to the usage of weak coherent laser pulses. In this work, we investigate the advantage of using single-photon sources compared to weak coherent pulses for different quantum communication setups of coin flipping in a theoretical, as well as experimental approach.

QI 21.7 Wed 16:15 B305

Optimization and readout-noise analysis of a hot vapor EIT memory on the Cs D1 line — •Luisa Esguerra[1,2], Leon Messner[1,3], Elizabeth Robertson[1,2], Norman Vincenz Ewald[1], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany.

Efficient, noise-free quantum memories are indispensable components for the realization of quantum repeaters, which will be crucial for long distance quantum communication [1, 2]. We have realized a technologically simple, in principle satellite-suited quantum memory in Cesium vapor, based on electromagnetically induced transparency (EIT) on the ground states of the Cs D1 line [3]. We focus on the simultaneous optimization of end-to-end efficiency and signal-to-noise level in the memory, and have achieved light storage at the single-photon level with end-to-end efficiencies up to 13(2)%. Simultaneously we achieve a minimal noise level corresponding to $\bar{\mu}_1 = 0.07(2)$ signal photons, for which we present strategies for further minimization. Furthermore, improvements for the next implementation of the experiment are introduced.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] J. Wallnöfer et al., Commun Phys 5, 169 (2022)
[3] L. Esguerra, et al., arXiv:2203.06151 (2022)

QI 22: Quantum Technologies II (joint session Q/MO/QI)

Time: Wednesday 14:30–16:30 Location: E214

See Q 36 for details of this session.

QI 23: Poster II (joint session QI/Q)

Time: Wednesday 16:30–19:00 Location: Empore Lichthof

QI 23.1 Wed 16:30 Empore Lichthof

New techniques to improve zero-noise extrapolation on superconducting qubits — •Kathrin Koenig[1,2], Thomas Wellens[1], and Finn Reinecke[1,2] — [1]Fraunhofer IAF, Freiburg, Germany — [2]University of Freiburg, Germany

Currently available quantum computing hardware suffers from errors due to environmental influences, nearest-neighbour interactions and imperfect gate operations. To achieve robust quantum computing, there are techniques like error mitigation by zero-noise extrapolation [1]. We propose a method for estimating the strength of the error occurring in a given quantum circuit in order to improve the result of this extrapolation. Furthermore, the impact of gate errors on observable expectation values can be reduced by noise tailoring, which converts arbitrary errors into stochastic Pauli errors [2]. Using these techniques, we elaborate on the implementation of error mitigation on a superconducting quantum computer and its impact on the computation of expectation values.

[1] He, A. et al., Zero-noise extrapolation for quantum-gate error mitigation with identity insertions, Phys. Rev. A 102, 012426 (2020)

[2] Wallman, J. J.; Emerson, J., Noise tailoring for scalable quantum computation via randomized compiling, Phys.Rev. A 94, 052325 (2016)

QI 23.2 Wed 16:30 Empore Lichthof

Introducing Non-Linear Activations into Quantum Generative Models — •Mykolas Sveistrys[1,2], Kaitlin Gili[2], and Chris Ballance[2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Department of Physics, University of Oxford, Clarendon Laboratory, Parks Road, Oxford OX1 3PU, U.K.

One prominent difference between most classical generative models and current quantum ones is linearity: classical neural-network-based models require non-linear activations for quality training, while embedding such activations in quantum models is challenging due to the linearity of quantum mechanics. We introduce a quantum generative model that adds non-linear activations via a neural network structure onto the standard Born Machine framework - the Quantum Neuron Born Machine (QNBM). We utilize a previously introduced Quantum Neuron subroutine, which is a repeat-until-success circuit with mid-circuit measurements and classical control. We then compare the QNBM to the linear Quantum Circuit Born Machine (QCBM). With gradient-based training, we show that while both models can easily learn a trivial uniform probability distribution, on a more challenging class of distributions, the QNBM achieves an almost 3x smaller error rate than a QCBM with a similar number of tunable parameters. We therefore provide evidence that suggests that non-linearity is a useful resource in quantum generative models, and we put forth the QNBM as a new model with good generative performance and potential for quantum advantage.

QI 23.3 Wed 16:30 Empore Lichthof

Quantum low-precision neural networks and their classical counterparts — •Felix Soest, Konstantin Beyer, and Walter Strunz — Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany

With increasing accessibility of quantum computing devices and the successes of classical machine learning, efforts have been made to combine the two. Whether using quantum resources can provide an advantage to trainability or generalisability remains an open question, as the size of classical neural networks is much larger than what current quantum technologies can offer. Moreover, a clear indication of a quantum advantage is usually hard to identify. An often considered ansatz is that of parametrised unitaries, where the quantum machine learning model comprises multiple layers the parameters of which are trained classically. It has recently been shown that these models have classical surrogates [1], allowing for a classical benchmark to compare these models to. However, classical feed-forward neural networks can in general not be mapped to unitaries, in part due to the lack of irreversibility. Therefore we aim to construct a framework using intermediate measurements which has a classical counterpart. The resulting network is a parametrised quantum channel that allows us to reproduce classical low-precision networks as a special case. Allowing for quantum operations in this framework extends the classical regime, providing a good benchmark.

[1] Schreiber et al. arXiv:2206.11740

QI 23.4 Wed 16:30 Empore Lichthof

Learning Quantum Processes — Kerstin Beer[1], Dmytro Bondarenko[1,2], Terry Farelly[1], Younes Javanmard[1], Tobias J. Osborne[1], Debora Ramaciotti[1], Nils Renziehausen[1], Robert Salzmann[1,3], •Viktoria-Sophie Schmiesing[1], Robin Syring[1], Nils Zolitschka[1], and Ramona Wolf[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover — [2]Stewart Blusson Quantum Matter Institute, University of British Columbia — [3]Department of Applied Mathematics and Theoretical Physics, University of Cambridge

Machine learning and quantum computing are both emerging topics of research. In this poster, we tackle the issue of learning quantum processes. To do so, we use dissipative quantum neural networks.

QI 23.5 Wed 16:30 Empore Lichthof

Exact Qubit Resonance Calibration and Power Narrowing — •Ivo Mihov and Nikolay Vitanov — Department of Physics, St Kliment Ohridski University of Sofia, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

At resonance, pulse shapes do not affect the population transfer; nevertheless, pulse shapes play a vital role in shaping the resonance response curves of a qubit. The response curves react differently to Rabi frequency increases, where some exhibit power broadening (e.g. rectangular pulses) but other ones do not change their width. In this work, the experimental frequency response curves of various pulse shapes were validated against theoretical predictions. Also, the effects of symmetrical truncation of Lorentzian-shaped pulses to different degrees were examined. More significantly, a solid power narrowing pattern was observed in Lorentzian pulses.

QI 23.6 Wed 16:30 Empore Lichthof

The QuMIC project - Towards a scalable ion trap with integrated high-frequency control — •Sebastian Halama[1] and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Ion traps are a promising candidate for a scalable quantum computer [1]. A major challenge is the integration of qubit control into the device. With the microwave near-field approach [2], qubit control realized by microwave conductors that are integrated into the ion trap naturally scale with the trap itself. However, the microwave signal generation currently takes place outside of the vacuum chamber in which the ion trap is located. The QuMIC project researches and develops novel highly integrated BiCMOS chips at high frequencies and their hybrid integration with quantum electronics like ion traps. This approach enables the scalability of a quantum computer to a large number of qubits and a drastic reduction in the number of required high-frequency lines, which also benefits the cooling capabilities of the cryostat used to cool down the ion trap to around 4 K. We describe the setup of a cryogenic ion trap apparatus for rapid testing of traps, such as the ion traps with integrated microwave sources developed for QuMIC. We will report on the current status of the project.

[1] Chiaverini et al., Quantum Inf Comput **5**, 419-439 (2005)

[2] Ospelkaus et al., Phys. Rev. Lett. **101**, 090502 (2008)

QI 23.7 Wed 16:30 Empore Lichthof

Tailored based composite pulses for NV-color centers towards the realization of ensembles-based quantum tokens — •Jan Thieme, Josselin Bernardoff, Ricky-Joe Plate, and Kilian Singer — Experimentalphysik I, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel

We present numerical and experimental results of the application of tailored composite pulses [1] to shape the excitation profile addressing only selected resonances of quantum states in the system. By using analytical methods applied to the Rosen-Zener excitation model [2], we derive excitation profiles for a broadband excitation profile with respect to detuning and pulse duration. Towards this goal we are using an arbitrary waveform generator to supply these pulses to single nitrogen-vacancy color centers [3]. In the outlook we will describe how this scheme is relevant for the realization of ensemble-based quantum tokens [4].

[1] B. T. Torosov and N. V. Vitanov, Phys. Rev. A 83, 053420 (2011). [2] N. Rosen and C. Zener, Phys. Rev. 40, 502 (1932). [3] A. Schmidt, J. Bernardoff, K. Singer, J. P. Reithmaier and C. Popov, Physica Status Solidi A, 216, 1900233 (2019). [4] https://www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/diqtok

QI 23.8 Wed 16:30 Empore Lichthof

Quantum speed limit dependence on the number of controls in a qubit array. — •David Pohl, Fernando Gago-Encinas, and Christiane P. Koch — Arnimallee 14, 14195 Berlin

Qubit arrays form the basic unit of quantum computers. As such, it is desirable to be able to manipulate each qubit as needed. However, including a local control on every qubit is not scalable to a large number of qubits. On the other hand, reducing the number of controls might be sufficient for manipulation but slow down the implementation of quantum gates, bringing the system closer to the decoherence limit. Here, we investigate how quickly quantum gates can be implemented depending on the number of local controls. In particular, we show how the quantum speed limit (the shortest time to generate a quantum gate) increases when reducing the number of controls. We determine this limit for a universal set of gates for different 3-qubit systems using Krotov's optimization method.

QI 23.9 Wed 16:30 Empore Lichthof

Towards realizing an ultra-high vacuum chamber and experimental control of trapped ion systems using surface traps. — •Maharshi Pran Bora, Ulrich Warring, Florian Hasse, Deviprasath Palani, Phillip Kiefer, Apurba Das, Lucas Eisenhart, Tobias Spanke, and Tobias Schaetz — Physikalisches Institut, Freiburg, Albert-Ludwigs-Universität, Deutschland

Trapped ion systems are promising platforms for realizing quantum systems for quantum simulations and quantum information processing.The scalability and performance of these trapped ion systems depends crucially on the vacuum apparatus in which the trap is operated in and also on the efficiency and robustness of the experimental control of these systems. The project firstly aims at designing and characterizing an ultra-high vacuum chamber for the Phoenix surface trap produced at the Sandia National Laboratories . The Phoenix trap is a state of the art linear surface trap with high optical access. The scope of the project will include reaching an vacuum pressure of less than 10^{-9} Pa and consideration of an optimum design for the proper functioning of the trap . Secondly, to attain better experimental control, addressing of individual ions with a local beam using piezo devices will be also explored in this project . The calibration and characterization of the piezo driven platform will be reported. Hence, this project will aim at providing an improved understanding of the impact of UHV design and experimental control on the quality of operation of trapped ion systems.

QI 23.10 Wed 16:30 Empore Lichthof

Towards Quantum Control of Calcium Ions for the use in Molecular Spectroscopy — •Manika Bhardwaj, Josselin Bernardoff, Jan Thieme, Daqing Wang, and Kilian Singer — Experimentalphysik I, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel

We are building a measurement methodology for selective spectroscopy of long-lived states with a calcium ion. We want to use binary search on the $4^2S_{1/2}$-$3^2D_{5/2}$ transition of the calcium atom for the resonance search. Through the use of composite pulses techniques, we will change the narrow excitation profile with a passband pulse [1] for binary search. The final goal is to employ this method to identify the long-lived states of the lanthanoid molecular ions [2] targeting their use in molecular quantum information processing platforms.

References:

[1] B. T. Torosov, and N. V. Vitanov, Physical Review A 83, 053420 (2011).

[2] K. Groot-Berning, T. Kornher, G. Jacob, F. Stopp, S. T. Dawkins, R. Kolesov, J. Wrachtrup, K. Singer, and F. Schmidt-Kaler, Physical Review Letters 123, (2019).

QI 23.11 Wed 16:30 Empore Lichthof

Optimising gate performance of transmon qubits coupled by a central tunable bus — •Alexander Möller[1,2], Matthias G. Krauss[2], Daniel Basilewitsch[2,3], and Christiane P. Koch[2] — [1]Technische Universität Berlin, Berlin, Germany — [2]Freie Universität Berlin, Berlin, Germany — [3]Universität Innsbruck, Innsbruck, Austria

For transmon qubits coupled via a transmission line cavity, optimal control theory (OCT) has identified the quasi-dispersive regime to be optimal for universal quantum computing. For a single control driving the harmonic coupler, both local and entangling gates can be implemented with high fidelity and short gate durations [Goerz et al., *npj Quantum Information* **3**, 37 (2017)]. In an analogous manner we aim at exploring the transmon parameter landscape for a system of two transmons addressed by a third transmon acting as a tunable bus. We investigate how the anharmonicity of this central coupler affects the implemented gates and the OCT optimisation. Here we especially focus on the controllability of the two-transmon-subsystem as well as the achievable gates for different pulse durations and from this determine their respective quantum speed limit. Furthermore, we present an effective analytical model for the coupling between the outer transmons.

QI 23.12 Wed 16:30 Empore Lichthof

Single qubit gate optimization based on ORBIT cost functions — •Catharina Broocks[1,2], Max Werninghaus[1], Niklas Glaser[1,2], Federico Roy[1,3], and Stefan Filipp[1,2,4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik Department, Technische Universität München, Garching, Germany — [3]Theoretical Physics, Saarland University, Saarbrücken, Germany — [4]Munich Center for Quantum Science and Technologies (MCQST), Munich, Germany

Analytic control solutions for qubit gates are limited by the knowledge about modeled experimental hardware properties. To achieve high-fidelity gates for superconducting qubit devices, we optimize pulse parameters of analytic solutions with respect to experimental feedback loops. As cost function the ground state population after a net-identity series of Clifford gates is used. For small parameter sets, the parameter-landscape can serve as a reference to verify numerical system models and provide insight into the sensitivity and correlation of individual parameters. To find an optimal parameter configuration, we apply simultaneous multi-parameter optimization of single-qubit gates in form of CMA-ES closed-loop optimization. We analyze the behavior of the optimization algorithm when using features such as sensitivity adjustment, influence of various noise contributions and the design of the cost function to achieve a reliable and complete convergence of the algorithm. The optimization routine can then be used to verify and address various optimal control problems, such as robustness and avoidance of leakage out of the qubit subspace.

QI 23.13 Wed 16:30 Empore Lichthof

Predicting the minimum control time of quantum protocols with artificial neural networks — •Sofia Sevitz[1], Nicolás Mirkin[1], and Diego A. Wisniacki[1,2] — [1]Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, Buenos Aires, Argentina — [2]CONICET - Universidad de Buenos Aires, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires, Argentina

Quantum control relies on the driving of quantum states without the loss of coherence, thus the leakage of quantum properties onto the environment over time is a fundamental challenge. One work-around is to implement fast protocols, hence the Minimal Control Time (MCT) is of upmost importance. Here, we employ a machine learning network in order to estimate the MCT in a state transfer protocol. An unsupervised learning approach is considered by using a combination of an autoencoder network with the k-means clustering tool. The Landau-Zener (LZ) Hamiltonian is analyzed given that it has an analytical MCT and a distinctive topology change in the control landscape when the total evolution time is either under or over the MCT. We obtain that the network is able to not only produce an estimation of the MCT but also gains an understanding of the landscape's topologies. Similar results are found for the generalized LZ Hamiltonian while limitations to our very simple architecture were encountered.

QI 23.14 Wed 16:30 Empore Lichthof

Error Budget for the Sørensen-Mølmer Gate — •Susanna Kirchhoff[1,2], Frank Wilhelm-Mauch[1,2], and Felix Motzoi[3] — [1]Institute of Quantum Computing Analytics (PGI 12), Forschungszentrum Jülich, Germany — [2]Theoretical Physics, Saarland University, Saarbrücken, Germany — [3]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich, Germany

The Sørensen-Mølmer gate is an entangling gate for ion qubits, where the entanglement is achieved by a bichromatic laser beam. The gate speed and fidelity are limited by leakage to other levels. We present a detailed expression for the fidelity including higher Lamb-Dicke orders and propose methods to improve gate speed and fidelity.

QI 23.15 Wed 16:30 Empore Lichthof

Optimizing for an arbitrary Schrödinger cat state — •Matthias G. Krauss[1], Anja Metelmann[2], Daniel M. Reich[1], and Christiane P. Koch[1] — [1]Freie Universität, Berlin, Germany — [2]Karlsruhe Institute of Technology, Karlsruhe, Germany

Schrödinger cat states are non-classical superposition states that are useful in quantum information science, for example for computing or sensing. Optimal control theory provides a set of powerful tools for preparing such superposition states, for example in experiments with superconducting qubits [Ofek, et al. *Nature* **536**, 2016]. We present a set of cat state functionals which provide more freedom to the optimization algorithms, compared to state-to-state functionals. By using Krotov's method [Reich et al. *J. Chem. Phys.* **136**, 2012], we demonstrate their application by optimizing the dynamics of a Kerr-nonlinear system with two-photon driving and analyze the robustness of the cat state preparation under single and two-photon decay. In addition, we explore the generation of cat states in higher order Kerr systems. Furthermore, we show the versatility of the framework by applying it to a Jaynes-Cummings model and optimize towards arbitrary entangled cat states. We identify the strategy of the obtained control fields and determine the quantum speed limit as a function of the cat state's excitation. Finally, we extend the investigation to open quantum systems to analyze the benefit of reoptimization together with the changes in the control strategy induced by decay.

QI 23.16 Wed 16:30 Empore Lichthof

Operation of a microfabricated 2D trap array — •Marco Valentini[1], Matthias Dietl[1,2], Silke Auchter[1,2], Michael Dieter[1,2], Philip Holz[3], Clemens Rössler[2], Thomas Monz[1,3], Philipp Schindler[1], and Rainer Blatt[1,3,4] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Alpine Quantum Technologies GmbH, 6020 Innsbruck, Austria — [4]Institute for Quantum Optics and Quantum Information, 6020 Innsbruck, Austria

We investigate scalable surface ion traps for quantum simulation and quantum computing. We have developed a microfabricated surface trap consisting of two parallel contiguous linear trap arrays with 9 trapping sites each. An interconnected three-metal-layer structure provides addressing of the DC electrodes across the chip and shielding of the silicon substrate. The trap fabrication is carried out by Infineon Technologies in an industrial facility, which allows for complex electrode designs and ensures high process reproducibility. We demonstrate trapping and shuttling of multiple ions in the trap array, and form square and triangular ion-lattice configurations with up to six ions. We characterize stray electric fields and measure ion heating rates between 131(13) and 470(50) ph/s in several trapping sites. Furthermore, we engineered our setup to control independently the RF voltage in between the two linear trap arrays, and we will make use of it to demonstrate motional coupling of ions across the lattice.

QI 23.17 Wed 16:30 Empore Lichthof

Engeneering of tin vacancies in diamond by lattice charging — •Vladislav Bushmakin[1,2], Oliver von Berg[1], Santo Santonocito[1], Sreehari Jayaram[1], Petr Siyushev[1], Rainer Stöhr[1,2], Andrej Denisenko[1,2], and Jörg Wrachtrup[1,2] — [1]Universität Stuttgart, 3. Physikalisches Institut, Allmandring, 13, 70569, Stuttgart, Germany — [2]Max-Plank-Institut für Festkörperforschung Heisenbergstraße 1, 70569 Stuttgart, Germany

Recent advances in the integration of spin-bearing solid-state defects in optical cavities for efficient spin-photon entanglement are mostly associated with silicon vacancy in diamond. Meanwhile, the implantation of diamond with heavier group IV ions promises similar performance but at elevated temperatures above 1 K, which contrasts with the stringent requirement of approximately 100 mK for the coherent manipulation of the SiV electron spin. However, the generation of defects involving heavier atoms, such as tin is accompanied by a high density of defects induced by ion implantation. Here we present a method of reduction of the implantation-induced density of defects by implanting through the Boron-doped charged lattice with a subsequent etching of the damaged layer. The given method is an extension of the conventional implantation technique and hence significantly less experimentally demanding than techniques relying on CVD overgrowth or HPHT annealing. Additionally, it provides better accuracy of implantation and allows for the efficient generation of tin vacancies with a narrow inhomogeneous zero-phonon line distribution.

QI 23.18 Wed 16:30 Empore Lichthof

Robust and miniaturized Zerodur based optical and vacuum systems for quantum technology applications — •Sören Boles[1], Jean Pierre Marburger[1], Moritz Mihm[3], André Wenzlawski[1], Ortwin Hellmig[1], Klaus Sengstock[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU, Mainz — [2]Institut für Laserphysik, UHH, Hamburg — [3]Centre for Quantum Technologies, NUS, Singapore

In the ongoing quantum revolution of science, many current studies aim to bring quantum systems to market maturity, such as quantum computers and quantum sensors. Ongoing efforts attempt to increase the accessibility of such systems, while minimizing size, mass and power requirements.

We previously demonstrated the succesful use of stable optical and laser systems based on the glass ceramic Zerodur in space borne atom interferometry experiments, e.g. FOKUS, KALEXUS and MAIUS.

On this poster, we present current developments of Zerodur to metal vacuum flanges, enabling accessible, yet mechanically and thermally stable vacuum systems. Furthermore, we report on the ongoing effort of the construction of a passively pumped Zerodur vacuum chamber for quantum sensoric applications, using optical activation of passive pumps and atom dispensers to demonstrate a MOT.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM2266B, 50WP1433 & 50WP2103.

QI 23.19 Wed 16:30 Empore Lichthof

Spin coherence control in an optically pumped magnetometer for space-borne magnetomyography — •Simon Nordenström[1], Victor Lebedev[1], Stefan Hartwig[1], Kirti Vardhan[2], Sascha Neinert[2,3], Jenichi Felizco[3], Martin Jutisz[2,3], Markus Krutzik[2,3], and Thomas Middelmann[1] — [1]Physikalisch-Technische Bundesanstalt, Berlin, Germany — [2]Humboldt-Universität zu Berlin, Berlin, Germany — [3]Ferdinand-Braun-Institut, Berlin, Germany

Detecting astronauts' neuromuscular degeneration with conventional methods such as surface or needle electromyography is inadequate or too detrimental. Optically pumped magnetometers (OPMs), on the other hand, allow for flexible handling and non-invasive measurements, utilizing the unique properties of alkali atom vapors interacting with external magnetic fields and laser light.

In this poster, we report on our progress in implementation of minimally necessary field control facilities to support the highest performance of the OPM, compatible with measurements on a space station. We investigate the balance between atomic spin coherence relaxation processes, anticipated dynamic range and response bandwidth in a magnetically perturbing environment. We present the anticipated system design and test results under lab conditions.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50WM2168 and 50WM2069.

QI 23.20 Wed 16:30 Empore Lichthof

Miniaturized fiber-based endoscope with direct laser written antenna structures — •Stefan Dix[1], Jonas Gutsche[1], Erik Waller[1,2], Georg von Freymann[1,2], and Artur Widera[1] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

Fiber-based endoscopic sensors are established and widely applied as local fluorescence detectors for various samples, replacing bulky microscopes. Such sensors require the integration of sensing objects, such as nitrogen-vacancy (NV) centers in diamond and microwave antennas on small scales. Here, the microwave (MW) field addresses a transition in the NV center for magnetic field sensing. The MW fields needed are usually created using thin conducting wires or chip-based antennas close to the diamond sample. These approaches either lead to fragile, bulky, or inefficient sensor tips.

Here, we present a robust fiber-based endoscope with a direct laser written silver antenna structure close to a 50 μm multimode fiber core for optimal efficiency. Using such an endoscope, we measure an ODMR sensitivity of 17.8 $\mathrm{nT}/\sqrt{\mathrm{Hz}}$ by probing 15 μm large diamonds entirely through the endoscope. Furthermore, we demonstrate a new method for measuring distances based on measurements of the Rabi frequency.

QI 23.21 Wed 16:30 Empore Lichthof

Status and perspective of a next generation, GHz bandwidth, on-demand single-photon source — •Felix Moumtsilis[1], Max Mäusezahl[1], Moritz Seltenreich[1], Jan Reuter[2,3], Hadiseh Alaeian[4], Harald Kübler[1], Matthias Müller[2], Charles Stuart Adams[5], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Forschungszentrum Jülich GmbH, PGI-8, Germany — [3]Universität zu Köln, Germany — [4]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, USA — [5]Department of Physics, Joint Quantum Centre (JQC), Durham University, UK

The ultimate challenge of coherent experiments in thermal vapors lies in the inevitable movement of atoms that must be overcome to profit from this highly scalable and miniturizable platform e.g. for high fidelity Rydberg logic gates. GHz interaction energies and nanosecond dephasing times in a thermal rubidium vapor demand equally fast coherent control of the atomic excitations, movement, and density.

Here we report on the current state, technical challenges, and the perspective of our next generation single photon source based on the Rydberg blockade. This involves an electronic pulse shaping system with sub-nanosecond jitter, two state-of-the-art 1010 nm pulsed fiber amplifiers, an ultra narrow yet high-contrast wavelength filtering of single photons, high NA focussing, and detection. Beyond our established micrometer thick wedged cells, we investigate novel glass cell geometries requiring a whole new set of manufacturing technologies.

QI 23.22 Wed 16:30 Empore Lichthof

Magnetometry with NV centers and Waveguide-Assisted Detection Channels — •Sajedeh Shahbazi[1], Michael Hoese[1], Michael K. Koch[1,2], Vibhav Bharadwaj[1,3], Johannes Lang[1], Argyro N. Giakoumaki[3], Roberta Ramponi[3], Fedor Jelezko[1,2], Shane M. Eaton[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Ulm, Germany — [3]Institute for Photonics and Nanotechnologies (IFN) - CNR, Milano, 20133, Italy

The negatively charged Nitrogen-Vacancy(NV) center in diamonds has shown great success in nanoscale, high-sensitivity magnetometry. Efficient fluorescence detection is crucial for improving sensitivity and for practical sensor-integrated devices. One way to approach such a goal is using ultrafast laser writing waveguides on the diamond to create such an on-chip integrated quantum sensor. Here, we present femtosecond laser-written type II waveguides on a diamond surface, integrated with NV centers a few nanometers below the diamond surface while covering the entire mode field of waveguides [1]. We experimentally verify the coupling efficiency and the detection of magnetic resonance signals through the waveguides to perform magnetic field sensing. In the future, our approach will enable the development of two-dimensional sensing arrays facilitating spatially and temporally correlated magnetometry.

[1] M. Hoese et al., Phys. Rev. Applied 15, 054059 (2021)

QI 23.23 Wed 16:30 Empore Lichthof

Experimentation platform towards a standardized characterization of ion traps for industrial and academic users — •Hemanth Kalathur[1], André P. Kulosa[1], Erik Jansson[1], Elena Jordan[1], Jan Kiethe[1], Nicolas Spethmann[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Leibniz Universität Hannover, Hannover

Enabling technologies for quantum technologies (QT), such as ion traps, have become indispensable in the fields of quantum computing, quantum simulation, and quantum sensing. A successful commercialization of QT requires extensive knowledge exchange between research and industry.

The Quantum Technology Competence Center (QTZ) at PTB has the central goal of becoming the bridge between research and industry in Germany. The user facility "Ion Traps" of QTZ will provide a user-friendly experimentation platform for the standardized characterization of ion traps. In the long term, the performance of ion traps, e.g. ion micromotion and heating rates will be characterized. We will use incorporated automated routines to enable intuitive access to our measurement platform for collaborators even with a non-physics background. Here, we report about our experimentation platform in operation and the first comprehensive characterization of an ion trap as a cornerstone for the future standardization activities of QTZ.

QI 23.24 Wed 16:30 Empore Lichthof

Absorption sensing mode in radio frequency electrometry using Rydberg atoms in hot vapors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Chang Liu[1], Harald Kübler[2], and James P. Shaffer[1] — [1]Quantum Valley Idea Laboratories , 485 Wes Graham Way, Waterloo, ON N2L 6R1, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffendwaldring 57, 70569 Stuttgart

We present progress in atom-based RF E-field sensing using Rydberg atoms in hot vapors. There are two distinct strategies to detect the electric field strength of the RF wave, namely the Autler-Townes limit, where the splitting of the dressed states is proportional to the incident RF electric field strength and the amplitude regime, where we determine the electric field by measuring the difference of transmission in the presence of the RF electromagnetic field. We present theoretical calculations for the amplitude regime, using a two photon excitation scheme, that show how the scattering of the probed transition changes in the presence of the RF electromagnetic field. We find an analytical expression in the thermal limit with finite wave vector mismatch that yields an accurate approximation compared to full density matrix calculation in the strong coupling limit. Our work extends the understanding of the detection of weak RF E-fields with Rydberg-atom based RF sensors. Furthermore, we present a three photon excitation scheme, with which residual Doppler broadening is suppressed. This enables a spectral resolution comparable to the Rydberg state decay rate, the spectral bandwith limitation.

QI 23.25 Wed 16:30 Empore Lichthof

Measurement of the phase-matching function in PPKTP waveguides — •Jan-Lucas Eickmann, Florian Lütkewitte, Kai-Hong Luo, Michael Stefszky, Laura Padberg, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Single-photon sources with high purity are a prerequisite for the development of practical photonic quantum computation. Spontaneous parametric downconversion in periodically poled potassium titanyl phosphate (PPKTP) is a promising approach to generate spectrally pure quantum light by achieving a phase-matching function perpendicular to the pump function. However, the phase-matching function varies with the condition of waveguide fabrication and the quality of periodic poling. Therefore, a precise measurement of the phase matching dependence is crucial for integrated photonic quantum source engineering. In this work, we present a method for measuring the phase-matching function in PPKTP waveguides by exploiting sum-frequency generation. Using the measured phase-matching function, we reconstruct the joint spectral intensity (JSI) for different pump fields to assure the spectral purity of the heralded photon. We observe that the phase matching results in JSI functions with a tilt of around 60°, deviating 15° from a symmetric function required for optimum pure state preparation.

QI 23.26 Wed 16:30 Empore Lichthof

Control of NV centers in nanodiamonds for sensing applications — •Dennis Lönard and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern, Erwin-Schroedinger-Str. 46, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) color center in diamond is an essential platform for magnetic field sensing for technical and biological applications. One major advantage is that the spin state of the NV-center can be read out optically via the fluorescence. Different spin manipulation schemes, like Ramsay or Hahn echo sequences, have been proposed to influence the interaction between the final spin state and the magnetic field that is to be measured. However, the experimentally achieved sensitivities to outer magnetic fields is still far from their theoretical limits, each measurement scheme having its own set of limitations, often due to the dephasing of the spin states of neighboring NV-centers. I will present our work to further improve the limits of sensing, spanning from technical control to the prospect of combining different methods of manipulating and sensing the NV center and exploiting their multi-level structure.

QI 23.27 Wed 16:30 Empore Lichthof

Predicting coupling efficiency of KTP waveguides and fibers by mode measurement — •Florian Lütkewitte, Jan-Lucas Eickmann, Kai Hong Luo, Michael Stefszky, Laura Padberg, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

Reliable generation of photonic quantum states is of high importance for fundamental physics and quantum networks. Due to its unique dispersion properties, spontaneous parametric downconversion (SPDC) in potassium titanyl phosphate (KTP) has gathered extensive research attention as a source of heralded single photons in the telecom range. Fiber-based devices allow for plug-and-play usage omitting time-intensive free-space coupling. Integration of SPDC sources in fiber networks can be achieved with fiber-pigtailed KTP waveguides. However, single-mode waveguides in KTP show imperfect overlap with single-mode fibers due to their asymmetry and a size-mismatch between modes. Thus, optimized mode-adapted fibers are required to obtain a plug-and-play heralded photon source in KTP. In this work, we measured the mode profile of waveguides and several tapered fibers. Comparing the mode overlap, the optimal waveguide-fiber combination has been determined with upper-bound coupling efficiency of $(90 \pm 1)\%$, based on the mode overlap integral over their measured mode profile.

QI 23.28 Wed 16:30 Empore Lichthof

Integrated optics for scaling up the performace of ion based quantum computers — •Steffen Sauer[1,2], Carl-Frederik Grimpe[3], Anastasiia Sorokina[1,2], Guochun Du[3], Pascal Gehrmann[1,2], Tunahan Gök[6,7], Radhakant Singh[6,7], Pragya Sah[6,7], Babita Negi[7], Maxim Lipkin[6,7], Stephan Suckow[6], Elena Jordan[3], Tanja Mehlstäubler[3,4,5], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [5]Laboratorium für Nano- und Quantenengineering, Hannover, Germany — [6]AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany — [7]Chair of Electronic Devices, RWTH Aachen University, Aachen, Germany

Ions trapped on chips are one of the most promising approaches for quantum computers. The approach offers the advantage of high fidelity, long coherence time and scalability. In addition, the ion physics and trap chip technology are well understood. The key component for the scalability of this quantum computers are integrated optical devices, such as waveguides to transport light or grating outcouplers to emit *m beams to the ions. In the joint project ATIQ, this approach is being pursued with the aim of realising a quantum computer with 40 qubits (ions). We present simulations of integrated optical components, their applications on chips and our characterization setups.

QI 23.29 Wed 16:30 Empore Lichthof

Towards a Micro-Integrated Optically Pumped Magnetometer for Biomagnetism in Space — •Kirti Vardhan[1], Sascha Neinert[1,2], Jenichi Felizco[2], Marc Christ[1,2], Kai Gehrke[2], Andreas Thies[2], Olaf Krüger[2], Martin Jutisz[1,2], Mustafa Gündoğan[1,2], Victor Lebedev[3], Stefan Hartwig[3], Simon Nordenström[3], Thomas Middelmann[3], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany — [3]Physikalisch-Technische Bundesanstalt, Berlin, Germany

Detecting astronauts' neuromuscular degeneration with conventional methods such as surface or needle electromyography is inadequate or too detrimental. Optically pumped magnetometers (OPMs), on the other hand, allow for flexible handling and non-invasive measurements, utilizing the unique properties of alkali atom vapors interacting with external magnetic fields and laser light.

In this poster, we report on our progress towards a miniaturised, ruggedized OPM sensor head based on in-house fabricated MEMS cells for measuring biomagnetic signals in a moderately shielded environment. To this end we compare the performance of first prototypes of a micro-integrated sensor to a functional lab-scale magnetometer setup.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50WM2168 and 50WM2169.

QI 23.30 Wed 16:30 Empore Lichthof

Additive manufacturing, micro-integration and semiconductor fabrication for compact cold atom systems — Marc Christ, •Alisa Ukhanova, Simon Kanthak, Thomas Flisgen, Conrad Zimmermann, Jörg Fricke, Olaf Brox, Andrea Knigge, Wolfgang Heinrich, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik, Berlin

Atom-based quantum sensors allow time- and field-sensing applications with an unrivalled precision compared to their classical counterparts. While lab-based operation of cold atom-based devices is well established, a transition to mobile applications requires miniaturized subsystems with reduced complexity, high stability and low size, weight and power requirements. At FBH, we start to address the miniaturization of the sensor*s physics package towards cm-scale systems, including micro-integrated, vacuum-compatible optical systems for atom trapping and manipulation, compact, 3D-printed vacuum chambers and diffraction grating based atom sources. This poster presents an overview of our efforts towards this goal.

This work is supported by FBH and partially supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant number 50WM1949 and 50WM2070.

QI 23.31 Wed 16:30 Empore Lichthof

Fiber-coupled NV Ensembles in Microdiamond as miniaturized Magnetic Field Probes — •Jonas Homrighausen[1], Jens Pogorzelski[2], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, University of Applied Sciences, Münster, Germany — [2]Department of Electrical Engineering and Computer Science, University of Applied Sciences, Münster, Germany

NV centers in diamond are a very promising candidate for precise measurement of magnetic fields. Especially NV ensembles offer the inherent ability for threedimensional reconstruction of the magnetic field vector while being optically adressable in an optically detected magnetic resonance (ODMR) setup. We utilize these properties by coupling NV ensembles in microdiamond to optical fibers in order to create magnetic probes with high spatial resolution. This however poses challenges, amongst which the efficient delivery of microwave exciation to the fiber tip. In this poster, different methods are discussed for this particular application. We use finite element simulations to compare microwave structures and investigate the according ODMR results. Furthermore, we analyse the effect of crystal orientation with respect to locally homogeneous microwave and magnetic fields.

QI 23.32 Wed 16:30 Empore Lichthof

Towards Optically Integrated Trapped Ion Quantum Computing — •Marco Schmauser[1], Philipp Schindler[1], Thomas Monz[1], Marco Valentini[1], Clemens Rössler[2], Klemens Schüppert[2], Bernhard Lamprecht[3], and Rainer Blatt[1,4] — [1]Universität Innsbruck, Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Joanneum Research, Weiz, Austria — [4]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften

Trapped ion quantum computers are known to be large and complex experiments. One of the reasons for this is that light guidance between lasers and ions is done mainly by free-beam optics, which means that the overall system requires a lot of space and is susceptible to drifts and vibrations. The only way to make such a system compact and scalable is to increasingly integrate functionality, in this specific case optical elements, from external components directly into the ion trap. To solve this problem, a method has been developed to write single-mode and polarization-maintaining waveguides directly into quartz glass using ultrashort laser pulses. These light guides can be tuned to a specific wavelength, ranging from UV to near infrared. The next step is to realize an ion trap with such integrated waveguides. In this context, the approach of a microstructured trap is pursued, which allows for a scalable trap architecture and is compatible with industrial production. In parallel, an integrated cryogenic quantum computing system is being built to enable fast trap changes and additionally investigate the light delivery to the trap chip.

QI 23.33 Wed 16:30 Empore Lichthof

Quantum memory in noble-gas nuclear spins with alkali metal vapour as optical interface — •Norman Vincenz Ewald[1], Tianhao Liu[2], Luisa Esguerra[1,3], Ilja Gerhardt[4], and Janik Wolters[1,3] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]Physikalisch-Technische Bundesanstalt, FB 8.2 Biosignale, Berlin — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin — [4]Leibniz University Hannover, Institute of Solid State Physics, Light and Matter Group, Hannover

Quantum memories with storage times well beyond 1 s will spawn manifold applications in quantum communication and information processing, e.g. as quantum token for secure authentication. We present our first steps towards a quantum memory with long storage time in a mixture of the noble gas ^{129}Xe and an alkali metal vapour of ^{133}Cs. A custom glass cell at about room temperature contains both species and is placed inside a table-top magnetic shield. Information will be stored in the collective excitation of nuclear spins of ^{129}Xe, which exhibit hours-long coherence times [1]. ^{133}Cs serves as optical interface for signal photons, which we store in a collective spin excitation using EIT [2]. Coherent information transfer to the noble gas spins is based on spin-exchange collisions and will be controlled by synchronisation of Larmor precession [3].

[1] C. Gemmel et al., *Eur. Phys. J. D* **57**, 303–320 (2010).
[2] L. Esguerra et al., arXiv:2203.06151 (2022).
[3] O. Katz et al., *Phys. Rev. A* **105**, 042606 (2022).

QI 23.34 Wed 16:30 Empore Lichthof

Rack-mounted Laser Systems for Quantum Computing with Be$^+$ and Ca$^+$ Ions — •Gunnar Langfahl-Klabes[1], Niels Kurz[2], Malte Stoepper[1,2], Stephan Hannig[1], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Institute of Quantum Optics, Leibniz University Hannover

Co-locating quantum processing units based on ion traps with classical computers in data centers requires highly integrated, transportable, modularized, turn-key laser systems in an overall form factor that complies with 19-inch rack-mount standards.

The ion trap-based quantum computer of Quantum Valley Lower Saxony (QVLS-Q1) uses Be$^+$ ions as qubits and Ca$^+$ ions for sympathetic cooling. Within three half-height server racks we provide all of the necessary lasers for cooling, repumping, and detection. Our systems feature four monolithic rack drawers that contain customized setups for sum-frequency generation, second-harmonic generation, and frequency shifting. All rack-mounted laser outputs are fiber-coupled. Free-space components for ablation and photoionization are placed close to the vacuum chamber.

The wavelengths used in our setup range from deep-UV to near-IR (235, 313, 375, 397, 422, 470, 515, 626, 854, 866, 1051, 1552 nm). With red light at 626 nm we realize a laser stabilization setup via Doppler-free iodine spectroscopy for the Be$^+$ cooling and detection laser system at 313 nm.

We report on the current status of our laser systems.

QI 23.35 Wed 16:30 Empore Lichthof

Towards coherent single praseodymium ion quantum memories in optical fiber microcavities — •Sören Bieling[1], Nicholas Jobbitt[1], Roman Kolesov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Universität Stuttgart, 70569 Stuttgart, Germany

Rare earth ions doped into solids show exceptional quantum coherence in their ground-state hyperfine levels. These spin states can be efficiently addressed and controlled via optical transitions and are thus ideally suited to serve as quantum memories and nodes of quantum networks. However, while long storage times, high storage efficiencies and storage on the single photon level have all been demonstrated separately, they could not yet be achieved simultaneously. We aim to demonstrate both long and efficient single quantum storage in the ground-state hyperfine levels of single Pr^{3+} ions doped into yttrium orthosilicate (YSO) by integrating them as a membrane into optical high-finesse fiber-based Fabry-Pérot microcavities. This allows for efficient addressing and detection of individual ions. We report on the design, commissioning and initial characterization of a next-gen cryogenic scanning microcavity as well as on its experimental integration into and design of a self-built vector magnet. It allows for future coherence prolongation by operating under a zero first-order Zeeman (ZEFOZ) shift magnetic field alongside dynamical decoupling sequences. Together with the Purcell enhanced emission and ultrapure Pr^{3+}:YSO membranes this strives to realize efficient and coherent spin-photon interfaces suitable for deployment in scalable quantum networks.

QI 23.36 Wed 16:30 Empore Lichthof

Towards the implementation of microwave near-field entangling gates in a cryogenic surface-electrode ion trap apparatus — •Niklas Orlowski[1], Chloë Allen Ede[1], Niels Kurz[1], Sebastian Halama[1], Timko Dubielzieg[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany

We discuss ion loading using different lasers for the ablation, ionization, cooling and detection of Beryllium ions and describe measures taken to isolate ions from environmental influences, for example by using vibrational decoupling, electromagnetic shielding, and an XUHV-environment [1]. We demonstrate hyperfine state preparation and manipulation with microwave pulses and discuss requirements on radial mode stability for the implementation of entangling microwave quantum gates [2].

[1] Dubielzig et al. RSI 92.4 (2021): 043201
[2] Zarantonello et al. PRL 123, 260503

QI 23.37 Wed 16:30 Empore Lichthof

Synthesis of depth confined nitrogen vacancy centers in diamond — •Karolina Schüle[1], Christoph Findler[1,2], Johannes Lang[1,2], and Fedor Jelezko[1,3] — [1]Institute for Quantum Optics, Ulm University, Ulm, Germany — [2]Diatope GmbH, Ummendorf, Germany — [3]Center for Integrated Quantum Science and Technology (IQST), Ulm, Germany

The negatively charged nitrogen-vacancy center (NV) is a paramagnetic defect (S=1) in diamond which shows coherence times T2 up to milliseconds even at room temperature. The NV is a promising candidate for quantum applications as its spin state can be initialized, read out optically, and manipulated by a microwave field. One way to fabricate NV centers is ion implantation where nitrogen is added into a single crystal diamond layer followed by an annealing process. The depth of the implanted nitrogen can be adjusted by the implantation energy. Larger kinetic energies are leading to deeper NV centers. At the same time, however, the depth distribution gets also broader limiting the degree of depth confinement. This contradicts the goal of homogeneous properties of the NVs beneficial for e.g. NMR applications. Using the method of indirect overgrowth, where implanted nitrogen is buried below a nanometer-thin capping layer of diamond. The resulting depth of the NV centers is decoupled from the implantation ion energy. Here, we show outstanding depth confinement resulting in single NVs which are located at a depth of around 20 nm confined in a range of approx. 1.4 nm. These NV centers are exhibiting a T2 up to ~100 μs.

QI 23.38 Wed 16:30 Empore Lichthof

Industrially microfabricated ion traps for quantum information processing — •Schey Simon[1,2], Pfeifer Michael Dieter Josef[1,3], Glantschnig Max[1,4], Anmasser Fabian[1,3], Abu Zahra Mohammad[1], Auchter Silke[1,3], Brandl Matthias[1], Schüppert Klemens[1], Colombe Yves[1], and Rössler Clemens[1] — [1]Infineon Technologies Austria AG, Villach, Austria — [2]Stockholm University, Stockholm, Sweden — [3]University of Innsbruck, Austria — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Infineon Technologies is fabricating 2D and 3D ion trap chips in its industrial facilities [1,2]. This poster gives an overview of our work towards large-scale, reliable ion traps.

We are developing multiple fabrication processes on silicon and dielectric substrates for, e.g., multi-metal stacks with low resistance at cryogenic temperatures, and surfaces resilient to UV laser beam exposure, which we characterize using analytical tools (cryogenic probe station, KPFM microscopy). Together with partners, we design and produce ion traps with integrated optical waveguides, and traps for ion shuttling with ~200 electrodes, that will be operated with a custom cryo-compatible electronic chip. We present a second-generation ion trap socket that allows fast exchange of traps, which we use in our ion trapping lab and make available to our partners.

[1] Ph. Holz, S. Auchter et al., Adv. Quantum Technol. 3, 2000031 (2020)
[2] S. Auchter, C. Axline at al., Quantum Sci. Technol. 7, 035015 (2022)

QI 23.39 Wed 16:30 Empore Lichthof

Characterization of single-photon emitters in hexagonal boron nitride at room temperature — •Leonora Meier[1], Pablo Tieben[2], Stefan Kück[1], Andreas Schell[2], and Marco López[1] — [1]PTB, Braunschweig, Deutschland — [2]Leibniz Universität, Hannover, Deutschland

In this work we present a study on point defects of hexagonal boron nitride (hBN) which exhibit high brightness and narrow band single photon properties. So far, several samples containing hBN defects with different concentrations have been fabricated and characterized. The characterization is performed in terms of their spectrum, single-photon purity (g(2)(0)) and stability.

It has been observed that different emitters with hBN defects exhibit different spectra, even though the single-photon purity of g(2)(0) is less than 0.3. The single-photon emission stability remains a challenge. Blinking and bleaching were observed even though the time period of stability differs greatly between different emitters.

To improve the stability of the single-photon emission, different annealing procedures will be applied; for example, heating the sample to 500°C. In addition, the variation of photoluminescence as a function of an in-plane magnetic field will be studied to determine whether hBN point defects can be used as a magnetic sensor.

QI 23.40 Wed 16:30 Empore Lichthof

Near Field Modeling for Quantum Gate Operation — •Axel Hoffmann[1], Florian Ungerechts[2], Rodrigo Munoz[2], Brigitte Kaune[2], Teresa Meiners[2], Christian Ospelkaus[2,3], and Dirk Manteuffel[1] — [1]Institut für Hochfrequenztechnik, Hannover, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Hannover, Leibniz Universität Hannober — [3]PTB Braunschweig, Braunschweig

Surface-electrode ion traps with integrated microwave conductors for near-field quantum control are a promising approach for scaleable quantum computers. The goal of the QVLS-Q1 Project is to realize a scaleable quantum computer based on surface-electrode ion traps. Realizing quantum gate operations with magnetic near-field control comes with high demands on the electromagnetic field design, regarding spatial field distribution and radiation efficiency. Typically the wave length of the gate frequency is much larger than the entire application. Therefore common criteria to design efficient radiating structures can not be applied in a straight forward way. Additionally the spatial distribution, especially the position of the field minimum, is constrained to match specific requirements. These challenges will be discussed in this poster, emphasizing on the possibilities to face the complex goal of minimizing gate errors. A systematic approach will be shown including advanced simulation approaches.

QI 23.41 Wed 16:30 Empore Lichthof

Single Photon Sources at Telecom Wavelengths — •Jonas Grammel[1], Julian Maisch[2], Nam Tran[2], Thomas Herzog[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency.

QI 23.42 Wed 16:30 Empore Lichthof

Packaging and Microfabrication Technology for Scalable Trapped Ion Quantum Computer — •Nila Krishnakumar[1,2,3], Friederike Giebel[1,2,3], Eike Iseke[1,2,3], Konstantin Thronberens[1,2,3], Jacob Stupp[1,2,3], Amado Bautista-Salvador[1,2,3], and Christian Ospelkaus[1,2,3] — [1]PTB, Bundesallee 100, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]LNQE, Schneiderberg 39, 30167 Hannover

Ion traps are a leading platform for scalable quantum computing. A physical implementation is based on microfabricated surface-electrode ion traps. A multilayer fabrication method [1] allows geometries which are impossible in single-layer traps. Thick and planarized dielectric-metal layers provide flexibility and better signal routing. The multilayer method requires microfabrication techniques such as UV Photolithography, Reactive Ion Etching(RIE), electroplating and more. Improving the efficiency and yield of the fabrication flow involves testing and updating each technology.

For scalability and hybrid integration of different control techniques, we discuss the implementation of TSVs (Through substrate vias) and better packaging technologies such as flip-chip bonding. As an alternative to the conventional wire bonding which limits the packaging density, a solder free thermocompression method proposed in [2] using gold stud bumps for flip-chip bonding is studied.

[1] A. Bautista-Salvador et al., New J. Phys. 21, 043011, Patent DE 10 2018 111 220 (2019)
[2] M. Usui et al.,(ICEP-IAAC) pp. 660-665 (2015)

QI 23.43 Wed 16:30 Empore Lichthof

Multi-Output Quantum Pulse Gate: a High-Dimensional Temporal-Mode Decoder — •Laura Serino, Jano Gil-Lopez, Michael Stefszky, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

Future quantum technologies will require the implementation of complex quantum communication (QC) networks. Temporal modes (TMs) provide an appealing high-dimensional encoding alphabet based on the time-frequency degree of freedom of photons, leading to important advantages for QC applications. A TM-based QC scheme requires the simultaneous detection of multiple TMs of single photons, which has not yet been achieved.

In this work, we demonstrate high-dimensional single-photon TM decoding with a multi-output quantum pulse gate (mQPG). The mQPG is a device that provides simultaneous projection of multiple TMs onto all the elements of a chosen alphabet (or their superpositions) and maps each result onto a different output frequency. We demonstrate that the mQPG is compatible with single-photon-level input states from a full set of five-dimensional mutually unbiased bases, and we characterize its performance through a detector tomography. We then proceed to demonstrate a proof-of-principle decoder for high-dimensional quantum key distribution based on the mQPG.

QI 23.44 Wed 16:30 Empore Lichthof

Two Stage Quantum Frequency Conversion of SnV-Resonant Photons to the Telecom C-Band — •David Lindler, Tobias Bauer, Marlon Schäfer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Tin-Vacancy-Centers (SnV) in diamond are a promising candidate for Quantum Nodes in quantum communication networks that store and distribute quantum information [1,2]. Transferring the spin state of the SnV-Center onto single photons enables the exchange of information between these nodes over long distances through optical fiber links. The photons are converted into the low-loss telecom bands via quantum frequency down-conversion, to avoid the problem of high loss in fibers for SnV-resonant photons at 619 nm.

We here present a two-stage scheme for quantum frequency conversion of SnV-resonant photons to the telecom C-band based on difference frequency generation in PPLN waveguides. The two step process 619 nm – 2061 nm = 885 nm, 885 nm – 2061 nm = 1550 nm drastically reduces noise at the target wavelength compared to the single stage process 619 nm – 1030.5 nm = 1550 nm, due to pumping in the long wavelength regime. We will present the characterization of key components as well as first results on conversion efficiency and conversion induced noise count rates.

[1] J. Görlitz et al., npj Quant.Inf. 8, 45 (2022).
[2] R. Debroux et al., Phys. Rev. X 11, 041041 (2021).

QI 23.45 Wed 16:30 Empore Lichthof

Entangled Photon Pair Source based on Photonic Chips with Spontaneous Four-Wave-Mixing and Pulsed PDH-Locking — •Maximilian Mengler, Erik Fitzke, Jakob Kaltwasser, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

For many applications, such as quantum key distribution (QKD), entangled photon pairs are desirable. We use the process of spontaneous four-wave-mixing to create such pairs in microring resonators on silicon nitride photonic chips. Results in terms of, for example, pair generation rate and coincidental-over-accidental ratio obtained from two distinct chips with different setups, specifications and waveguide geometries will be presented and compared. As the chips are intended as sources for our QKD-System, which is based on time-bins, the PDH-technique used for the locking of the microring resonators to the pump light was adapted to work with pulsed light.

QI 23.46 Wed 16:30 Empore Lichthof

Cavity-enhanced fluorescence of ensemble NV centers — •Kerim Köster[1], Maximilian Pallmann[1], Rainer Stöhr[2], Julia Heupel[3], Cyril Popov[3], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institute für Technologie (KIT) — [2]3. Physikalisches Institut, University of Stuttgart — [3]Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel

Building a long-distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. A crucial component of this device is an efficient, coherent spin-photon interface. Coupling color centers in diamond to a microcavity is a promising approach therefore.

In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement in a single well-collectable mode. We observe cavity-enhanced fluorescence spectra of an ensemble of shallow-implanted nitrogen vacancy centers in diamond and report a significant Purcell-enhancement of the zero-phonon line (ZPL). Furthermore, the emission yields temporal bunching of ZPL photons, which indicates a collective behavior in the emission process that can be attributed to superfluorescence.

QI 23.47 Wed 16:30 Empore Lichthof

The Twente-Münster high-speed quantum key distribution link — •Niklas Humberg[1], Alejandro Sánchez-Postigo[1], Daan Stellinga[2], Pepijn Pinkse[2], and Carsten Schuck[1] — [1]Departement for Quantum Technology, Münster, Germany — [2]University of Twente, Enschede, Netherlands

To build a pan-European network for quantum communication, many local nodes are needed to provide every city with access to quantum-secure encryption. One such link between local nodes is being developed between the University of Twente (UT) and the Westfälische Wilhelms-Universität Münster (WWU), to open a secure communication channel between the Netherlands and Germany. High-speed generation of quantum keys over the roughly 85km long dark fiber will be achieved by using wavelength division multiplexing into several frequency channels that operate in parallel. The qubit preparation and detection will be done using silicon nitride-on-insulator photonic integrated circuits. The receiver chip will integrate an interferometer with a 150 ps low-loss delay line in one arm for time bin encoding and an arrayed waveguide grating (AWG) for demultiplexing the wavelength channels. Each AWG output channel will be equipped with an efficient and low-noise superconducting nanowire single-photon detector, which have timing accuracies that are significantly better than the optical delay in the interferometer. We show progress on the chip design and the fabrication of detector devices.

QI 23.48 Wed 16:30 Empore Lichthof

Photon emission from a segmented ion-trap – cavity system: simulation and implementation — •Stephan Kucera, Max Bergerhoff, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Atom-photon interfaces [1,2] are basic requirements for quantum networks with single trapped ions. The efficiency of such interfaces has been shown to increase significantly by the use of resonators [3]. Following this direction, we are developing a new segmented ion trap for $^{40}Ca^{+}$ ions with an integrated fiber cavity [4,5] envisaging the implementation of a high-rate and high-purity quantum repeater cell (QR-cell) according to [6,7] on the basis of single-photon emission.

[1] C. Kurz et al., Nat. Commun. 5, 5527 (2014)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[3] M. Meraner et al., Phys. Rev. A 102, 052614 (2020)
[4] H. Takahashi et al., New J. Phys. 15, 053011 (2013)
[5] B. Brandstätter et al., AIP 84, 123104 (2013)
[6] D. Luong et al., Appl. Phys. B 122, 96 (2016)
[7] V. Krutyanskiy et al. arXiv preprint arXiv:2210.05418 (2022)

QI 23.49 Wed 16:30 Empore Lichthof

Polarisation-independent Conversion of single photons from infrared to ultraviolet — •Alireza Aghababaei — Nußallee 12, 53115 Bonn

Wavelength conversion at the single-photon level is required to forge a quantum network from distinct quantum devices. Such devices could include solid-state emitters of single or entangled photons, as well as network nodes based on atoms or ions. We convert single photons emitted from an III-V semiconductor quantum dot at 853nm via sum frequency conversion to the wavelength of the strong transition of Yb ions at 370nm. In this poster, we will present a sagnac setup that allows polarization-independent frequency conversion.

QI 23.50 Wed 16:30 Empore Lichthof

Polarization stabilization of an urban telecom fiber link — •Jonas Meiers, Christian Haen, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Many quantum network designs rely on glass fibers to transmit quantum information encoded into the polarization of photons [1]. Long glass fiber links, especially those deployed outside a laboratory environment are exposed to environmental influences that change the birefringence of the fiber and, as a result, the polarization of transmitted light [2], degrading the polarization-encoded information.

Here, we present the polarization stabilization of a 14 km long urban fiber link running through Saarbrücken, by utilizing lasers as polarization reference and a Gradient-Descent algorithm for error correction. This stabilization provides the necessary transmission process fidelity for quantum communication experiments, which we demonstrate by high-fidelity entanglement distribution with photon pair sources, or by quantum repeater operations.

[1] S. Neumann et al., Nat. Commun. 13, 6134 (2022)
[2] O. Karlsson et al., Journal of Lightwave Technology, 18 (2000)

QI 23.51 Wed 16:30 Empore Lichthof

Observation of quantum Zeno effects for localized spins — •Vitalie Nedelea — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

One of the main dephasing mechanisms for the localized carrier spins in semiconductors is the coupling to the fluctuating nuclear spin environment. Here we present an experimental observation on the effects of the quantum back action under pulsed optical measurements of spin ensemble and demonstrate that the nuclei-induced spin relaxation can be influenced. We show that the fast measurements freeze the spin dynamics and increase the effective spin relaxation time, the so-called quantum Zeno effect. Furthermore, we demonstrate that if the measurement rate is comparable with the spin precession frequency in the effective magnetic field, the spin relaxation rate increases and becomes faster than in the absence of the measurements, an effect known as the quantum antiZeno effect. A theory describing both regimes allows us to extract the system parameters and the strength of the quantum back action.

QI 23.52 Wed 16:30 Empore Lichthof

Quantum Computation and Simulation with Neutral Alkaline-Earth-like Ytterbium Rydberg Atoms in Optical Tweezers — •Nejira Pintul[1], Tobias Petersen[1], Benjamin Abeln[1], Marcel Diem[1], Oscar Murzewitz[1], Koen Sponselee[1], Christoph Becker[1,2], and Klaus Sengstock[1,2] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, Deutschland — [2]Institut für Laserphysik, Universität Hamburg, Deutschland

Experiments with neutral cold atoms trapped in reconfigurable optical tweezer arrays have recently developed into one of today's leading platforms for quantum simulation and computation, due to the innate scalability, single atom control and Rydberg blockade mechanism for generating two-atom entangling gates. However, to achieve fault-tolerant quantum computing, current atomic life- and coherence times still need improvement to increase fidelities in preparation, gate operation and read-out. Here we present our pathway in constructing an optical tweezer experiment utilizing the alkaline-earth-like atom ^{171}Yb. This isotope offers a multitude of viable advantages for encoding novel high-fidelity qubit and error correction architectures, such as the presence of a highly coherent metastable state, a two valence-electron structure with an optically active ion core and single-photon Rydberg transitions. Main milestones include the characterization of two microscope objectives, the design of magnetic coils along with electric field compensation, the development of homogeneous 2D tweezer holograms and mobile dipole traps for efficient array initialization.

QI 23.53 Wed 16:30 Empore Lichthof

Polarization-preserving quantum frequency conversion for entanglement distribution in trapped-atom based urban area quantum networks — •Tobias Bauer and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

In quantum communication networks information is stored in internal states of quantum nodes, which can be realized e.g. in trapped ions like 40Ca+ [1]. By transferring the states onto flying quantum bits, i.e. photons, it is possible to exchange information between these nodes over long distances via optical fiber links. In order to minimize attenuation in fibers, which is particularly high for typical transition frequencies of trapped ions, quantum frequency down-conversion of the transmitted photons to low-loss telecom bands is utilized [2].

We present a high-efficiency, rack-integrated quantum frequency converter for polarization-preserving conversion of 40Ca+-resonant photons to the telecom C-band. This converter is highly suited for real-world application in entanglement distribution experiments in urban area fiber networks, e.g. photonic entanglement [3] or creation of remote entanglement of atomic systems.

[1] C. Kurz et al., Phys. Rev. A. 93, 062348 (2016)
[2] M. Bock, P. Eich et al., Nat. Commun. 9, 1998 (2018)
[3] E. Arenskötter, T. Bauer et al., arXiv:2211.08841

QI 23.54 Wed 16:30 Empore Lichthof

high sensitivity magnetometry with NV centers in diamond at zero field — •Muhib Omar, Arne Wickenbrock, Dmitry Budker, Georgios Chatzidrosos, Till Lenz, Omkar Dungel, and Joseph Rebeirro — Helmholtz Institut Mainz, Deutschland

We investigate a magnetometric protocol for sensing weak ac magnetic fields inside magnetic shieldings using ensembles of Nitrogen-Vacancy (NV) centres in diamond. The aim is to utilise this sensor for zero to ultra low field NMR detection, promising improved Signal-to-Noise ratio by the smaller standoff distance to a NMR sample this type of magnetometer would allow compared to standard optically pumped magnetometers. We present a scheme to enhance photon collection to improve so called shot noise limited sensitivity of magnetic field detection of this sensor type and a scheme that would allow measuring weak ac fields stroboscopically without being limited by effects dominating at very low fields like strain and NV-NV dipolar coupling.

QI 23.55 Wed 16:30 Empore Lichthof

Compact and portable atomic vapor memory for single photon storage — •Alexander Erl[1,2,3], Leon Messner[3,2], Martin Jutisz[3], Luisa Esguerra[2,1], Elizabeth Robertson[2,1], Norman Vinzenz Ewald[2], Elisa Da Ros[3], Mustafa Gündoğan[3], Markus Krutzik[3,4], and Janik Wolters[2,1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Berlin, Germany — [3]Humboldt-Universität zu Berlin, Institut für Physik, Berlin, Germany — [4]Ferdinand-Braun-Institut, Institut für Höchstfrequenztechnik, Berlin, Germany

Quantum memories for single photons are a key component of quantum repeaters for sattelite-based quantum communication over long distances [1,2]. Memories on sattelites for feasible quantum repeater networks must be compact, maintainable and scalable. Reliable storage and retrieval of photons on demand would make a significant contribution to memory assisted quantum key distribution.

We present a compact, rack-mounted, stand-alone warm vapor quantum memory based on electromagnetically induced transparency (EIT) on the Cs D1 line at 895 nm [3]. This mobile setup realizes high fidelity light storage at single photon level with minimal readout noise level.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)
[2] N. Sangouard et. al., arXiv:0906.2699 (2009)
[3] L. Esguera, et al., arXiv:2203.06151 (2022)

QI 23.56 Wed 16:30 Empore Lichthof

Quantum network with interacting network qubits — •Emanuele Distante, Severin Daiss, Stefan Langenfeld, Stephan Welte, Philip Thomas, Lukas Hartung, Olivier Morin, and Gerhard Rempe — Max Planck Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Quantum networks can be realized out of single atoms trapped at the centre of optical resonators which stand at the network nodes and are then connected via optical fibres. In this platform, quantum information is stored into the long-lived ground states of an atom, and the resonator provide an efficient way to entangle the atomic states with flying optical photons. Traveling over the network via the fibres, photons can not only distribute the entanglement over large distance but also provide a means for making two largely separated atoms interact. In this poster we will show how this effective long-distance interaction can be exploited for the realization of different protocols. First, we present a quantum logic gate between distant atoms[1], which denote a rudimental example of distributed quantum computation, then we show the realization of a novel quantum teleportation scheme[2], as well as realization of joint nondestructive measurement on distant qubits leading to entanglement[3].

[1] S. Daiss *et al.*, Science **371**, 614-617 (2021)
[2] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 130502 (2021)
[3] S. Welte *et al.*, Nat. Phot. **15**, 504-509 (2021)

QI 23.57 Wed 16:30 Empore Lichthof

Measuring the temporal mode function of photonic states — •Olivier Morin, Stefan Langenfeld, Matthias Körber, Philip Thomas, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Quantum physics, and quantum information in particular, relies on the accurate control of the quantum states. For optical states, while some well-establish techniques exist for the characterization of polarization and spatial degrees of freedom, it remains a non-trivial task to measure the temporal mode function of a photonic quantum state. Here we present an easy-to-implement and accurate solution [1]. Our method is based on homodyne measurements. We show that the proper processing of the auto-correlation function can give access to any complex-valued temporal mode function. Beyond the theoretical principle, we also consider the experimental constraints and provide the key aspects to obtain a trustworthy reconstruction. We have tested our method on an advanced temporal shape and reach a fidelity as high as 99.4%. This technique has also been used to characterize the complex-valued temporal shape of a single photon emitted from a CQED system. Hence, we believe that this method can be applied to many other systems and become a standard routine in quantum optics laboratories.

[1] O. Morin *et al.*, Phys. Rev. A **101**, 013801 (2020)

QI 23.58 Wed 16:30 Empore Lichthof

Characterization of Polarization Drifts on a Deployed Inter-City Fiber Link for Quantum Communication — •Pritom Paul[1,2], Gregor Sauer[2,1], Shreya Gouravaram Navalur[2,1], and Fabian Steinlechner[2,1] — [1]Institute of Applied Physics, Friedrich Schiller University Jena, Albert-Einstein-Straße 15, 07745 Jena, Germany. — [2]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Straße 7, 07745, Germany.

Quantum communication involves the transmission of quantum information between two or more distant nodes in a network by encoding it, for example into the polarization state of photons. Such photons can be transmitted to distant nodes via free space or fiber-based links. In our experiment, we use a fiber link to transmit such photons.

The state of polarization of light changes with propagation along an optical fiber. These changes are irregular over time and occur due to perturbations from the environment such as temperature fluctuations throughout the day as well as the actual movement of the fibers. In the end, one must compensate for these polarization changes in order to effectively readout the quantum correlations in the polarization degree of freedom[1]. In this work, we want to understand the different aspects of these polarization changes on a 150km deployed fiber link between Jena and Erfurt in order to develop and improve our existing polarization compensation techniques. We report on the current status of the project.

[1] C.Z. Peng, et.al, Phys. Rev. Lett. 98, 010505(2007).

QI 23.59 Wed 16:30 Empore Lichthof

Towards optical tweezer arrays for cavity based quantum information processing — •Matthias Seubert, Lukas Hartung, Stephan Welte, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

In recent decades, single neutral atoms in a strongly coupled optical resonator have developed to a powerful tool for quantum information processing and network application [1]. Increasing the number of individually controllable atoms in this platform provides the possibility to increase the efficiency of existing protocols by multiplexing, and additionally opens the way towards novel information processing and network protocols. However, this requires precise control of the atom position within the cavity mode which is a challenging demand.

Here, we show the implementation of a tweezer setup, capable of positioning atoms within an optical cavity, using a 2D acousto-optic deflector. ^{87}Rb atoms are first loaded at the center of the cavity, then transferred into optical tweezers and finally repositioned at sub-wavelength precision. In this manner, tweezer arrays allow one to load a deterministic number of atoms and to move individual atoms from a strongly coupled to a non-coupled position. In the future, this setup offers the possibility to address individual atoms, detect or rotate their state and generate single atom-photon entanglement.

[1] A. Reiserer and G. Rempe, Rev. Mod. Phys. 87, 1379 (2015)

QI 23.60 Wed 16:30 Empore Lichthof

A quantum frequency converter for the connection of Rb atoms in a cavity over long distances — •Maya Büki, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institute für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Rubidium atoms in a cavity are a promising platform for realizing long-distance quantum networks as the atomic ground states can be efficiently entangled with optical photons [1]. However, photons entangled with Rb atoms are typically at a wavelength (λ_{Rb} = 780 nm) which is unfavourable for long-distance communication due to intrinsic fiber losses in this regime. To efficiently transport the quantum information encoded in optical polarisation qubits over long distances, a wavelength conversion to the telecom regime (λ = 1460 – 1565 nm) is necessary.

Here, we demonstrate such a polarisation conserving quantum frequency converter (QFC) in a Sagnac configuration [2] and investigate the possibilities of increasing the signal-to-noise ratio (SNR) by choosing a suitable final wavelength. Provided a good SNR and high fidelities, the QFC represents one of the many necessary building blocks to establish a long distance quantum network. Furthermore, it can be used to connect diverse platforms operating at different wavelengths, thus forming a hybrid quantum network which takes advantage of the specific capability of each system.

[1] A. Reiserer, G. Rempe, Rev. Mod. Phys. **87**, 1379 (2015).
[2] R. Ikuta *et al.*, Nat. Commun. **9**, 1997 (2018).

QI 23.61 Wed 16:30 Empore Lichthof

Transport waveforms for through-junction ion transport on surface-electrode ion traps for a QCCD architecture — •Rodrigo Munoz[1], Florian Ungerechts[1], Axel Hoffmann[1,2], Brigitte Kaune[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Register-based ion traps are among the leading approaches for scalable quantum processors. These are defined by the spatial division of different operations such as storage, state preparation and readout. A fundamental characteristic of the register-based approach is the translation of ions to reach the different registers of the QCCD architecture. Here, we discuss registers interconnected through a x-junction. We will focus on the necessary through-junction transport.

We will present the different constraints applied to our optimization algorithm in order to obtain trapping potentials for different ion species. Besides, we will also discuss additional conditions that allow a reliable trough-junction transport.

QI 23.62 Wed 16:30 Empore Lichthof

A Quantum Network Node with Crossed Fiber Cavities — •Tobias Frank[1], Gianvito Chiarella[1], Pau Farrera[1], Manuel Brekenfeld[1], Joseph Christesen[1,2], and Gerhard Rempe[1] — [1]MPQ, Hans-Kopfermann-Str. 1, 85748Garching, Germany — [2]NIST, Boulder, Colorado 80305, USA

Recent development in the field of optical cavity QED mainly concern a further reduction of the mode volumes of the resonators, driven by the development of fiber-based Fabry-Perot cavities (FFPCs) [1], and an increase in the number of well-controlled modes the emitters can couple to. We implemented an experiment which combines these two experimental advancements in a single platform consisting of single neutral atoms trapped at the center of two crossed FFPCs. Exploiting the possibilities provided by this platform, we have realized a quantum network node that couples to two spatially and spectrally distinct quantum channels. The node functions as a passive heralded quantum memory [2], achieving a heralded average state fidelity of 94.7 ± 0.2 % and neither requires amplitude- or phase-critical control fields [3] nor error-prone feedback loops [4]. Our platform is therefore excellently suited for the realization of future large-scale quantum networks and quantum repeaters.

[1] Hunger et al., New J. Phys. 12, 065038 (2010)
[2] Brekenfeld et al., Nature 591, 570 (2020)
[3] Specht et al., Nature 473, 190 (2011)
[4] Kalb et al., Phys. Rev. Lett. 114, 220501 (2015)

QI 23.63 Wed 16:30 Empore Lichthof

Nondestructive detection of photonic qubits — •Pau Farrera, Dominik Niemietz, Stefan Langenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching, Germany

Qubits encoded in single photons are very useful to distribute quantum information over remote locations, but at the same time are also very fragile objects. The loss of photonic qubits (through absorption, diffraction or scattering) is actually the main limitation in the maximum reachable quantum communication distance. In this context, the nondestructive detection of photonic qubits is a great scientific challenge that can help tracking the qubit transmission and mitigate the loss problem. We recently implemented such a detector [1] with a single atom coupled to two crossed fiber-based optical resonators, one for qubit-insensitive atom-photon coupling and the other for atomic-state detection. We achieve a nondestructive detection efficiency of 79(3)% conditioned on the survival of the photonic qubit, a photon survival probability of 31(1)%, and we preserve the qubit information with a fidelity of 96.2(0.3)%. To illustrate the potential of our detector we show that it can provide an advantage for long-distance entanglement and quantum-state distribution, resource optimization via qubit amplification, and detection-loophole-free Bell tests.

[1] D. Niemietz et al., Nature 591, 570-574 (2021)

QI 23.64 Wed 16:30 Empore Lichthof

Towards a compact polarization entanglement source based on WGMR — •Sheng-Hsuan Huang[1,2], Thomas Dirmeier[1,2], Golnoush Shafiee[1,2], Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91108, USA

Crystalline Whispering Gallery Mode Resonators (WGMR) made from nonlinear materials have been proven to be compact and efficient sources of quantum states, e.g. squeezed states [1] or narrow-band heralded single photons[2,3]. Another feature of WGMR is, that it is possible to couple two pump beams propagating in opposite directions at the same time. As a result, we can treat the WGMR similar to a Sagnac interferometer which is simultaneously a pair of two independent and indistinguishable SPDC sources. Combined, these features make WGMR a potential platform for developing compact and narrow-band entanglement sources.

In our presentation, we discuss the concept and progress of developing a compact polarization entanglement source based on a WGMR that is pumped from two directions.

[1]A. Otterpohl, et.al., Optica 6, 1375-1380 (2019)
[2]J. U. Fürst, et al., Physical review letters 104.15 153901 (2010)
[2]M. Förtsch, et al., Physical Review A 91(2) 023812 (2015)

QI 23.65 Wed 16:30 Empore Lichthof

Apparatus design for scalable cryogenic trapped-ion quantum computing experiments — •Lukas Kilzer, Tobias Pootz, Celeste Torkzaban, Timko Dubielzig, and Christian Ospelkaus — Institute of Quantum Optics, Leibniz University Hannover

Further progress in trapped-ion quantum computing requires a dramatic increase in the number of ion qubits that can interact with each other. We describe the design of cryogenic demonstrator machines for this task, focusing on the implementation of surface-electrode ion traps. Trap design and implementation is facilitated through the use of a universal interchangeable socket. The apparatus design is based on a vibration isolated cold head to cool a cryogenic vacuum system to temperatures around 5K. The apparatus features a high density of DC control lines to support transport of qubits through complex processor structures including junctions, dedicated storage, detection and manipulation registers. Multi-qubit quantum gates can be implemented through the use of chip-integrated microwave methods. Two setups are currently under construction, the first being based on $^{9}Be^{+}$ qubits and $^{40}Ca^{+}$ ions for sympathetic cooling; the second setup will be based on $^{43}Ca^{+}$ qubits and $^{88}Sr^{+}$ cooling ions. The first setup will benefit from our experience with the $^{9}Be^{+}$ qubit, whereas the second setup with longer wavelengths for cooling and detection will be amenable for integrated chip-integrated photonics. The system has been designed to accommodate the integration of new components for scaling as the development of the underlying enabling technologies progresses.

QI 24: Integrated Photonics II (joint session Q/QI)

Time: Wednesday 17:00–19:00 Location: A320

See Q 44 for details of this session.

QI 25: Quantum Entanglement II

Time: Thursday 11:00–13:00 Location: B302

QI 25.1 Thu 11:00 B302

Quantifying multiparticle entanglement with randomized measurements — Sophia Ohnemus[1], Heinz-Peter Breuer[1,2], and •Andreas Ketterer[1,2,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104, Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104, Freiburg, Germany — [3]Fraunhofer Institut für Angewandte Festkörperphysik IAF, Tullastr. 72, 79108 Freiburg, Germany

Randomized measurements constitute a simple measurement primitive that exploits the information encoded in the outcome statistics of samples of local quantum measurements defined through randomly selected bases. In this work we exploit the potential of randomized measurements in order to probe the amount of entanglement contained in multiparticle quantum systems as quantified by the multiparticle concurrence. We further present a detailed statistical analysis of the underlying measurement resources required for a confident estimation of the introduced quantifiers using analytical tools from the theory of random matrices. The introduced framework is demonstrated by a series of numerical experiments analyzing the concurrence of typical multiparticle entangled states as well as of ensembles of output states produced by random quantum circuits under the influence of noisy gate operations.

QI 25.2 Thu 11:15 B302

Highly entangled graph states — •Zahra Raissi — Department of Physics, Virginia Tech, Blacksburg, VA 24061, USA

Multipartite entanglement is at the very heart of quantum information theory. Among all possible entangled states, k-uniform and absolutely maximally entangled (AME) states, have attracted much attention for a wide range of tasks such as measurement-based quantum computing, quantum networking and quantum error correction. Moreover, many efforts have also focused on showing if the relevant sets of states are also graph states.

The connection between classical codes and k-uniform states has been shown to provide a systematic method of constructing a large set of k-uniform states. In our work, we first show that a much larger class of k-uniform states can be obtained by starting from the graph state representation and asking what is the most general form of the adjacency matrix that is consistent with k-uniformity? With this, we uncover a large class of graph states that are maximally multipartite entangled. At least some of these are inequivalent under stochastic-local-operations and classical communication.

In the second part of our work, we propose and analyze deterministic protocols to generate them. We propose and evaluate deterministic methods to generate multi-photon qudit graph states from multi-level quantum emitters. We present several different explicit protocols that can produce various states either using a single emitter together with time-delayed feedback, or using multiple coupled quantum emitters.

QI 25.3 Thu 11:30 B302

Entanglement from Wehrl Moments using Deep Learning — •Jérôme Denis, François Damanet, and John Martin — University of Liège

In recent years, artificial neural networks (ANNs) have become an increasingly popular tool for studying problems in quantum theory, and in particular entanglement theory. In this work, we analyse to what extent ANNs can provide us with an accurate estimate of the geometric measure of entanglement of pure and mixed symmetric multiqubit states on the basis of a few moments of the Husimi function (Wehrl moments) of the state. We compare the results we obtain by training ANNs with the use of convergence acceleration methods and find that these algorithms do not compete with ANNs when given the same input data. This opens up perspectives for the estimation of SU(2) invariant quantities that should be more easily accessible in experiments than full state tomography.

QI 25.4 Thu 11:45 B302

Constructing generalized SSC witnesses for bound entangled Bell-diagonal states of unequal local dimensions — •Johannes Moerland[1,2], Nikolai Wyderka[1], Hermann Kampermann[1], and Dagmar Bruss[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, D-40225 Düsseldorf, Germany — [2]Universität Göttingen, Friedrich-Hund-Platz 1, D-37073 Göttingen, Germany

We extend a class of bipartite mixed quantum states, so-called Bell diagonal states, to the case where the dimensions of the subsystems do not match. These states are canonically expressed in a unitary operator basis. To investigate their entanglement properties, we generalize a separability criterion originally derived for hermitian operator bases by Sarbicki, Scala and Chruściński to the case of non-hermitian bases. We then construct entanglement witnesses for arbitrary bipartite quantum states that are equivalent to said separability criterion. While for Bell diagonal states with subsystems of matching dimension our results are equivalent to the CCNR criterion, we show that our witnesses outperform CCNR by constructing appropriate bound entangled states of unequal dimensions.

QI 25.5 Thu 12:00 B302

General class of continuous variable entanglement criteria — Martin Gärttner[1,2,3], •Tobi Haas[4], and Johannes Noll[3] — [1]ITP, Heidelberg, Germany — [2]PI, Heidelberg, Germany — [3]KIP, Heidelberg, Germany — [4]QuIC, Brussels, Belgium

We present a general class of entanglement criteria for continuous variable systems. Our criteria are based on the Husimi Q-distribution and allow for optimization over the set of all concave functions rendering them extremely general and versatile. We show that several entropic criteria and second moment criteria are obtained as special cases. Our criteria reveal entanglement of families of states undetected by any commonly used criteria and provide clear advantages under typical experimental constraints such as finite detector resolution and measurement statistics.

QI 25.6 Thu 12:15 B302

Bipartite entanglement and the arrow of time — •Markus Frembs — Griffith University, Gold Coast, Australia

We provide a new perspective on the close relationship between entanglement and time. Our main focus is on bipartite entanglement, where this connection is foreshadowed both in the positive partial transpose criterion due to Peres [A. Peres, Phys. Rev. Lett., 77, 1413 (1996)] and in the classification of quantum within more general non-signalling bipartite correlations [M. Frembs and A. Döring, arXiv:2204.11471]. Extracting the relevant common features, we identify a necessary and sufficient condition for bipartite entanglement in terms of a compatibility condition with respect to time orientations in local observable algebras, which express the dynamics in the respective subsystems. We discuss the relevance of the latter in the broader context of von Neumann algebras and the thermodynamical notion of time naturally arising within the latter.

See arXiv:2207.00024 for details.

QI 25.7 Thu 12:30 B302

Average Correlation as an Indicator for Nonclassicality — •Michael Erich Nicolas Tschaffon, Johannes Seiler, and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Since their introduction, Bell inequalities have been used to verify nonclassicality of bipartite qubit states. While being a popular tool to test and even quantify nonclassicality, Bell inequalities suffer from being complicated to construct experimentally and cumbersome to evaluate and analyse theoretically. We suggest a solution to this trade-off between accurate predictions and simplicity. For this purpose, we introduce another quantity as a new indicator for nonclassicality: average correlation. It has both advantages of indicating whether a state is nonclassical, while still being simple to calculate and measure. We show that based on average correlation we obtain new inequalities that can be used to test nonclassicality. Moreover, we discuss how average correlation can even be used to classify all bipartite qubit states.

QI 25.8 Thu 12:45 B302

Number-phase uncertainty relations and bipartite entanglement detection in spin ensembles — Giuseppe Vitagliano[1,2], Matteo Fadel[3,4], Iagoba Apellaniz[2,5], Matthias Kleinmann[6,2], Bernd Lücke[7], Carsten Klempt[7,8], and •Géza Tóth[2,9,10,11] — [1]Institute for Quantum Optics and Quantum Information, AT-1090 Vienna, Austria — [2]UPV/EHU, ES-48080 Bilbao, Spain — [3]ETH Zürich, CH-8093 Zürich, Switzerland — [4]University of Basel, CH-4056 Basel, Switzerland — [5]Mondragon Unibertsitatea, ES-20500 Mondragón, Spain — [6]Universität Siegen, DE-57068 Siegen, Germany — [7]Leibniz Universität Hannover, DE-30167 Hannover, Germany — [8]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, DLR-SI, DE-30167 Hannover, Germany — [9]DIPC, ES-20080 San Sebastián, Spain — [10]IKERBASQUE, Basque Foundation for Science, ES-48011 Bilbao, Spain — [11]Wigner RCP, HU-1525 Budapest, Hungary

We present a method to detect bipartite entanglement and EPR steering based on number-phase-like uncertainty relations in split spin ensembles. In particular, we show how to detect bipartite entanglement in an unpolarized Dicke state of many spin-1/2 particles. We demonstrate the utility of the criteria by applying them to a recent experiment given in K. Lange et al. [Science 360, 416 (2018)]. Our methods also work well if split spin-squeezed states are considered. We discuss how to handle experimental imperfections.

[1] G. Vitagliano et al., arXiv:22104.05663.

QI 26: Quantum Control (joint session QI/Q)

Time: Thursday 11:00–13:00 Location: B305

Invited Talk QI 26.1 Thu 11:00 B305

Quantum firmware: optimal control for quantum simulators — •Tommaso Calarco — Forschungszentrum Jülich, 52428 Jülich, Deutschland — Universität zu Köln, 50937 Köln, Deutschland

Quantum optimal control has been shown to improve the performance of quantum technology devices up to their limits in terms e.g. of system size and speed of operation. This talk will review our recent results with a variety of quantum technology platforms, focusing in particular on ultracold atoms, and introduce our newly developed software for automatic calibration of quantum operations - the fundamental building block of next-generation quantum firmware.

QI 26.2 Thu 11:30 B305

Optimal Control in the Chopped Random Basis — •Matthias Müller — Forschungszentrum Jülich GmbH

We are at the verge of the second quantum revolution where quantum technology leaves the lab and enters industrial products. Fragile quantum systems with their unique features like superposition and entanglement can offer new perspectives in computation, communication and sensing/metrology. However, they need sophisticated mechanisms of control to perform the desired tasks. Quantum Optimal Control has proven to be a powerful tool to accomplish this task. I will report on the optimization in the dressed chopped random basis (dCRAB) [1], a versatile and robust approach to Quantum Optimal Control, that allows both closed-loop and open-loop optimization with limited pulse bandwidth and guaranteed convergence in a broad range of typical applications. The interplay of constraints, control resources and noise [2,3] is crucial for the overall performance of the controlled operation which obeys fundamental bounds that can be found also in full quantum control [4].

[1] M.M. Müller et al., Rep. Prog. Phys. 85 076001 (2022) [2] S. Lloyd et al., PRL 113, 010502 (2014) [3] M.M. Müller et al., arxiv:2006.16113 (2020) [4] S. Gherardini et al., Phys. Rev. Research 4 (2), 023027 (2022)

QI 26.3 Thu 11:45 B305

Graph test for controllability of qubit arrays — •Fernando Gago-Encinas, Monika Leibscher, and Christiane P. Koch — Freie Universität Berlin, Arnimallee 14, 14195 Berlin

Universal quantum computing requires evolution-operator controllability of the system used as quantum processing unit. Given a specific architecture characterized by the two-qubit couplings and local controls it uses, we seek to determine whether it is controllable or not. The standard test constructing the dynamical Lie algebra becomes demanding and even unfeasible already for a relatively small number of qubits. We present a controllability test for arrays of coupled qubits based on graph theory that significantly broadens the number of cases that can be analyzed. We showcase the algorithm for different examples, including some systems based on IBM's devices.

QI 26.4 Thu 12:00 B305

Optimal Control of Bipartite Entanglement with Local Unitary Control — •Emanuel Malvetti — Department of Chemistry, Technische Universität München, Lichtenbergstr. 4, 85737 Garching, Germany — Munich Centre for Quantum Science and Technology & Munich Quantum Valley, Schellingstr. 4, 80799 München, Germany

A pure quantum state on a bipartite system can always be transformed into a diagonal form using local unitary transformations. This is the well-known Schmidt decomposition. Here we consider a closed bipartite system with local unitary control. The Schmidt decomposition allows us to define a reduced control system on the Schmidt values, which is equivalent to the original control system. We will explicitly describe this reduced control system and study its properties. In particular, we will treat the case of rank one drift Hamiltonians and some low dimensional cases in detail.

QI 26.5 Thu 12:15 B305

Taking Markovian Quantum Dynamics to Thermal Limits: Principles, Practice, and Perspectives — •Thomas Schulte-Herbrüggen[1,2], Frederik vom Ende[1,2], Emanuel Malvetti[1,2], and Gunther Dirr[3] — [1]Technical University of Munich (TUM) — [2]Munich Centre for Quantum Science and Technology (MCQST) and Munich Quantum Valley (MQV) — [3]Institute of Mathematics, Universität Würzburg

To begin with, consider the following engineering problem: Which quantum states can be reached by coherently controlling n-level quantum systems coupled to a thermal bath in a switchable Markovian way? We address this question by giving (inclusions for) reachable sets of coherently controllable open quantum systems with switchable coupling to a thermal bath of temperature T as an additional resource.

A core problem reduces to the dynamics of the eigenvalues of the density operator. It translates into a toy model of studying points in the standard simplex allowing for two types of controls: (i) permutations within the simplex, (ii) contractions by a dissipative semigroup. We show how toy-model solutions pertain to the reachable set of the original controlled Markovian quantum system. Beyond the case $T = 0$ (amplitude damping) we present results for $0 < T < \infty$ by using recent methods of extreme points of the d-majorisation polytope.

We give illustrating examples, experimental applications, and perspectives at the intersection of control theory with resource theory.

Refs.: Proc. MTNS (2022), 1069 and 1073

QI 26.6 Thu 12:30 B305

Tailoring feedback control loops to work best where it matters the most — •Robin Oswald — ETH Zürich

Experiments in AMO physics rely on many feedback control loops stabilizing quantities such as temperatures, magnetic fields and laser phase, frequency and intensity. In most cases, PID controllers are used for these tasks, but they only allow for coarse adjustment of the relevant trade-offs. Here, I will present methods to augment and tailor control loops to be particularly effective in one or several narrow frequency bands, i.e. where there are particularly strong disturbances or where the apparatus is especially vulnerable to them, or both. Using examples from our trapped-ion laboratory I will illustrate how we can leverage these techniques to improve the performance of the feedback loops, and ultimately our experiments.

QI 26.7 Thu 12:45 B305

Unitary Interpolation — •Michael Schilling, Matthias Müller, and Felix Motzoi — Forschungszentrum Jülich, Jülich, Deutschland

The generation of matrix exponentials and associated differentials, required to determine the time evolution of quantum systems, is frequently the primary source of running time in quantum control problems. We introduce two ideas for the time efficient approximation of matrix exponentials of linear parametric Hamiltonians. We modify the Trotter and Suzuki-Trotter product formulas from approximation to interpolation schemes to improve their accuracy. To achieve our target fidelities within a single interpolation step and avoid the need of exponentiation, we furthermore define the interpolation on a grid of interpolation intervals. We demonstrate a speed up of at least an order of magnitude when compared with eigenvalue decomposition, Runge-Kutta and Suzuki-Trotter based approaches. This holds true independent of system dimension, for problems with few time dependent controls.

QI 27: Precision Measurements with Optical Clocks (joint session Q/QI)

Time: Thursday 11:00–13:00 Location: E001

See Q 47 for details of this session.

QI 28: Spin Qubits

Time: Thursday 11:00–13:00 Location: F428

Invited Talk QI 28.1 Thu 11:00 F428

Conveyor-mode single-electron shuttling in Si/SiGe for a scalable quantum computing architecture — •Inga Seidler[1], Tom Struck[1], Ran Xue[1], Stefan Trellenkamp[2], Hendrik Bluhm[1], and Lars R. Schreiber[1] — [1]JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany — [2]Helmholtz Nano Facility (HNF), Forschungszentrum Jülich, Jülich, Germany

Small spin-qubit registers defined by single electrons confined in Si/SiGe quantum dots operate successfully and connecting these could permit scalable quantum computation. Shuttling the electron qubit between registers is a natural choice for high-fidelity coherent links. We demonstrate proof-of-principle of shuttling of a single electron by a gate induced propagating wave-potential in Si/SiGe. Independent from its length only four sinusoidal control signals and low tuning effort are required. We transfer a single electron over a distance of 420 nm and observe a high single-electron shuttling fidelity of 99.42+-0.02 % including a reversal of direction [1]. Theoretical considerations of dephasing mechanisms promise coherent transport over 10 um [2]. Measuring the sensor response while transferring the electron enables us to detect the electron motion. Our shuttle can be readily embedded in industrial fabrication of Si/SiGe qubit chips and paves the way to solving the signal-fanout problem for a fully scalable semiconductor quantum-computing architecture.

[1] I.Seidler et al., npj Quant. Inf. 8, 100 (2022). [2] V. Langrock et al., arXiv:2202.11793.

QI 28.2 Thu 11:30 F428

Driven non-local gates in double quantum dot spin qubits — •Stephen McMillan and Guido Burkard — Universität Konstanz, Konstanz, Deutschland

A critical element towards the realization of quantum networks is non-local coupling between nodes. Scaling connectivity beyond nearest-neighbor interactions requires the implementation of a mediating interaction often termed a “quantum bus”. Cavity photons have long been used as a bus by the superconducting qubit community, but it has only recently been demonstrated that spin-based qubits in double quantum dot architectures can reach the strong coupling regime [1,2] and exhibit spin-spin interactions via real or virtual photons [3,4]. Two-qubit gate operations are predicted in the dispersive regime where cavity loss plays a less prominent role [5]. Here we explore the potential for driving entanglement, in the context of a CNOT operation, between two non-local single-spin qubits dispersively coupled to a common mode of a superconducting resonator. [1] X. Mi et al., Nature 555, 599 (2018) [2] N. Samkharadze et al., Science 359, 1123 (2018) [3] F. Borjans et al. Nature 577, 195 (2020) [4] P. Harvey-Collard et al. arXiv:2108.01206 (2021) [5] M. Benito et al. Phys. Rev. B 100, 081412(R) (2019)

QI 28.3 Thu 11:45 F428

Cavity QED with hybrid quantum-dot donor systems — •Jonas Mielke[1], Jason R. Petta[2], and Guido Burkard[1] — [1]University of Konstanz, Konstanz, Germany — [2]University of California, Los Angeles, USA

Nuclear spins show exceptionally long coherence times but the underlying good isolation from their environment is a challenge when it comes to controlling nuclear spin qubits.

A hybrid system in which an electron is shared between a quantum dot (QD) and ^{31}P donor atom implementing a e^--spin-nuclear spin flip-flop qubit has been realized. Employing ac-magnetic fields, this system can be harnessed to couple the nuclear spin to microwave cavity photons [1,2]. A related system with an electron confined in a double QD and subject to a B-field gradient constitutes a flopping mode e^--spin qubit that couples to cavity photons by electrical means [3,4].

We envision an architecture combining the key ideas of the two aforementioned systems and theoretically investigate the interaction between a nuclear spin with a microwave cavity by electrical means. We demonstrate nuclear spin readout [5] and a cavity mediated nuclear spin $\sqrt{i\mathrm{SWAP}}$-gate with a gate fidelity approaching 95% [6].

[1] Tosi et al., PRB 98, 075131 (2018)
[2] Tosi et al., Nat. Comm. 8, 450 (2017)
[3] Benito et al., PRB 96, 235434 (2017)
[4] Mi et al., Nature 555, 7698 (2018)
[5] Mielke et al., PRX Quantum 2, 020347 (2021)
[6] Mielke et al., arXiv:2209.10026 (2022)

QI 28.4 Thu 12:00 F428

Perspectives for a solid-state-based quantum register based on NV centers aligned along linear crystal defects in diamond — •Reyhaneh Ghassemizadeh, Wolfgang Körner, Daniel F. Urban, and Christian Elsässer — Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108 Freiburg, Germany

Due to its outstanding coherence properties, the negatively charged nitrogen-vacancy defect (NV center) in diamond has an excellent potential for implementing qubits in future solid-state-based quantum computing hardware. However, the structuring of point defects on the atomic scale remains an experimental challenge. We present a theoretical study using density functional theory (DFT) on the interaction between one dimensional crystal defects (dislocations) and NV centers [1]. We evaluate to which extent dislocation lines that are naturally present in diamond may be used for structuring NV centers. We model the most common types of dislocations in diamond and evaluate their influence on the defect formation energy, structural geometry, electronic defect levels and zero-field splitting (ZFS) parameters of NV centers in close proximity. Our simulations reveal that dislocations potentially trap NV defects with an energy release of up to 3 eV. In general, the properties of NV centers at dislocations show strong deviations with respect to their bulk values. However, the lowest energy configuration of a NV center at the core of a 30° partial glide dislocation shows very bulk-like properties. This opens the perspective to align multiple functional NV centers in a linear-chain arrangement.

[1] R. Ghassemizadeh, et al., Phys. Rev. B 106, 174111 (2022)

QI 28.5 Thu 12:15 F428

Controlling nuclear spin qubits in silicon carbide — •Pierre Kuna[1], Erik Hesselmeier[1], Di Liu[1], Vadim Vorobyov[1], Florian Kaiser[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]LIST, Luxembourg

The V2 color center in silicon carbide (SiC) emerged as promising CMOS compatible optically interfaced spin systems in solid state materials. V2 centers combine excellent spin and optical properties, i.e., ms spin coherence times and transform limited optical linewidth, even after nanophotonic integration[1]. Additionally, the di-atomic lattice of SiC provides an elegant pathway to further expand on existing quantum computing approaches demonstrated in the diamond counterpart.

Here, we present theoretical considerations and experimental results towards high-fidelity nuclear spin control in SiC. Using the V2 center as the control (electron) spin, and the surrounding nuclear spins as computational qubits, our first goal is to implement single shot readout (SSR). With this enabling technique, we plan to implement quantum computational algorithms on multiple nuclear spins.

We strive to demonstrate significantly increased fidelities and coherence times based the half-integer control spin, which results in a frozen core that prevents nuclear spin flip-flops. Additionally, the different gyromagnetic ratios of 29-silicon and 13-carbon nuclear spins should allow us to dynamically couple and decouple nuclear spins using an external magnetic field, which can increase the complexity of attainable quantum computing circuits.

[1] C. Babin et al., Nat. Mater. 21, 67 (2022)

QI 28.6 Thu 12:30 F428

Control and coherence of tin-vacancy qubits in diamonds — •C. Waas, H. Beukers, M. Pasini, N. Codreanu, J. Brevoord, L. De Santis, Z. Ademi, S. Niese, F. Gu, V. Dobrovitski, J. Borregaard, and R. Hanson — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628CJ Delft, The Netherlands

Color centers in diamonds are promising building blocks for realizing quantum network nodes, thanks to their good optical and spin properties as well as the naturally occurring ^{13}C-memory qubits in the diamond. Using NV centers, a multi-node network and teleportation of qubit states between non-neighboring nodes have been demonstrated (1). However, the optical properties of the NV currently hinder on-chip integration and scaling-up of quantum networks.

The tin-vacancy (SnV) center emerged as a resourceful alternative platform thanks to its improved optical properties, the second-long relaxation times expected around 1K, and compatibility with nanophotonic integrated devices, thanks to the first-order insensitivity to electric field fluctuations arising from its symmetry properties. Together with the recent developments in diamond nanofabrication techniques and hybrid integrated photonics, this makes the SnV interesting for realizing scalable platforms and on-chip devices. Here we report on the fabrication of single SnV centers in diamond and the investigation of their optical and spin coherence properties. Furthermore, we present our work towards spin-state control of the SnV qubit state at 1K.

(1) Hermans S. et al. Qubit teleportation between non-neighbouring nodes in a quantum network. Nature 605, 663-668 (2022).

QI 28.7 Thu 12:45 F428

Manipulating electron spin entanglement with a scanning tunnelling microscope — •Carsten Henkel[1] and Baruch Horovitz[2] — [1]Universität Potsdam, Institut für Physik und Astronomie — [2]Ben Gurion University of the Negev, Department of Physics, Beer Sheva, Israel

The tunnel current of a scanning microscope contains, in its fluctuations, information about localised spin sites in the contact region. In a magnetic field, this provides an alternative take on electron spin resonance spectroscopy. We showed previously that the features of the current spectrum can be explained by two localised spins that provide interfering tunnelling pathways [1]. The two spins experience effective exchange and Dzyaloshinskii-Moriya couplings and decay channels when the electronic contacts are integrated out [2]. Observed spin spectra can be fitted to the results of a master equation [3]. We report on voltage quenches and current measurements that manipulate the two-spin state and analyse its entanglement [2].

[1] B. Horovitz and A. Golub, Phys. Rev. B 99 (2019) 241407(R)
[2] B. Horovitz and C. Henkel, Phys. Rev. B (Lett.) 104 (2021) L081405
[3] Y. Manassen, M. Jbara, M. Averbukh, Z. Hazan, C. Henkel, and B. Horovitz, Phys. Rev. B 105 (2022) 235438

QI 29: Quantum Thermodynamics and Open Quantum Systems II

Time: Thursday 14:30–16:30 Location: B302

QI 29.1 Thu 14:30 B302

The role of generalized entropies in thermodynamics — •Bilal Cantürk — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Generalized entropies have direct consequences on the foundations of thermodynamics, statistical mechanics, information theory, and quantum thermodynamics [1]. Based on formal group theory, a generalized entropy so-called universal group entropy was proposed in [2] which covers some other generalized entropies as its special cases. In our studies [3,4] we investigated whether universal group entropy and its special cases satisfy some fundamental physically accessible conditions such as stability of the average value of the physical observables and the third law of thermodynamics. I will present our findings, their possible implications, and their compatibility with some recent studies [5]. References [1] Lostaglio, M. Rep. Prog. Phys. 82, 114001 (2019). [2] Tempesta, P. Ann.Phys. (N Y) 365, 180 (2016). [3] Canturk, B., et. al. Ann Phys (N Y) 377, 62 (2017). [4] Canturk, B., et. al. Int. J. Mod. Phys. B 32, 1850274 (2018). [5] Oikonomou, T., et. al. Phys. A: Stat. Mech. Appl. 578, 126126 (2021).

QI 29.2 Thu 14:45 B302

Correlations facilitate ergotropy transmission — •Rick Simon, Janet Anders, and Karen Hovhannisyan — University of Potsdam, Institut für Physik und Astronomie, 14476 Potsdam, Germany

Ergotropy quantifies the amount of unitarily extractable work stored in a system, and it is routinely used to measure the “charge level” of quantum batteries. A fundamental primitive in any (future) quantum power grid will be transmitting ergotropy from one system to another. Here we study energy-preserving unitary transmission channels for the case where both systems are qubits. More specifically, we take two noninteracting qubits and apply a joint unitary that commutes with the total Hamiltonian. When the initial state is factorized, we find that part of the transmitted ergotropy will necessarily be lost. However, the transmission can be lossless when the initial state is correlated. Moreover, despite the fact that no energy is injected into the total system during the transmission, the receiver may gain more ergotropy than is lost by the emitter. This extra gain is achieved at the expense of the correlations between the systems, which affects the reusability of the transmission channel. The degradability problem of the transmission-facilitating correlations is mitigated by the fact that these correlations need not be finely tuned. Indeed, by analyzing large sets of randomly sampled initial states, we found that, for a fixed (high enough) value of mutual information, most initial states incur no losses during ergotropy transmission.

QI 29.3 Thu 15:00 B302

Nonequilibrium quantum thermodynamics in open systems: the influence of initial correlations — •Alessandra Colla[1], Niklas Neubrand[1], and Heinz-Peter Breuer[1,2] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Finding a consistent formulation of quantum thermodynamics for general nonequilibrium processes is a fundamental and relevant question of recent research that has prompted the development of several proposals for the definition of basic thermodynamics quantities such as work, heat and entropy production. We have recently put forth one such approach (Phys. Rev. A 105, 052216) which relies on techniques of open quantum systems to determine an effective Hamiltonian as the operator for internal energy. The original formulation of the approach assumes factorizing initial conditions between the system of interest and the bath. We show here that the theory may be extended to any initial system-bath correlations with the important result that the effective Hamiltonian is unaffected by the presence of the initial correlations.

QI 29.4 Thu 15:15 B302

Long-time equilibration can determine transient thermality — •Karen Hovhannisyan[1], Somayyeh Nemati[1], Carsten Henkel[1], and Janet Anders[1,2] — [1]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany — [2]Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK

When two initially thermal many-body systems start interacting strongly, their transient states quickly become non-Gibbsian, even if the systems eventually equilibrate. To see beyond this apparent lack of structure during the transient regime, we use a refined notion of thermality, which we call g-local. A system is g-locally thermal if the states of all its small subsystems are marginals of global thermal states. We numerically demonstrate for two harmonic lattices that whenever the total system equilibrates in the long run, each lattice remains g-locally thermal at all times, including the transient regime. This is true even when the lattices have long-range interactions within them. We compare our findings with the well-known two-temperature model. While its standard form is not valid beyond weak coupling, we show that at strong coupling it can be partially salvaged by adopting the concept of a g-local temperature.

QI 29.5 Thu 15:30 B302

power output, efficiency and role of the thermodynamic limit in nonequilibrium open quantum opto-mechanical engines — •Paulo José Paulino de Souza[1], Igor Lesanovsky[1,2], and Federico Carollo[1] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems,The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Cavity systems constitute a paradigmatic setting for optomechanical energy conversion. Experiments with atoms coupled to cavity modes are typically realized in nonequilibrium conditions, described by phenomenological models which cannot be derived via a weak system-bath coupling. This makes their interpretation as quantum engines challenging. Here, we present an effective, yet fully consistent, thermodynamic description for cavity-atom optomechanical systems, which exploits their nonequilibrium nature to achieve an energetic balance in terms of the persistent heat currents. To investigate the impact of collective behavior on their performance, we derive two thermodynamic limits, related to a weak and a strong optomechanical coupling, respectively. We illustrate our ideas focussing on a time-crystal quantum engine and discuss mechanical power generation, energy-conversion efficiency, and the emergence of metastable behavior in both limits.

QI 29.6 Thu 15:45 B302

A Rydberg ion quantum engine — •Wilson Martins[1], Igor Lesanovsky[1,2], and Federico Carollo[1] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham,NG7 2RD, United Kingdom

We present and analyse a protocol for operating a quantum engine. Our engine is based on trapped laser-driven Rydberg ions, which constitute a quantum simulation platform where internal and external degrees of freedom can be controlled precisely. Our engine operates under out-of-equilibrium conditions in a setting where external laser-driving competes with dissipation and coherent interaction. We show that for a system of two trapped ions extractable work can be stored in the relative external motion of the trapped ions. We explore a driving protocol and quantify the stored work via the so-called ergotropy: the maximum amount of work that can be obtained from a quantum system.

QI 29.7 Thu 16:00 B302

Measurement feedback models of friction beyond the diffusive limit — •Michael Gaida and Stefan Nimmrichter — Universität Siegen, Deutschland

A typical approach to open quantum systems of motional degrees of freedom is often described in the limit of Brownian motion, which naturally arises from either weak coupling to thermal environments or from weak continuous monitoring.

Here we go beyond the diffusive description and provide a general Markovian measurement feedback model for friction: It involves randomly occur- ring POVM measurements of momentum combined with unitary feedback operations. This enables us to describe arbitrary linear or nonlinear friction forces for quantum particles and quantum op- tomechanical systems.

For linear friction, we find that our model is equivalent to a random position measurement feedback process involving squeezing. Moreover, we highlight the connection to dissipative spontaneous collapse models.

QI 29.8 Thu 16:15 B302

Initial Correlations in Open Quantum Systems: Constructing Linear Dynamical Maps and Master Equations — •Niklas Neubrand[1], Alessandra Colla[1], and Heinz-Peter Breuer[1,2] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

We investigate the dynamics of open quantum systems which are initially correlated with their environment. Our strategy [1, 2] is to analyze how given, fixed initial correlations modify the evolution of the open system with respect to the corresponding uncorrelated dynamical behavior with the same fixed initial environmental state, described by a completely positive dynamical map. We show that, for any predetermined initial correlations, one can introduce a linear dynamical map on the space of operators of the open system which acts exactly like the proper dynamical map on the set of physical states and represents its unique linear extension. Furthermore, we demonstrate that this construction leads to a linear, time-local master equation with generalized Lindblad structure involving time-dependent, possibly negative transition rates. Finally, we illustrate the formalism with the Jaynes-Cummings model and consider the reduced dynamics of a two-level atom which is initially correlated with a single-mode radiation field.

[1] A. Colla, N. Neubrand, and H.-P. Breuer, New J. Phys., 2022
[2] N. Neubrand, Master Thesis, Uni Freiburg, 2022, DOI 10.6094/UNIFR/231431

QI 30: Quantum Algorithms

Time: Thursday 14:30–16:30 Location: B305

Invited Talk QI 30.1 Thu 14:30 B305

Adaptive constant-depth circuits for manipulating non-abelian anyons — Sergey Bravyi[1], Isaac Kim[2], Alexander Kliesch[3], and •Robert König[3] — [1]IBM T.J. Watson Research — [2]University of California, Davies — [3]Technische Universität München

We consider Kitaev's quantum double model based on a finite group G and describe quantum circuits for (a) preparation of the ground state, (b) creation of anyon pairs separated by an arbitrary distance, and (c) non-destructive topological charge measurement. We show that for any solvable group G all above tasks can be realized by constant-depth adaptive circuits with geometrically local unitary gates and mid-circuit measurements. Each gate may be chosen adaptively depending on previous measurement outcomes. Constant-depth circuits are well suited for implementation on a noisy hardware since it may be possible to execute the entire circuit within the qubit coherence time. Thus our results could facilitate an experimental study of exotic phases of matter with a non-abelian particle statistics. We also show that adaptiveness is essential for our circuit construction. Namely, task (b) cannot be realized by non-adaptive constant-depth local circuits for any non-abelian group G. This is in a sharp contrast with abelian anyons which can be created and moved over an arbitrary distance by a depth-1 circuit composed of generalized Pauli gates.

Preprint available at arXiv:2205.01933.

QI 30.2 Thu 15:00 B305

Performance of Portfolio Optimization with QAOA — •Vanessa Dehn and Thomas Wellens — Fraunhofer Institut für Angewandte Festkörperphysik IAF, Freiburg, Deutschland

The quantum approximate optimization algorithm (QAOA) is a promising candidate to solve the portfolio optimization problem more efficiently than classical computers in case of a large number of assets. For a given list of assets, the problem is formulated as a quadratic binary optimization problem and studied using different versions of QAOA (different mixers). To solve the problem with good performance, we discuss technical aspects such as providing a good choice of the penalty factor in case of the standard version of QAOA and deducing suitable initial circuit parameters as starting point for the classical optimizer [1]. Furthermore, we investigate the warm-start version of QAOA and evaluate to what extent the improved performance of WS-QAOA is due to quantum effects.

[1] S. Brandhofer, D. Braun, V. Dehn, G. Hellstern, M. Hüls, Y. Ji, I. Polian, A. Singh Bhatia and T. Wellens, arXiv:2207.10555

QI 30.3 Thu 15:15 B305

Excitations of Quantum Many-Body Systems via Purified Ensembles: A Unitary-Coupled-Cluster-based Approach — Carlos L. Benavides-Riveros[1,2], Lipeng Chen[2], Christian Schilling[3,4], •Sebastián Mantilla[2], and Stefano Pittalis[5] — [1]Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Università di Trento, Trento, Italy. — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [4]Ludwig-Maximilians-Universität München, München, Germany — [5]CNR-Istituto Nanoscienze, Modena, Italy

State-average calculations based on mixture of states are increasingly being exploited across chemistry and physics as versatile procedures for addressing excitations of quantum many-body systems. If not too many states should need to be addressed, calculations performed on individual states are also a common option. Here we show how the two approaches can be merged into one method, dealing with a generalized yet single pure state. Implications in electronic structure calculations are discussed and for quantum computations are pointed out.

The talk is based on: Phys. Rev. Lett. 129, 066401 (2022).

QI 30.4 Thu 15:30 B305

Purified-Ensembles Variational Quantum Algorithm for Excited States — •Cheng-Lin Hong[1], Lexin Ding[1], Carlos L. Benavides-Riveros[2,3], Luis Colmenarez[2], and Christian Schilling[1] — [1]LMU Munich, Munich, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]INO-CNR BEC Center,Trento, Italy

Variational quantum algorithms (VQA) can obtain an approximation ground state of the target Hamiltonian. Methods based on VQA for calculating excited states currently involve high-depth unitary implementation or specific previously-found ground states. To directly extend the VQA framework to excited states, we propose an algorithm based on the purification of weighted ensemble states. This algorithm uses the Gross-Oliveira-Kohn (GOK) variational principle and chooses the appropriate set of weights to construct a BCS-like state; the exponential form of the BCS-like state allows efficient implementation on near-term quantum devices. Combined with variational quantum circuits, we can obtain all excited states we want.

QI 30.5 Thu 15:45 B305

Guaranteed efficient energy estimation of quantum many-body Hamiltonians using ShadowGrouping — •Alexander Gresch[1] and Martin Kliesch[1,2] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf — [2]Institute for Quantum-Inspired and Quantum Optimization, Hamburg University of Technology

Energy estimation in quantum many-body Hamiltonians is a paradigmatic task in various research fields. In particular, an efficient estimation procedure may be crucial in achieving a quantum advantage for a practically relevant problem. Variational quantum algorithms (VQAs) are among the leading approaches for achieving this goal. However, the measurement effort due to the high required accuracy constitutes a crucial bottleneck.

In this work, we aim to find an optimal energy estimation strategy for single-qubit measurements with rigorous performance guarantees. Given any empirical estimator $\hat{E}$ of the energy E relying on different Pauli basis measurements, we derive a tail bound for the estimator $\hat{E}$. Finding the optimal Pauli bases, we show to be NP-hard. Therefore, we develop a heuristic yet efficient estimation strategy based on our tail bound. It combines shadow estimation methods with grouping strategies for Pauli strings. Therefore, we call it *ShadowGrouping*. Numerically, we demonstrate that ShadowGrouping outperforms state-of-the-art methods in estimating the electronic ground-state energies of various small molecules. Hence, this work provides a promising way, e.g., to tackle the measurement bottleneck of VQAs.

QI 30.6 Thu 16:00 B305

Programmable adiabatic demagnetization for systems with trivial and topological excitations — •Anne Matthies[1,2], Achim Rosch[1], Mark Rudner[3], and Erez Berg[2] — [1]University of Cologne, Cologne, Germany — [2]Weizmann Institute of Science, Rehovot, Israel — [3]University of Washington, Seattle, USA

Preparing the ground state of a many-body Hamiltonian on a quantum device is of central importance, both for quantum simulations of molecules and materials, and for a variety of quantum information task. We propose a simple, robust protocol to prepare a low-energy state of an arbitrary Hamiltonian on a quantum computer. The protocol is inspired by the *adiabatic demagnetization* technique, used to cool solid state systems to extremely low temperatures. The adiabatic cooling protocol is demonstrated via an application to the transverse field Ising model. We use half of the qubits to model the system and the other half as a bath. Each bath spin is coupled to a system spin. In a strong magnetic field, the bath spins are prepared in the polarized ground state. By an adiabatic downward sweep of the magnetic field, we change the energy of the bath spins and allow for resonant processes that transfer entropy from the system to the bath qubits. After each cycle, the bath is reset to the ground state.

We find that the performance of the algorithm in the presence of a finite error rate depends on the nature of the excitations of the system; systems with non-local (topological) excitations are more difficult to cool. Finally, we explore ways to partially mitigate this problem.

[arXiv:2210.17256]

QI 30.7 Thu 16:15 B305

Variational quantum amplitude estimation on noisy quantum processors — •Tobias Nauck, Thomas Wellens, and Andreas Ketterer — Fraunhofer Institut für Angewandte Festkörperphysik

The quantum amplitude estimation algorithm provides a quadratic speedup over classical Monte Carlo methods in the task of approximately evaluating integrals. This maximum speedup can, however, only be achieved with quantum circuits of exponentially growing depths which is unfeasible on noisy intermediate-scale quantum processors. In order to tackle the problem of impractically large circuit depths, we develop a hybrid algorithm that approximates circuits with depths exceeding a predefined threshold using a classical variational approximation. To do so, we maximize the fidelty between the invovled circuits and an appropriate variational circuit of low depth on neighboring qubits. In terms of numerical simulations, we show how the introduced variational algorithm depends on the choice of the aforementioned threshold depth and discuss its vulnerability to noise in terms of quantum gate errors.

QI 31: Single Quantum Emitters (joint session Q/QI)

Time: Thursday 14:30–16:30 Location: E214

See Q 53 for details of this session.

QI 32: Quantum Optics and Quantum Information with Rigid Rotors (joint session MO/Q/QI)

Time: Thursday 14:30–16:30 Location: F102

See MO 17 for details of this session.

QI 33: Quantum Networks II (joint session QI/Q)

Time: Thursday 14:30–16:30 Location: F428

QI 33.1 Thu 14:30 F428

A quantum interface between NV center matter qubits and Thulium rare-earth ion quantum memory compatible light — •M.C. Roehsner[1], M. Iuliano[1], A.J. Stolk[1], M. Sholkina[1], N. Alfasi[1], T. Chakraborty[1], W. Tittel[1,2], and R. Hanson[1] — [1]QuTech & Kavli Institute of Nanoscience, Delft University of Technology — [2]Department of Applied Physics, University of Geneva & Schaffhausen Institute of Technology, Geneva

Quantum networks promise to enable applications ranging from secure communication to fundamentally new kinds of computation. However, the individual components of quantum networks may be realized with different kinds of physical systems, requiring specialized interfaces. Here we present our work towards interfacing a diamond Nitrogen Vacancy (NV) center, well suited as a local quantum processing network node [1], with light compatible with Tm-based rare-earth ion quantum memories, well suited for long-range quantum repeaters [2]. We demonstrate two-photon quantum interference between photons emitted from an NV center with weak coherent light resonant with a Tm-based memory, probing the indistinguishability of the photons created by these disparate sources, using a low noise two-step quantum frequency conversion process. Furthermore, we present latest results towards teleporting a memory-compatible time-bin qubits into the NV center. With this quantum interface between different physical systems, we aim to bridge the gap between two key network components. [1] Hermans, S.L.N. et al. Nature 605 (2022) [2] Davidson J.H. et al. Phys. Rev. A 101 (2020)

QI 33.2 Thu 14:45 F428

Space-borne quantum memories for global quantum networking — •Mustafa Gündoğan[1], Jasminder Sidhu[2], Daniel Oi[1], and Markus Krutzik[1] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]University of Strathclyde

Exponential losses in optical fibres limit the transmission of quantum information to around few hundred kilometres. Quantum repeaters based on the heralded storage of entangled photon pairs were proposed to increase this direct transmission limit. Nevertheless, these architectures are still limited to around few thousand kilometres.

In this talk I will present our proposal for placing quantum memories on board orbiting satellites to enable quantum networking at a truly global scale. The first idea relies on building a network of satellites equipped with QM with storage times of <1s. One can then create a quantum repeater in space to cover global distances [1]. The second idea is to use a single orbiting satellite equipped with two QMs: one with long (~h) and the other short (~ms) storage times. Quantum information is then shuttled across the globe in a time-delayed quantum repeater fashion. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant number 50WM2055.

[1] M. Gündoğan *et. al.*, npj Quantum Information **7**, 128 (2021)

QI 33.3 Thu 15:00 F428

Towards remote entanglement of single erbium dopants — •Alexander Ulanowski[1], Fabian Salamon[1], Benjamin Merkel[1], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

In a future quantum internet, coherent emitters will exchange quantum states over global distances, preferably using optical fibers to establish entanglement between remote spins. To this end, erbium dopants are a promising platform due to the optical transition in the telecom band enabling low-loss distribution of photons. To realize an efficient spin-photon interface for single dopants, we embed a thin erbium doped crystal into a tuneable high-finesse Fabry-Perot resonator. In our experiment we achieve up to 110-fold Purcell enhancement while the coherence is preserved up to the lifetime limit by avoiding proximal interfaces [1]. Using spectral multiplexing gives us access to hundreds of individual dopants which exhibit a low spectral diffusion (< 0.2 MHz) currently limited by the nuclear spin bath [2]. To further improve the spectral stability and enable entanglement generation via photon interference, we thus investigate spin-free ^{29}Si crystals as a possible host material [3]. Furthermore, we expect considerable stability improvement by applying real-time feedback on the emitter frequency. This opens perspectives for long-distance entanglement at kilohertz rates.

[1] B. Merkel et al., Phys. Rev. X 10, 041025 (2020).
[2] A. Ulanowski et al., Sci. Adv. 8, eabo4538 (2022).
[3] Y. Liu et al., Journ. Cryst. Growth, 126733 (2022).

QI 33.4 Thu 15:15 F428

Hong-Ou-Mandel Interference in LNOI — •Silia Babel, Laura Bollmers, Marcello Massaro, Kai Hong Luo, Michael Stefszky, Federico Pegoraro, Philip Held, Harald Herrmann, Christof Eigner, Benjamin Brecht, Laura Padberg, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany

A quantum computer can be built solely using single photons sources, linear optics and single photon detectors. For the realisation of a photonic quantum computer, a particular interest has been devoted to the study of integrated networks since these offer many advantages such as stability, the possibility of compact devices and high efficiency, and thus provide scalability. The foundation of these integrated networks are directional couplers and interference between single photons.

A interesting platform for this purpose is Lithium Niobate on Insulator (LNOI) since it combines the advantages of conventional lithium niobate, such as a wide transparency window and high nonlinear coefficients, with a high integration density. To show that this material is suited for the realisation of integrated quantum networks, we demonstrate Hong-Ou-Mandel interference (HOMI) of telecom photons on a balanced directional coupler. We designed and fabricated the coupler in-house and achieve a raw HOMI visibility of (93.5±0.7)%. Our work demonstrates a crucial building block for integrated quantum networks based on LNOI.

QI 33.5 Thu 15:30 F428

Portable warm vapor memory — •Martin Jutisz[1], Elisa Da Ros[1], Alexander Erl[2,3], Leon Messner[1,3], Luisa Esguerra[3,2], Janik Wolters[3,2], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Warm vapor memories have seen significant progress in terms of efficiency and storage time in recent years. Their low complexity makes them a promising candidate for operation in non-lab environments including space-based applications. As necessary element of quantum repeaters, memories operating in space could advance global quantum communication networks [1].

We will present the overall status of integration and test of a portable rack-mounted system. The implementation of the optical memory is based on electromagnetically induced transparency on the Cesium D1 line at 894 nm. Three lasers are frequency stabilized to provide pump, signal and control pulses. Automated locking is realized via a FPGA-based tool for laser frequency stabilization. The storage platform is provided by a heated Cesium vapour cell in a three-layer magnetic shield. Possibilities of micro integration are also being investigated.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWK) under grant number 50RP2090.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)

QI 33.6 Thu 15:45 F428

Single erbium dopants in nanophotonic resonators — •Jakob Pforr[1,2], Andreas Gritsch[1,2], Alexander Ulanowski[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Single erbium dopants in nanophotonic resonators are promising for the realization of quantum networks owing to their outstanding optical and spin coherence properties [1] and their large spectral multiplexing potential [2]. Previous experiments used yttrium-based host crystals, in which erbium is integrated in well-defined sites. However, these crystals are not compatible with established nanofabrication techniques, which hinders scalable integration into on-chip photonic circuits. To address this challenge, we have spectroscopically studied ensembles of erbium dopants in silicon nanostructures. After optimizing the erbium implantation procedure, we have observed two well-defined lattice sites with narrow inhomogeneous broadening (< 1 GHz), narrow homogeneous linewidths (< 0.01 MHz) and optical lifetimes of 0.2 ms [3]. In one-dimensional photonic crystal resonators ($Q > 10^4$, $V \sim \lambda^3$), we observe single dopants with a 60-fold Purcell-enhanced emission. We will present studies of the optical coherence, spectral diffusion, spin properties and spectral multiplexing capability of these devices.

[1] Merkel et. al. 2020. PRX 10(4): 041025.
[2] Ulanowski et. al. 2021. SciAdv 8(43): eabo4538.
[3] Gritsch et. al. 2021. PRX 12(4): 041009.

QI 33.7 Thu 16:00 F428

High fidelity single-shot readout of telecom emitters in a Fabry-Perot resonator — •Fabian Salamon[1,2], Alexander Ulanowski[1,2], Johannes Früh[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Erbium dopants are prime candidates for the realisation of extended quantum networks, as they combine second-long ground state coherence with a coherent optical transition in the telecommunication window, where loss in optical fibers is minimal [1].

To implement quantum information processing in this novel platform, we perform single-shot readout of the spin state by resonantly driving the optical transition and detecting the subsequently emitted photons. We overcome the challenge that erbium lacks a cycling transition [2] by using a Fabry-Perot resonator with a narrow linewidth (50 MHz) [3] in order to selectively enhance the readout transition.

Combined with our recent advances in spectral multiplexing [4], the successful implementation of high-fidelity single-shot readout is a key step towards high-rate entanglement of distant erbium dopants.

[1] A. Reiserer, arXiv:2205.15380 (2022).
[2] M. Raha et al., Nat. Commun. 11, 1605 (2020).
[3] B. Merkel, A. Ulanowski & A. Reiserer, Phys. Rev. X 10, 041025 (2020).
[4] A. Ulanowski, B. Merkel & A. Reiserer, Sci. Adv. 8, eabo4538 (2022).

QI 33.8 Thu 16:15 F428

Electromagnetically Induced Transparency in hollow-core light-cages: Simulation tool and experimental preparation — •Dominik Ritter[1], Esteban Gómez-López[1], Jisoo Kim[2], Markus Schmidt[2,4], Harald Kübler[3], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Leibniz Institute of Photonic Technology, 07702 Jena, Germany — [3]University of Stuttgart, 70569 Stuttgart, Germany — [4]Otto Schott Institute of Material Research, 07743 Jena, Germany

Quantum repeaters and memories are needed to overcome efficiently the losses of long-distance quantum networks [1]. A promising system to host a quantum memory is atomic vapours, which can be enhanced with guiding photonic structures [2].

We will present a simulation program and experimental measurements for enhanced light matter interaction in hollow-core light-cages (LC) inside a warm cesium vapor cell. The program calculates the absorption spectra of alkali vapors under Electromagnetically Induced Transparency (EIT). Propagation of light pulses through the bare atomic vapor and the LC are simulated, where a linear loss model is assumed. This use of the LC would lead towards controllable time delay of photons in an easy to use and easy to implement device and eventually a reliable platform for a quantum memory for single photons using the EIT-storage scheme [3].

[1] P. v. Loock et al., Adv. Quantum Technol. 3, 1900141 (2020). [2] K. F. Reim et al., Phys. Rev. Lett. 107, 053603 (2011). [3] J. Wolters et al., Phys. Rev. Lett. 119, 060502 (2017).

QI 34: Concepts and Methods III

Time: Friday 11:00–13:00 Location: B302

QI 34.1 Fri 11:00 B302

Quantum Bell Inequalities from Information Causality — •Prabhav Jain[1], Mariami Gachechiladze[1], and Nikolai Miklin[2] — [1]TU Darmstadt, Germany — [2]Heinrich-Heine-Universität Düsseldorf, Germany

Characterizing the set of quantum correlations in the space of all possible non-signalling theories is a hard but important problem. For a given Bell scenario, quantum bell inequalities which bound the set of possible observed correlation are relevant not only as a theoretical interest but for several applications such as QKD etc. A fundamental goal is to 'derive' this quantum set from physical/empirical principles without assuming any of the formalism.

In this work, we propose to use information causality as one such physical principle. We derive new quantum Bell inequalities for arbitrary measurement settings and outcomes in a bipartite scenario while improving on some previous known results by obtaining the tightest bounds so far for such scenarios. We also investigate how our new polynomial inequalities in the observed probability distributions relate to other well known principles such as macroscopic locality and almost quantum correlations.

QI 34.2 Fri 11:15 B302

Solution of the convex single-body quantum marginal problem and its physical relevance — •Julia Liebert[1], Federico Castillo[2], Jean-Philippe Labbé[3], Arnau Padrol[4], Eva Philippe[4], Rolando Reiner[1], and Christian Schilling[1] — [1]University of Munich (LMU), Munich, Germany — [2]Pontificia Universidad Catolica de Chile, Macul, Chile — [3]École de Technologie Supérieure, Montréal, Canada — [4]Sorbonne Université, Paris, France

The single-body quantum marginal problem asks whether given single-body reduced density matrices are compatible to some multipartite quantum state. In a recent breakthrough, A. Klyachko has solved this general problem on an abstract mathematical level. Urged by the limited scope of that solution to artificially small quantum systems, we explain why the convex-relaxed variant of that compatibility problem is the more relevant one for practical purposes. By using tools from convex analysis, we then provide a comprehensive solution to the latter problem for any multipartite quantum state with a fixed spectrum, leading to a complete hierarchy of necessary and sufficient spectral constraints which are valid for systems of arbitrary size. In the context of fermions and bosons, these novel conditions lead to a physical relevant generalization of Pauli's famous exclusion principle.

QI 34.3 Fri 11:30 B302

Compensating for non-linear distortions in controlled quantum systems — •Juhi Singh[1,2], Robert Zeier[1], Tommaso Calarco[1,2], and Felix Motzoi[1] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany

Predictive design and optimization methods for controlled quantum systems depend on the accuracy of the system model. Any distortion of the input fields in an experimental platform alters the model accuracy and eventually disturbs the predicted dynamics. These distortions can be non-linear with a strong frequency dependence so that the field interacting with the microscopic quantum system has limited resemblance to the input signal. We present an effective method for estimating these distortions which is suitable for non-linear transfer functions of arbitrary lengths and magnitudes provided the available training data has enough spectral components. Using a quadratic estimation, we have successfully tested our approach for a numerical example of a single Rydberg atom system. The transfer function estimated from the presented method is incorporated into an open-loop control optimization algorithm allowing for high-fidelity operations in quantum experiments.

QI 34.4 Fri 11:45 B302

Entanglement Batteries — •Ye-Chao Liu, Otfried Gühne, and Stefan Nimmrichter — Universität Siegen, Siegen, Germany

Quantum entanglement is an essential resource for many kinds of applications like quantum communication over a quantum network, eventually realizing the quantum internet. The unavoidable noise and losses between the links call for additional hardware that can gradually build up and store entanglement for later use – an entanglement battery.

In this contribution, we introduce the concept of entanglement batteries charged by repeated interactions with a provided stream of Bell pairs. We show that, although perfect SWAP and iSWAP gates can both fully charge entanglement batteries using Bell states, their behaviors differ significantly if the charging interaction strength is restricted to a partial swap or even fluctuates. We compare two exemplary charging protocols: one that repeatedly uses a single Bell state for charging, and another one that uses a fresh Bell state for each charging step. We further assess the performance of entanglement charging under losses.

QI 34.5 Fri 12:00 B302

Device-independent randomness extraction from almost separable multipartite states — •Giacomo Carrara, Federico Grasselli, Hermann Kampermann, Dagmar Bruss, and Gláucia Murta — Heinrich-Heine-Universität Düsseldorf

Bell inequalities represent a fundamental tool for many quantum information tasks that exploit nonlocality. In particular they can be used for device-independent (DI) protocols, where the parties do not need to trust or characterize the underlying systems and measurement devices. Specifically, the violation of a Bell inequality allows to certify the randomness of the parties' outcomes with respect to a potential eavesdropper. Even though entanglement is necessary for the violation of a Bell inequality, the relation between nonlocality and entanglement is more intricate than one might expect. In [*Phys. Rev. Lett.*, **108**, 100402 (2012)] the authors show that maximal DI randomness can be obtained, in the bipartite scenario, from almost separable states. In this work, we extend this result to the multipartite scenario. In particular, we analyze the amount of randomness that can be extracted from a state arbitrarily close to a fully separable state using a suitably chosen multipartite Bell inequality. In order to achieve this result, we employ both standard numerical convex optimization and analytical methods.

QI 34.6 Fri 12:15 B302

Symmetry restoration of mean-field approaches: Rationalization through quantum information theory — •Javier Faba[1,2], Vicente Martín[1], Luis Robledo[2], Lexin Ding[3], and Christian Schilling[3] — [1]Center for Computational Simulation, Universidad Politécnica de Madrid, Campus Montegancedo, 28660 Boadilla del Monte, Madrid, Spain — [2]Departamento de Física Teórica and CIAFF, Universidad Autónoma de Madrid, 28049 Madrid, Spain — [3]Faculty of Physics, Arnold Sommerfeld Centre for Theoretical Physics (ASC), Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München, Germany

The quantum many-body problem is of central importance in various subfields of the quantum sciences, particularly in quantum chemistry, solid state and nuclear physics. A promising solution strategy — developed and primarily used so far only in nuclear physics — is based on the following wisdom: Starting from a mean-field solution one systematically improves the variational energy by introducing different levels of quantum correlation through a restoration of the symmetries broken by the former.

In this talk, we will rationalize this general wisdom by providing a concise definition of quantum correlation in this context. To be more specific, we will explain how quantum information concepts can help us in order to describe the correlation structure of mean field and symmetry restored ground states of relevant models that exhibit spontaneous symmetry breaking of both abelian and non abelian symmetries.

QI 34.7 Fri 12:30 B302

Rescaling decoder for 2D topological quantum color codes on 4.8.8 lattices — Pedro Parrado Rodriguez[1], •Manuel Rispler[2,3], and Markus Müller[2,3] — [1]Department of Physics, College of Science, Swansea University, — [2]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [3]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich, Germany

Fault-tolerant quantum computation relies on scaling up quantum error correcting codes in order to suppress the error rate on the encoded quantum states. Topological codes, such as the surface code or color codes, are leading candidates for practical scalable quantum error correction and require efficient and scalable decoders. In this work, we propose and study the efficiency of a decoder for two-dimensional topological color codes on the 4.8.8 lattice (also known as the square-octagon code), by building on the work of Sarvepalli and Raussendorf [Phys. Rev. A 85, 022317 (2012)], for color codes on hexagonal lattices. The decoder is based on a rescaling approach, in which syndrome information on a part of the qubit lattice is processed locally, and then the lattice is rescaled iteratively to smaller sizes. We find a threshold of 6.0% for code capacity noise.

QI 34.8 Fri 12:45 B302

Exploiting Graph Symmetries for Quantum Dynamics Algorithmically — •Armin Johannes Römer[1,2], Robert Zeier[3], and Thomas Schulte-Herbrüggen[1,4,5] — [1]Technische Universität München (TUM) — [2]Forschungszentrum Jülich GmbH, IEK-9 — [3]Forschungszentrum Jülich GmbH, PGI-8 (Quantum Control) — [4]Munich Center for Quantum Science and Technology (MCQST) — [5]Munich Quantum Valley e.V. (MQV)

Coupled n-level systems (spins) can classically be represented as coloured graphs, where vertices relate to local spins and differently coloured edges stand for pairwise couplings of different type.

We present an efficient algorithm to exploit graph symmetries for arriving at symmetry-adapted bases. Its core scales classically with the number of spins as vertices of the graph: *its input is merely the graph's adjacency matrix*, it avoids calculating the underlying graph automorphism group, *and its output is a transformation matrix into a symmetry adapted basis.* It connects the Weisfeiler-Leman algorithm, known from graph isomorphism problems, with cutting-edge versions of calculating central idempotents in MAGMA.

We demonstrate how classical graph symmetry carries over to quantum Hilbert space. Worked examples illustrate principles and practice in a manner applicable to, e.g., quantum simulation, quantum dynamics, and quantum information.

QI 35: Quantum Computers: Algorithms and Benchmarking

Time: Friday 11:00–13:00 Location: B305

QI 35.1 Fri 11:00 B305

Advantages of Measurement-based Variational Quantum Eigensolvers — •Anna Schroeder[1,2], Matthias Heller[3], and Mariami Gachechiladze[2] — [1]Merck KGaA, Frankfurter Str. 250, Darmstadt, Germany — [2]Quantum Computing Group, TU Darmstadt, Mornewegstr. 30, Darmstadt, Germany — [3]Fraunhofer IGD, Darmstadt, Germany

The variational quantum eigensolver (VQEs) is a hybrid algorithm to compute the lowest eigenvalue and its corresponding eigenvector for a given operator. The idea is to optimize classically over a parametrized quantum circuit, the ansatz, to generate a quantum state that minimizes the cost function, typically the expectation value of the Hamiltonian. Recently, a different approach to VQE has been considered. Ferguson et al., PRL 2021 discussed unifying the VQE framework with measurement-based quantum computing (MB-VQE). Here instead of parametrizing gates, one starts with highly entangled resource states (e.g., graph states) and optimizes over local measurements. This scheme has already demonstrated an advantage over the gate-based model for small perturbations of Toric code Hamiltonians, as it allows for more compact construction of certain ansaetze while enjoying shallower circuit depths - an imperative property for implementation on NISQ hardware. In our work, we deepen the investigation of MB-VQE advantage by considering more general resource states and larger classes of Hamiltonians, which helps us develop a more rigorous understanding of the advantageous ansaetze in MB-VQE for given problem classes.

QI 35.2 Fri 11:15 B305

Molecular Quantum Circuit Design — •Jakob Kottmann — Institut for Computer Science, University of Augsburg

An integral part of science is the formulation of simple concepts capable to capture the essential aspects of complex processes. A prominent examples is the reduction of molecules to simple graphs with the atomic nuclei as vertices connected by edges representing so - called chemical bonds.

Design principles for the construction of quantum circuits are in high demand and are currently being researched heavily - current methodologies however often lack simplicity and interpretability.

Here, an interpretable design concept for quantum circuits based on chemical graphs is presented. It provides physical insight and interpretaility for each individual circuit element and leads to heuristics for the construction, optimisation, and interpretation of quantum circuits suitable for ground state preparation.

QI 35.3 Fri 11:30 B305

Perspectives of running DMFT calculations on NISQ hardware — •Jannis Ehrlich, Daniel F. Urban, and Christian Elsässer — Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany

Quantum computers promise to enhance numerical calculations of correlated electron systems. While the simulation of full electronic systems is far out of reach due to the large number of states that need to be considered, effective model systems can already be implemented on currently available NISQ devices. The Dynamical Mean Field Theory (DMFT) is such an embedding approach, in which the Greens function of a correlated orbital has to match both, the orbitals description as site of a regular lattice and as impurity in an Anderson impurity model (AIM). Both models are solved in an iterative self-consistency loop, where the solution of the AIM is the limiting part of DMFT calculations on conventional computers today. Here, we introduce a possible way of solving the AIP on a quantum computer using hybrid approaches like the variational quantum eigensolver (VQE). We present results of experiments on IBMQ hardware for the two-site DMFT model. Moreover, we show how state-of-the-art error mitigation strategies improve the results. A post-correction scheme is presented to ensure physical symmetries in the final self-consistent Greens function and self-energy and we derive and discuss the requirements on the quantum hardware needed for a successful implementation of the algorithm.

QI 35.4 Fri 11:45 B305

QRydDemo - Quantum Computing with Rydberg Atoms — •Sebastian Weber[1], Philipp Ilzhöfer[2], Govind Unnikrishnan[2], Ratnesh Kumar Gupta[2], Jiachen Zhao[2], Jennifer Krauter[2], Achim Scholz[2], Moritz Wilke[2], Alice Pagano[3], Daniel Jaschke[3], Nicolai Lang[1], Nastasia Makki[1], Hans Peter Büchler[1], Simone Montangero[3], Jürgen Stuhler[4], Tilman Pfau[2], and Florian Meinert[2] — [1]Institute for Theoretical Physics III and IQST, University of Stuttgart, Germany — [2]5th Institute of Physics and IQST, University of Stuttgart, Germany — [3]Institute for Complex Quantum Systems, Ulm University, Germany — [4]Toptica Photonics AG, Gräfelfing, Germany

The QRydDemo Consortium aims to realize a quantum computer demonstrator with up to 500 atomic qubits trapped in arrays of optical tweezers. Exciting the atoms with lasers to Rydberg states, allows for rapidly switching interactions between the atoms on and off, enabling the implementation of fast and high-fidelity gate operations. Our quantum processor based on the optical tweezer architecture promises many exciting new possibilities. One novel aspect we aim to explore is the potential to change the qubit connectivity during a quantum computation. I will provide an overview of the QRydDemo project and demonstrate our online emulator that allows future users of our hardware to get familiar with QRydDemo's native gate operations.

QI 35.5 Fri 12:00 B305

Proposed method to produce large multipartite nonlocality and benchmark quantum computers — •Jan Lennart Bönsel[1], Otfried Gühne[1], and Adán Cabello[2] — [1]Universität Siegen, Germany — [2]Universidad de Sevilla, Spain

Nonlocality is a characteristic of quantum mechanics that does not occur in a local realistic model. Thus, nonlocality is an interesting property to exclude local realistic models, which can be tested by Bell inequalities. Mermin- and Ardehali-Bell inequalities can be formulated for a large number of qubits N. For these inequalities, the ratio of the quantum violation to the classical bound increases exponentially in N. In practice, the amount of nonlocality that can be produced is limited by noise and restrictions on the possible qubit interactions. In addition, to certify nonlocality, a number of terms that grows exponentially with the number of qubits have to be measured, which becomes infeasible for systems with many qubits.

In this work, we address this problem. On the one hand, we consider the Ardehali-Bell operator for the linear cluster state, which can be prepared by nearest neighbour interactions only. On the other hand, we investigate how the violation of the Bell inequality can be estimated by measuring the terms of the Bell operator at random. For this purpose, we study the confidence level for an observed violation given the number of measured observables. As the linear cluster state is important for quantum computations and can be readily prepared on many quantum computing platforms, the violation of the Bell inequality could serve as a benchmark for quantum computers.

QI 35.6 Fri 12:15 B305

Principles of Quantum Functional Testing — Nadia Milazzo[1,2,3], Olivier Giraud[2], •Giovanni Gramegna[1], and Daniel Braun[1] — [1]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany — [2]Université Paris Saclay, CNRS, LPTMS, Orsay 91405, Franc — [3]ColibrITD, 91, rue du Faubourg Saint-Honoré 75008 Paris

Testing the functionality of quantum devices will be needed as their availability increases. In this context, a complete characterization of the quantum channel implemented by the device is unfeasible except for the simplest and smallest quantum chips. Rather, quantum functional testing aims at determining as fast as possible whether the device can be accepted or rejected according to the producer pecifications on the key characterizing parameters. In particular, it is desirable to waste as little time as possible on devices that do not function properly. We investigate the possibility to speed up the testing process by using repetition of the channel: on one hand this would increase the impact of coherent errors enhancing their detectability, on the other hand the amplification of incoherent errors might have the opposite effect. This also motivates the introduction of non-greedy adaptive experimental design, where the decision on whether to repeat the channel or more generally which sequence of measurement to perform is established based on the information already gathered from previous measurements. Finally, we investigate the impact of different decision criteria on the efficiency of the testing procedure

QI 35.7 Fri 12:30 B305

Characterizing crosstalk of superconducting transmon processors — •Andreas Ketterer and Thomas Wellens — Fraunhofer Institut für Angewandte Festkörperphysik IAF, Tullastr. 72, 79108 Freiburg, Germany

Currently available quantum computing hardware based on superconducting transmon architectures realizes networks of hundreds of qubits with the possibility of controlled nearest-neighbor interactions. However, the inherent noise and decoherence effects of such quantum chips considerably alter basic gate operations and lead to imperfect outputs of the targeted quantum computation. In this talk we focus on the characterization of crosstalk effects which manifest themselves in correlations between simultaneously executed quantum gates on neighboring qubits. After a short explanation of the origin of such correlations we show how to efficiently and systematically characterize the magnitude of such crosstalk effects on an entire quantum chip using the randomized benchmarking protocol. In particular, we demonstrate the introduced protocol by running it on real quantum hardware provided by IBM. Lastly, we use the gained information in order to propose novel and more accurate means to simulate noisy quantum hardware by devising an appropriate crosstalk-aware noise model.

QI 35.8 Fri 12:45 B305

Noise mitigating adaptive quantum tomography — •Adrian Aasen and Martin Gärttner — Kirchhoff-Institut für Physik, Universität Heidelberg, Heidelberg, Germany

Quantum tomography is the process of reconstructing density matrices, or quantum states, and is the golden standard for state discrimination. It is quite an active field partially due to the recent development and benchmarking requirements of quantum computers and hardware. Common for all near term quantum devices is that they are noisy. Knowing how readout errors affect the tomographic estimate and how to mitigate the effect of noise is of significant interest. We leverage two strategies to reduce the overall experimental cost and improve control over noise in experimental setups. Firstly, we limit the use of noisy measurements to fit within a "noise budget". Subsequently we give a theoretical prescription for how to derive an optimal set of measurements within these restrictions, given some noise model. Secondly, we use adaptive strategies, suitable for both maximal likelihood estimation and Bayesian inference, to maximize information extraction per measurement. Combining these two strategies provide an optimal protocol to reach a desired reconstruction accuracy in a noisy environment.

QI 36: Quantum Metrology (joint session QI/Q)

Time: Friday 11:00–13:00 Location: F428

QI 36.1 Fri 11:00 F428

Super-Resolution Imaging with Multiparameter Quantum Metrology in Passive Remote Sensing — •Emre Köse and Daniel Braun — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

We study super-resolution imaging theoretically using a distant n-mode interferometer in the microwave regime for passive remote sensing, used e.g., for satellites like the "soil moisture and ocean salinity (SMOS)" mission to observe the surface of the Earth. We give a complete quantum mechanical analysis of multiparameter estimation of the temperatures on the source plane. We find the optimal detection modes by combining incoming modes with an optimized unitary that enables the most informative measurement based on photon counting in the detection modes and saturates the quantum Cramér-Rao bound from the symmetric logarithmic derivative for the parameter set of temperatures. In our numerical analysis, we achieved a quantum-enhanced super-resolution by reconstructing an image using the maximum likelihood estimator with a pixel size of 3 (km), which is ten times smaller than the spatial resolution of SMOS with comparable parameters. Further, we find the optimized unitary for uniform temperature distribution on the source plane, with the temperatures corresponding to the average temperatures of the image. Even though the corresponding unitary was not optimized for the specific image, it still gives a super-resolution compared to local measurement scenarios for the theoretically possible maximum number of measurements.

QI 36.2 Fri 11:15 F428

Activation of metrologically useful genuine multipartite entanglement — •Róbert Trényi[1,2,3], Árpád Lukács[1,4,3], Paweł Horodecki[5,6], Ryszard Horodecki[5], Tamás Vértesi[7], and Géza Tóth[1,2,8,3] — [1]Dept. of Theoretical Physics, U. of the Basque Country UPV/EHU, Bilbao, Spain — [2]DIPC, San Sebastián, Spain — [3]Wigner Research Centre for Physics, Budapest, Hungary — [4]Dept. of Mathematical Sciences, Durham University, United Kingdom — [5]International Centre for Theory of Quantum Technologies, University of Gdansk, Gdansk, Poland — [6]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdansk University of Technology, Gdansk, Poland — [7]Institute for Nuclear Research, Debrecen, Hungary — [8]IKERBASQUE, Bilbao, Spain

In quantum metrology, the usefulness of a quantum state is determined by how much it outperforms separable states. For the maximal metrological usefulness genuine multipartite entanglement (GME) is required. In order to improve the usefulness of a quantum state we consider a scheme of having several of its copies. With this scheme, it is possible to find a large class of practically important entangled states that can achieve maximal metrological performance in the limit of many copies, whereas in the single copy case these states can even be non-useful. Thus, we essentially activate quantum metrologically useful GME. Moreover, this maximal usefulness is attained exponentially fast with the number of copies and it can be achieved by measurements of simple correlation observables. We also give examples of improving the usefulness outside of the above mentioned class.

QI 36.3 Fri 11:30 F428

Quantum metrology with ultracold chemical reactions — Seong-Ho Shinn[1], Uwe R. Fischer[1], and •Daniel Braun[2] — [1]Seoul National University — [2]Eberhard Karls University Tübingen

Classical chemical reactions are routinely used for extremely sensitive detection schemes in chemical, biological, and medical analysis, and have even been employed in the search for dark matter. Now we show that coherent, ultracold chemical reactions harbor great potential for quantum metrology [1]: In an atom-molecule Bose-Einstein condensate (BEC), a weak external perturbation can generate elementary excitations, "reactons", of a reaction field. In an appropriate atom-dominant parameter regime this translates to the coherent creation of molecules which can be selectively detected with modern spectroscopic techniques. This promises to improve the viability of previously proposed BEC-based sensors for gravitational waves and other physical quantities, for which so far no practical read-out scheme could be demonstrated.

[1] Seong-Ho Shinn, Uwe R. Fischer, and Daniel Braun, arXiv:2208.06380

QI 36.4 Fri 11:45 F428

Quantum metrology from randomized measurements — •Satoya Imai[1], Otfried Gühne[1], and Géza Tóth[2,3,4,5] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [2]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain — [3]Donostia International Physics Center (DIPC), ES-20080 San Sebastian, Spain — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [5]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

A central task in quantum metrology is to consider a parameter encoding on a quantum system and to improve schemes to reach optimal precision. To reach higher precision, precise control of state preparation and favorable measurements may be necessary. In practice, however, unavoidable noise effects, such as magnetic field fluctuations, may affect the estimation accuracy. A key idea to address this situation is to perform a random measurement on the quantum system and access local unitary invariants. This procedure motivates the study of quantum metrology without a common reference frame between several parties. In this talk, we present a systematic method to investigate the estimation sensitivity in the dynamics based on nonlinear interaction Hamiltonians. We show that the well-known Heisenberg scaling is achievable and even better scaling is attainable.

QI 36.5 Fri 12:00 F428

Closed-loop Quantum Optimal Control for Electronic Spins — •Thomas Reisser[1,2], Marco Rossignolo[3,4], Matthias M. Müller[1], Felix Motzoi[1], Fedor Jelezko[3], Simone Montangero[4,5], and Tommaso Calarco[1,2] — [1]Forschungszentrum Jülich GmbH — [2]University of Cologne — [3]Ulm University — [4]Università degli Studi di Padova — [5]INFN, Sezione di Padova

To unlock the full potential of many quantum technologies, quantum optimal control (QOC) algorithms and strategies are used to enhance and enable operations on a quantum system. While some methods depend on simulations and good models of the system, it can be helpful to close the loop with an experiment in order to tweak the given controls for a specific setup. The Quantum Optimal Control Suite (QuOCS) is designed to perform black-box optimization in connection with an arbitrary experiment or simulation. Due to its interface with the experiment control software Qudi [1] is has been used successfully for the optimization of pulses for color centers in diamond and also two-qubit gates with Rydberg Atoms [2]. We show the main features of the QuOCS software package and report on recent developments and applications of QOC on electron spins in crystals with a focus on quantum sensing.

References:

[1] J. M. Binder et al., Qudi: A modular python suite for experiment control and data processing, SoftwareX (2017)

[2] A. Pagano et al., Error budgeting for a controlled-phase gate with strontium-88 rydberg atoms, PRR (2022)

QI 36.6 Fri 12:15 F428

Quantum Wasserstein distance based on an optimization over separable states — •Géza Tóth[1,2,3,4] and József Pitrik[4,5,6] — [1]Theoretical Physics and EHU Quantum Center, University of the Basque Country UPV/EHU, ES-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), ES-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, ES-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, HU-1525 Budapest, Hungary — [5]Alfréd Rényi Institute of Mathematics, HU-1053 Budapest, Hungary — [6]Department of Analysis, Institute of Mathematics, Budapest University of Technology and Economics, HU-1111 Budapest, Hungary

We define the quantum Wasserstein distance such that the optimization is carried out over bipartite separable states rather than bipartite quantum states in general, and examine its properties. Surprisingly, we find that its self-distance is related to the quantum Fisher information. We discuss how the quantum Wasserstein distance introduced is connected to criteria detecting quantum entanglement. We define variance-like quantities that can be obtained from the quantum Wasserstein distance by replacing the minimization over quantum states by a maximization. We extend our results to a family of generalized quantum Fisher information.

[1] G. Tóth and J. Pitrik, arXiv:2209.09925.

QI 36.7 Fri 12:30 F428

Infrared laser absorption magnetometry with Ensembles of Nitrogen-Vacancy centres — •Felipe Perona[1,2], Julian Bopp[2], Jonas Wollenberg[2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut (FBH), Berlin, Germany — [2]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany

Magnetometers based on ensembles of Nitrogen-Vacancy (NV) centres have shown sub-nanotesla sensitivities [1]. The applied measurement concept relies on the detection and analysis of the intensity of the NV's red fluorescence, which, under the proper conditions, encodes the value of a magnetic field at the defect location. A less explored approach is using the infrared absorption of the NV centre at 1042 nm as a medium to read its local magnetic environment [2]. This strategy avoids the necessity of implementing high photon collection efficiencies, improves the read-out contrast, and simplifies the sensing setup, allowing a higher degree of integration. In this work, we implement infrared laser absorption magnetometry and demonstrate that such magnetometer can reach high sensitivities. To maximize this sensitivity, we engineer the NV density of our diamonds and optimize it for this task. We integrate the concept into a compact device towards enabling miniaturized, portable magnetometers.

[1] H. Clevenson et al., "Broadband magnetometry and temperature sensing with a light-trapping diamond waveguide", Nat. Phys., 11:5, 2015 [2] V. Acosta et al., "Broadband magnetometry by infrared-absorption detection of nitrogen-vacancy ensembles in diamond", Appl. Phys. Lett., 97:17, 2010

QI 36.8 Fri 12:45 F428

Gradient Magnetometry with Atomic Ensembles — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zoltán Zimborás[1,2,3], Philipp Hyllus[1], and Géza Tóth[1,3,4] — [1]Department of Physics, University of the Basque Country UPV/EHU, P. O. Box 644, E-48080 Bilbao, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain

We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information for various types of ensembles, such as for example, a single atomic ensemble with an arbitrary density profile, where the atoms cannot be addressed individually and which is a very relevant case for experiments.

We present a method to find spin states for gradient magnetometry with two spatially separated atomic ensembles based on states for sensing a global phase shift, such as the GHZ state or the Dicke state.

[1] I. Apellaniz et al., Phys. Rev. A, 97 053603 (2018)
[2] G. Vitagliano et al., arXiv:2104.05663 (2021)

QI 37: Quantum Many Body Systems

Time: Friday 14:30–16:15 Location: F428

QI 37.1 Fri 14:30 F428

Metastable discrete time-crystal resonances in a dissipative central spin system — •Albert Cabot[1], Federico Carollo[1], and Igor Lesanovsky[1,2] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We consider [1] the non-equilibrium behavior of a central spin system where the central spin is periodically reset to its ground state. The quantum mechanical evolution under this effectively dissipative dynamics is described by a discrete-time quantum map. Despite its simplicity this problem shows surprisingly complex dynamical features. In particular, we identify several metastable time-crystal resonances. Here the system does not relax rapidly to a stationary state but undergoes long-lived oscillations with a period that is an integer multiple of the reset period. At these resonances the evolution becomes restricted to a low-dimensional state space within which the system undergoes a periodic motion. Generalizing the theory of metastability in open quantum systems, we develop an effective description for the evolution within this long-lived metastable subspace and show that in the long-time limit a non-equilibrium stationary state is approached. Our study links to timely questions concerning emergent collective behavior in the "prethermal" stage of a dissipative quantum many-body evolution as well as to the phenomenon of quantum synchronization. [1] A. Cabot et al., Phys. Rev. B 106, 134311 (2022)

QI 37.2 Fri 14:45 F428

Haldane phase in one-dimensional systems of Rydberg atoms — •Johannes Mögerle and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, 70550 Stuttgart, Germany

Quantum many body physics features a wide range of interesting phenomena. This includes new, so-called topological quantum phases, which appear due to entanglement. One of the earliest proposed such phase is the Haldane phase in a one-dimensional Spin 1 chain, which later was found to be a symmetry protected topological phase. A promising platform to realize all kinds of topological phases are Rydberg atoms with their strong and tunable interactions.

This work focuses on numerically simulating the Haldane phase in a parameter regime which is accessible in Rydberg systems. Moreover, we are proposing a concrete example of experimental parameters using a three level system in Rubidium atoms to realize a groundstate close to the famous AKLT state.

QI 37.3 Fri 15:00 F428

Series expansions with multiple quasi-particle types for the dual Dicke-Ising model — •Andreas Schellenberger, Lea Lenke, and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

The established approach of perturbative continuous unitary transformations (pCUT) constructs effective quantum many-body Hamiltonians in a perturbative series that conserve the number of one quasi-particle type. We extend the pCUT method to similarity transformations – dubbed pcst^{++} – allowing for multiple quasi-particle-types with complex-valued energies. This enlarges the field of application to closed and open quantum many-body systems with unperturbed operators corresponding to arbitrary superimposed ladder spectra. To illustrate the new possibility of the pcst^{++} method to specifically tackle interacting light-matter systems, we discuss the dual Dicke-Ising model. We determine low-energy spectral properties and investigate potential conversion processes between different quasi-particle types.

QI 37.4 Fri 15:15 F428

Reviving product states in the disordered Heisenberg chain — •Henrik Wilming[1], Tobias J. Osborne[1], Kevin S.C. Decker[2], and Christoph Karrasch[2] — [1]Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Technische Universität Braunschweig, Institut für Mathematische Physik, Mendelssohnstraße 3, 38106

When a generic quantum system is prepared in a simple initial condition, it typically equilibrates toward a state that can be described by a thermal ensemble. A known exception are localized systems which are non-ergodic and do not thermalize, however local observables are still believed to become stationary. Here we demonstrate that this general picture is incomplete by constructing product states which feature periodic high-fidelity revivals of the full wavefunction and local observables that oscillate indefinitely. The system neither equilibrates nor thermalizes. This is analogous to the phenomenon of weak ergodicity breaking due to many-body scars and challenges aspects of the current MBL phenomenology, such as the logarithmic growth of the entanglement entropy. To support our claim, we combine analytic arguments with large-scale tensor network numerics for the disordered Heisenberg chain. Our results hold for arbitrarily long times in chains of 160 sites up to machine precision.

QI 37.5 Fri 15:30 F428

Linked-cluster expansions of perturbed topological phases — •Viktor Kott, Matthias Mühlhauser, and Kai Phillip Schmidt — FAU, Erlangen-Nürnberg, Deutschland

We investigate the robustness of Kitaev's toric code in a uniform magnetic field on the square and honeycomb lattice by perturbative linked cluster expansions using a full graph decomposition. In particular, the full graph decomposition allows to correctly take into account the non-trivial mutual exchange statistics of the elementary anyonic excitations. This allows us to calculate the ground-state energy and excitation energies of the topological phase which are then used to study the quantum phase transitions out of the topologically ordered phase as a function of the field direction.

QI 37.6 Fri 15:45 F428

Systematic Analysis of Diagonal Ordering Patterns in Bosonic Lattice Models with Algebraically Decaying Density-Density Interactions — •Jan Alexander Koziol[1], Antonia Duft[1], Giovanna Morigi[2], and Kai Phillip Schmidt[1] — [1]Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrücken, Germany

We propose a general approach to analyse diagonal ordering patterns in bosonic lattice models with algebraically decaying density-density interactions on arbitrary lattices. The key idea is a systematic search for the energetically best order on all unit cells of the lattice up to a given extent. Using resummed couplings we evaluate the energy of the ordering pattern in the thermodynamic limit using finite unit cells. We apply the proposed approach to the atomic limit of the extended Bose-Hubbard on a triangular lattice at fillings $f = 1/2$ and $f = 1$. We investigate the ground-state properties of the antiferromagnetic long-range Ising model on the triangular lattice and determine a six-fold degenerate plain-stripe phase to be the ground state for finite decay exponents. We also probe the classical limit of the Hamiltonian describing Rydberg atom arrangements on the sites and links of the Kagome lattice.

QI 37.7 Fri 16:00 F428

Series expansions in open and non-Hermitian quantum many-body systems with multiple quasi-particle types — •Lea Lenke, Andreas Schellenberger, and Kai Phillip Schmidt — FAU Erlangen-Nürnberg

The established approach of perturbative continuous unitary transformations (pCUT) constructs effective quantum many-body Hamiltonians in a perturbative series that conserve the number of one quasi-particle type. We extend the pCUT method to similarity transformations – dubbed pcut^{++} – allowing for multiple quasi-particle-types with complex-valued energies. This enlarges the field of application to closed and open quantum many-body systems with unperturbed operators corresponding to arbitrary superimposed ladder spectra. To this end a generalized counting operator is combined with the quasi-particle generator for open quantum systems recently introduced by Schmiedinghoff and Uhrig [1]. The pcut^{++} then yields model-independent quasi-particle conserving effective Hamiltonians and Lindbladians allowing a linked-cluster expansion similar to the conventional pCUT method. We illustrate the application of the pcut^{++} method by discussing representative open and non-Hermitian quantum systems.

[1] G. Schmiedinghoff and G. S. Uhrig, "Efficient flow equations for dissipative systems", (2022), arXiv:2203.15532 [cond-mat.quant-ph].

Physics Education Division
Fachverband Didaktik der Physik (DD)

Susanne Heinicke
Westfälische Wilhelms-Universität Münster
Fachbereich Physik
Institut für Didaktik der Physik
Wilhelm-Klemm-Straße 10
48149 Münster
susanne.heinicke@uni-muenster.de

Die Tagung 2023 findet in Präsenz an der Leibniz Universität Hannover statt.

Übersicht über Hauptvorträge und Fachsitzungen

(Hörsaal DD HS 2.202, Seminarräume DD 108, DD 110, DD 111, DD 405 und DD 407; Poster Empore Lichthof)

Plenarvortrag des Fachverbands Didaktik der Physik

PV III	Tue	9:00– 9:45	E415	**Educational Transformation at a Critical Time: The essential roles and promise of physicists** — •Noah Finkelstein

Preisträgervorträge

DD 35.1	Tue	12:15–12:35	DD 108	**Durchführung eines MINT-Berufsinformationstags für die Mittelstufe in Form eines Digitalkongresses** — •Sebastian Bauer
DD 35.2	Tue	12:35–12:55	DD 108	**... mehr als nur Physik in the lænd** — •Pirmin Gohn, •Hermann Klein
DD 39.1	Tue	14:40–15:20	DD HS 2.202	**Die Welt der Smartphone-Experimente mit phyphox** — •Sebastian Staacks, •Christoph Stampfer
DD 39.2	Tue	15:20–16:00	DD HS 2.202	**Entwicklung und Beforschung von Unterrichtskonzeptionen** — •Thomas Wilhelm

Hauptvorträge

DD 1.1	Mon	11:00–12:00	DD HS 2.202	**Welchen Beitrag kann die Hochschul-Fachdidaktik zur Lehre der Physik als Haupt- und Nebenfach leisten?** — •Christian Kautz
DD 40.1	Tue	16:30–17:30	DD HS 2.202	**Zwischen Corona und KI: Wo steht die Hochschullehre und wie geht sie weiter?** — •Peter Salden
DD 47.1	Wed	12:10–13:10	DD HS 2.202	**Reflexivität zu Sprache und Physiklernen durch Fallverstehen? Eine kasuistische Begleitveranstaltung zu Schulpraktika im Lehramtsstudium** — •Thorid Rabe, Andreas Helzel

Fachsitzungen

DD 1.1–1.1	Mon	11:00–12:00	DD HS 2.202	**Eröffnung und Hauptvortrag 1: Kautz**
DD 2.1–2.3	Mon	12:00–13:00	DD 108	**Inklusion**
DD 3.1–3.3	Mon	12:00–13:00	DD 110	**Digitale Medien I**
DD 4.1–4.3	Mon	12:00–13:00	DD 111	**Quantenphysik I**
DD 5.1–5.3	Mon	12:00–13:00	DD 405	**Hochschuldidaktik I**
DD 6.1–6.2	Mon	12:00–12:40	DD 407	**Interesse und Persönlichkeit I**
DD 7.1–7.3	Mon	14:30–15:30	DD 108	**Lehr-Lernforschung I**
DD 8.1–8.3	Mon	14:30–15:30	DD 110	**Digitale Medien II**
DD 9.1–9.3	Mon	14:30–15:30	DD 111	**Quantenphysik II**

DD 10	Mon	14:30–15:30	DD 405	**Workshop Lehramtsstudie KFP/DPG**
DD 11.1–11.3	Mon	14:30–15:30	DD 407	**Nature of Science, Geschichte**
DD 12.1–12.3	Mon	16:00–17:00	DD 108	**Lehr-Lernforschung II**
DD 13.1–13.3	Mon	16:00–17:00	DD 110	**Digitale Medien III**
DD 14.1–14.3	Mon	16:00–17:00	DD 111	**Quantenphysik III**
DD 15.1–15.3	Mon	16:00–17:00	DD 405	**Hochschuldidaktik II**
DD 16.1–16.3	Mon	16:00–17:00	DD 407	**Lehreraus- und -fortbildung I**
DD 17.1–17.3	Mon	17:00–19:00	Empore Lichthof	**Poster – Außerschulisches Lernen**
DD 18.1–18.4	Mon	17:00–19:00	Empore Lichthof	**Poster – Bildung für nachhaltige Entwicklung**
DD 19.1–19.4	Mon	17:00–19:00	Empore Lichthof	**Poster – Physikunterricht: Inklusion, Sprache, Anregungen**
DD 20.1–20.7	Mon	17:00–19:00	Empore Lichthof	**Poster – Quantenphysik**
DD 21.1–21.4	Mon	17:00–19:00	Empore Lichthof	**Poster – Lehr-Lernforschung**
DD 22.1–22.12	Mon	17:00–19:00	Empore Lichthof	**Poster – Neue / digitale Medien**
DD 23.1–23.4	Mon	17:00–19:00	Empore Lichthof	**Poster – Lehreraus- und -fortbildung**
DD 24.1–24.5	Mon	17:00–19:00	Empore Lichthof	**Poster – Neue Konzepte**
DD 25.1–25.4	Mon	17:00–19:00	Empore Lichthof	**Poster – Praktika und Experimente**
DD 26.1–26.3	Mon	17:00–19:00	Empore Lichthof	**Poster – Astronomie**
DD 27.1–27.11	Mon	17:00–19:00	Empore Lichthof	**Poster – Hochschuldidaktik**
DD 28.1–28.3	Mon	17:00–19:00	Empore Lichthof	**Poster – Weitere fachdidaktische Forschung**
DD 29.1–29.3	Mon	17:00–19:00	Empore Lichthof	**Poster – Arbeitsgruppen Physikdidaktik Quo vadis**
DD 30.1–30.3	Tue	11:00–12:00	DD 108	**Lehr-Lernforschung III**
DD 31.1–31.3	Tue	11:00–12:00	DD 110	**Praktika und neue Praktikumsversuche**
DD 32.1–32.3	Tue	11:00–12:00	DD 111	**Quantenphysik IV**
DD 33.1–33.3	Tue	11:00–12:00	DD 405	**Interesse und Persönlichkeit II**
DD 34.1–34.3	Tue	11:00–12:00	DD 407	**Lehreraus- und -fortbildung II**
DD 35.1–35.2	Tue	12:15–12:55	DD 108	**Impulse aus der Unterrichtspraxis – Vorträge Lehrerpreis**
DD 36.1–36.2	Tue	12:15–12:55	DD 110	**Digitale Medien IV**
DD 37.1–37.2	Tue	12:15–12:55	DD 405	**Hochschuldidaktik III**
DD 38.1–38.2	Tue	12:15–12:55	DD 407	**Bildung für nachhaltige Entwicklung I**
DD 39.1–39.2	Tue	14:30–16:00	DD HS 2.202	**Preisträgersymposium Didaktik**
DD 40.1–40.1	Tue	16:30–17:30	DD HS 2.202	**Hauptvortrag 2: Salden**
DD 41	Tue	18:00–19:30	DD HS 2.202	**Mitgliederversammlung FV DD**
DD 42.1–42.3	Wed	11:00–12:00	DD 108	**Lehr-Lernforschung IV**
DD 43.1–43.3	Wed	11:00–12:00	DD 110	**Experimente I**
DD 44.1–44.3	Wed	11:00–12:00	DD 111	**Quantenphysik V**
DD 45.1–45.3	Wed	11:00–12:00	DD 405	**Hochschuldidaktik IV**
DD 46.1–46.3	Wed	11:00–12:00	DD 407	**Bildung für nachhaltige Entwicklung II**
DD 47.1–47.1	Wed	12:10–13:10	DD HS 2.202	**Hauptvortrag 3: Rabe & Helzel**
DD 48.1–48.3	Wed	14:30–15:30	DD 108	**Lehr-Lernforschung V**
DD 49.1–49.3	Wed	14:30–15:30	DD 110	**Experimente II**
DD 50.1–50.3	Wed	14:30–15:30	DD 111	**Quantenphysik VI**
DD 51.1–51.3	Wed	14:30–15:30	DD 405	**Hochschuldidaktik V**
DD 52.1–52.3	Wed	14:30–15:30	DD 407	**außerschulisch/Hochschule**
DD 53.1–53.1	Wed	16:00–17:30	DD 108	**Workshop Studienreformforum**

Mitgliederversammlung des Fachverbands Didaktik der Physik

Dienstag 18:00–19:30 DD HS 2.202

- Genehmigung der Tagesordnung
- Genehmigung des Protokolls vom 22.03.2022
- Berichte aus den Arbeitsgruppen
- Termine
- Verschiedenes

Sessions

– Invited Talks, Prize Talks, Contributed Talks, and Posters –

DD 1: Eröffnung und Hauptvortrag 1: Kautz

Time: Monday 11:00–12:00 Location: DD HS 2.202

Invited Talk DD 1.1 Mon 11:00 DD HS 2.202

Welchen Beitrag kann die Hochschul-Fachdidaktik zur Lehre der Physik als Haupt- und Nebenfach leisten? — •Christian Kautz — Technische Universität Hamburg, Hamburg, Deutschland

Lehrende der Physik, besonders im Grundlagenbereich und im Nebenfach, beobachten häufig, dass Studierende deutlich weniger aus den Lehrveranstaltungen mitnehmen als sie, die Lehrenden, sich wünschen. Mit den empirischen Methoden der Fachdidaktik lassen sich diese Beobachtungen zunächst objektivieren und konkretisieren, bevor dann gezielt Methoden genutzt werden können, um den Lernerfolg sowohl in kleinen als auch in großen Lehrveranstaltungen deutlich zu verbessern. Hierzu gehören neben Maßnahmen zur Steigerung der (Inter-)Aktivität der Studierenden auch solche, die das Erkennen konkreter Schwierigkeiten bei den Studierenden erlauben. Dies soll anhand von konkreten Beispielen aus verschiedenen Themenbereichen verdeutlicht und mit Testdaten von Studierenden auch aus großen Grundlagenvorlesungen belegt werden. Davon ausgehend wird die Bedeutung der Fachdidaktik für die fachliche Lehre der Physik und physik-naher Fächer an Hochschulen und Universitäten diskutiert.

DD 2: Inklusion

Time: Monday 12:00–13:00 Location: DD 108

DD 2.1 Mon 12:00 DD 108

Interaktionen von Schüler:innen mit UDL-basiertem Lernmaterial — •Franziska Klautke und Heike Theyssen — Universität Duisburg-Essen, Didaktik der Physik

Das Universal Design for Learning (UDL) stellt einen Rahmen für die Materialentwicklung und Unterrichtsplanung dar, um zunehmender Diversität im Unterricht zu begegnen. Auf diese Weise sollen Lernbarrieren reduziert und durch das Bereitstellen von Wahlangeboten Zugangsmöglichkeiten offeriert werden. Es ist jedoch weitgehend unklar, unter welchen Voraussetzungen Schüler:innen in der Lage sind, Wahlmöglichkeiten selbständig zur Unterstützung des eigenen Lernprozesses, insbesondere beim Experimentieren, zu nutzen. Um dies zu untersuchen, wird eine nach UDL-Prinzipien gestaltete Lerngelegenheit zum Planen und Aufbauen von Experimenten mit digitalem Arbeitsheft und realen Experimenten entwickelt und erprobt. Im Vortrag werden Ergebnisse zum Lernverhalten der Schüler:innen, insb. zur Nutzung der Wahl- und Unterstützungsangebote, vorgestellt.

DD 2.2 Mon 12:20 DD 108

Energie und Energieumwandlungen im inklusiven Unterricht — Kolkenbrock David[1], Kissenbeck Andreas[3], Brackertz Stefan[1], Schröder René[2] und •Schulz Andreas[1] — [1]Universität zu Köln — [2]Universität Bielefeld — [3]Gesamtschule Köln-Holweide

Alle Prozesse im Universum und im Leben sind mit Energieumwandlungen verbunden. Daher sind diese ein Unterrichtsthema am Übergang von der Mittel- zur Oberstufe. Hierzu wurde ein Konzept zur Behandlung im inklusiven Unterricht der Klassenstufe 10 entworfen.

Es wurde eine Differenzierungsmatrix nach Sasse entwickelt, die es Schüler*innen ermöglicht, beim Lernen ihren Schwierigkeitsgrad, aber auch die Art ihres Zugangs selbst zu wählen. Dabei haben sich die Schüler*innen abweichend vom Ursprungskonzept der Differenzierungsmatrix nicht individuell, sondern in Gruppen durch die Matrix bewegt und mussten sich so der Herausforderung stellen, trotz unterschiedlicher Voraussetzungen tatsächlich einen Weg zur Zusammenarbeit zu entwickeln. Um dies zu ermöglichen, wurde statt dem verbreiteten Schema "Motivation - Definition des Energiebegriffs - Anwendung" zu folgen, der Energiebegriff an Hand von Umwandlungsprozessen eingekreist und so weit heraus geschärft, dass eine formale Definition am Ende der Einheit fast unnötig wurde. Dabei wurden v.a. fächerübergreifende Beispiele aus der Energieversorgung verwendet und auch das Problem der Energieentwertung behandelt.

Das Konzept wurde in der Gesamtschule Köln-Holweide in 5 Unterrichtseinheiten sowie einer Vergleichsklasse erprobt und in allen Details evaluiert. Diese Evaluation wird hier präsentiert

DD 2.3 Mon 12:40 DD 108

Auswirkung von Wahlfreiheit beim Experimentieren — •Laura Sührig[1], Roger Erb[1], Holger Horz[2], Albert Teichrew[1], Mark Ullrich[2] und Jan Winkelmann[3] — [1]Institut für Didaktik der Physik, Goethe-Universität Frankfurt — [2]Pädagogische Psychologie, Goethe-Universität Frankfurt — [3]Pädagogische Hochschule Schwäbisch Gmünd

Es ist eine anspruchsvolle Aufgabe, Fachunterricht nicht mehr an einer fiktiven Homogenität der Schülerschaft auszurichten, sondern so zu gestalten, dass er allen Schüler*innen gerecht wird. Im Physikunterricht ist das Experimentieren ein wesentlicher Zugang, um Wissen oder Arbeitsweisen zu vermitteln. Damit Schüler*innen beim Experimentieren individuelle Lernwege vollziehen und ihren Lernprozess mitgestalten können, haben wir ein Unterrichtskonzept für inklusive Schüler*innenexperimente entwickelt, welches eine Wahl aus experimentellen Zugängen ermöglicht und damit individuellen Voraussetzungen und Interessen gerecht wird. Dieses Konzept wurde in Form einer Unterrichtseinheit an hessischen und thüringischen Schulen verschiedener Schulzweige evaluiert. In der zugehörigen Studie wird die Auswirkung der Wahlfreiheit auf die Schüler*innen untersucht, sowie die Sichtweise der Lehrkräfte auf das Konzept in den Blick genommen. In dem Vortrag werden die Ergebnisse der Studie vorgestellt.

DD 3: Digitale Medien I

Time: Monday 12:00–13:00 Location: DD 110

DD 3.1 Mon 12:00 DD 110

Grafische und interaktive Aufgaben für digitale Kenntnistests Physik — •Karen Brösamle[1], Achim Eichhorn[2], Hanno Käss[2] und Günther Kurz[2] — [1]Philipp-Matthäus-Hahn-Schule, Nürtingen — [2]Hochschule Esslingen

Physik wird von Lernenden oft auf das Anwenden von Formeln reduziert, ohne ein tieferes Verständnis für Zusammenhänge zu entwickeln. Lernende scheitern daher häufig an unbekannten oder komplexeren Problemstellungen.

Dementsprechend wurden Tests zum generellen physikalischen Vorgehen ("Methoden"), sowie zu spezifischen Inhalten ("Elektrische Felder") konzipiert, die methodische Fertigkeiten, Fachwissen und dessen Verständnis, sowie Problemlösekompetenz systematisch erfassen. Dabei stand die Entwicklung interaktiver und grafischer Aufgaben im Fokus. Die optisch ansprechenden Aufgaben wurden mit dem Moodle-PlugIn Stack mit JSXGraph umgesetzt.

Auf Grundlage hinterlegter Kompetenzraster wird ein gezieltes Feedback gegeben. Die Analyse der Lösungen hinsichtlich dieser Kompetenzen ermöglicht ein individuelles Feedback, das explizit Stärken bzw. Defizite rückmeldet. Die Tests erfüllen somit eine mehrfache Funktion: (1) Erfassung des Leistungsniveaus, (2) individuelles Feedback als Handlungsvorschlag, (3) detaillierte Rückmeldung an die Lehrperson, (4) Lernaufgabe durch integrierte Hilfestellungen.

Der Beitrag stellt den erreichten Stand der Arbeiten und erste Testresultate vor.

DD 3.2 Mon 12:20 DD 110

Schülerlaborstudie zum Einsatz von Augmented Reality in der Elektrizitätslehre — •Florian Frank, Christoph Stolzenberger und Thomas Trefzger — Julius-Maximilians-Universität Würzburg, Lehrstuhl für Physik und ihre Didaktik

Mit Hilfe von Augmented-Reality (AR)-Apps können virtuelle Objekte und Texte in Echtzeit in die reale Welt (z.B. auch bei physikalischen Experimenten) eingefügt werden. Es wurden zwei Einsatzmöglichkeiten von AR für die schulische

E-Lehre identifiziert: die Darstellung von didaktischen Modellen und die Messung von physikalischen Größen. Im Projekt PUMA (PhysikUnterricht Mit Augmentierung) wurde ausgehend davon die AR-App "PUMA : Spannungslabor" entwickelt.

Die Lernförderlichkeit der App wurde im Rahmen einer Schülerlaborstudie evaluiert. Nach Abschluss des Elektrizitätslehre-Anfangsunterrichts erarbeiten die Lernenden dort innerhalb eines Projekttages die Kerninhalte der Elektrizitätslehre mit Bezugnahme auf didaktische Analogiemodelle erneut. Mittels Pre-/Post-Test-Design wurde die Entwicklung des konzeptuellen Verständnisses (in Form von Fachwissen und Auftretenshäufigkeit von fehlerhaften Schülervorstellungen) erhoben, mit zusätzlicher Erhebung der kognitiven Last, des räumlichen Vorstellungsvermögens und der Technikaffinität. Die Darstellung der didaktischen Modelle durch AR wurde dabei verglichen mit der Darstellung per Simulation oder per Infografiken, die Messung per AR mit der Messung mittels Multimetern.

Im Vortrag werden das Studiendesign, das Schülerlabor mitsamt Interventionsmaterial sowie erste vorläufige Ergebnisse vorgestellt.

DD 3.3 Mon 12:40 DD 110

Eine App für eine Selbstlerneinheit zum Millikanversuch — •Sascha Manuel Lubisch und Michaela Schulz — Universität Bielefeld

Vorgestellt wird eine App, mit deren Hilfe sich die Schüler und Schülerinnen selbstständig in die Grundlagen des Millikanversuchs einarbeiten können. Diese Selbstlerneinheiten wurden für verschiedene Leistungsstufen und Versuchssettings konzipiert.

Als Teil dieser Selbstlerneinheit sind Lernvideos mit realen Aufbauten erstellt worden, die zur Wiederholung und Vertiefung der Lerneinheiten eingesetzt werden. Zudem wird in den Videos der Umgang mit dem Realexperiment demonstriert. Zum Abschluss jeder Lerneinheit folgt ein Multiple-Choice-Test.

Im Anschluss an der Lerneinheit oder auch für den separaten Einsatz im Unterricht, kann der Millikan-Versuch als Videoexperiment durchgeführt werden und die Elementarladung mittels Schwebemethode oder Gleichfeldmethode ermittelt werden. Die Schülerinnen und Schüler arbeiten dabei mit einem zufällig hochgeladenen Video, so dass leicht unterschiedliche Ergebnisse ein reales Messerlebnis simuliert.

DD 4: Quantenphysik I

Time: Monday 12:00–13:00 Location: DD 111

DD 4.1 Mon 12:00 DD 111

Forschungsbasierte Entwicklung von Lernmaterialien zu Feynman-Diagrammen — •Merten Dahlkemper[1,2], Pascal Klein[2], Andreas Müller[3], Sascha Schmeling[1] und Jeff Wiener[1] — [1]CERN, Geneva, Switzerland — [2]Universität Göttingen, Göttingen, Germany — [3]Université de Genève, Geneva, Switzerland

Seit weit über 30 Jahren wird diskutiert, ob und wie Elementarteilchenphysik in der Schule behandelt werden sollte. In dieser Zeit wurden einige konkrete und forschungsbasierte Vorschläge gemacht, wie Konzepte aus der Teilchenphysik an SuS vermittelt werden können. Eine dabei häufig verwendete fach-nahe Darstellung ist das sog. Feynman-Diagramm. Jedoch ist bislang sehr wenig darüber bekannt, wie diese Repräsentationsform von SuS wahrgenommen und verstanden wird.

In dem vorliegenden Projekt geht es darum, Lernmaterialien zu Feynman-Diagrammen so zu gestalten, dass sie lernförderlich für Konzepte der Elementarteilchenphysik sind. Diese Materialien wurden mit SuS im Alter von 16 bis 19 Jahren mittels Akzeptanzbefragungen unter Verwendung von Eye-Tracking erprobt.

In dem Beitrag wird einerseits der Designprozess des Prototyps der Lernmaterialien, andererseits Ergebnisse zum Verständnis von Feynman-Diagrammen und deren Anwendung in Problemlösungsprozessen vorgestellt.

DD 4.2 Mon 12:20 DD 111

Der Treffpunkt Quantenmechanik als Cross Reality Labor — •Tim Ruhe und Marlene Doert — Technische Universität Dortmund

Der Treffpunkt Quantenmechanik an der TU Dortmund ist ein Lehr-Lern-Labor für Schüler:innen und durch aktive Mitentwicklung seitens der Studierenden eng mit der Lehramtsausbildung im Fach Physik verzahnt. Thematisch liegt der Schwerpunkt auf der Durchführung von Schlüsselexperimenten und der Sichtbarmachung quantenmechanischer Effekte. Durch den Widerspruch zur klassischen Erwartung werden kognitive Dissonanzen erzeugt, welche nur durch eine quantenmechanische Betrachtung aufgelöst werden können. Im Rahmen des Projekts CrossLab werden beispielhafte Versuche als lebensnahe Simulationen in einer 3D Umgebung (Unreal Engine) umgesetzt. Der Einsatz von Virtual Reality ermöglicht dabei eine verbesserte Sichtbarmachung der relevanten Beobachtungen und eine Entkopplung der Durchführung vom Ort des Lehr-Lern-Labors, die vor allem vor dem Hintergrund des Distanzlernens relevant ist. Im Rahmen des Vortrags werden die Ziele des Vorhabens sowie erste Ergebnisse vorgestellt.

DD 4.3 Mon 12:40 DD 111

FeynGame: Feynman-Diagramme spielerisch erarbeiten — •Robert Harlander, Sven Yannick Klein und Magnus Schaaf — RWTH Aachen University, Aachen, Germany

Der Vortrag stellt das graphische Programm FeynGame vor, das den didaktischen Zugang zu Feynman-Diagrammen auf spielerische Weise ermöglicht. Letztere bilden ein zentrales theoretisches Werkzeug, mit dessen Hilfe sich Teilchenreaktionen darstellen lassen, wie sie beispielsweise am Large Hadron Collider beobachtet werden. Feynman-Diagramme legen einerseits eine sehr einfache Interpretation solcher Reaktionen nahe. Andererseits können sie in mathematische Ausdrücke übersetzt werden, aus denen sich quantitative Aussagen zu der jeweiligen Teilchenreaktion berechnen lassen.

FeynGame bietet didaktische Zugänge für unterschiedliche Erfahrungsstufen: vom einfachen Klick- und Zeichenspiel über die Einübung der fundamentalen Wechselwirkungen bis hin zur mathematischen Darstellung der Streuamplituden.

DD 5: Hochschuldidaktik I

Time: Monday 12:00–13:00 Location: DD 405

DD 5.1 Mon 12:00 DD 405

Belastungsquellen in der Studieneingangsphase Physik — •Simon Z. Lahme, Jasper C. Cirkel, Larissa Hahn, Susanne Schneider und Pascal Klein — Universität Göttingen, Deutschland

Die Studieneingangsphase im Fach Physik wird von vielen Studierenden als große Herausforderung und oft als belastend wahrgenommen. An der Universität Göttingen wurde daher über das erste Studienjahr hinweg in einer wöchentlichen Panel-Studie die von den Physik-Studienanfänger:innen wahrgenommene Belastung gemessen. Es ergab sich ein charakteristischer zeitlicher Verlauf der wahrgenommenen Belastung entlang der spezifischen Phasen eines Semesters (Vorlesungszeit, Prüfungszeit, vorlesungsfreie Zeit, ...) mit einer hohen Ausprägung der wahrgenommenen Belastung ab der siebten Vorlesungswoche bis zum Ende der ersten Prüfungsphase. Zur weiteren Aufklärung wurden die Teilnehmenden gebeten, zu jedem Erhebungszeitpunkt die drei für sie momentan bedeutsamsten Belastungsquellen anzugeben. Die insgesamt etwa 3400 genannten Belastungsquellen wurden im Rahmen einer qualitativen Inhaltsanalyse in einem Kategoriensystem zusammengefasst und kodiert. Dieses unterteilt sich in die drei übergeordneten Bereiche universitäre, private und globale Belastungsquellen, die durch entsprechende Kategorien ausgeschärft werden. Im Vortrag werden das Kategoriensystem in seiner Konzeption, die Bedeutung der Belastungsquellen in den unterschiedlichen Phasen der Studieneingangsphase Physik und erste Implikationen für die Hochschullehre diskutiert.

DD 5.2 Mon 12:20 DD 405

Auswirkungen einer Online-Intervention (Mindset, Lerntechniken) auf den Studieneinstieg — •Malte Diederich[1], Verena Spatz[1] und Anna Bauer[2] — [1]Technische Universität Darmstadt — [2]Universität Paderborn

Der Studiengang Physik stellt viele Studierende vor große Herausforderungen. Implizite Theorien (Mindsets nach Dweck) über Intelligenz und den Erwerb von Fähigkeiten können dabei beeinflussen, wie die Studierenden mit diesen Herausforderungen umgehen. Internationale Literatur zeigt hier, dass das Mindset zum Einen einen Einfluss u.a. auf Lernziele, Attributionen und teilweise auch auf Noten hat, zum Anderen mit einer kurzen Online-Intervention positiv beeinflusst werden kann. Vor diesem Hintergrund ist es das Ziel der AG Mindset, diese Forschung für den MINT-Bereich in Deutschland zu spezifizieren. Daher wurden in den letzten Jahren eine bereichsspezifische Skala und eine Online-Intervention entwickelt. In einer aktuellen Studie soll die Wirkung dieser Online-Intervention in der Studieneingangsphase untersucht werden. Dazu wurde im WiSe22/23 in Paderborn in einem Mixed-Methods-Ansatz Vorstellungen von Physikstudierenden zum Studienerfolg erhoben. An der Umfrage nahmen 56 Studierende teil, wovon 16 Studierende auch die Intervention absolvierten. Im Vortrag werden erste Ergebnisse der Erhebung vorgestellt.

DD 5.3 Mon 12:40 DD 405

Lernmaterialien für die Studieneingangsphase Physik — •Kai Cardinal[1], Andreas Borowski[3], Julia Franken[2], Philipp Schmiemann[2] und Heike Theyssen[1] — [1]Universität Duisburg-Essen, Didaktik der Physik — [2]Universität Duisburg-Essen, Biology Education Research and Learning Lab — [3]Universität Potsdam, Didaktik der Physik

In der Studieneingangsphase Physik spielt das fachspezifische Wissen eine zentrale Rolle für den Studienerfolg. Es konnte gezeigt werden, dass in Physik neben dem Konzeptverständnis insb. die Fähigkeit zur Wissensanwendung, d.h. das Finden eines geeigneten Ansatzes und die Ausarbeitung der Lösung unter Nutzung allgemeiner Rechenfähigkeiten, den Studienerfolg vorhersagt. Im Verbundprojekt EASTER (Einfluss der Förderung spezifischer Wissensarten auf Studienerfolg in Biologie und Physik) sollen deshalb diese Fähigkeiten gezielt mit Hilfe von Begriffsnetzen und Lösungsbeispielen gefördert werden. Im Wintersemester 2022/23 wurden die Lernmaterialien in jeweils einer Lerngruppe pilotiert. Die Lösungsbeispiele orientieren sich strukturell an dem Modell des wissenszentrierten Problemlösens nach Friege. Die Begriffsnetze orientieren sich strukturell an dem Basismodell Konzeptbildung nach Oser. Inhaltlich beziehen sich die Lernmaterialien auf Themen des ersten Fachsemesters, insb. die Mechanik. Im Vortrag werden die Konzeption der verschiedenen Lernmaterialien und erste Ergebnisse der Pilotierung vorgestellt.

DD 6: Interesse und Persönlichkeit I

Time: Monday 12:00–12:40 Location: DD 407

DD 6.1 Mon 12:00 DD 407

Bildungsherausforderungen von wohnungslosen SchülerInnen und ihre naturwissenschaftliche Identität — •Matthias Fischer und Manuela Welzel-Breuer — Pädagogische Hochschule Heidelberg, Heidelberg, Deutschland

Straßenschulen ermöglichen wohnungslosen Jugendlichen das Nachholen eines Schulabschlusses unter Berücksichtigung ihrer Lebensumstände. Während die Schulabbruchsquote von wohnungslosen SchülerInnen ein Vielfaches der durchschnittlichen Abbruchsrate in Deutschland ist, erzielen Straßenschulen oftmals hohe Erfolgsquoten beim Nachholen von Schulabschlüssen. Folglich stellt sich die Frage, was wir von Straßenschulen lernen können, um wohnungslosen SchülerInnen auch an Regelschulen hochwertige Bildungsangebote unterbreiten zu können. Mit Hilfe einer Interviewstudie mit insgesamt 24 naturwissenschaftlichen Lehrkräften und Verantwortlichen von Straßenschulen haben wir die Lernvoraussetzungen von wohnungslosen SchülerInnen im naturwissenschaftlichen Unterricht untersucht. Dabei wird unter anderem von verschiedenen Herausforderungen der Jugendlichen in naturwissenschaftlichen Lernsituationen berichtet. Bei Betrachtung dieser Schwierigkeiten unter Berücksichtigung des theoretischen Konstrukts der naturwissenschaftlichen Identität (Rabe & Krey, 2018) wird deutlich, dass viele wohnungslose Jugendliche eine solche Identität während der Regelschulzeit nicht ausbilden konnten. Die Interviews führen darüber hinaus zu der Annahme, dass im Laufe des Schuljahrs an der Straßenschule eine naturwissenschaftliche Identität gefördert wird, was sich wiederum positiv auf die individuellen Lernprozesse auswirkt.

DD 6.2 Mon 12:20 DD 407

Untersuchung des Zugehörigkeitsgefühls (Sense of Belonging) Physikstudierender in der Studieneingangsphase — •Markus Sebastian Feser[1], Inka Haak[2] und Thorid Rabe[2] — [1]Universität Hamburg — [2]Martin-Luther-Universität Halle-Wittenberg

Die Studieneingangsphase wird von Studierenden, die sich für einen physikbezogenen Studiengang entscheiden haben, oftmals als überaus herausfordernd empfunden, wie eine Vielzahl an Unterschungen bereits gezeigt hat. Aktuelle Studien lassen vermuten, dass der Studienverlauf von Physikstudierenden nicht nur von ihren kognitionsbezogenen Personenmerkmalen wie Fachinteresse oder akademisches Selbstkonzept, sondern maßgeblich auch durch zwei verschiedene Zugehörigkeitsgefühle der Studierenden bedingt wird: ihrem University Belonging und ihrem Sense of Belonging to Science. In der VeSP-Be-Studie untersuchen wir daher, inwieweit University Belonging und Sense of Belonging to Science Einflussfaktoren für den Studienerfolg von Physikstudierenden in der Studieneingangsphase darstellen. Zu diesem Zweck haben wir von April bis Juni 2022 insgesamt N = 263 Physikstudierende des zweiten Hochschulsemesters und unterschiedlicher Studiengänge an insgesamt 20 Hochschulen in Deutschland mittels eines Onlinefragebogens anonym und freiwillig befragt. Im Vortrag berichten wir ausgewählte Befunde dieser Onlinebefragung.

DD 7: Lehr-Lernforschung I

Time: Monday 14:30–15:30 Location: DD 108

DD 7.1 Mon 14:30 DD 108

Vernetztes Lernen des Basiskonzepts Energie im fächerdifferenzierten und integrierten naturwissenschaftlichen Unterricht — •Dennis Dietz und Claus Bolte — Freie Universität Berlin

In den vergangenen Jahren wurde vielfach bemängelt, dass Schüler*innen das Energiekonzept nur wenig vernetzt und damit auch wenig erfolgreich erlernen (u.a. Eisenkraft et al., 2014; Lancor, 2014). Um den identifizierten Verständnisproblemen entgegenzuwirken, wurden zahlreiche Unterrichtsvorschläge für das Energiekonzept entwickelt, die sich vor allem auf Fragen der Konzeptualisierung des Energiebegriffs konzentrieren (u.a. Fortus et al., 2019), dabei jedoch die Möglichkeit der Integration der naturwissenschaftlichen Unterrichtsfächer in ein Fach "Naturwissenschaften" außer Acht lassen. Im Rahmen dieses Beitrags werden Ergebnisse aus einer Feldstudie im Kontroll- und Interventionsgruppen-Design vorgestellt, in der der Einfluss eines integrierten naturwissenschaftlichen Unterrichts in der Doppeljahrgangsstufe 7/8 auf die Vernetzungsleistungen von Schüler*innen im Energiekonzept untersucht wurde. Mit einem eigens entwickelten Analyseverfahren (Dietz & Bolte, 2021) haben wir inhaltsanalytisch Essays zum Energiekonzept von insgesamt 410 Schüler*innen in Bezug auf die Strukturierungsdimensionen "vertikales Vernetzungsniveau", "horizontale Vernetzung" und "fachliche Richtigkeit" untersucht. Für alle drei Strukturierungsdimensionen können wir statistisch signifikante positive Effekte des integrierten naturwissenschaftlichen Unterrichts nachweisen. Im Rahmen unseres Vortrags stellen wir das Design der Studie sowie ausgewählte Ergebnisse zur Diskussion.

DD 7.2 Mon 14:50 DD 108

Embodiment: Mit Sport Physik unterrichten — •Sascha Therolf und André Bresges — Universität zu Köln

Embodiment umfasst eine Reihe neuer Theorien aus der Kognitions- wissenschaft. Demzufolge ist die Wahrnehmung des Menschen zuerst eine Körperwahrnehmung, und die entsprechenden Verarbeitungsstra- tegien sind darauf optimiert. Lässt sich demnach Mechanik wirksamer unterrichten, wenn man das Körpergefühl der Schüler:innen einbezieht und trainiert? Dies hätte Folgen nicht nur für den dauerhaften Auf- bau von physikalischen Konzepten und Modellvorstellungen, sondern auch für die Gesundheitserziehung und das Well-Being von Kindern und Jugendlichen. In unserem neuen Lehr-Lernkonzept trainieren wir Basiskonzepte der Mechanik entlang von Newton*s Gesetzen zusammen mit einer einfachen und sicheren Übung für den Unterricht, dem Taktilen Reaktionstraining (TRT). Erste Schulversuche zeigen einen hochsignifikanten Zusammenhang mit der Stabilität Jugendlicher: Bei einem simulierten *S-Bahn-Schubsen*, einen hochgefährlichen Ereignis bei Jugendlichen die mit öffentlichen Verkehrsmitteln reisen, konnten 52 von 75 Jugendlichen die am Training teilgenommen haben einem normierten Stoß auf die Schulter stand halten, während in der Gruppe die nicht an diesem integrierten Physikunterricht teilgenommen haben 25 von 37 Schüler:innen über die simulierte Bahnsteigkante geschubst wurden.

DD 7.3 Mon 15:10 DD 108

Energie und Radioaktivität - eine schwierige Beziehung — •Axel-Thilo Prokop und Ronny Nawrodt — Universität Stuttgart, 5. Physikalisches Institut -Abt. Physik und ihre Didaktik, Pfaffenwaldring 57, 70569 Stuttgart

Radioaktivität stellt einen der Begriffe der Physik dar, der Laien häufig auch bekannt ist. Die Charakterisierung von Vorstellungen zu diesem Thema ist bereits seit Jahrzenten Forschungsgegenstand der Physikdidaktik, dies gilt jedoch nicht für Lehramtsstudierende. Ziel dieser Arbeit war es Vorstellungen zum Thema Radioaktivität für Lehramtsstudierende zu beschreiben. Dabei untersuchten wir im Rahmen eines halbstrukturierten, problemzentrierten Interviews und anschließender qualitativer Inhaltsanalyse z.B. ob Lehramtsstudierende sachgerecht zwischen Bestrahlung und Kontamination differenzieren können. Innerhalb der Beschreibungen der Lehramtsstudierenden sticht dabei die Energie als übergreifendes Konzept hervor, die geeignet scheint eine Vielzahl von Vorstellungen zu erklären.

DD 8: Digitale Medien II

Time: Monday 14:30–15:30 Location: DD 110

DD 8.1 Mon 14:30 DD 110

Practical teaching of nonlinear optics and spectroscopy with the virtual-reality laser laboratory femtoPro — •Stefan Müller[1], Tobias Brixner[1], Andreas Müller[1,2], and Sebastian von Mammen[2] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Games Engineering, Institut für Informatik, Universität Würzburg, Am Hubland, 97074 Würzburg

We have developed "femtoPro," an interactive teaching and training simulation of an ultrafast laser laboratory in virtual reality (VR) [1,2]. femtoPro implements physical models to calculate Gaussian beam propagation, the modulation of ultrashort laser pulses by optical elements as well as linear and nonlinear light–matter interaction in real time on stand-alone VR headsets. We have designed a practical lab course with several tutorial missions featuring step-by-step instructions on how to set up, align, and operate telescopes, optical delay lines, or interferometers, for example. We discuss the application of the program in the context of practical academic teaching. The program can also be used for practical exercises for high-school students, to train optics experts, to supplement laser-safety courses, and to enthuse the general public about optics and lasers.

[1] S. Müller, T. Brixner, A. Knote, W. Schnepp, S. Truman, A. Vetter, and S. von Mammen, in The International Conference on Ultrafast Phenomena (UP) 2022, Technical Digest Series (Optica Publishing Group, 2022), paper W4A.42.
[2] "femtoPro," (2022). https://www.femtopro.com.

DD 8.2 Mon 14:50 DD 110

phytet: technology enhanced physics teaching — •Wolfgang Lutz[1], Sebastian Haase[2], Markus Elsholz[1], Jan-Philipp Burde[3], Thomas Wilhelm[4] und Thomas Trefzger[1] — [1]Universität Würzburg — [2]Freie Universität Berlin — [3]Universität Tübingen — [4]Universität Frankfurt

In der Didaktik werden innovative Ideen für das Lehren und Lernen entwickelt, die jedoch oftmals nicht den Weg in den Unterricht finden. Diese als Theorie-Praxis-Problem bekannte Diskrepanz zwischen Forschung und Schulalltag ist oft darauf zurückzuführen, dass sich Wissenschaft mit nicht praxisrelevanten Problemen auseinandersetzt und Lehrkräfte bei der Entwicklung neuer Unterrichtsmaterialien nicht involviert werden. Anders ist es beim Forschungsansatz Design-Based-Research, bei dem Expert:innen aus beiden Bereichen zusammenarbeiten, um theoriebasiert eine neue Unterrichtskonzeption zu entwickeln und gleichzeitig zu erforschen.

Vor diesem Hintergrund wurden im Kontext von Flipped Classroom und ausgehend vom Elektronengasmodell in der E-Lehre sowie dem Sender-Strahlungs-Empfänger-Konzept in der Optik zwei Unterrichtskonzeptionen entwickelt. Diese wurden über drei Jahre in Interventionen mit insgesamt knapp 4500 Schüler:innen erprobt und weiterentwickelt. Dieser Vortrag behandelt die in diesem Zusammenhang entstandenen und auf der Lernplattform www.phytet.de zur kostenfreien Nutzung verfügbaren Unterrichtsmaterialien, darunter zahlreiche Lernvideos, Quizaufgaben, interaktive Bildschirmexperimente, Übungsblätter und Anleitungen für Schulexperimente sowie Heimexperimente.

DD 8.3 Mon 15:10 DD 110

Digitale Messwerterfassung mit Mikrocontrollern: Konnektivität, Datenauswertung, Nutzeroberflächen — •Fabian Bernstein und Thomas Wilhelm — Goethe-Universität Frankfurt

Moderne Mikrocontroller - wie z.B. der Raspberry Pi Pico (W), die Espressif ESP32-Boards oder Mikrocontroller der Arduino-Familie - sind außerordentlich leistungsfähig, kostengünstig und vielversprechend für die digitale Messwerterfassung im Physikunterricht, zumal eine Vielfalt an Sensoren und Aktuatoren für diese Systeme verfügbar sind. Die reine Erfassung von Messdaten auf dem Mikrocontroller ist allerdings für unterrichtliche Zwecke nicht ausreichend: Vielmehr müssen schülergerechte Abläufe gestaltet werden, die insbesondere den Datentransfer vom Mikrocontroller zu Endgeräten wie PCs, Smartphones oder Tablets sowie grafische Nutzeroberflächen und Möglichkeiten der Datenauswertung miteinschließen. Der Vortrag stellt verschiedene Werkzeuge wie Microsoft Datastreamer, die Phyphox Arduino-Library und MIT App Inventor zur Gestaltung solcher komplexen Umgebungen vergleichend vor und beleuchtet deren Vor- und Nachteile im Hinblick auf den Unterrichtseinsatz. Darüber hinaus werden Erfahrungen aus einer Lehrkräftefortbildung an der Goethe-Universität Frankfurt zur digitalen Messwerterfassung mit diesen Systemen berichtet und zur Diskussion gestellt.

DD 9: Quantenphysik II

Time: Monday 14:30–15:30 Location: DD 111

DD 9.1 Mon 14:30 DD 111

Zeitdynamik von Qubits am Beispiel des assistierten Tunnelns — •Jonas Bley[1], Vieri Mattei[2], Simon Goorney[2], Jacob Sherson[2] und Stefan Heusler[3] — [1]Rheinland-Pfälzische Technische Universität, Kaiserslautern — [2]Purdue Universität in West Lafayette, Indiana, US — [3]Westfälische Wilhems-Universität, Münster

In diesem Vortrag wird ein einfaches und allgemeines Modell für die Zeitdynamik einzelner Qubits vorgestellt. Als Anwendungsbeispiel wird das Tunneln als prominenter Effekt der Quantenphysik mit vielen Anwendungsgebieten diskutiert. Das kürzlich vorgeschlagene SUPER-Prinzip (Swing-UP of a quantum EmitteR population) mit nicht-resonanten Laserpulsen wurde auf den Kontext des Tunnelns übertragen. Dazu wurde die Software Quantum Composer von Quatomic und ein zeitlich veränderliches Doppelmuldenpotential verwendet und gezeigt, dass durch die richtige Frequenz die Tunnelwahrscheinlichkeit um ein Vielfaches erhöht werden kann. Die didaktischen Möglichkeiten dieses Ansatzes, der die Forschung mit der Hochschullehre verbinden kann, werden diskutiert. Zusätzlich wird der Lehrende-Entwickler-Dialog dargestellt und Ergebnisse dieses Dialoges in Form der ersten Bloch-Kugel-Darstellung im Quantum Composer präsentiert.

DD 9.2 Mon 14:50 DD 111

Analyse und evidenzbasierte Konzeption von Qubit-Modellen — •Anna Donhauser[1], Stefan Küchemann[1], Lukas Sigl[2], Björn Ladewig[1], Judith Gabel[1] und Jochen Kuhn[1] — [1]Ludwig-Maximilians-Universität München — [2]Technische Universität München

Die Modellbildung nimmt eine zentrale Rolle in der Fachphysik und Fachdidaktik ein. Je komplexer, abstrakter oder unsichtbarer diese physikalischen Zusammenhänge sind, desto notwendiger werden Modelle. Folglich braucht gerade die Quantenphysik allgemein und Quantentechnologie im Speziellen Methoden zur Visualisierung ihrer Phänomene. Existierende Qubit-Modelle bieten kontextspezifische Vorteile, geraten jedoch schnell an ihre Grenzen, weshalb Lehrende für eine vollständige Erklärung quantenphysikalischer Zusammenhänge auf unterschiedliche Modelle zurückgreifen müssen. Die Lernwirksamkeit der einzelnen Qubit-Modelle, Vorteile und Schwierigkeiten im Umgang mit bestehenden Visualisierungen wurden im Rahmen einer Eyetracking-Studie überprüft. Die Ergebnisse dieser Studie dienten der Entwicklung eines neuen Modells. Unser Anspruch bei der Konzeption einer Visualisierung zentraler Quanten-Phänomene wie Superposition, Verschränkung und Registerzustände von Qubit-Systemen, bestand darin, umfassend einsetzbar zu sein und die Vorteile vorhandener Repräsentationen zu vereinen.

Im Vortrag werden die gängigsten Darstellungen kontrastiert und das auf Basis der Eyetracking-Studie rekonstruierte, neue Modell vorgestellt.

DD 9.3 Mon 15:10 DD 111

Eyetracking-Studie zur visuellen Verarbeitung verschiedener Qubit-Modelle — •Anna Donhauser[1], Stefan Küchemann[1], Eva Rexigel[2], Alda Arias[2], Jonas Bley[2] und Jochen Kuhn[1] — [1]Ludwig-Maximilians-Universität München — [2]Technische Universität Kaiserslautern

Die Modellbildung nimmt eine zentrale Rolle in der Fachphysik und Fachdidaktik ein. Je komplexer, abstrakter oder unsichtbarer diese physikalischen Zusammenhänge sind, desto notwendiger werden Modelle. Folglich ist es gerade im Bereich der Quantenphysik und Quantentechnologien erforderlich, Methoden zur Visualisierung und modellhaften Beschreibung grundlegender Phänomene zu verwenden.

Über die Güte eines Modells entscheiden neben seiner möglichst vielseitigen Einsatzfähigkeit auch dessen Zugänglichkeit für verschiedene Zielgruppen, ohne dabei an fachlicher Richtigkeit einzubüßen. Bislang ist jedoch unklar, welche der existierenden Qubit-Modelle für welchen Adressatenkreis am besten geeignet ist. Für eine vollständige Erklärung quantenphysikalischer Zusammenhänge müssen Lehrende sogar auf unterschiedliche Modelle zurückgreifen. Aus diesem Grund untersuchen wir in einem ersten Schritt die visuelle Verarbeitung verschiedener Qubit-Modelle im Rahmen einer Eyetracking-Studie. Im Vortrag wird diese Studie und deren Ergebnisse präsentiert.

DD 10: Workshop Lehramtsstudie KFP/DPG

Time: Monday 14:30–15:30 Location: DD 405

60 min. Workshop

DD 11: Nature of Science, Geschichte

Time: Monday 14:30–15:30 Location: DD 407

DD 11.1 Mon 14:30 DD 407

Welche Kontexte von physikalischen Lernaufgaben finden Studierende des Lehramts an Grundschulen interessant? — •Christoph Maut, Burkhard Priemer und Steffen Wagner — Humboldt-Universität zu Berlin

Die von Personen wahrgenomme Interessantheit eines Lerngegenstandes spielt eine entscheidende Rolle für die Interessengenese. Deshalb wurden $n = 151$ Studierende des Lehramts an Grundschulen befragt, wie sie die Interessantheit der Kontexte von elf Physikaufgaben aus verschiedenen Themengebieten bewerten und dies begründen. Aus den Begründungen wurde ein Kategoriensystem entwickelt, welches die drei kontextbezogenen Kategorien Alltags-, Lern- und Professionskontext ableitet. In diesem Vortrag werden exemplarisch Lernaufgaben vorgestellt, um für die Zielgruppe besonders interessante Aufgaben und Kontexte aufzuzeigen.

Das Erhebungsverfahren lässt sich auch für andere universitäre Lehrveranstaltungen nutzen, um für Studierende interessante Lernaufgaben zu entwickeln. Mithilfe des Kategoriensystems können darüber hinaus Informationen über Aufgabenkontexte, die für unterschiedliche Zielgruppen relevant sind, erfasst werden.

DD 11.2 Mon 14:50 DD 407

”Mach dein Gehirn fit für Physik” - eine digitale Lerneinheit zur Förderung des Growth Mindset — •Laura Goldhorn[1], Thomas Wilhelm[1] und Verena Spatz[2] — [1]Institut für Didaktik der Physik, Goethe-Universität Frankfurt, Deutschland — [2]Didaktik der Physik, TU Darmstadt, Deutschland

Während Schüler:innen mit einem Fixed Mindset in herausfordernden Lernsituationen schnell aufgeben, lassen sich jene mit einem Growth Mindset nicht so schnell abschrecken, ganz unabhängig vom jeweiligen Könnens- und Wissensstand der Schüler:innen. Zu Beginn des Physikunterrichts, in der 7. Jahrgangsstufe, haben die meisten ein physikbezogenes Growth Mindset, doch dieser Anteil sinkt schon im ersten Lernjahr stark ab, während die Überzeugung einer notwendigen Physik-Begabung (Fixed Mindset) von mehr und mehr Schüler:innen vertreten wird.

Um dieser Entwicklung entgegenzuwirken und das Growth Mindset in Physik zu stärken, wurde eine Lerneinheit entwickelt, die curriculumsunabhängig eingesetzt werden kann. Auf Basis der Neuroplastizität wird das Lernen erklärt. *Mach dein Gehirn fit für Physik* ist ein digitales Angebot für Schüler:innen der Sekundarstufe I, das die Elemente der bewährten Mindsetinterventionen (z.B. von Yeager und Dweck) mit einem Physik-Thema verknüpft, um fachspezifisch das Growth Mindset zu vermitteln.

DD 11.3 Mon 15:10 DD 407

Science Denial im Physikunterricht adressieren: Die Bayesian Updating Activity. — •Marcus Kubsch — IPN Leibniz Institut für die Pädagogik der Naturwissenschaften und Mathematik, Kiel

Naturwissenschaften spielen eine zentrale Rolle in der heutigen Welt und für das Verständnis und die Bewältigung von globalen Herausforderungen wie dem Klimawandel. Der öffentliche Diskurs im Kontext dieser Herausforderungen offenbart jedoch immer wieder, dass naturwissenschaftliche Erkenntnisse abgelehnt werden. Die Folgen können dramatisch sein und zu gesellschaftlicher Ohnmacht in Anbetracht real existierender Gefahren führen. Allerdings ist diese Art von Science Denial jedoch keineswegs durch einen reinen Mangel an Fachwissen zu erklären. Das Problem sitzt tiefer und beginnt bei den Vorstellungen davon und dem Wissen darüber, wie (naturwissenschaftliches) Wissen entsteht und welche Eigenschaften es hat. Um ein angemessenes Verständnis davon zu entwickeln wie naturwissenschaftliches Wissen entsteht, benötigen SchülerInnen Unterstützung. Aktuelle physikdidaktische Forschung hat erste Hinweise geliefert, dass die Integration einer Bayesian Updating Activity in den Prozess der Auswertung und Analyse von Daten SchülerInnen dabei unterstützt adäquatere Vorstellungen über die Natur naturwissenschaftlichen Wissens zu entwickeln. Im Vortrag wird die Bayesian Updating Activity sowie ein digitales Tool zur Unterstützung von SchülerInnen bei der Anwendung dieser vorgestellt und Möglichkeiten zur Integration in den Physikunterricht diskutiert.

DD 12: Lehr-Lernforschung II

Time: Monday 16:00–17:00 Location: DD 108

DD 12.1 Mon 16:00 DD 108

Entwicklungsorientierte physikdidaktische Forschung - ausgewählte Aspekte der Vorbereitung, Durchführung und Auswertung entsprechender Studien — •Roland Berger — Universität Osnabrück

In seinem Gastbeitrag zur Tagung ”Physikdidaktik - Quo vadis?” in 2021 hat der Erziehungswissenschaftler Ewald Terhart in seinem ”Außenblick” auf die Physikdidaktik die Stärkung ”entwicklungsorientierter fachdidaktischer Forschung” als wichtiges Ziel hervorgehoben. Als eine geeignete Möglichkeit dieses Anliegen zu stärken erscheint die Verknüpfung der Entwicklung und Implementation innovativer Konzepte und Materialien mit der empirischen Klärung relevanter Forschungsfragen. Auf der Basis eigener Erfahrungen und einschlägiger Literatur werden im Vortrag ausgewählte Aspekte der Vorbereitung, Durchführung und Auswertung entsprechender Studien diskutiert. Ein wesentliches Ziel ist dabei die Anregung und Unterstützung entwicklungsorientierter physikdidaktischer Forschung mit direktem Schulbezug.

DD 12.2 Mon 16:20 DD 108

Erkenntnisse aus dem wissenschaftstheoretischen Strukturalismus zum Umgang mit Schüler*innenvorstellungen im Physikunterricht — •Frederik Dilling — Universität Siegen

Die Analyse typische Schüler*innenvorstellungen zu zentralen Begriffen der Physik gehört zu einem Schwerpunkt physikdidaktischer Forschung. Dies liegt unter anderem an der hohen Praxisrelevanz, da insbesondere problematische Vorstellungen einen adäquaten Kompetenzaufbau behindern können. Betrachtet man die häufig untersuchten Begriffe, darunter zum Beispiel die Kraft in der Mechanik oder die Wärme in der Thermodynamik, so fällt auf, dass diese Begriffe eine wesentliche Gemeinsamkeit haben, welche sich mit dem Ansatz des wissenschaftstheoretischen Strukturalismus zur Rekonstruktion empirischer Theorien als Theoretizität beschreiben lässt. Im Strukturalismus werden theoretische und nichttheoretische Begriffe unterschieden. Theoretische Begriffe sind referenzlos und ihre Bedeutung wird erst innerhalb einer Theorie geklärt. Damit setzt die Messung eines theoretischen Begriffes auch bereits die Gültigkeit ebendieser Theorie voraus. Die Theoretizität eines Begriffes führt aus epistemologischen Gründen zu Herausforderungen beim Lernen - theoretische Begriffe sind nicht ohne Weiteres der Beobachtung zu entnehmen, sondern müssen aktiv konstruiert werden. Hierin kann eine Ursache für die vielfältigen - zum Teil auch nicht zielführenden - Vorstellungen von Schüler*innen im Physikunterricht gesehen werden. In dem Vortrag soll die Diskussion um Schüler*innenvorstellungen durch Impulse aus dem wissenschaftstheoretischen Strukturalismus ergänzt werden.

DD 12.3 Mon 16:40 DD 108

Theoretischer Output von Design-Based Research in der deutschsprachigen Physikdidaktik — •Claudia Haagen-Schützenhöfer und Markus Obczovsky — Universität Graz, Institut für Physik, Graz, Österreich

Ein zentrales Ziel von Physikdidaktik ist die Verbesserung des Physikunterrichts in der Schulpraxis. Zu diesem Zweck werden häufig Unterrichtskonzeptionen, Unterrichtsmaterialen und dgl. entwickelt. Ein Teil dieser Entwicklungen sind forschungsbasiert und stützen sich dabei auf das Paradigma des Design-Based Research (DBR). Der Logik dieses Paradigmas folgend geht der Output von DBR-Projekten über Unterrichtskonzeptionen usw. hinaus und beinhaltet neben lokale Theorien über Lehr-Lernprozesse im spezifischen Gegenstandsbereich auch *Design-Wissen”. Beides soll zu einem kumulativen, gegenstandsspezifischen Wissensaufbau beitragen, und in verwandte Gegenstandsbereiche und Kontexte transferierbar sein. Mitunter wird kritisiert, dass bei DBR-Projekten häufig der praktische Output im Zentrum steht, und der theoretische Output selten systematisch berichtet wird. Derartige Leerstellen sind für das Desiderat eines kumulativen Wissensaufbaus über gegenstandsspezifische Lehr-Lernprozesse in Physik und Design-Frameworks sowie für die synergetische Nutzung dieses Wissens problematisch. Um diesen vermuteten Leerstellen empirisch auf den Grund zu gehen, werden physikdidaktische Konferenzbeiträge inhaltsanalytisch untersucht. Wir stellen erste Ergebnisse der Analyse von DPG- und GDGP-Tagungsbandbeiträgen der letzten 20 Jahre in Hinblick auf die Darstellung von DBR-Projekten vor.

DD 13: Digitale Medien III

Time: Monday 16:00–17:00 Location: DD 110

DD 13.1 Mon 16:00 DD 110

PUMA : Spannungslabor - AR-Funktionalität, Simulation und Bluetooth LE-Messwerterfassung — •Christoph Stolzenberger, Florian Frank und Thomas Trefzger — Julius-Maximilians-Universität Würzburg, Lehrstuhl für Physik und ihre Didaktik

Für die Vermittlung der Elektrizitätslehre in der Sekundarstufe I werden meist Analogiemodelle genutzt. Zur Unterstützung dieser Art der Vermittlung wurde die Applikation *PUMA : Spannungslabor* konzipiert. Die App kann im Unterricht eingesetzt werden, um für reale Experimente passgenaue Visualisierungen eines Druck- oder Höhenanalogiemodells bereitzustellen. Hierfür können die Modellansichten entweder mithilfe von Augmented Reality (AR) über das Realexperiment überblendet oder mittels einer optisch dem Realexperiment nachempfundenen Simulation dargestellt werden. Die Simulation kann auch außerhalb des Unterrichts bzw. der Experimentiersituation zur Vor- oder Nachbereitung genutzt werden.

Zusätzlich zu der Darstellung der Analogiemodelle bietet die AR-Funktionalität der App über eine Bluetooth-LE-Schnittstelle die Möglichkeit, reale Messwerte mit in die Darstellung zu integrieren. Dies ermöglicht die Nutzung der Applikation für halb-quantitative und quantitative Experimente.

Im Vortrag werden die verschiedenen Funktionalitäten der Applikation *PUMA : Spannungslabor* anhand von Beispielen für den Physikunterricht präsentiert.

DD 13.2 Mon 16:20 DD 110

PUMA : Magnetlabor * Ein AR-Lehr-Lern-Labor zum Themengebiet (Elektro-) Magnetismus in der Sekundarstufe I — •Hagen Schwanke, Annika Kreikenbohm und Thomas Trefzger — Universität Würzburg

Die Sekundarstufe I bietet zum Thema der Elektrizitätslehre viele Experimente zur Anwendung einer augmentierten Lernumgebung. Die in dem Projekt PhysikUnterricht Mit Augmentierung (PUMA) entwickelte Applikation PUMA: Magnetlabor soll hauptsächlich die Modelle der magnetischen Felder sichtbar machen. Die Applikation ermöglicht einen Einblick in die Materie und macht das Unsichtbare sichtbar, indem sie die Realexperimente mit digitalen Inhalten überlagert. In diesem Vortrag wird zunächst die Frage geklärt, warum sich Augmented Reality (AR) zum Thema Magnetismus anbietet. Daraufhin wird die freiverfügbare Applikation und deren Einbindung in ein Lehr-Lern-Labor vorgestellt. Dabei werden beispielhaft einzelne Stationen der Lernumgebung thematisiert, welche auf Grundlage eines Schülerexperimentiersatzes konzipiert wurden. Eine Herausforderung stellt u.a. die richtige Gestaltung von Aufgaben zur förderlichen Anwendung von AR dar.

DD 13.3 Mon 16:40 DD 110

Physik mit GeoGebra — •Roger Erb und Albert Teichrew — Institut für Didaktik der Physik, Goethe-Universität Frankfurt

Die Dynamische Geometrie-Software GeoGebra ist ein Werkzeug, das im Mathematikunterricht oft eingesetzt wird. Es lässt sich allerdings auch im Physikunterricht in Verbindung mit Experimenten verwenden, wenn diese bestimmten Anforderungen genügen. Zu einer besonders ertragreichen Ergänzung wird dies dann, wenn eine physikalische Modellierung des Experiments vorgenommen wird, bei der sich Parameter einstellen lassen, die auch im realen Experiment veränderbar sind. Im Vortrag werden Beispiele aus der Optik, der Elektrizitätslehre und der Mechanik vorgestellt und durch Ergebnisse aus dem Unterrichtseinsatz ergänzt.

DD 14: Quantenphysik III

Time: Monday 16:00–17:00 Location: DD 111

DD 14.1 Mon 16:00 DD 111

Versuchsangebote im Rahmen von QuantumFrontiers MasterClasses — •Tim Overwin, Azadeh Ghanbari, Hendrik Preuss und Rainer Müller — Institut für Fachdidaktik der Naturwissenschaften, Abt. Physik und Physikdidaktik, TU Braunschweig, Deutschland

Im Rahmen des Exzellenzclusters QuantumFrontiers werden MasterClasses konzipiert, die Themen aus den Forschungsbereichen des Clusters vermitteln. Die Zielgruppe sind dabei vor allem Schüler*innen der gymnasialen Oberstufe, aber auch Angebote für Lehrkräfte und ausgesuchte Schüler*innengruppen werden konzipiert. Die Lernenden sollen durch eine Kombination aus Workshops, eigenständigem Lernen und Experimentieren, Laborführungen und Kontakt zu Wissenschaftler*innen an ein konkretes Forschungsthema herangeführt werden.

An den beiden Clusterstandorten Braunschweig und Hannover werden Kurse zu verschiedenen Themen konzipiert in deren Durchführungen auch Wissenschaftler*innen der beteiligten Institutionen LUH, PTB und TU BS mit einbezogen werden. Somit verfolgen die MasterClasses nicht nur das Ziel die Schüler*innen für Physik zu begeistern, sondern bieten ebenfalls eine wertvolle Lehrerfahrung für (Nachwuchs-)Wissenschaftler*innen.

Die größte inhaltliche Herausforderung dieses Formats ist die Aufarbeitung aktueller Forschungsthemen - thematisch oft gar nicht oder nur teilweise in den Lehrplänen verankert - auf ein angemessenes fachliches Niveau. Beispiele dafür sind die Konzepte der Quantenkryptographie oder die Funktionsweise eine Quantencomputers.

DD 14.2 Mon 16:20 DD 111

Modularer, preiswerter 3D-gedruckter Aufbau für Experimente mit NV-Zentren in Diamant — •Marina Peters[1], Jan Stegemann[1], Ludwig Horsthemke[2], Nicole Langels[1], Matthias Hollmann[1], Nils Haverkamp[3], Stefan Heusler[3], Peter Glösekötter[2] und Markus Gregor[1] — [1]Fachbereich Physikingenieurwesen, FH Münster — [2]Fachbereich Elektrotechnik und Informatik, FH Münster — [3]Institut für Didaktik der Physik, WWU Münster

Mit der wachsenden Bedeutung von Quantentechnologie in Industrie und Forschung steigt der Bedarf an erschwinglichen, flexiblen und robusten Laborexperimenten für die Sekundarstufe II und das Physikstudium. Mit diesem modularen, 3D-gedruckten, kostengünstigen (< 250 €) Open Source Experimentierset [1] können SchülerInnen und Studierende die Eigenschaften von Quantensystemen am Beispiel von NV-Zentren in Diamant kennenlernen. Die optischen Komponenten befinden sich in 3D-gedruckten Würfeln [2,3], die frei auf einem Raster angeordnet werden können. Das vorgestellte Set ermöglicht Versuche zur Magnetometrie mittels optically detected magenetic resonance (ODMR) und bietet eine Brücke zu den Anforderungen moderner Quantentechnologie. [1] www.O3Q.de [2] Diederich, B. et al. Nat Commun 11, 5979 (2020) [3] Haverkamp, N. et al. Phys Educ 57 025019 (2022)

DD 14.3 Mon 16:40 DD 111

Modulare Low-Cost Experimente zur Wellen- und Quantenoptik — •Nils Haverkamp, Alexander Pusch und Stefan Heusler — Universität Münster

In der Oberstufe gibt es nur selten Gelegenheiten, Experimente als Schülerexperiment durchzuführen. Dies hängt mit der zunehmenden Komplexität und den damit einhergehenden Kosten für entsprechende Aufbauten zusammen.

In diesem Vortrag wird ein modulares Experimentierset vorgestellt. Mit diesem Set können verschiedene Experimente aus dem Bereich der Wellen- und Quantenoptik, wie beispielsweise das Michelson Interferometer, aufgebaut werden. Durch den Einsatz von 3D-Druck kann das Material günstig selbst nachgebaut werden, sodass das Material für Schülerexperimente sogar mehrfach angeschafft werden kann. Dazu sind die 3D-Dateien, Aufbauanleitungen und auch Unterrichtsmaterialien kostenlos verfügbar.

DD 15: Hochschuldidaktik II

Time: Monday 16:00–17:00 Location: DD 405

DD 15.1 Mon 16:00 DD 405

Erarbeitung eines spiralcurricularen Blended Learning Konzepts für die Mathematikausbildung der Studiengänge Lehramt Physik — •Lydia Kämpf und Frank Stallmach — Universität Leipzig, Institut für Didaktik der Physik, Prager Straße 36, 04317 Leipzig

In den Studiengängen Lehramt Physik an der Universität Leipzig sind in den ersten Semestern nur jeweils 10 Leistungspunkte für die Physik-Fachausbildung vorgesehen. Deshalb sind Seminare zu den mathematischen Methoden in den Physikkursen eingebettet. Sie sind an den aktuellen physikalischen Problemen ausgerichtet und werden mit den Studierenden just-in-time besprochen. Derzeit erarbeiten wir zu diesen mathematischen Methodenseminaren ein modulübergreifendes Blended Learning Konzept, in dem über digitale Lehrformate wie Lehrvideos und Simulationen sowie Präsenzseminare die mathematischen Inhalte vermittelt und mit den physikalischen Anwendungen verknüpft werden. Die Videos dienen der Strukturierung des Selbststudiums. Sie enthalten u. a. interaktive Aufgabenstellungen und formative Tests, um den Studierenden ein Feedback mit konkreten Handlungsvorschlägen zu geben. Die Anwendungen auf physikalische Problemstellungen werden in den vertiefenden Mathematikseminaren mittels kollaborativer Lehr-Lern-Sequenzen bearbeitet. Entsprechende Lehrsequenzen zu den Thematiken komplexe Zahlen, Reihenentwicklungen und Vektoranalysis sind gegenwärtig in der Erprobungsphase. Die Lehr-Lern-Konzepte, erste Ergebnisse ihrer Evaluation und der spiralcurriculare Ansatz werden im Beitrag exemplarisch vorgestellt.

DD 15.2 Mon 16:20 DD 405

Fachdidaktische Seminare für die Theoretische Physik — •Philipp Scheiger[1,2], Ronny Nawrodt[2] und Holger Cartarius[1] — [1]Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena — [2]Physik und ihre Didaktik, Universität Stuttgart, 70569 Stuttgart

Die Verknüpfung von Fachwissen (content knowlegde, CK) und fachdidaktischem Wissen (pedagogical content knowledge, PCK) kann die Qualität von Erklärungen bei Studierenden erhöhen und das Fachwissen verbessern. Diese Erkenntnisse haben wir zum Anlass genommen fachdidaktische Seminare zu entwickeln, die Vorlesungen der Theoretischen Physik begleiten und ergänzen. Lernziele der Seminare sind die Förderung/Festigung des allgemeinen Verständnisses der theoretischen Physik und das Herausarbeiten ihrer Relevanz für die Schulphysik, die Demonstration von Lern- und Lehrtechniken, die kognitiv aktivieren, anhand der Vorlesungsinhalte und das Sprechen und Diskutieren über Physik üben. Konkret werden die Inhalte der klassischen Mechanik und der Elektrodynamik (CK) mit fachdidaktischem Wissen (PCK) zur Natur der Naturwissenschaften, Worked Examples, Didaktische Rekonstruktion, Schülervorstellungen, Peer Instruction und die Versprachlichung/Verbildlichung von Formeln verknüpft. In diesem Vortrag möchten wir dieses Vorgehen motivieren und beispielhaft unsere Umsetzung skizzieren.

DD 15.3 Mon 16:40 DD 405

Interaktive Lern- und Übungsaufgaben in der Physiklehramtsausbildung — •Bianca Watzka — Otto-von-Guericke-Universität Magdeburg

Lernen ist ein aktiver und konstruktiver Prozess. Mittels interaktiver Aufgaben lässt sich eine Aktivierung der Lernenden in jedem Lehrformat realisieren. Offen ist die Frage, ob es Unterschiede im Bearbeitungserfolg und der Änderung des Professionswissens beim Lernen mit interaktiven Aufgaben unter verschiedenen Lehrformaten gibt. Ein interaktives Aufgabenset wurde mittels drei verschiedener Methoden gelehrt und in drei aufeinanderfolgenden Jahren evaluiert. Die Stichprobe (N=66) stellten Lehramtsstudierende der Physik. Diese bearbeiteten einen Lernpfad mit interaktiven Aufgaben, um sich selbst fachdidaktisches Wissen zu einem Thema zu erarbeiten. Die Analyse erfolgte auf der Grundlage von xAPI-Daten als auch Akzeptanz- und TPACK-Fragebögen. Die Ergebnisse zeigten keine signifikanten Unterschiede im Bearbeitungserfolg und Professionswissen zwischen der Online- und Präsenzlehre. Jedoch zeigten die im Selbststudium Lernenden signifikant kürzere Bearbeitungszeiten, ein deutlich chaotischeres Lernverhalten, einen geringeren Bearbeitungserfolg und geringere Zuwächse in Facetten des Professionswissens.

DD 16: Lehreraus- und -fortbildung I

Time: Monday 16:00–17:00 Location: DD 407

DD 16.1 Mon 16:00 DD 407

Neue Wege in der naturwissenschaftsübergreifenden Fachdidaktik an der Universität Konstanz durch die Integration von DiKoLAN — •Anna Henne[1], Philipp Möhrke[1], Lars-Jochen Thoms[1,2] und Johannes Huwer[1,2] — [1]Universität Konstanz, Deutschland — [2]PHTG, Kreuzlingen, Schweiz

Im Rahmen des vom BMBF geförderten Projekts *edu 4.0 - Digitalisierung in der Lehrerbildung* der QLB wird seit Sommersemester 2021 eine fachübergreifende Veranstaltung für die Naturwissenschaften Biologie, Chemie und Physik angeboten. Ziel der Veranstaltung ist die Förderung digitaler Basiskompetenzen angehender Lehrkräfte mit speziellem Fokus auf den naturwissenschaftlichen Unterricht. Dazu werden sukzessiv die sieben zentralen Kompetenzbereiche digitaler Kompetenzen für das Lehramt in den Naturwissenschaften nach DiKoLAN (Becker et al., 2020) behandelt. Die Studierenden wenden das in den einzelnen Kompetenzbereichen erworbene Professionswissen schließlich bei der Gestaltung einer digital gestützten Unterrichtseinheit an und führen diese im Seminar exemplarisch mit den Seminarteilnehmenden durch. Somit erfahren die Teilnehmenden digitale Unterrichtsgestaltung und dafür notwendige Kompetenzen sowohl aus der Perspektive des Lehrenden als auch des Lernenden. Exemplarisch wird das Lernmodul Messwert- und Datenerfassung im naturwissenschaftlichen Unterricht vorgestellt. Die Lehrveranstaltungsevaluation zeigte einen positiven Anstieg der Selbstwirksamkeitserwartungen der Studierenden (Henne et al., 2022). Der Kurs dient somit als Best-Practice-Beispiel und als Vorlage für die Gestaltung neuer Kurse.

DD 16.2 Mon 16:20 DD 407

Evaluationsergebnisse des Lehrkonzepts zur Förderung digitaler Kompetenzen im Verbundprojekt DiKoLeP — •Thomas Schubatzky[1], Jan-Philipp Burde[2], Rike Grosse-Heilmann[3], Josef Riese[3] und David Weiler[2] — [1]Universität Innsbruck, Österreich — [2]Universität Tübingen, Deutschland — [3]RWTH Aachen, Deutschland

Digitale Medien spielen eine immer größer werdende Rolle im physikalischen Fachunterricht. Für eine lernförderliche Integration digitaler Medien braucht es aber dahingehend professionalisierte Lehrkräfte. Angehende Physiklehrkräfte sollen deshalb während ihres Studiums auch Kompetenzen zum fachdidaktisch begründeten Einsatz digitaler Medien entwickeln. Im Verbundprojekt Digitale Kompetenzen von Lehramtsstudierenden im Fach Physik (DiKoLeP) der RWTH Aachen und der Universitäten Graz, Innsbruck und Tübingen wird daher ein übergeordnetes Lehrkonzept mit standortspezifischen Ausprägungen entwickelt, implementiert und evaluiert. Durch dieses Lehrkonzept sollen fachspezifische, digitale Kompetenzen von Lehramtsstudierenden der Physik gefördert werden. Im Vortrag werden die grundlegenden Ideen des Lehrkonzepts sowie vorläufige Ergebnisse der standortübergreifenden Evaluation mit bisher N ~ 55 Studierenden vorgestellt. Daraus werden Implikationen für die digitalisierungsbezogene Lehramtsausbildung im Allgemeinen abgeleitet sowie die Weiterentwicklung des Lehrkonzepts diskutiert.

DD 16.3 Mon 16:40 DD 407

Förderung digitaler Kompetenzen in der schulstufenübergreifenden Lehrkräftebildung — •Lisa Stinken-Rösner[1] und Simone Abels[2] — [1]Universität Bielefeld — [2]Leuphana Universität Lüneburg

Eine Besonderheit der Lehrkräftebildung an der Leuphana ist, dass Studierende des Lehramts für Grundschule und Sekundarstufe gemeinsam die naturwissenschaftsdidaktischen Module im Bachelor besuchen. Dabei werden Dozierende und Studierende vor die Herausforderung gestellt, fachübergreifende naturwissenschaftsdidaktische Konzepte zu adressieren ohne die jeweiligen Fachspezifika aus den Augen zu verlieren. Um dieser zu begegnen, wurden im Projekt "FoLe - digital" digitale Medien systematisch in die etablierte Modulstruktur - der schrittweisen Spezifizierung der Inhalte ausgehend von der theoretischen Auseinandersetzung mit fachübergreifenden Schwerpunkten hin zur praxisorientierten Anwendung in den verschiedenen Schulstufen - implementiert, um sowohl fachdidaktische als auch digitale Kompetenzen zu fördern.

Unabhängig von der gewählten Schulstufe weisen die Studierenden nach dem Besuch der Module statistisch signifikant positivere Einstellungen sowie eine höhere Selbstwirksamkeitserwartung gegenüber dem Lehren und Lernen mit digitalen Medien auf. Ebenfalls konnte eine signifikante Zunahme der selbst eingeschätzten professionellen Kompetenzen hinsichtlich des Einsatzes digitaler Medien im Fachunterricht (TPACK) belegt werden. Der Vergleich zwischen den Schulstufen zeigte jedoch, dass, abhängig von der Schulstufe, quantitative und qualitative Unterschiede in der Nutzung digitaler Medien existieren.

DD 17: Poster – Außerschulisches Lernen

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 17.1 Mon 17:00 Empore Lichthof

Labs on Tour - MINT-Angebote im Nachmittags- und Freizeitbereich — •Maria Hinkelmann, Heidrun Heinke und Tobias Winkens — RWTH Aachen University, I. Physikalisches Institut IA

Bei Labs on Tour handelt es sich um ein Projekt, das in Kooperation mit der StädteRegion Aachen MINT-Angebote für Kinder und Jugendliche in den Nachmittags- und Freizeitbereich bringen soll. Dafür sollen möglichst ansprechende und niederschwellige vierwöchige Kurse mit jeweils 90-minütigen Einheiten entstehen, welche im Regelfall nachmittags in Schulen in der StädteRegion Aachen umgesetzt werden. Der Fokus soll dabei nicht exklusiv auf dem fachlichen Wissen liegen, sondern darauf die Schüler:innen für MINT-Themen zu motivieren, ihnen Freude an Naturwissenschaften zu vermitteln und dabei Hemmschwellen abzubauen. Ein erster exemplarischer Kurs zum Thema experimentelle Kompetenzen wurde auf Grundlage verschiedener Materialien des Physik-Schülerlabors der RWTH Aachen konzipiert sowie pilotiert. Weitere Kurse werden aktuell sowohl im Physik-Schülerlabor als auch in anderen Fächern, wie beispielsweise im Biologie-Schülerlabor zum Thema Citizen Science, entwickelt. Langfristig soll eine Vielzahl verschiedener Kurse aus unterschiedlichen Themenbereichen entstehen und in der gesamten StädteRegion Aachen angeboten werden. Dadurch soll ein inhaltlich vielfältiges und flexibel buchbares Angebot entstehen, um mit dem Projekt möglichst viele Schüler:innen zu erreichen. Die gewonnenen Erkenntnisse bei der Konzipierung und Durchführung der Kurse sollen darüber hinaus in den Erfahrungsaustausch zwischen MINT-Clustern in Deutschland einfließen.

DD 17.2 Mon 17:00 Empore Lichthof

MINTastisch: ein Ferienprogramm für junge Schüler:innen — •Jan Winkelmann, Lutz Kasper, Kevin Kärcher, Susanne Ihringer, Ann-Katrin Krebs und Hans-Dieter Körner — Pädagogische Hochschule Schwäbisch Gmünd

Das Projekt MINTastisch ist eine Gemeinschaftsaktion des Lehr-Lern-Labors UNICORNER, dem Zentrum für naturwissenschaftliche Bildung und dem Institut der Naturwissenschaften; alle drei Teil der PH Schwäbisch Gmünd. Mit Angeboten für Schüler:innen von neun bis zwölf Jahren wurden in den Oster-, Pfingst-, Sommer- und Herbstferien 2022 an jeweils drei Nachmittagen die Bereiche Chemie, Physik, Biologie und Informatik abgedeckt. Um für die MINT-Fächer und deren spezielle Arbeitsweisen zu begeistern, stand das selbstständige Arbeiten, der affektive Zugang zum jeweiligen Fach und die Erhöhung des Selbstkonzepts im Fokus. Auf dem präsentierten Poster werden die Inhalte des physikalischen Ferienangebots zu ersten Erfahrungen auf dem Gebiet der Astronomie vorgestellt. Hierfür wurden der Tageshimmel und insbesondere der Sonnenverlauf beobachtet und von den Kindern eigene Sonnenuhren sowie einfache Quadranten gefertigt und der Umgang damit eingeübt.

Das Angebot wurde durch das Schülerlabor-Förderprogramm im Rahmen des Aktionsprogramms Aufholen nach Corona für Kinder und Jugendliche durch das BMBF gefördert.

DD 17.3 Mon 17:00 Empore Lichthof

MINT LIGA und Forschungsclub - Bildungsziele und motivierende Methoden im außerschulischen Lernen — •Anne Geese und Dina Al Kharabsheh — Institut für die FAchdidaktik der Naturwissenschaften, Abteilung Physik und Physikdidaktik, TU Braunschweig

Während der schulische Bildungsauftrag durch Curricula klar umrissen ist, öffnen sich außerschulische MINT-Angebote einem Spektrum von möglichen Bildungszielen, die auf unterschiedlichste Weisen erlangt werden können. Währende der Forschungsclub changING auf Rollenvorbilder setzt, um junge Frauen für ein technisches Studium zu begeistern, ermöglicht die MINT LIGA aufsuchende Angebote in bildungsbenachteiligten Regionen. So werden Zielgruppen erreicht, die ohne familiaäre Unterstützung und ohne ausreichende Infrastruktur die vielfältigen Uni-Angebote anders nicht nutzen können. Wir skizzieren die anvisierten Bildungsziele und geben Best-Practice-Einblicke.

DD 18: Poster – Bildung für nachhaltige Entwicklung

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 18.1 Mon 17:00 Empore Lichthof

Literature Review zu Schülervorstellungen über die naturwissenschaftlichen Grundlagen des Klimawandels — •Sarah Wildbichler[1], Thomas Schubatzky[1] und Claudia Haagen-Schützenhöfer[2] — [1]Universität Innsbruck, Institut für Fachdidaktik — [2]Universität Graz, Institut für Physik, Fachbereich Physikdidaktik

Der aktuelle Klimawandel stellt die größte Herausforderung für die Menschheit im 21. Jahrhundert dar. Für den naturwissenschaftlichen Unterricht ist deshalb eine Auseinandersetzung mit dieser Thematik zentral. Daher gibt es vielfältige Bestrebungen, den Klimawandel auch in Physiklehrpläne und somit in den Physikunterricht im deutschsprachigen Raum aufzunehmen, wie etwa aktuelle Petitionen zeigen. Dazu ist aus fachdidaktischer Sicht ein Überblick über domänenspezifische Schülervorstellungen nötig. Denn für die forschungsbasierte Entwicklung und Evaluation von Lernumgebungen sowie für die Planung von Unterricht im Sinne der didaktischen Rekonstruktion ist die Kenntnis von Schülervorstellungen eine zentrale Vorbedingung. Zu Vorstellungen zum Klimawandel wurden bereits mehrere Untersuchungen durchgeführt, eine systematische Zusammenschau der zentralen Vorstellungen fehlt jedoch bis dato. Diesem Desiderat wird im Rahmen eines Literature Reviews nachgegangen. Dazu werden bereits publizierte Forschungsergebnisse der letzten 20 Jahre untersucht, um damit die Grundlage für die Entwicklung von Lernangeboten, welche Schülervorstellungen zum Klimawandel berücksichtigen, zu ermöglichen. Im Beitrag werden die (vorläufigen) Ergebnisse des Reviews vorgestellt.

DD 18.2 Mon 17:00 Empore Lichthof

Wissen zum Klimawandel, Klimaangst und Umwelteinstellung: Beforschung der Knowledge-Action Gap im Schülerlabor Labs4Future — •Jonathan Grothaus, Markus Elsholz und Thomas Trefzger — Uni Würzburg

Das Poster stellt ein an das Schülerlabor Labs4Future angegliedertes Forschungsvorhaben vor. Von Interesse ist der Effekt des Treatments Labs4Future auf typischerweise didaktisch beforschte Konstrukte (Wissen, Interesse), sowie psychologische Konstrukte (Umwelteinstellung, Klimaangst, Hoffnung zum Klimawandel). Anhand leitfadengestützter Interviews werden Mechanismen der Aktivierung der Verbindung von Wissen (Knowledge) und Handeln (Action) untersucht. Das Schülerlabor ist zweitägig und hat als Zielgruppe 14-15-jährige Schüler:innen der 9. Klasse. Behandelt werden die Bereiche (Erd)Systemwissen (Tag 1) und Handlungs- und Effektivitätswissen (Tag 2), d.h. die gesellschaftlichen und individuellen Handlungsoptionen und Einsparpotentiale. Fundiert ist Labs4Future dabei auf einem neu erarbeiteten klimadidaktischen Framework, das Erkenntnisse der Umweltpsychologie, Soziologie und Naturwissenschaftsdidaktik vereint. Die Beforschung folgt einem Pre-Post-Follow-Up Design mit dem Treatment Labs4Future. Quantitativ markante Schüler:innen werden ausgewählt, und zu leitfragengestützten Interviews eingeladen, die insb. die nicht quantitativ erhobenen Aspekte des Frameworks in den Blick nehmen sollen (soziale Normen, internale Attribution, Kommunikation).

DD 18.3 Mon 17:00 Empore Lichthof

Argumentieren zur Klimaphysik im Lehr-Lern-Labor PHyLa — •Kay Burger, Engin Kardaş und Tobias Ludwig — Pädagogische Hochschule Karlsruhe, Institut für Physik und Technische Bildung, Karlsruhe, Deutschland

Die Klimakrise gilt als die größte Herausforderung des 21. Jahrhunderts. Da es sich um die Zukunft der Bewohnbarkeit des Planeten handelt, liegt dieses Thema nicht nur im wissenschaftlichen, sondern auch im gesellschaftlichen und politischen Fokus. Damit Schüler:innen die Herausforderungen dieses socio-scientific issues (SSI) bewältigen und daran teilhaben können, müssten sie die notwendigen physikalischen Gesetze und Konzepte verstehen, um vor diesem Hintergrund Entscheidungen in ihrem Alltag treffen zu können (z. B. Sadler et al., 2006). Daneben ist es aber von Bedeutung, dass künftige Generationen in der Lage sind, zur Klimakrise naturwissenschaftliche Argumente zu bilden und zu evaluieren. Vor diesem Hintergrund werden im Lehr-Lern-Labor PHyLa an der PH Karlsruhe schwerpunktmäßig Projekttage zu physikalischen Aspekten der Klimakrise entwickelt und beforscht. Fokus ist dabei, dass Schüler:innen der Primarstufe und Sekundarstufe (Analog-)Experimente zum Klimawandel selbstständig durchführen. Im Fokus der Projekttage steht das Erlernen von klimaphysikalischen Aspekten sowie das naturwissenschaftlichen Argumentieren von Schüler:innen aufgrund von vorgegebenen oder selbst aufgenommenen Daten und experimentellen Beobachtungen. Dieser Beitrag zeigt die inhaltlichen Schwerpunkte der geplanten Projekttage zur Klimakrise und skizziert das geplante Forschungsvorhaben.

DD 18.4 Mon 17:00 Empore Lichthof

Projektseminar Klimawandel und Nachhaltigkeit: ein Seminar zur Förderung von Bildung für nachhaltige Entwicklung (BNE) — •Timo Graffe, Johannes Frank Lhotzky und Klaus Wendt — Johannes Gutenberg-Universität, Mainz, Deutschland

Die Themen Klimawandel und Nachhaltigkeit spielen in der universitären Lehre eine immer zentralere Rolle. Studierende agieren als Multiplikator:innen für eine nachhaltige Entwicklung, da sie die Führungskräfte, Expert:innen und Lehrkräfte von morgen bilden. Doch wie bindet man solche Inhalte transferfähig in die Strukturen der universitären Lehre ein? Die JGU Mainz will dazu einen Beitrag leisten und im Rahmen eines Projektseminars die Entwicklung solcher Nachhaltigkeitskompetenzen bei Ihren Studierenden stärken. In diesem entwickeln Studierende in interdisziplinären Kleingruppen Nachhaltigkeitsprojekte. Der Design-Based-Research-Ansatz bietet die Möglichkeit ein solches Seminar auf Grundlage von Forschungsergebnissen aus Physikdidaktik und BNE zu konzipieren, durchzuführen und zu evaluieren. Durch den iterativen Prozess dieses Forschungsansatzes kann so optimierter Prototyp eines solchen Seminars gestaltet werden. Dabei wird verschiedenen Herausforderungen begegnet: Wie kann ein Seminar konzeptionell so aufgestellt werden, dass es sowohl interdisziplinäre Ansprüche als auch die hochschulcurricularen Standards erfüllt? Wie sollte das Seminar inhaltlich aufgebaut sein, sodass es neben festen Instruktionsphasen auch handlungsorientierte Konstruktionsphasen beinhaltet. Das Poster soll eine mögliche Lösung dieser Fragen veranschaulichen und den bisherigen Konzeptionsprozess aufzeigen.

DD 19: Poster – Physikunterricht: Inklusion, Sprache, Anregungen

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 19.1 Mon 17:00 Empore Lichthof

(Sprachliche) Hürden beim Lernen mit Repräsentationen — •Kerstin Gresens und Hendrik Härtig — Universität Duisburg-Essen

In naturwissenschaftlichen Texten werden verschiedene Repräsentationsformen genutzt (z. B. Grafen, Bilder, Formeln). In unterschiedlichen Studien wurden bereits einige Hürden beim Lernen mit Repräsentationen belegt. Im Fach Physik sind diese Hürden an der Universität erhoben worden. So haben z. B. Nguyen & Rebello (2009 & 2011) Studierende zu Schwierigkeiten bei der Nutzung verschiedener Repräsentationsformen beim Problemlösen interviewt. Im schulischen Umfeld werden Schwierigkeiten vor allem im Fach Biologie erhoben (z. B. Dittmar et al., 2017). Inwieweit die Befunde aus anderen Altersgruppen und Disziplinen auf den Physikunterricht in der Sek. I übertragbar sind, ist unklar. Daher ist das Ziel der Studie, Schwierigkeiten im Umgang mit Repräsentationsformen im Physikunterricht der Sek. I zu identifizieren. Auf dem Poster werden die Konzeption , sowie erste Ergebnisse dieser Studie vorgestellt. Dazu werden über eine qualitative Befragung Erkenntnisse sowohl aus Sortieraufgaben (Repertory-Grid-Technique), als auch dem Lauten Denken gewonnen.

DD 19.2 Mon 17:00 Empore Lichthof

Physik und Tontechnik — •Jürgen Kirstein und Volkhard Nordmeier — Freie Universität Berlin, Didaktik der Physik

Audiomedien sind ein fester Bestandteil unserer Lebenswelt. Sie transportieren Musik, Wort und O-Töne, begleiten Bilder in Fernsehen und Kino und sind heute dank digitaler Kommunikationstechnologie an jedem Ort und jederzeit verfügbar. Die Produktion dieser Medien ist uns jedoch weniger vertraut. Insbesondere die der Audioproduktion und den (analogen) Geräten der Studiotechnik (Schallwandler, Signalbearbeitung, -transport und -speicherung) zugrundeliegenden physikalischen Prinzipien werden in der Regel im Physikunterricht nicht oder nur beispielhaft thematisiert. Die Tontechnik bietet dabei eine Fülle von kontextorientierten Lerngelegenheiten zu grundlegenden Themen der Schulphysik und liefert damit einen relevanten Beitrag zur multiperspektivischen Wahrnehmung der Physik wie auch zum Erwerb von Medienkompetenz im Physikunterricht.

DD 19.3 Mon 17:00 Empore Lichthof

Entwicklung praxistauglicher, inklusiver MINT-Vermittlungskonzepte für die Schule — •Giulia Pantiri, Lea Mareike Burkhardt, Thomas Wilhelm, Volker Wenzel, Arnim Lühken und Dieter Katzenbach — Goethe-Universität Frankfurt

Schon seit längerer Zeit besteht ein erheblicher Handlungs- und Forschungsbedarf hinsichtlich praxiserprobter und lernwirksamer Unterrichtskonzepte für den inklusiven fachübergreifenden naturwissenschaftlichen Unterricht. In diesem Kontext ist das vom BMBF geförderte Design-Based-Research-Projekt E^2piMINT angesetzt, in dem ein innovatives Vermittlungskonzept für die Sekundarstufe I entwickelt, getestet und evaluiert wird. Dazu entwickelt ein Team aus Vertreter:innen aller drei Naturwissenschaftsdidaktiken sowie der Sonderpädagogik unter Einbezug von Lehrkräften an Kooperationsschulen Vermittlungskonzepte, die zunächst im Schülerlabor GoetheLab der Universität Frankfurt unter kontrollierten Bedingungen erprobt und evaluiert werden. An diese erste Phase schließen sich zwei Design- und Re-Design-Zyklen an, die in den Schulen stattfinden, um die praktische Wirksamkeit im Unterricht zu erforschen. Untersucht werden u.a. sowohl das konzeptionelle Verständnis und die Veränderung von Schüler:innenvorstellungen als auch das Interesse der Lernenden. Das Poster zeigt Ideen des ersten Designs für den inklusiven fachübergreifenden MINT-Unterrichts auf, wie es im Schülerlabor eingesetzt werden wird.

DD 19.4 Mon 17:00 Empore Lichthof

Differenzierte Anleitungen für physikalische Heimexperimente mit dem Smartphone — •Marie Böwe[1], Simon Becher[1], Julius Grabs[1,2], Bastian Miersch[1,2], Kevin Gebhardt[1,2] und Holger Cartarius[1] — [1]AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena — [2]Lehrstuhl Pädagogische Psychologie, Friedrich-Schiller-Universität Jena, 07743 Jena

Jeder kennt es, Experimente kommen im Physikunterricht zu kurz. Die Gründe dafür sind zahlreich: zu wenige Lehrmittel, nicht genügend Zeit im Unterricht oder zu wenige Lehrkräfte. Unser Projekt beschäftigt sich mit differenzierten Arbeitsblättern für Smartphoneexperimente, die online für jeden zur Verfügung stehen und sich ohne Zugriff auf eine physikalische Gerätesammlung durchführen lassen. Die Arbeitsblätter werden für drei Anforderungsbereiche gestaltet. Ein Beispiel zum Thema Druck verwendet einen einfachen Aufbau aus Haushaltsgegenständen und einem Smartphone, um den Lernenden die Massenbestimmung von alltagsüblichen Objekten nahe zu führen. Dieses und weitere Beispiele möchten wir vorstellen.

DD 20: Poster – Quantenphysik

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 20.1 Mon 17:00 Empore Lichthof

Quantenphysik zum Anfassen - Von Papierstreifen zu Reißverschlüssen — •Franziska Greinert[1] und Malte S. Ubben[2] — [1]TU Braunschweig, Braunschweig, Deutschland — [2]WWU Münster, Münster, Deutschland

Quantenphysikalische Modellierungen sind fachlich komplex und oft unanschaulich. Dieses Poster stellt einige Ansätze vor, wie quantenphysikalische Ideen dennoch mittels haptischer Modelle dargestellt werden können. Dazu werden Modelle aus dem 3D-Drucker, Modelle aus Papierstreifen und Modelle aus Stoff gegenübergestellt und auf Grenzen und Potentiale für Schülervorstellungen untersucht. Die Modelle sind dabei vor allem mit dem Ziel entwickelt worden, unter Verwendung von wenig mathematischem Grundwissen topologische Ideen zu transportieren und zu visualisieren.

DD 20.2 Mon 17:00 Empore Lichthof

Teaching quantum effects using non-linear optics in laboratory courses — •Jennifer Heiss, Shreya Kumar, Simone D'Aurelio, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, 70569 Stuttgart

Quantum technologies are rapidly developing and have tremendous potential to revolutionize communication, computing, and sensing. It is crucial for the preparation of the quantum workforce and the education of future teachers that quantum technologies are part of higher education. In particular, practical training in quantum technologies helps to improve their understanding and allows them to gain hands-on experience in working with quantum optics. Here, we show how two key concepts of quantum technologies, entanglement and quantum interference, can be taught and studied in laboratory courses. These experiments are designed to be performed independently by students, starting with planning the experimental setups and afterwards building the experiments step by step. The first experiment deals with the generation of entangled photon pairs using parametric down-conversion. The setup allows to study various types of entanglement and to perform both fundamental quantum experiments as well as measurements for characterizing the entangled states. The second experiment aims at performing a Hong-Ou-Mandel experiment and a so-called Bell measurement. These form the basis for many quantum technology applications like quantum teleportation.

DD 20.3 Mon 17:00 Empore Lichthof

Die Rolle mathematischer Repräsentationen für das Verständnis quantenphysikalischer Prinzipien — •Moritz Förster und Gesche Pospiech — TU Dresden, Professur für Didaktik der Physik

Im Forschungsprojekt wird die Rolle des mathematischen Formalismus für das Verstehen grundlegender quantenphysikalischer Prinzipien untersucht. Es wird die Frage gestellt, welche Aspekte einer mathematischen Beschreibung von Zwei-Zustands-Systemen zu einem konzeptionellen Verständnis beitragen und nicht nur prozedurale Rechenfertigkeiten fördern.

Dabei wird der Fokus im ersten Studienteil auf die Aus- und Weiterbildung von Lehrpersonen gelegt. Um qualitativ Einblick in Lernprozesse und Einstellungen zu gewinnen, werden Teaching Experiments mit Lehramtsstudierenden und Lehrpersonen durchgeführt, in welchen Akzeptanz gegenüber einer formalen Behandlung der Quantenphysik sowie die Frage, welchen konkreten Beitrag die Mathematik zum Verstehen von Quantenphysik beitragen kann, untersucht wird.

Im zweiten Teil der Studie werden diese Erhebungsinstrumente für Lernende der Sekundarstufe II angepasst und analoge Fragestellungen untersucht. Der Fokus liegt darauf, zu untersuchen, inwiefern eine mathematische Beschreibung von Quantenphysik auch bei Schüler:innen zum Verständnis beiträgt.

DD 20.4 Mon 17:00 Empore Lichthof

Konzeption von experimentellen Kursen in Quantentechnologien für Berufstätige — •Alda Arias Suarez[1,2], Anna Donhauser[2], Eva Rexigel[1,2], Jonas Bley[1], Artur Widera[1] und Jochen Kuhn[2] — [1]Rheinland-Pfälzische Technische Universität, Kaiserslautern — [2]Ludwig-Maximilians-Universität München, München

Das rasante Wachstum der Quantentechnologien in der Industrie erhöht den Bedarf an qualifizierten Fachkräften in diesem Bereich, der nicht allein durch Hochschulabsolventen gedeckt werden kann. Deshalb entwickelt die Rheinland-Pfälzische Technische Universität (RPTU) einen interdisziplinären Fernstudiengang zu Quantentechnologien für Berufstätige. Der neue Studiengang (QUANTUK) basiert auf drei Bausteinen: Grundkurse zu den mathematischen und physikalischen Grundlagen der Quantentechnologien, Vertiefungskurse in theoretischen und anwendungsbezogenen Bereichen wie Quantencomputern und Quantensensorik, und Praktika mit Experimenten sowie numerische Projekte in den Quantentechnologien.

Mit diesem Poster wird das Konzept und die fachdidaktischen Ansätze der Praktika vorgestellt, die durch Experimente die theoretischen Kursinhalte elaborieren. Zusätzlich werden aktuelle Herausforderungen, wie eine geeignete, den experimentellen Lernprozess unterstützende Visualisierungen, präsentiert.

DD 20.5 Mon 17:00 Empore Lichthof

Analyse Graphischer Repräsentationen zu Qubits — •Eva Rexigel[1,2], Anna Donhauser[2], Jonas Bley[1], Alda Arias[1,2], Artur Widera[1] und Jochen Kuhn[2] — [1]RPTU Kaiserslautern Landau, Kaiserslautern — [2]LMU München, München

Quantentechnologien erfahren immer größeres wssenschaftliches und auch gesellschaftliches Interesse, und werden somit auch im Bereich der Hochschullehre immer relevanter. Eine wichtige Rolle nehmen hierbei Quanten-Bits, sog. Qubits, ein. Analog zu den klassischen Bits können sich Qubits im Zustand 0 oder 1 befinden. Darüber hinaus ist jedoch auch jede Superposition dieser beiden Basiszustände möglich. In einem System aus mehreren Qubits ist außerdem jede Superposition der gemeinsamen Basiszustände zulässig. Aktuell gibt es keine einheitliche graphische Darstellung von Qubit-Systemen. Populäre graphische Repräsentationen, wie die Blochkugel, bieten kontextspezifische Vorteile. Sie sind im Allgemeinen jedoch nicht universell anwendbar. Für eine vollständige Erklärung quantentechnologischer Zusammenhänge müssen Lehrende deshalb auf unterschiedliche graphische Repräsentationen zurückgreifen.

Ausgehend von aktuellen Forschungserkenntnissen werden die derzeit genutzten graphisch-visuellen Repräsentationen zu Qubit-Systemen hinsichtlich ihrer Einsazufähigkeit untersucht. Der Fokus liegt dabei auf der Analyse der jeweiligen repräsentationalen Funktion und den damit einhergehenden kognitiven Aufgaben. Das Ziel ist, spezifische Vorteile und mögliche Lernhindernisse bei der graphischen Darstellung von Qubit-Systemen zu identifizieren.

DD 20.6 Mon 17:00 Empore Lichthof

Students Exactly Derive Quantization and its Universality — •Hans-Otto Carmesin — Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

Quantization and its relation to general relativity provide an exciting problem of physics [1]. Based on the mathematics of class 11, students exactly derive the universality of quantization from the equivalence principle, EP, of general relativity. We introduce a measurement of a gravitational parallax distance r by using a pair of hand leads [2]. So, that distance is an element of physical reality. Additionally, we use the EP and the Lorentz factor. With it, we exactly derive a universal position factor $\varepsilon_E(r)$ providing the energy of a falling object [2,3]. With it, we exactly derive quantization and its universality.

Moreover, the present result is a basis for far reaching results, see e. g. [2]. Experiences about teaching in classes, research clubs and general study courses at a university are presented.

[1] Einstein, A. and Podolski, B. and Rosen, N. (1935): Can the quantum-mechanical description of physical reality be considered complete? Phys. Rev., 47, pp. 777-780.
[2] Carmesin, H.-O. (December 2022): Unification of Spacetime, Gravity and Quanta. Berlin: Verlag Dr. Köster.
[3] Burisch, C. et al. (2022): Universum Physik Gesamtband S2, Berlin: Cornelsen Verlag.

DD 20.7 Mon 17:00 Empore Lichthof

Demonstration Experiment for a Quantum Computer — •Philipp Schöneberg[1], Phil Immanuel Gustke[1], and Hans-Otto Carmesin[1,2,3] — [1]Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — [2]Hohenwedeler Weg — [3]Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

Quantum computers provide a potential for very fast computations [1, 2]. So, quantum computers are especially interesting for students at high schools, professional schools or at universities [3]. For such students, a demonstration experiment is very useful. Here, we present a demonstration experiment that is based on an interferometer and that provides a CNOT quantum gate. For it, we modified a similar experiment [4]. We present the demonstration experiment, experimental results and an extension to a universal set of quantum gates. Moreover, we show how quantum algorithms such as the Groover algorithm can be provided by such a universal set of quantum gates.

[1] Arute, F. et al. (2019): Quantum supremacy using a programmable superconducting processor. Nature, 574, pp. 505-511.
[2] Zhong, H. et al. (2020): Quantum computational advantage using photons. Science 370/6523, pp. 1460-1463.
[3] Gerke, F. et al. (2021): Ermittlung von Anforderungen an künftige Quanten-Fachkräfte. PhyDid B, pp. 495-500.
[4] Lopes, J. H. et al. (2018): Experimental realization of a quantum CNOT gate for orbital angular momentum and polarization with linear optical elements. arXiv: 1807.06065v1, pp. 1-5.

DD 21: Poster – Lehr-Lernforschung

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 21.1 Mon 17:00 Empore Lichthof

Embodied Cognition im Physikunterricht?! — •André Meyer und Gunnar Friege — Institut für Didaktik der Mathematik und Physik, AG Physikdidaktik, Leibniz Universität Hannover

Im Physikunterricht sollen die Lernenden u.a. lernen, physikalische Phänomene zu verstehen und Probleme zu lösen. Verschiedene Untersuchungen mit teils analytischen und teils empirischen Schwerpunkten zeigen Möglichkeiten auf, wie körperliche Erfahrungen mit theoretischem Wissen verzahnt werden können. Die Grundlage für diese Untersuchungen bilden kognitionswissenschaftliche Theorien unter dem Sammelbegriff Embodied Cognition.

Vorgestellt werden eine Analyse zur Theorie Embodied Cognition und zu Ansätzen sowie Ergebnissen empirischer Studien. Der Schwerpunkt liegt dabei auf dem Lehren und Lernen von Physik. Zudem werden Ergebnisse aus Interviews mit Lehrkräften von Gymnasien, Gesamtschulen und Schulen mit reformpädagogischen Ansätzen zu Embodied Cognition in der Schulpraxis präsentiert.

DD 21.2 Mon 17:00 Empore Lichthof

Zweistufiges Messinstrument zum konzeptionellen Verständnis von Abbildungsvorgängen an der Sammellinse — •Daniel Römer und Jan Winkelmann — Pädagogische Hochschule Schwäbisch Gmünd

Bei der Vermittlung von physikalischen Inhalten ist das Anknüpfen an das Vorwissen der Schüler:innen essenziell, dazu gehört auch das Erkennen der alternativen Vorstellungen der Lernenden. Dieses Projekt folgt der Hypothese, dass fehlverstandene Idealisierungen zu alternativen Konzepten führen können und eine explizite Auseinandersetzung mit ihnen lernförderlich sein kann. Zur Analyse der Wirksamkeit eines solchen Ansatzes bedarf es einer verfahrensökonomischen Methode für die Erhebung der vorherrschenden Konzepte der Lernenden. Dafür wurde, aufbauend auf einem bestehenden Instrument von Teichrew & Erb (2019), ein Test zu Schüler:innenvorstellungen zu Abbildungsvorgängen in der geometrischen Optik entwickelt. Anders als bei bestehenden Messinstrumenten, wird hier bewusst von strahlenoptischen Darstellungen Abstand genommen, um den Fokus auf ein konzeptionelles Verständnis zu legen. Der zweistufige Test (Antwort und Begründung) erweitert das bereits bestehende Messinstrument für die Anfangsoptik um Items zu Abbildungen an der Sammellinse. Der Test selbst sowie erste Ergebnisse der Pilotierung werden auf dem Poster vorgestellt.

DD 21.3 Mon 17:00 Empore Lichthof

Untersuchung visueller Strategien beim Umgang mit Repräsentationen elektrischer Stromkreise — •Stefanie Peter und Olaf Krey — Universität Augsburg

Beim Erlernen physikalischer Konzepte spielen externe Repräsentationen eine wichtige Rolle. In der Elektrizitätslehre können verschiedene Arten von visuellen Repräsentationen elektrischer Stromkreise anhand ihrer Abstraktheit unterschieden werden. Das Spektrum reicht von standardisierten Schaltplänen bis hin zu Fotografien von real aufgebauten Schaltungen. Der Umgang mit diesen Repräsentationen bereitet Lernenden Schwierigkeiten, was sich beispielsweise darin äußert, dass die Translation zwischen den Repräsentationen nicht gelingt oder fälschlicher Weise Symmetrie als Kriterium zur Beurteilung der Funktionsfähigkeit herangezogen wird. In unserem Forschungsvorhaben soll in den Blick genommen werden, auf welche Weise Lernende Repräsentationen elektrischer Stromkreise beim Lösen von Aufgaben aus der Elektrizitätslehre nutzen. Hierfür werden Aufgaben für eine Eye-Tracking-Studie entwickelt, in der die visuelle Aufmerksamkeit beim Lösen von Aufgaben mit den verschiedenen Repräsentationsformen untersucht wird. Damit wollen wir uns zum einen der Frage widmen, welche visuellen Strategien beim Bearbeiten der Aufgaben zu elektrischen Stromkreisen identifiziert werden können, und zum anderen, welchen Einfluss die Art der Repräsentation auf die Strategie der Lernenden hat. Die entwickelten Aufgaben für die Eye-Tracking Studie sollen im Mittelpunkt der Präsentation stehen.

DD 21.4 Mon 17:00 Empore Lichthof

Diagnose von Kompetenzfacetten zur Variablenkontrollstrategie — •Tobias Winkens und Heidrun Heinke — RWTH Aachen University

Die Förderung experimenteller Fähigkeiten und Kompetenzen ist wesentlich für das Erlernen einer naturwissenschaftlichen Grundbildung bei SchülerInnen. Gerade im experimentellen Prozess ist die Anwendung der Variablenkontrollstrategie (VKS) zur Feststellung von Ursache-Wirkungs-Beziehungen nicht nur in der Physik, sondern vielmehr in allen Naturwissenschaften essentiell notwendig. Zur Erfassung der Kompetenzen im Bereich der VKS wird in der Literatur ein Modell mit vier VKS-Teilfähigkeiten und ein entsprechendes Diagnoseinstrument vorgeschlagen. Dessen Weiterentwicklung kann zur Operationalisierung der VKS und daraus folgend für die Differenzierung unterschiedlich gestufter Fähigkeitsniveaus innerhalb der VKS-Teilfähigkeiten genutzt werden und damit die Basis eines Kompetenzmodells zur VKS bilden. Die Differenzierung unterschiedlicher Antworten von Probanden im Testinstrument in Fähigkeitsniveaus ermöglicht die Anwendung adaptiver Teststrategien und weiter individualisierter Diagnostik-, Feedback- und damit Lern-Möglichkeiten für ein vertieftes Verständnis der VKS.

DD 22: Poster – Neue / digitale Medien

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 22.1 Mon 17:00 Empore Lichthof

Verwendung von ML zur Auswertung von Concept Maps in der Mechanik — •Tom Bleckmann und Gunnar Friege — Institut für Didaktik der Mathematik und Physik, Leibniz Universität Hannover, Deutschland

Eine Verwendung von Concept Maps als formatives Assessment ist im Schulalltag nur schwer umsetzbar, da eine qualitative Analyse der Relationen zwischen miteinander vernetzten Begriffen sehr zeitaufwendig sein kann. Damit Lehrkräfte trotzdem mit Concept Maps arbeiten und darauf aufbauend Lernenden Feedback geben können, erforscht diese Arbeit eine neue Art der Auswertung unter Verwendung überwachter maschineller Lerntechniken. Durch diese soll eine zeitnahe automatische Auswertung einer Concept Map zum Thema Mechanik erfolgen. Die Gesamtergebnisse zeigen, dass bereits mit den ersten Modellen eine gute Übereinstimmung zwischen Mensch und Maschine erreicht werden konnten. Allerdings lassen sich auch Einflüsse auf die Performance, wie z.B. die Verwendung von Formeln, nachweisen. Perspektivisch soll auf der Basis der Ergebnisse ein automatisches Feedbacktool entwickelt und von Lehrkräften im Schuljahr 2023/2024 eingesetzt werden.

DD 22.2 Mon 17:00 Empore Lichthof

Digitalisierungsbezogene Kompetenzen angehender Physiklehrkräfte — •Muriel Schaber und Gunnar Friege — Leibniz Universität Hannover

Die aktuellen Entwicklungen zeigen, dass Lehrkräfte spezifische Kompetenzen im Umgang mit digitalen Geräten und Medien benötigen * sie sind schon jetzt essenziell und gewinnen weiter an Bedeutung. Besonders von Interesse für den Aufbau dieser professionsbezogenen Kompetenzen ist das Lehramtsstudium. Begleitend zum Unterrichtspraktikum Physik im Masterstudium wird der Einsatz (digitaler) Medien durch angehende Physiklehrkräfte untersucht. Umgesetzt wird dies als qualitative Studie, die sowohl die Planung, die Umsetzung im Unterricht, als auch die anschließende Reflexion der Studierenden in den Blick nimmt. Ausgewertet werden die Daten vor dem Hintergrund eines aus einschlägigen Kompetenzmodellen entwickelten integrativen Modells zu professions- und digitalisierungsbezogenen Kompetenzen angehender (Physik-)Lehrkräfte.

Dieses Projekt ist Teil des Projekts *Leibniz-Prinzip* an der Leibniz Universität Hannover und wird im Rahmen der Qualitätsoffensive Lehrerbildung gefördert (Förderkennzeichen 01JA1806).

DD 22.3 Mon 17:00 Empore Lichthof

The Interferometer Building - Conducting Experiments in a virtual environment — Gunnar Friege[1] and •Dirk Brockmann-Behnsen[2] — [1]Leibniz Universität Hannover, IDMP, AG Physikdidaktik, Welfengarten 1a, 30167 Hannover — [2]Leibniz Universität Hannover, IDMP, AG Physikdidaktik, Welfengarten 1a, 30167 Hannover

This paper presents the interferometer building. This is a virtual reality institute in which the user can use various digital media on the subject of interferometry. These include experiments that can be carried out directly in the virtual environment, interactive screen experiments and digital worksheets. The virtual environment was developed within the framework of the erasmus-plus-funded project STEM Digitalis.

DD 22.4 Mon 17:00 Empore Lichthof

Anwendungen der Interferometrie als interaktive Bildschirmexperimente — •Hendrik Maas, Stina Scheer und Gunnar Friege — Leibniz Universität Hannover, Institut für Didaktik der Mathematik und Physik, AG Physikdidaktik

Der Interferometrie kommt in Lehrplänen der gymnasialen Oberstufe eine bedeutsame Rolle zu, dennoch beschränken sich vor allem die experimentellen Möglichkeiten in Schulen oft auf einfache Experimente mit dem Michelson- und dem Mach-Zehnder-Interferometer. In diesem Beitrag werden Interferometrie-Experimente vorgestellt, die sich in Form von interaktiven Bildschirmexperimenten (IBE) in den Unterricht einbinden lassen. Bei den Experimenten handelt es sich um ein Analogieexperiment zur Gravitationswellendetektion, ein Experiment mit dem Sagnac-Interferometer zur Drehratenmessung und ein Experiment mit dem Michelson-Stern-Interferometer zur Bestimmung des Winkeldurchmessers einer Sternattrappe. Die entwickelten IBE's wurden darüber hinaus einer Usability-Untersuchung mit Lehramtsstudierenden unterzogen, deren Ergebnisse ebenfalls vorgestellt werden.

DD 22.5 Mon 17:00 Empore Lichthof

Virtual-Reality-Experimente Plus — •Johannes Lhotzky[1], William Lindlahr[1,2] und Klaus Wendt[1] — [1]Johannes Gutenberg-Universität Mainz — [2]FH Südwestfalen, Medienpädagogik/-technik

Der forschend-entwickelnde Physikunterricht lebt von seinen Experimenten und von der aktiven Auseinandersetzung und Untersuchung physikalischer Phänomene und zugehöriger Fragestellungen. Wegen hohem Gefahrenpotential, das bspw. von radioaktiven Stoffen, Lasern oder Hochspannung ausgeht, gibt es Versuche, die heute nicht oder nur erschwert im Unterricht (als Schülerexperiment) durchgeführt werden können. Eine Möglichkeit, dennoch eigenständiges Experimentieren in den Unterricht einzubinden, bieten die an der JGU entwickelten Virtual-Reality-Experimente (VRE). Diese bilden in einer digitalen, aber authentischen Welt reale Physik zu gegeben Themenbereichen ab. Innerhalb der VRE können die Versuche mit den dazugehörigen Apparaturen und Geräten gefahrlosbenutzt, selbstgesteuert bedient und laden dabei zu weitestgehend freiem Experimentieren ein. Um die Experimente für Lehrende und Lernende optimal und niederschwellig zur Verfügung zu stellen, wurden neben einfachen Veröffentlichungskanälen der Software zusätzlich auch spezielle Begleitunterlagen zu den verfügbaren VRE konzipiert. Die Materialien bestehen aus Handreichungen für die Lehrpersonen und Experimentieranweisungen sowie weiterführenden Unterrichtsmaterialien, die die Lernenden ansprechen und kognitiv aktivieren sollen. Aktuell verfügbare VRE, deren Konzeption sowie die Begleitmaterialien für Lehrkräfte und Lernende werden präsentiert.

DD 22.6 Mon 17:00 Empore Lichthof

Augmented Reality Experimente AR.X (download, print, cut, explore) — •Johannes Lhotzky und Klaus Wendt — Johannes Gutenberg-Universität Mainz

”Augmented Reality” (erweiterte Realität, kurz AR) ermöglicht die Ergänzung einer realen Umgebung mit virtuellen Objekten, Einblendungen oder Erläuterungen. So ist eine Simulation von Experimenten in natürlicher Umgebung ohne Abstraktion auf schematische Darstellungen möglich, was die Schüler:innen den realen Ablauf des Experimentierens ”begreifen” lässt. Die vorgestellten Anwendungen erfassen durch die Kamera eines mobilen Endgeräts reale Platzhalter in Form von Kärtchen, die durch AR Technik zu echten Experimentiergelegenheiten erweitert werden. Als aktuelles Themengebiet haben wir zunächst die Optik gewählt und möchten damit unser AR.X Konzept auf das Experimentieren mit Stromkreisen erweitern. Obwohl die Themenbereiche in der Schule auch im Realexperiment gut realisierbar sind, werden auch in diesem Bereich Experimente aus unterschiedlichen Gründen oftmals nicht oder nur sehr begrenzt von den Lernenden eigenständig durchgeführt. Zudem ist die Gestaltungsmöglichkeit der Platzierung der Experimente in der Unterrichtsreihe auf klassische, lineare Formate beschränkt. Durch die AR.X Umgebung können Unterrichtsinhalte sowohl in synchronen als auch asynchronen Unterrichtsformaten realisiert werden. Für die Nutzung der Anwendung wird lediglich ein kompatibles Endgerät (Android bzw. iOS/iPadOS), sowie die ausgedruckten (kostenlosen) Targets benötigt.

DD 22.7 Mon 17:00 Empore Lichthof

Das Projekt PUMA (PhysikUnterricht Mit Augmentierung) — •Florian Frank, Stefan Kraus, Annika Kreikenbohm, Hagen Schwanke, Christoph Stolzenberger und Thomas Trefzger — Julius-Maximilians-Universität Würzburg, Lehrstuhl für Physik und ihre Didaktik

Durch *Augmented Reality* (AR) können Realobjekte mit zusätzlichen digitalen Informationen überlagert werden, was neue Arten des Lernens ermöglicht. Internationale Studien beschreiben verschiedene Vorteile von AR-gestützten Lernumgebungen. Die professionelle Entwicklung und Evaluation von AR-Applikationen für den physikalischen Schulunterricht ist daher das Ziel des Projekts PUMA (PhysikUnterricht Mit Augmentierung). Unter diesem Projektdach werden in kleinen Teams (u.a. im Rahmen von Dissertationsvorhaben) Applikationen für die Vermittlung ausgewählter physikalischer Themen der Sekundarstufe 1 konzipiert und realisiert.

PUMA : Spannungslabor thematisiert einfache elektrische Stromkreise sowie grundlegende elektrische Konzepte und visualisiert gängige Analogiemodelle.

PUMA : Magnetlabor dient als Grundlage für ein Lehr-Lern-Labor zum Themengebiet des (Elektro-) Magnetismus und erweitert die Realexperimente u.a. mit unsichtbaren Feldlinien.

PUMA : Optiklabor wird als WebAR-Anwendung zur Simulation von Optik-Versuchen entwickelt.

Auf dem Poster werden die einzelnen Applikationen vorgestellt, sowie ein Einblick in die begleitende fachdidaktische Forschung gegeben.

DD 22.8 Mon 17:00 Empore Lichthof

PUMA : Optiklabor - Optimierungsbedarf in der Optiklehre, Lösungsansätze via WebAR & ein erstes Studiendesign auf der Grundlage von Design-Based Research — •Stefan Kraus und Thomas Trefzger — Julius-Maximilians-Universität Würzburg

Die Optiklehre der Sekundarstufe I sieht sich stets mit Schüler(fehl)vorstellungen konfrontiert, die sich aus den Alltagserfahrungen heraus gebildet haben und hartnäckig halten. Zudem müssen die Schülerinnen und Schüler den Umgang mit Modellvorstellungen wie beispielsweise zur Zusammensetzung des Lichts oder der Bildentstehung an Spiegeln und Linsen lernen. Diesen erhöhten Abstraktionsgrad leichter zugänglich, ja sogar die Experimente im heimischen Umfeld haptisch begreifbar zu machen, sind Ziele der webbasierten Augmented Reality Simulation ”PUMA : Optiklabor”. Das Projekt PUMA (Physik-Unterricht mit Augmentierung) des Lehrstuhls für Physik und ihre Didaktik der Universität Würzburg widmet sich den Chancen des sinnvollen Einsatzes von eigens entwickelten Augmented Reality Applikationen im Physikunterricht. Der Beitrag erörtert Problemfelder der Optiklehre und gibt erste Anwendungsbeispiele für den Einsatz einer AR-Simulation. Aus den identifizierten Problemen wird ein Set von AR-gestützten Experimenten entwickelt, das nach dem Prinzip von Design-Based Research in mehreren Schritten evaluiert und optimiert wird. Im Laufe der Iterationen wird der Teilnehmerkreis von Experteninterviews mit Lehrkräften bis hin zu einer größeren Zahl von Schülerinnen und Schülern erweitert.

DD 22.9 Mon 17:00 Empore Lichthof

VIANA 2.0 - eine APP zur Videoanalyse im Physikunterricht — •Volkhard Nordmeier und Dirk Schwarzhans — Freie Universität Berlin, Didaktik der Physik

Für den naturwissenschaftlichen Unterricht bieten mobile Endgeräte, Computer und digitale Videotechnik eine sehr gute Alternative zu den klassischen Verfahren der Erfassung und Analyse von Bewegungsdaten. Die (computergestützte) Videoanalyse wird daher auch im Physikunterricht inzwischen vielfach eingesetzt. Dabei wird ein realer Bewegungsvorgang z. B. per Smartphone- oder Tablet-Kamera zunächst aufgezeichnet. Der digitale Videoclip der Bewegung besteht aus einer Reihe von Einzelbildern, über die sich die Bewegung eines Objektes dann verfolgen lässt - manuell ’per Hand’ (mit Finger oder Eingabestift) oder auch automatisiert. In den letzten Jahrzehnten wurden viele Videoanalysesysteme vorgestellt. Neben den kommerziellen Lösungen existieren weiterhin auch Freewarelösungen wie z. B. VIANA (seit ca. 25 Jahren!). VIANA wurde in den letzten Jahren als APP für den Einsatz auf mobilen Endgeräten (iPads) stetig weiterentwickelt und bietet inzwischen auch die Möglichkeit einer automatischen Objekterkennung. Die Entwicklung der Software, Einsatzbeispiele und aktuelle technische Neuerungen werden vorgestellt.

DD 22.10 Mon 17:00 Empore Lichthof

Entwicklung eines 360° Serious Games zu Tätigkeiten von Forschenden in der Physik — •Benedikt Weiss, Moritz Kriegel und Verena Spatz — Technische Universität Darmstadt, Hochschulstraße 12

Schüler_innen haben oft ein stark verkürztes Bild der Arbeitsweisen von Naturwissenschaftler_innen, was zu naiven, stereotypischen Vorstellungen über dieses Berufsfeld führen kann. Besonders die theoretische Physik spielt bei den Vorstellungen der Lernenden über Physik eine stark untergeordnete Rolle. Diese unvollständigen Vorstellungen über den physikalischen Forschungsalltag können dazu führen, dass Entscheidungen hinsichtlich der späteren Berufswahl basierend auf falschen Annahmen getroffen werden. Es zeigt sich, dass Berufskenntnisse neben Interessen und Fähigkeiten einen relevanten inneren Faktor in Berufswahlprozessen darstellen.

Vor diesem Hintergrund wurden in einem aktuellen Projekt die Tätigkeiten von Forschenden in einem Sonderforschungsbereich der Kern- und Astrophysik mittels Interview- und Fragebogenstudie differenziert erfasst. Auf dieser Grundlage wurde ein digitales Serious Game entwickelt und erprobt, welches die verschiedenen Facetten der Arbeitsweisen von Forschenden aus der experimentellen sowie der theoretischen Physik in einer authentischen 360°-Umgebung adressatengerecht darstellt. Auf dem Poster werden die Konzeption und die Umsetzung dieses 360° Serious Games präsentiert. Außerdem werden erste Ergebnisse der Evaluation aus einer Think-Aloud-Befragungen von Schüler_innen der 7. bis 9. Jahrgangsstufe vorgestellt.

DD 22.11 Mon 17:00 Empore Lichthof

Physik im Fitnessstudio - Visualisierung physikalischer Größen — •Pawel Jakub Knebloch und Thomas Wilhelm — Institut für Didaktik der Physik, Goethe-Universität Frankfurt

Es wurde bereits vorgeschlagen, bei mechanischen Inhalten wie dem Hebelgesetz oder dem Flaschenzug verschiedene Fitnessgeräte aus dem Fitnessstudio zu betrachten. Diese können aber nicht mit in den Physikunterricht genommen werden und Messungen sind schwierig, so dass sich Fotos oder Videos im Unterricht anbieten. Neu ist der Vorschlag, auch bei quasistatischen Bewegungen die Videoanalyse mit „measure dynamics“ zur Veranschaulichung von Kräften, Kraftarmen, Drehmomenten und Wegen zu verwenden. Das Poster zeigt einige Beispiele auf.

DD 22.12 Mon 17:00 Empore Lichthof

Dynamische Modelle und Augmented Reality-Experimente zur Lorentzkraft — •Alexander Koch und Albert Teichrew — Goethe Universität Frankfurt

Im Rahmen des physikalischen Praktikums für Lehramtsstudierende der Goethe-Universität Frankfurt werden zwei Experimente zum Thema Lorentzkraft mit dynamischen Modellen erweitert. Die Leiterschaukel ist als dynamisches Modell in GeoGebra konstruiert worden, das Modell zum Fadenstrahlrohr ist zudem auch für ein Augmented Reality-Experiment geeignet. Beide Modelle werden in einer digitalen Lernumgebung eingesetzt, um den Lernprozess der Studierenden anzuleiten und zu unterstützen. Neben dem theoretischen Hintergrund sind Verständnisfragen als Freitext- und Multiple-Choice-Aufgaben sowie die Hypothesenbildung und -überprüfung Teil der Lernumgebung. Die Erweiterung des Praktikumsversuchs wird hinsichtlich der Akzeptanz der digitalen Lernumgebung und des Einsatzes von Augmented Reality-Experimenten sowie des erworbenen Wissens evaluiert.

DD 23: Poster – Lehreraus- und -fortbildung

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 23.1 Mon 17:00 Empore Lichthof

Physiklehrkräfte-Fortbildung mit Fokus auf NOS im SFB 1319 ELCH — •Linda Zwick und Rita Wodzinski — Universität Kassel, Hessen, Deutschland

Die Kenntnisse darüber, was Physiklehrkräfte zu *nature of science* (NOS) wissen bzw. welche Vorstellungen ihr Wissenschaftsverständnis prägen, begrenzen sich in Deutschland auf wenige Studien. Es gibt zwar empirisch gestützte Hinweise, wie sich Aspekte von NOS lernförderlich im Unterricht einbinden lassen, doch inwiefern diese Lehrkräften bekannt sind und ob sie diese im eigenen Unterricht mit Bezug auf aktuelle Forschung einsetzen, ist nicht bekannt.

Vorgestellt wird eine Lehrkräftefortbildung mit Fokus auf NOS, die das Ziel verfolgt, Physiklehrkräfte für NOS am Beispiel aktueller Aktivitäten im SFB 1319 ELCH (Extremes Licht für die Analyse und Kontrolle von molekularer CHiralität) zu sensibilisieren. Das Vorhaben zur Umsetzung, erste Ableitungen aus der Durchführung und erhobene Vorstellungen zum Wissenschaftsverständnis der Lehrkräfte werden präsentiert.

DD 23.2 Mon 17:00 Empore Lichthof

Lernstilpräferenzen und individuelle Förderung im Studium — •Leonie Jung, Martin Dickmann, Anita Stender und Heike Theyssen — Universität Duisburg-Essen

An Universitäten ist die Heterogenität von Studierendengruppen längst Realität. Um den Studienerfolg für alle zu verbessern, wird die Passung zwischen individuellen Lernvoraussetzungen und institutionellen Rahmenbedingungen der Studierenden als ein Schlüsselelement angesehen. In Anlehnung an Röpke, Zaric und Schroeder (2018) können Lernstilpräferenzen als lernrelevante Facette von Heterogenität angesehen werden, die bei der Gestaltung von individuellen Lerngelegenheiten Berücksichtigung finden sollte. Eine strukturelle Neugestaltung des Sekundarstufe I Studiengangs für das Lehramt Physik an der Universität Duisburg-Essen ermöglicht eine Implementation individuell fördernder Lerngelegenheiten zur Herstellung dieser Passung. Laut des etablierten Modells von Felder and Silverman (1988) wird angenommen, dass Lernende bezüglich der Präsentation, der Wahrnehmung, der Verarbeitung bzw. dem Verständnis von Informationen unterschiedliche Präferenzen haben. Eine gezielte Anpassung von Lernangeboten an Lernstilpräferenzen soll zu einer besseren Kompetenzwahrnehmung und Motivation führen sowie die Entwicklung fachlicher Kompetenzfacetten der Studierenden fördern. Auf dem Poster wird ein Einblick in das Projekt gegeben und erste Ergebnisse bezüglich der Erfassung und Berücksichtigung von Lernstilpräferenzen Studierender werden präsentiert.

DD 23.3 Mon 17:00 Empore Lichthof

Digitale Sensoren in der Lehramtsausbildung — •Katharina Stütz, Nicolas Braatz, Felix Weiss und Ronny Nawrodt — Physik und ihre Didaktik, Universität Stuttgart, 70569 Stuttgart

Die Forderung nach digitalen Kompetenzen bei Lehrenden ist nicht erst seit der Pandemie in der öffentlichen Diskussion. Als Multiplikatoren garantieren sie den Transfer dieser Fähigkeiten in die nächsten Generationen. Die digitalen Kompetenzen und der Umgang mit digitaler Sensorik muss daher einen zentralen Platz in der Ausbildung von Lehramtsstudierenden einnehmen. Wir präsentieren zwei beispielhafte Experimente aus der Lehrveranstaltung zu digitalem Physikunterricht im Master an der Universität Stuttgart und zeigen, wie diese praxisnah in die Ausbildung implementiert werden kann.

DD 23.4 Mon 17:00 Empore Lichthof

Mehr Denken, weniger Rechnen - auch für das Lehramtsstudium? — •Martin Dickmann, Cornelia Geller, Hendrik Härtig und Heike Theyssen — Universität Duisburg-Essen, Essen, Deutschland

Ausgehend von aktuellen Befunden der Unterrichts- und Professionalisierungsforschung wurde an der Universität Duisburg-Essen ein spezifischer Bachelorstudiengang für das Sek I-Lehramt an nicht gymnasialen Schulformen neu konzipiert und eingeführt. Ziele der Neukonzeption waren eine Fokussierung auf unterrichtsrelevante Fähigkeiten und Kenntnisse, eine Kompetenzerhöhung durch horizontale und vertikale Vernetzung von Fachinhalten auch mit fachdidaktischen Themen und eine Motivationssteigerung durch stärkere Unterrichtsbezüge und Kompetenzerleben. Zugunsten von konzeptuellen Betrachtungen wurde der Mathematisierungsgrad verringert und die aktive Lernzeit durch abwechslungsreiche Formen von Instruktion und Konstruktion erhöht. Auf dem Poster werden die Struktur des neuen Studiengangs, konkrete Beispiele und erste Erfahrungen vorgestellt.

DD 24: Poster – Neue Konzepte

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 24.1 Mon 17:00 Empore Lichthof

Weiterentwicklung der Frankfurt/Grazer Optikkonzeption: Akzeptanz der Lehrkräfte — •Markus Obczovsky und Claudia Haagen-Schützenhöfer — Universität Graz, Österreich

Ein zentrales Ziel der Physikdidaktik ist es, Lehrkräfte zu unterstützen physikalische Themen lernwirksam und nachhaltig zu unterrichten. Zur Unterstützung von Lehrkräften wurde daher z. B. die Frankfurt/Grazer Optikkonzeption entwickelt, sowie Schülermaterialien in einem schulbuchähnlichen Format mit altersgerechten Schülertexten, Darstellungen und Aufgaben zur Verfügung gestellt. Aufgrund einer Verschiebung des Inhaltsbereichs Optik von der 8. auf die 6. Schulstufe im Rahmen einer Lehrplanreform in Österreich wurden diese Schülermaterialien überarbeitet und an die neue Altersgruppe angepasst. Es gibt Hinweise darauf, dass Lehrkräfte an der Universität entwickelte Unterrichtskonzeptionen teilweise nicht annehmen oder wesentliche Elemente dieser nicht erkennen. Um Lehrkräfte optimal bei ihrer Arbeit zu unterstützen und Hürden der Akzeptanz für den Einsatz im eigenen Unterricht vorab zu identifizieren, sollten Lehrkräfte deshalb bereits bei der Entwicklung von Unterrichtskonzeptionen und deren Unterrichtsmaterialien involviert werden. Daher wurde in einem Online-Fragebogen gezielt Rückmeldung einiger Lehrkräfte eingeholt, sowie in einer Fortbildungsveranstaltung für Lehrkräfte gemeinsam verschiedene Aspekte der Schülermaterialien diskutiert. Die Ergebnisse dieser Befragung und Diskussion, sowie die folgende Adaption des Unterstützungsangebotes werden auf einem Poster vorgestellt.

DD 24.2 Mon 17:00 Empore Lichthof

Wie scheitern Schüler*innen am verständnisvollsten? — •Julia Hiniborch und Gunnar Friege — Leibniz Universität Hannover, IDMP AG Physikdidaktik, Welfengarten 1A, 30167 Hannover

Durch den Unterrichtsansatz Productive Failure wird das Verständnis neuer Lerninhalte besonders geschult; dies haben verschiedene Studien gezeigt. Begründet wird diese erhöhte Lernwirksamkeit dadurch, dass die Schüler*innen ihr Vorwissen aktivieren, sich über ihre Bewusstseinslücken bewusst werden und Tiefenstrukturen erkennen. Bei jüngeren Schüler*innen hat sich gezeigt, dass sich diese lernförderlichen Effekte nicht einstellen. Zurückgeführt wurde dies darauf, dass diese nicht gemerkt haben, dass ihnen Wissen fehlt.

Wird das Verständnis mehr gefördert, wenn die Schüler*innen explizit dazu angeregt werden, ihr Vorwissen zu aktivieren, sich über ihre Bewusstseinslücken bewusst zu werden und die Tiefenstruktur zu erkennen?

Ergebnisse einer empirischen Studie aus 10. und 11. Physikklassen werden präsentiert. Schüler*innen lernen dabei unter verschiedenen Interventionsbedingungen die kinematischen Zusammenhänge des Freien Falls. Rückmeldungen von den beteiligten Lehrkräften werden im Rahmen von Experteninterviews eingeholt. Mit diesen Interviews und mithilfe von Wissenstests soll die Frage geklärt werden, wie Schüler*innen am verständnisvollsten scheitern.

DD 24.3 Mon 17:00 Empore Lichthof

Studieren Erfahrbar Machen: Realitätsnahe Einblicke in ein Physikstudium für Schüler:innen — •Ahmad Asali[1], Volker Meden[2], Heidrun Heinke[3] und Stefan Roth[4] — [1]Institut Physik II, RWTH Aachen — [2]Institut für Theorie der Statistischen Physik, RWTH Aachen — [3]Institut Physik I, RWTH Aachen — [4]Institut Physik III, RWTH Aachen

Die Fachgruppe Physik an der RWTH Aachen hat zur Verbesserung des Übergangs zwischen Schule und Hochschule das Programm SEM (Studieren Erfahrbar Machen) entwickelt und zwischen Mai und September 2022 umgesetzt. In diesem Programm konnten 28 Schüler:innen mit Interesse an einem Physikstudium den realistischen Verlauf des Studiums aus erster Hand erfahren. Das Programm wurde hybrid (in Präsenz und online) über die RWTH Moodle Plattform angeboten und dauerte für jede der insgesamt 7 Kohorte 3 Wochen. Die Teilnehmenden erhielten vollständige Lehrmaterialien (Vorlesungsskripten, Vorlesungsvideos, Übungsblätter) zu jeweils zwei ausgewählten Ausschnitten aus den Veranstaltungen Experimentalphysik 1 und Mathematische Methoden der Physik 1 des ersten Semesters des Bachelorstudiums Physik und nahmen an je einem Übungstutorium zu jedem der beiden Fächer teil. Zusätzlich wurden tägliche Fragestunden, so wie e-Tests und phyphox Experimente zur Vertiefung organisiert. Das Poster fasst die Erfahrungen mit dem ersten Jahrgang zusammen.

DD 24.4 Mon 17:00 Empore Lichthof

Rechnen mit Licht - Null-Basen in der Raumzeit-Algebra — •Martin Erik Horn — iu - International University of Applied Sciences, Campus Berlin — ISM - International School of Management, Campus Berlin

Die Spezielle Relativitätstheorie wird üblicherweise in Koordinatensystemen dargestellt, die durch zeit- und raumartige Basisvektoren aufgespannt werden. Dies knüpft an unsere Erfahrungswelt an, da wir ausschließlich räumliche und zeitliche Distanzen messen und wahrnehmen.

Mit lichtartigen Größen werden wir im täglichen Leben normalerweise nicht konfrontiert. Dennoch können wir mit ihnen rechnen - und es ist interessant, sich eine Welt vorzustellen, deren mathematische Bausteine aus Basisvektoren der Länge Null bestehen.

Dies wird im Beitrag im Kontext der Geometrischen Algebra diskutiert. Es wird gezeigt, wie mit Lichtvektoren gerechnet werden kann und wie sich diese als Linearkombinationen von Dirac-Matrizen fassen lassen.

DD 24.5 Mon 17:00 Empore Lichthof

Embodiment: Mit Sport Physik unterrichten — •Sascha Therolf und André Bresges — Universität zu Köln

Embodiment umfasst eine Reihe neuer Theorien aus der Kognitions- wissenschaft. Demzufolge ist die Wahrnehmung des Menschen zuerst eine Körperwahrnehmung, und die entsprechenden Verarbeitungsstra- tegien sind darauf optimiert. Lässt sich demnach Mechanik wirksamer unterrichten, wenn man das Körpergefühl der Schüler:innen einbezieht und trainiert? Dies hätte Folgen nicht nur für den dauerhaften Aufbau von physikalischen Konzepten und Modellvorstellungen, sondern auch für die Gesundheitserziehung und das Well-Being von Kindern und Jugendlichen. In unserem neuen Lehr-Lernkonzept trainieren wir Basiskonzepte der Mechanik entlang von Newton*s Gesetzen zusammen mit einer einfachen und sicheren Übung für den Unterricht, dem Taktilen Reaktionstraining (TRT). Erste Schulversuche zeigen einen hochsignifikanten Zusammenhang mit der Stabilität Jugendlicher: Bei einem simulierten *S-Bahn-Schubsen*, einen hochgefährlichen Ereignis bei Jugendlichen die mit öffentlichen Verkehrsmitteln reisen, konnten 52 von 75 Jugendlichen die am Training teilgenommen haben einem normierten Stoß auf die Schulter stand halten, während in der Gruppe die nicht an diesem integrierten Physikunterricht teilgenommen haben 25 von 37 Schüler:innen über die simulierte Bahnsteigkante geschubst wurden. Das Poster stellt das Konzept und die Ergebnisse vor und lädt mit einem kompakten TRT Kurs zum Mitmachen ein.

DD 25: Poster – Praktika und Experimente

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 25.1 Mon 17:00 Empore Lichthof

Wirksame Augmented Reality-Experimente im physikalischen Praktikum — •Mareike Freese, Lion Cornelius Glatz, Albert Teichrew und Roger Erb — Institut für Didaktik der Physik, Goethe-Universität Frankfurt

Augmented Reality (AR) bietet als digitales Werkzeug neue Möglichkeiten, die auch in der Lehre immer häufiger zum Einsatz kommen (Altinpulluk, 2019). Im Rahmen des Projektes WARP-P (Wirksame AR im Praktikum Physik) werden ausgewählte Experimente des Elektrizitätslehre-Praktikums mit passenden dynamischen Modellen zu AR-Experimenten transformiert. Eingebettet in eine digitale Lernumgebung wird der naturwissenschaftliche Erkenntnisprozess der Lehramtsstudierenden erlebbar: Anstatt die Versuchsanleitung rezeptartig abzuarbeiten, werden mithilfe der dynamischen Modelle Hypothesen generiert und anschließend im Experiment direkt überprüft (Teichrew & Erb, 2020a). Mithilfe von Tablets wird das Kamerabild des (realen) Experiments mit dem Modell und den in ihm abgebildeten physikalischen Größen in Echtzeit überlagert (Teichrew & Erb, 2020b). Nach dem Einsatz des AR-Experiments können die Studierenden die Richtigkeit ihrer Modellannahmen in Kontrollfragen mit Musterantworten überprüfen. Über den gesamten Verlauf wird das Projekt qualitativ und quantitativ evaluiert. Auf dem Poster werden die Ergebnisse aus den Studierendenbefragungen und die Selbstwirksamkeitsentwicklung vorgestellt.

DD 25.2 Mon 17:00 Empore Lichthof

Kostengünstige Simulation der Röntgen- und Elektronenbeugung mit Hilfe von optischen Gittern — •Hubertus Giefers — Humboldt Gymnasium, Bad Pyrmont, Deutschland

Beugungsversuche mit Röntgen- oder Elektronenstrahlen sind im schulischen Unterricht oft auf wenige Substanzen wie NaCl oder Graphit beschränkt. Eine Alternative zur Darstellung von Laue- und Debye-Scherrer-Aufnahmen stellen die Beugungsmuster nach Koppelmann dar, wobei auf dem Lehrmittelmarkt solche Beugungsgitter kaum erhältlich sind. In diesem Beitrag werden neu entwickelte Beugungsgitter für solche optischen Analogieversuche sowie die didaktische Hinführung vorgestellt. Die 2D-Transmissionsgitter zeigen Beugungsmuster ähnlich denen echter Materialsysteme und sie können mit Hilfe eines Lasers und des Transmissionsgitters im Diaformat kostengünstig und schnell gezeigt werden. Die neuen Transmissionsgitter sind so aufgebaut, dass die grobe Struktur für das menschliche Auge sichtbar auf dem Dia erkennbar ist, die Mikrostruktur für den Beugungsversuch allerdings erst mit dem Mikroskop/Diaprojektor. Eine qualitative Auswertung der Beugungsmuster kann mit der Bragg-Gleichung erfolgen, da die auftretenden Beugungswinkel klein sind. Im Folgenden eine Auswahl an Beugungsgittern: verschiedene 2D-Bravais-Gitter; einkristalline, pulverförmige und amorphe Substanzen; "Graphitpulver"; Legierungen/intermetallische Verbindungen; isotrope/texturierte Substanzen; große Moleküle; Quasikristalle; Temperatureinflüsse. Im Hochschulbereich sind diese Transmissionsgitter in der Lehre zur Festkörperphysik interessant.

DD 25.3 Mon 17:00 Empore Lichthof

Warum flackert das Fahrradlicht bei langsamer Fahrradfahrt? — •Daniel Kanning und Michaela Schulz — Universität Bielefeld

Das Fahrrad ist zum einen ein Lehrgegenstand aus der Lebenswirklichkeit der Schülerinnen und Schüler und zum anderen bildet es viele Themengebiete des Physikunterrichts ab. Aus diesen Gründen kann das Thema Fahrrad in allen Klassenstufen angewendet werdet.

Mit Hilfe der Frage "Warum das Licht bei langsamer Fahrradfahrt flackert"können vielfältige Aspekte, z.B. aus der Elektrodynamik, Elektrik, Mechanik sowie psychophysiologische Gesichtspunkte des Sehvorgangs thematisiert werden. Ausgehend von dieser Frage können Hypothesen zur Funktionsweise der Bauelemente einer Fahrradlichtanlage formuliert werden.

Es werden dazu Experimente mit realen Dynamos und Fahrradleuchten sowie unterstützende Aufgaben für die Sekundarstufe II vorgestellt. Darüber hinaus eignet sich die Eingangsfrage um weitere Erkenntnisse über die Beleuchtungsanlage zu erhalten, wie z.B. die Identifizierung von wichtigen Bauteilen in einer LED-Fahrradlampe.

DD 25.4 Mon 17:00 Empore Lichthof

Experimente zur Relativitätstheorie im Schülerlabor — •Jörg Schneider und Holger Cartarius — AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena

Die spezielle Relativitätstheorie ist als Teil des Physikunterrichts der gymnasialen Oberstufe fest in den Bildungsplänen verankert. Anders als in anderen Teilgebieten des Physikunterrichts gibt es aber so gut wie keine (Schüler-)Experimente, anhand derer sich relativistische Prinzipien und Effekte im Rahmen der Schule bzw. eines Schülerlabors veranschaulichen und untersuchen lassen.

Um diesen Nachteil auszugleichen, wurden auf Grundlage der Mikrocontrollerplattform Arduino und einer Modelleisenbahn ein Versuchsaufbau entwickelt, welcher Simulationen mit konkreten, greifbaren Experimenten verbindet. Mit Hilfe von diesen lassen sich die relativistischen Effekte der Zeitdilatation und die Längenkontraktion untersuchen, indem man z.B. das Zeitverhalten bewegter Uhren oder den Zerfall und die Lebensdauer bewegter, instabiler Teilchen in Form einer Kombination aus Simulation und Analogieversuch betrachtet.

Auf dem Poster werden der experimentelle Aufbau und zugehöriges Lehr- und Lernmaterial vorgestellt. Außerdem werden erste Ergebnisse aus der Erprobung in unserem Schülerlabor präsentiert.

DD 26: Poster – Astronomie

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 26.1 Mon 17:00 Empore Lichthof

Grundlegendes über den Mars mathematisch verpackt — •Eleen Hammer und Holger Cartarius — AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena

Der Mars steht neben dem Mond im Fokus der meisten staatlichen und privaten Weltraumagenturen und -unternehmen. Dementsprechend viel wird in seine Erforschung investiert, genauso viel darüber publiziert und in medialen Schlagzeilen an die Allgemeinheit gebracht. Der Mars erreicht damit eine umfassende

Medienpräsenz. Doch da Astronomie nur in drei der 16 Bundesländer als eigenständiges Fach in der Sekundarstufe I unterrichtet wird, bleiben diese Schlagzeilen für viele Schüler*innen der Sekundarstufe I die primären Informationsquellen, die ihnen aktuelles, aber sehr spezifisches Wissen zum Mars vermitteln.

Auf diesem Poster wird gezeigt, dass man allgemeinbildendes Wissen zum Mars - wie besondere topologische Merkmale des Mars, seine Atmosphäre, astrophysikalische Parameter im Vergleich zu unserer Erde - auch im Mathematikunterricht vermitteln kann. Dazu sehen Sie exemplarische Anwendungsaufgaben, die sowohl die Kriterien eines modernen, kompetenzorientierten Mathematikunterrichts erfüllen als auch astronomisches Grundwissen näherbringen.

DD 26.2 Mon 17:00 Empore Lichthof

Wie sieht eigentlich das Sonnensystem aus? - Empirische Erhebung mentale Modelle Lernender zu Objekten im Sonnensystem — •Maximilian Loch und Malte S. Ubben — WWU Münster, Münster, Deutschland

Astronomie ist seit jeher ein interessantes Thema für Lernende. Doch nicht nur die Wissenschaft, sondern auch die Medien bieten eine Vielzahl von Darstellungen astronomischer Objekte. Durch die Medien werden diese oft aus dem Kontext gerissen, wodurch im Inhaltsfeld Astronomie in weiterführenden Schulen interessant wird, welche Vorstellungen und mentalen Modelle die Lernenden zu astronomischen Objekten im Sonnensystem aufgebaut haben. Um einen Einblick in die mentalen Modelle zur Darstellung unseres Sonnensystems zu erhalten, wurde in der hier vorgestellten Studie eine qualitative Erhebung von gezeichneten Darstellungen unseres Sonnensystems von verschiedenen Zielgruppen gesammelt und analysiert. Zusätzlich wurden zur Reflexion anregende Fragen gestellt, die mögliche Lücken bei der zeichnerischen Darstellung aufgreifen.

DD 26.3 Mon 17:00 Empore Lichthof

Students Derive an Exact Solution of the Flatness Problem — •Hans-Otto Carmesin — Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

The global flatness of space is an exciting problem of cosmology [1]. Based on the cosmological principle and mathematics of class 11, students derive an exact solution of that problem: We introduce a measurement of a gravitational parallax distance r by using a pair of hand leads [2]. So, that distance is an element of physical reality. Additionally, we use the equivalence principle and the Lorentz factor. With it, we exactly derive a universal position factor $\varepsilon_E(r)$ providing the energy of a falling object [2, 3]. With it, we derive the Friedmann Lemaître equation, FLE, as well as the global flatness of space, exactly.

An interesting byproduct is the exact derivation of the global dynamics, FLE, from the local position factor $\varepsilon_E(r)$. Moreover, the present result is a basis for far reaching results, see e. g. [2, 4]. Experiences about teaching in classes, research clubs and general study courses at a university are presented. [1] Guth, A. (1981): Inflationary universe: A possible solution to the horizon and flatness problems. Physical Review D, 23, pp. 347-356. [2] Carmesin, H.-O. (December 2022): Unification of Spacetime, Gravity and Quanta. Berlin: Verlag Dr. Köster. [3] Burisch, C. et al. (2022): Universum Physik Gesamtband S2, Berlin: Cornelsen Verlag. [4] Carmesin, H.-O. (2020): The Universe Developing from Zero-Point Energy: Discovered by Making Photos, Experiments and Calculations. Berlin: Verlag Dr. Köster.

DD 27: Poster – Hochschuldidaktik

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 27.1 Mon 17:00 Empore Lichthof

Offene Projektaufgaben mit Smartphone-Experimenten für die Studieneingangsphase Physik — •Simon Z. Lahme[1], Matthias Fipp[1], Andreas Müller[2] und Pascal Klein[1] — [1]Universität Göttingen, Deutschland — [2]Universität Genf, Schweiz

Smartphones werden in der Hochschullehre besonders während der Covid-19-Pandemie, aber auch darüber hinaus in Laborpraktika, für Demonstrationsexperimente in der Vorlesung oder für experimentelle Übungsaufgaben eingesetzt. In vielen Fällen beschränkt sich die Nutzung dieser digitalen Technologien aber auf eine kurze Arbeitsphase von wenigen Minuten bis Stunden. An der Universität Göttingen ist daher im Sinne des undergraduate research-Ansatzes ein Konzept entwickelt worden, bei dem sich die Studierenden in Kleingruppen von drei bis fünf Personen über einen Zeitraum von zwei Monaten im Rahmen einer Projektarbeit vertieft mit jeweils einem Smartphone-Experiment auseinandersetzen. Die Projektaufgaben adressieren verschiedene Themen im Gebiet der Mechanik und weisen einen hohen Offenheitsgrad auf. Sie sollen bei den Studierenden neben der Vertiefung und Vernetzung der Vorlesungsinhalte vor allem Neugier, das Interesse am Fach und das Gefühl der sozialen Eingebundenheit fördern. Die Implementation erfolgte im Wintersemester 2022/23 bei Erstsemesterstudierenden im Physik-Haupt- und -Zweifächerbachelorstudiengang im Rahmen des Übungsbetriebs zur Grundlagenvorlesung Experimentalphysik I. Auf dem Poster werden das Design der insgesamt sechs entwickelten Experimentierprojektaufgaben sowie erste Erfahrungen aus der Implementation dieser Aufgaben in die Hochschullehre präsentiert.

DD 27.2 Mon 17:00 Empore Lichthof

Entwicklung von Unterstützungsmaterialien für Theoretische Physik (PSΦ: Theoretische Physik) — •Nilab Abbas, Anna B. Bauer und Peter Reinhold — Universität Paderborn, Deutschland

Das Lehr-Lernzentrum Physiktreff der Universität Paderborn unterstützt während der Studieneingangsphase sowohl Lehrende bei der Gestaltung von Veranstaltungen als auch Studierende beim Bewältigen verschiedener Anforderungen des Physikstudiums. Eine wesentliche Anforderung ist der Erwerb physikalischer Problemlösefähigkeiten. Dies geschieht durch das Bearbeiten von wöchentlichen Übungsaufgaben. Studien zeigen jedoch, dass die Problemlösefähigkeiten von Studienanfänger:innen nicht auf einem ausreichenden Niveau entwickelt werden und ihr Erwerb eine der größten Herausforderungen ist. Um die Student:innen beim Erwerb von Problemlösefähigkeiten zu unterstützen, werden durch den Physiktreff evidenzbasiert Unterstützungsmaßnahmen für u.a. die Theoretische Physik entwickelt. Diese Veranstaltung wird als besonders abstrakt und schwer empfunden. In dem hier vorgestellten Projekt werden basierend auf erhobenen Schwierigkeiten (Problemlösen, mathematische Methoden & Wissenschaftsverständnis) passgenaue (digitale) Selbstlernmaterialien zur Vermittlung von Problemlösefähigkeiten in der Theoretischen Physik entwickelt und hinsichtlich ihrer Lernwirksamkeit evaluiert. Das Poster zeigt, wie basierend auf den identifizierten typischen Schwierigkeiten und Herausforderungen beim Problemlösen passgenaue Unterstützungsmaterialien entwickelt werden.

DD 27.3 Mon 17:00 Empore Lichthof

Entwicklung einer modularen Workshop-Reihe: "Präsentieren von Fachinhalten in der Physik" — •Anna B. Bauer[1] und Katharina Brassat[2] — [1]Universität Paderborn, Deutschland — [2]ehem. Universität Paderborn, Deutschland

Obwohl das Kommunizieren von Fachinhalten in Wort und Schrift in der Forschung, späteren Arbeitswelt und insbesondere im Rahmen der Abschlussarbeiten in der Physik eine hohe Relevanz besitzt, werden die Studierenden darauf meist nur implizit und durch intensive Betreuung durch die Lehrenden in den einzelnen Arbeitsgruppen vorbereitet. Im Rahmen des Lehr-Lernzentrum Physiktreff, das an der Universität Paderborn ein Unterstützungsangebot für Dozent:innen und Student:innen der Physik darstellt, ist deswegen eine modulare Workshopreihe in Kooperation mit Fachwissenschaftler:innen entwickelt und evaluiert worden. Zur Erhöhung der Relevanzwahrnehmung und Akzeptanz der Angebote werden diese nach dem Ansatz des Cognitive-Apprenticeships auf Basis realer Produkte von Wissenschaftler:innen entwickelt. In den einzelnen Modulen wird das Schreiben von wissenschaftlichen Arbeiten, das Präsentieren in den Formaten Vortrag und Poster, sowie auch die Recherche und das Lesen von Fachliteratur adressiert. Die Workshops bestehen typischerweise aus Selbstlernmaterialien sowie einer individuellen Betreuungssituation oder Lehrveranstaltung, in der die Fragen der Lernenden beantwortet sowie Feedback zu ihren Produkten gegeben wird. Das Poster zeigt die Workshopreihe sowie ausgewählte Evaluationsdaten.

DD 27.4 Mon 17:00 Empore Lichthof

Entwicklung eines Workshops zum Schreiben physikalischer Arbeiten auf universitärem Niveau — •Michael Rüsing[1] und Anna Bauer[2] — [1]Institut für Angewandte Physik, TU Dresden, Nöthnitzer Straße 61, 01187 Dresden — [2]Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn

Wissenschaftliche Texte und grafische Darstellung von Messdaten sind für Physiker:innen das zentrale Medium, um Forschungsergebnisse zu kommunizieren und zu dokumentieren. Trotz der zentralen Relevanz ist die Schreibausbildung in den meisten Physik-Curricula deutscher Hochschulen nicht explizit verankert. Dies stellt Physik-Studierende, sowie deren Betreuende, insbesondere bei der Erstellung der Qualifikationsarbeiten, wie Bachelor und Master-Arbeiten, vor besondere Herausforderung. In dem Projekt wird deswegen ein Workshop nach dem Prinzip des "Cognitive-Apprenticeship" zum fachspezifischen Schreiben und der Darstellung von Messdaten auf universitärem Niveau entwickelt und evaluiert. Für eine möglichst passgenaue Gestaltung des Angebotes sind Studierende und fortgeschrittene Wissenschaftler:innen an zwei Standorten, der TU Dresden und der Universität Paderborn, zu ihren Herausforderungen beim Schreiben befragt worden. Auf dem Poster wird die Eingliederung des Angebotes in die Workshopreihe "Präsentieren von Fachinhalten" des Physiktreffs an der Uni Paderborn sowie die didaktische und inhaltliche Gestaltung des Workshops vorgestellt.

DD 27.5 Mon 17:00 Empore Lichthof

Welches mathematische Komplexitätsniveau erwarten Physikdozierende? — •Dennys Gahrmann[1], Irene Neumann[2] und Andreas Borowski[1] — [1]Universität Potsdam — [2]Leibniz-Institut für die Pädagogik der Naturwissenschaften und Mathematik

Einer der wichtigsten Prädiktoren für den Studienerfolg in der Studieneingangsphase ist das mathematische Vorwissen. Eine Mehrheit der aktuellen Tests erheben im Bereich der Mathematik allerdings vermehrt Rechenfähigkeiten. Es gibt aber Forderungen, Aufgaben höherer Komplexität in Studieneingangstests zu verwenden. Aus diesem Kontrast ergibt sich die Frage, welche Sichtweise Physikdozierende des ersten Semesters haben. Um diese Frage zu beantworten, wurden Aufgaben aus dem bundesweiten Studieneingangstest von 1978 und weitere Aufgaben aus verschiedenen Tests ausgewählt und Dozierenden des ersten Semesters in einer Online-Umfrage zum Rating bereitgestellt. Die Analyse der $N = 78$ ausgefüllten Fragebögen ergab, dass vor allem Aufgaben auf einem geringeren Komplexitätsniveau als relevant angesehen werden.

DD 27.6 Mon 17:00 Empore Lichthof

Open Educational Resources für den Hochschulbereich: Anschauliche Vektoranalysis für die Studieneingangsphase — •Larissa Hahn[1], Simon Blaue[1], Patrick Höhn[2], Nina Merkert[2] und Pascal Klein[1] — [1]Universität Göttingen, Deutschland — [2]TU Clausthal, Deutschland

Die Vektoranalysis stellt Studienanfänger:innen nachweislich vor Schwierigkeiten. In der Vektoranalysis werden Konzepte der Vektorrechnung und der höherdimensionalen Analysis verknüpft, um die physikalisch-technische Welt mathematisch zu beschreiben. Außerdem werden die mathematischen Fähigkeiten von Studienanfänger:innen zunehmend heterogener. Vor diesem Hintergrund werden daher im Rahmen der niedersächsischen Förderlinie "Förderung von OER an Niedersächsischen Hochschulen" als Kooperation zwischen der Physikdidaktik der Universität Göttingen, der Abteilung Computational Material Sciences/Engineering der TU Clausthal und dem Simulationswissenschaftlichen Zentrum Clausthal-Göttingen innovative Lehr-/Lernmaterialien zu verschiedenen Konzepten der Vektoranalysis entwickelt. Dies umfasst die Konzeption digitaler Lernumgebungen sowie wissenschaftsnaher Anwendungsbeispiele unter Berücksichtigung vielseitiger didaktischer Ansätze, wie multipler Repräsentationen, Simulationen und Eye-Tracking. Diese werden als flexibel einsetzbare Open Educational Resources (OER) auf der Plattform *twillo* für Studierende sowie Lehrende physikalisch-technischer Studiengänge aufbereitet. Dieser Beitrag stellt erste im Rahmen des Projekts entstandene digitale Lehr-/Lernangebote vor.

DD 27.7 Mon 17:00 Empore Lichthof

Triangulation von Verbal- und Blickdaten: Eine Eye-Tracking-Studie — •Julia Hofmann[1], Larissa Hahn[1], Katarina Jelicic[2], Ana Sušac[2] und Pascal Klein[1] — [1]Universität Göttingen, Deutschland — [2]Universität Zagreb, Kroatien

Eye-Tracking erlangt in der physikdidaktischen Forschung immer mehr Bedeutung, da durch diese Methode Rückschlüsse auf kognitive Prozesse von Lernenden möglich sind. Studien weisen darauf hin, dass eine tiefgreifende Interpretation von Blickdaten nur mit weiteren qualitativen Datenquellen möglich sei. In einer kontrollierten Eye-Tracking-Studie wurden 16 Studierende des ersten Semesters aufgefordert Aufgaben zum Hertzsprung-Russell-Diagramm und zu Vektorfeldern zu lösen und auf drei unterschiedliche Arten ihren Bearbeitungsprozess zu verbalisieren. Im Retrospective Thinking Aloud beschreiben sie ihren Bearbeitungsprozess, nachdem die Aufgabe gelöst wurde. Im Cued Retrospective Thinking Aloud erhalten die Studierenden ein Video ihrer eigenen Blickdaten anhand dessen der Bearbeitungsprozess beschrieben werden soll. Im Concurrent Thinking Aloud sprechen sie ihre Gedanken während des Lösens der Aufgabe laut aus. Ziel der Studie ist es zu untersuchen, welchen Einfluss die Methode der Triangulation von Blick- und Verbaldaten durch Retrospective, Cued Retrospective und Concurrent Thinking Aloud auf die kognitive Belastung, das Blickverhalten und den Informationsgehalt der Erklärungen beim Problemlösen hat.

DD 27.8 Mon 17:00 Empore Lichthof

Systematische Implementierung von Inklusion im Physik-Lehramtsstudium durch das Teilprojekt Isi in PROFJL[2] — •Julius Grabs[1,2], Bastian Miersch[1,2], Kevin Gebhardt[1,2], Florian Kuss[1,2], Holger Cartarius[1], Stefanie Czempiel[2] und Bärbel Kracke[2] — [1]AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena — [2]Lehrstuhl Pädagogische Psychologie, Friedrich-Schiller-Universität Jena, 07743 Jena

Im Rahmen des Teilprojekts Inklusion systematisch implementieren (Isi) des QLB-Projekts PROFJL[2] an der Friedrich-Schiller-Universität Jena entstand im Vertiefungsseminar „Digitales Lernen und Lehren in der Werkstattschule Jena" am Lehrstuhl Pädagogische Psychologie ein Studierendenprojekt, in dem differenzierte Anleitungen für physikalische Smartphone-Experimente entwickelt und öffentlich zugänglich gemacht werden. Grundgedanke des Seminars war es, eine digitale Lerneinheit für die Klassenstufen fünf und sechs der Werkstattschule Jena zu planen. Damit einhergehend sollten die Hürden für ein freies Experimentieren in Heimarbeit so niedrig wie möglich gehalten werden. Das Hauptaugenmerk liegt darauf, dass Schülerinnen und Schüler die Experimente zu Hause durchführen, innerhalb einer einzigen PDF-Datei ausfüllen und anschließend der Lehrkraft schicken oder präsentieren können. Inzwischen wird der Ansatz in einem Seminar der Physikdidaktik fortgesetzt, sodass immer mehr Experimente zusammenkommen. Auf diesem Poster wird die Konzeptidee vorgestellt.

DD 27.9 Mon 17:00 Empore Lichthof

Physics Education Research-orientierte digitale Lehrmaterialien für Studienanfänger — •Claudia Schäfle und Michaela Weber — Technische Hochschule Rosenheim, Deutschland

In diesem Beitrag werden der Online-Selbstlernkurs POWER (Physik Online Warm-up für ERstsemester) sowie drei Open Eductional Ressources SMART-vhb - Einheiten vorgestellt, die bei der virtuellen Hochschule Bayern (vhb) allen kostenlos zur Verfügung stehen. Die Themenauswahl orientiert sich an den Physik-Inhalten zu Beginn eines Ingenieurstudiums an einer Hochschule für angewandte Wissenschaften. Die Lernziele sind an den Mindestanforderungskatalog Physik der cosh-Gruppe (Cooperation Schule-Hochschule) Baden-Württemberg angelehnt.

Die Darstellung der Themen orientiert sich an der Forschung und Erkenntnissen zum Konzeptverständnis der amerikanischen Physics Education Research. Insbesondere werden graphische Repräsentationen eingesetzt, die den Aufbau eines vertiefteren Konzeptverständnis fördern, aber bisher in der deutschsprachigen Physiklehrbuchliteratur für Hochschulen wenig Einzug erhalten haben. Bewegungsdiagramme in der Kinematik ermöglichen ein schrittweises Erfassen des vektoriellen Charakters der Geschwindigkeit und Beschleunigung. Freikörperbilder zur Darstellung von Kräften sind anschlussfähig an das "Freischneiden" in der Technischen Mechanik. Die Energiebilanzen im System ermöglichen eine klare Unterscheidung zwischen der Energieübertragung zwischen System und Umgebung und der Energieumwandlung im System, die eine direkte Erweiterung zum ersten Hauptsatz ermöglichen.

DD 27.10 Mon 17:00 Empore Lichthof

5 Jahre Studienreform-Forum — Amr El Miniawy[1], •Annemarie Sich[2], Lisa Lehmann[3], Manuel Längle[4], Sophie Penger[2] und Stefan Brackertz[2] — [1]Humboldt-Universität zu Berlin, Fachschaftsinitiative Physik — [2]Universität zu Köln, Fachschaft Physik — [3]Technische Universität Dresden, Fachschaft Physik — [4]Universität Wien, Studienvertretung Physik

Seit 2018 sammelt das Studienreform-Forum Beispiele für die Weiterentwicklung von Studiengängen, Pilotprojekte usw. Anders als bei vielen anderen hochschuldidaktischen Ansätzen ist der Blick dabei nicht auf die Gestaltung einer bestimmten Lehrveranstaltung beschränkt, sondern es wird immer versucht, die Verbindung herzustellen zwischen Studiengangskonzeption, didaktischem Konzept einzelner Veranstaltungen und der Kultur im Fachbereich. Besonderer Fokus liegt zudem darauf, die Debatten dahinter mit zu dokumentieren und hochschulpolitisch einzuordnen.

Im Rahmen der Postersession werden die bisherigen Ergebnisse vorgestellt.

DD 27.11 Mon 17:00 Empore Lichthof

Studiengang-Diagramme - hands on — Annemarie Sich[1], Manuel Längle[2], Philipp Hell[3], •Sophie Penger[1] und Stefan Brackertz[1] — [1]Universität zu Köln, Fachschaft Physik — [2]Universität Wien, Studienvertretung Physik — [3]Universität Innsbruck

Läuft das Physikstudium im deutschsprachigen Raum im Großen und Ganzen überall auf die gleiche Art ab oder sind die Strukturen von Standort zu Standort verschieden? Wie lässt sich die Ähnlichkeit von Studiengangsstrukturen feststellen? Um solche Fragen strukturiert beantworten zu können, ist ein öffentlich zugängliches Online-Tool entstanden, das es erlaubt, diese Darstellung halbautomatisiert aus den Informationen der Modulhandbücher zu erstellen. (http://studiengang-diagramm.de) Die so erzeugten Darstellungen sollen nicht nur der Beforschung der Studiengänge dienen, sondern gleichzeitig für die Arbeit in den Fachbereichen nutzbar sein.

Inzwischen sind mehr als 40 Studiengang-Diagramme entstanden, die sich in den Reformdebatten vor Ort und bei der Studienberatung oftmals als nützlich erwiesen haben, ein systematischer universitäts-übergreifender Vergleich steht aber noch aus. Wir möchten mit einem Mitmach-Poster dazu einladen, gemeinsam auf der Tagung damit zu beginnen. Es darf gekritzelt werden.

DD 28: Poster – Weitere fachdidaktische Forschung

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 28.1 Mon 17:00 Empore Lichthof

Identitätsaushandlungen von Schüler*innen zu MINT im Anfangsunterricht — •Lisa-Marie Christ[1], Olaf Krey[1], Frederik Bub[2] und Thorid Rabe[2] — [1]Universität Augsburg — [2]Martin-Luther-Universität Halle-Wittenberg

Das BMBF-geförderte Forschungsprojekt IdentMINT untersucht über zwei Schuljahre Identitätsaushandlungen und Zugänge von Schüler*innen (SuS) zu den Naturwissenschaften (NW) während des Anfangsunterrichts in den Fächern Physik und Chemie. In Fragebogenerhebungen und leitfadengestützten Interviews wird herausgearbeitet, wie SuS ihre MINT-Identitäten konstruieren, sich zu NW positionieren und wie sich einzelne Aspekte von MINT-Identitäten während des Fachunterrichts entwickeln. Zudem werden außerschulische Lern- und Begegnungsmöglichkeiten mit MINT in den Blick genommen, die als eine weitere Zugangsmöglichkeit der SuS zu MINT zu deren Identitätsarbeit beitragen können. Des Weiteren wird analysiert, wie SuS Genderidentitäten und MINT-Identitäten aufeinander beziehen und miteinander verhandeln. Im Rahmen von Workshops werden die Befunde mit Lehrpersonen der beteiligten Schulen und Akteur*innen außerschulischer Lernorte diskutiert, um Leitlinien und Handlungsmöglichkeiten für eine verbesserte MINT-Bildung in Zusammenhang mit dem Anfangsunterricht in Physik und Chemie zu erarbeiten. Außerdem werden Angebote an den außerschulischen Lernorten unter Berücksichtigung der Befunde und der schulischen Bedarfe neu konzipiert oder weiterentwickelt.

DD 28.2 Mon 17:00 Empore Lichthof

Physik und ich? Identitätsaushandlungen im naturwissenschaftlichen Anfangsunterricht — •Frederik Bub[1], Thorid Rabe[1], Lisa-Marie Christ[2] und Olaf Krey[2] — [1]Martin-Luther-Universität Halle-Wittenberg — [2]Universität Augsburg

Wie positionieren sich Schüler*innen in Bezug auf Naturwissenschaften und wie prägt der Anfangsunterricht das Verhältnis zu Physik und Chemie? Im vom BMBF geförderten Projekt IdentMINT werden Zugänge und Identitätsaushandlungen von Schüler*innen zu den Naturwissenschaften während des schulischen Anfangsunterrichts in Physik und Chemie untersucht (vgl. zur Projektstruktur Poster von Christ et al.). Einen Ausgangspunkt der Studie bildet der Befund, dass Naturwissenschaften zwar häufig als relevant angesehen werden, aber dennoch in Bildungswegentscheidungen wenig berücksichtigt werden. In der Studie wird die Phase des Anfangsunterrichts mit längsschnittlich angelegten qualitativen und quantitativen Erhebungen in den Blick genommen, um besser zu verstehen, inwiefern diese Phase prägend für die weiteren naturwissenschaftlichen Bildungswege ist. In einer Fragebogenerhebung in den sechsten Klassen an fünf Gymnasien wurden unter anderem naturwissenschaftsbezogene Einstellungen, Interessen, Selbstkonzept und Selbstwirksamkeitserwartungen als Teilaspekte der eigenen (MINT-) Identität erhoben. Wir geben einen Einblick in das Sample und erste Befunde aus dem ersten Erhebungszeitpunkt sowie einen Ausblick auf die weitere längsschnittliche Erhebung.

DD 28.3 Mon 17:00 Empore Lichthof

Physiklehrbücher im Fokus der fachdidaktischen Forschung - ein internationaler Literatur-Review — •Gabriela Jonas-Ahrend[1], Marika Kapanadze[2], Alexander Mazzolini[3] und Fadeel Joubran[4] — [1]Universität Paderborn — [2]Ilia State University, Tbilisi, Georgien — [3]Swinburne University of Technology, Melbourne, Australien — [4]Arab Academic College for Education, Haifa, Israel

Physiklehrbüchern, analog oder digital, wird eine große Bedeutung für das Lernen und Lehren von Physik sowie bei der Implementation neuer Lehrpläne zugesprochen. In diesem Poster werden die Ergebnisse eines internationalen Literatur-Reviews von über 100 forschungsbasierten, englischsprachigen Publikationen über die Entwicklung und Evaluation von Physiklehrbüchern sowie deren Rolle für das Lehren und Lernen vorgestellt. Das Ziel des Reviews ist a) ein Überblick über PTEL (Physics Textbook Evaluation Literature) zu erhalten und b) den Einfluss auf die Entwicklung von Physiklehrbüchern zu untersuchen. Verschiedene Aspekte von Lehrbüchern wie Inhalt, Pädagogik und Präsentation werden umfassend, qualitativ und quantitativ, in der vorliegenden Literatur analysiert. Es gibt wenig Hinweise, dass diese Analysen von Lehrbuchautoren oder Lehrkräften berücksichtigt werden. Der Einfluss von PTEL auf die Entwicklung neuer Lehrbücher kann aus den analysierten Publikationen nicht nachgewiesen werden.

DD 29: Poster – Arbeitsgruppen Physikdidaktik Quo vadis

Time: Monday 17:00–19:00 Location: Empore Lichthof

DD 29.1 Mon 17:00 Empore Lichthof

Graduiertenschule Physikdidaktik — •Christoph Kulgemeyer — Universität Bremen

Doktorierende in der Physikdidaktik brauchen sehr häufig mehr als drei Jahre bis zur Promotion. Es kommt auch an vielen Standorten vor, dass Doktorierende nach drei Jahren die Universität in Richtung Referendariat verlassen, ohne die Promotion abgeschlossen zu haben. Häufig führt das dann sogar zum Abbruch des Promotionsvorhabens. Ein möglicher Grund dafür ist, dass die Naturwissenschaftsdidaktik inzwischen einen weit fortgeschrittenen Methodenkanon entwickelt hat. Anders als in Disziplinen wie z.B. der Psychologie werden diese wissenschaftlichen Methoden aber nur selten im Studium sondern in der Regel problemorientiert erst im Laufe der Promotion erworben. Das kann zudem dazu führen, dass zwar die eigenen Methoden beherrscht werden, aber Studien in anderen Bereichen zunehmend nicht mehr voll eingeschätzt werden können. Eine standortübergreifende Graduiertenschule (vorrangig digital) könnte dazu beitragen, (a) das zeitintensive Einarbeiten in grundlegende Methoden zu verkürzen und dadurch die Promotionsdauer zu verringern, (b) die Expertise von Standorten in einzelnen Methoden miteinander zu vernetzen und (c) dadurch den wissenschaftlichen Austausch erhöhen.

Im Nachklang der Tagung Quo Vadis Physikdidaktik hat sich eine Arbeitsgruppe formiert, die sich der Entwicklung einer solchen hauptsächlich digitalen und dezentralen Graduiertenschule annimmt. Die Arbeitsgruppe ist offen für Personen, die sich in ihr engagieren möchten und stellt auf diesem Poster den Stand der Arbeit vor.

DD 29.2 Mon 17:00 Empore Lichthof

Arbeitsgruppe Portal Physikdidaktik — •Susanne Heinicke[1] und Jan-Philipp Burde[2] — [1]Universität Münster — [2]Universität Tübingen

Im Prozess der Initiative "Physikdidaktik - Quo vadis?" haben sich verschiedene Arbeitsgruppen gebildet, unter anderem die Arbeitsgruppe "Portal Physikdidaktik". Ziel der Zusammenarbeit der Arbeitsgruppe ist es, die Sichtbarkeit unserer physikdidaktischen Arbeit in Forschung und Entwicklung durch die Einrichtung einer Online-Plattform zu steigern.

Der Beitrag stellt die bisherigen Überlegungen zur Arbeit der AG Portal Physikdidaktik vor und lädt zu Diskussion und Mitarbeit ein.

DD 29.3 Mon 17:00 Empore Lichthof

Arbeitsgruppe Hochschuldidaktik — •Susanne Heinicke[1] und Micol Alemani[2] — [1]Universität Münster — [2]Universität Potsdam

Im Prozess der Initiative "Physikdidaktik - Quo vadis?" haben sich verschiedene Arbeitsgruppen gebildet, unter anderem die Arbeitsgruppe Hochschuldidaktik. Ziel der Zusammenarbeit der Arbeitsgruppe Hochschuldidaktik ist es, nationale und internationale Projekte und Ergebnisse aus Forschung und Entwicklung zu den Studiengängen der Physik (Lehramt und Fachwissenschaft) zusammenzutragen, zu vernetzen und stärker sichtbar zu machen und auf diese Weise zu einer stärker forschungsbasierten Lehre und Ausbildung der Physik beizutragen.

Der Beitrag stellt die bisherigen Überlegungen zur Arbeit der AG Hochschuldidaktik vor und lädt zu Diskussion und Mitarbeit ein.

DD 30: Lehr-Lernforschung III

Time: Tuesday 11:00–12:00 Location: DD 108

DD 30.1 Tue 11:00 DD 108

Lernwirksamkeit von Analogiemodellen zum elektrischen Potenzial — •Alina Hindriksen, Michael Kahnt und Roland Berger — Universität Osnabrück

Für die Veranschaulichung von Potenzial und Spannung im elektrischen Stromkreis werden in der Literatur verschiedene Analogiemodelle vorgeschlagen. Die Lernwirksamkeit der Analogiemodelle wird vermutlich sowohl von deren spezifischen Vor- und Nachteilen, als auch den individuellen Lernvoraussetzungen der SchülerInnen beeinflusst.

Im Vortrag wird eine Studie vorgestellt, in der diese Einflüsse bei der Einführung des elektrischen Potenzials im Mittelstufenunterricht (a) mit einem Höhenmodell ("Stäbchenmodell"), (b) dem Fahrradkettenmodell sowie (c) modellfrei hinsichtlich der Lernwirksamkeit untersucht wurden.

Die Ergebnisse zeigen, dass im Unterricht mit Höhenmodell implizit ein Lernen über Modelle stattgefunden hat, und dass das Fahrradkettenmodell sowie die modellfreie Einführung dem Höhenmodell in einem verzögerten Nachtest zum Potenzialbegriff mit kleinem Effekt überlegen sind. Darüber hinaus zeigen sich in Abhängigkeit vom Fachinteresse differenzielle Effekte, die im Vortrag vorgestellt werden.

DD 30.2 Tue 11:20 DD 108

Das Potenzial (in) der Fahrradkettenanalogie — •Michael Kahnt — Universität Osnabrück, Barbarastr. 7, 49076 Osnabrück

Im Elektrizitätslehreunterricht der Mittelstufe werden verschiedene Modelle und Analogien genutzt, um Schülerinnen und Schülern die Idee des geschlossenen Kreislaufs, die Kontinuitätsvorstellung des Elektronenstroms oder den Spannungsbegriff verständlich zu machen. Die Stärke der Fahrradkette als Analogie besteht darin, dass sie den Schülerinnen und Schülern vertraut ist. Daher ist ein Unterricht für die Elektrizitätslehre der Mittelstufe entwickelt worden, in dem durchgängig auf die Fahrradkette zurückgegriffen wird. Die Fahrradkette bietet durch ihr anschauliches Wirkungsgefüge aus Antrieb, Strom und Widerstand die Möglichkeit, die zentralen Begriffe Spannung, Elektronenstrom und Widerstand gleichzeitig einzuführen, um so die Beziehung der drei Begriffe untereinander als wesentliches Mittel ihrer Differenzierung zu nutzen. Darüber hinaus wird die Fahrradkettenanalogie verwendet, um den Spannungsbegriff im Sinne eines Potenzialunterschieds auszuschärfen. In einer Akzeptanzbefragung wurde der Frage nachgegangen, ob Schülerinnen und Schülern der Potenzialbegriff mithilfe der Fahrradkette verständlich gemacht werden kann. Von dieser Akzeptanzbefragung wird im Vortrag berichtet.

DD 30.3 Tue 11:40 DD 108

Vorstellungen von Studierenden zum elektrischen Stromkreis — •Bernadette Schorn[1], Mareike Ablass[1] und Alexander Voigt[2] — [1]Europa-Universität Flensburg — [2]Hochschule Flensburg

Im Rahmen der Schülervorstellungsforschung sind seit den 1970er Jahren eine enorme Anzahl von Studien zu Themen der Physik durchgeführt worden. In den Arbeiten zum elektrischen Stromkreis zeigen sich bei Schüler:innen sowohl national als auch international eine Reihe von Schülervorstellungen und Lernschwierigkeiten. Typische Vorstellungen wie z. B. die Stromverbrauchsvorstellung lassen sich auch bei Studierenden der Physik (Haupt- oder Nebenfach) sowie Lehramtsstudierenden der Physik feststellen (Fromme 2018, Burde et al. 2022). Zur Untersuchung der Vorstellungen von Sachunterrichtsstudierenden und Studierenden der Ingenieurwissenschaften zu grundlegenden Konzepten des elektrischen Stromkreises und möglichen Veränderungen des konzeptionellen Verständnisses durch Lehrveranstaltungen wurden an der Europa-Universität Flensburg und der Hochschule Flensburg Befragungen durchgeführt. Die Datenerhebungen erfolgten mithilfe des 2T-SEC-Tests (Ivanjek et al. 2021) in einem Zwei-Gruppen-Prätest-Posttest-Design. Im Vortrag werden erste Ergebnisse zum konzeptionellen Verständnis der Proband:innen im Allgemeinen sowie erste Ergebnisse der Interventionsstudien vorgestellt.

DD 31: Praktika und neue Praktikumsversuche

Time: Tuesday 11:00–12:00 Location: DD 110

DD 31.1 Tue 11:00 DD 110

Evaluating digital experimental tasks for physics laboratory courses — •Simon Z. Lahme[1], Lucija Rončević[2], Pekka Pirinen[3], Ana Sušac[2], Antti Lehtinen[3], Andreas Müller[4], and Pascal Klein[1] — [1]U Göttingen, Germany — [2]U Zagreb, Croatia — [3]U Jyväskylä, Finland — [4]U Geneva, Switzerland

As physics laboratory courses are an integral part of studying physics, many approaches have been pursued to evaluate their quality, e.g., regarding the improvement of conceptual understanding, the students' motivation, or the acquisition of adequate concepts about experimental physics. So far, most approaches either evaluate laboratory courses in its entirety like a course evaluation or focus on the students' development of (specific) competencies. However, even though experimental tasks are the backbone of any laboratory course concept, specific instruments to evaluate single experimental tasks are missing. Both approaches mentioned above are unsuitable for that aim since typical laboratory courses consist of multiple tasks and the development of competencies takes place on a larger time scale than the execution of single tasks. Thus, as part of the EU-co-funded DigiPhysLab-project (Developing Digital Physics Laboratory Work for Distance Learning), we developed a questionnaire to explicitly evaluate the quality of a single experimental task. The questionnaire has been discursively developed and softly validated within our project group and is now available in four languages. In the contribution, we share our ideas behind and our experiences with the use of this instrument for piloting experimental tasks that were developed in the scope of the DigiPhysLab-project.

DD 31.2 Tue 11:20 DD 110

Several Experiments Developed during Teaching the Physics Experiment Course — •Jung-Bog Kim — Korea National University of Education, Cheongju, Rep. Korea — Johannes Gutenberg University, Mainz

I would like to present several experiments which have been developed in the regular course teaching physics experiments to physics teachers. These experiments were introductory level and published in physics education journals (such as The Physics Teacher and Physics Education). I will focus on points on how I can get ideas to improve, create, revise, or teach.

DD 31.3 Tue 11:40 DD 110

Investigating students' views about experimental physics in German laboratory classes — •Micol Alemani[1], Erik Teichmann[1], and Heather J. Lewandowski[2,3] — [1]Institut für Physik und Astronomie Universität Potsdam, Potsdam, Germany — [2]Department of Physics, University of Colorado, Boulder, USA — [3]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, USA

Among the large variety of learning goals in physics laboratory courses, an often implicit but crucial aspect is to develop students' views and attitudes about experimental physics to align with practicing experimental physicists. With this explicit goal in mind, we have transformed our laboratory courses at the University of Potsdam (UP) to provide students with an authentic laboratory experience. Our course transformation was assessed using a new, German version of the Colorado Learning Attitudes Science Survey for Experimental Physics (E-CLASS). The E-CLASS is a research-based and internationally widely used test that assesses students' beliefs and attitudes about the nature of experimental physics. In this talk, we present how we translated the E-CLASS into German (creating the so-called GE-CLASS) and set-up a centralized automated system for instructors. Such a system allows laboratory instructors of European German speaking countries to easily use the E-CLASS to assess the impact of their courses along this one dimension of learning. First results using the GE-CLASS at UP are presented. A comparison between the international E-CLASS and GE-CLASS results for physics-major students is discussed.

DD 32: Quantenphysik IV

Time: Tuesday 11:00–12:00 Location: DD 111

DD 32.1 Tue 11:00 DD 111

Seminar mit fachdidaktischem Schwerpunkt im Modul Theoretische Quantenphysik — •Malte Petersen[1], Philipp Scheiger[1,2], Stefan Aehle[1], Martin Ammon[3] und Holger Cartarius[1] — [1]AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena — [2]Physik und ihre Didaktik, Universität Stuttgart, 70569 Stuttgart — [3]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena

Die Quantenphysik ist bzw. wird ein wichtiger Bestandteil deutscher Bildungspläne. Im Rahmen des Vortrags wird ein fachdidaktisches Vertiefungsseminar als Pflichtveranstaltung zur Vorlesung der theoretischen Quantenphysik vorgestellt, das besonders den Blick der angehenden Lehrkräfte für (neue) Herausforderungen schärft. Im Seminar erfahren die Studierenden bei der Aufarbeitung der verschiedenen Thematiken mit kognitiv aktivierenden Methoden wie der Peer-Instruction und der Arbeit in Kleingruppen, wie sie selbst Lernende aktivieren können. Da Schülerinnen und Schüler insbesondere bei der Quantentheorie nicht auf ihre Alltagserfahrung intuitiv zurückgreifen können, werden Analogieexperimente mittels Polarisationsfiltern thematisiert und mögliche Fehlvorstellungen aufgedeckt. Es wird gemeinsam untersucht, inwiefern die unterschiedlichen Zugänge zu elementaren Themen, wie die Heisenbergsche Unbestimmtheitsrelation, Fehlvorstellungen (re-)produzieren und wie angehende Lehrkräfte diesen entgegenwirken können. Fortgeschrittene Themen wie die Verschränkung und die Quantenkryptographie werden ebenfalls im Seminar diskutiert.

DD 32.2 Tue 11:20 DD 111

Entwicklung einer Lehrerfortbildung zur Quantenphysik: Von Bedarfsanalyse bis zur Produktion von Unterrichtsmaterialien — •Stefan Aehle[1], Philipp Scheiger[1,2] und Holger Cartarius[1] — [1]AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena — [2]Physik und ihre Didaktik, Universität Stuttgart, 70569 Stuttgart

Mit dem hohen Stellenwert, den die Quantenphysik in kommenden Lehrplänen einnehmen wird, beziehungsweise schon eingenommen hat, steigt vielerorts der Bedarf an guten Lehr-Lern-Materialen zur Gestaltung des Unterrichts. Lehrkräfte haben bei diesem Thema die Aufgabe, Wissen und Konzepte vermitteln zu müssen, die von Natur aus gegensätzlich zu unserer Erfahrungswelt stehen und die nicht Teil des eigenen Studiums waren. Um diesen Bedarf zu decken, Wissenslücken zu füllen, Fehlvorstellungen aufzuklären, und gleichzeitig Materialien und Strategien für Quantenphysikunterricht anzubieten, werden wir eine Lehrerfortbildung in Thüringen anbieten. Basierend auf bereits in der Literatur vorhandenen erprobten Unterrichtskonzepten, wird dazu ein multiperspektivischer Ansatz ausgearbeitet, der versucht, klassische (Schul-)Experimente, quantenphysikalische Realexperimente und Analogieversuche so miteinander zu kombinieren, dass Lernenden unterschiedliche Zugänge zum Thema ermöglicht werden. Vorgestellt werden Materialien, Konzepte und erste Ergebnisse.

DD 32.3 Tue 11:40 DD 111

Interessensförderung zur Quantenphysik in einem Nebenfach-Praktikum Physik — •Sebastian Nell und Heidrun Heinke — RWTH Aachen University, I. Physikalisches Institut IA

Das Inhaltsfeld der Quantentechnologie wird in den nächsten Jahrzehnten zentraler Bestandteil physikalischer Forschung weltweit und auch in Deutschland sein und damit auch in den Fokus der Nachwuchsförderung rücken. Vor diesem Hintergrund entwickelt das Schülerlabor Physik der RWTH Aachen SCIphyLAB gemeinsam mit dem Exzellenzcluster ML4Q (Matter and Light for Quantum Computing) Versuche zu grundlegenden quantenphysikalischen Phänomenen und bereitet diese so auf, dass sie von Schüler:innen und Studierenden verschiedener nicht-physikalischer Studiengänge genutzt werden können.

In den physikalischen Nebenfachpraktika können interessierte Studierende der Chemie, der Informatik und der Materialwissenschaften die entwickelten Versuche im Rahmen einer individuellen Förderung durchführen und ergänzend Forschungslabore zu dem Thema besuchen. Ziel ist es, das Interesse der Studierenden am Thema Quantentechnologien als zukunftsträchtigem interdisziplinären Forschungsfeld zu wecken. Der Beitrag stellt neben dem Grundkonzept des Programms auch Ergebnisse aus den ersten drei Durchläufen vor.

DD 33: Interesse und Persönlichkeit II

Time: Tuesday 11:00–12:00 Location: DD 405

DD 33.1 Tue 11:00 DD 405

Aushandlungsprozesse zu Physik: Fallstudien zu Bildungswegentscheidungen von Oberstufenschülerinnen — •Freja Kressdorf und Thorid Rabe — MLU Halle

Vor dem Hintergrund des Gendergaps von Mädchen und Frauen im MINT-Bereich (insb. in der Physik) besteht unser Interesse darin, zu untersuchen, wie Bildungswegentscheidungen von Schülerinnen zustande kommen. Zur Untersuchung dieser von Identitätsarbeit geprägten Aushandlungsprozesse zu Physik wurden narrativ angelegte Interviews mit MINT-interessierten Oberstufenschülerinnen (n=9) in einem längsschnittlichen Design geführt. Die transkribierten Daten werden im Sinne der Methode „Rekonstruktion narrativer Identität“ nach Lucius-Hoene & Deppermann (2002) analysiert.

Trotz durchgängig hohem Interesse an Physik sind die Vorstellungen der Schülerinnen zu Physik und zur eigenen Zukunft sehr heterogen. Oberflächlich vermeintlich gleiche Entscheidungskriterien (z.B. die Vereinbarkeit von Familie und Beruf) besitzen für die Individuen vielfältige Bedeutungen auf verschiedenen Ebenen. Auch spielen der Wunsch nach Heimatnähe sowie das Bedürfnis nach finanzieller Sicherheit für die Schülerinnen sehr unterschiedliche Rollen im Entscheidungsprozess. Beispielsweise ist für eine Probandin Selbstständigkeit und für die andere Probandin soziale Rückversicherung bestimmend.

Im Rahmen des Vortrags wird der theoretische Hintergrund kurz angerissen und das Erhebungsdesign vorgestellt. Anschließend werden exemplarisch die Analysen von zwei Fällen einander gegenübergestellt, diskutiert und im Kontext bisheriger Ergebnisse verortet.

DD 33.2 Tue 11:20 DD 405

Die (Ab-)Wahl von Physik und Zusammenhänge zu Fachinteresse und Brain Type der Lernenden — •Julia Welberg[1], Daniel Laumann[1,2] und Susanne Heinicke[1] — [1]Westfälische Wilhelms-Universität Münster — [2]Universität Paderborn

Beim Übergang von der Sekundarstufe I zur Sekundarstufe II bietet sich Schülerinnen und Schülern das erste Mal die Möglichkeit sich unter Beachtung gewisser Rahmenbedingungen für oder gegen ein Schulfach zu entscheiden. Dabei nehmen einerseits schulische Umstände Einfluss auf das Wahlverhalten der Lernenden, andererseits spielen auch das Interesse am Fach oder gewisse Persönlichkeitsmerkmale eine Rolle. Zu letztgenannten zählen u.a. die in diesem Beitrag vorstellten Ausprägungen zum ”Empathisieren” und ”Systematisieren” (”Brain Type”). Bei einer stark systematisierenden Disziplin wie der Physik erscheint es plausibel, dass eine Neigung zum Systematisieren zu einem besseren Zugang und damit höheren Interesse am Physikunterricht führen kann, was eine Weiterwahl des Faches in der Oberstufe zur Folge haben könnte. Im Beitrag werden diese Konstrukte und ihre Ausprägungen bei Lernenden der Sekundarstufe I und II vorgestellt und ihr Einfluss auf Fachinteresse und Wahlverhalten Physik diskutiert.

DD 33.3 Tue 11:40 DD 405

Fachwahl von Lehramtsstudierenden im Zusammenhang mit Fachinteresse und Brain Type — •Daniel Laumann[1,2], Julia Welberg[1] und Susanne Heinicke[1] — [1]Westfälische Wilhelms-Universität Münster — [2]Universität Paderborn

In Studien mit Lernenden konnte gezeigt werden, dass ein Zusammenhang zwischen dem sogenannten ”Brain Type”, ausgedrückt durch die Neigung zum Systematisieren oder Empathisieren, dem Fachinteresse an Physik und der Weiterwahl von Physik in der Oberstufe besteht. Es erscheint somit denkbar, dass sich entsprechende Zusammenhänge auch hinsichtlich der Studienwahl zeigen und sich z.B. vermehrt systematisierend veranlagte Personen für ein Studium der Physik entscheiden. Um dies zu überprüfen, wurden Lehramtsstudierende der Physik und Lehramtsstudierende anderer Fächer hinsichtlich ihres Brain Types untersucht und um eine retrospektive Einschätzung ihres Fachinteresses sowie eine Abfrage ihrer Kurswahl in der Oberstufe gebeten. Im Beitrag werden die Ergebnisse dieser Studie vorgestellt, um Erkenntnisse zu gewinnen inwiefern der Brain Type und das Fachinteresse an Physik die Fachwahl von Lehramtsstudierenden beeinflussen.

DD 34: Lehreraus- und -fortbildung II

Time: Tuesday 11:00–12:00 Location: DD 407

DD 34.1 Tue 11:00 DD 407

Professionalisierung angehender Lehrkräfte zur Arbeit mit Arduino für die Umsetzung eines digital transformierten Fachunterrichts — •Angelika Bernsteiner[1], Thomas Schubatzky[2], Philipp Spitzer[1] und Claudia Haagen-Schützenhöfer[1] — [1]Universität Graz, Österreich — [2]Universität Innsbruck, Österreich

In einem Design-Based-Research-Projekt wird an der Universität Graz eine Lehrveranstaltung zur Professionalisierung angehender Lehrkräfte mathematisch-naturwissenschaftlicher Fächer zur Umsetzung eines digital transformierten Fachunterrichts entwickelt und beforscht. Basierend auf Vorerhebungen wurde die Lehrveranstaltung in zwei Teile mit den beiden inhaltlichen Schwerpunkten Digitale Messwerterfassung mit Arduino-Mikrocontrollern und Umgang mit Falschinformationen strukturiert. Das Design der Lerngelegenheiten erfolgt entlang von Design-Kriterien. Im Sommersemester 2022 wurde das prototypische Lehrveranstaltungsdesign erstmalig implementiert. Lernwirksamkeit und Lernprozesse wurden mithilfe eines Mixed-Methods-Ansatzes erhoben und analysiert. Die Forschungsergebnisse führten zur Ausschärfung der Design-Kriterien und zum Re-Design einzelner Lerngelegenheiten. Im Wintersemester 2022/23 werden die Implementierung und Beforschung des weiterentwickelten Designs umgesetzt. Der Vortrag bietet Einblick in das Design und das datenbasierte Re-Design von Teil 1 der Lehrveranstaltung, insbesondere in die Implementierung von Peer-Tutoring, Unterrichtsvignetten und Lerngelegenheiten zur Förderung eines Verständnisses für digitale Transformation.

DD 34.2 Tue 11:20 DD 407

Videovignetten zu Lernendenvorstellungen in der Lehramtsausbildung — •David Weiler, Lutz Kasper und Hannes Helmut Nepper — Pädagogische Hochschule Schwäbisch Gmünd, Schwäbisch Gmünd, Deutschland

Im Erasmus+ Projekt "Videovignetten in Naturwissenschaft, Technik und Textil" (VidNuT) werden an acht Standorten in vier Ländern Videovignetten zu Lernendenvorstellungen für den Einsatz in der Lehrkräfteaus- und -fortbildung entwickelt. Dabei entstehen am Projektstandort Schwäbisch Gmünd Vignetten zu Vorstellungen aus der Optik und der Mechanik. In einem fachübergreifenden Seminarkonzept werden hier allgemeine Inhalte zu Lernendenvorstellungen, deren Ursachen und Umgangsstrategien wie Conceptual Change eingeführt und in fachspezifischen Gruppen vertieft. Dort wird den Studierenden eine exemplarische Auswahl von Videovignetten zu fachtypischen Lernendenvorstellungen auf einer Weiterentwicklung der Lernplattform Unterrichtonline.org präsentiert. Der Einsatz der Vignetten bietet dabei den Vorteil, die Identifikation solcher Vorstellungen von Lernenden in ihren Aussagen und Handlungen an realitätsnah gestalteten konkreten und komplexitätsreduzierten Beispielen zu üben und geeignete Reaktionsmodi zu entwickeln. Dabei sind einzelne Vignetten mit Entscheidungsmöglichkeiten im Video versehen, die den weiteren Fortgang des Videos bestimmen. Im Vortrag werden einzelne Vignetten und erste Erfahrungen aus der Erprobung des Seminars vorgestellt.

DD 34.3 Tue 11:40 DD 407

Akzeptanz digitaler Medien im Lehr-Lern-Labor — •Johannes Lhotzky und Klaus Wendt — Johannes Gutenberg-Universität Mainz

Physiklehrkräfte sind technisch gut versiert, motiviert und nutzen dennoch digitale Medien nur sehr eingeschränkt. Untersuchungen konstatieren dabei gewisse Ressentiments bei zeitlich fehlenden Selbstwirksamkeitserfahrungen im Einsatz digitaler Medien, dies gerade auch bei Physiklehrkräften. Um diesem Umstand bereits in der ersten Phase der Lehrkräftebildung zu begegnen, wurde an der JGU Mainz im Rahmen der vom BMBF geförderten Qualitätsoffensive Lehrerbildung ein speziell ausgerichtetes Lehr-Lern-Labor (LLL) für den Master of Education entwickelt. Innerhalb dieser Lehrveranstaltungen werden die Studierenden zu einer vertieften Beschäftigung mit digitalen Medien mit dem Fokus auf Physikunterrichtsspezifika geführt und zur praktischen Auseinandersetzung mit diversen Medien vom einfachen Codieren auf Calliope, Arduino zur programmierbaren Flugdrohne und Robotersystemen motiviert. Mithilfe eines Mixed-Methode-Ansatzes, bestehend aus Fragebogen und Gruppendiskussionen, werden in einem Prä-Post-Design die Ausgangslagen, die Wissensfundamente der Lernenden und die persönliche Dispositon identifiziert sowie die Wirkung des Seminarbesuchs auf die Studierenden evaluiert. Konzeptionell orientiert sich die Untersuchung des Akzeptanz- und Relevanzempfindens von zukünftigen Lehrkräften mithilfe des TPACK und SAMR-Modells. Im Vortrag werden das Seminarkonzept sowie die Forschungsergebnisse präsentiert.

DD 35: Impulse aus der Unterrichtspraxis – Vorträge Lehrerpreis

Time: Tuesday 12:15–12:55 Location: DD 108

Prize Talk DD 35.1 Tue 12:15 DD 108

Durchführung eines MINT-Berufsinformationstags für die Mittelstufe in Form eines Digitalkongresses — •Sebastian Bauer — Humboldt-Gymnasium Vaterstetten, Baldham, Germany — Träger des DPG-Lehrerpreises 2021

Am Humboldt-Gymnasium Vaterstetten (HGV) gibt es seit einigen Jahren die Schülerforschungsgruppe HASE (Humboldt-Academy for Science and Engineering), an der naturwissenschaftlich interessierte Schülerinnen und Schüler der 8.-10. Jahrgangsstufe teilnehmen können, um an eigenen Projekten zu tüfteln und zu forschen.

Die Teilnehmer organisieren jährlich in der Woche vor Ostern den MINT-Berufsinformationstag "OsterHASE" für die gesamte 8. Jahrgangsstufe (ca. 200 Schüler:innen), zu dem Wissenschaftler, Ingenieure und andere Personen mit naturwissenschaftlich-technischen Berufen als Vortragende eingeladen werden.

Da im Schuljahr 2019/2020 OsterHASE coronabedingt ausfiel, wurde die Planung für das kommende Schuljahr angepasst. Anstatt einer Präsenzveranstaltung wurde die Videokonferenz-Plattform der Schule genutzt, um den Berufsinformationstag als digitalen Kongress durchzuführen. Dies erlaubte in der Folge die Einladung von ausländischen Referenten, YouTube-Influencern und ehemaligen Schüler:innen des HGV, die von ihren ersten Semestern an der Uni erzählten.

Im Vortrag berichte ich von den Erfahrungen mit meinen "HASEn" und dem PfingstHASE-Digitalkongress 2021.

Prize Talk DD 35.2 Tue 12:35 DD 108

... mehr als nur Physik in the lænd — •Pirmin Gohn[1,2] und •Hermann Klein[1,2] — [1]Schülerforschungszentrum phaenovum, Baden-Württemberg, Lörrach — [2]Hans-Thoma-Gymnasium, Baden-Württemberg, Lörrach — Träger des DPG-Lehrerpreises 2022

Seit fast 20 Jahren ist das phænovum in Lörrach eines der landes- und bundesweit erfolgreichsten Schülerforschungszentren im Bereich Physik. Hervorgegangen ist es aus einer langjährigen Physik-Arbeitsgemeinschaft an Südbadens größtem Gymnasium. Zahlreiche Erfolge bei nationalen und internationalen Wettbewerben (Jugend forscht, IYPT, Physik-Olympiade, Quanta, ICYS) waren für phænovum-Schüler ein Sprungbrett in ein MINT-Studium. Darüber hinaus ergänzten wir Betreuer diese Nachwuchsförderung im Bereich Physik durch interdisziplinäre Projekte wie die Teilchenphysikwochen, den trinationalen Schülerwettbewerb metaksi und den Aufbau einer stærnwarte. In dem Vortrag möchten wir die Rahmenbedingungen vorstellen, die solch eine jahrelange erfolgreiche Förderung von Schülern im Bereich der Physik ermöglichten und einige der in den letzten Jahren realisierten Projekte vorstellen.

DD 36: Digitale Medien IV

Time: Tuesday 12:15–12:55 Location: DD 110

DD 36.1 Tue 12:15 DD 110

Virtual-Reality-Experimente: Neueste Entwicklungen – Radioaktivität und Elektromagnetismus — •William Lindlahr[1,2], Johannes Lhotzky[2], Florian Bennert[2] und Klaus Wendt[2] — [1]Fachhochschule Südwestfalen, Medienpädagogik/Medientechnik — [2]Universität Mainz, Arbeitsgruppe Larissa

Zur Umsetzung der Strategie der Kultusministerkonferenz "Bildung in der digitalen Welt" im Physikunterricht wurde an der Johannes Gutenberg-Universität Mainz in den vergangenen Jahren das Konzept der Virtual-Reality-Experimente (VRE) entwickelt. Dabei handelt es sich um Simulationen naturwissenschaftlicher Schulversuche, die besonders realitätsnah in einer virtuellen Welt umgesetzt werden und gleichzeitig weitreichende experimentelle Möglichkeiten für Schülerinnen und Schüler anbieten.

Durch die Auswahl nach fachdidaktischen Kriterien sollen VRE die Rolle des Experiments im Unterricht stärken und dessen Einsatzmöglichkeiten erweitern.

Zur Simulation eignen sich insbesondere Versuche, die in Schülerhand mit Gefahren verbunden sind, wie bspw. beim Themengebiet Radioaktivität. Andere Experimente können von Zusatzdarstellungen in der virtuellen Welt profitieren.

Im Vortrag werden die Grundlagen des Konzepts mit Einsatzmöglichkeiten im Unterricht, das bestehende Portfolio sowie die neuesten Entwicklungen zu den Themen Radioaktivität und Elektromagnetismus (Hall-Effekt) präsentiert.

DD 36.2 Tue 12:35 DD 110

Virtual-Reality-Experimente: Neueste Entwicklungen - Atomphysik — Johannes Lhotzky[1], William Lindlahr[1,2], Florian Bennert[1] und •Klaus Wendt[1] — [1]Johannes Gutenberg-Universität Mainz — [2]FH Südwestfalen, Medienpädagogik/-technik

Virtual-Reality-Experimente (VRE) stellen realistische 3D-Simulationen naturwissenschaftlicher Versuche dar. Innerhalb einer modellierten und authentischen digitalen Laborumgebung kann mit den Experimenten und den zur Verfügung stehenden Geräten frei und selbstgesteuert experimentiert werden. Dabei sollen vor allem Experimente umgesetzt werden, deren Anschaffungen für die Schule nicht realisierbar sind oder von denen zu hohe Gefahrenpotentiale bei Schülerexperimenten ausgehen. VRE ermöglichen durch ihre digitale Verfügbarkeit neue Partizipationsmöglichkeiten auf Seiten der Schüler:innen, die sonst nicht oder nur sehr erschwert realisierbar sind. Vorgestellt wird das neu entwickelte Experimente der Braunschen Röhre zur Untersuchung bewegter Ladungen in elektrischen Feldern sowie das VRE zum Frank-Hertz-Experiment zur Untersuchung der Energiequantelung als entscheidendem Aspekt der Quantenmechanik. Die Experimente stellen wesentliche Bausteine der Atom- und Quantenphysik dar und bieten essentielle Lerngelegenheiten in diesem Themengebiet. Als Ausblick wird der Lernbegleiter "Atomi" konzeptionell eingeführt und vorgestellt.

DD 37: Hochschuldidaktik III

Time: Tuesday 12:15–12:55 Location: DD 405

DD 37.1 Tue 12:15 DD 405

Programmieren zur Lösungseingabe in Selbsttests — •Dominik Giel — Hochschule Offenburg, Badstraße 24, 77652 Offenburg

Selbsttests in Lernmanagementsystemen (LMS) ermöglichen es Studierenden, den eigenen Lernfortschritt einzuschätzen. Im Gegensatz zur Einreichung und Korrektur vollständig ausformulierter Aufgabenlösungen nutzen LMS überwiegend die Eingabe der Lösung im Antwort-Auswahl-Verfahren (Single-Choice). Nach didaktischen Ansatz *Physik durch Informatik* geben die Lernenden statt dessen ihre Aufgabenlösungen in einer Programmiersprache ins LMS ein, was eine automatisierte Rückmeldung erleichtert und das Erreichen einer höheren Kompetenzsstufe fördert. Es wurden zwölf LMS-Selbsttests erstellt, bei denen die Lösungen zu einer Lehrbuch-Aufgabenstellung jeweils durch Eingabe in einer Programmiersprache und von einer Kontrollgruppe im Antwort-Auswahl-Verfahren abgefragt wurden. Ergebnisse aus dem ersten Einsatz dieser Selbsttests für die Lehrveranstaltung Physik im Studiengang Biotechnologie werden vorgestellt.

DD 37.2 Tue 12:35 DD 405

Erstellung von Animationen zur Experimentalphysik I mit *manim* — •Carlo von Carnap, Jan-Hendrik Müller und Pascal Klein — Universität Göttingen, Deutschland

Manim (***m**athematical **anim**ations*) ist eine quelloffene Python-Bibliothek zur Erstellung mathematischer und physikalischer Animationen. Ursprünglich von Grant Sanderson (*3Blue1Brown*) ins Leben gerufen, wird ein nun weiterer *manim*-Zweig von einer kleinen Community mit dem Ziel höherer Stabilität und besserer Dokumentation zur allgemeinen Nutzung weiterentwickelt. Als Codebasiertes Werkzeug bietet *manim* die Möglichkeit sehr präziser Darstellungen quantitativer Inhalte.

In diesem Vortrag sollen diese Python-Bibliothek und einige hiermit erstellte Kurzanimationen zur Experimetalphysik I vorgestellt werden. Die Animationen umfassen dabei die Themenbereiche Mechanik und Wärme und haben zum Ziel, einen anschaulichen Zugang zu mathematischen Konzepten in physikalischer Anwendung zu bieten. Die Zielgruppe der Studienanfänger:innen profitieren unserer Ansicht nach von Zugängen dieser Art, da sie die Theoriebildung und Mathematisierung stützen können. Im Vortrag wird ebenfalls auf Limitationen betreffend der Darstellung komplexerer physikalischer Systeme eingegangen.

DD 38: Bildung für nachhaltige Entwicklung I

Time: Tuesday 12:15–12:55 Location: DD 407

DD 38.1 Tue 12:15 DD 407

Mit STEAM und 6E zukunftsorientierten Unterricht gestalten — •Jannik Henze und André Bresges — Universität zu Köln, Köln, Deutschland

Wie können Schüler:innen dazu gebracht werden innovative Ansätze für die Zukunft zu entwickeln und ihre Fähigkeiten in Wissenschaft, Kunst und digitaler Technologien auf diesem Weg zu nutzen? Schulen sind auf der Suche nach Strategien zur Förderung moderner Kompetenzen. Wissenschaftliches und kritisches Denken sind bereits wichtige Kompetenzen, die durch naturwissenschaftlichen Unterricht gefördert werden können. Auf der Grundlage des STEAM-Paradigmas und des 5E-Ansatzes der Biological Sciences Curriculum Study (BSCS) haben wir ein pädagogisches Konzept entwickelt und im schulischen Kontext getestet, welches den 5E-Ansatz um eine sechste Phase ergänzt, um eine Reflexion des Gelernten zuzulassen. Dieser Vortrag richtet sich an die Frage wie Lehrpersonen fortgebildet werden können um Schüler:innen zu selbstwirksamen Handeln in einer von Sensoren, Computern und dem Internet der Dinge geprägten Welt anzuleiten.

DD 38.2 Tue 12:35 DD 407

Physikbezogene BnE didaktisch rekonstruiert — •Kai Bliesmer und Michael Komorek — Carl von Ossietzky Universität Oldenburg

Im Verbund der Oldenburger Lehr-Lern-Labore (OLELA) richtet die Physikdidaktik ein Schüler:innen- und Bürger:innenlabor für Energie- und Klimabildung ein. Die Verknüpfung zwischen physikalischer Bildung und dem Konzept BnE wird im neuen Labor dadurch realisiert, dass die didaktische Strukturierung der Angebote durch nachhaltigkeitsrelevante Fragen und Probleme kontextualisiert (Nentwig & Waddington 2005) wird. Um geeignete Kontexte zu identifizieren und fachdidaktisch aufzubereiten, wird das Modell der Didaktischen Rekonstruktion (Kattmann et al. 1997; Duit et al. 2012) adaptiert, indem die im Modell formulierten obligatorischen Fragen mit Blick auf die Verknüpfung zwischen Physik und BnE neu ausgerichtet werden. Als konzeptionelle Rahmung für BnE ziehen wir hierbei das Nachhaltigkeitsdreieck (Serageldin 1996; Pufé 2017; von Hauff 2014) und die SDGs (A/RES/70/1) heran. Im Beitrag werden der spezifische Einsatz der Didaktischen Rekonstruktion sowie die dabei herausgearbeiteten Nachhaltigkeitskontexte vorgestellt und daran das Konzept einer "Physikalischen Bildung für nachhaltige Entwicklung" diskutiert.

DD 39: Preisträgersymposium Didaktik

Time: Tuesday 14:30–16:00 Location: DD HS 2.202

Verleihung des DPG-Lehrerpreises 2022

Prize Talk DD 39.1 Tue 14:40 DD HS 2.202

Die Welt der Smartphone-Experimente mit phyphox — •Sebastian Staacks und •Christoph Stampfer — RWTH Aachen University, II. Physikalisches Institut A, Aachen, Germany — Träger des Georg-Kerschensteiner-Preises 2023

Die Open Source App "phyphox" wurde an der RWTH Aachen mit dem Ziel entwickelt, die in unseren Smartphones verbauten Sensoren für Experimente in der Physik-Lehre zugänglich zu machen. Während dies sicherlich die zugänglichste Form Smartphone-basierter Experimente darstellt, sind seit der Veröffentlichung von phyphox viele Schnittstellen entstanden, die die Möglichkeiten der Geräte-internen Sensoren erweitern und neue Einsatzszenarien erschließen.

In diesem Vortrag werden verschiedenste Formate vorgestellt, in denen phyphox eingesetzt werden kann. Dies umfasst unter anderem einfache didaktische Experimente, faszinierende Messungen im Alltag, Elektronikprojekte in Verbindung mit Arduino oder MicroPyhton sowie netzwerkgestützte kollaborative Experimente mit hunderten Teilnehmenden in einem Hörsaal oder sogar weltweit.

Insbesondere die letzten dieser Beispiele profitieren von den erweiterten Schnittstellen von phyphox. Eine Bluetooth-Schnittstelle erlaubt das Einbinden externer Sensoren und macht es insbesondere in Verbindung mit einer dedizierten Arduino- und MicroPython-Bibliothek auch für Programmieranfänger leicht, Messwerte aus eigenen Projekten in phyphox darzustellen. Die Netzwerkschnittstelle wiederum ermöglicht es, die Messergebnisse vieler Experimentatoren komfortabel und noch während des Experiments zusammenzuführen.

Prize Talk DD 39.2 Tue 15:20 DD HS 2.202

Entwicklung und Beforschung von Unterrichtskonzeptionen — •Thomas Wilhelm — Institut für Didaktik der Physik, Goethe-Universität Frankfurt — Träger des Robert-Wichard-Pohl-Preises 2023

Die Lehre in Schule und Universität setzt immer voraus, dass die Physik für die Zielgruppe geeignet aufgearbeitet wird. Wird ein entsprechendes Programm an durchdachten Leitideen entwickelt, spricht man von einer Unterrichtskonzeption.

In dem Vortrag werden Grundprinzipien der Entwicklung von und der Forschung zu Unterrichtskonzeptionen aufgezeigt. Dabei geht es auch darum, wie die Physikdidaktik vom Vorbild der Ingenieurswissenschaften lernen kann. Schließlich wird ein Einblick in die aktuelle Entwicklung und Beforschung von Unterrichtskonzeptionen gegeben.

DD 40: Hauptvortrag 2: Salden

Time: Tuesday 16:30–17:30 Location: DD HS 2.202

Invited Talk DD 40.1 Tue 16:30 DD HS 2.202

Zwischen Corona und KI: Wo steht die Hochschullehre und wie geht sie weiter? — •Peter Salden — Zentrum für Wissenschaftsdidaktik (Ruhr-Universität Bochum)

In den vergangenen 20 Jahren hat sich die Hochschullehre spürbar gewandelt. Auf eine Phase des Experimentierens mit Lehrinnovationen folgte die Zeit der notgedrungenen Online-Lehre während der Corona-Pandemie. Nun ist die Lehre auf den Campus zurückgekehrt - doch dies könnte nur eine Atempause sein, denn weitere Veränderungen zeichnen sich bereits deutlich ab. Beispiele dafür sind Anwendungen zur Analyse von Lerndaten oder KI-basierte Schreibtools wie das Programm ChatGPT, die das Potential haben, sowohl die Lehre als auch die Produktion wissenschaftlicher Erkenntnis insgesamt zu verändern.

Welche zentralen Erkenntnisse können die Hochschulen aus der Corona-Zeit für die Lehre mitnehmen - gerade auch im Lichte hochschuldidaktischer Evidenz? Welche Themen werden Lehre und Lernen als nächstes prägen? Der Vortrag zeigt Entwicklungslinien auf und ordnet ein, welche Prinzipien trotz allen Wandels für die Gestaltung von Lernprozessen in den Hochschulen unverändert bleiben werden.

DD 41: Mitgliederversammlung FV DD

Time: Tuesday 18:00–19:30 Location: DD HS 2.202

90 Minuten

DD 42: Lehr-Lernforschung IV

Time: Wednesday 11:00–12:00 Location: DD 108

DD 42.1 Wed 11:00 DD 108

Diagnostik physikalischer Problemlösefähigkeiten mit maschinellem Lernen — •Fabian Kieser und Peter Wulff — Pädagogische Hochschule, Heidelberg

Die Erfassung und Förderung physikalischer Problemlösefähigkeiten ist ein wichtiges und aktuelles Thema der physikdidaktischen Forschung. Problemlösen ist allerdings ein komplexer kognitiver Prozess. Zum Lösen naturwissenschaftlicher Probleme ist ein tiefes Verständnis von Prinzipien und Konzepten der jeweiligen Fachdomäne notwendig. Aufgaben, die die Problemlösekompetenz überprüfen, müssen also über das Abfragen von Routinen hinaus gehen. Dies macht eine individualisierte Auswertung und zielgerichtetes Feedback aufwändig. Für die Optimierung dieser Problemlöseprozesse bieten computerbasierte Auswerteverfahren zusätzliche Ressourcen, weil der Lernprozess auf abstrakter Ebene begleitet wird, sodass Lehrende entlastet werden. In dieser Studie werden die Möglichkeiten zur Analyse physikalischer Problemlösefähigkeiten mit maschinellem Lernen untersucht. Besonderes Potential bieten die Methoden der modernen Textverarbeitung (Natural Language Processing), die auf Techniken des maschinellen Lernens zurückgreifen, um natürliche Sprache computerbasiert zu analysieren. Um die Methoden an die spezifische Sprache der Schülerantworten anzupassen, werden eigens KI-Modelle (bspw. Neuronale Netze) trainiert, mit dem Ziel, in textbasierten Antworten zu offenen physikalischen Problemlöseaufgaben den physikalischen Ansatz zu detektieren. Erste Ergebnisse werden vorgestellt und Möglichkeiten für den Einsatz im schulischen Kontext diskutiert.

DD 42.2 Wed 11:20 DD 108

Reduktion kognitiver Belastung beim selbstständigen Experimentieren mithilfe von Videoinstruktion — •Nico Wiersig und Rainer Müller — TU Braunschweig, Institut für Fachdidaktik der Naturwissenschaften, Germany

Selbstständiges Experimentieren von Lernenden spielt im Physikunterricht aller Jahrgangsstufen eine bedeutende Rolle sowohl für die Vermittlung fachlicher Inhalte und Konzepte als auch für die Ausbildung prozessbezogener Kompetenzen und die Kultivierung naturwissenschaftlicher Einstellungen zur Erkenntnisgewinnung. Gleichzeitig stellt es Lernende häufig vor große Herausforderungen bei der Bewältigung experimenteller Aufgabenstellungen, die sowohl den prozeduralen als auch den konzeptuellen Lernerfolg stark beeinträchtigen können. Um dem entgegenzuwirken werden im Rahmen der vorgestellten Forschungen auf Basis der "Cognitive Load Theory" beeinträchtigende Faktoren kognitiver Belastung im experimentellen Arbeiten identifiziert und Instruktionsmaterialien entwickelt und evaluiert, um die kognitive Belastung zu reduzieren und somit den Lernerfolg durch das Experimentieren zu steigern. Die zentrale Idee ist dabei der Einsatz von Videoinstruktionen zum Experimentieren, die sich die Vorteile digitaler Informationsvermittlung zunutze machen, um typische Quellen extrinsischer Belastung zu kompensieren und Vertiefung in lernbezogene kognitive Aktivitäten anzuregen. Der Vortrag bietet einen Überblick über die bereits erfolgte qualitative Forschung zu relevanten Belastungsfaktoren beim Experimentieren sowie die aktuellen quantitativen Ansätze zur Erprobung und Evaluation der Instruktionsmaterialien.

DD 42.3 Wed 11:40 DD 108

Förderung der Reflexionskompetenz im Lehr-Lern-Labor — •Jens Damköhler, Markus Elsholz und Thomas Trefzger — Julius Maximilians-Universität, Würzburg, Deutschland

Die Fähigkeit und Bereitschaft von Lehrkräften zur Reflexion eigener Erfahrungen, in den vergangenen Jahren zunehmend als Reflexionskompetenz modelliert, wird u.a. im Bereich der Professionalisierung als sehr bedeutsam angesehen. Gelegenheiten zur Stärkung ihrer Reflexionskompetenz durch Erprobung und Einübung von Reflexionsprozessen erhalten Lehrkräfte im ersten Ausbildungsabschnitt vor allem im Rahmen von Praxisphasen, wie z.B. Lehr-Lern-Laboren (LLL) mit iterativen Ansätzen. An der Universität Würzburg führen Studierende im LLL der Physikdidaktik mehrere Praxisphasen in zeitlichem Abstand durch, zwischen denen Überarbeitungsphasen und Veranstaltungen zur gezielten Förderung von Reflexionsprozessen stattfinden. Im Rahmen einer Dissertation werden Aspekte der Reflexionskompetenz sowie deren Entwicklung in der Durchführungsphase des LLL untersucht.

Im Vortrag wird das Vorhaben vorgestellt, wobei der Schwerpunkt auf der Beschreibung der Konzeption und Durchführung der Maßnahmen liegt, die zur Förderung der Reflexionskompetenz entwickelt wurden.

DD 43: Experimente I

Time: Wednesday 11:00–12:00 Location: DD 110

DD 43.1 Wed 11:00 DD 110

phyphox: Exploration neuer Experimentierideen anhand der länderspezifischen Kernlehrpläne an deutschen Schulen — •Dustin Kirwald[1], Niklas Westermann[2], Dominik Dorsel[3], Sebastian Staacks[4], Christoph Stampfer[5] und Heidrun Heinke[6] — [1]I. Physikalisches Institut A, RWTH Aachen, Deutschland — [2]I. Physikalisches Institut A, RWTH Aachen, Deutschland — [3]II. Physikalisches Institut A, RWTH Aachen, Deutschland — [4]II. Physikalisches Institut A, RWTH Aachen, Deutschland — [5]II. Physikalisches Institut A, RWTH Aachen, Deutschland — [6]I. Physikalisches Institut A, RWTH Aachen, Deutschland

Die Smartphone-App phyphox nutzt wahlweise interne Sensoren oder externe Sensorik via Bluetooth Low Energy und stellt die Messdaten live dar. Mit Hilfe interaktiver Auswertungswerkzeuge lassen sich so viele interessante und didaktisch gewinnbringende Experimente unter anderem für die schulische Lehre verwirklichen. Neben thematisch erweiterten Experimentiermöglichkeiten bieten smartphone-gestützte Experimente eine moderne und schülerzugewandte Möglichkeit der digitalen Messwerterfassung. Passend dazu sehen sowohl die Kultusministerkonferenz als auch die bundeslandsspezifischen Lehrpläne (wie die Kernlehrpläne in NRW) eine Einbindung digitaler Messwerterfassung in Bildungskontexten des Physikunterrichts vor. Hierzu sind auf Grundlage einer intensiven Auseinandersetzung mit den Lehrplänen ausgewählter Bundesländer Experimentierideen entwickelt und systematisiert worden, die sich unter Einbindung der App phyphox sowie interner bzw. externer Sensorik durchführen lassen.

DD 43.2 Wed 11:20 DD 110

Differenzierte Heimexperimente mit dem Smartphone – Entwicklung in einem Seminar im Physik-Lehramtsstudium — •Leif Brossmann[1], Florian Bauer[1], Julius Grabs[1,2], Bastian Miersch[1,2], Kevin Gebhardt[1,2], Florian Kuss[1,2], Stefanie Czempiel[2], Bärbel Kracke[2] und Holger Cartarius[1] — [1]AG Fachdidaktik der Physik und Astronomie, Friedrich-Schiller-Universität Jena, 07743 Jena — [2]Lehrstuhl Pädagogische Psychologie, Friedrich-Schiller-Universität Jena, 07743 Jena

In einem Seminar im Physik-Lehramtsstudium der Friedrich-Schiller-Universität Jena werden Experimente mit drei verschiedenen, differenzierten Arbeitsblättern zur Anleitung konzipiert. Diese sollen so gestaltet sein, dass in der Regel nicht auf eine physikalische Gerätesammlung zurückgegriffen werden muss, sondern die Versuche als Heimexperimente durchgeführt werden können. Dieser Ansatz wurde durch eine Kooperation zwischen Pädagogischer Psychologie und Physikdidaktik an der FSU Jena entwickelt und entstand dort im Teilprojekt Inklusion systematisch implementieren (Isi) des QLB-Projekts PROFJL[2]. In diesem Vortrag werden die Lehrveranstaltungen an der Universität und vor allem Arbeiten von Studierenden aus dem Seminar vorgestellt. Als Beispiel dient ein Experiment zum Fadenpendel, das mit seinen drei im Anforderungsniveau differenzierten Arbeitsblättern präsentiert wird.

DD 43.3 Wed 11:40 DD 110

Eine Zeitprojektionskammer für den Schulunterricht — •Laura Rodríguez Gómez, Jochen Kaminski, Klaus Desch, Johannes Streun und Malte Koch — Physikalisches Institut, Universität Bonn

Dem Physikunterricht der gymnasialen Oberstufe fehlt es an forschungsnahen Realexperimenten. Besonders die Bereiche Strahlung und Materie sowie Atom- und Kernphysik sind davon betroffen. So kann im Unterricht nur schwer ein Einblick in moderne Forschung geboten werden. In diesem Vortrag wird ein Projekt vorgestellt, in dem ein neues Experiment für den Physikunterricht entwickelt wird. Im Zentrum dieses Experiments steht ein Teilchendetektor - eine sogenannte Zeitprojektionskammer. Dieser Detektortyp wird auch an großen Experimenten der Grundlagenforschung eingesetzt. Mit ihm ist es möglich, Teilchenspuren in drei Dimensionen und in Echtzeit zu rekonstruieren. Die aufgenommenen Daten können digital ausgewertet werden, sodass anhand der Auswertung Konzepte des Arbeitens mit digitalen Datenmengen vermittelt werden können. Im Rahmen des Projekts wird der Detektor fertiggestellt, sowie Materialien für Lehrende und Lernende erstellt und getestet. In einem mehrstufigen Testverfahren wird so eine Unterrichtsreihe entwickelt, die anhand von Messungen mit dem Detektor einen Einblick in den Forschungsprozess mit Detektoren bietet. Dieser Vortrag stellt den Detektor sowie ein erstes didaktisches Konzept für dessen Einsatz im Schulunterricht vor. Es wird erörtert, wie ein echter Forschungsdetektor für den Schulunterricht zugänglich gemacht werden kann.

DD 44: Quantenphysik V

Time: Wednesday 11:00–12:00 Location: DD 111

DD 44.1 Wed 11:00 DD 111

Quantenphysik in Klasse 9: Ergebnisse einer Akzeptanzbefragung für ein Spin-First-Unterrichtskonzept — •Carsten Albert[1,2] und Gesche Pospiech[2] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden — [2]Technische Universität Dresden

Die meisten schulischen Konzepte zur Quantenphysik richten sich an die Oberstufe und thematisieren nach wie vor häufig traditionelle Inhalte. Im aktuellen fachdidaktischen Diskurs zeichnet sich jedoch ab, dass hier neue schulische Zugänge benötigt werden - auch bereits für die Mittelstufe. In diesem Kontext sind Elemente der Quanten-IT wie Qubits für einen Einstieg konzeptuell äußerst vielversprechend.

Im Rahmen einer Promotion wird in diesem Zusammenhang ein Design-Based-Research-Projekt durchgeführt, das sich die Entwicklung eines holistischen und phänomenorientierten Lehrkonzeptes zur Quantenphysik in Klasse 9 zum Ziel gesetzt hat. Der bereits aus der Theorie entwickelte erste Konzeptentwurf baut auf einem Spin-First-Ansatz auf.

In einem ersten empirischen Entwicklungsschritt wurden Akzeptanzbefragungen durchgeführt, um einen ersten Eindruck von Lernverläufen und Verständnisschwierigkeiten im Rahmen des Vermittlungskonzeptes herauszuarbeiten und das Konzept vor dem ersten Unterrichtseinsatz zu optimieren.

Im Vortrag werden das Konzept und die Konzeptgestaltung skizziert, um darauf aufbauend die ersten Ergebnisse der Akzeptanzbefragungen vorzustellen.

DD 44.2 Wed 11:20 DD 111

Gymnasiale Quantenphysik mit Dualität — •Hans Peter Dreyer — Universität Zürich

Albert Einstein fand die Dualität des Lichts 1909. Louis de Broglie stiess 1923 auf den Wellenaspekt des Elektrons indem er Einsteins Ideen erweiterte. Erwin Schrödinger war von Einstein auf de Broglies Ideen hingewiesen worden, als er den "Feldskalar Psi" einführte. Mit der Wahrscheinlichkeitsinterpretation von Schrödingers Wellen überwand 1926 Max Born schliesslich die klassische Unverträglichkeit von Wellen- und Teilchenbild.

Eine in der Schweiz erprobte Unterrichtseinheit für das Nicht-MINT-Gymnasium folgt in rund 16 Lektionen dem skizzierten Weg, benützt aber die Geschichte nur dann, wenn sie auch Einsichten in "nature of science" ermöglicht. Die Auswertung von Fragebogen weist auf eine signifikante Konzeptentwicklung in Richtung Quantenmechanik hin. Eine qualitative Auswertung von Lerntagebüchern zeigt, dass die Welle-Teilchen-Dualität in diesem Umfeld eine Sprech- und Lernhilfe bietet.

Obwohl Born schon 1968 gegenüber Landé einen Streit um Dualismus als überflüssig bezeichnete, setzten sich Brachner und Fichter seit 1977 mit ihrem Dogma "Es gibt keinen Dualismus" im deutschen Sprachraum durch.

In diesem Beitrag wird der Rolle der Dualität bei der Entwicklung der Fachwissenschaft und beim Einstieg in die Quantenmechanik auf der Sekundarstufe II nachgegangen, die Unterrichtseinheit skizziert und auf Grund der Evaluation vorgeschlagen, die im Angelsächsischen unproblematische "duality" zu nutzen.

DD 44.3 Wed 11:40 DD 111

Quantenphysik in der Sekundarstufe II in Südkorea und Deutschland — •Andreas J C Woitzik[1,2], Taegyoung Lee[3] und Nam-Hwa Kang[3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg im Breisgau, Bundesrepublik Deutschland — [2]Freiburg Advanced Center of Education, Fahnenbergplatz, 79085 Freiburg im Breisgau, Bundesrepublik Deutschland — [3]Korea National University of Education, 250, Taeseongtabyeon-ro, Gangnae-myeon, Heungdeok-gu, Cheongju-si, Chungcheongbuk-do, 28173, Republik Korea

Die Quantenphysik ist etablierter Inhalt der Physik der Sekundarstufe II. Durch die neuen KMK-Bildungsstandards aus dem Jahr 2022 werden viele Bildungspläne in Deutschland aktuell überarbeitet oder wurden bereits angepasst. Wir vergleichen diese Entwicklung mit den beabsichtigten Änderungen des Physikcurriculums in der Republik Korea anhand des überarbeiteten Bildungsplans in Baden-Württemberg aus dem Jahr 2022. Dabei gehen wir zunächst auf die Rahmenbedingungen in den beiden Ländern ein und vergleichen im Anschluss die inhaltlichen Anpassungen beider Länder gegenüber den vorherigen Bildungsplänen. Wir stellen fest, dass die letzten Bildungspläne aus den Jahren 2015 und 2016 recht ähnlich sind und die neuen Bildungspläne unterschiedliche Richtungen einschlagen.

DD 45: Hochschuldidaktik IV

Time: Wednesday 11:00–12:00 Location: DD 405

DD 45.1 Wed 11:00 DD 405

Analyse studentischer Fehlvorstellungen mittels des Force Concept Inventory — •Silke Stanzel — TH Rosenheim

Das Force Concept Inventory (FCI) ist ein weltweit etabliertes Diagnoseinstrument für das Konzeptverständnis der Newtonschen Mechanik (physport.org). Es besteht aus 30 Single Choice Fragen zur Kinematik und zu Kräften. Viele der zur Wahl stehenden Distraktoren spiegeln weit verbreitete Fehlvorstellungen wider.

Wir haben Ergebnisse des FCI aus einem Zeitraum von neun Jahren von knapp 5000 Studienanfängern der Ingenieurwissenschaften an der TH Rosenheim ausgewertet. Mit der Methode der Item Response Curves (Morris 2006) wird für jede einzelne Frage die relative Häufigkeit sowohl der richtigen als auch aller falschen Antwortoptionen als Funktion der im Test erreichten Gesamtpunktzahl aufgetragen. Der Vergleich mit Daten von Universitäten der USA bestätigt die Aussagekraft dieser Darstellung hinsichtlich der Charakteristik der Antwortoptionen und damit der Testqualität. Insbesondere lassen sich auf diese Weise Distraktoren identifizieren, die gängige Fehlvorstellungen adressieren. Zu den am häufigsten gewählten Antworten gehören Fehlvorstellungen zum dritten Newtonschen Axiom und zur Annahme, jeder Bewegung liege eine Kraft in Bewegungsrichtung zu Grunde. Die vorgestellte Analyse dient als Grundlage zur Weiterentwicklung von Lehrsequenzen.

DD 45.2 Wed 11:20 DD 405

Lehr-Lernüberzeugungen und Lehrhandeln studentischer Tutor*innen — •Robin Dexheimer-Reuter, Verena Spatz und Thomas Trebing — Didaktik der Physik, TU Darmstadt, Hochschulstraße 12, 64289 Darmstadt

Studentische Tutor*innen leisten an vielen Universitäten einen wichtigen Beitrag zur Lehre, empirisch ist ihre Arbeit jedoch bisher nur wenig untersucht. Im Kontext universitärer Informatiklehre konnten beispielsweise Auswirkungen von Lehr-Lernüberzeugungen der Tutor*innen auf ihre Bewertung durch die Studierenden nachgewiesen werden. Vergleichbare Untersuchungen im Bereich der universitären Physikübungen fehlen bisher jedoch. So ist es weitgehend unklar, inwiefern sich die Lehr-Lernüberzeugungen von Physik-Tutor*innen, vermittelt über ihr Lehrhandeln, auf den Erfolg der Studierenden in der betreffenden Lehrveranstaltung auswirken (entsprechend dem Mediationsmodell der COACTIV Studie für schulischen Mathematikunterricht). Folglich untersucht das aktuelle Projekt in mehreren Grundlagen- und Nebenfachlehrveranstaltungen am Fachbereich Physik der TU Darmstadt dieses Mediationsmodell. Das Lehrhandeln ist hierbei operationalisiert durch die von den Studierenden wahrgenommene Lehrqualität. Des Weiteren werden die Klausurnote und die Zufriedenheit der Studierenden mit der Betreuung erfasst. Im Vortrag werden die Erhebungsinstrumente und erste ausgewählte Ergebnisse der Haupterhebung aus dem WiSe 2023/24 vorgestellt.

DD 45.3 Wed 11:40 DD 405

Was Physiklehrkräfte über Wissen wissen - Abbild pädagogischer Handlungskompetenz — •Lukas Mientus und Andreas Borowski — Universität Potsdam

Für expertenhafte Planung von Physikunterricht ist die Betrachtung und Vernetzung vielfältiger Wissensfacetten unabdingbar. Diese können jedoch bezogen auf einen spezifischen Lerngegenstand stark variieren. Die Methode der Content Representation (tabellarische Darstellung des situationsbezogenen Wissens) kann einer Lehrkraft helfen das eigene Wissen strukturiert darzustellen. In Content Representations werden daher so genannte Big Ideas einer Thematik individuell identifiziert und anschließend unter verschiedenen Aspekten in Abhängigkeit der Lerngruppe diskutiert. Dieses Vorgehen bewerten Lehrkräfte als gewinnbringend um einen klaren Blick auf den Unterrichtsgegenstand zu erhalten und das Bewusstsein für Ihre eigene Professionalität anzuregen. In einer explorativen Studie wurde erstmals eine deutschsprachige Content Representation mit N=8 Physiklehrenden unterschiedlicher Expertise durchgeführt. Unterschiede und Gemeinsamkeiten zwischen den Vergleichsgruppen aus Lehrkräften, Studierenden und Fachdidaktiker*innen konnten nachgewiesen werden. In einer weiteren Arbeit wurde die Vereinbarkeit der fachlich orientierten Methode mit den Bildungsstandards der Sekundarstufe II verglichen, da besonders hier das Spannungsfeld zwischen Kompetenz- und Inhaltsorientierung hoch zu sein scheint. Der Vortrag gibt einen fundierten Einblick in die Content Representations und verdeutlicht das Potential der Methode für bevorstehende Unterrichtsvorbereitungen.

DD 46: Bildung für nachhaltige Entwicklung II

Time: Wednesday 11:00–12:00 Location: DD 407

DD 46.1 Wed 11:00 DD 407

Visions for Climate - Didaktische Konzeption einer interdisziplinären Vorlesungsreihe zum Klimawandel — •Christopher Newton, Timo Graffe, Johannes Frank Lhotzky, Holger Tost und Klaus Wendt — JGU, Mainz, Deutschland

Hochschulen haben ein großes Potenzial als Schnittstelle zwischen Lehre, Forschung und Transfer, die Gesellschaft nachhaltiger zu gestalten. Einzelne Fachdisziplinen sind in Hinblick auf die angebotenen Lehrveranstaltungen im Bereich Klimawandel und Nachhaltigkeit inhaltlich stark voneinander getrennt und den Studierenden fehlt eine ganzheitliche Perspektive auf die Thematik. An dieser Stelle setzt "Visions for Climate" als interdisziplinäre Ringvorlesung der Universität Mainz an. Diese veranschaulicht ausgehend von einer positiven Zukunftsvision Aspekte zu Klimaentwicklung, Klimagerechtigkeit und Nachhaltigkeit aus völlig unterschiedlichen Fachperspektiven und führt diese zusammen. Die 17 UN-Nachhaltigkeitsziele ziehen sich dabei als roter Faden durch die Vorlesungsreihe. Neben der bloßen Wissensvermittlung ist angestrebt auch Nachhaltigkeitskompetenzen und Selbstwirksamkeit fördern. Wie muss eine solche Vorlesung gestaltet sein, damit sie diesen Ansprüchen gerecht wird? Durch Analyse der aktuellen Forschungsliteratur wurde auf didaktischen Grundsätzen wie den "Elf Merkmalen guten Physikunterrichts" nach Merzyn aufbauend, ein didaktisches Konzept erarbeitet, worauf ein erster Durchgang der Veranstaltung basiert. Im Vortrag werden die didaktischen Entscheidungen für eine lernwirksamere Vorlesungsgestaltung aufgezeigt.

DD 46.2 Wed 11:20 DD 407

Das Schülerlabor Labs4Future: Eine Verbindung von Wissen über den Klimawandel und effektiven Handlungsoptionen — •Jonathan Grothaus, Markus Elsholz und Thomas Trefzger — Uni Würzburg

Vorgestellt wird im Vortrag ein zweitägiges, erprobtes (N=350) außerschulisches Angebot für 14-15-jährige Schüler:innen der 9. Klasse. Didaktisches Kernziel ist Verbindung von Wissen über den Klimawandel (Knowledge) mit gesellschaftlichen, sowie individuellen Handlungsoptionen (Action). Anhand theoretischer umweltpsychologischer und naturwissenschaftsdidaktischer Überlegungen soll eine Überbrückung der Knowledge-Action-Gap erreichen werden.

Nach einer kurzen Übersicht über das zugrundeliegende klimadidaktische Framework, sowie die an das Schülerlabor angegliederte didaktische Forschung, beschreibt der Hauptteil des Vortrags die Abschnitte des Schülerlabors und stellt im Unterricht einsetzbare Materialien vor:

Die Vermittlung des Erdsystemwissens, d.h. wie Prozesse bislang im stabilen Gleichgewicht ineinandergreifen (Treibhauseffekt, Kohlenstoffkreislauf, Klimadaten). Darauf aufbauend wird der Abschnitt des Handlungs- und Effektivitätswissens präsentiert: Die Hauptquellen der persönlichen Treibhausgasemissionen (Wohnen, Mobilität und Konsum) werden aus individueller und politischer Sicht untersucht und Handlungsstrategien entwickelt. Unter Anwendung des zuvor Gelernten entwickeln die Schüler:innen Strategien zur Entlarvung von Fake News und rhetorische Strategien, um für sinnvolle, d.h. effektive Klimaschutzmaßnahmen zu argumentieren.

DD 46.3 Wed 11:40 DD 407

Vorstellungen von deutschsprachigen Jugendlichen zum Klimawandel — •Rainer Wackermann[1], Thomas Schubatzky[2], Carina Wöhlke[1], Claudia Haagen-Schützenhöfer[3], Marco Jedamski[1], Kasimir Lindemann[1] und Kai Cardinal[4] — [1]Didaktik der Physik, Ruhr-Universität Bochum, Deutschland — [2]Institut für Fachdidaktik und Institut für Experimentalphysik, Universität Innsbruck, Österreich — [3]Fachbereich Physikdidaktik, Karl-Franzens-Universität Graz, Österreich — [4]Didaktik der Physik, Universität Duisburg-Essen, Deutschland

Ein grundlegendes Verständnis des Klimawandels kann Personen dabei helfen, falsche oder widersprüchliche Darstellungen besser einzuschätzen, um so am gesellschaftlichen Diskurs zum Thema Klimawandel teilhaben zu können. Die Erfassung von Lernendenvorstellungen ist außerdem zentral für die Entwicklung von Lernangeboten. Um Aussagen über das Verständnis von zentralen fachlichen Inhalten zum Klimawandel zuverlässig treffen zu können, wurde der Klimawandelkonzepttest CCCI-422 entwickelt, geprüft und erfolgreich validiert. Der CCCI-422 umfasst dabei die Inhaltsbereiche *Die Atmosphäre unserer Erde*, *Der Unterschied zwischen Klima und Wetter*, *Das Klima als System*, *Der Kohlenstoffkreislauf* und *Der Treibhauseffekt*. In der Hauptstudie wurden mit diesem Instrument die fachlichen Vorstellungen zum Klimawandel von über 700 Jugendlichen im deutschsprachigen Raum erfasst. Im Beitrag werden umfangreich zentrale Befunde auf Ebene der Inhaltsbereiche und auf Ebene der Einzelitems berichtet. Zudem wird ein Ausblick auf darauf angepasste Lernangebote gegeben.

DD 47: Hauptvortrag 3: Rabe & Helzel

Time: Wednesday 12:10–13:10 Location: DD HS 2.202

Invited Talk DD 47.1 Wed 12:10 DD HS 2.202

Reflexivität zu Sprache und Physiklernen durch Fallverstehen? Eine kasuistische Begleitveranstaltung zu Schulpraktika im Lehramtsstudium — •Thorid Rabe und Andreas Helzel — Martin-Luther-Universität Halle-Wittenberg

Praxisphasen im Lehramtsstudium werden von Lehrenden und Studierenden als relevant eingeschätzt. Wie aber können sie so ausgestaltet werden, dass nicht nur ein Eintauchen in die Praxis stattfindet, sondern eine Rückbindung an fachdidaktische Perspektiven auf Physikunterricht erfolgt und ein reflexiver Habitus ausgeprägt werden kann?

Als einen möglichen Zugang stellen wir eine kasuistisch ausgestaltete Begleitveranstaltung zu Schulpraktika zur Diskussion, die im Rahmen des QLB-Projekts KALEI2 an der MLU Halle-Wittenberg in den letzten Jahren implementiert wurde. Während ihres Schulpraktikums dokumentieren Studierende Fälle, in denen Sprache und Physiklernen thematisch werden. Im Anschluss an das Praktikum wird eine Auswahl dieser Fälle unter eben dieser Perspektive analysiert und reflektiert.

Im Rahmen des Vortrags werden Inhalte und Struktur der Veranstaltung selbst und ihre Einbindung in das Lehramtsstudium insgesamt vorgestellt und begründet. Darüber hinaus geben wir einen Einblick in Befunde aus der Begleitforschung, die auf der Auswertung von Gruppendiskussionen bzw. -aufgaben mit der Dokumentarischen Methode basieren. Fokussiert wird auf die Orientierungen der Studierenden zu Sprache und Physiklernen und ihren Umgang mit den Anforderungen der Fallarbeit.

DD 48: Lehr-Lernforschung V

Time: Wednesday 14:30–15:30 Location: DD 108

DD 48.1 Wed 14:30 DD 108

Multiple Repräsentationen und Zeichenaktivitäten als Zugänge zu Vektorfeldkonzepten — •Larissa Hahn und Pascal Klein — Universität Göttingen, Deutschland

Um Vektorfeldkonzepte wie die Divergenz in physikalischen Kontexten anzuwenden, ist ein konzeptionelles Verständnis notwendig. Bisherige empirische Forschungsergebnisse zeigten hierbei studentische Schwierigkeiten im Umgang mit dem Divergenzkonzept auf, die sich beispielsweise auf die visuelle Interpretation von Richtungsableitungen zurückführen lassen. Im Einklang mit lerntheoretischen Erkenntnissen fordern sie daher den Einsatz multipler Repräsentationen bei der Vermittlung dieser Konzepte. Zu diesem Zweck wurden Lehr-/Lernmaterialien entwickelt, die einen visuellen Zugang zum Divergenzkonzept anhand multipler Repräsentationen und Zeichenaktivitäten ermöglichen. Der Einfluss der Zeichenaktivitäten als Zwischensubjektfaktor wurde in zwei Wirksamkeitsstudien mit $N = 54$ und $N = 84$ Physikstudierenden der Studieneingangsphase untersucht. Dabei zeigte sich ein positiver Effekt des Lehr-/Lernmaterials auf verschiedene Leistungsindikatoren. Zusätzlich stellt dieser Beitrag Ergebnisse zur Analyse der visuellen Aufmerksamkeit bei der Bearbeitung des Materials (mit bzw. ohne Zeichnen) und beim anschließenden Problemlösen via Eye-Tracking vor.

DD 48.2 Wed 14:50 DD 108

Lernen durch Zeichnen — •Peter Michael Westhoff und Susanne Heinicke — Westfälische Wilhelms-Universität Münster

Einstein, da Vinci, Darwin, Jobs und Penrose - alles namhafte Wissenschaftler und Erfinder, von denen bekannt ist, dass viele ihrer Arbeiten auf eindrückliche Zeichnungen, selbsterstellte Skizzen und Abbildungen zurückzuführen sind. Wie effektiv die Methoden des Zeichnens für das Lernen ist und inwiefern sie sich von anderen Methoden abgrenzt, ist bislang wenig bekannt. In dem Projekt wird der Frage nachgegangen, wie diese Methode für das selbständige und das Lernen und Erinnern in formalen Lernsettings der (Hoch-)Schule eigenen und sinnvoll ein- und umgesetzt werden kann. Dabei wird u.a. betrachtet, wie sich die Kreativität und weitere Persönlichkeitsmerkmale im Bezug auf Lernförderlichkeit auswirken. Im Beitrag werden erste Ergebnisse aus Studien vorgestellt.

DD 48.3 Wed 15:10 DD 108

Modelle und Modellieren aus der Sicht von Mathematik- und Physiklehrkräften — •Simon Kraus[1] und Frederik Dilling[2] — [1]Universität Siegen, Didaktik der Physik — [2]Universität Siegen, Didaktik der Mathematik

Modelle und der Prozess des Modellierens sind zentrale Begriffe im Mathematik- und Physikunterricht und ihren entsprechenden Didaktiken. Aus Sicht des Physikunterrichts liegt der Fokus dabei meist auf dem Modell als fertigem Produkt, während der Mathematikunterricht die prozesshaften Aspekte stärker betont. Diese unterschiedliche Schwerpunktsetzung resultiert aus der Fokussierung auf die Theorieentwicklung auf der einen und auf das Lösen konkreter Probleme auf der anderen Seite. Beide Fächer haben jedoch gemeinsam, dass ihre Modelle überwiegend mathematische Modelle sind und der Ausgangspunkt jeweils ein reales Objekt oder Phänomen ist.

Im Vortrag werden Teilergebnisse einer Interviewstudie mit Lehrkräften der Fächer Mathematik und Physik zu deren Sichtweise auf die Begriffe des Modells und des Modellierens vorgestellt und vor dem Hintergrund der Theorie diskutiert. Dabei steht im Vordergrund, welche Gemeinsamkeiten und Unterschiede sich in Abhängigkeit von der jeweiligen Fächerperspektive ergeben und inwieweit Modelle als Produkt bzw. das Modellieren als Prozess in den Unterricht in den jeweiligen Fächern eingebunden werden.

DD 49: Experimente II

Time: Wednesday 14:30–15:30 Location: DD 110

DD 49.1 Wed 14:30 DD 110

Fächerübergreifende Ansätze zwischen Physik und Kunst am Beispiel von optischen Experimenten und künstlerischen Lichtinstallationen — •Nathalie Wolke, Yvonne Webersen und Daniel Laumann — Universität Paderborn, Paderborn, Deutschland

Die Fachdisziplinen Physik und Kunst werden nicht nur im gesellschaftlichen, sondern auch im schulischen Kontext häufig als konträr zueinander angesehen. Dies spiegelt sich zum Beispiel im gymnasialen Fächerkanon wider: so wird das sprachlich-literarische-künstliche Aufgabenfeld in NRW vom mathematisch-naturwissenschaftlich-technischem Aufgabenfeld abgegrenzt.

Durch die Verknüpfung beider Fächer bieten sich allerdings vielfältige Lernmöglichkeiten im Rahmen eines fächerübergreifenden Physikunterrichtes: Beispielsweise lassen sich durch die Gestaltung eigener (Video-) Lichtinstallationen sowohl künstlerische als auch physikbezogene Kompetenzen der Schülerinnen und Schüler fördern. Auch ermöglicht ein derart ausgerichteter Unterricht prinzipiell unterschiedliche Interessenstypen zu adressieren.

Im Vortrag werden zwei grundsätzliche Möglichkeiten der Verknüpfung von künstlerischen und physikalischen Themen am Beispiel des Optikunterrichts in der Mittelstufe vorgestellt: der analytische und der gestaltende Ansatz. Beide lassen sich prinzipiell auch auf andere physikalische Themenbereiche und Klassenstufen übertragen.

DD 49.2 Wed 14:50 DD 110

Physik mit Barrique – Eine Weinprobe in 50 Experimenten (Teil 1) — •Patrik Vogt[1] und Lutz Kasper[2] — [1]Institut für Lehrerfort- und -weiterbildung Mainz — [2]Pädagogische Hochschule Schwäbisch Gmünd

Physik und Wein? Gerät hier die Kontextorientierung nicht doch auf Abwege? Zugegeben, Wein sollte im Schulkontext eine zurückhaltende Rolle spielen. Und auch als Physiklehrkraft möchte man vielleicht zum Feierabend einmal mit ganz "undienstlicher" Absicht einen Wein genießen. Und doch schließt das nicht aus, mit (noch) wachem Verstand, geübten Blick und der notwendigen Neugierde die Physik auch hier im Alltag zu entdecken. Wie so oft ergeben sich aus solchen Beobachtungen faszinierende Fragen und Vermutungen, die nach weiteren Experimenten verlangen. Ein Einblick in einige experimentelle "Nachwirkungen" solcher Beobachtungen wird in diesem Vortrag gegeben.

Im ersten Teil beschäftigen wir uns zunächst mit dem Öffnen von Weinflaschen in einer erstaunlichen methodischen Vielfalt und zeigen, wie ein noch junger Wein in weniger als einer Minute belüftet werden kann. Danach widmen wir uns neben den auf der Hand – oder besser auf dem Gaumen – liegenden komplexen gustatorischen Wahrnehmungen den akustischen und optischen Erscheinungen.

DD 49.3 Wed 15:10 DD 110

Physik mit Barrique – Eine Weinprobe in 50 Experimenten (Teil 2) — •Lutz Kasper[1] und Patrik Vogt[2] — [1]Pädagogische Hochschule Schwäbisch Gmünd — [2]Institut für Lehrerfort- und -weiterbildung Mainz

Den zweiten Teil des Vortrags beginnen wir mit antiken Erfindungen, welche leicht den Eindruck eines erhobenen Zeigefingers wecken könnten und uns um Maßhalten mahnen. Dafür entwickelten die alten Meister Automaten, die eine strenge Zuteilung aus Weinkrügen ermöglichen oder auch das Mischen von Wein und Wasser regelten. Passend dazu stellen wir intelligente Gläser vor, die in der Lage sind, denjenigen – und nur denjenigen, die beim Einschenken über die Stränge schlagen, allen bereits im Glas befindlichen Wein wieder zu entziehen.

Der "Antikenabteilung" folgt eine Reihe von Experimenten, die am besten unter dem Stichwort "Partytricks" zusammengefasst werden können. Im physikalischen Sinn geht es dabei um teils spektakuläre Anwendungen der Mechanik: von kleineren "Schwerpunktzaubereien" bis zu Vorführungen, mit denen Sie Ihre Gäste beim nächsten Mal beeindrucken werden.

DD 50: Quantenphysik VI

Time: Wednesday 14:30–15:30 Location: DD 111

DD 50.1 Wed 14:30 DD 111

Einführung in die Quantenphysik über die Astronomie — •Tobias Reinsch[1], Lukas Maczewsky[2], Philipp Scheiger[3], Holger Cartarius[3] und Ronny Nawrodt[1] — [1]Physik und ihre Didaktik, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Erasmus-Gymnasium Rostock, Kopenhagener Str. 2/3, 18107 Rostock — [3]Friedrich-Schiller-Universität, August-Bebel-Str. 4, 07743 Jena

Die Quantenrevolution 2.0 erfordert neben einem vertieften theoretischen Verständnis von Verschränkung, Wellenfunktionen und deren Eigenschaften vor allem praktische Fähigkeiten, um diese Technologien in der Praxis umsetzen zu können. Für die Arbeit an Quantentechnologien müssen Studierende daher ein breites Spektrum experimenteller Fertigkeiten erlernen. Damit dies einer breiten Gruppe an Studierenden zugänglich gemacht wird, bedarf es einem aktivierenden Einstieg. Erfahrungsgemäß haben Schüler*innen und Studierende ein hohes Interesse an der Astronomie, unabhängig ihrer schulischen Leistungen. Wir stellen daher einen Einstieg in die Quantenphysik über die Astronomie vor. Fertigkeiten aus den Bereichen Photonik, Messtechnik und Atomphysik werden anschließend für das Kennenlernen moderner Quantensensoren aus NV-Zentren in Diamanten angewendet. Des weiteren verknüpfen wir auf klassischem Weg mehrere Bereiche der moderenen Physik mit der Quantenphysik. Dieser Zugang eignet sich für Schüler*innen, Lehramtsstudierende sowie für Ingenieure, die bisher wenig Berührungspuntke mit der Quantenphysik hatten.

DD 50.2 Wed 14:50 DD 111

Kompetenzlevel für das European Competence Framework for Quantum Technologies — •Franziska Greinert und Rainer Müller — TU Braunschweig, Institut für Fachdidaktik der Naturwissenschaften, Germany

Mit der Entwicklung moderner Quantentechnologien zur Industriereife ergibt sich ein neuer Bedarf an Fachkräften, die beispielsweise Quantensensoren bedienen oder Quantenalgorithmen an bestimmte Anwendungsfälle anpassen können. Im europäischen Quantum Flagship Koordinierungsproject Qucats, dem Nachfolgeprojekt zum QTEdu CSA, wird die Aus- und Weiterbildung von Fachkräften im Bereich der Quantentechnologien vorangetrieben. Dabei bietet das European Competence Framework for Quantum Technologies eine gemeinsame „Sprache“, eine Orientierungshilfe für die Planung und den Vergleich von Bildungsangeboten. Die zugehörigen Qualification Profiles liefern in ihrer Betaversion eine erste Sammlung möglicher Profile für die Qualifizierung, die durch Weiterbildungskurse oder ein entsprechendes Studium erreicht werden können. Thematisiert werden der aktuelle Weiterentwicklungsstand des Frameworks, konkret die Ergänzung von Kompetenzleveln, und die geplanten Schritte auf dem Weg zu einem europäischen Zertifikationsschema mit Lernzielen und Beispielaufgaben.

DD 50.3 Wed 15:10 DD 111

Fehlvorstellungen zur Superposition in der Quantenphysik — Andreas J. C. Woitzik[1,2] und •Oliver Passon[3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg im Breisgau, Bundesrepublik Deutschland — [2]Freiburg Advanced Center of Education, Fahnenbergplatz, 79085 Freiburg im Breisgau, Bundesrepublik Deutschland — [3]Bergische Universität Wuppertal, Gaußstr. 20, 42119 Wuppertal, Bundesrepublik Deutschland

Die Quantenphysik ist etablierter Inhalt der gymnasialen Oberstufenphysik. In den letzten Jahrzehnten werden dabei verstärkt Zugänge aus der informationstheoretischen Formulierung der Quantentheorie diskutiert und durch die neuen KMK-Bildungsstandards aus dem Jahr 2022 befördert, bei denen sich die konzeptionellen und begrifflichen Schwerpunkte im Vergleich zu den bisherigen Elementarisierungen verändern. Gleichzeitig gibt es ein wachsendes Angebot populärwissenschaftlicher Darstellungen zu neuen Quantentechnologien, wie Quantencomputern. In diesem Vortrag beschreiben wir Ungenauigkeiten und Fehler in diesen Darstellungen, insbesondere in Bezug auf den Begriff der Superposition und machen Empfehlungen, um Missverständnisse zu vermeiden.

DD 51: Hochschuldidaktik V

Time: Wednesday 14:30–15:30 Location: DD 405

DD 51.1 Wed 14:30 DD 405

Aktuelle Befunde aus der Begleitforschung zum Quereinstiegsmasters im Fach Physik an der Freien Universität Berlin — •Novid Ghassemi und Volkhard Nordmeier — Freie Universität Berlin

Alternative Wege in den Lehrer*innenberuf wurden in den vergangenen Jahren in nahezu allen Bundesländern geschaffen. Um die Qualität dieser alternativen Wege gewährleisten zu können, bedarf es empirischer Forschung zu den Kompetenzen der über alternative Wege qualifizierten Lehrer*innen. Der alternative Weg des Quereinstiegs während des Studiums wird an der Freien Universität seit 2016 in Form das Modellstudiengangs *Q-Master* erprobt und durch Forschung begleitet: Im Studienfach Physik wird exemplarisch die Ausprägung und Entwicklung fachlicher Aspekte professioneller Handlungskompetenz längsschnittlich erfasst und mit Studierenden des regulären Lehramtsmasters an der FU Berlin verglichen. Ergänzt wird dieses Vorgehen durch Interviews zu zwei Befragungszeitpunkten. Die Ergebnisse der quantitativen Begleitforschung deuten auf eine Ausprägung und Entwicklung professioneller Kompetenzen der Q-Masterstudierenden hin, welche mit Studierenden des regulären Lehramtsmaster vergleichbar ist. Die Auswertung der Interviewdaten deutet bislang darauf hin, dass weniger geradlinige Berufsbiografien nicht nur bei Q-Masterstudierenden vorkommen. Als wertvoll für die spätere Berufspraxis schätzen die Studierenden das Praxissemester sowie fachdidaktische und bildungswissenschaftliche Lehrveranstaltungen ein, während der Nutzen umfänglicher fachwissenschaftlichen Lehrinhalte in Frage gestellt wird.

DD 51.2 Wed 14:50 DD 405

Studieneingangsvoraussetzungen und -verlauf im Studiengang Maschinenbau — •Dennys Gahrmann[1], Günther Kurz[2], Irene Neumann[3] und Andreas Borowski[1] — [1]Universität Potsdam — [2]Hochschule Esslingen — [3]Leibniz-Institut für die Pädagogik der Naturwissenschaften und Mathematik

In MINT-Studiengängen sind hohe Abbruchsquoten zu verzeichnen. Als Hauptgrund sind fachliche Anforderungen im Grundstudium zu sehen. Gerade an den Hochschulen für Angewandte Wissenschaften (HAW) verschärft sich das Problem durch das breite Spektrum an Hochschulzugangsberechtigungen (HZB mit Allgemeiner Hochschulreife und den vielfältigen Fachhochschulreifen des 2. Bildungswegs). Um differenzierte Einblicke in die Vorkenntnisse der Studienanfänger:innen zu erhalten, wurden an der HAW Esslingen im Studiengang Maschinenbau von WS 2016/17 bis WS 2019/20 Wissen, Fähigkeiten und Fertigkeiten im Bereich der Physik (Test in MC-Format) erhoben. Die Testinhalte orientieren sich an den Bildungsstandards und dem cosh-Mindestanforderungskatalog Physik. Es liegt eine große Anzahl an Datensätzen, inklusive den Klausurergebnissen des 1. und 2. Fachsemesters und die Note der Vorprüfung respektive Exmatrikulation vor. Im Vortrag werden Analysen vorgestellt, wie das Vorwissen im Bereich Physik den Studienerfolg im Grundstudium, insbesondere in Abhängigkeit der HZB, beeinflusst.

DD 51.3 Wed 15:10 DD 405

WE-Heraeus-Vorlesungskonzept für Lehramtsstudierende — •Thomas Filk — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str.3, 79104 Freiburg

Im Rahmen einer Wilhelm-und-Else-Heraeus-Seniorprofessur entwickle ich ein Vorlesungskonzept speziell für Lehramtsstudierende, das in diesem Vortrag vorgestellt wird. Die Themenauswahl der Vorlesung umfasst viele Bereiche, die für die Schule zwar wichtig sind, in den Standardvorlesungen für Lehramtsstudierende jedoch oft nicht behandelt werden: Astrophysik, Kosmologie, Klimaphysik, Photovoltaik, usw. aber auch Themen wie Philosophie und Geschichte der Physik, Wissenschaftstheorie, Fehl- bzw. Alltagsvorstellungen, etc.

Parallel zur Vorlesung wird eine Materialsammlung erstellt, die es nicht nur den an der Vorlesung beteiligten Studierenden sondern auch bereits im Beruf befindlichen Lehrer*innen ermöglicht, sich in die bearbeiteten Teilgebiete einzuarbeiten. Es werden nicht nur die physikalischen Zusammenhänge und theoretischen Grundlagen zu den Themen beschrieben, sondern es soll auch die Brücke zu möglichen Elementarisierungsformen bzw. die Motivation im Unterricht behandelt werden. Die Struktur dieser Materialsammlung sowie Zugangsmöglichkeiten werden ebenfalls in meinem Vortrag beschrieben. Die Themen können für eine Vorlesung nahezu frei kombiniert werden. Die Themensammlung wird umfangreicher sein, als es dem Inhalt einer Vorlesungsreihe entspricht, und soll ständig erweitert werden. Für die Zukunft ist auch daran gedacht, andere Wissenschaftler*innen in die Erstellung solcher Materialien für Lehrer*innen einzubeziehen.

DD 52: außerschulisch/Hochschule

Time: Wednesday 14:30–15:30 Location: DD 407

DD 52.1 Wed 14:30 DD 407

Students discover the Schwarzschild metric at a free fall tower — •Hans-Otto Carmesin — Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

Astrophysics and general relativity motivate students. As a preparation, we introduce a measurement of a gravitational parallax distance r by using a pair of hand leads [1]. So, that distance is an element of physical reality. Additionally, we use an acceleration sensor of a mobile phone in order to discover the weightlessness at a free fall tower [2]. With it, we obtain the equivalence principle, EP. Note that we require mathematics of class 11 only. Using the real distance r, the Lorentz factor and the EP, we derive a universal position factor providing the energy of a falling object [1,3]. With it, we derive the gravitational redshift, the gravitational time dilation and the Schwarzschild metric, exactly. Interesting applications include gravitational lenses, black holes and autonomous vehicles. Moreover, based on the gravitational parallax distance r and the Schwarzschild metric, the Schrödinger equation is derived [1,3]. Experiences from teaching in classes and general study courses at a university are presented.

[1] Carmesin, H.-O. (December 2022): Unification of Spacetime, Gravity and Quanta. Berlin: Verlag Dr. Köster. [2] Könemann, T. et al. (2015): Concept for a next-generation drop tower system. Advances in Space Research, 55, pp. 1728-1733. [3] Burisch, C. et al. (2022): Universum Physik Gesamtband S2, Berlin: Cornelsen Verlag.

DD 52.2 Wed 14:50 DD 407

Prüfungsformen im Physikstudium — •Amr El Miniawy[1], Annemarie Sich[2], Lisa Lehmann[3], Manuel Längle[4], Sophie Penger[2] und Stefan Brackertz[2] — [1]Humboldt-Universität zu Berlin, Fachschaftsinitiative Physik — [2]Universität zu Köln, Fachschaft Physik — [3]Technische Universität Dresden, Fachschaft Physik — [4]Universität Wien, Studienvertretung Physik

Die Corona-Zeit hat neu Bewegung in die Diskussion um Prüfungsformate gebracht: Einerseits hat die 1:1-Übertragung klassischer Formate (ins Digitale) vielfach deren strukturelle Grenzen aufgezeigt. Andererseits konnten Lehrende durch aufgehobene Format-Verpflichtungen ihre Prüfungen kreativ weiterentwickeln.

Meist sind diese neuen Formate mit großem Einsatz hands-on unter Einbeziehung der Studierenden iterativ entwickelt worden. Die Ergebnisse sind oft bemerkenswert und dennoch wurde wenig auf den Stand der didaktischen Forschung zum Thema Prüfungen Bezug genommen. Das Studienreformforum hat zahlreiche neue Prüfungsformate gesammelt und dies nachgeholt. Dabei wurden auch didaktische Knackpunkte für die Gestaltung von Prüfungsformaten im Physikstudium erarbeitet. Beides wird vorgestellt.

DD 52.3 Wed 15:10 DD 407

Der Maritime Makerspace - ein schwimmender außerschulischer Lernort der Universität zu Köln — •André Bresges — Institut für Physikdidaktik, Universität zu Köln, Albertus-Magnus-Platz, 50931 Köln

Europas Zukunft wird weniger von Kohle, aber mehr von Wasser abhängen. Zum Einen stützt sich die Versorgung mit elektrischer Energie auf große Windparkfelder auf der Nordsee; zum anderen soll grüner Wasserstoff in Äquatornähe produziert und mit Schiffen zu europäischen Häfen befördert werden. Damit steht die Energieversorgung plötzlich in einem Ressourcenkonflikt mit der Güterversorgung, die ebenfalls zu 70% auf dem Seeweg statt findet. Noch legen die Kernlehrpläne der MINT Fächer aber wenig Gewicht auf relevante Inhalte im maritimen Kontext wie der Hydrodystatik - wichtig zum Verständnis des Auftriebs von Schiffen - und der Hydrodynamik, die für Antrieb und Stabilisierung von Schiffen und für die Energiewandlung mit Hilfe von Windrotoren und Wasserkraftwerken von zentraler Bedeutung ist. Kenntnisse der Hydrosonographie wären wichtig um die Schallabstrahlung der Windrotoren unter Wasser zu verstehen, und ihre Auswirkungen z.B. auf die große Population der Schweinswale in der Nordsee zu minimieren. Der Maritime Makerspace an der Universität zu Köln wurde daher zusammen mit dem Institut für Zoologie entwickelt und lädt Schüler:innen dazu ein, physikalische Konzepte aus der Maritimen Domäne in enger Verbindung mit den Sustainable Development Goals 14(Life below Water) zu erkunden.

DD 53: Workshop Studienreformforum

Time: Wednesday 16:00–17:30 Location: DD 108

DD 53.1 Wed 16:00 DD 108

Workshop: Alternative Übungskonzepte — •Amr El Miniawy[1], Lisa Lehmann[2], Manuel Längle[3] und Simon Tautz[4] — [1]Humboldt-Universität zu Berlin — [2]Technische Universität Dresden — [3]Universität Wien — [4]Christian Albrechts Universität Kiel

Übungen sind ein wichtiger Bestandteil des Physikstudiums und machen einen großen Teil der Arbeit sowohl der Studierenden als auch der Lehrenden aus.[1] Typischerweise gibt es eine gute Betreuungsrelation und dennoch bleiben sie oftmals hinter den Möglichkeiten zurück: Betretenes Schweigen und wenig sinnvolles Anschreiben einer Musterlösung an die Tafel haben wohl alle schon einmal erlebt. Eine systematische Erhebung im Rahmen einer Masterarbeit hat jüngst bestätigt, dass noch immer fast überall wenig kognitiv anregende Formate vorherrschen, bei denen z.B. der große Aufwand, der typischerweise in die Korrektur von Abgaben gesteckt wird, auch tatsächlich produktiv gemacht wird, um Studierende bei ihrem Lernfortschritt zu unterstützen. [2] Im Workshop wollen wir ausgehend von dieser Erhebung die aktuelle Situation reflektieren sowie alternative Modelle vor- und zur Diskussion stellen.

[1] vergleiche Handreichung KFP: https://www.kfp-physik.de/dokument/KFP_Handreichung_Konzeption-Studiengaenge-Physik-101108.pdf

[2] vergleiche z.B.: Praetorius et al. 2018: Generic dimensions of teaching quality: the German framework of Three Basic Dimensions. In: ZDM Mathematics Education 50, 407*426 (2018). https://doi.org/10.1007/s11858-018-0918-4

Working Group on Equal Opportunities
Arbeitskreis Chancengleichheit (AKC)

Agnes Sandner
Sprecherin des AKC
sandner@akc.dpg-physik.de

Overview of Invited Talks and Sessions

(Lecture hall F128; Poster Empore Lichthof)

Invited Talks

AKC 1.1	Mon	14:30–15:15	F128	**Vordenkerinnen in Physik und Philosophie** — •Betti Hartmann, •Carla Schriever
AKC 1.2	Mon	15:15–16:00	F128	**Physik-Projekt-Tage – Ein Workshop für Schülerinnen der Oberstufe** — Anna Albrecht, •Anna Benecke, Dietmar Block, Franko Greiner, Andreas Hinzmann, Roman Kogler

Sessions

AKC 1.1–1.2	Mon	14:30–16:00	F128	**AKC 1**
AKC 2.1–2.1	Mon	17:00–18:30	Empore Lichthof	**AKC 2**

Sessions

– Invited Talks and Posters –

AKC 1: AKC 1

Time: Monday 14:30–16:00 Location: F128

Invited Talk AKC 1.1 Mon 14:30 F128

Vordenkerinnen in Physik und Philosophie — •Betti Hartmann[1] und •Carla Schriever[2] — [1]Department of Mathematics, University College London, United Kingdom — [2]International University of Applied Sciences (IU) Hannover, Germany

Sei es in den Geistes- oder in den Naturwissenschaften: schon immer haben Frauen bedeutende Beiträge zur Philosophie oder Physik geleistet. Doch den meisten Menschen sind weder diese Wissenschaftlerinnen noch ihre Leistungen präsent. In ihrem Vortrag präsentieren die Autorinnen des Buches solche *Vordenkerinnen* und machen bewusst, dass sich diese Ausgrenzung durch die gesamte Wissenschaftsgeschichte zieht * von der Antike bis ins 21. Jahrhundert. Dabei stellen sie immer wieder spannende Synergien zwischen den jeweiligen Wissenschaftlerinnen heraus und lassen den Dialog zwischen den Disziplinen über die Jahrhunderte lebendig werden.

Invited Talk AKC 1.2 Mon 15:15 F128

Physik-Projekt-Tage – Ein Workshop für Schülerinnen der Oberstufe — Anna Albrecht[2], •Anna Benecke[1], Dietmar Block[4], Franko Greiner[4], Andreas Hinzmann[2] und Roman Kogler[3] — [1]Université catholique de Louvain, CP3 — [2]Universität Hamburg, Inst. f. Exp. Physik — [3]DESY Hamburg, CMS Group — [4]CAU Kiel, Inst. f. Exp. and Appl.Phys.

Gleichstellungsarbeit ist gerade auch in der Physik ein wichtiges Thema. Dies zeigen nicht zuletzt die Einschreibezahlen von Studentinnen in den Physikstudiengängen. In Kiel z.B. liegt der Prozentsatz von der Frauen hier bei etwa 15%. Die Gleichstellungsarbeit erst an der Universität zu beginnen genügt daher nicht. Statt dessen müssen bereits die Schulen einbezogen werden. Mit den Physik-Projekt-Tagen (PPT) wurde ein viertägiger Workshop nur für Schülerinnen ins Leben gerufen. Die Teilnehmerinnen haben die Möglichkeit, zu Schuljahresbeginn vier Tage lang in einem Projekt ihrer Wahl zu experimentieren, ihr Interesse an Physik zu steigern und Netzwerke über Schulgrenzen hinweg aufzubauen.

Die Projekte umspannen verschiedene Forschungsfelder der Physik und reichen von Teilchenphysik, über Laserphysik und Plasmaphysik bis hin zu Nanowissenschaften. Zur Qualitätssicherung und Weiterentwicklung dieser Veranstaltung werden die PPT von einer kritischen Evaluation begleitet. Das Konzept der PPT, Inhalte und ausgesuchte Ergebnisse der Evaluation werden vorgestellt. Seit 2015 ist das Projekt im Instrumentenkasten für Gleichstellungsarbeit der DFG.

AKC 2: AKC 2

Time: Monday 17:00–18:30 Location: Empore Lichthof

AKC 2.1 Mon 17:00 Empore Lichthof

Faszination Wissenschaft! Brücken bauen für die nächste Generation von Wissenschaftlern — •Angelica Zacarias[1], Jürgen Henk[2], Ruzin Aganoglu[3] und Agnes Sandner[3] — [1]Max-Planck-Institut für Mikrostrukturphysik, Halle (Saale), Deutschland — [2]Halles Schülerlabor für Physik, MLU Halle-Wittenberg, Deutschland — [3]Arbeitskreis Chancengleichheit der Deutsche Physikalische Gesellschaft

Sich verändernde Schlüsselkompetenzen für Lernende, Gesellschaft und Arbeitsmarkt erfordern zeitgemäße Konzepte für das Lehren, Lernen und Management schulischer Bildungssysteme. Dazu gehört auch praxisorientiertes Lernen. Wir haben festgestellt, dass außerschulische Lernerfahrungen jüngere Generationen dazu motivieren, nicht nur ein naturwissenschaftlich orientiertes Studium zu wählen, sondern eine wissenschaftlich orientierte Karriere zu verfolgen.

Wir präsentieren in diesem Poster einen wirkungsvollen Ansatz zur Unterstützung dieser Lernerfahrungen. Basierend auf dem weltweiten Zugang zu erfahrenen Wissenschaftlern in kurzen Webinar-Sessions lernen die jüngeren Generationen angehender Wissenschaftler nicht nur ihre Arbeit kennen, sondern sprechen auch über die Wege zu einer wissenschaftlichen Karriere.

Working Group "Young DPG"
Arbeitskreis junge DPG (AKjDPG)

Mareike Hetzel
Institut für Quantenoptik
Leibniz Universität Hannover
Welfengarten 1
30167 Hannover
hetzel@iqo.uni-hannover.de

Bernd Meyer-Hoppe
Institut für Quantenoptik
Leibniz Universität Hannover
Welfengarten 1
30167 Hannover
b.meyer@iqo.uni-hannover.de

Vivienne Leidel
Physikalisches Institut
Im Neuenheimer Feld 226
69120 Heidelberg
leidel@jdpg.de

Be welcome to this year's program of the Working Group "Young DPG"!

To those, who are new to the conference and are feeling lost in view of the various sessions, we want to offer the chance to build a solid foundation and to learn about the hot topics of the conference. You are cordially invited to visit the tutorials on Sunday afternoon and learn about quantum simulation and computing as well as molecular spectroscopy!

With our PhD-Symposium we want to explore the fascinating physics of many-body physics in ultracold quantum systems. The symposium is especially designed to give an introduction into the topic and will feature well known experts on the field.

Be welcome to join the tower building contest on Tuesday right after the plenary talk and to explore Hannover's night life during the pub crawl on Tuesday evening.

We are looking forward to seeing you at our events!

Overview of Invited Talks and Sessions

Invited Talks

AKjDPG 1.1	Sun	17:00–17:45	B305	**A Tutorial on Quantum Simulation** — •Christian Gross
AKjDPG 1.2	Sun	17:45–18:30	B305	**Developing utility scale quantum computers with trapped ions** — •Winfried Hensinger
AKjDPG 2.1	Sun	17:00–17:45	B302	**New perspectives in the investigation of ultrafast molecular dynamics** — •Andrea Trabattoni
AKjDPG 2.2	Sun	17:45–18:30	B302	**Femtosecond spectroscopy in the condensed and gas phase** — •Lukas Bruder

Invited Talks of the joint PhD-Symposium – Many-body Physics in Ultracold Quantum Systems

See SYPD for the full program of the symposium.

SYPD 1.1	Thu	14:30–15:00	E415	**Entanglement and quantum metrology with microcavities** — •Jakob Reichel
SYPD 1.2	Thu	15:00–15:30	E415	**Many-body physics in dipolar quantum gases** — •Francesca Ferlaino
SYPD 1.3	Thu	15:30–16:00	E415	**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — •Markus Greiner
SYPD 1.4	Thu	16:00–16:30	E415	**Quantum gas in a box** — •Zoran Hadzibabic

Sessions

AKjDPG 1.1–1.2	Sun	17:00–18:30	B305	**Tutorial Quantum Simulation and Computing**
AKjDPG 2.1–2.2	Sun	17:00–18:30	B302	**Tutorial Molecular Spectroscopy**

Sessions

– Tutorials –

AKjDPG 1: Tutorial Quantum Simulation and Computing

Time: Sunday 17:00–18:30 Location: B305

Tutorial AKjDPG 1.1 Sun 17:00 B305

A Tutorial on Quantum Simulation — •Christian Gross — Physikalisches Institut, Universität Tübingen

Quantum simulation is one of the upcoming quantum technologies. In this tutorial we provide an introduction to quantum simulation and discuss different flavors and platforms. We highlight the state of the art of the field for the simulation of fermionic Hamiltonians and discuss key techniques and experiments. We will also discuss the close interconnection between quantum simulation and quantum computation.

Tutorial AKjDPG 1.2 Sun 17:45 B305

Developing utility scale quantum computers with trapped ions — •Winfried Hensinger — Sussex Centre for Quantum Technologies, Department of Physics and Astronomy, University of Sussex, Brighton BN1 9QH, United Kingdom

Trapped ions are arguably the most mature technology capable of constructing practical quantum computers. Most disruptive quantum computing applications require quantum error correction with quantum computers operating in the fault-tolerant quantum computing operating modus, therefore requiring hundred thousands or millions of qubits. While prototype trapped ion quantum computers have already been built featuring performance specifications featuring world-leading performance specifications, the next challenge consists to develop technologies capable of supporting operation with large number of qubits.

In this tutorial presentation I will provide an introduction to the general field of trapped ion quantum computing and explain key concepts including the fabrication of ion trap microchips. I will will focus on techniques capable of scaling to large qubit numbers including the use of long wavelength radiation for the scalable implementation of trapped ion quantum information processing.

In order to be able to build large scale device, a quantum computer needs to be modular. I will discuss different approaches to modularity and report a recent demonstration to couple different quantum computing modules with specifications sufficient for fault-tolerant quantum computing.

AKjDPG 2: Tutorial Molecular Spectroscopy

Time: Sunday 17:00–18:30 Location: B302

Tutorial AKjDPG 2.1 Sun 17:00 B302

New perspectives in the investigation of ultrafast molecular dynamics — •Andrea Trabattoni — Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg, 22607, Germany — Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Imaging the microscopic world in real space and real time is a grand challenge of science. In this context, the landscape of techniques to image ultrafast molecular dynamics is vast, including promising and powerful methods such as lightwave-driven scanning tunnelling microscopy or photoelectron diffraction. In this tutorial, the main methods and results in the field of ultrafast molecular physics will be presented, with a particular emphasis on laser-induced electron diffraction (LIED) in terms of experimental results and advanced modeling. Possible perspectives toward the future advancement of time-resolved molecular imaging will be discussed.

Tutorial AKjDPG 2.2 Sun 17:45 B302

Femtosecond spectroscopy in the condensed and gas phase — •Lukas Bruder — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3 79104 Freiburg

Molecular processes can be extremely fast and often involve many degrees of freedom. This poses a major challenge for experiments. The problem can be tackled with femtosecond spectroscopy, which allows to resolve the molecular dynamics in real-time. The majority of femtosecond spectroscopy is performed in the condensed phase, which is the natural environment of most molecular processes. On the contrary, experiments in the gas phase allow to study molecular model systems such as isolated molecules and molecular complexes. This provides a complementary view on the molecular dynamics. Hence, both approaches are important in order to improve our understanding of molecular dynamics.

In this tutorial I will give a basic introduction to femtosecond spectroscopy including coherent multidimensional spectroscopy and discuss the technical differences for experiments in the condensed phase and gas phase.

Index of Exhibitors

Exhibition venue
Leibniz Universität Hannover, Lichthof (Main Building), Welfengarten 1, 30167 Hannover

Exhibition opening hours

Tuesday, March 7	10:30 – 19:00
Wednesday, March 8	10:30 – 19:00
Thursday, March 9	10:30 – 19:00

The entrance is free!

Company — **Booth No.**

AHF analysentechnik AG — **2**
Kohlplattenweg 18, 72074 Tübingen
AHF provides optical filters, LED/laser light sources, image splitters and quality monitoring tools for professional and challenging (fluorescence) microscopy. Customers benefit from long-term and interdisciplinary expertise.

Ametek, TMC GmbH — **13**
Rudolf-Diesel-Straße 16, 40670 Meerbusch
Optische Tische

Bernhard Halle Nachfl. GmbH Optische Werkstätten — **6**
Hubertusstraße 10, 12163 Berlin
Polarisationsoptik, Linsensysteme, Optische Komponenten

CAEN ELS S.R.L. — **16**
AREA Science Park - SS14 km 163,5, 34149 Basovizza, Trieste, Italy
High Performance Power Supplies, ZERO FLUCS Precision Current Measurement, Beamline Electronic Instrumentation, MicroTCA and FMC

Cryoandmore Budzylek GbR — **40**
Hermann-Cossmann-Straße 19, 41472 Neuss
Closed Cycle Kühler 4K / Open Cycle Flow Kryostate 1.7K / Nitrogen Kryostat / Spares

CryoVac GmbH & Co. KG — **17**
Langbaurghstraße 13, 53842 Troisdorf
Helium-Bad und Verdampferkryostate, Temperaturmess- und Regelgeräte

Deutsche Forschungsgemeinschaft (DFG) — **41**
53170 Bonn
Information und Beratung zu den Förderprogrammen der DFG

Exail SAS — **37**
3, rue Sophie Germain, 25000 Besançon, France
Photonic components and systems for Quantum Technologies

GWU-Lasertechnik Vertriebsgesellschaft mbH — **14**
Bonner Ring 9, 50374 Erftstadt
Abstimmbare Lasersysteme & OPOs; Kristalle (Laser, nicht-lineare); Echelle-Spektrografen; Fiberlaser

Hamamatsu Photonics Deutschland GmbH 18
Arzbergerstraße 10, 82211 Herrsching
We are a manufacturer of optoelectronic components for highest demands. Small quantities, customization, or series production, whatever you need: We will find a solution. Talk to us at booth 18 (Lichthof)

Hiden Analytical Europe GmbH 34
Kaiserswerther Straße 215, 40474 Düsseldorf
Quadrupol Massenspektrometer: Restgas-/Oberflächen-/Cluster-/ Molekularstrahlanalyse; SIMS/SNMS/ToF-qSIMS-/TPD-Workstations; Gas-Analyse-Geräte , MIMS & DEMS; Plasmadiagnostik- & Energie-Analysatoren

Hositrad/Holland 9
De Wel 44, 3871 MV Hoevelaken, The Netherlands
CF, KF, ISO, UHV-Vakuumbauteile, Elektrische Durchführungen, Membranbalgen, Special Products

Hübner Photonics 46
Heinrich-Hertz-Straße 2, 34123 Kassel
HÜBNER PHOTONICS: Single-Frequenz CW DPSS-, Faser- und durchstimmbare Laser, UV bis Mid-IR, von 10 mW bis 130 W

Ingenieurbüro Dr. Walter Luhs 21
Freiburger Straße 33, 79427 Eschbach
Praktikumsversuche für Anfänger und Fortgeschrittene, Rubin Laser, Jod Laser, Pr:YLF Laser

ISEG Spezialelektronik GmbH 48
Bautzner Landstraße 23, 01454 Radeberg / Rossendorf
Hochspannungsversorgungen, Hochspannungsnetzgeräte, HV-DC/DC- Konverter

Jäger Computergesteuerte Messtechnik GmbH 11
Rheinstraße 4, 64653 Lorsch
Jäger Computergesteuerte Messtechnik GmbH – ADwin-Echtzeitsysteme für schnelle, freiprogrammierbare Steuer- und Regelaufgaben

JUST VACUUM GmbH 3
Daimlerstraße 17, 66849 Landstuhl
Vakuumtechnik

Kashiyama Europe GmbH 25
Leopoldstraße 244, 80807 München
Vacuum Solutions

LIOP-TEC GmbH 44
Industriestraße 4, 42477 Radevormwald
Gepulste ns Dye-laser Systeme, Optomechanik

Lumibird 7
2 rue Paul Sabatier, 22300 Lannion, France
Laser

mechOnics AG 50
Papferding 44 a, 85461 Bockhorn
Mikropositionierer mit Piezoträgheitsantrieb und Schrittmotor, Piezo- und Schrittmotorsteuerungen

Menlo Systems GmbH **32+33**
Bunsenstraße 5, 82152 Martinsried
Frequency Combs, Quantum Systems, Ultrastable Lasers, FS Lasers, THz System

MG Optical Solutions GmbH **43**
Industriestraße 23, 86919 Utting/Ammersee
Laser Servo and Controller / Spectroscopy / DBR-Laser / Wavelength Meter, Spectrum Analyzer / MIR Spectrometers, Detectors and Camera / Terahertz Imaging Systems and Laser

MRC Systems GmbH Medizintechnische Systeme **31**
Hans-Bunte-Straße 10, 69123 Heidelberg
Laser Strahlstabilisierung

Munich Quantum Valley **8**
Leopoldstraße 244, 80807 München
Munich Quantum Valley promotes quantum science and quantum technologies in Bavaria and offers various research positions, especially in connection to quantum computing.

PlanQC GmbH **15**
Lichtenbergstraße 8, 85748 Garching
Planqc quantum computing atom by atom

Qioptiq Photonics GmbH & Co. KG **29**
Königsallee 23, 37081 Göttingen
Präzisionsoptik und Mechanik, Faseroptik, Aufbausysteme, Optische Tische

Qlibri **42**
Geschwister-Scholl-Platz 1, 80539 München
Ludwig-Maximilians-Universität München open micro-resonators and micromirrors for ultra-sensitive absorption microscopy and as a cryogenic quantum optics platform

Quantum Design GmbH **5**
Im Tiefen See 58, 64293 Darmstadt
Magnetometer, supral. Magnetsysteme, Elektronik-Komp., CCD-,ICCD, EMCCD-Detektoren, Spektrographen

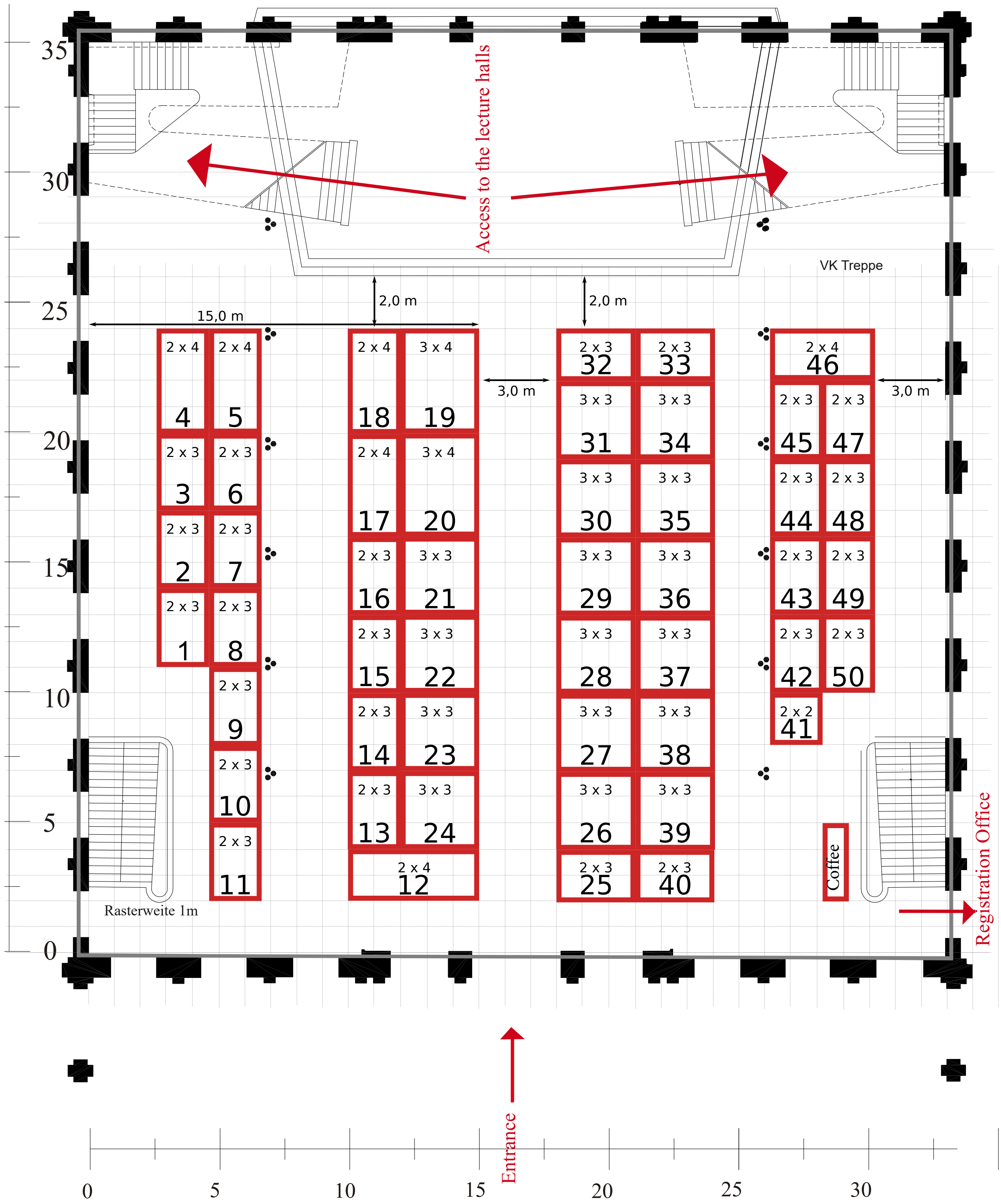
qutools GmbH **28**
Kistlerhofstraße 70 Geb. 88, 81379 München
Quantum Physics Education, Photon Counter, Time Tagger, Displacement Measurement

Radiant Dyes Laser Acc. GmbH **30**
Friedrichstraße 58, 42929 Wermelskirchen
Dye Laser cw & gepulst, Ti:Sa Laser cw & gepulst, Excimer Laser, Optomechanik, Laserzubehör

Schäfter + Kirchhoff GmbH Optics, Metrology and Photonics **45**
Kieler Straße 212, 22525 Hamburg
Polarization-maintaning fiber optic components including laser beam coupler, fiber collimators, fiber cables, polarization analyzers and fiber port clusters

Stand Map Exhibition Hannover 2023

Leibniz Universität Hannover, Welfengarten 1, 30169 Hannover



Quelle: LUH

Overview Lecture Rooms / Campus

Hörsaalliste / Lecture Rooms

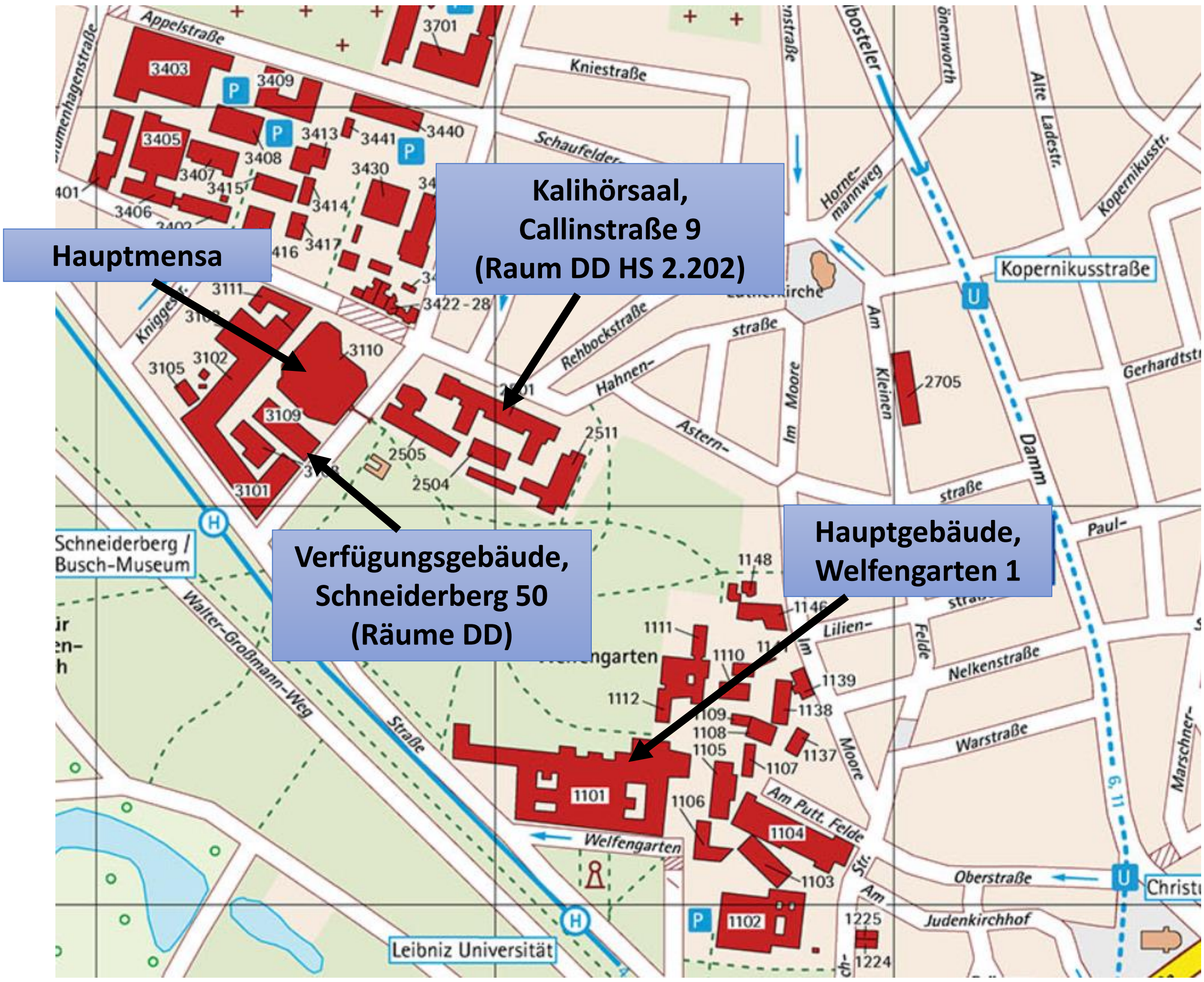
SAMOP

Hauptgebäude Welfengarten 1
Lichthof
Empore Lichthof
A320
B302
B305
F102
F107
F128
F142
F303
F335 (Senatssitzungssaal)
F342 (kleiner Physikhörsaal)
F428
F442
E001
E214 (großer Physikhörsaal)
E415 (Audimax)

Fachverband Didaktik / Physics Education Division

Verfügungsgebäude Schneiderberg 50
DD 108
DD 110
DD 111
DD 203
DD 205
DD 309 (Kaffee)
DD 405
DD 407

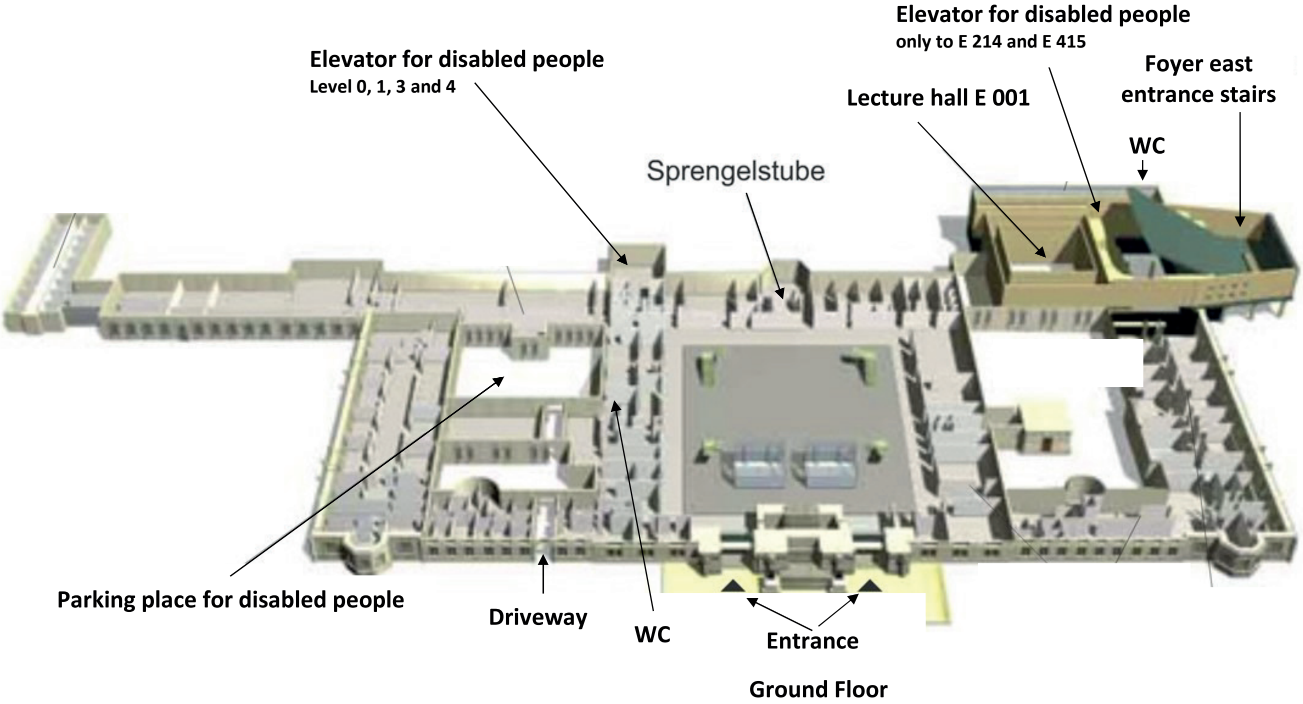
Altbau Chemie, Callinstraße 9
DD HS 2.202 (Kalihörsaal)



Quelle: LUH

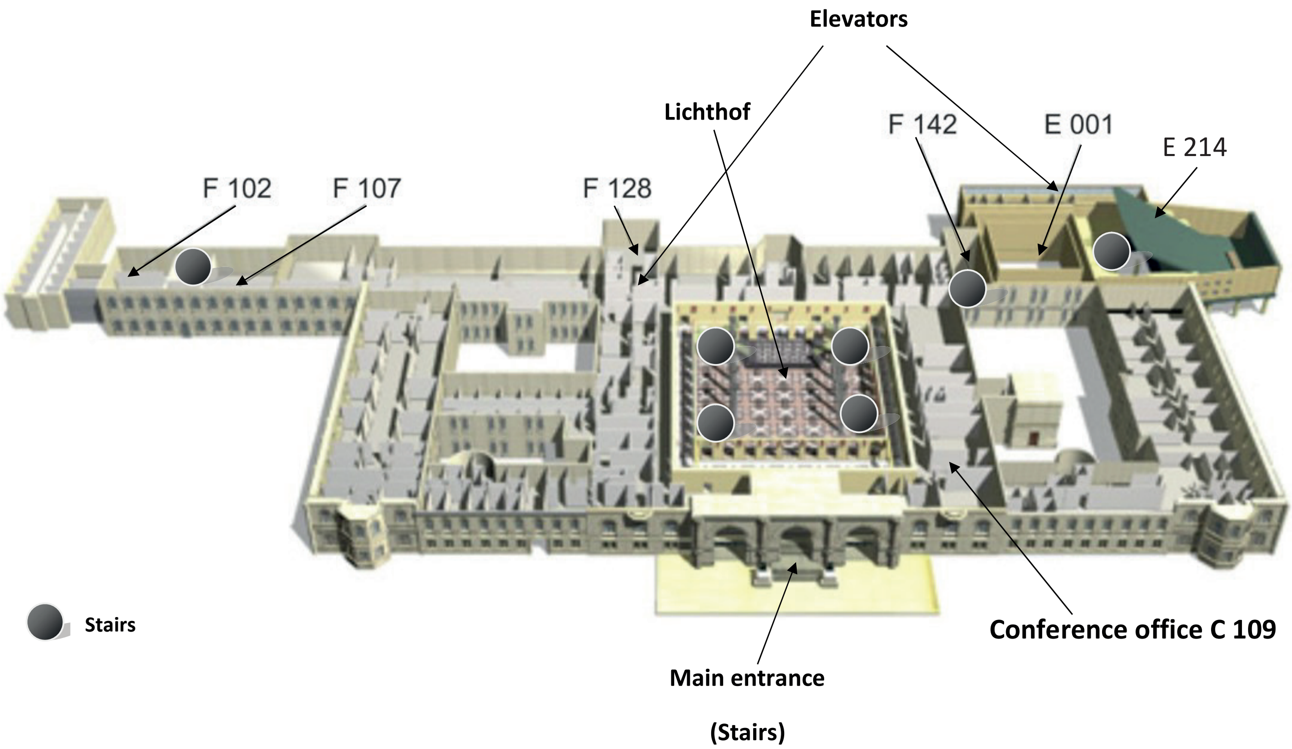
Map Level 0 and Guide for disabled persons

(Source: Pressestelle Leibniz Universität Hannover)



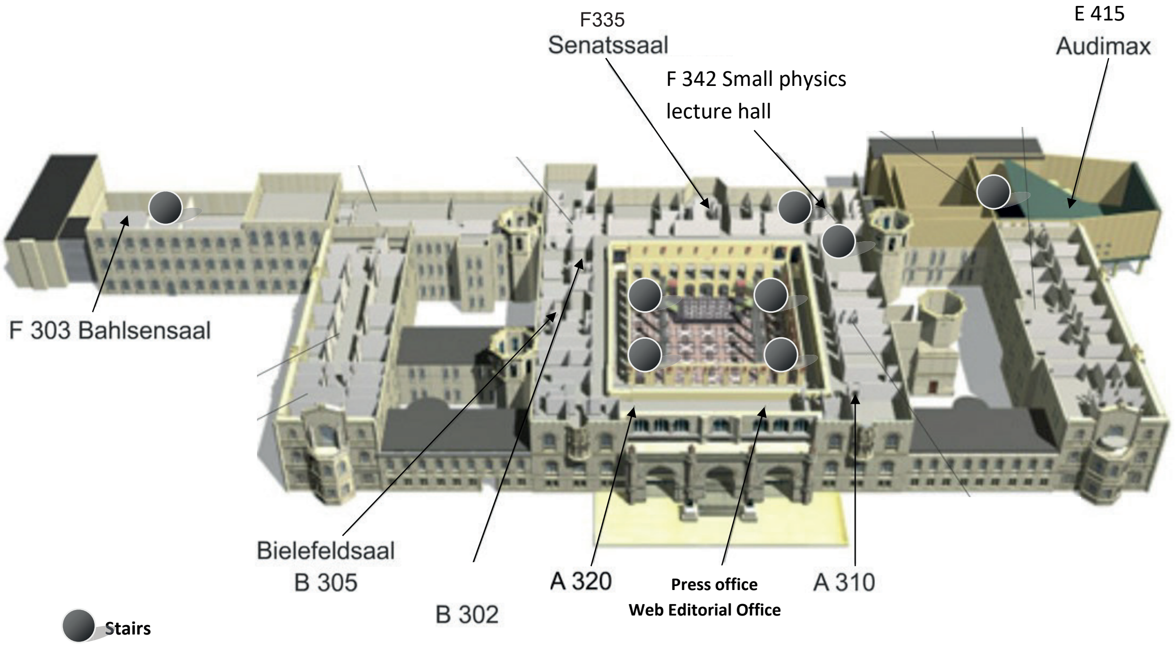
Map Level 1

(Source: Pressestelle Leibniz Universität Hannover)



Map Level 3

(Source: Pressestelle Leibniz Universität Hannover)



Map Level 4

(Source: Pressestelle Leibniz Universität Hannover)