# Atomic Physics Division
# Fachverband Atomphysik (A)

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## 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 |

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| 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.

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| 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.

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| 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.

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| 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.

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| 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.

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| 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.

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| 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.

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| 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

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| 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)** |

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| 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

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

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

A 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.

A 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).

A 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.

A 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.

A 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.

A 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.

A 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

A 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)

## 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.

References

[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 $\alpha Z$** — •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 multiconfigurational 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 $\pi$** — •Helmut Schmidt — LMU München

Lösungen der Schrödingergleichungen können in ein Polynom mit der Basis $2\pi$ 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 $2\pi$, 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: $hGc^5s^8/m^{10}\sqrt{\pi^4 - \pi^2 - 1/\pi - 1/\pi^3} = 1.00000$

## 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 $\kappa$, 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 $\kappa$ from its ideal value $\kappa = 0$. A determination of $\kappa$ 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

A 4.1 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, and E. A. Power, J. Chem. Phys. **44**, 4148 (1966).
[2] E. A. Power and T. Thirunamachandran, Phys. Rev. A **47**, 2539 (1993).
[3] P. Barcellona, R. Passante, L. Rizzuto, and S. Y. Buhmann, Phys. Rev. A **94**, 012705 (2016).

A 4.2 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] Stefan Yoshi Buhmann, David T. Butcher and Stefan Scheel. New Journal of Physics 14, 083034 (2012).
[2] Sebastian Fuchs, J. A. Crosse and Stefan Yoshi Buhmann. Phys. Rev. A 95, 023805 (2017).
[3] David T. Butcher, Stefan Y. Buhmann, Stefan Scheel, New Journal of Physics 14, 113013 (2012).

A 4.3 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)

A 4.4 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 $\Delta \mathrm{T} = \mathrm{T}_1 - \mathrm{T}_2$ . 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).

A 4.5 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.

A 4.6 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 $a_\mu$. Recent experimental results by Fermilab reinforce the discrepancy, displaying a deviation of $4.2\,\sigma$ [1]. Particles Beyond Standard Model (BSM) can contribute to $a_\mu$ 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 $a_\mu$ 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)

A 4.7 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).

A 4.8 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)

## 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 multi-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

A 8.1 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.

A 8.2 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.

A 8.3 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.

A 8.4 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).

A 8.5 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)

A 8.6 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.

A 8.7 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.

A 8.8 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.

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

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

**Invited Talk** A 9.1 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).

A 9.2 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 $\mu$m laser pulses were used to excite the system, respectively. A 1.3 $\mu$m 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)

A 9.3 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]

A 9.4 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).

A 9.5 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.

A 9.6 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.

References:
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.

A 9.7 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)

## 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 $4s_{1/2} \to 3d_{5/2}$ 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, 1020 Vienna, Austria — [2]EPFL, BM 3110 Station 17, CH-1015 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 interaction 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 $1\,\mathrm{cm}^2$ 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, 67663 Kaiserslautern, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 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 nonequilibrium 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 $\sigma_m$ 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 $\sigma_5$ 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 multicenter 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 $^{6}Li$ 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 $6s^2\,{}^1\mathrm{S}_0 - 6s6p\,{}^3\mathrm{P}_1$ 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 narrowband 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 de 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 $\gamma$-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 engineered 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 $\gamma$-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 $1 \times 10^{-18}$ 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 $^1S_0 \rightarrow {}^3P_1$ (657 nm, 370 Hz linewidth) and $^1S_0 \rightarrow {}^1D_2$ 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 multicoincidence 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 importantly, 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 ($\gamma$) 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 groundstate 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

A 15.1 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 $2 \ell$, where $\ell$ 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.

A 15.2 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).

A 15.3 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 $250 \times 10^3$ ultracold $^{87}$Rb atoms prepared in the magnetic insensitive state $|F = 1, m_F = 0\rangle$. 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.

A 15.4 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.

A 15.5 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.

A 15.6 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.

A 15.7 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.

A 15.8 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.

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

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

**Invited Talk** A 16.1 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.

A 16.2 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.

A 16.3 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.

A 16.4 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.

A 16.5 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 super-ohmic 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)

A 16.6 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).

A 16.7 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.

## 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 sublevels 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 $\delta$-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 Bohr-magneton), 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 $\mu$J 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 $\mu$m) 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 ultracold 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-$\beta$ 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 Feshbach 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 $^3$P$_2$ and $^3$P$_0$ 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 $^1$S$_0$ to $^3$P$_1$ laser-cooling transition under magic trapping conditions. I will present our results to control single atoms under conditions, for which the $^1$S$_0$ to $^3$P$_1$ 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 $\sim$13 $\mu$m 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 5$\mu$m 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 efficient laser-driven acceleration of heavy ions to kinetic energies above 7MeV/u, was proposed [1]. Previously, it was found that target heating 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 $0.05\,\mathrm{meV} - 3.2\,\mathrm{eV}$, 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 (MC-QST), 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 $5.0\times10^{14}$ 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.

References :
[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 $\gamma$-spectrum following the $\alpha$-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 $\gamma$-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 $\mu$m 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

A 21.1 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 $\sigma$ and $\pi$ 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.

A 21.2 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)

A 21.3 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)

A 21.4 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.

A 21.5 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)

A 21.6 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)

A 21.7 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 $\beta$ stands for differences between the TDMs defining the first and last light-matter interaction in a TA-sequence. We find that $\beta \approx 30°$ is an optimal choice to disentangle the D and A-signals. This proves the non-orthogonality within the *"orthogonal"* D-A system.

A 21.8 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.

## 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 induced 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 contrasts 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

A 25.1 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)

A 25.2 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

A 25.3 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).

A 25.4 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.

A 25.5 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.

A 25.6 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.

A 25.7 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.

A 25.8 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 $\alpha$-hemolysin ($\alpha$-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.

## 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 $1s2s\,^3S_1 \rightarrow 1s2s\,^3P_J$ 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 $1s2s\,^3S_1 \rightarrow 1s2s\,^3P_{0,1,2}$ 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-Universtität 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 offline 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 $2.1{\cdot}10^6$ 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 $5f^76d7s7p\,^9D_3$ and $5f^86d7s\,^9D_3$. 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 ultra-long 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 ($P_{\text{avg}} \approx 25\,\text{kW}$, $I_{\text{peak}} \approx 3 \cdot 10^{14}\,\text{W/cm}^2$) [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 $\mu$K 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 ultranarrow 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-

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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

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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 $\mu$m 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 (MCQST), 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 subradiant 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 $n\,^2\mathrm{P}_{3/2}$ 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 $^{88}\mathrm{Sr}^+$ 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 $1.1 \times 10^{-18}$ 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 $^{27}\mathrm{Al}^+$ 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 $\mathrm{Al}^+$ clock using a single $^{40}\mathrm{Ca}^+$ 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 $\mu$T 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 $^{171}\mathrm{Yb}^+$ 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 $^{87}\mathrm{Sr}$, both of which feature small sensitivities to variations of $\alpha$. 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 radio-frequency 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 $1\times10^{-18}$. 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, Philipps-Universität Marburg, Hans-Meerwein-Straße 4, 35032 Marburg, Germany

Small polar molecules provide large enhancements of $\mathcal{P},\mathcal{T}$-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 photoelectron 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 K$\alpha$ 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 K$\alpha$ 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 $5 \times 10^{-11}$. 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

A 32.1 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.

A 32.2 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.

A 32.3 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.

A 32.4 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 IQ$^{ST}$, 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.

A 32.5 Fri 15:30 F342

**Large-momentum-transfer atom interferometers with $\mu$rad-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 $\mu$rad 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 $\mu$rad 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.

A 32.6 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.

A 32.7 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)$^2$).

A 32.8 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 interferometry on fountain trajectories. We demonstrate the necessary methods 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.

# 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. Spectroscopy 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 groundstate 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 $4d \to 5p$ 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 Univer-

sity 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

A 34.1 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.

A 34.2 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.

A 34.3 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 $\lambda = 267$ 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]

A 34.4 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.

A 34.5 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 I4*d* photoemission time delay $\tau_{I4d}$ on the molecular species.

The experiment 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 I4*d* 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 $\tau_{I4d}$ 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)).

A 34.6 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

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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

A 34.7 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).

A 34.8 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 I4$d$ 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.