Atomic Physics Division
Fachverband Atomphysik (A)

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Overview of Invited Talks and Sessions

(Lecture halls A-H1, A-H2, and A-H3; Poster P)

Invited Talks

A 2.1	Mon	14:00–14:30	A-H1	**Attosecond pulse control with sub-cycle, infrared waveforms** — •Miguel Angel Silva-Toledo, Yudong Yang, Roland E. Mainz, Giulio Maria Rossi, Fabian Scheiba, Phillip D. Keathley, Giovanni Cirmir, Franz X. Kärtner
A 6.1	Tue	10:30–11:00	A-H1	**Synthetic chiral light for control of achiral and chiral media** — •Nicola Mayer, David Ayuso, Misha Ivanov, Olga Smirnova
A 14.1	Wed	10:30–11:00	A-H1	**Synchrotron radiation experiments with highly charged ions** — •Jose R. Crespo López-Urrutia, Steffen Kühn, Moto Togawa, Marc Botz, Jonas Danisch, Joschka Goes, René Steinbrügge, Sonja Bernitt, Chintan Shah, Maurice A. Leutenegger, Ming Feng Gu, Marianna Safronova, Jakob Stierhof, Thomas Pfeifer, Jörn Wilms
A 17.1	Wed	14:00–14:30	A-H1	**Isomer depletion via nuclear excitation by electron capture with electron vortex beams** — •Yuanbin Wu, Christoph H. Keitel, Adriana Pálffy
A 22.1	Thu	10:30–11:00	A-H1	**Optimizing large atomic structure calculations with machine learning** — •Pavlo Bilous, Adriana Pálffy, Florian Marquardt
A 23.1	Thu	10:30–11:00	A-H2	**Chemistry of an impurity in a Bose-Einstein condensate** — •Arthur Christianen, Ignacio Cirac, Richard Schmidt
A 24.1	Thu	10:30–11:00	A-H3	**Spectroscopy of a Highly Charged Ion Clock with Sub-Hz Uncertainty** — •Lukas J. Spiess, Steven A. King, Peter Micke, Alexander Wilzewski, Tobias Leopold, Erik Benkler, Nils Huntemann, Richard Lange, Andrey Surzhykov, Robert Müller, Lisa Schmöger, Maria Schwarz, José R. Crespo López-Urrutia, Piet O. Schmidt
A 31.1	Fri	10:30–11:00	A-H1	**Cavity-enhanced optical lattices for scaling neutral atom quantum technologies** — •Jan Trautmann, Annie J. Park, Valentin Klüsener, Dimitry Yankelev, Immanuel Bloch, Sebastian Blatt
A 32.1	Fri	10:30–11:00	A-H2	**High-resolution DR spectroscopy with slow cooled Be-like Pb^{78+} ions in the CRYRING@ESR storage ring** — •Sebastian Fuchs, Carsten Brandau, Esther Menz, Michael Lestinsky, Alexander Borovik Jr, Yanning Zhang, Zoran Andelkovic, Frank Herfurth, Christophor Kozhuharov, Claude Krantz, Uwe Spillmann, Markus Steck, Gleb Vorobyev, Regina Hess, Volker Hannen, Dariusz Banaś, Michael Fogle, Stephan Fritzsche, Eva Lindroth, Xinwen Ma, Alfred Müller, Reinhold Schuch, Andrey Surzhykov, Martino Trassinelli, Thomas Stöhlker, Zoltán Harman, Stefan Schippers

Invited talks of the joint symposium Laboratory Astrophysics (SYLA)

See SYLA for the full program of the symposium.

SYLA 1.1	Mon	14:00–14:30	Audimax	**Probing chemistry inside giant planets with laboratory experiments** — •Dominik Kraus

SYLA 1.2	Mon	14:30–15:00	Audimax	**Inner-shell photoabsorption of atomic and molecular ions** — •Stefan Schippers
SYLA 1.3	Mon	15:00–15:30	Audimax	**Molecular Astrophysics at the Cryogenic Storage Ring** — •Holger Kreckel
SYLA 1.4	Mon	15:30–16:00	Audimax	**Observing small molecules in stellar giants - High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air** — •Guido W. Fuchs
SYLA 2.1	Mon	16:30–17:00	Audimax	**State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments** — •Christian P. Endres, Paola Caselli, Stephan Schlemmer
SYLA 2.4	Mon	17:30–18:00	Audimax	**A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions** — •Donatella Loru, Amanda L. Steber, Johannes M. M. Thunnissen, Daniël B. Rap, Alexander K. Lemmens, Anouk M. Rijs, Melanie Schnell
SYLA 2.5	Mon	18:00–18:30	Audimax	**Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses** — •Jason Lee, Denis Tikhonov, Bastian Manschwetus, Melanie Schnell

Invited talks of the joint PhD symposium Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

See SYPD for the full program of the symposium.

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Invited talks of the joint symposium SAMOP Dissertation Prize 2022 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt
SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron's Atomic Mass** — •Sascha Rau

Invited talks of the joint symposium Rydberg Physics in Single-Atom Trap Arrays (SYRY)

See SYRY for the full program of the symposium.

SYRY 2.1	Wed	10:30–11:00	Audimax	**Many-body physics with arrays of Rydberg atoms in resonant interaction** — •Antoine Browaeys
SYRY 2.2	Wed	11:00–11:30	Audimax	**Optimization and sampling algorithms with Rydberg atom arrays** — •Hannes Pichler
SYRY 2.3	Wed	11:30–12:00	Audimax	**Slow dynamics due to constraints, classical and quantum** — •Juan P. Garrahan
SYRY 3.3	Wed	14:30–15:00	Audimax	**New frontiers in quantum simulation and computation with neutral atom arrays** — •Giulia Semeghini

SYRY 3.4	Wed	15:00–15:30	Audimax	**New frontiers in atom arrays using alkaline-earth atoms** — •Adam Kaufman
SYRY 3.5	Wed	15:30–16:00	Audimax	**Spin squeezing with finite range spin-exchange interactions** — •Ana Maria Rey

Invited talks of the joint symposium Quantum Cooperativity of Light and Matter (SYQC)

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	10:30–11:00	Audimax	**Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide** — •Arno Rauschenbeutel
SYQC 1.6	Thu	12:00–12:30	Audimax	**Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments** — •Susana F. Huelga
SYQC 2.1	Thu	14:00–14:30	Audimax	**Quantum simulation with coherent engineering of synthetic dimensions** — •Paola Cappellaro
SYQC 2.6	Thu	15:30–16:00	Audimax	**Quantum Fractals** — •Cristiane Morais-Smith

Sessions

A 1.1–1.2	Mon	11:00–13:00	AKjDPG-H18	**Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses (joint session AKjDPG/A)**
A 2.1–2.4	Mon	14:00–15:15	A-H1	**Interaction with strong or short laser pulses I**
A 3.1–3.6	Mon	14:00–15:30	A-H2	**Precision spectroscopy of atoms and ions I (joint session A/Q)**
A 4.1–4.9	Mon	14:00–16:15	MO-H5	**X-ray FELs (joint session MO/A)**
A 5	Mon	16:30–17:00	A-MV	**Annual General Meeting**
A 6.1–6.5	Tue	10:30–12:00	A-H1	**Interaction with strong or short laser pulses II**
A 7.1–7.7	Tue	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC I (joint session A/Q)**
A 8.1–8.4	Tue	16:30–18:30	P	**Atomic systems in external fields**
A 9.1–9.5	Tue	16:30–18:30	P	**Collisions, scattering and correlation phenomena**
A 10.1–10.10	Tue	16:30–18:30	P	**Interaction with strong or short laser pulses**
A 11.1–11.4	Tue	16:30–18:30	P	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
A 12.1–12.15	Tue	16:30–18:30	P	**Ultracold Atoms and Plasmas (joint session Q/A)**
A 13.1–13.15	Tue	16:30–18:30	P	**Precision Measurements and Metrology I (joint session Q/A)**
A 14.1–14.6	Wed	10:30–12:15	A-H1	**Interaction with VUV and X-ray light**
A 15.1–15.7	Wed	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC II (joint session A/Q)**
A 16.1–16.7	Wed	10:30–12:30	Q-H11	**Precision Measurements and Metrology IV (joint session Q/A)**
A 17.1–17.5	Wed	14:00–15:30	A-H1	**Collisions, scattering and correlation phenomena**
A 18.1–18.6	Wed	14:00–15:30	Q-H11	**Precision Measurements and Metrology V (joint session Q/A)**
A 19.1–19.5	Wed	14:00–15:15	A-H2	**Precision spectroscopy of atoms and ions II (joint session A/Q)**
A 20.1–20.21	Wed	16:30–18:30	P	**Precision spectroscopy of atoms and ions (joint session A/Q)**
A 21.1–21.9	Wed	16:30–18:30	P	**Highly charged ions and their applications**
A 22.1–22.7	Thu	10:30–12:30	A-H1	**Charged ions and their applications**
A 23.1–23.6	Thu	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC III (joint session A/Q)**
A 24.1–24.6	Thu	10:30–12:15	A-H3	**Precision spectroscopy of atoms and ions III (joint session A/Q)**
A 25.1–25.8	Thu	10:30–12:30	Q-H10	**Ultracold Atoms and Molecules I (joint session Q/A)**
A 26.1–26.7	Thu	14:00–15:45	A-H1	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
A 27.1–27.5	Thu	14:00–15:30	Q-H10	**Ultracold Atoms and Molecules II (joint session Q/A)**
A 28.1–28.3	Thu	16:30–18:30	P	**Interaction with VUV and X-ray light**
A 29.1–29.22	Thu	16:30–18:30	P	**Ultra-cold atoms, ions and BEC (joint session A/Q)**

A 30.1–30.16	Thu	16:30–18:30	P	**Precision Measurements and Metrology II (joint session Q/A)**
A 31.1–31.6	Fri	10:30–12:15	A-H1	**Ultra-cold atoms, ions and BEC IV (joint session A/Q)**
A 32.1–32.5	Fri	10:30–12:00	A-H2	**Precision spectroscopy of atoms and ions IV (joint session A/Q)**
A 33.1–33.5	Fri	10:30–11:45	Q-H14	**Rydberg Systems (joint session Q/A)**

Annual General Meeting of the Atomic Physics Division

Monday 16:30–17:00 A-MV

A 1: Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses (joint session AKjDPG/A)

Time: Monday 11:00–13:00 Location: AKjDPG-H18

Tutorial A 1.1 Mon 11:00 AKjDPG-H18

Atoms and molecules in strong fields and how to observe times and phases — •Manfred Lein — Institute of Theoretical Physics, Leibniz University Hannover

The interaction of strong laser fields with atoms and molecules leads to a number of nonlinear, i.e., multiphoton processes such as above-threshold ionization, high-harmonic generation, or frustrated tunnel ionization. This talk reviews the fundamental mechanisms and theoretical methods related to these processes. We will also review schemes for observing the spatiotemporal properties of strong-field dynamics, including for example ionization times, target structure, and the phases of electron wave packets.

Tutorial A 1.2 Mon 12:00 AKjDPG-H18

Ultrafast light-matter interaction: Measuring and controlling quantum dynamics with attosecond and femtosecond flashes of light — •Christian Ott — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Ultrafast light-matter interaction is an exciting aspect of modern quantum physics, directly resolving the fastest motion of electrons inside and in between atoms and molecules that constitute the matter that is surrounding us, where the coherence times can be as short as femtoseconds or even attoseconds. Strong laser fields are available as pulsed flashes of light, with durations of only a few optical oscillation periods in the single-digit femtosecond regime, and an electric field strength that becomes comparable to the electromagnetic binding forces within atoms and molecules. These pulses allow one to measure, understand and control the electron dynamics in natural quantum systems at a fundamental level. In combination with new attosecond light sources at extreme ultraviolet and x-ray wavelengths, derived from high-order harmonic generation or at (x-ray) free-electron laser facilities, this allows one to obtain dynamic fingerprints that are very specific for each atomic species (i.e., time-resolved ultrafast x-ray spectroscopy).

In this lecture I will give a basic introduction into this research topic with focus on absorption spectroscopy of atoms and molecules, and how the resonant transmission of ultrashort and intense light pulses through an absorbing target can be modified and controlled with strong fields and how the control of the dipole response of light-matter interaction develops on the ultrafast timescale.

A 2: Interaction with strong or short laser pulses I

Time: Monday 14:00–15:15 Location: A-H1

Invited Talk A 2.1 Mon 14:00 A-H1

Attosecond pulse control with sub-cycle, infrared waveforms — •Miguel Angel Silva-Toledo[1,3], Yudong Yang[1], Roland E. Mainz[1], Giulio Maria Rossi[1], Fabian Scheiba[1,2,3], Phillip D. Keathley[4], Giovanni Cirmir[1,2], and Franz X. Kärtner[1,2,3] — [1]Center for Free-Electron Laser Science CFEL and Deutsches Elektronen-Synchrotron DESY, Notkestrasse e 85, 22607 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Physics Department, Universität Hamburg, Jungiusstrasse 9, 20355 Hamburg — [4]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Sub-femtosecond shaping of light fields driving high-harmonic generation (HHG) allows amplitude- and phase-control of coherent extreme ultraviolet and soft X-ray radiation. Here, we experimentally demonstrate such control in the energy range covering $\sim$ 30 - 200 eV using tailored, sub-cycle pulses (i.e., shorter than their main oscillation period), delivered by an optical parametric amplification-based waveform synthesizer. Sub-cycle pulse synthesis is realized by coherently combining near-infrared ($\lambda_0 \sim 0.8\mu$m, $\sim$ 6 fs, $\sim 150\mu$J) and infrared ($\lambda_0 \sim 1.6\mu$m, $\sim$ 8 fs, $\sim 500\ \mu$J) pulses which, after varying their carrier envelope and relative phases, lead to the direct generation of spectrally controlled isolated attosecond pulses (IAPs). Attosecond-resolved measurements characterize the temporal profile of the generated IAPs. Experimental observations are also combined with HHG simulations. Our study will aid research on optimal driver fields for efficient and tunable HHG.

A 2.2 Mon 14:30 A-H1

Reconstruction of Tunnel Ionization Dynamics in Dielectrics from Injection Harmonics — Peter Jürgens[1], •Benjamin Liewehr[2], Björn Kruse[2], Christian Peltz[2], Tobias Witting[1], Anton Husakou[1], Arnaud Rouzeé[1], Mikhail Ivanov[1], Thomas Fennel[1,2], Mark J. J. Vrakking[1], and Alexandre Mermillod-Blondin[1] — [1]Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany — [2]Institute for Physics, University of Rostock, Germany

The nonlinear response of dielectric solids to strong fields enables high-harmonic generation that has been studied extensively in the context of light-driven intraband charge dynamics and interband recombination [1,2]. However, it was shown recently that these mechanisms do not explain the emission of low harmonic orders which are instead dominated by the strong field tunneling excitation that drives Brunel and injection currents [3]. Based on an ionization-radiation model, we examine signatures and scaling behavior of ionization induced harmonics to reveal the strong-field-induced nonlinearity in time-resolved, low-order wave-mixing experiments in amorphous SiO_2. From the identified injection signal, the tunnel-ionization trace is reconstructed [4], which opens routes for improved control in femtosecond laser processing of solids.

[1] T. T. Luu, et al. Nature **521**, 498 (2015)
[2] G. Vampa, et al. Nature **522**, 462 (2015)
[3] P. Jürgens, B. Liewehr, B. Kruse, et al. Nat. Phys. **16**, 1035 (2020)
[4] P. Jürgens, et al. (accepted) arXiv:2108.03053 (2021)

A 2.3 Mon 14:45 A-H1

Electron dynamical mechanisms for high-harmonic generation in Fibonacci quasicrystals — •Francisco Navarrete and Dieter Bauer — Institut für Physik-Universität Rostock

The mechanism of high-harmonic generation (HHG) in solids has been theoretically studied over the last two decades, and experimentally verified a decade ago [1]. While many conclusions have been drawn for this process in periodic crystals, it has also been predicted a strong dependence of the HHG spectrum on the topology of the sample [2]. Recently, by the study of a Fibonacci chain, it has been demonstrated that quasicrystals might constitute excellent materials for HHG due to their higher yield [3], when compared with crystals of the same composition. In this presentation, we will discuss the electron-dynamics responsible for HHG in Fibonacci quasicrystals when compared to both crystals and amorphous materials. We will describe the crystal-momentum resolved [4] contributions as well as mechanisms that might explain the yield enhancement as well as the parity of the harmonics in each material.

[1] Shambhu Ghimire *et al*, *Nat. Phys.* **7**, 138(2011)
[2]Christoph Jürß and Dieter Bauer, *Phys. Rev. B* **99**, 195428 (2019)
[3]Jia-Qi Liu and Xue-Bin Bian, *Phys. Rev. Lett.* **127**, 213901 (2021)
[4]Francisco Navarrete, Marcelo F. Ciappina and Uwe Thumm, *Phys. Rev. A* **100**, 033405(2019)

A 2.4 Mon 15:00 A-H1

Making non-adiabatic photoionization adiabatic — •Jonathan Dubois, Ulf Saalmann, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

We consider the process of tunnel ionization of atoms driven by circularly polarized (CP) pulses. An intuitive semiclassical picture of tunnel ionization by a static laser field is an electron ionizing through the potential barrier induced by the laser field with constant energy, referred to as the adiabatic ionization. When the laser field alternates in time, such as it is the case for CP pulses, the energy of the electron changes in time, and at the tunnel exit, it is distributed in a range of energy on the order of the ponderomotive energy of the laser. The adiabatic picture no longer holds, and the ionization process is referred to as nonadiabatic. Extensive theoretical and experimental studies are performed in the attosecond community to probe and understand these nonadiabatic effects in photoionization.

Our goal is to understand nonadiabatic processes in CP pulses using electron trajectories in the combined laser and Coulomb fields. We map the electron dynamics in a frame which rotates with the laser field, referred to as the rotating frame (RF). Our results show that in the RF, counter-intuitively, the energy of the electron is constant during tunnel ionization, and as a consequence follows the picture of adiabatic ionization. This allows us to understand and predict, for instance, the role played by ring currents in atoms and the shape of the laser envelope, and to shed light on classical-quantum correspondence.

A 3: Precision spectroscopy of atoms and ions I (joint session A/Q)

Time: Monday 14:00–15:30 Location: A-H2

A 3.1 Mon 14:00 A-H2

Sympathetic cooling of macroscopically separated ions via image-current coupling — •Christian Will[1], Matthew Bohman[1,2], Markus Wiesinger[1,2], Fatma Abbass[4], Jack Devlin[2,7], Stefan Erlewein[2,7], Markus Fleck[2,8], Julia Jäger[1,7], Barbara Latacz[2], Peter Micke[7], Andreas Mooser[1], Daniel Popper[4], Elise Wursten[1,2,7], Klaus Blaum[1], Yasuyuki Matsuda[8], Christian Ospelkaus[5,6], Wolfgang Quint[9], Jochen Walz[3,4], Christian Smorra[2,4], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernphysik — [2]RIKEN — [3]Helmholtz-Institut Mainz — [4]Johannes Gutenberg-Universität Mainz — [5]Leibniz Universität Hannover — [6]Physikalisch-Technische Bundesanstalt — [7]CERN — [8]University of Tokyo — [9]GSI Helmholtzzentrum für Schwerionenforschung GmbH

A general-purpose cooling technique that achieves mK-temperatures for species without suitable laser transitions is of interest for a wide range of AMO experiments with trapped charged particles. We present recently published results on sympathetically cooling a single proton in a Penning trap with laser-cooled beryllium ions located in a different trap (Bohman et al., Nature, 2021). Coupling is achieved via image currents induced in adjacent trap electrodes, allowing a macroscopic separation between the two species. This techniques allows cooling of any trapped charged particle, with a particular focus on exotic species such as antimatter or highly-charged ions.

This talk will cover the most recent experimental results as well as future prospects based on simulation work.

A 3.2 Mon 14:15 A-H2

Implementing Sympathetic Laser Cooling and a Josephson Junctions based Voltage Source for the Measurement of the Nuclear Magnetic Moment of ^{3}He^{2+} — •Annabelle Kaiser[1], Antonia Schneider[1], Andreas Mooser[1], Stefan Dickopf[1], Marius Müller[1], Alexander Rischka[1], Stefan Ulmer[2], Jochen Walz[3], and Klaus Blaum[1] — [1]Max-Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]RIKEN, Wako, Japan — [3]Johannes Gutenberg-University and Helmholtz-Institute, Mainz, Germany

The Heidelberg 3He-experiment is aiming at the first direct high-precision measurement of the nuclear magnetic moment of ^{3}He^{2+}, with a relative uncertainty on the 10^{-9} level. The helion nuclear magnetic moment is an important parameter for the development of hyperpolarized 3He-NMR-probes for absolute magnetometry.

The measurement is performed using a cryogenic four Penning-trap setup, with techniques presented in [1]. To achieve the mandatory frequency stability for spin-state detection, a single ^{3}He^{2+} ion will be prepared at temperatures of a few mK via sympathetic laser cooling with ^{9}Be$^+$. To further improve the stability, the noise generated by the voltage sources applied to the trap electrodes can be reduced by implementing Josephson junctions as a voltage source. The tuning will be achieved by switching a low-noise DAC in series to the Josephson junctions, aiming at an absolute voltage stability better than 70nV over two minutes. The setup and status of the project will be presented.

[1] Mooser et al, J. Phys.: Conf. Ser. 1138 012004 (2018)

A 3.3 Mon 14:30 A-H2

High-precision measurement of the hyperfine structure of ^{3}He$^+$ in a Penning trap — •Antonia Schneider[1], Bastian Sikora[1], Stefan Dickopf[1], Marius Müller[1], Natalia S. Oreshkina[1], Alexander Rischka[1], Igor 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 Institute for Nuclear Physics, Saupfercheckweg 1, D-69117, Heidelberg, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan — [3]Institute for Physics, Johannes Gutenberg-University Mainz, Staudinger Weg 7, D-55099 Mainz, Germany — [4]Helmholtz Institute Mainz, Staudingerweg 18, D-55128 Mainz, Germany

We investigated the ground-state hyperfine structure of a single ^{3}He$^+$ ion in a Penning trap to directly measure the zero-field hyperfine splitting, the bound electron g-factor and the nuclear g-factor with a relative precision of $3 \cdot 10^{-11}$, $2 \cdot 10^{-10}$ and $8 \cdot 10^{-10}$, respectively. The latter allows for the determination of the g-factor of the bare nucleus with a relative precision of $8 \cdot 10^{-10}$ via our accurate calculation of the diamagnetic shielding constant. This constitutes the first direct calibration for ^{3}He nuclear magnetic resonance (NMR) probes and an improvement of the precision by one order of magnitude compared to previous indirect results [1]. The measured zero-field hyperfine splitting allows us to determine the Zemach radius, which characterizes the electric and magnetic form factors, with a relative precision of $7 \cdot 10^{-3}$.

[1] Y. I. Neronov and N. N. Seregin, Metrologia, **51** (2014) 54.

A 3.4 Mon 14:45 A-H2

Optimal laser cooling of a single ion in a radiofrequency trap — •Daniel Vadlejch[1], André Kulosa[1], Henning Fürst[1,2], Oleg Prudnikov[3], and Tanja Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Institute of Laser Physics, 630090, Novosibirsk, Russia

We present a systematic study of quench cooling of a single ion trapped in a linear radiofrequency (RF) Paul trap. In our experiments, a narrow electronic quadrupole transition near 411 nm in ^{172}Yb$^+$ is used for resolved sideband cooling [1]. The cooling transition is effectively quench-broadened by means of a laser at 1650 nm, coupling the excited state of the transition to a higher-lying, fastly decaying state. We control the broadening via the intensity of the quenching field and distinguish different regimes of laser cooling. We show optimum cooling parameters for rapid cooling towards the motional ground state of the trap and discuss their impact on the population distribution of Fock states during the cooling process. The presented work builds the fundament for further multi-ion experiments, e.g, using large mixed-species crystals with different cooling properties for optical clocks [2].

[1] D. Kalincev et al., *Quantum Sci. Technol.* **6**, 034033 (2021).
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019).

A 3.5 Mon 15:00 A-H2

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

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. We plan to perform high-precision spectroscopy on single MHI in the Penning-trap setup of Alphatrap [1], initially focusing on the hyperfine structure of HD$^+$. This will allow extracting the bound g factors of the constituent particles and coefficients of the hyperfine hamiltonian. The latter can be compared with high-precision ab initio theory [2] and are important for a better understanding of rovibrational spectroscopy performed on this ion.

In the future, we aim to extend our methods to single-ion rovibrational laser spectroscopy of H_2^+ enabling the ultra precise determination of fundamental constants, such as $m_\mathrm{p}/m_\mathrm{e}$ [3]. The development of the required techniques will be an important step towards spectroscopy of an antimatter $\overline{\mathrm{H}}_2^-$ ion [4]. In this contribution, I will present an overview of the experimental setup and first measurement results of the hyperfine structure of HD^+.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] J.-Ph. Karr, *et al.* Phys. Rev. A **102**, 052827 (2020)
[3] J.-Ph. Karr, *et al.*, Phys. Rev. A **94**, 050501(R) (2016)
[4] E. Myers, Phys. Rev. A **98**, 010101(R) (2018)

A 3.6 Mon 15:15 A-H2

Enhanced Dipolar Interactions — •Artur Skljarow[1], Benyamin Shnirman[1], Xiaoyu Cheng[1], Charles S. Adams[2], Tilman Pfau[1], Robert Löw[1], and Hadiseh Alaeian[3] — [1]5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, Germany — [2]JQC Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, United Kingdom — [3]Department of Physics & Astronomy, Purdue Quantum Science & Engineering Institute, Purdue University, West Lafayette, IN, USA

The interest in nonlinear quantum optics based on strong photon-photon interactions continuously grows with time as it might lead to an all-optical quantum network.

Atoms aligned in a 1D chain or 2D lattice show stronger interactions than in an arbitrary 3D arrangement as they exchange photons in a favored direction. A wide variety of ultracold experiments makes use of this fact by trapping individual atoms in 1D or 2D optical traps or tweezers and probing their interaction with a free-space laser beam. In contrast to the ultracold experiments, here we create confined 1D light fields, well below the diffraction limit, with engineered nanophotonic devices and immerse them in a thermal cloud of atoms. As a result, we observe the first realization of repulsive blue-shifted dipole-dipole interactions in a thermal vapor. Additionally, we demonstrate the power of nanophotonics by boosting those interactions by almost one order of magnitude via a Purcell modification hence, creating a highly nonlinear medium.

A 4: X-ray FELs (joint session MO/A)

Time: Monday 14:00–16:15 Location: MO-H5

A 4.1 Mon 14:00 MO-H5

Following excited-state chemical shifts in molecular ultrafast x-ray photoelectron spectroscopy — •Dennis Mayer[1], Fabiano Lever[1], David Picconi[1], Jan Metje[1], Skirmantas Alisauskas[2], Francesca Calegari[3], Stefan Düsterer[2], Christopher Ehlert[4], Raimund Feiffel[5], Mario Niebuhr[1], Bastian Manschwetus[2], Marion Kuhlmann[2], Tomaso Mazza[6], Matthew S. Robinson[1,3], Richard J. Squibb[5], Andrea Trabattoni[3], Mans Wallner[5], Peter Saalfrank[1], Thomas J.A. Wolf[7], and Markus Gühr[1] — [1]University of Potsdam, Germany — [2]DESY, Hamburg, Germany — [3]CFEL, Hamburg, Germany — [4]HITS gGmbH, Heidelberg, Germany — [5]University of Gothenburg, Sweden — [6]European XFEL GmbH, Hamburg, Germany — [7]Stanford PULSE Institute, Menlo Park, USA

We demonstrate the capabilities of time-resolved x-ray photoelectron spectroscopy with a study of the UV-excited dynamics of 2-thiouracil conducted at the FLASH free electron laser in Hamburg, Germany. By probing sulfur 2p core electrons, we discover that a significant part of the excited-state population relaxes to the ground state within 220-250fs. Observed spectral shifts can be directly attributed to a charge redistribution over the molecule during the relaxation process. Additionally, we observe a 250fs oscillation in the kinetic energy of the excited-state population which reveals a coherent population exchange among electronic states.

A 4.2 Mon 14:15 MO-H5

How to produce nuclear-polarized hydrogen molecules and for what they can be used — •Ralf Engels — Institut für Kernphysik, FZ Jülich/GSI Darmstadt

In accelerator experiments polarized proton/deuteron beams and hydrogen/deuterium targets are an important tool to investigate the spin dependence of the nuclear forces. Both can be made with a polarized atomic beam source, a modern version of a Rabi apparatus. By recombination of these atoms hyper-polarized H_2, D_2 and HD molecules in many hyperfine substates are produced and can be used for further applications. For example, the recombination process itself and his dependence on the electron spin, surface materials or external radiation can be investigated as well as the coupling of the nuclear spins with the rotational magnetic moment. In nuclear physics the polarized molecules allow to increase the target density and with polarized molecular ions a better stripping injection into storage rings is possible. Further applications may be the use as polarized fuel for fusion reactors or the search for an electric dipole moment of the nucleons.

A 4.3 Mon 14:30 MO-H5

Correlation fingerprints in the x-ray induced Coulomb explosion of iodopyridine — •Benoît Richard[1,2,3], Julia Schäfer[1,4], Zoltan Jurek[1], Robin Santra[1,2,3,4], and Ludger Inhester[1,2] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Department of Physics, Universität Hamburg, Notkestr. 9-11, 22607 Hamburg, Germany — [4]Department of Chemistry, Universität Hamburg, Martin-Luther-King-Platz 6, 20146 Hamburg, Germany

Coulomb explosion induced by XFEL radiation is a promising experimental tool to image individual molecules. However, the amount of information about the original molecule geometry that can be inferred from the measured final momenta of the produced ions is presently unknown. In particular, the data acquired by state of the art multi-coincidence measurement techniques contains information about correlations between the different measured ions, but how to exploit this extra information for geometry reconstruction is currently unclear. In this work we propose a first step in this direction. To this end we analyze simulation data for the x-ray induced Coulomb explosion of 2-iodopyridine and describe its fragmentation dynamics. Crucially, we show that a collision between two ions during the Coulomb explosion causes strong and possibly measurable correlations between their final momenta.

A 4.4 Mon 14:45 MO-H5

Universal Reconstruction of Nanoclusters from Wide-Angle X-Ray Diffraction Patterns with Physics-Informed Neural Networks — •Thomas Stielow and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock

Single-shot diffraction imaging by soft X-ray laser pulses is a valuable tool for structural analysis of unsupported and short-lived nanosystems, while the exact inversion of the scattering patterns still proves challenging [1]. Deep learning, on the other hand, is widely used in data sciences for the extraction of information from images and has recently been used to accelerate parameter reconstructions from wide-angle scattering patterns [2]. Here, we show how a deep neural network can be used to reconstruct complete three-dimensional object models of uniform, convex particles from single two-dimensional wide-angle scattering patterns. Through physics-informed training the reconstructions achieve unprecedented levels of detail on real-world experimental data [3].

[1] I. Barke *et al.* Nat. Commun. **6**, 6187 (2015).
[2] T. Stielow *et al.* Mach. Learn.: Sci. Technol. **1**, 045007 (2020).
[3] T. Stielow and S. Scheel, Phys. Rev. E **103**, 053312 (2021).

A 4.5 Mon 15:00 MO-H5

Ultrafast Auger spectroscopy of 2-thiouracil — •F. Lever[1], D. Mayer[1], D. Picconi[1], J. Metje[1], S. Alisauskas[2], F. Calegari[2], S. Düsterer[2], C. Ehlert[3], R. Feifel[4], M. Niebuhr[1], B. Manschwetus[2], M. Kuhlmann[2], T. Mazza[6], M. S. Robinson[5], R. J. Squibb[4], A. Trabattoni[5], M. Wallner[4], P. Saalfrank[1], T. J. A. Wolf[7], and M. Gühr[1] — [1]Universität Potsdam — [2]Deutsches Elektronen Synchroton (DESY) — [3]Heidelberg Institute for Theoretical Studies — [4]Department of Physics, Gothenburg University — [5]Center for Free-Electron Laser Science (CFEL) — [6]European XFEL — [7]SLAC, Stanford

Investigating the effects of UV exposure in thionucleobases can shed light on the mechanisms that cause the formation of DNA lesions. In this talk, we show how ultrafast x-ray spectroscopy can be used to gain information on such processes. We study the sulfur 2p Auger spectrum of 2-thiouracil in a uv-pump, x-ray probe experiment at the free electron laser FLASH. We observe ultrafast dynamics in the electron kinetic energy spectrum, happening on time scales of 100fs to 1ps. Using a simple coulomb model for the electron binding energies, aided by quantum chemical calculations of the electronic states energy, we deduce an elongation of the C-S bond on a 100fs time scale. The geometric changes trigger internal conversion from the initally excited S2 state to the S1 state. For longer pump-probe delays, the observerd timescales provide evidence for inter system crossing from the S1 state to the triplet manifold [1].

[1] F Lever et al 2020 J. Phys. B: At. Mol. Opt. Phys. 54 014002

A 4.6 Mon 15:15 MO-H5

Control of bionanoparticles with electrical fields — •Jannik Lübke[1,2,3], Lena Worbs[1,2], Armando Estillore[1], Amit Samanta[1], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Hamburg, Germany — [3]Center for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany

Single-particle imaging (SPI) experiments at free-electron lasers (FELs) promise high-resolution imaging of the structure and dynamics of nanoparticles and macromolecules. Guiding sample particles into the focus of an FEL, diffraction patterns of individual particles can be collected. Sufficient amounts of patterns of identical nanoparticles are needed to overcome the inherently small signal-to-noise ratio and reconstruct the underlying 3D structure. Optimized delivery of identical nanoparticles is key to efficient and successful SPI experiments. Here, we present an approach for the production of purified high-density beams of a broad variety of biological nanoparticles, demonstrated on a large protein. We establish control through electric fields, aiming at charge state or conformational state selectivity. This is especially relevant for soft biological samples, such as proteins or protein complexes, which in uncontrolled environment are prone to structural instability.

A 4.7 Mon 15:30 MO-H5

Tracing Inner-Shell-Ionization-Induced Dynamics of Water Molecules Using an X-ray Free-Electron Laser and Ab-Initio Simulations — •Ludger Inhester[1], Till Jahnke[2], Renaud Guillemin[3], and Maria Novella Piancastelli[3,4] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]European XFEL, Schenefeld — [3]Sorbonne Université, CNRS, LCPMR, Paris — [4]Uppsala University, Uppsala

The response of molecules to ionizing radiation is of utmost relevance to many research areas. Multi-coincidence signals from experiments at x-ray free-electrons lasers provide us new opportunities to study the dynamics of molecules upon inner-shell ionization. In a recent experiment at the European XFEL, water vapor has been exposed to intense x-ray pulses and all the resulting ion fragments have been recorded in coincidence. In this talk, I will discuss how through ab-initio simulations of the multiphoton multiple ionization and fragmentation dynamics we could identify distinct signatures in the ion momentum data with different break-up patterns. By combining experimental results and theoretical modeling, we were able to image the dissociation dynamics of water after core-shell ionization and subsequent Auger decay in unprecedented detail and uncover fundamental dynamical patterns relevant for the radiation damage in aqueous environments. [1]

[1] T. Jahnke et al., Phys. Rev. X 11, 041044 (2021)

A 4.8 Mon 15:45 MO-H5

Competition of interatomic Coulombic decay and autoionization in doubly excited helium nanodroplets — •Björn Bastian, Jakob D. Asmussen, Ltaief B. Ltaief, Akgash Sundaralingam, Catharina I. Vandekerckhove, and Marcel Mudrich — Department of Physics and Astronomy, Aarhus University, DK

Double-excitation states in helium atoms are an important model system to study electron-electron correlation. Doubly excited atoms can autoionize and the interference with the direct ionization pathway gives rise to characteristic Fano peaks in the photoexcitation spectrum [1] which has also been observed in helium nanodroplets [2]. In dimers or clusters, the de-excitation energy can instead be transferred and cause ionization of the environment. Theory has shown, that this interatomic Coulombic decay (ICD) pathway becomes fast at small interatomic distances and competes with autoionization especially in large environments [3].

We present photoion-photoelectron coincidence spectra around the Fano resonance below the N=2 ionization threshold in helium nanodroplets that have been recorded at our new endstation at the AMO-Line of the ASTRID2 synchrotron at Aarhus. Slow electrons reveal ICD or secondary inelastic scattering. Highly resolved electron spectra recorded at various photon energies across the Fano resonance reveal the details of the decay process.

[1] Domke et al. *Phys. Rev. Lett.* **66**, 1306 (1991). [2] LaForge et al. *Phys. Rev. A* **93**, 050502 (2016). [3] Jabbari et al. *Chem. Phys. Lett.* **754**, 137571 (2020).

A 4.9 Mon 16:00 MO-H5

Simulating Molecular Diffraction Patterns using CMIdiffract — •Nidin Vadassery[1,3], Sebastian Trippel[1,2], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Physics, Universität Hamburg — [3]Department of Chemistry, Universität Hamburg

The structure and time-dependent dynamics of molecules in the gas phase reveal a plethora of information about fundamental processes in nature. X-rays and electrons are typically used to image the molecular structure using diffraction techniques. In that respect, x-ray pulses provided by XFELs have the potential to study the chemical dynamics of gaseous molecules on the ultrafast time scale with sub-picometer spatial resolution. Here, we present our computational results using CMIdiffract, an in-house software package developed to compare experimental diffraction images with theory. The package incorporates various aspects of x-ray diffraction experiments, e.g., angular distributions of molecular samples.

A 5: Annual General Meeting

Time: Monday 16:30–17:00 Location: A-MV

Annual General Meeting

A 6: Interaction with strong or short laser pulses II

Time: Tuesday 10:30–12:00 Location: A-H1

Invited Talk A 6.1 Tue 10:30 A-H1

Synthetic chiral light for control of achiral and chiral media — •Nicola Mayer[1], David Ayuso[1,2], Misha Ivanov[1], and Olga Smirnova[1] — [1]Max-Born-Institut, Berlin, Germany — [2]Imperial College, London, United Kingdom

Light that is chiral in the dipole approximation can be synthetized by combining two or more beams with commensurate frequencies in a non-collinear or tightly-focused setup. The interaction of this particular type of light with a chiral sample leads to giant enantio-sensitive responses [1]. Moreover, the combination of chiral light with Gaussian beams carrying orbital angular momentum (OAM) gives rise to vortexes with azimuthally-varying handedness [2]. Here, we demonstrate new ways in which synthetic chiral can be used to shape the response in both achiral and chiral media. Specifically, we demonstrate the excitation of time-dependent chiral superpositions of atomic states whose handedness can be probed by standard Photoelectron Circular Dichroism methods [3]. Moreover, we demonstrate that chiral OAM beams shape the near- and far-field high-harmonic generation (HHG) signal from isotropic samples of chiral molecules in a topological manner, i.e. the spatial distribution of the HHG signal is described by an integer topological charge.

[1] D. Ayuso et al., Nat. Phot., 2019, 13 (12), 866-871
[2] N. Mayer et al., Chiral topological light, in preparation
[3] N. Mayer et al., Imprinting chirality on atoms using synthetic chiral light, arXiv:2112.02658

A 6.2 Tue 11:00 A-H1

Retrieval of the internuclear distance in a molecule from photoelectron momentum distributions using convolutional neural networks — •Nikolay Shvetsov-Shilovski and Manfred Lein — Leibniz Universität Hannover, Hannover, Germany

We train and use a convolutional neural network (CNN) to recognize the internuclear distance of a two-dimensional H_2^+ molecule from the photoelectron momentum distribution produced by a strong few-cycle laser pulse [1]. We show that the CNN trained on a dataset consisting of a few thousand images can retrieve the internuclear distance with the mean absolute error less than 0.1 a.u.

We investigate the effect of the focal averaging on the retrieval of the internuclear distance. The CNN trained on a set of focal averaged momentum distributions also shows good performance in recognizing of the internuclear distance: the corresponding mean absolute error does not exceed 0.2 a.u. Furthermore, we compare the application of the CNN with an alternative approach based on the direct comparison of the momentum distributions.

[1] N. I. Shvetsov-Shilovski and M. Lein, submitted to Phys. Rev.A, arXiv:2108.08057.

A 6.3 Tue 11:15 A-H1

Torus-knot angular momentum in attosecond pulses from high-harmonic generation — •Björn Minneker[1,2,3], Birger Böning[2,3], Anne Weber[1], and Stephan Fritzsche[1,2,3] — [1]Theoretisch Physikalisches Institut, Friedrich-Schiller-Universität, Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Helmholtz Institut, Jena, Germany

We investigated the dynamical symmetry related to the conservation of torus-knot angular momentum (TKAM) in attosecond bursts from high harmonic generation. In particular, we discuss the characterization of the TKAM for bicircular Laguerre-Gaussian driving beams. Since the orbital angular momentum of the emitted harmonics is not a good quantum number anymore, a different kind of angular momentum is required to characterize them, namely the TKAM. We developed an intuitive model which relates the characteristic parameters τ and γ of the TKAM to the geometry of a torus knot. This is done for both the driving beam and the harmonic radiation. In addition, we found a geometric relation between τ and γ. We hope that our contribution can help to get intuitively access to this form of angular momentum. Furthermore, TKAM maid help to improve the spectroscopical classification of high harmonics driven by bicircular beams.

A 6.4 Tue 11:30 A-H1

High-harmonic generation in finite Haldanite flakes — •Christoph Jürss and Dieter Bauer — Institute of Physics, University of Rostock

In topological insulators, edge states are important for the electron dynamics. The edge states allow a dissipation-less transport of electric current, whereas the bulk is an insulator. In this work, we investigate the contribution of the edge states to the high-order harmonic generation in the Haldane model. Finite "Haldanite" flakes of different sizes are considered. Compared to the spectrum for the respective bulk system, the finite flakes show several additional peaks in the energy region below the band-gap between valence and conduction band. We find that some peaks depend on the flake size. This talk focuses on the origin of this size dependency.

A 6.5 Tue 11:45 A-H1

Time Delay and Nonadiabatic Calibration of the Attoclock and TDSEQ result — •Ossama Kullie[1] and Igor Ivanov[2] — [1]Theoretical Physics, Institute of Physics, University of Kassel — [2]Centre for Relativistic Laser Science, Gwangju, Republic of Korea

The 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 ionization. In earlier works of the the adiabatic field calibration our real tunneling time showed a good agreement with the experimental data of the attoclock [1]. In the present work [1], we show that our model can explain the experimental results in the nonadiabatic field calibration, where we reach a good agreement with the experimental data of Hofmann et al [2]. Moreover, our result is confirmed by a new numerical integration of the Time-dependent Shrödinder equation, see Ivanov et al [2]. Our model is appealing because it offers a clear picture of the multiphoton and tunneling parts. Surprisingly, at a field 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. Kullie arXiv:2005.09938v3, O. Kullie PRA 92, 052118, 2015. [2] Iogr Ivanov et al, J. of Mod. Opt. **66**, 1052, 2019. [3] Phys. Rev. A **89**, 021402, 2014.

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

Time: Tuesday 10:30–12:15 Location: A-H2

A 7.1 Tue 10:30 A-H2

Imaging the interface of a qubit and its quantum many-body environment — Sidharth Rammohan[1], •Aritra Mishra[2], Shiva Kant Tiwari[1], Abhijit Pendse[1], Anil. K. Chauhan[3], Rejish Nath[4], Alexander Eisfeld[2], and Sebastian Wüster[1] — [1]Indian Institute of Science Education and Research, Bhopal, India — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Palacký University, Olomouc, Czechia — [4]Indian Institute of Science Education and Research, Pune, India

Decoherence affects all quantum systems and impedes quantum technologies. In this contribution, we theoretically demonstrate that for a Rydberg atom in a Bose-Einstein condensate, experiments can image the system environment interface that is central for decoherence [1]. High precision absorption images of the condensate can capture transient signals that show real time buildup of the mesoscopic entangled states in the environment. The tuning of the decoherence time scales is possible even from nano seconds to micro seconds using the principle quantum number. As a result, probing is possible even before other sources of decoherence kick in [2]. Finally, we discuss the case in which the system is under a constant microwave drive. This simple modification drastically changes the Hamiltonian as well as the system dynamics, making it non-Markovian, which we study using an advanced numerical technique called the Hierarchy of Pure States [3].

[1] S. Rammohan, et al., (2020), URL https://arxiv.org/abs/2011.11022
[2] S. Rammohan, et al., *Phys. Rev. A.* 103, 063307 (2021)
[3] D. Suess, et al., *Phys. Rev. Lett.* 113, 150403 (2014)

A 7.2 Tue 10:45 A-H2

Observation of Feshbach Resonances between $^{138}Ba^+$ and ^6Li — •Fabian Thielemann[1], Pascal Weckesser[1,2], Joachim Welz[1], Wei Wu[2], Thomas Walker[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs Universität, Freiburg — [2]Max Planck Institut für Quantenoptik, Garching

The experimental control over Feshbach resonances in ensembles of ultracold atoms has lead to breakthrough results in the field. An ion, overlapped with a cloud of ultracold atoms, exhibits a longer range interaction potential and can offer a high degree of control at the single particle level. Reaching the ultracold regime, at which Feshbach resonances emerge, in hybrid traps has so far proven difficult due to micromotion heating. In this talk we present the first observation of Feshbach resonances between ions and atoms by immersing a single $^{138}Ba^+$ ion into a cloud of ultracold ^6Li atoms and demonstrate tunability of the two-body and three-body scattering rate of the atom-ion system.

A 7.3 Tue 11:00 A-H2

Observation of Hole Pairing in Mixed-Dimensional Fermi-

Hubbard Ladders — •Sarah Hirthe[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Petar Bojovic[1,2], Annabelle Bohrdt[3,4], Fabian Grusdt[5,2], Eugene Demler[3,6], Immanuel Bloch[1,2,5], and Timon Hilker[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Harvard University,Cambridge, USA — [4]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA — [5]Ludwig-Maximilians-Universität, Munich, Germany — [6]ETH Zurich, Zurich, Switzerland

Doping an antiferromagnet lies at the heart of many strongly correlated systems and the pairing of dopants in particular is believed to play a key role in the emergence of high-Tc superconductivity. In the talk I will discuss our recent direct observation of hole-pairing due to magnetic order in a Fermi-Hubbard type system in our Lithium quantumgas microscope. We engineer mixed-dimensional Fermi-Hubbard ladders in which the tunneling along the rungs is suppressed, while enhanced spin exchange supports singlet formation, thus drastically increasing the binding energy. We observe pairs of holes preferably occupying the same rung of the ladder. We furthermore find indications for repulsion between pairs when there is more than one pair in the system.

A 7.4 Tue 11:15 A-H2

Adiabatic charge pumping in bosonic Chern insulator analogs — •Isaac Tesfaye, Botao Wang, and André Eckardt — TU Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Deutschland

Mimicking fermionic Chern insulators with bosons has drawn a lot of interest in experiments by using, for example, cold atoms [1,2] or photons [3].
Here we present a scheme to prepare and probe a bosonic Chern insulator analog by using an ensemble of randomized bosonic states.
By applying a staggered superlattice, we identify the lowest band with individual lattice sites. The delocalization over this band in quasimomentum space is then achieved by introducing on-site disorder or local random phases.
Adiabatically turning off the superlattice then gives rise to a bosonic Chen insulator, whose topologically non-trivial property is further confirmed from the Laughlin-type quantized charge pumping.
Our protocol may provide a useful tool to realize and probe topological states of matter in quantum gases or photonic waveguides.

[1] Aidelsburger, Monika, et al. "Measuring the Chern number of Hofstadter bands with ultracold bosonic atoms." Nature Physics 11.2 (2015): 162-166.
[2] Cooper, N. R., J. Dalibard, and I. B. Spielman. "Topological bands for ultracold atoms." Reviews of modern physics 91.1 (2019): 015005.
[3] Ozawa,Tomoki, et. al. "Topological photonics." Rev. of Mod. Phys. 91.1 (2019): 015006

A 7.5 Tue 11:30 A-H2

Machine learning universal bosonic functionals — •Benavides-Riveros Carlos L.[1], Schmidt Jonathan[2], and Fadel Matteo[3] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle (Saale), Germany — [3]Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

The one-body reduced density matrix γ plays a fundamental role in describing and predicting quantum features of bosonic systems, ultra-cold gases or Bose-Einstein condensates. The recently proposed reduced density matrix functional theory for bosonic ground states establishes the existence of a universal functional F[γ] that recovers quantum correlations exactly. Based on a novel decomposition of γ, we have developed a method to design reliable approximations for such universal functionals [1]. Our results demonstrate that for translational invariant systems the constrained search approach of functional theories can be transformed into an unconstrained problem through a parametrization of a Euclidian space. This simplification of the search approach allows us to use standard machine learning methods to perform a quite efficient computation of both F[γ] and its functional derivative. For the Bose-Hubbard model, we present a comparison between our approach and the quantum Monte Carlo method.

[1] Phys. Rev. Research 3, L032063 (2021).

A 7.6 Tue 11:45 A-H2

Fibre cavity based quantum network node with trapped Yb ion — •Santhosh Surendra, Pascal Kobel, Ralf Berner, Moritz Breyer, and Michael Köhl — Physikalisches institute, University of Bonn, Bonn, Germany

Quantum networks are promising to revolutionise information exchange and cryptography. An important part of these networks are nodes where quantum states can be stored, and manipulated. In this work, we investigate such a quantum communication node formed by a trapped Yb ion coupled to an optical fibre cavity. Using a resonant fibre cavity for the electric dipole transition at 370nm, we are able to collect the emitted photons with high efficiency, which carry quantum information from node to node via their polarisation. We use pulsed excitation to realise a fibre coupled, deterministic single photon source, where the photons are entangled with the hyperfine states of the ion with a high fidelity of 90.1(17)%. The state of the trapped ion represents the quantum memory, which is used to realise a memory enhanced quantum key distribution protocol (BBM92), being the first step towards realising a quantum repeater node.

A 7.7 Tue 12:00 A-H2

Pattern formation in quantum ferrofluids: From supersolids to superglasses — •Jens Hertkorn[1], Jan-Niklas Schmidt[1], Mingyang Guo[1], Fabian Böttcher[1], Kevin S. H. Ng[1], Sean D. Graham[1], Paul Uerlings[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany — [2]MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, USA

Pattern formation is a ubiquitous phenomenon observed in nonlinear and out-of-equilibrium systems. In equilibrium, ultracold dipolar quantum gases have been shown to host superfluid quantum droplet patterns, which realize a supersolid phase. Here we theoretically study the phase diagram of such quantum ferrofluids in oblate trap geometries and discover a wide range of exotic states of matter. Beyond the supersolid droplet regime, we find crystalline honeycomb and amorphous labyrinthine states with strong density connections. These patterns, combining superfluidity with a spontaneously broken spatial symmetry, are candidates for a new type of supersolid and superglass, respectively. The stabilization through quantum fluctuations allows one to find these patterns for a wide variety of trap geometries, interaction strengths, and atom numbers. Our study illuminates the origin of the various possible morphologies of quantum ferrofluids, highlights their emergent supersolid and superglass properties and shows that their occurrence is generic of strongly dipolar interacting systems.

A 8: Atomic systems in external fields

Time: Tuesday 16:30–18:30 Location: P

A 8.1 Tue 16:30 P

Numerical Studies of atom-based microwave eletric field sensing in hot vapors — •Matthias Schmidt[1], Fabian Ripka[1], Chang Liu[1], Harald Kübler[1,2], 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, Pfaffenwaldring 57, D-70569 Stuttgart, Germany

We present progress in atom-based microwave electric field sensing using Rydberg atoms in hot vapors. We find 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 microwave. We present a simplified theoretical model where we consider the small microwave intensity as an induced detuning of the coupling laser. With this model we can analytically investigate the main contribution to the transmission signal and find a simple relation between the change of the transmission and the incident RF electric field strength. Furthermore we present a three photon excitation scheme, with which residual Doppler broadening is suppressed. This enables a spectral resolution comparable to the Rydberg state decay rate, the spectral bandwith limitation.

A 8.2 Tue 16:30 P

Interaction of atoms with cylindrically polarized Laguerre-Gaussian beams — •Shreyas Ramakrishna[1,2,3], Jiri Hofbrucker[1,2], 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

The excitation of atoms with a single valence electron by cylindrically polarized Laguerre-Gaussian beams is analyzed within the framework of first-order perturbation theory. For cylindrically polarized Laguerre-Gaussian beams, we show that the magnetic components of the electric-quadrupole field varies significantly in the beam cross-section with beam waist and radial distance from the beam axis. Furthermore, we discuss the influence of varying magnetic components of the electric-quadrupole field in the beam cross-section on the sublevel population of a localized atomic target. In addition, we calculate the total excitation rate of electric quadrupole transition (4s $^2S_{1/2}$ - 3d $^2D_{5/2}$) in a mesoscopic target of Ca^+ ion. Our calculation shows that the cylindrically polarized Laguerre-Gaussian beams are more efficient in driving electric quadrupole transition in the mesoscopic atomic target than circularly polarized beams.

A 8.3 Tue 16:30 P

Quadrupole transitions with continuous dynamical decoupling — •Víctor José Martinez Lahuerta[1], Lennart Pelzer[2], Ludwig Krinner[2], Kai DIetze[2], Piet Schmidt[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

Continuous dynamical decoupling provides a powerful method to protect decoherence on atomic transitions due to magnetic field fluctuations or electric quadrupole shifts. Here, we analyze the structure of the effective basis under one and two layers of continuous dynamical decoupling. We use this to characterize quadrupole transitions among dynamically decoupled, dressed states, as relevant for ion clocks. Additionally, we characterize effective selection rules and Rabi frequencies.

Finally, this is applied to a quadrupole transition in Ca+ showing accordance with experimental results.

A 8.4 Tue 16:30 P

Quantum Mpemba Effect in simple spin models — •Simon Kochsiek, Federico Carollo, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

In the context of both classical and quantum out-of-equilibrium systems the characteristic time scale that is needed to reach stationarity is of central importance. In particular, if properties of the steady state are to be exploited, the relaxation time is the central hurdle and metastable regions become problematic. In a recent work [1] it was shown that the (quantum) Mpemba Effect provides a way of preparing the initial state of the dynamics such that its overlap with slowly decaying modes is minimized.

We investigate the quantum Mpemba Effect in simple spin systems. While the transformation which annihilates the overlap with the slowest decay mode is difficult to implement practically, we show, that even simple product transformations can lead to a significant speed-up of relaxation. Furthermore we explore the connection between system size and interaction strength with the achievable amount of acceleration.

[1] F. Carollo *et al.*, Phys. Rev. Lett. **127**, 060401 (2021)

A 9: Collisions, scattering and correlation phenomena

Time: Tuesday 16:30–18:30 Location: P

A 9.1 Tue 16:30 P

photoionization time delay in 2D model systems — •sajjad azizi, ulf saalmann, and jan-michael rost — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Time delay is a hot topic, which is discussed and measured mostly for atoms, i.e. spherical single-center objects. In molecules, the interpretation is considerably more challenging since there is a dependence on the direction, and the molecule has a finite extension. We study this problem for 2D short- and long-range model systems.

A 9.2 Tue 16:30 P

Charge-exchange three-body reaction with participation of stau $\tilde{\tau}$ — •Renat A. Sultanov — Odessa College, Department of Mathematics, 201 W. University Blvd., Odessa, Texas 79764, USA

We report computational results for a few-body charge-exchange reaction with participation of heavy, long-lived, SUSY supersymmetric particle stau $\tilde{\tau}$ (or tau slepton) [1]. Specifically, the cross sections and rates are computed for the following three-body reaction:

$$(pX^-) + {}^4\mathrm{He}^{++} \to ({}^4\mathrm{He}^{++}X^-) + p, \tag{1}$$

where p is a proton, ${}^4\mathrm{He}^{++}$ is a helium nucleus and X^- is stau. The mass of X^- is ∼125 GeV [1]. Stau is a supersymmetric partner of τ-lepton. The quasi-stable negatively charged NLSP (next-to-lightest supersymmetric particle) X^- can make Coulomb bound states with nuclei and severely affect the early Big Bang Nucleosynthesis (BBN) era nuclear reactions [2,3]. A detailed few-body approach based on a modified Faddeev-Hahn-type equation formalism [4] is applied to the charge-transfer reaction (1) in this work.

1. CMS Collaboration, *Eur. Phys. J. C* 80:189 (2020).
2. M. Pospelov, *Phys. Rev. Lett.* **98**, 231301 (2007).
3. K. Hamaguchi, T. Hatsuda, M. Kamimura, Y. Kino, T. T. Yanagida, *Phys. Lett. B* **650** 268 (2007).
4. R. A. Sultanov and S. K. Adhikari, *J. Phys. B* **32**, 5751 (1999).

A 9.3 Tue 16:30 P

Multi-electron transfers and -excitations in near-adiabatic collisions of Xe52+,54+ +Xe at the ESR Storage ring — •Siegbert Hagmann[1], Pierre-Michel Hillenbrand[1,2], Jan Glorius[1], Uwe Spillmann[1], Yuri Litvinov[1], Yuri Kozhedub[6], Ilya Tupitsyn[6], Michael Lestinsky[1], Alexander Gumberidze[1,3], Sergij Trotsenko[1,4], Hermann Rothard[7], Enrico DeFilippo[8], Emmanouel Benis[9], Stefan Nanos[9], Robert Grisenti[1,2], Nikos Petridis[1,2], Shahab Sanjari[1], Carsten Brandau[1], Esther Menz[1], Timo Morgenroth[1], and Thomas Stöhlker[1,4,5] — [1]GSI Helmholtz-Zentrum Darmstadt — [2]Inst. f. Kernphysik, Univ. Frankfurt — [3]Extreme Matter Institut EMMI, GSI Darmstadt — [4]Helmholtz Inst. Jena — [5]Inst. f. Optik u. Quantenelektronik, U. Jena — [6]Dep. of Physics, St Petersburg State Univ. — [7]CIMAP, Ganil, Caen France — [8]INFN Catania ,Italy — [9]Univ. of Ioannina, Greece

In near adiabatic collisions of bare to He-like Xe ions with Xe atoms multi-electron transfer processes are studied by measuring the emitted target- and projectile K- and L- x rays in coincidence with projectiles which have captured 3 to 6 electrons, and with time of flight of recoiling Xe target ions. We find that in the projectiles a wide range of electron levels even with main quantum numbers n>5 are excited- extending to a very significant population of Rydberg levels, all dependent on capture multiplicity; a strong contribution of K x rays from high n shells indicates that outer shell transfer avoids Yrast states l=n-1 but dominantly prefers low l states of the projectile with l=1.

A 9.4 Tue 16:30 P

Compton Polarimetry on the polarization transfer in hard x-ray Rayleigh scattering — •Wilko Middents[1,2], Günter Weber[2,3], Uwe Spillmann[3], Marco Vockert[1,2], Philip Pfäfflein[1,2,3], Alexandre Gumberidze[3], Sophia Strnat[4,5], Andrey Surzhykov[4,5], Andrey Volotka[1,6], and Thomas Stöhlker[1,2,3] — [1]IOQ, FSU Jena — [2]Helmholtz Institut Jena — [3]GSI Darmstadt — [4]PTB, Braunschweig — [5]TU Braunschweig — [6]ITMO University

For photon energies up to the MeV range, the fundamental photon-matter interaction process of elastic scattering, where both the energy of the incident and the scattered photon are the same is dominated by Rayleigh scattering. This process, referring to the 2nd order QED process of a photon being scattered on a bound electron exhibits a high degree of sensitivity to the polarization characteristics of the incoming photons. Thus precisely determining the poliarization of the incident and scattered photon beam allow a stringent tests of the underlying theory. For this purpose, we performed an experiment at the 3rd generation synchrotron facility PETRA III of DESY, Hamburg, scattering a highly linearly polarized hard x-ray beam with a photon energy of 175 keV on a gold target. The polarization characteristics of the scattered beam were analyzed within and out of the polarization plane of the incident synchrotron beam using a prototype 2D-sensitive silicon strip detector, developed within the SPARC collaboration, that can be utilized as a highly sensitive Compton polarimeter. We will present both experimental details as well as first results of this beamtime.

A 9.5 Tue 16:30 P

orientation recovery for scattering images from molecules using deep learning — •SIDDHARTHA PODDAR, ULF SAALMANN, and JAN MICHAEL ROST — Max Planck Institute for the Physics of Complex Systems, Noethnitzer Strasse 38, Dresden, Germany

The recovery of a molecule's orientation in coherent-diffractive imaging with intense Xray-pulses is tackled with a deep neural network. This network provides the a priori unknown orientation for each image within the set of single-molecule scattering images. By means of this information it is possible to reconstruct the 3D structure of the molecule from a dedicated subset of 2D projections.

A 10: Interaction with strong or short laser pulses

Time: Tuesday 16:30–18:30 Location: P

A 10.1 Tue 16:30 P

Adiabatic models for the bicircular attoclock — •Paul Winter and Manfred Lein — Leibniz University Hannover

Using counter-rotating bicircular laser fields in an attoclock setup has some big advantages when studying ionization dynamics in strong fields: The field is quasilinear in the close temporal vicinity of the maximal electric field, where ionization is most probable, but nevertheless rescattering is avoided in contrast to purely linearly polarized fields.

The well-defined direction of the field at the ionization time enables us to look at orientation dependencies in the ionization of molecules. An important parameter range is the adiabatic limit, i.e. small Keldysh parameter $\gamma = \sqrt{2I_p}\,\frac{\omega}{E} \ll 1$. In this regime the ionization can be described by a two step model, where the electron travels classically after tunneling out. A crucial factor in these adiabatic models is the location of the exit point where the classical motion starts. The main observable is the attoclock shift of the electron final momentum due to the attractive Coulomb force towards the parent ion.

We compare two-dimensional simulations of the time-dependent Schrödinger equation for HeH^+ and H_2 to results from adiabatic models. A connection of the attoclock shifts to molecular properties such as dipole moment and polarizability arises due to the angle-dependent Stark shift of the ionisation potential.

A 10.2 Tue 16:30 P

Time operator, real tunneling in strong field interaction and the attoclok — •Ossama Kullie — Theoretical Physics, Institute of Physics, University of Kassel

In our work we found a relation to calculate the tunneling time in the attoclock experiment in both cases, the adiabatic and nonadiabatic field calibration [1,2]. Our real tunneling time can be derived from an observable, i.e. a time-energy ordinary commutation relation or a time operator. In addition, it is constructed from Fujiwara-Kobe time operator and the well-known Aharonov-Bohm time operator. The specific form of the time operator is not decisive and a dynamical time operator of a system refers to the intrinsic time of the system. The result 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 [3,4]. [1] To be submitted. [2] O. kullie, PRA **92**, 052118 (2015). [3] O. Kullie, Ann. of Phys. **389**, 333 (2018). [4] O. Kullie, Qauntum report **02**, 233 (2020).

A 10.3 Tue 16:30 P

Non-sequential double ionization of Ne by elliptically polarized laser pulses — •Fang Liu[1,2,3], ZhangJin Chen[4], Birger Böning[1,2,3], and Stephan Fritzsche[1,2,3] — [1]Helmholtz Institute Jena, Jena, Germany — [2]FSU, Jena, Germany — [3]GSI, Darmstadt, Germany — [4]Shantou University, Shantou, China

We show through simulation that an improved quantitative rescattering model (QRS)[1] 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 of Ne exposed to intense elliptically polarized laser pulses with a wavelength of 788 nm at a peak intensity of 5.0×10^{14} W/cm^2. We analyze the asymmetry in the doubly charged ion momentum spectra that were observed by H. Kang *et al.*[2] in the transition from linearly to elliptically polarized laser pulses. Our model reproduces their experimental data well. In addition, we find that this ellipticity-dependent asymmetry is due to the drift velocity along the minor axis of the polarization ellipse. It is indicated that the correlated electron momentum distributions along the minor axis provide access to the subcycle dynamics of recollision and distinguish recollisions before and after the zero crossing of the field. Futhermore, our results demonstrate that the NSDI process can be driven by the elliptically polarized laser pulses.

[1]Z. Chen *et at.*, Phys. Rev. Lett. **79**, 033409 (2009).

[2]H. Kang *et at.*, Phys. Rev. Lett. **120**, 223204 (2018).

A 10.4 Tue 16:30 P

Accurate atomic states in the strong-field approximation with application to the Coulomb asymmetry — •Birger Böning[1,2] and Stephan Fritzsche[1,2,3] — [1]Helmholtz-Institut Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Friedrich-Schiller-Universität, Jena, Germany

Strong-field ionization experiments are routinely performed with a variety of atomic targets. While such measurements play an important role for understanding light-matter interactions, theoretical models often treat the target atoms in a simplified manner and neglect most of their characteristic properties. Often major experimental findings are therefore only qualitatively understood. In particular, the angular distributions of photoelectrons in above-threshold ionization exhibit an asymmetry due to the Coulomb force between photoion and the field-dressed continuum electron if the process is driven by an elliptically polarized laser pulse. Here, we demonstrate how strong-field and atomic structure theories can be brought together to closely model such observations. More precisely, we combine a partial-wave representation of the so-called strong-field approximation with target-specific initial and continuum states from atomic many-body computations. We show that our implementation reproduces the Coulomb asymmetry for lithium, argon and xenon targets in agreement with experiment if a target-specific distorted-Volkov continuum is used for the active electron.

A 10.5 Tue 16:30 P

Modeling ultrafast plasma formation in dielectrics using FDTD — •Jonas Apportin, Christian Peltz, Benjamin Liewehr, Björn Kruse, and Thomas Fennel — Institute for Physics, Rostock, Germany

The Finite-Differences-Time-Domain (FDTD) method provides a realtime solution to Maxwell's equations on a spatial grid that can be easily extended by rate equations for e.g. ionization and is therefore optimally suited for the modeling of nonlinear laser-material interaction and plasma formation in dielectrics close to the damage threshold. The material response is modeled using nonlinear Lorentz oscillators for Kerr-type nonlinearities [1] and Brunel as well as injection currents associated with the excitation of electrons into the conduction band for higher order nonlinearities [2]. Along with strong field ionization, plasma formation is induced by impact ionization which is strongly dependent on the electron velocities. To avoid simulating the full electron velocity distributions required for the calculation of the impact ionization rates, we apply an effective rate equation model for the electron temperatures and drift velocities, by estimating equilibrium distributions. First simulation results for strong and ultrashort laser pulses tightly focused into thin fused silica films ($d \approx 10\mu m$) show the formation of a pronounced ionization grating.

[1] C. Varin et al., Comput. Phys. Commun. **222** 70-83 (2018)
[2] P. Jürgens et al., Nature Physics **160**, 1035-1039 (2020)

A 10.6 Tue 16:30 P

Theoretical description of relativistic tunnel ionization in highly charged ions by high intensity laser with the HILITE experiment — •Priyanka Prakash[1], Stefan Ringleb[1], Markus Kiffer[1], Nils Stallkamp[1,2], Bela Arndt[5], Axel Printschler[1], Sugam Kumar[6], Manuel Vogel[2], Wolfgang Quint[2,4], Thomas Stöhlker[1,2,3], and Gerhard G. Paulus[1,3] — [1]Friedrich-Schiller-Universität, Jena — [2]GSI Helmotzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Helmholtz Institute, Jena — [4]Ruprecht-Karls-Universität Heidelberg, Heidelberg — [5]Goethe Universität Frankfurt, Frankfurt — [6]Inter-University Accelerator Centre, New Delhi

With the HILITE (**H**igh-**I**ntensity **L**aser **I**on-**T**rap **E**xperiment) Penning trap we plan to investigate relativistic tunnel ionization with highly charged ions. High-intensity laser pulses of the order of $10^{19}\,\frac{W}{cm^2}$ from the JETI laser facility will be utilized. One of the resulting phenomena of high-intensity light-matter interaction is tunnel ionization, which is dominant at these parameters. We present related calculations for our setup from recent relativistic tunnel ionization theories. A comparison with results from the non-relativistic ADK theory is also made. The expected yields of ionizations is calculated considering the single-particle ionization rate and the overlap of the pulse with the ion cloud and the results of the theories are compared with each other.

A 10.7 Tue 16:30 P

Characterization of a Resonator for Non-Destructive Ion Detection — •Axel Printschler[1], Stefan Ringleb[1], Markus Kiffer[1], Nils Stallkamp[1,2], Bela Arndt[3], Priyanka Prakash[1], Sugam Kumar[4], Wolfgang Quint[2,5], Manuel Vogel[2], Gerhard Paulus[1,6], and Thomas Stöhlker[1,2,6] — [1]Friedrich-Schiller-Universität, Jena — [2]GSI Helmotzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Goethe Universität Frankfurt, Frankfurt — [4]Inter-University Accelerator Centre, New Delhi — [5]Ruprecht-Karls-Universität Heidelberg, Heidelberg — [6]Helmholtz Institute, Jena

Laser systems with intensities of the order of $10^{20}\,\frac{W}{cm^2}$ have electric fields that are similar to the electric fields in highly-charged ions which makes them interesting targets for laser experiments. HILITE (High Intensity Laser Ion Trap Experiment) supplies an ion target designed for the particular needs at different laser facilities.

To provide a well defined ion cloud, the ions should be as cool as possible. A common way to cool them to sub-meV energies is resistive cooling. A coil is connected in parallel to an electrode into which moving ions induce a current. When the motion frequency of the ions matches the resonance frequency of the resonator, this current is amplified resonantly, enabling efficient non-destructive detection. In resonance the ions transfer their energy to the resonantor and hence are cooled.

In order to increase the resonator's quality factor, a superconducting NbTi wire is used for the coil. We will present the assembly, properties and characterization measurements of the axial resonator.

A 10.8 Tue 16:30 P

Quantum mechanical aspects of high harmonic generation with Laguerre-Gaussian beams — •Shahram Panahiyan[1,2] and Frank Schlawin[1,2] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

High harmonic generation has been intensively investigated for the past decades due to its fundamental and technological importance [1]. A recent study on the quantum nature of the high harmonic generation demonstrated the generation of Schrödinger cat states in the transmitted fundamental mode [2]. Given that light can carry both spin and orbital angular momentum [3], we study the quantum mechanical aspects of high harmonic generation with Laguerre-Gaussian beams. Specifically, we are interested in the role of orbital angular momentum and its interplay with spin angular momentum for the creation of optical "cat" and "kitten" states as well as modification from one to another one.

[1] K. Amini, et al., Rep. Prog. Phys., 82, 116001 (2019).
[2] M. Lewenstein et al., Nat. Phys., 17 1104 (2021).
[3] L. Allen, et al., Phys. Rev. A 45, 8185 (1992).

A 10.9 Tue 16:30 P

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 as a function of a pump-probe delay in the picosecond range. The characteristic behavior of the harmonic signal is traced back to underlying phonon dynamics.

A 10.10 Tue 16:30 P

Classical model for collisional delays in attosecond streaking at solids — •Elisabeth A. Herzig[1], Lennart Seiffert[1], and Thomas Fennel[1,2] — [1]Universität Rostock — [2]MBI Berlin

Scattering of electrons in solids is at the heart of laser nanomachining, light-driven electronics, and radiation damage. Accurate theoretical predictions of the underlying dynamics require precise knowledge of low-energy electron transport involving elastic and inelastic collisions. Recently, real-time access to electron scattering in dielectric nanoparticles via attosecond streaking has been reported [1,2]. Semiclassical transport simulations [3] enabled to identify that the presence of the field inside of a dielectric nanosphere cancels the influence of elastic scattering, enabling selective characterization of the inelastic scattering time [1]. However, so far a clear picture of the underlying physics was lacking. Here, we present an intuitive classical model for the prediction of collision-induced contributions to the delays in attosecond streaking at solids.

[1] L. Seiffert et al., Nat. Phys. 13, 766-770 (2017)
[2] Q. Liu et al., J. Opt. 20, 024002 (2018)
[3] F. Süßmann et al., Nat. Commun. 6, 7944 (2015)

A 11: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Tuesday 16:30–18:30 Location: P

A 11.1 Tue 16:30 P

Probing Ion-Rydberg hybrid systems using a high-resolution pulsed ion microscope — •Viraatt Anasuri, Nicolas Zuber, Moritz Berngruber, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

Here, we present our recent studies on Rydberg atom-Ion interactions and the spatial imaging of a novel type of molecular ion using a high-resolution ion microscope. The ion microscope provides an exceptional spatial and temporal resolution on a single atom level, where a highly tuneable magnification ranging from 200 to over 1500, a resolution better than 200nm and a depth of field of more than 70*m were demonstrated. A pulsed operation mode of the microscope combined with the excellent electric field compensation enables the study of highly excited Rydberg atoms and ion-Rydberg atom hybrid systems. Using the ion microscope, we observed a novel molecular ion, where the bonding mechanism is based on the interaction between the ionic charge and an induced flipping dipole of a Rydberg atom [1]. Furthermore, we could measure the vibrational spectrum and spatially resolve the bond length and the angular alignment of the molecule. The excellent time resolution of the microscope enables probing of the interaction dynamics between the Rydberg atom and the ion. [1] N. Zuber, V. S. V. Anasuri, M. Berngruber, Y.-Q. Zou, F. Meinert, R. Löw, T. Pfau, Spatial imaging of a novel type of molecular ions, arXiv preprint arXiv:2111.02680 (2021).

A 11.2 Tue 16:30 P

Creating spin spirals with tunable wavelength in a disordered Heisenberg spin system — •Eduard Jürgen Braun[1], Titus Franz[1], Lorenz Luger[1], Maximilian Müllenbach[1], André Salzinger[1], Sebastian Geier[1], Clément Hainaut[2], Gerhard Zürn[1], and Matthias Weimüller[1] — [1]Physikalisches Instut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Université de Lille, CNRS, UMR 8523, France - PhLAM - Physique des Lasers, Atomes et Molécules

We present a novel method to create a spin spiral in a Heisenberg spin system composed of Rydberg atoms. We have designed a protocol that allows to create a spin spiral of a fixed wavevector q for an interacting spin system composed of two different angular momentum Rydberg states of Rubidium. By creating a constant electric gradient field around a fixed offset electric field one can achieve a linear detuning between the two Rydberg levels as function of position. As a consequence, after applying a $\frac{\pi}{2}$-pulse the wavelength can be tuned by the duration for which the gradient field is applied. We investigate numerically how the disorder in our system and the interaction can disturb the spiralization as well as how fast the electric fields can be ramped in order to still adiabatically follow the Rydberg states in the Stark map. The subsequent relaxation dynamics of the spirals for varying wavefector q gives insight into the mode of transport in the Heisenberg spin system. First numerical simulations with few atoms in 1D suggest that we might find a localized regime for sufficiently strong disorder in the system.

A 11.3 Tue 16:30 P

Towards an optogalvanic flux sensor for nitric oxide based on Rydberg excitations — •Fabian Munkes[1,5], Patrick Kaspar[1,5], Yannick Schellander[2,5], Lars Baumgärtner[3,5], Philipp Neufeld[1,5], Lea Ebel[1,5], Jens Anders[3,5], Edward Grant[4], Robert Löw[1,5], Tilman Pfau[1,5], and Harald Kübler[1,5] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [3]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [4]Department of Chemistry, The University of British Columbia, 2036 Main Mall, Vancouver, BC Canada V6T 1Z1 — [5]Center for Integrated Quantum Science and Technology, Universität Stuttgart

We demonstrate the applicability of a new kind of gas sensor based on Rydberg excitations. From a gas mixture the molecule in question is excited to a Rydberg state. By succeeding collisions with all other gas components this molecule becomes ionized and the emerging electrons can be measured as a current. We investigate the excitation efficiency dependent on the used laser powers, the applied charge-extraction voltage as well as the overall gas pressure.

A 11.4 Tue 16:30 P

Self-organization of facilitated Rydberg excitations — •Jana Bender, Patrick Mischke, Tanita Klas, Thomas Niederprüm, and Herwig Ott — Department of Physics and research center OPTIMAS, Technische Universität Kaiserslautern, Germany

We investigate the facilitation dynamics in a Rydberg system and the expected phase transition resulting from the interplay between driving strength and excitation decay.

In an off-resonantly driven cloud of atoms, the strong dipole-dipole interactions between two Rydberg states will compensate the laser detuning for a specific interatomic distance. For high enough driving strength, this results in a spreading of correlated excitations. We investigate the predicted non-equilibrium steady state phase transition between this active phase and the absorbing phase in which the spread of excitations is suppressed. The influence of disorder in our system might introduce additional, more complex phases dominated by excitation avalanches. Due to a loss of excited atoms, the system self-organizes from the acive phase towards the phase transition.

Our results show a persistant algebraic distribution of excitation cluster sizes independent of starting parameters when the system approaches the phase transition. We observe varying exponents which hint towards the influence of disorder in our system.

A 12: Ultracold Atoms and Plasmas (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

A 12.1 Tue 16:30 P

Controlling multipole moments of magnetic chip traps — •Tobias Liebmann and Reinhold Walser — Institute of Applied Physics, TU Darmstadt, Hochschulstr. 4a, 64289 Darmstadt, Germany

Magnetic chip traps are a standard tool for trapping atoms [1, 2]. These are robust devices with multiple fields of use ranging from fundamental physics experiments [3] to applications of inertial sensing [2]. While magnetic traps do provide good confinement potentials, they are not perfectly harmonic. In particular, they do exhibit cubic anharmonicities. In this contribution, we discuss a method for designing printable two-dimensional wire guides which compensate unfavorable multipole moments. Parametrizing a wire shape with suitable basis functions allows us to calculate the magnetic induction field using the Biot-Savart law from Magnetostatics. This enables us to control the multipole moments in proximity to the trap minimum.

[1] J. Reichel, and V. Vuletic, eds. *Atom chips* (John Wiley & Sons, Weinheim, 2011).
[2] M. Keil, et al., *Fifteen years of cold matter on the atom chip: promise, realizations, and prospects*, Journal of Modern Optics **63**, 1840 (2016).
[3] D. Becker, et al., *Space-borne Bose-Einstein condensation for precision interferometry*, Nature **562**, 391 (2018).

A 12.2 Tue 16:30 P

Optical zerodur bench system for the BECCAL ISS quantum gas experiment — •Faruk Alexander Sellami[1], Jean Pierre Marburger[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and THE BECCAL TEAM[1,3,4,5,6,7,8,9,10,11] — [1]Inst. für Physik, JGU Mainz — [2]ILP, UHH — [3]Inst. für Physik, HUB — [4]FBH, Berlin — [5]IQ & IMS, LUH — [6]ZARM, Bremen — [7]Inst. für Quantenoptik, Univ. Ulm — [8]DPG-SC — [9]DPG-SI — [10]DPG-QT — [11]OHB

BECCAL is a NASA-DLR collaboration, which will be a facility for the study of Bose Einstein Condensates consisting of potassium and rubidium atoms in the microgravity environment of the International Space Station (ISS). An essential component of the apparatus is the optical system, which takes over laser light distribution and frequency stabilization for several light fields. To ensure this, all system components must for instance be able to cope with vibrations during rocket launch and temperature fluctuations during the campaign. To this end, we are using and extending a toolkit based on the glass-ceramic Zerodur, that has already successfully been used on numerous space missions, like FOKUS, KALEXUS or MAIUS. This poster discusses the optical modules developed for BECCAL. 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 12.3 Tue 16:30 P

Improved Laser System for Optical Trapping of Neutral Mercury — •Rudolf Homm, Tatjana Beynsberger, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Cold Hg-atoms in a magneto-optical trap offer opportunities for various experiments. The two stable fermionic isotopes are interesting with regard to a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. The five stable bosonic isotopes can be used to form ultra cold Hg-dimers through photo-association in connection with vibrational cooling by applying a specific excitation scheme.

The laser system consists of an MOFA-Setup at 1014.8 nm followed by two consecutive frequency-doubling stages. Due to a new high-power diode and a 50 W-pump laser at 976 nm the fundamental power was amplified up to 12 W. This results in up to 5 W at 507.4 nm after the first frequency-doubling cavity.

The limiting factor in generating high power at 253.7 nm so far, was the degradation of the non-linear BBO-crystal used in the second frequency-doubling stage. To avoid this problem, we developed and tested a cavity with elliptical focusing [1,2]. This new cavity produces over 700 mW at 253.7 nm without a sign of degradation. We will report on the status of the experiments.

[1] Preißler, D., *et al.*, *Applied Physics B* **125** (2019): 220
[2] Kiefer, D., *et al.*, *Laser Physics Letters* **16** (2019): 075403

A 12.4 Tue 16:30 P

Generation of time-averaged potentials using acusto-optical deflectors — •Vera Vollenkemper, Henning Albers, Sebastian Bode, Alexander Herbst, Knut Stolzenberg, Ernst M. Rasel, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167, Hannover, Germany

The production of degenerated quantum gases in optical dipole traps is a cornerstone of many modern experiments in atomic physics. To achieve ultracold temperatures evaporative cooling is commonly used. However, the long timescales of a few seconds for conventional evaporative cooling represent a bottleneck for many applications like inertial sensors, where high repetition rates are essential. Time-averaged optical potentials are a technique to shorten these timescales and therefore significantly increasing the repetition rate. Among other methods, these potentials can be implemented using an 2D acusto-optical deflector (AOD) modulating the trapping laser beam. Due to the nonlinearity of the AOD the input frequency ramps are not exactly imprinted on the beam and therefore the exact form of the potential in the trap is unknown. To investigate the resulting shape of the trapping potential a test stand was set up. We test the influence of different RF-sources, lens systems and modulation techniques. The generated trap geometries are analyzed using a large beam profiling camera. We compare the measured potentials and frequency ramps imprinted on the laser beam to the theoretically expected ones.

A 12.5 Tue 16:30 P

A first two-dimensional magneto-optical trap for dysprosium — •Jianshun Gao, Christian Gölzhäuser, Karthik Chandrashekara, Joschka Schöner, Valentina Salazar Silva, Lennart Hooenen, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold atoms offer an ideal platform to explore new quantum phenomena due to their great experimental controllability and a high degree of isolation. Being the most magnetic element, dysprosium presents not only a tunable short-range contact interaction but also a competing isotropic long-range dipole-dipole interaction. Making use of this competition, novel many-body quantum states were discovered, including liquid-like droplets, droplet crystals, and most recently supersolids. Our new group, Quantum Fluids, at Heidelberg University is designing a novel compact experimental set-up which will be based on the first two-dimensional magneto-optical trap (2D-MOT) to produce a high-flux beam of slow dysprosium atoms, instead of the more standard Zeeman slower design. Additionally, combining a crossed-optical dipole trap, a tuneable accordion lattice optical trap, a tailorable in-plane trap, and a tunable magnetic environment, will give us a great opportunity to investigate many-body phenomena occurring in dipolar gases confined in two-dimensional spaces. At the Erlangen 22 conference, I would like to present the design and implementation of our 2D-MOT.

A 12.6 Tue 16:30 P

A modular optics approach for a new quantum simulation apparatus — •Vivienne Leidel[1], Malaika Göritz[1], Marlene Matzke[1], Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Selim Jochim[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany) — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching (Germany)

In order to conduct quantum simulation with ultracold trapped Lithium-6 atoms, a multitude of optical elements is needed. By dividing our setup into modules that can be easily moved and exchanged, we hope to become more efficient both in implementing new setups and tweaking existing ones. Additionally, reducing degrees of freedom as much as possible will yield more stable alignments.

Examples for this passive stability are our double pass modules for acousto-optic modulators, which are used to detune a cooling and a repumping beam.

The first cooling stage of the experiment is a 2D-MOT. As available laser power is crucial for a fast loading rate, we use a bowtie configuration and prepare flat-top beam profile using an optical diffuser. We use a high-power TA-SHG laser system providing 1W of laser power.

This Laser is locked to the Lithium-6 D2 transition using a modulation transfer scheme to ensure minimal drifts in frequency.

A 12.7 Tue 16:30 P

Erbium-Lithium: Towards a new mixture experiment — •Florian Kiesel, Alexandre De Martino, and Christian Gross — Eberhard Karls Universität Tübingen, Physikalisches Institut, Auf der Morgenstelle 14, 72076 Tübingen

Ultra cold fermions can not be cooled below 10% of the Fermi temperature efficiently. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Testing this approach, we are building a new two species ultra cold quantum gas experiment. Its goal is to overlap fermionic lithium and bosonic erbium using a dipole trap at a tune-out wavelength. Doing this, we are planning to trap and cool both species separately. Transporting the atoms into the science chamber will be done optically, but aided by magnetic levitation. In the course of this, a transport distance of up to 1 m has to be demonstrated. The following sympathetic cooling by an intentionally kept classical erbium gas of the lithium cloud, enables to overcome the limiting factor of exponentially rising thermalization time of spin-mixture cooling. There, the great mass imbalance does not only help to cool lithium more efficiently, but it also gives rise to the chance of exploring polaron and impurity physics. In the future using the interspecies Feshbach resonances, this mixture could allow to exhibit in process cooling of qubits to stabilize long sequences of gate operations.

A 12.8 Tue 16:30 P

Simulating atom dynamics in grating magneto-optical trap — •Aaditya Mishra[1], Hendrik Heine[1], Joseph Muchovo[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, Callinstr. 36, D-30167 Hannover, Germany

Ultracold atoms provide exciting opportunities in precision measurements using atom interferometers, quantum information and testing fundamental physics. Grating magneto-optical traps (gMOTs) in conjunction with atom chips provide an efficient and compact source of cold atoms. However, experimentally tuning the gMOT parameters for trapping maximum number of atoms is rather challenging, given the laborious installation of several microfabricated test gratings and re-establishing the ultra-high vacuum required for trapping.

In this poster, I will present a computational simulation of atom dynamics emerging from atom-light interactions, as well as gMOT parameter optimization for atom cooling and trapping. This is useful for quick analysis of various design techniques for gMOTs and atom chips.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II), DLR 50RK1978 (QCHIP) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

A 12.9 Tue 16:30 P

Point-spread-function engineering for 3D atom microscopy — •Tangi Legrand[1], Carrie Ann Weidner[2], Brian Bernard[3], Gautam Ramola[1], Richard Winkelmann[1], Dieter Meschede[1], and Andrea Alberti[1] — [1]Institut für Angewandte Physik der Universität Bonn, Bonn, Germany — [2]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark — [3]École normale supérieure Paris-Saclay, Gif-sur-Yvette, France

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 when the position in this direction is inferred from the defocus. It is shown how phase-front engineering can be used to detect atoms' positions with submicrometer resolution in the three dimensions using a single image acquisition. By means of a spatial light modulator, we imprint a phase modulation in the Fourier plane of the imaging system, resulting in a superposition of Laguerre-Gaussian modes at the camera. As a result, the so-called point spread function of the imaging system exhibits a spiraling intensity distribution along the line of sight. The angle of the spiraling distribution encodes the position in the third dimension. As a proof of concept, we set up an optical experiment reproducing the conditions of a quantum gas microscope. The choice and optimization of the mode superposition and an implementation scheme for Bonn's quantum walk setup is discussed. This method can find applications in other quantum gas experiments to extend the domain of quantum simulation from two to three dimensions.

A 12.10 Tue 16:30 P

Development of a laser system for Hg-photoassociation — •Tatjana Beynsberger, Rudolf Homm, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

The trapping of cold Hg-atoms in magneto-optical traps in combination with the fact that Hg consists of stable fermionic and bosonic isotopes provides the opportunity for a number of different experiments. For the two fermionic isotopes the $^1S_0 - {}^3P_0$ transition could prove valuable for defining a new time standard based on an optical lattice clock. A matter of particular interest for the bosonic isotopes is the formation of ultra cold Hg-dimers via photoassociation, where two colliding atoms absorb a photon to form an excited molecule, and subsequent vibrational cooling employing a specific excitation scheme. A laser system to be used for photoassociation needs to fulfill certain requirements, namely a narrow line width and sufficient power while also being tunable. The photoassociation laser system, when finished, consists of an interference filter-stabilized external cavity diode laser with an emission at 1016.4 nm, a tapered amplifier, and two consecutive frequency-doubling stages, the latter includes a cavity with elliptical focus designed to reduce crystal degradation. Our goal is to achieve several tens of milliwatt for the frequency-quadrupled light. We will report on the current status of the laser system.

A 12.11 Tue 16:30 P

A Compact Optical Lattice Quantum Simulator for Random Unitary Observables — •Naman Jain and Philipp Preiss — Max Planck Institute of Quantum Optics, Garching, Germany

The recent advances in probing complex quantum many-body systems at the level of single constituents allow us to pose incisive questions regarding the dynamics of such systems. Combining approaches from quantum information theory with state-of-the-art quantum simulation techniques may lead to new ways of characterizing itinerant quantum systems more generally. We pursue this in our project UniRand by realizing a new, widely applicable approach to measuring global quantum state properties in a system of ultracold atoms in an optical lattice - using random unitary operations. The strategy promises an entirely new toolbox for state characterization and device verification. To this end, we are developing a new, compact apparatus for the preparation of small-scale fermionic quantum gases in optical lattices with short cycle times. The design features a 2D MOT atomic source, a nanocoated glass cell and high-resolution imaging. Here, we report on the progress of this new experimental setup.

A 12.12 Tue 16:30 P

Towards hybrid quantum systems of ultracold Rydberg atoms, photonic and microwave circuits at 4 K — •Cedric Wind, Julia Gamper, Hannes Busche, and Sebastian Hofferberth — Institut für Angewandte Physik, Universität Bonn, Germany

The strong interactions of ultracold Rydberg atoms can be exploited not only for neutral atom quantum computing and simulation, but also to implement a growing toolbox of nonlinear single photon devices in Rydberg quantum optics (RQO). Following demonstrations of e.g. single photon sources, optical transistors, or quantum gates, it is our goal to bring RQO closer to practical applications by realizing networks of such devices "on-a-chip". Moreover, as Rydberg atoms couple strongly to microwaves, RQO provides a promising route towards optical read-out of superconducting qubits, e.g. in combination with electromechanical oscillators. However, unlike most experiments with ultracold Rydberg atoms to date, all these applications require cryogenic temperatures to suppress thermal noise.

Here, we present our progress towards a closed-cycle cryogenic ultracold atom apparatus that will allow us to trap and manipulate atoms near integrated photonic chips and microwave circuits. Besides reduced thermal noise, we also expect that the improved vacuum due to cryopumping eliminates the need to bake the system and allows for a rapid sample exchange. The cryogenic environment should also suppress blackbody-induced decay of Rydberg excitations, a major limitation in quantum simulation and information processing applications.

A 12.13 Tue 16:30 P

Autler-Townes spectroscopy of Rydberg ions in coherent motion — •Alexander Schulze-Makuch[1], Jonas Vogel[1], Marie Niederländer[1], Bastien Gely[1,2], Arezoo Mokhberi[1], and Ferdinand Schmidt-Kaler[1,3] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]ENS Paris-Saclay, 91190 Gif-sur-Yvette, France — [3]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

The exaggerated polarizability of Rydberg atoms and ions has led to significant interest in the cold atom and ion community. Due to their enhanced electric field sensitivity, electric kicks on a Rydberg ion result in large state dependent forces which can be used to generate entanglement in a multi-ion crystal in the sub-μs timescale [1]. We use electric kicks to excite a Rydberg ion into a coherent motional state. Observing now the Stark shift in the Rydberg spectrum allows for the determination of the state polarizability. By microwave-coupling Rydberg nS and mP states, with opposite sign of polarizability, we aim for dressing the state and engineering the polarizability. We present Autler-Townes spectroscopy measurements with a single trapped ion probing thermal and coherent motional excitations in the trapping fields, and eventually the engineering of the effective polarizability, important for gate operations [2].

[1] Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019) [2] Zhang et al., *Nature* **580**, 7803 (2020)

A 12.14 Tue 16:30 P

Towards the formation of ultracold ion-pair-state molecules — •Martin Trautmann, Anna Selzer, Lukas Müller, Michael Peper, and Johannes Deiglmayr — Leipzig University, Department of Physics and Geosciences, 04103 Leipzig, Germany

Recently it was proposed that a gas of long-range Rydberg molecules (LRM) may be converted into a gas of ultracold molecules in ion-pair states (UMIPS) by stimulated deexcitation [1,2]. UMIPS may facilitate the creation of a strongly correlated plasma with equal-mass charges [3], a system hitherto unavailable for laboratory studies, and provide a source of ultracold anions, *e.g.* for the sympathetic cooling of anti-protons [4]. To explore the proposed route towards the creation of UMIPS, we first create a gas of Cs_2 LRMs using photoassociation (PA). By referencing the PA laser to an atomic spectroscopy via an electronic-sideband-locked transfer cavity, we can stabilize the PA lasers frequency to arbitrary molecular resonances with frequency fluctuations of less than 0.3 MHz per day. To drive the transition towards UMIPS, we have set up a pulsed Mid-IR laser with pulse energies around 1 mJ and a transform-limited bandwidth of 130 MHz. This improved spectroscopic setup will be presented together with the current status of our experiments.

[1] M. Peper, J. Deiglmayr, J. Phys. B 53, 064001 (2020) [2] F. Hummel *et al.*, New J. Phys. 22, 063060 (2020) [3] F. Robicheaux *et al.*, J. Phys. B 47, 245701 (2014) [4] C. Cerchiari *et al.*, Phys. Rev. Lett. 120, 133205 (2018)

A 12.15 Tue 16:30 P

Towards a photonic phase gate using stationary light polaritons — •Lorenz Luger[1], Annika Tebben[1], Eduard J. Braun[1], Titus Franz[1], Maximilian Müllenbach[1], André Salzinger[1], Sebastian Geier[1], Clement Hainaut[1,2], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Im Neuenheimer Feld 226 — [2]Université Lille, CNRS, UMR 8523 -PhLAM-Physique des Lasers, Atomes et Molécules, Lille, France

We work towards a photonic phase gate where a target photon experiences a phase shift of pi depending on the presence of a control photon. By using quantum states, a superposition of atomic coherences and electromagnetic light fields, we take advantage of the long storage times of atomic coherences and the fast transport properties of light fields. The light fields couple an atomic ground state to a long-lived Rydberg state where the fields are chosen such that no short-lived excited states are populated. These quantum states are called dark state polaritons and we incorporate a so-called stationary light polariton where these dark state polaritons are coupled. We aim to achieve a mode coupling like that of a Bragg grating with sharp transmission resonances by finding particular field parameters. In presence of a Rydberg excitation, called Rydberg impurity, the coupling is modified, leading to reflection of an incoming target probe field. By using a Sagnac interferometer this switch between transmission and reflection is transformed in a photonic pi phase gate.

A 13: Precision Measurements and Metrology I (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

A 13.1 Tue 16:30 P

Towards dual species interferometry in space: MAIUS-B laser system — •Pawel Arciszewski[1], Klaus Döringshoff[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ZARM, Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation, Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

The first production of a space-borne BEC carried out during the MAIUS-1 sounding rocket mission in January 2017 paved the way for more advanced experiments with an ultra-cold matter in space. The goal of upcoming MAIUS-2 and MAIUS-3 missions is to perform dual-species interferometry onboard a sounding rocket to investigate the weak equivalence principle.

To make that possible a new laser system was developed. The designed equipment can provide the light needed for simultaneous laser cooling of rubidium and potassium and further stages used in atom interferometry experiments. Moreover, the system has to be robust and reliable to meet the demands of a sounding rocket mission.

We report on the current status of the system, its assembly process, and used technologies as well, as tests carried out to assure the equipment can face the present needs of the mission.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WP1432.

A 13.2 Tue 16:30 P

Third-order atomic Raman diffraction in microgravity — •Sabrina Hartmann[1], Jens Jenewein[1], Sven Abend[4], Albert Roura[2], and Enno Giese[1,3,4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institut für Quantentechnologien, DLR — [3]Institut Angewandte Physik, TU Darmstadt — [4]Institut für Quantenoptik, Leibniz Universität Hannover

Large-momentum-transfer (LMT) applications such as sequential pulses, higher-order Bragg diffraction and Bloch oscillations are essential tools to increase the enclosed area of an atom interferometer and thus, its sensitivity. However up to now only sequential pulses have routinely been employed with Raman diffraction.

We show theoretically [1] that double Raman diffraction [2,3] enables third order diffraction. We compare the process to a sequence of first-order pulses with the same total momentum transfer and demonstrate that third-order diffraction gives higher diffraction efficiencies for ultracold atoms. Hence, it is a competitive tool for atom interferometry with BECs in microgravity which increases the momentum transfer by a factor of six. Moreover, it allows us to reduce the complexity of the experimental setup and the total duration of the diffraction process.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

[1] *PRA* **102**, 063326 (2020). [3] *PRL* **103**, 080405 (2009).
[2] *PRA* **101**, 053610 (2020).

A 13.3 Tue 16:30 P

Towards high-precision Bragg atom interferometry using rubidium Bose-Einstein condensates — •Dorothee Tell[1], Christian Meiners[1], Henning Albers[1], Ann Sabu[1,2], Klaus H. Zipfel[1], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Deutschland — [2]Cochin University of Science and Technology (CUSAT), Kerala, India

The Very Long Baseline Atom Interferometry (VLBAI) facility at the university of Hannover aims for high precision measurements of inertial quantities. Goals span from contributions to absolute geodesy as well as fundamental physics at the interface between quantum mechanics and general relativity. The VLBAI facility makes use of a freely falling ensemble of ultracold atoms as a probe for inertial forces, interrogating the atoms in an interferometer scheme using near-resonant light pulses.

Here we present details of the fast, all-optical preparation of rubidium Bose-Einstein condensates in time-averaged dynamic optical dipole traps. We will show first proof-of-principle Bragg beam splitting and interferometry in a reduced baseline of up to 30 cm. Prospects and challenges of extending the free fall distance to more than 10 m in the frame of the VLBAI facility will be discussed.

We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 as well as CRC 1227 (DQ-mat), project B07. The VLBAI facility is a major research equipment funded by the DFG.

A 13.4 Tue 16:30 P

Second-quantized effective models for Raman diffraction with center-of-mass motion — •Nikolija Momčilović[1], Alexander Friedrich[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt

Two-photon Raman transitions are commonly used to facilitate $\pi/2$- and π-pulses in atom interferometry, and are the analogue of beam splitters and mirrors in optical interferometers. In practice, these transitions are driven by laser light which can be described semi-classically as quasi-coherent states. Thus quantization effects are averaged out due to the broad photon distribution in typical beams. However, technological progress moves towards the use of optical cavities due to their superior optical properties. Theoretical modeling of such configurations demands a second-quantized description of the light fields which we pursue based on the light-matter interaction of two second-quantized single-mode light fields and an effective two-level atom. In our contribution we derive and investigate a two-photon Rabi model with center-of-mass motion including intensity-dependent operator-valued couplings between the light field and the center-of-mass motion. We show, that under certain approximations we obtain an effective Jaynes-Cummings model with a center-of-mass dependent detuning.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

A 13.5 Tue 16:30 P

Light-pulse atom interferometry with quantized light fields — •Tobias Assmann[1], Fabio Di Pumpo[1], Katharina Soukup[1], Enno Giese[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt — [3]Institute of Quantum Technologies, German Aerospace Center (DLR)

The analogues of optical elements in light-pulse atom interferometers are generated from the interaction of matter waves with light, where the latter is usually treated as a classical field. Nonetheless, light fields are inherently quantum, which has fundamental implications for atom interferometry.

In particular, *quantized* light fields lead to a reduced visibility in the observed interference [J. Chem. Phys. **154**, 164310 (2021)]. This loss is a consequence of the encoded which-way information about the atom's path. However, the quantum nature of the atom-optical elements also offers possibilities to mitigate such effects: We demonstrate that involving superpositions in every light field yields an improved visibility, and an infinitely-strong coherent state recovers full visibility. Moreover, entanglement between all light fields can erase information about the atom's path and by that partially recovers the visibility.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) due to an enactment of the German Bundestag under grant DLR 50WM1956 (QUANTUS V).

A 13.6 Tue 16:30 P

Hybridized atom interferometer with an opto-mechanical resonator — •Ashwin Rajagopalan[1], Lee Kumanchik[2,3], Claus Braxmaier[2,3], Felipe Guzmán[4], Ernst M. Rasel[1], Sven Abend[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover — [2]DLR - Institute of Space Systems, Bremen — [3]University of Bremen - Center of Applied Space Technology and Microgravity (ZARM),Bremen — [4]Department of Aerospace Engineering & Physics, Texas A&M University, College Station, TX 77843, USA

Vibrational noise coupling through the inertial reference mirror hinders the atom interferometer (AI) performance, so we use a novel optomechanical resonator (OMR) in order to suppress it. We have utilized the OMR signal to resolve a T = 10 ms AI fringe, which would have otherwise been obscured by an average ambient vibrational noise of 3.2 mm/s^2 in our laboratory. By incorporating the OMR in our AI we could demonstrate operation in a noisy environment without the use of bulky vibration isolation equipment, therefore paving a way for miniaturization of the AI sensor head. We show our sensor fusion concept and discuss prospects for tailored setups by design and implementation of customized OMRs.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967. This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

A 13.7 Tue 16:30 P

Multi-axis quantum gyroscope with multi loop atomic Sagnac interferometry — •Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[1,2], Matthias Gersemann[1], Dennis Schlippert[1], Sven Abend[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

The interferometric Sagnac phase shift can be used for rotation detection in inertial navigation. We are designing a transportable demonstrator aiming at a multi-axis inertial sensor, not only for the precise measurement of rotations but also for accelerations. This poster will give an overview of the multi-loop atomic Sagnac interferometry theory, and present a preliminary system design for the demonstrator with Bose-Einstein condensates (BECs) of 87Rb atoms.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and through the CRC 1227 (DQ-mat), as well as support from DLR with funds provided by the BMWi under grant no. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

A 13.8 Tue 16:30 P

Single-photon transitions in atom interferometry — •Alexander Bott[1], Fabio Di Pumpo[1], Enno Giese[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, Darmstadt D-64289, Germany — [3]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Differential measurements with atom interferometers have been employed for the measurement of gravity gradients and are promising for the detection of gravitational waves. By using only a single laser to create atom interferometers in a differential setup, phase noise from secondary laser beams cannot influence the measurement. However, with a single laser two-photon transitions are no longer possible. Instead, single-photon transitions have to be employed to create the interferometers. In our contribution we perform a detailed discussion of possible types of single-photon transitions and investigate their advantages and draw-backs for atom interferometers. Specifically, we focus on the effects of the coupling induced by the dispersion relation of the laser driving the single-photon transitions in earth-bound experiments.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

A 13.9 Tue 16:30 P

Absolute light-shift compensated laser system for a twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Martina Gebbe[2], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice interferometry is a method to form symmetric interferometers featuring matter waves with large relative momentum by employing two counterpropagating optical lattices. A limiting factor here is loss of contrast, linked to the AC-Stark effect from far detuned light. This contribution presents the realisation of an absolute light-shift compensation and its potential to increase the interferometric contrast. The optical setup utilizes two independent frequency doubling stages. Key features are beam overlap on an interference filter with low power loss and coupling of high optical power in a photonic crystal fiber, opening up possibilities for new records in momentum transfer.

This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50WM1952-1957 (Q-V-Ft), DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+), the VDI with funds provided by the BMBF under grant no. VDI 13N14838 (TAIOL) and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC-2123 QuantumFrontiers 390837967.

A 13.10 Tue 16:30 P

An ytterbium setup for gravity measurements at VLBAI — •Ali Lezeik[1], Abhishek Purohit[1], Klaus Zipfel[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover - Institut für Quantenoptik — [2]Institute for Satellite Geodesy and Inertial Sensing - German Aerospace Center (DLR)

Atoms such as strontium (Sr) and ytterbium (Yb) have no magnetic moments in their spin-singlet ground state making them nearly insensitive to external magnetic fields and hence appealing for precision measurements through atomic interferometry. Furthermore, Yb's high mass and hence low expansion rate in addition to its narrow clock transition in the optical frequency range creates an ideal candidate for gravity measurements tests.

We present the Yb-174 setup for producing a robust, high-flux source of laser-cooled ytterbium atoms for the Very Large Baseline Atomic Interferometry (VLBAI) facility [1,2]. We present the laser system, the cooling sequence, the transfer cavity for frequency stabilization of the cooling beams, and a clock cavity for the 1156nm clock transition beam. We outline possible implementations of this system for atom-interferometric tests of the universality of gravitational redshift [3].

[1] É. Wodey et al., J. Phys. B: At. Mol. Opt. Phys. 54 035301 (2021)

[2] D. Schlippert et al., arXiv:1909.08524 (2019)

[3] C. Ufrecht, ..., C. Schubert, D. Schlippert, E. M. Rasel, E. Giese, arxiv:2001.09754 (2020)

A 13.11 Tue 16:30 P

An overview of Very Long Baseline Atom Interferometry facility — •Abhishek Purohit[1], Klaus H. Zipfel[1], Ali Lezeik[1], Dorothee Tell[1], Christian Meiners[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Germany — [2]German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

Our Very Long Baseline Atom Interferometry (VLBAI) facility aims for a complementary method to the state-of-the-art gradiometers and gravimeters when operated with a single atomic species, and for quantum tests of the universality of free fall at levels comparable to the best classical tests and beyond in a mode with two atomic species.

We discuss the main components of the Hannover VLBAI facility: the sources for ultra-cold atom samples, a magnetically shielded interferometry zone, state-of-the-art vibration isolation and gravity gradient mapping and modeling with an uncertainty below the 10 nm/s^2 level. We also show the design and target performance for applications in geodesy and tests of fundamental physics.

The VLBAI facility is a major research equipment funded by the DFG. We acknowledge support from the CRCs 1128 *geo-Q* and 1227

DQ-mat

A 13.12 Tue 16:30 P

Testing trapped atom interferometry with time-averaged optical potentials — •Knut Stolzenberg, Sebastian Bode, Alexander Herbst, Henning Albers, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

Time-averaged optical potentials can be used to realise flexible quantum sensors, for example by exploiting the tunnel effect for beam splitters and recombiners.
We use an acousto-optical deflector (AOD) to diffract the laserlight of a 55 W MOPA with a wavelength of 1064 nm to create dynamic time-averaged traps such as harmonic and double well potentials.
We demonstrate creation of a ^{87}Rb BEC in a crossed optical dipole trap and our first results on coherent beam splitting by momentum driven tunneling, showing stable interference patterns 37 ms after the BEC is split at a potential barrier.

A 13.13 Tue 16:30 P

Analytic Theory for Diffraction Phases in Bragg Interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

High-fidelity Bragg pulses operate in the quasi-Bragg regime. While such pulses enable an efficient population transfer essential for state-of-the-art atom interferometers, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of these interferometers. We demonstrate that the diffraction phase when measuring relative atom numbers originates from the fact that quasi-Bragg beam splitters and mirrors are fundamentally multi-port operations governed by Landau-Zener physics (Siemß et al., Phys. Rev. A 102, 033709).

We develop a multi-port scattering matrix representation of the popular Mach-Zehnder atom interferometer and discuss the connection between its phase estimation properties and the parameters of the Bragg pulses. Furthermore, our model includes the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

A 13.14 Tue 16:30 P

Systematic Approach To Phaseshifts of Matter Wave Interferometers in Weekly Curved Spacetimes — •Michael Werner and Klemens Hammerer — Institut für theoretische Physik, Leibniz Universität Hannover, Germany

We present a systematic approach to calculate all relativistic phase-shift effects in matter wave interferometer (MWI) experiments up to (and including) order 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 'parametrized post-Newtonian' (PPN) formalism. We collect general phase-shift formulas for a variety of well-known MWI schemes and calculate 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.

A 13.15 Tue 16:30 P

Universal atom interferometer simulator — •Gabriel Müller, Christian Struckmann, Stefan Seckmeyer, Florian Fitzek, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The simulation of matter-wave light-pulse interaction is crucial for designing and understanding atom interferometry (AI) experiments. However, the usual approach of solving the associated system of ordinary differential equations is limited by a quadratic scaling with the number of coupling states. Here, the universal atom interferometer simulator (UATIS) [1] overcomes this limitation with log-linear scaling while solving the problem of atom-light diffraction in the elastic case for all regimes. By interpreting a light-pulse beam as an external potential, UATIS achieves high numerical accuracy while maintaining great flexibility. We propose intuitive methods for assembling various atom-light interactions into AI sequences. We expect UATIS to lead to a straightforward modelling of experiments and to be promoted to a widely used tool.

[1] Fitzek et al. Universal atom interferometer simulation of elastic scattering processes. Sci Rep 10, 22120 (2020).

A 14: Interaction with VUV and X-ray light

Time: Wednesday 10:30–12:15 Location: A-H1

Invited Talk A 14.1 Wed 10:30 A-H1

Synchrotron radiation experiments with highly charged ions — •Jose R. Crespo López-Urrutia[1], Steffen Kühn[1], Moto Togawa[1], Marc Botz[1], Jonas Danisch[1], Joschka Goes[1], René Steinbrügge[2], Sonja Bernitt[1,3], Chintan Shah[1,4], Maurice A. Leutenegger[4], Ming Feng Gu[5], Marianna Safronova[6], Jakob Stierhof[7], Thomas Pfeifer[1], and Jörn Wilms[7] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]DESY, 22607 Hamburg, Germany — [3]Helmholtz-Institut Jena, 07743 Jena, Germany — [4]NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA — [5]Space Sciences Laboratory, UC Berkeley, CA 94720, USA — [6]Dept. of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA — [7]Dr. Karl Remeis-Observatory, 96049 Bamberg, Germany

Synchrotrons provide intense, highly monochromatic X-rays which we use for exciting highly charged ions (HCI) produced and confined in electron beam ion traps. This gives access to a regime of radiation-matter interaction dominant in hot astrophysical plasmas such as active galactic nuclei, accretion disks, and stellar radiative cores as well as coronae. Unlike neutrals, HCI thrive under those extreme conditions, modifying energy transfer and delivering spectral lines for diagnostics. Space missions need laboratory-tested theory for their science goals. We study X-ray photoexcitation and photoionization of HCI, test the related theory with unprecedented accuracy, solve two longstanding astrophysical questions, and enable future stringent tests of quantum electrodynamic calculations in complex isoelectronic sequences.

A 14.2 Wed 11:00 A-H1

Influence of multiple transitions for Quantum Coherent Diffractive Imaging — •Björn Kruse[1], Benjamin Liewehr[1], Christian Peltz[1], and Thomas Fennel[1,2] — [1]Institute for Physics, University of Rostock, Germany — [2]Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany

Coherent diffractive imaging (CDI) of isolated helium nanodroplets has been successfully demonstrated with a lab-based HHG source [1] operating in the vicinity of the 1s - 2p transition of helium. Near such strong resonances, a non-linear theoretical description including quantum coherence is required. We developed a density matrix-based scattering model in order to include quantum effects in the local medium response and explored the signatures of transition from linear to non-linear CDI for the resonant scattering from Helium nanodroplets [2]. We found substantial departures from the linear response case for already experimentally reachable pulse parameters. An important next step in this approach is the implementation of additional levels next to the 1s - 2p transition. This way, we can describe multiple non-resonant transitions and study transient shifts of energy levels as well as light-induced coupling in pump-probe scenarios. Particularly, their influence on CDI experiments is currently unknown as these effects are usually measured in the gas phase in attosecond transient absorption experiments [3].

[1] D. Rupp et al., Nat. Commun. **8**, 493 (2017)
[2] B. Kruse et al., J. Phys. Photonics **2**, 024007 (2020)
[3] P. Birk et al., J. Phys. B: At. Mol. Opt. Phys. **53** 124002 (2020)

A 14.3 Wed 11:15 A-H1

Towards Two-Dimensional Spectroscopy in X-Ray Quantum Optics — •Lukas Wolff and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Advanced spectroscopic techniques based on the precise control of timing and phase properties of light pulses are well-established throughout the long-wavelength part of the electromagnetic spectrum. In the recent past, considerable progress has also been achieved in the x-ray and XUV-regime. In the hard x-ray regime where the implementation of such control schemes is still challenging, Mößbauer nuclei featuring exceptionally narrow resonances can be employed to split light from modern high-brilliance coherent x-ray sources into double-pulses with characteristic spectral features. High-precision control of the relative phase between these double-pulses was demonstrated recently using fast mechanical motion of nuclear targets.

Here, we propose a new technique for the analysis of 2D spectra obtained via time- and frequency-resolved measurements in the hard x-ray regime using a tunable Mößbauer reference absorber and exploiting mechanical phase control. To demonstrate advantages and limitations of the approach, we extract spectral properties of ensembles of Mössbauer nuclei from simulated data. Our findings may help to pave the way towards studies of more complex spectral structures or nonequilibrium phenomena in Mößbauer science.

A 14.4 Wed 11:30 A-H1

Fast resonant adaptive x-ray optics via mechanically-induced refractive-index enhancements — •Miriam Gerharz and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In this project we introduce a concept for fast resonant adaptive 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, that can be associated with an additional contribution on resonance to the real part of the refractive index while the imaginary part remains unchanged. Hence, we can achieve polarization control by mechanically-induced birefringence without changes in absorption. We theoretically and experimentally demonstrate the approach with a x-ray polarization interferometer, in which the interference is controlled by the mechanically-induced birefringence. This setup can be used for temporal gating and provides a sensitive tool for a noise background analysis on sub-Ångstrom level.

A 14.5 Wed 11:45 A-H1

Reconstruction of s-state radial wave functions from photoionization cross-section data — •Hans Kirschner, Alexander Gottwald, and Mathias Richter — Physikalisch-Technische Bundesanstalt, Abbestraße 2-12 D-10587 Berlin-Charlottenburg

The atomic photoionization cross-section can be determined by an integral transformation, containing the final and the initial radial state of the unbound and bound electron, respectively. For the calculation of the cross-section, previous works used Hartree-Fock or even more advanced approaches to model the initial electron wave function. We reversed the process and reconstructed s-state initial radial wave functions in real space from photoionization cross-section data of Ne 2s, Ar 3s and Kr 4s in the VUV and soft x-ray region. To evaluate the radial integral, the final state was approximated by a Coulomb wave function. For the initial state, we assumed a linear combination of Slater-type orbitals with adjustable parameters. These parameters were fitted to measurement data through the integral transformation. Markov Chain Monte Carlo methods were applied to receive the best parameter fit with additional probability distributions. With the resulting parameter space the initial radial wave functions with uncertainty was calculated. Density functional theory was consulted for comparison. Despite systematic deviations, the general behavior of the radial wave functions was reconstructed.

A 14.6 Wed 12:00 A-H1

Inner-shell multiple photodetachment of silicon anions — •Ticia Buhr[1], Alexander Perry-Sassmannshausen[1], Michael Martins[2], Simon Reinwardt[2], Florian Trinter[3,4], Alfred Müller[1], Stephan Fritzsche[5,6], and Stefan Schippers[1] — [1]Justus-Liebig-Universität Gießen, Giessen — [2]Universität Hamburg, Hamburg — [3]Goethe-Universität Frankfurt am Main, Frankfurt am Main — [4]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin — [5]Helmholtz-Institut Jena, Jena — [6]Friedrich-Schiller-Universität Jena, Jena

A sensitive tool for studying the interactions between the valence and the core electrons is inner-shell ionization of negative ions. In the present work, m-fold photodetachment (m=3–6) of silicon anions via K-shell excitation and ionization have been experimentally investigated in the photon energy range of 1830 eV to 1900 eV [1] using the PIPE setup [2] at the synchrotron PETRA III. All cross sections exhibit a threshold behavior that is masked by prethreshold resonances associated with the excitation of a 1s electron to higher, either partly occupied or unoccupied atomic subshells. The experimental cross sections are in good agreement with the results of multiconfiguration Dirac–Fock calculations if small energy shifts are applied to the calculated resonance positions and detachment thresholds.

[1] A. Perry-Sassmannshausen *et al.*, Phys. Rev. A **104**, 053107 (2021).
[2] S. Schippers *et al.*, X-Ray Spectrometry **49**, 11 (2020).

A 15: Ultra-cold atoms, ions and BEC II (joint session A/Q)

Time: Wednesday 10:30–12:15 Location: A-H2

A 15.1 Wed 10:30 A-H2

Hole-induced anomaly in the thermodynamic behavior of a 1D Bose gas — •Giulia De Rosi[1], Riccardo Rota[2], Grigori E. Astrakharchik[1], and Jordi Boronat[1] — [1]Universitat Politècnica de Catalunya, Barcelona, Spain — [2]Ecole Polytechnique Fédérale de Lausanne, Switzerland

We reveal an intriguing anomaly in the temperature dependence of the specific heat of a one-dimensional Bose gas. The observed peak holds for arbitrary interaction and remembers a superfluid transition, but phase transitions are not allowed in 1D. The presence of the anomaly signals a region of unpopulated states which behaves as an energy gap and is located below the hole branch in the excitation spectrum. The anomaly temperature is of the same order of the energy of the maximum of the hole branch. We rely on the Bethe Ansatz to obtain the specific heat exactly and provide interpretations of the analytically tractable limits. The dynamic structure factor is computed with the Path Integral Monte Carlo method for the first time. We notice that at temperatures similar to the anomaly threshold, the energy of the thermal fluctuations become comparable with the maximal hole energy. This excitation pattern experiences the breakdown of the quasiparticle description for any value of the interaction strength at the anomaly, similarly to any superfluid phase transition at the critical temperature. We provide indications for future observations and how the hole anomaly can be employed for in-situ thermometry, identifying different collisional regimes and understanding other anomalies in atomic, solid-state, electronic and spin-chain systems. [arXiv:2104.12651 (2021)].

A 15.2 Wed 10:45 A-H2

Signatures of radial and angular rotons in a two-dimensional dipolar quantum gas — •Sean Graham[1], Jan-Niklas Schmidt[1], Jens Hertkorn[1], Mingyang Guo[1], Fabian Böttcher[1], Matthias Schmidt[1], Kevin Ng[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5th Institute of Physics and Center for Integrated Quantum Science and Technology IQST, University of Stuttgart, Germany — [2]MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, USA

We observed signatures of radial and angular roton modes and their contribution to droplet formation in an oblate dipolar quantum gas. Roton modes have a finite momentum that can be significantly populated in dipolar quantum gases when dipole-dipole interactions are strong relative to hard-core interactions. For stronger dipole-dipole interactions the condensate will crystallize into droplets. Near this crystallization transition we extract the static structure factor from in-situ density fluctuations. We identify the presence of a radial roton by a peak at finite momentum in the radial structure factor that appears near the transition. Additional peaks are observed in the angular structure factor corresponding to the population of the angular roton mode. Finally, a comparison to simulated mode patterns from the extended Gross-Pitaevski equation shows good agreement with our results.

A 15.3 Wed 11:00 A-H2

Two-body correlations in imbalanced quantum systems — •Carl Heintze[1], Keerthan Subramanian[1], Sandra Brandstetter[1], Marvin Holten[1], Philipp Preiss[1,2], and Selim Jochim[1] — [1]Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Max Planck Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Superfluidity in strongly correlated systems still poses a challenging task for experimentalists and theorists. Explaining the phenomenon with pair formation enables us to tackle the problem in the limit of strongly bound particles building up molecules (BEC limit) and delocalized zero momentum pairs (BCS limit). Nevertheless, complete and verified theories of strongly correlated regimes in between are still missing. Additionally, there are ongoing discussions about the pairing mechanisms, the breakdown of superfluidity and the rich phase diagram in imbalanced systems.

Our experiment focuses on the emergence of correlations and collective behaviour in many particle systems from the few-particle limit. The apparatus enables us to prepare small quantum systems (two to twelve particles) deterministically in a two-dimensional harmonic oscillator and to image the final state with spin and single particle resolution. Therefore, we can extract the in-situ two-body correlations in momentum as well as in real space. By using spectroscopic measurements, we are also able to measure excitation spectra.

Recently we achieved to prepare imbalanced systems (3+1, 6+3, 6+1 particles) and to measure their momentum correlations.

A 15.4 Wed 11:15 A-H2

An impurity with a resonance in the vicinity of the Fermi energy — •Mikhail Maslov, Mikhail Lemeshko, and Artem Volosniev — IST Austria, Am Campus 1, 3400 Klosterneuburg, Austria

We study an impurity with a resonance level whose energy coincides with the Fermi energy of the surrounding Fermi gas. An impurity causes a rapid variation of the scattering phase shift for fermions at the Fermi surface, introducing a new characteristic length scale into the problem. We investigate manifestations of this length scale in the self-energy of the impurity and in the density of the bath. Our calculations reveal a model-independent deformation of the density of the Fermi gas, which is determined by the width of the resonance. To provide a broader picture, we investigate time evolution of the density in quench dynamics, and study the behavior of the system at finite temperatures. Finally, we briefly discuss implications of our findings for the Fermi-polaron problem.

A 15.5 Wed 11:30 A-H2

Dynamics of atoms within atoms — •Shiva Kant Tiwari[1], Felix Engel[2], Marcel Wagner[3,4], Richard Schmidt[3,4], Florian Meinert[2], and Sebastian Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India — [2]Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany

Recent experiments with Bose-Einstein condensates have entered a regime in which thousands of ground-state condensate atoms fill the Rydberg-electron orbit. After the excitation of a single atom into a highly excited Rydberg state, scattering off the Rydberg electron sets ground-state atoms into motion, such that one can study the quantum-many-body dynamics of atoms moving within the Rydberg atom. Here we study this many-body dynamics using Gross-Pitaevskii and truncated Wigner theory. Our simulations focus in particular on the scenario of multiple sequential Rydberg excitations on the same Rubidium condensate which has become the standard tool to observe quantum impurity dynamics in Rydberg experiments. We investigate to what extent such experiments can be sensitive to details in the electron-atom interaction potential, such as the rapid radial modulation of the Rydberg molecular potential, or p-wave shape resonance. Finally, we explore the local dynamics of condensate heating.

A 15.6 Wed 11:45 A-H2

Quantum Rabi dynamics of trapped atoms far in the deep strong coupling regime — •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

The coupling of a two-level system with a field mode, whose fully quantized field version is known as the quantum Rabi model (QRM), is among the central topics of quantum physics and recent quantum information technologies. When the coupling strength reaches the field mode frequency, the full QRM Hamiltionian comes into play, where excitations can be created out of the vacuum.

We demonstrate a novel approach for the realization of a periodic variant of the quantum Rabi model using two coupled vibrational modes of cold atoms in optical potentials, which has allowed us to reach a Rabi coupling strength of 6.5 times the bosonic field mode frequency, i.e., far in the so called deep strong coupling regime. For the first time, the coupling term dominates over all other energy scales. Field mode creation and annihilation upon e.g., de-excitation of the two-level system here approach equal magnitudes, and we observe the atomic dynamics in this novel experimental regime, revealing a subcycle timescale raise in field mode excitations, in good agreement with theoretical predictions.

A 15.7 Wed 12:00 A-H2

orbital many-body dynamics of bosons in the second bloch band of an optical lattice — •jose vargas[1], marlon nuske[1,2,3], raphael eichberger[1,2], carl hipper[1], ludwig mathey[1,2,3], and andreas hemmerich[1,2,3] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

We explore Josephson-like dynamics of a Bose-Einstein condensate of rubidium atoms in the second Bloch band of an optical square lattice providing a double well structure with two inequivalent, degenerate energy minima. This oscillation is a direct signature of the orbital changing collisions predicted to arise in this system in addition to the conventional on-site collisions. The observed oscillation frequency scales with the relative strength of these collisional interactions, which can be readily tuned via a distortion of the unit cell. The observations are compared to a quantum model of two single-particle modes which reproduces the observed oscillatory dynamics and show the correct dependence of the oscillation frequency on the ratio between the strengths of the on-site and orbital changing collision processes.

A 16: Precision Measurements and Metrology IV (joint session Q/A)

Time: Wednesday 10:30–12:30 Location: Q-H11

Invited Talk A 16.1 Wed 10:30 Q-H11

Searching for physics beyond the Standard Model with isotope shift spectroscopy — •Elina Fuchs — CERN, Department for Theoretical Physics — Leibniz Universität Hannover — Physikalisch-Technische Bundesanstalt (PTB) Braunschweig

I will present searches for New Physics beyond the Standard Model using precision isotope shift spectroscopy with a focus on the King plot method and new avenues with Rydberg states.

A 16.2 Wed 11:00 Q-H11

Metamirrors as platform for next-generation ultra-stable laser cavities — •Steffen Sauer[1,2], Johannes Dickmann[1,2], Liam Shelling Neto[1,2], and Stefanie Kroker[1,2,3] — [1]TU

Braunschweig, Institute for Semiconductor Technology, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany — [2]LENA Laboratory for Emergng Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The key ingredients of today′s most precise quantum optics experiments are laser cavities, e.g. in interferometric gravitational wave detectors and atomic clocks. These cavities are based on two highly reflective mirrors with required reflectivities of > 99.997 %. Additionally, cavities will play a key role in future dark matter research. The currently most stable laser cavities are limited by the mirror coating noise. A highly promising approach for the reduction of thermal noise is the implementation of metamirrors. Metamirrors are formed by laterally structured optical sub-wavelength nanostructures, which are designed to manipulate the near-field of the impinging light. Thus, the reflectivity can theoretically reach 100 % with only one structured layer. In this contribution, we present the current progress in the field of metamirrors for ultra-stable laser cavities, including thermal noise computation and reflectivity measurements.

A 16.3 Wed 11:15 Q-H11

Precision Optical Techniques in the ALPS II Experiment — •Todd Kozlowski — University of Florida, Gainesville, USA

On behalf of the ALPS Collaboration. The Any Light Particle Search II (ALPS II) is a "light-shining-through-the-wall" experiment currently in commissioning at DESY. ALPS II will search for axion-like particles (ALPs), a family of hypothetical particles outside of the Standard Model which have a feeble coupling to the electromagnetic field, motivated by exciting astrophysical hints. The experiment aims to detect light which has undergone photon-ALP and subsequent ALP-photon conversion in the presence of a magnetic field. ALPS II utilizes a pair of 122-meter long high finesse Fabry-Perot optical resonators to improve detection sensitivity. One of the resonators will store 150 kW of circulating light to improve the amplitude of the generated axion field. The second resonator, located on the other side of a light-tight (but ALP transparent) barrier, will build up the regenerated laser field to gain a factor >10,000 in signal enhancement. The resulting signal, on the order of 1 photon/day, can then either be counted by a cryogenic photon counter or detected as modulation of a reference field. The experiment requires a control scheme to allow for the two cavities to both be held simultaneously on resonance with the same frequency of light, without any light from the first resonator entering the second. I will discuss the optical technologies utilized in this experiment, including nested optical offset phase locking, heterodyne interferometric readout of ultra-low optical fields, and alignment sensing and control. I will also present updates from the in-progress experimental commissioning.

A 16.4 Wed 11:30 Q-H11

Tailoring narrower phase-matching bandwidth with resonant quantum pulse gate — •Dana Echeverria-Oviedo, Michael Stefszky, Jano Gil-Lopez, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Warburguer Str. 100, 33098, Paderborn, Germany.

Time-frequency quantum metrology has been shown to saturate the quantum Cramér-Rao lower bound -the ultimate precision limit imposed by quantum mechanics- if temporal-mode selective measurements can be implemented. These can be realized with a so-called quantum pulse gate, a dispersion engineered sum-frequency generation between shaped pulses. In practice, the achievable resolution of such measurements is limited by the finite phase-matching bandwidth of the quantum pulse gate. It is of paramount importance to tailor narrower phase-matching bandwidths to alleviate this limitation and push technology further towards practical applications. We propose a resonant quantum pulse gate, which is comprised of two coupled waveguide cavities that reduce the phase-matching bandwidth, one of them the nonlinear cavity in which the interaction takes place, the other an additional linear cavity which helps to select only one single resonance. Our design facilitates a reduction in phase-matching bandwidth by several orders of magnitude compared to existing devices. In this talk, we report on the current progress in which our team is working with great effort.

A 16.5 Wed 11:45 Q-H11

Integrated broadband PDC source for quantum metrology — •René Pollmann, Franz Roeder, Matteo Santandrea, Tim Wörmann, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Broadband quantum light is a vital resource for quantum metrology applications such as quantum spectroscopy, quantum optical coherence tomography or entangled two photon absorption. To produce light suitable for these applications we implemented a broadband (10 THz) non-degenerate type-II parametric down conversion source in a 40 mm long periodically poled $LiNbO_3$ waveguide. The broadband nature of the created photon pairs yields a very short correlation time (100 fs), while the narrowband CW pump ensures strict frequency anticorrelations. This high degree of time frequency entanglement makes the created state ideal for driving two photon absorption.
Furthermore, the bandwidth of the produced biphotons can be tuned from 1 THz to 10 THz by adjusting the operating temperature of the source.
A broadband, bright source of quantum light also enables its use as an active element of so-called SU(1,1)-interferometers for applications in spectroscopy with undetected photons.

A 16.6 Wed 12:00 Q-H11

Influence of Spontaneous Brillouin Scattering in Cascaded Fiber Brillouin Amplification for Fiber-Based Optical Frequency Dissemination — •Jaffar Kadum and Sebastian Koke — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The roadmap towards the redefinition of the SI Second in terms of an optical atomic clock transition demands a comparison between remote optical clocks. Ultra-stable coherent frequency dissemination via interferometric fiber links (IFLs) is currently the only available method to compare the best optical clocks at the level of their uncertainty over continental scales. Fiber Brillouin amplifiers (FBAs) are an attractive alternative to conventional Erbium-doped fiber amplifiers due to high gain and greatly reduced back-reflection sensitivity [1]. FBA exploits the stimulated Brillouin scattering (SBS) effect initiated by the nonlinear interactions of signal and counterpropagating pump wave. However, the spontaneous Brillouin scattering (SpBS) resulting from thermally excited acoustic waves [2] degrades the signal-to-noise ratio, which may become limiting for IFLs longer than currently demonstrated. To gain deeper insight into the properties of amplified SpBS in cascaded FBA and to optimize future longer FBA-based IFLs, we developed a simulation model, which will be introduced and discussed in this contribution. 1.O. Terra et al. , *Brillouin amplification in phase coherent transfer of optical frequencies over 480 km fiber,* Opt. Express 18, (2010). 2.R.W. Boyd et al., *Noise initiation of stimulated Brillouin scattering,* Phys. Rev. A, 42, (1990).

A 16.7 Wed 12:15 Q-H11

Pertubation of trapping standards — •Martin Kernbach[1,2], Paul Oskar Sund[1], and Andreas W. Schell[1,2] — [1]Leibniz Universtity Hannover — [2]Physikalisch-Technische Bundesanstalt Braunschweig

Levitation platforms like quadrupole traps or optical tweezers are established tools for various experiments. Trapped particles are strongly isolated from their environment. This makes for example single ions accessible as individual quantum systems. Also particles up to the micrometer regime are trappable, which gives access to their even more complex properties, like internal degrees of freedom, chemical composition, or chemical reactions under well defined artificial environmental conditions.

As a first step toward a nanoparticle levitation platform we have set up a quadrupole trap with electro spray injection and in combination with a confocal microscope. The parameter range allows for trapping of nanometer to micrometer sized particles. The optical fingerprint of these particles are taken by Raman spectroscopy. As a second step we simulate trapping with respect to the driving field, atmospheric conditions or cooling. The experimental setup is designed to enable driving potentials of arbitrary waveform for particles on the micrometer scale. With these prerequisites experimental testing of promising exotic drivings can be realized. Effects on trapping speed and equilibrium temperature are expected to be confirmed.

A 17: Collisions, scattering and correlation phenomena

Time: Wednesday 14:00–15:30 Location: A-H1

Invited Talk A 17.1 Wed 14:00 A-H1

Isomer depletion via nuclear excitation by electron capture with electron vortex beams — •YUANBIN WU[1], CHRISTOPH H. KEITEL[1], and ADRIANA PÁLFFY[1,2] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

Long-lived excited states of atomic nuclei, known as nuclear isomers, can store a large amount of energy over long periods of time, with a very high energy-to-mass ratio. Dynamical external control of nuclear state population has proven so far very challenging, despite groundbreaking incentives for a clean and efficient energy storage solution. Here, we describe a protocol to achieve the external control of the isomeric nuclear decay via the process of nuclear excitation by electron capture [1] with electron vortex beams whose wavefunction has been especially designed and reshaped on demand [2]. This can lead to the controlled release of the stored nuclear energy. We show theoretically that the use of tailored electron vortex beams can increase the depletion of isomers by 2 to 6 orders of magnitude compared to so far considered depletion mechanisms and provides a handle for manipulating the capture mechanism [2].

[1] Y. Wu, C. H. Keitel, A. Pálffy, Phys. Rev. Lett. 122, 212501 (2019).
[2] Y. Wu, S. Gargiulo, F. Carbone, C. H. Keitel, A. Pálffy, arXiv: 2107.12448.

A 17.2 Wed 14:30 A-H1

Spectroscopy of metastable states of Si^- — •SUVAM SINGH, CHUNHAI LYU, CHRISTOPH KEITEL, and ZOLTÁN HARMAN — Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

In this work [1], we have calculated photodetachment cross sections (PDCS), electron affinities, fine-structure splittings, transition energies, and radiative lifetimes of all the metastable states of the Si^- ion. All atomic state functions for the description of Si and Si^- ion have been generated by the Multiconfiguration Dirac-Hartree-Fock method. Here, we have used the grasp2K and RATIP codes to carry out dedicated calculations of the PDCS of all anionic states of Si^- at two specific photon energies, namely, at 0.89 eV and 1.95 eV. The choice of the photon energies is motivated by very recent low-background measurements with the Cryogenic Storage Ring (CSR) of the Max Planck Institute for Nuclear Physics (MPIK) in Heidelberg, Germany. The PDCS are used in analyzing experimental data obtained by the CSR at MPIK. To independently predict the electron affinities, fine-structure splittings, transition energies, and radiative lifetimes, we have used the MCDHF method in combination with the relativistic configuration interaction approach. These calculations were performed using the GRASP2018 code, performing a systematic expansion of the atomic states in terms of a large number of configuration state functions to obtain accurate predictions. Detailed results will be presented during the conference.

Reference: [1] D. Müll *et al.*, Phys. Rev. A, **104** (2021) 032811.

A 17.3 Wed 14:45 A-H1

First experimental results on electron-impact ionisation of La^{1+} with a new energy-scan systems — •B. MICHEL DÖHRING[1,2], ALEXANDER BOROVIK JR[1], KURT HUBER[1], ALFRED MÜLLER[1], and STEFAN SCHIPPERS[1] — [1]Justus-Liebig-Universität Gießen — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt (Germany)

For the investigation of resonance structures in electron-impact ionisation cross sections one needs to be able to scan these cross sections in small electron-energy steps. In order to meet this requirement we have developed a new fast energy-scan system for a new recently commissioned high-power electron gun [1]. This new gun extends the range of experimentally available electron energies from previously 1 keV [2] to now 3.5 keV. As compared to the old gun, the new one has more electrodes. This enables us to more flexibly control the transport of the electron beam. However, this also required a completely new development of the scanning system. We will report on first experimental results on single and multiple ionisation of La^{1+} ions. The new data compare well with earlier measurements [3] and extend the known energy range by a factor of two.

[1] A. Müller et al., 1988 Phys. Rev. Lett. **61** 70.
[2] B. Ebinger et al., 2017 Nucl. Instrum. Meth. B **408** 317.
[3] A. Müller et al., 1989 Phys. Rev. A **40** 3584.

A 17.4 Wed 15:00 A-H1

Dielectronic recombination of Ne^{2+} at the Cryogenic Storage Ring — •LEONARD W. ISBERNER[1], MANFRED GRIESER[2], ROBERT VON HAHN[2], ZOLTÁN HARMAN[2], ÁBEL KÁLOSI[3], CHRISTOPH H. KEITEL[2], CLAUDE KRANTZ[4], DANIEL PAUL[3], STEFAN SCHIPPERS[1], SUVAM SINGH[2], ANDREAS WOLF[2], and OLDŘICH NOVOTNÝ[2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]Columbia Astrophysics Laboratory, Columbia University, New York, 10027 New York, USA — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

In the past three decades, electron-ion recombination has been successfully investigated by employing the merged-beams technique in magnetic heavy-ion storage rings. Because of the limited magnetic rigidity, recombination studies were restricted to ions with low mass-over-charge ratio. The combination of mass-independent storage in electrostatic storage rings with the excellent vacuum conditions of cryogenic environments is a promising approach to enable the investigation of recombination processes in low-charged heavy ions, which are important, e.g., for astrophysics. Here we report on a first recombination study of $Ne^{2+} + e^- \rightarrow Ne^+$ in the electrostatic Cryogenic Storage Ring (CSR) located at the Max Planck Institute for Nuclear Physics in Heidelberg. We have observed resonant recombination features in agreement with quantum-theoretical predictions. Our results clearly demonstrate the feasibility of atomic recombination studies with heavier species at CSR.

A 17.5 Wed 15:15 A-H1

Three-charge-particle collwions between antiprotons ($\bar{p}$) and muonic hydrogen atoms (H_μ) at low-energies — •RENAT A. SULTANOV — Odessa College, Department of Mathematics, 201 W. University Blvd., Odessa, Texas 79764, USA

A detailed few-body treatment is performed for two low-energy three-charge-particle reactions. The first reaction is between an antiproton $\bar{p}$ and a ground state muonic deuterium $D\mu^-$ - a bound state of a negative muon μ^- and the deuterium nucleus D. The second reaction is between $\bar{p}$ and a muonic tritium $T\mu^-$. In the first reaction additional final-state nuclear $\bar{p}D$ interaction inside the ($\bar{p}D$) antiprotonic atom is taken into account and the effect of the strong $\bar{p}D$ nuclear forces on the reaction cross-sections and rates is computed. It was found that at low energy collisions, $E_{coll} \sim 10^{-3}$–10^{-1}eV, the influence of the strong interaction is significant, i.e. the reaction cross sections and rates are increased by ∼300%. In the second reaction the final state $\bar{p}T$ nuclear interaction has also been included and the effect was approximately estimated. Modified Faddeev-type equations have been applied to the three-body systems [1, 2].

1. R. A. Sultanov, D. Guster, and S. K. Adhikari, *Atoms* **6**, 18 (2018).
2. R. A. Sultanov and D. Guster, *J. Phys. B: At. Mol. Opt. Phys.* **46**, 215204 (2013).

A 18: Precision Measurements and Metrology V (joint session Q/A)

Time: Wednesday 14:00–15:30 Location: Q-H11

A 18.1 Wed 14:00 Q-H11

A two-way free-space link for optical frequency comparisons — •Jingxian Ji[1,2], Alexander Kuhl[1], Atif Shehzad[1], and Sebastian Koke[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

Optical clock networks connected by phase-coherent links have enormous potential in basic and applied sciences such as geodesy, astronomy and global navigation satellite systems. Free-space links extend fiber-based connection capabilities and offer to connect a larger community of users. In future, free-space links may even link earthbound stations, satellites or the international space station.

Here we investigate a two-way free-space frequency comparison link using a continuous wave laser signal. Through this two-way approach, the influence of the path length fluctuations is supressed by processing the beat signals at the two end points. This system enables us to characterize the non-reciprocity of free-space connections, i.e., the fundamental uncertainty limit. Different from earlier publications, we elimate the interferometric noise contributions completely. By this we achieve fractional frequency comparison uncertainties below 10^{-21} for the averaging time of only 1000 s showing a significant improvement in resolution. This result opens the way to the high-resolution frequency comparison with simple electronics over free-space links.

A 18.2 Wed 14:15 Q-H11

Highly stable transportable UV laser system for an optical clock — •Benjamin Kraus[1,2], Stephan Hannig[1,2], Sofia Herbers[1,2], Fabian Dawel[1], Johannes Kramer[1], Constantin Nauk[1,2], Christian Lisdat[1], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks provide the most precise frequency standards. They enable high accuracy tests of fundamental physics, relativistic geodesy, and a possible future redefinition of the SI second. For side-by-side clock comparisons, accurate transportable optical clocks are necessary. We present a rack-integrated highly stable clock laser system at 267.4 nm for a transportable Al^+ clock. The system consists of a fibre laser at 1069,6 nm locked to a cavity designed to reach fractional frequency instabilities as low as 10^{-16}. Two sequential single-pass second harmonic generation stages are hermetically sealed inside an aluminium box to form a robust, compact, and stable fibre-coupled frequency quadrupling module. The setup is interferometrically phase-stabilized, enabling second long probe times.

A 18.3 Wed 14:30 Q-H11

Rubidium vapor-cell frequency reference based on 5S to 5D two-photon transition for space applications — •Julien Kluge[1,2], Klaus Döringshoff[1,2], Daniel Emanuel Kohl[1], Aaron Strangfeld[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik

Optical frequency standards based on two-photon spectroscopy using rubidium vapor are a promising candidate for realization of simple and compact optical clocks for space applications.

In this presentation, we show the development of an optical clock working at the rubidium 5S to 5D two-photon transition at 778 nm. For short timescales, a fractional frequency in-stability in the order of 10^{-13} is achieved in a setup with a small size, weight and power (SWaP) budget. Details of the corresponding vapor cell assembly, the supporting simulations and its parameters are shown as well. Recent progress towards miniaturization and automated operation of the physics package enables the future development of a compact and reliable setup to meet the stringent requirements of a prospective space mission.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50RK1971, 50WM2164.

A 18.4 Wed 14:45 Q-H11

Towards a strontium optical frequency reference based on Ramsey-Bordé interferometry — •Ingmari C Tietje[1], Oliver Fartmann[1], Martin Jutisz[1], Conrad L Zimmermann[2], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut GmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We present the status of our optical frequency reference based on Ramsey-Bordé interferometry using the $^1S_0 \rightarrow {}^3P_1$ intercombination line in strontium. Next to the current state of the atom interferometer based on a thermal atomic beam, we will present details of our compact and high-flux atomic oven as well as the cavity-stabilised laser system at 689 nm.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WM1852 and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

A 18.5 Wed 15:00 Q-H11

Dynamical decoupling for a robust Lorentz Symmetry test with $^{172}Yb^+$ ions — •Chih-Han Yeh[1], Kai C. Grensemann[1], Laura S. Dreissen[1], Henning A. Fürst[1,2], Dimitri Kalincev[1], André P. Kulosa[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We report on our progress of a novel test of local Lorentz invariance (LLI) in the electron-photon sector using the meta-stable electronic F-state of trapped $^{172}Yb^+$ ions [1]. The Zeeman structure of the F-state contains highly relativistic, orthogonally oriented electron orbitals which provide access for testing LLI violation. A potential violation would lead to an anomalous fluctuation of the energy splitting between the substates. We measure this fluctuation via detection of the population imbalance after a dynamical decoupling (DD) [2] sequence. This sequence uses rf pulses to suppress magnetic field noise for enabling long coherence times.

Starting with a single ion, we have demonstrated coherent excitation to the F-state via an electric octupole transition [3]. A coherence time of several seconds has been achieved with the DD sequence in the F-state. With these preparations, we have recently demonstrated a 24 h-run of the LLI test sequence and are now evaluating the systematics.

[1] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [2] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018). [3] H. A. Fürst et al., *Phys. Rev. Lett.* **125**, 163001 (2020)

A 18.6 Wed 15:15 Q-H11

A dual-species multi-ion clock — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Jonas Keller[1], Nishant Bhatt[1], Moritz von Boehn[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The best optical ion clocks achieve systematic uncertainties around 1×10^{-18} enabling new applications such as relativistic geodesy with cm-level height resolution [1] and advancing the search for physics beyond the standard model. The major drawback of single-ion clocks is the low signal-to-noise ratio due to quantum projection noise which requires averaging times of several weeks to achieve a matching systematic uncertainty. Increasing the number of ions for example by a factor N ideally leads to N-times shorter averaging time for a given frequency resolution. Due to its intrinsically low sensitivities, $^{115}In^+$ is an ideal candidate for a multi-ion clock with low systematic shifts [2]. We characterize clock operation with an $^{115}In^+$ ion sympathetically cooled by an $^{172}Yb^+$ ion in a segmented linear Paul trap and discuss its systematic uncertainty budget at the 10^{-17}-level. We present our solution for scaling up the number of clock and cooling ions including the control of their order within the crystal and show multi-ion spectroscopy results that are optimized for contrast. The observed excitation agrees with our simple model, which accounts for the Debye-Waller effect due to the crystal dynamics after sympathetic cooling.

[1] T.E. Mehlstäubler et al., *Rep. Prog. Phys.* **81**, 6 (2018)
[2] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)

A 19: Precision spectroscopy of atoms and ions II (joint session A/Q)

Time: Wednesday 14:00–15:15 Location: A-H2

A 19.1 Wed 14:00 A-H2

Ionization potential, atomic and nuclear structure of $^{244-248}$Cm by laser spectroscopy — •Nina Kneip[1], Felix Weber[1], Magdalena A. Kaja[1], Christoph E. Düllmann[1,2,3], Christian M. Marquardt[4], Christoph Mokry[1,2], Petra J. Panak[4], Sebastian Raeder[2,3], Jörg Runke[1,3], Dominik Studer[1], Petra Thörle-Pospiech[1], Norbert Trautmann[1], and Klaus Wendt[1] — [1]Johannes Gutenberg University, 55099 Mainz — [2]Helmholtz Institute, 55099, Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt — [4]Karlsruhe Institute of Technology, 76131 Karlsruhe

Curium (Z=96) is located in the middle of the actinide series and has a half-filled atomic f shell with a ground state configuration $5f^7 6d7s^2$ $^9\mathrm{D}^o_2$. One ton of spent nuclear fuel, contains up to 20 g of ^{248}Cm, generated by multiple neutron capture of ^{238}U. This environmental aspect in combination with its long half-life of 328 Ma motivates fundamental laser spectroscopic studies on the actinide. Resonance ionization spectroscopy was applied to study the atomic and nuclear structure of the isotopes, $^{244-248}$Cm was spectroscopically investigated. Three different ground state transitions were used as first excitation steps. Scanning the laser around the expected value of the ionization potential (IP), numerous Rydberg levels and auto-ionizing levels were located. The IP was re-determined using field ionization and Rydberg convergence techniques for comparison. The hyperfine structure of ^{245}Cm and ^{247}Cm and the isotopic shift in the isotope chain $^{244-248}$Cm were measured for the first time by laser spectroscopy.

A 19.2 Wed 14:15 A-H2

A new type of spectroscopy: Direct observation of hyperfine transitions with energy differences of 10 neV and below — •Chrysovalantis Kannis — Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany — III. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany

Spectroscopy is a tool commonly used for the study of the energy levels of a sample. In most applications the sample is trapped, however this is not always feasible. An alternative type of spectroscopy includes a static external field and a moving sample. In particular, we use two opposed solenoidal coils which provide a static magnetic field with field direction reversal along the polarization axis. This produces a sinusoidal longitudinal (along the quantization axis) magnetic field component with a zero crossing between the coils. In addition to the longitudinal component, a radial component is also induced which is proportional to the gradient of the first and the distance from the center of the quantization axis.

For an atomic beam of metastable hydrogen with a kinetic energy of about 1 keV and a magnetic field configuration with a wavelength $\lambda \sim 10$ cm, the induced transitions correspond to an RF frequency $f = v/\lambda$ in the MHz range. Equivalently, the energy difference between various levels is of the order of 10^{-8} eV and below. These can be found between hyperfine substates of hydrogen atoms at low magnetic fields in the Breit-Rabi diagram. Here we present first measurements, their interpretation, and possible applications.

A 19.3 Wed 14:30 A-H2

Laser spectroscopy of muonic ions and other simple atoms — •Randolf Pohl — Johannes Gutenberg Universität Mainz

Laser spectroscopy of simple atoms is sensitive to properties of the atomic nucleus, such as its charge and magnetization distribution. This allows determining the nuclear parameters from atomic spectroscopy, but also limits the attainable precision for the determination of fundamental constants or the test of QED and the Standard Model. In light muonic atoms and ions, one negative muon replaces all atomic electrons, resulting in a calculable hydrogen-like system. Due to the muon's large mass (200 times the electron mass), the muon orbits the nucleus on a 200 times smaller Bohr radius, increasing the sensitivity of muonic atoms to nuclear properties by 200^3 = 10 million. Our laser spectroscopy of muonic hydrogen through helium has resulted in a 10fold increase in the precision of the charge radius of the proton, deuteron, and the stable helium nuclei. Next we're measuring the hyperfine splitting in muonic hydrogen to obtain information about the magnetization of the proton. In Mainz, we're setting up an experiment to determine the triton charge radius by laser spectroscopy of atomic tritium.

A 19.4 Wed 14:45 A-H2

Resonance ionization mass spectroscopy on Americium — •Matou Stemmler[1], Felix Weber[1], Christoph Düllmann[2,3,4], Dominik Studer[1], Anjali Ajayakumar[5], and Klaus Wendt[1] — [1]Institut of Physics, Johannes Gutenberg-Universität Mainz, Germany — [2]Department of Chemistry - TRIGA site, Johannes Gutenberg-Universität, Germany — [3]Helmholtz Institut Mainz, Germany — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt, Germany — [5]GANIL, France

Americium (Am, Z=95) is a transuranic member of the actinide series which can be produced artificially by neutron bombardment in nuclear reactors or explosions. All its isotopes are radioactive and the two most long-lived isotopes are ^{241}Am and ^{243}Am with half-lifes of $t_{1/2}$=432.2 y and $t_{1/2}$=7370 y respectively. Here we report on high resolution laser spectroscopy on Am. About $3 \cdot 10^{13}$ atoms of both isotopes ^{241}Am and ^{243}Am were prepared on zirconium foil and loaded into a resistively heated tantalum oven. A wide range tuneable, frequency doubled, continuous wave Titan:Sapphire laser was used for spectroscopy by injection locking of a high power pulsed Ti:Sa ring laser setup. Hyperfine structures of the two isotopes were investigated in two different ground state transitions, which served as first excitation steps for resonant ionisation via suitable autoionizing states. In addition, the isotope shift was determined in one of these transitions. Data analysis regarding the atomic structure of Am as well as hyperfine parameters extracted will be discussed.

A 19.5 Wed 15:00 A-H2

Laser spectroscopy of neptunium - excitation schemes, atomic structure and the ionization potential — •Magdalena Kaja, Dominik Studer, Felix Weber, Felix Berg, Nina Kneip, Tobias Reich, and Klaus Wendt — Johannes Gutenberg University, 55099 Mainz

Neptunium is a radioactive actinide and the first transuranic element. In particular, ^{237}Np is generated quantitatively within the nuclear fuel cycle with amounts on average ∼10 kg in each conventional pressurized water reactor each year. Due to its long half-live of $2.1{\cdot}10^6$ years and high radiotoxicity, it represents a major hazard in the final disposal of nuclear waste. Under environmental conditions, Np can be present in oxidation states +III to +VI and can form soluble species. In this context trace analysis of environmental samples is of high relevance. The development of efficient and selective laser ionization schemes plays an important role for Np spectroscopy and trace analysis.

The spectrum of Np has been studied at the Mainz Atomic Beam Unit, using widely tunable frequency-doubled Ti:Sapphire lasers. The ionization scheme development, spectra above and below the ionization potential (IP), as well as the electric field ionization technique, which allows the determination of the IP, are presented in this contribution. Narrow-band spectroscopy is planned to determine hyperfine structures and isotope shift. So far, only ^{237}Np has been studied by laser spectroscopy and only in broad-band mode. Therefore, high-resolution spectroscopy is planned on ^{237}Np and possibly on the short-lived isotope ^{239}Np.

A 20: Precision spectroscopy of atoms and ions (joint session A/Q)

Time: Wednesday 16:30–18:30 Location: P

A 20.1 Wed 16:30 P

Precise solution of the two-center Dirac equation using a finite-element-technique — •Ossama Kullie[1], Stephan Schiller[2], and Vladimir I. Koborov[3] — [1]Theoretical Physics, Institute of Physics, University of Kassel — [2]Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany — [3]Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia

In the field of spectroscopy of the molecular hydrogen ions H_2^+, HD^+ etc., precise experimental transition frequencies are compared with ab initio predictions [3]. The solution of the two-center Dirac problem, one electron in the field of two fixed nuclei at distance R, is therefore of interest. Here, $R \simeq 2\,\mathrm{Bohr}$. The numerical solution of the problem utilizes the finite-element method (FEM) [1,2]. Our technique allows determining the relativistic contribution to various rovibrational transition frequencies with spectroscopic accuracy. Our results are compared with perturbation theory based on the nonrelativistic one-body variational solution. The deviations found are smaller than the theory uncertainty stemming from uncalculated quantum-electrodynamic effects, and are therefore not resolvable experimentally. [1] O. Kullie et al, Chemical Physics Letters 383 (2004) 215-221. [2] O. Kullie, S. Schiller and V. I. Koborov, in preparation. [3] S. Alighanbari et al, Nature 581, 152 -158 (2020).

A 20.2 Wed 16:30 P

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian Jasin Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 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. In addition to the molecular ion, a well-controllable atomic ion is co-trapped, coupling strongly to the molecule 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. Here, we present the status of our experiment, aiming at high precision quantum logic spectroscopy of molecular oxygen ions.

A 20.3 Wed 16:30 P

Precision x-ray spectroscopy of transitions in He-like uranium at the CRYRING@ESR electron cooler — •Felix Martin Kröger[1,2,3], Steffen Allgeier[4], Andreas Fleischmann[4], Marvin Friedrich[4], Alexandre Gumberidze[3], Marc Oliver Herdrich[1,2,3], Daniel Hengstler[4], Patricia Kuntz[4], Michael Lestinsky[3], Bastian Löher[3], Esther Babette Menz[1,2,3], Philip Pfäfflein[1,2,3], Uwe Spillmann[3], Günter Weber[1,3], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI Jena, Fröbelstieg 3, Jena, Germany — [2]IOQ, FSU Jena, Max-Wien-Platz 1, Jena, Germany — [3]GSI, Planckstraße 1, Darmstadt, Germany — [4]KIP, RKU Heidelberg, Im Neuenheimer Feld 227, Heidelberg, Germany

We present the first application of metallic magnetic calorimeter detectors for high resolution x-ray spectroscopy at the electron cooler of CRYRING@ESR, the low energy storage ring of GSI-Darmstadt. Within the experiment, x-ray emission associated with radiative recombination cooler electrons and stored U^{91+} ions was studied. For this purpose, two maXs detectors were positioned under observation angles of 0° and 180° with respect to the ion beam axis. This report will focus on preliminary results of the data analysis, namely the first observation of the splitting of the $K_{\alpha 2}$ line into its fine-structure for a high-Z He-like system.

This research has been conducted in the framework of the SPARC collaboration, experiment E138 of FAIR Phase-0 supported by GSI. We acknowledge substantial support by ErUM-FSP APPA (BMBF n° 05P19SJFAA).

A 20.4 Wed 16:30 P

Towards the setup of a calcium beam clock — •Lara Becker and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, Bonn, Germany

Since the invention of atomic clocks the precision of time-keeping has been significantly enhanced and the clock stabilities reach even higher levels for systems based on optical transitions.

We would like to build a robust and compact optical clock which relies on a Ramsey-Bordé interferometer of a thermal beam of calcium and is envisaged attaining instabilities in the order of 10^{-16}. The goal is to implement the beam clock as an experiment to the students' laboratory course to allow physics master students access to this field of recent research.

We refer to the work at NIST [1] for the main setup and we report on the current status of our project.

[1] Judith Olson et al. "Ramsey-Bordé Matter-Wave Interferometry for Laser Frequency Stabilization at 10^{-16} Frequency Instability and Below". In: Physical Review Letters 123, 073202 (2019)

A 20.5 Wed 16:30 P

Towards 1S-2S Spectroscopy in Atomic Tritium — •Hendrik Schürg, Merten Heppener, Jan Haack, Gregor Schwendler, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany

The study of the hydrogen-deuterium isotope shift for the 1S-2S transition successfully demonstrated access to a high-precision result for the root-mean-square charge radius of the deuteron [1, 2]. We are currently setting up an experiment to perform a complementing measurement of the hydrogen-tritium 1S-2S isotope shift on magnetically trapped cold tritium atoms – allowing for a 400-fold improvement of uncertainty for the triton charge radius [3]. For an intermediate result, we plan to perform 1S-2S spectroscopy on hot tritium atoms inside a discharge. The excitation can be monitored using the optogalvanic signal induced by a change of conductivity in the hot gas. The available high-precision result for the 1S-2S transition frequency in atomic hydrogen [4] will be used to determine systematic effects in our apparatus. We will present details about our laser system and preliminary measurements with atomic hydrogen.

[1] C. G. Parthey et al. Phys. Rev. Lett. 104, 233001 (2010)
[2] U. D. Jentschura et al. Phys. Rev. A 83, 042505 (2011)
[3] S. Schmidt et al. J. Phys.: Conf. Ser. 1138, 012010 (2018)
[4] C. G. Parthey et al. Phys. Rev. Lett. 107, 203001 (2011)

A 20.6 Wed 16:30 P

Towards Magnetic Trapping of Atomic Hydrogen — •Merten Heppener, Gregor Schwendler, Jan Haack, Hendrik Schürg, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany

We are currently setting up an experiment to determine the root mean square triton charge radius via two-photon 1S-2S laser spectroscopy at 243 nm on magnetically trapped tritium atoms [1]. For preparation of trapping, an atomic hydrogen source including a microwave dissociation was set up, followed by a cryogenic nozzle and a magnetic quadrupole guide for velocity selection. In the future, it is planned to load the slow hydrogen atoms into a magnetic minimum trap using a cold lithium buffer gas, for which we will present the planned trap configuration. Parallel, a spectroscopy laser system at 243 nm is being developed. The available laser power for exciting the 1S-2S two-photon transition is increased in a stabilized enhancement cavity. The population of the hydrogen 2S state can be monitored by detecting quenched Lyman-α photons using micro-channel plate-based system. In the next stage, we will test our laser system on an atomic hydrogen sample.

[1] S. Schmidt et al. J. Phys. Conf. Ser. 1138, 012010 (2018)

A 20.7 Wed 16:30 P

Enhancing Atom-photon Interaction with Integrated Nano-photonic Resonators — •Xiaoyu Cheng[1], Benyamin Shnirman[1,4], Artur Skljarow[1], Hadiseh Alaeian[2], Wei Fu[3], Sunny Yang[3], Hong Tang[3], Markus Greul[4], Mathias Kaschel[4], Tilman Pfau[1], and Robert Loew[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany — [2]School of Electrical and Computer Engineering, Purdue University, Indiana, USA — [3]Department of Electrical Engineering, Yale University, Connecticut, USA — [4]Institut für Mikroelektronik Stuttgart (IMS-Chips), Stuttgart, Germany

We study hybrid devices consisting of thermal atomic vapours and Nano-photonic waveguides for manipulating the interaction of atoms with single photons. This allows applications of collective and cooperative effects in the field of quantum technologies. One goal here is to reach the strong coupling regime for a single atom interacting with the mode of photonic crystal cavity (PhC). Our first resonator design is a suspended photonic crystal cavity, which allows us to tightly confine the mode into the interaction region. We have fabricated these devices with a novel high selectivity under-etching technique. A second line of research is to make use of the Rydberg blockade effects to generate single photons. We work with high Q (Q>400000) resonators coupled with bus waveguides. This allows high intensities to excite the weak dipole transitions to Rydberg states. In addition, we plan to taper the waveguides to enhance the range of the evanescent field such that we will be less vulnerable to transit time effects and surface interactions.

A 20.8 Wed 16:30 P

Rydberg systems under a reaction microscope — •Max Althön, Markus Exner, Philipp Geppert, and Herwig Ott — TU Kaiserslautern

With our MOTRIMS-type reaction microscope we observed collisions between Rydberg atoms and ground state atoms. In these inelastic collisions, the Rydberg electron can change to a lower-lying state. The resulting energy is imparted onto the Rydberg core and the ground state atom as kinetic energy. We measured the final state distribution after these state-changing collisions and observed a wide range of possible final Rydberg states. State-changing collisions are a major decay channel of Rydberg atoms in a dense environment and are of importance for Rydberg molecules. Rydberg molecules are bound by the scattering interaction between the Rydberg electron and a ground state atom. In this context, we aim to directly photoassociate Trilobite molecules, which can be addressed efficiently due to 3-photon excitation. We also show how another type of Rydberg molecule can be used to create a Heavy-Rydberg system, which consists of an ion and anion bound in a high vibrational state.

Our sample consists of ^{87}Rb atoms in a crossed optical dipole trap. Using a 3-photon excitation scheme, atoms are excited to atomic or molecular Rydberg states and photoionized by a short laser pulse from a CO_2 laser after a variable evolution time. Following small homogeneous electric fields, the produced ions are subsequently detected by a time and position sensitive micro channel plate detector. This allows momentum resolved measurements of few-body Rydberg dynamics.

A 20.9 Wed 16:30 P

Most Precise g-Factor Comparison at Alphatrap — •Tim Sailer[1], Vincent Debierre[1], Zoltán Harman[1], Fabian Heisse[1], Charlotte König[1], Jonathan Morgner[1], Bingsheng Tu[4], Andrey Volotka[2,3], Christoph H. Keitel[1], Klaus Blaum[1], and Sven Sturm[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Helmholtz-Institut Jena, Jena — [3]Department of Physics and Engineering, ITMO University, St. Petersburg, Russia — [4]Institute of Modern Physics, Fudan University, Shanghai, China

The Alphatrap experiment is a cryogenic Penning-trap setup, designed to measure the g factor of the bound electron of heavy highly-charged ions (HCI) to provide tests of fundamental physics in strong fields. Recently, a novel measurement technique based on the coupling of ions as an ion crystal has been developed and applied to measure the most precise g-factor difference to date. By coupling two neon ions, $^{20}Ne^{9+}$ and $^{22}Ne^{9+}$, in a magnetron crystal, a coherent measurement of the Larmor frequency difference of the respective bound electrons becomes possible. The strong suppression of magnetic field fluctuations due to the close proximity of the ions results in a common behaviour of the electron spin states. This allows a determination of the isotopic shift of the g factor to an unprecedented precision of 5.6×10^{-13} relative to the absolute g factors, and, in combination with theory, resolves and confirms the QED contribution to the nuclear recoil for the first time. Alternatively, the result can be applied to improve upon the precision of the charge radius difference of the isotopes or to apply constraints on a potential fifth force in the Higgs portal mechanism.

A 20.10 Wed 16:30 P

A cold atomic lithium beam via a 2D MOT — •Hendrik-Lukas Schumacher, Marcel Willig, Gregor Schwendler, and Randolf Pohl — Johannes Gutenberg-Universität Mainz Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+

We plan to build a source for a very high flux of cold atomic Li for spectroscopy [1], and for using trapped cold Li as a buffer gas to enable trapping of atomic hydrogen, deuterium and tritium. Laser spectroscopy of atomic ^{6,7}Li has been used to determine the (squared) rms charge radius difference of the stable Li nuclei [2]. 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 [3]. Li with its unresolved hyperfine structure is an excellent testbed for precision studies of quantum interference [4].

In another line of research, we plan to trap large amounts of cold Li and use it as a cold buffer gas to enable trapping and laser spectroscopy of atomic hydrogen from a cryogenic beam [2].

[1] T.G. Tiecke, S.D. Gensemer, A. Ludewig, J.T.M. Walraven, Phys. Rev. A 80, 013409 (2009), arXiv
[2] S. Schmidt et al., J. Phys. Conf. Ser. accepted (2018), arXiv
[3] M. Horbatsch, E.A. Hessels, Phys.Rev. A 84, 032508 (2011)
[4] R. C. Brown et al., Phys.Rev. A 87, 032504 (2013)

A 20.11 Wed 16:30 P

Probing physics beyond the standard model using ultracold mercury — •Thorsten Groh, Quentin Lavigne, Felix Affeld, and Simon Stellmer — Physikalisches Institut, Universität Bonn, 53115 Bonn, Germany

Searches for physics beyond the standard model (SM) range from high-energy collision experiments to low-energy table-top experiments. Cosmological phenomena suggest the existence of yet undiscovered particles, described as dark matter.

Recently, it was proposed to employ high precision spectroscopy of atomic isotope shifts [Delaunay, PRD 96, 093001 (2017); Berengut, PRL 120, 091801 (2018)] to search for a new force carrier that directly couples quarks and leptons. Signatures of such new particles would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

Mercury is one of the heaviest laser-coolable elements and possesses five naturally occurring bosonic isotopes, all of which have been laser-cooled in a magneto-optical trap. We report on optimizing these trap parameters and we present our latest results of precision isotope spectroscopy in ultracold mercury on various optical transitions. Our King plot analysis of the nonlinearities indicates deviations from SM predictions.

A 20.12 Wed 16:30 P

Two-loop self-energy corrections to the bound-electron g-factor: M-term — •Bastian Sikora[1], Vladimir A. Yerokhin[2], Christoph H. Keitel[1], and Zoltán Harman[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

The theoretical uncertainty of the bound-electron g-factor in heavy hydrogenlike ions is dominated by uncalculated two-loop Feynman diagrams. Due to the presence of ultraviolet divergences, diagrams with two self-energy loops need to be split into the loop-after-loop (LAL) contribution and the so-called F-, M- and P-terms which require different numerical techniques. In our previous work, we have obtained full results for LAL and the F-term [1].

In this work, we present our results for the M-term contribution. This corresponds to the ultraviolet finite part of nested and overlapping loop diagrams in which the Coulomb interaction in intermediate states is taken into account exactly.

Our results are highly relevant for ongoing and future experiments with high-Z ions as well as for an independent determination of the fine-structure constant α from the bound-electron g-factor [2].

[1] B. Sikora, V. A. Yerokhin, N. S. Oreshkina, et al., Phys. Rev. Research 2, 012002(R) (2020).

[2] S. Sturm, I. Arapoglou, A. Egl, et al., EPJ ST 227, 1425 (2019)

A 20.13 Wed 16:30 P

Status of the ALPHATRAP *g*-factor experiment — •FABIAN HEISSE[1], CHARLOTTE KÖNIG[1], JONATHAN MORGNER[1], TIM SAILER[1], BINGSHENG TU[1,2], SVEN STURM[1], and KLAUS BLAUM[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Fudan University, China

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 up to hydrogen-like uranium [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 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 20.14 Wed 16:30 P

Pound method of stabilizing the trap frequencies of an ion trap — •MARTIN FISCHER[1], ATISH ROY[1], SEBASTIAN LUFF[1,2], MARKUS SONDERMANN[1,2], and GERD LEUCHS[1,2,3,4] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen- Nürnberg (FAU), Department of Physics, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada — [4]Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia

We report on the stabilization of the secular motion frequencies of an ion trapped in the potential of a Paul-trap by analyzing the phase of the reflected trapping filed. This is done by mixing the field reflected from the LC-circuit[1] made up by the helical resonator and the trap with the RF-drive frequency. By adjusting the relative phase of the two signals it is possible to determine how far the driving field is detuned from the resonance of the LC-circuit. Feeding this signal back to the RF-drive one can lock it to the resonance of the trap. In this way the power coupled into the trap system remains almost constant while the small relative variations of the drive field hardly change the magnitude of the trap frequencies. The stability of the method is measured by directly monitoring the trap frequencies visible in the detected fluorescence light when it is filtered by imaging it onto a knife edge.

[1] R. V. Pound, Review of Scientific Instruments **17**, 490-505 (1946)

A 20.15 Wed 16:30 P

maXs100: A 64-pixel Metallic Magnetic Calorimeter Array for the Spectroscopy of Highly-Charged Heavy Ions — •S. ALLGEIER[1], A. ABELN[1], M. FRIEDRICH[1], A. GUMBERIDZE[2], M.-O. HERDRICH[2,3,4], 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 CH. 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.

We present the MMC array maXs-100, which was used to investigate electron transitions in $\mathbf{U^{90+}}$ at CRYRING@FAIR. The detector features 8x8 pixels with a detection area of 1 cm^2 and a stopping power of 40 % for 100 keV X-rays. We discuss details of the two detector systems used during the beam time, including the cryogenic setup and magnetic shielding. An absolute energy calibration with eV-precision at 100 keV as well as an energy resolution of 40 eV (FWHM) at 60 keV were demonstrated, allowing for high-precision X-ray spectroscopy.

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

A 20.16 Wed 16:30 P

Laser photodetachment threshold spectroscopy at FLSR: the experiment preparation — •VADIM GADELSHIN[1], OLIVER FORSTNER[2,3,4], LOTHAR SCHMIDT[5], KURT STIEBING[5], DOMINIK STUDER[1], and KLAUS WENDT[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]Friedrich Schiller-Universität Jena — [3]Helmholtz-Institut Jena — [4]GSI Helmholtzzentrum Darmstadt — [5]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 for AMS nuclides, it is necessary to identify neutralization schemes for unwanted ions.

With this intention, a compact laser lab was constructed with an optical path, guiding laser beams into FLSR. The laser setup is based on a tunable Ti:Sapphire laser and a pulsed Nd:YAG laser, serving as a pump laser for Ti:Sapphire crystal and as a high-energy laser beam at 532 nm. The RF plasma ion source with a Rb charge exchange cell was installed to produce beams of negatively charged ions.

The results of the experiment preparation and of first tests will be presented. The proof-of-principle of the setup is carried out for O- and OH- ions. An overview of planned LPT studies will be given.

A 20.17 Wed 16:30 P

A variable out-coupling optical parametric oscillator for the laser system of the ground hyperfine splitting in muonic hydrogen experiment. — •AHMED OUF ON BEHALF OF THE CREMA COLLABORATION[1], SIDDARTH RAJAMOHANAN[1], LUKAS GOERNER[1], and RANDOLF POHL[2] — [1]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik — [2]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA +, Mainz, Germany

We are working on a measurement of the ground-state hyperfine splitting in the exotic muonic hydrogen atom, i.e. a proton orbited by a negative muon. From this measurement, we will be able to determine the parameters of the magnetization distribution inside the proton. The experiment requires a unique pulsed laser system delivering 5mJ pulses at a wavelength of 6.8 μm. The laser has to be triggered on detected muons which enter the apparatus at stochastic times with an average rate of about $\frac{1000}{s}$. Because of the short $2\mu s$ lifetime of the muon, the laser has to produce pulses within about $1\mu s$ after a random trigger. We use a novel Yb:YAG thin-disk laser with a line width less than 10 MHz at 1030nm, whose light output will be shifted in frequency by several OPO/OPA stages in 2 parallel branches at 3.15 μm and $2.1\mu m$, before a DFG yields the intense pulses at 6.8 μm. To enable easy optimization of the OPOs conversion we have developed an OPO cavity with variable finesse, based on polarization optics. We will present this cavity, an optimized specific PDH locking scheme, and first experimental results.

A 20.18 Wed 16:30 P

The muonic hydrogen ground state hyperfine splitting experiment — •AHMED OUF ON BEHALF OF THE CREMA COLLABORATION[1], SIDDARTH RAJAMOHANAN[1], LUKAS GOERNER[1], and RANDOLF POHL[2] — [1]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik, Mainz, Germany — [2]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA +, Mainz, Germany

The ground state hyperfine splitting (1S-HFS) in ordinary hydrogen (the famous 21 cm line) has been measured with 12 digits accuracy almost 50 years ago [1], but its comparison with QED calculations is limited to 6 digits by the uncertainty of the Zemach radius determined from elastic electron-proton scattering. The Zemach radius encodes the magnetic properties of the proton and it is the main nuclear structure that contributes to the hyperfine splitting (HFS) in hydrogen together with the proton polarizability. The ongoing experiment of the CREMA Collaboration at PSI aims at the first measurement of the 1S-HFS in muonic hydrogen (μp). The measurement aims at determining the proton structure effects referred to as the two-photon exchange with an accuracy of 1×10^{-4}, which is a hundredfold improved determination of (Zemach radius and the proton polarizability). Eventually, then this will improve the QED test using the 21 cm line by a factor of 100. We will present the current status of the experimental effort including the unique detection system and the novel laser development.

A 20.19 Wed 16:30 P

Study of Highly Charged Ions for the Tests of Bound-State QED — •Manasa Chambath[1], Khwaish Anjum[1,2], Patrick Baus[3], Gerhard Birkl[3], Kanika Kanika[1,4], Jeffrey Klimes[1,4,5], Wolfgang Quint[1], and Manuel Vogel[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [2]Delhi Technological University, Delhi, India — [3]Institute for Applied Physics, TU Darmstadt, Germany — [4]Heidelberg Graduate School for Fundamental Physics, Heidelberg, Germany — [5]Max Planck Institute for Nuclear Physics, Heidelberg, Germany

The high-precision measurement of the Zeeman splitting of fine- and hyper-fine structure levels can be performed using spectroscopy techniques. The Penning trap ARTEMIS at the HITRAP facility at GSI utilises the method of laser-microwave double-resonance spectroscopy to measure the magnetic moment and to test bound-state QED calculations by g-factor measurements of heavy, highly charged ions like Ar13+ and Bi82+. Non-destructive electronic detection is used to analyse and resistively cool the stored ions. Different ion species in the trap are resolved according to their charge-to-mass ratio by fixing the detection frequency and ramping over a range of trapping potentials. By selectively exciting the axial motion, Ar13+ ions are isolated from the ion cloud for the g-factor measurements. Studies are also done to determine the phase transition of dense ion clouds due to the discontinuous behaviour of spectral features during cooling.

A 20.20 Wed 16:30 P

Detector for Atomic Hydrogen — •Benedikt Tscharn, Hendrik-Lukas Schumacher, Gregor Schwendler, Jan Haack, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Excellenzcluster PRISMA+, Mainz, Germany

Laser spectroscopy is the most precise way to experimentally determine the RMS charge radius of light nuclei.[1] Performing it on muonic hydrogen has raised the proton radius puzzle, a 5.6σ difference to previous electron scattering experiments.[2] Measuring the isotope shift of the 1S-2S transition in atomic tritium will yield the radius of triton, the mirror nucleus to the helion, by two orders of magnitude improved precision.[1] Together with muonic hydrogen, deuterium and helium, this will allow for precise tests of nuclear theory.
The T-REX experiment aims to perform laser spectroscopy on cooled and trapped atomic tritium. The atomic tritium flux to the MOT where the measurement takes place has to be monitored with a non-destructive detector for optimisation. Since tritium is radioactive, hydrogen is used during build-up.
We have developed such a detector measuring the resistance change of a $5\mu m$ diameter tungsten wire due to recombination energy. It is sensitive to a hydrogen flux of 10^{17} atoms per second and can distinguish molecular and atomic hydrogen beams.

[1] S. Schmidt et al., J. Phys. Conf. Ser. (2018), arXiv 1808.07240
[2] R. Pohl et al., Nature 466.723, 213-216 (2010)

A 20.21 Wed 16:30 P

Recoil correction to the energy level of heavy muonic atoms — •Romain Chazotte[1,2] and Natalia Oreshkina[2] — [1]Universität Heidelberg — [2]Max-Plank-Institut

In this work, the relativistic recoil correction to the energies of heavy muonic atoms has been considered, based on the formalism suggested by Borie and Rinker.

Muonic atoms are atoms, which have a bound muon instead of an electron. The lifetime of a muon is long enough so it can be considered stable on the atomic scale. Additionally, an atom with a single bound muon can be considered as a hydrogenlike system. As muons are about 200 times heavier than electrons, they orbit around the nucleus 200 times closer. This leads to a larger contribution of all kinds of nuclear effects to the energy.

We calculated the recoil effect for the shell, sphere and Fermi nuclear models. The model and nuclear parameters dependence has been studied. The results have been compared with previous studies. They also can be used for the high-precision theoretical predictions of the spectra of heavy muonic atoms, and in the further comparison with experimental data, aiming at the extraction of the nuclear properties and parameters. In the future, a more rigorous quantum electrodynamics formalism can be applied for enhancing the accuracy of the relativistic recoil effect.

A 21: Highly charged ions and their applications

Time: Wednesday 16:30–18:30 Location: P

A 21.1 Wed 16:30 P

Non-perturbative dynamics in heavy-ion-atom collisions — •Pierre-Michel Hillenbrand[1,2], 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 fundamental 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+} 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, submitted

A 21.2 Wed 16:30 P

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

At heavy-ion storage rings, almost all experiments strongly benefit from cooled ion beams, i.e. beams which have a small longitudinal momentum spread and a small emittance. During the last two decades, laser cooling has proven to be a powerful tool for relativistic bunched ion beams, and its "effectiveness" is expected to increase further with the Lorentz factor (γ). The technique is based on resonant absorption (of photon momentum & energy) in the longitudinal direction and subsequent spontaneous random emission (fluorescence & ion recoil) by the ions, combined with moderate bunching of the ion beam. We will report on recent (May 2021) preliminarily results from a laser cooling beam experiment at the ESR at GSI in Darmstadt, Germany, where broadband laser cooling of a relativistic ion beam could be successfully demonstrated for the first time using a pulsed UV laser system with a high rep.-rate, variable pulse lengths and high UV power.

A 21.3 Wed 16:30 P

Redefined vacuum approach and gauge-invariant subsets in two-photon-exchange diagrams — •Romain Soguel[1], Andrey Volotka[2], Dmitry Glazov[3], and Stephan Fritzsche[1] — [1]Helmholtz-Institut Jena, Jena, 07743, Germany — [2]ITMO University, St. Petersburg, 197101, Russia — [3]St. Petersburg State University, St. Petersburg, 199034, Russia

Within bound-state QED, the interelectronic interaction is treated perturbatively as an expansion over the number of exchanged photons. So far, zeroth-order many-electron wave-function constructed as a Slater determinant (or sum of Slater determinants) with all electrons involved were used in the performed derivations. The vacuum redefinition in QED, which is extensively used in MBPT to describe the states with many electrons involved, is proposed as a path towards an extension of two-photon-exchange calculations to other ions and atoms.

The two-photon-exchange diagrams for atoms with single valence electron are investigated. Calculation formulas are derived for an arbitrary state within rigorous bound-state QED framework utilizing the redefined vacuum formalism. This approach enables the identification of gauge-invariant subsets at two- and three-electron diagrams and separate between the direct and exchange contributions at two-electron graphs. Thus, the consistency of the obtained results is verified by comparing the results for each identified subset in different gauges. The gauge invariance of found subsets is demonstrated both analytically (for an arbitrary state) as well as numerically for 2s, 2p1/2, and 2p3/2 valence electron in Li-like ions.

A 21.4 Wed 16:30 P

Laser Cooling of Relativistic Ion Beams Employing a Transportable Pulsed UV Laser System — •Benedikt Langfeld[1], Lars Bozyk[2], Michael Bussmann[3,4], Noah Eizenhöfer[1], Volker Hannen[5], Max Horst[1], Daniel Kiefer[1], Nils Kiefer[6], Sebastian Klammes[2], Thomas Kühl[2,7], Markus Löser[3], Xinwen Ma[8], Wilfried Nörtershäuser[1], Rodolfo Sanchez[2], Ulrich Schramm[3,9], Mathias Siebold[3], Peter Spiller[2], Markus Steck[2], Thomas Stöhlker[2,7,10], Ken Ueberholz[5], Thomas Walther[1,11], Hanbing Wang[7], Weiqiang Wen[7], and Danyal Winters[2] — [1]TU Darmstadt — [2]GSI Darmstadt — [3]HZDR Dresden — [4]CASUS Görlitz — [5]Uni Münster — [6]Uni Kassel — [7]HI Jena — [8]IMP Lanzhou — [9]TU Dresden — [10]Uni Jena — [11]HFHF Ffm

Laser cooling of relativistic ion beams has been shown to be a promising technology to generate bright ion beams. To strongly reduce intrabeam scattering, a well-known problematic effect for high-intensity ion beams, pulsed laser systems with broad bandwidths can be employed.

In this work, we present preliminary results from a recent (May 2021) laser cooling "beam experiment" at the ESR storage ring at GSI Helmholtzzentrum Darmstadt, employing relativistic C^{3+} ion beams and our tuneable high repetition rate UV laser system. We have developed a transportable master-oscillator-power-amplifier system, supplying Fourier transform limited pulses with a continuously adjustable pulse duration between 50 and 735 ps and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257.25 nm can be achieved, yielding > 200 mW during the beam experiment.

A 21.5 Wed 16:30 P

Sensitivity to new physics of isotope-shift studies using forbidden optical transitions of highly charged Ca ions — •Nils-Holger Rehbehn[1], Michael Karl Rosner[1], Hendrik Bekker[1,3], Julian Berengut[1,7], Piet Schmidt[2,8], Steven King[2], Peter Micke[2,1], Ming Feng Gu[6], Robert Müller[2,4], Andrey Surzhykov[2,4,5], and José Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Helmholz Institut Mainz, Johannes Gutenberg University, Germany — [4]Technische Universität Braunschweig, Germany — [5]Laboratory for Emerging Nanometrology Braunschweig, Germany — [6]Space Science Laboratory, University of California, Berkeley, USA — [7]School of Physics, University of New South Wales, Sydney, Australia — [8]Leibniz Universität Hannover, Germany

A hypothetical fifth force between neutrons and electrons 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 fifth force. We explore six forbidden transitions in highly charged (HCI) calcium, where some are suited for upcoming high-precision coherent laser spectroscopy. With this number of transitions it is possible to utilize the generalized King plot method, which will remove higher-order SM nonlinearities and thus more sensitivity to unknown forces. Currently further research is conducted in HCI Xe, which has a greater number of isotopes for the King plot.

A 21.6 Wed 16:30 P

From the first production run with CRYRING@ESR to the future — •Michael Lestinsky[1], Esther Menz[1,2,3], Zoran Andelkovic[1], Angela Bräuning-Demian[1], Wolfgang Geithner[1], Frank Herfurth[1], Stefan Schippers[4,5], Reinhold Schuch[6], Gleb Vorobjev[1], and Thomas Stöhlker[1,2,3] — [1]GSI Darmstadt — [2]HI Jena — [3]FSU Jena — [4]JLU Gießen — [5]HFHF Campus Gießen — [6]Stockholm University

With the installation and commissioning of the CRYRING@ESR facility being largely complete, the first heavy ion storage ring of the FAIR facility in Darmstadt is now in service as a user facility. The ring is able to store all ion species the GSI accelerator complex can produce as beams – from the lightest protons to bare uranium – and operates at significantly lower beam energy range down to few 100~keV/u. This opens new experiment opportunities and the SPARC collaboration at FAIR has proposed a rich research program on precision spectroscopy, slow atomic collisions and astrophysically relevant processes. During the 2021 beamtime period, first experimental installations of SPARC were successfully taken into operation and several experiment proposals were taken to data production. Even though the data analysis is still largely ongoing, it has already become apparent that the performance of the facility is largely meeting the high expectations. In addition we have been able to identify realistic opportunities for further improvement. We will give an overview of the storage ring, its performance, available and planned experimental installations, and invite discussion on further opportunities of the facility.

A 21.7 Wed 16:30 P

Production of a mixed highly charged ion Coulomb crystal — •Malte Wehrheim[1], Elwin A. Dijck[1], Christian Warnecke[1,2], Ruben Henninger[1], Michael Karl Rosner[1,2], Alvaro Garmendia[1], Andrea Graf[1], Julia Eff[1], Claudia Volk[1], Kostas Georgiou[1,3], Christopher Mayo[1,3], Lakshmi P. Kozhiparambil Sajith[1,3,4], Morten Will[1], José Ramon Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Heidelberg Graduate School for Physics — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen

Precise spectroscopy of highly charged ions (HCI) is a promising candidate for the search of physics beyond the standard model. As a precondition we demonstrate the co-trapping of Ar^{13+} in a precooled beryllium Coulomb crystal with the novel design of our cryogenic Paul trap. After the extraction of hot HCI (10^3K range) from our electron beam ion trap (EBIT) the desired charge state is selected and the HCI beam is brought into the Trap. The main chamber of our experiment CryPTEx-SC (Cryogenic Paul Trap Experiment - superconducting) combines the geometry of a linear Paul trap with a superconducting resonator for the most stable radiofrequency fields. There we achieve the preparation of mixed beryllium and HCI Coulomb crystals of variable size with mK temperatures. By characterizing our trap, we verify that the correct charge state was selected which will be used for a benchmark measurement of the $2p^2P_{1/2} \rightarrow {}^2P_{3/2}$ fine structure transition of Ar^{13+} using quantum logic spectroscopy.

A 21.8 Wed 16:30 P

DR experiment on Ne^{2+} at CRYRING@ESR — •Esther Babette Menz[1,2,3], Michael Lestinsky[1], Sebastian Fuchs[4,5], Weronika Biela-Nowaczyk[6], Alexander Borovik Jr.[4], Carsten Brandau[1,4], Claude Krantz[1], Gleb Vorobyev[1], Bela Arndt[1], Alexandre Gumberidze[1], Pierre-Michel Hillenbrand[1], Tino Morgenroth[1,2,3], Ragandeep Singh Sidhu[1], Stefan Schippers[4,5], and Thomas Stöhlker[1,2,3] — [1]GSI, Darmstadt — [2]Helmholtz-Institut Jena — [3]IOQ, Friedrich-Schiller-Universität Jena — [4]I. Phys. Institut, Justus-Liebig-Universität — [5]Helmholtz Forschungsakademie Hessen für FAIR, Campus Gießen — [6]Institute of Physics, Jagiellonian University Kraków

After its move from Stockholm to GSI, CRYRING@ESR is now back in operation with previously inaccessible ion species available from the accelerator complex as well as a smaller selection from a local injector. The first merged-beam measurements of dielectronic recombination (DR) were performed at the CRYRING@ESR electron cooler since its move from Stockholm using a newly established particle detection and data acquisition setup. We present results from a scheduled experiment on low-energy DR of Ne^{2+} in May 2021. Neon is an astrophysically abundant element and absolute DR rates for low charge states are important for the modelling of cold, photoionized plasmas such as planetary nebulas. We plan to continue our DR experiments with a series of other low charge state ions which are of key importance for the quantitative analysis of astrophysical data.

A 21.9 Wed 16:30 P

Cold highly charged ion dynamics in a superconducting Paul trap — •Elwin A. Dijck[1], Christian Warnecke[1,2], Malte Wehrheim[1], Julia Eff[1], Alvaro Garmendia[1], Andrea Graf[1], Ruben Henninger[1], Claudia Volk[1], Morten Will[1], Kostas Georgiou[1,3], Lakshmi P. Kozhiparambil Sajith[1,3,4], Christopher Mayo[1,3], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Heidelberg Graduate School for Physics — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen

By integrating a niobium superconducting radio-frequency resonator with a linear Paul trap, the CryPTEx-SC experiment demonstrates a new ion trap concept developed for achieving ultra-low noise conditions [1]. Filtering of the trap drive by the high quality factor of the resonator and suppression of magnetic field fluctuations by the Meissner–Ochsenfeld effect will be beneficial for precision spectroscopy of highly charged ions using quantum logic techniques. Highly charged ions are captured and sympathetically cooled by Be^+ ions in the superconducting ion trap. This enables the exploration of dynamics in mixed species Coulomb crystals consisting of ions with disparate charge-to-mass ratios.

[1] J. Stark et al., Rev. Sci. Instrum. **92**, 083203 (2021)

A 22: Charged ions and their applications

Time: Thursday 10:30–12:30 Location: A-H1

Invited Talk A 22.1 Thu 10:30 A-H1

Optimizing large atomic structure calculations with machine learning — •Pavlo Bilous[1], Adriana Pálffy[2], and Florian Marquardt[1] — [1]Max-Planck-Institut für die Physik des Lichts, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

Atomic structure calculations for heavy atoms and ions are computationally demanding due to the presence of strong electronic correlations. These corrections account for admixture of electronic configurations with excitations to unoccupied (virtual) or partially occupied orbitals. For systems with many electrons the number of such additional configurations becomes exponentially large. In this work, we make an attempt to employ a neural network to select which configurations do influence the physical quantity of interest (e.g. a transition energy or a hyperfine structure constant), and which can be omitted without significant loss of precision. As an example, we consider a highly charged Th^{35+} ion with the electronic configuration $4f^9$. This case allows for an electronic bridge scheme [1] relevant for a nuclear clock based on the 8 eV nuclear ^{229}Th isomeric state. In this approach, accurate electronic transition energies are required. The latter were obtained recently in Ref. [2] under usage of massive computational resources. We discuss how the required resources can be reduced by carrying out neural-network-assisted calculations instead.

[1] P. V. Bilous et al., Phys. Rev. Lett. 124, 192502 (2020).
[2] S. G. Porsev et al., Quantum Sci. Technol. 6(3), 034014 (2021).

A 22.2 Thu 11:00 A-H1

First storage of highly charged ions in an ultralow-noise superconducting radio-frequency ion trap — •Christian Warnecke[1,2], Elwin A. Dijck[1], Malte Wehrheim[1], Julia Eff[1], Alvaro Garmendia[1], Andrea Graf[1], Ruben Henninger[1], Claudia Volk[1], Morten Will[1], Lakshmi Priya Kozhiparambil Sajith[4], Kostas Georgiou[3], Christopher Mayo[3], Thomas Pfeifer[1], and José Ramon Crespo López-Urrutria[1] — [1]Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1 69117 Heidelberg Germany — [2]Heidelberg Graduate School for Physics, Im Neuenheimer Feld 226 69120 Heidelberg Germany — [3]School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK — [4]Deutsches Elektronen-Synchrotron (DESY), Humbolt Universität zu Berlin

To provide an environment free of noise induced by external alternating electromagnetic fields, we developed a quasi-monolithic, superconducting quadrupole resonator combined with a Paul trap reaching a very high Q-factor up to 2×10^5 at the working frequency of about 34 MHz. Such a high quality factor filters the radio-frequency trap drive noise significantly. Thus, heating rates of the radial modes are reduced. The cavity is a promising step to increase coherence times for quantum logic spectroscopy experiments, which will lead the way to future spectroscopy measurements with highly charged ions (HCI) in the Lamb-Dicke regime. Recently, first HCI have been successfully retrapped and sympathetically cooled with a single Be+ ion. We present the recent developement of our setup and first characterizations.

A 22.3 Thu 11:15 A-H1

Bound Electron *g* Factor Measurements of Highly Charged Tin — •Jonathan Morgner[1], Charlotte M. König[1], Tim Sailer[1], Fabian Heisse[1], Bingsheng Tu[3], Vladimir A. Yerokhin[2], Bastian Sikora[1], Zoltán Harman[1], José R. Crespo López-Urrutia[1], Christoph H. Keitel[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck Institut für Kernphysik, Heidelberg — [2]Center for Advanced Studies, St. Petersburg — [3]Institute of Modern Physics, Shanghai

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^{16} 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 of low 10^{-11}. Following this, 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 bound-electron g factors in highly charged ^{118}Sn will be presented. Over the course of several months, g factors for three different charge states have been measured, each allowing a unique test of QED in a heavy highly charged ion, probing different g-factor contributions. Furthermore, progress on a new EBIT setup is presented. This will eventually allow Alphatrap to inject and measure even heavier highly charged systems beyond hydrogenlike lead (Pb^{81+}).

A 22.4 Thu 11:30 A-H1

From single-particle picture to many electron QED — •Romain Soguel[1] and Andrey Volotka[2] — [1]Helmholtz-Institut Jena, Jena, 07743, Germany — [2]ITMO University, St. Petersburg, 197101, Russia

The redefined vacuum approach, which is frequently employed in the many-body perturbation theory, proved to be a powerful tool for formula derivation. Here, we elaborate this approach within the bound-state QED perturbation theory. In addition to general formulation, we consider the particular example of a single particle (electron or vacancy) excitation with respect to the redefined vacuum. Starting with simple one-electron QED diagrams, we deduce first- and second-order many-electron contributions: screened self-energy, screened vacuum polarization, one-photon exchange, and two-photon exchange. The redefined vacuum approach provides a straightforward and streamlined derivation and facilitates its application to any electronic configuration. Moreover, based on the gauge invariance of the one-electron diagrams, we can identify various gauge-invariant subsets within derived many-electron QED contributions.

The employment of the redefined vacuum approach allowed us to identify the gauge-invariant subsets, within the two-photon-exchange diagrams, at two- and three-electron diagrams and separate between the direct and exchange contributions at two-electron graphs. The gauge invariance of found subsets is demonstrated both analytically (for an arbitrary state) as well as numerically for 2s, 2p1/2, and 2p3/2 valence electron in Li-like ions.

A 22.5 Thu 11:45 A-H1

Dynamics of a trapped ion in a quantum gas: Effects of particle statistics — •Lorenzo Oghittu[1], Melf Johannsen[1], Antonio Negretti[1], and Rene Gerritsma[2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Van der Waals Zeeman Institute, Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands

We study the quantum dynamics of an ion confined in a radio-frequency trap in interaction with either a Bose or spin-polarized Fermi gas. To this end, we derive quantum optical master equations in the limit of weak coupling and the Lamb-Dicke approximations. For the bosonic bath, we also include the so-called Lamb-shift correction to the ion trap due to the coupling to the quantum gas as well as the extended Fröhlich interaction within the Bogolyubov approximation that have been not considered in previous studies. We calculate the ion kinetic energy for various atom-ion scattering lengths as well as gas temperatures by considering the intrinsic micromotion and we analyze the damping of the ion motion in the gas as a function of the gas temperature. We find that the ion's dynamics depends on the quantum statistics of the gas and that a fermionic bath enables to attain lower ionic energies.

A 22.6 Thu 12:00 A-H1

Water-assisted electron capture exceeds photorecombination in biological conditions — •Axel Molle[1,2], Oleg Zatsarinny[3], Thomas Jagau[2], Alain Dubois[1], and Nicolas Sisourat[1] — [1]Laboratoire de Chimie Physique - Matière et Rayonnement, Sorbonne Université, Paris, France — [2]Quantum Chemistry and Physical Chemistry, KU Leuven, Belgium — [3]Department of Physics and Astronomy, Drake University, Des Moines, USA

A decade ago, an electron-attachment process called *interatomic coulombic electron capture* has been predicted to be possible through energy transfer to a nearby neighbour. It has been estimated to be competitive with environment-independent photorecombination for selected examples of reaction partners. Its impact on biological systems, however, has yet to be investigated.

Here, we evaluate therefore the capability of alkali and alkaline earth metal cations to capture a free electron by assistance from a nearby water molecule. We introduce a characteristic distance r_{IC} for this energy transfer mechanism in equivalence to the Förster radius for energy transfer between chromophores which allows to estimate the quantum efficiency. We find r_{IC} bound from above. This water-assisted electron capture dominates over photorecombination beyond the second hydration shell of each alkali and alkaline earth cation for electron energies above a threshold. It will be measurable against photorecombination in an experiment around that threshold energy.

A 22.7 Thu 12:15 A-H1

Parity-violation studies with partially stripped ions — •Jan Richter[1,2], Anna V. Maiorova[3,4], Anna V. Viatkina[1,2,5,6], Dmitry Budker[5,6,7], and Andrey Surzhykov[1,2,8] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany — [3]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, Russia — [4]Petersburg Nuclear Physics Institute of NRC "Kurchatov Institute", Russia — [5]Helmholtz Institute Mainz, GSI Helmholtzzentrum für Schwerionenforschung, Germany — [6]Johannes Gutenberg University Mainz„ Germany — [7]Department of Physics, University of California, Berkeley, USA — [8]Laboratory for Emerging Nanometrology Braunschweig, Germany

We present a theoretical study of photoexcitation of highly charged ions from their ground states, a process which can be realized at the Gamma Factory at CERN. Special attention is paid to the question of how the excitation rates are affected by the mixing of opposite-parity ionic levels, which is induced both by 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 for the $1s_{1/2} \to 2s_{1/2}$ and $1s^2\ 2s_{1/2} \to 1s^2\ 3s_{1/2}$ (M1 + parity-violating-E1) transitions in hydrogen- and lithium-like ions, respectively. 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.

A 23: Ultra-cold atoms, ions and BEC III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H2

Invited Talk A 23.1 Thu 10:30 A-H2

Chemistry of an impurity in a Bose-Einstein condensate — •Arthur Christianen[1,2], Ignacio Cirac[1,2], and Richard Schmidt[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Techonology, Munich, Germany

In ultracold atomic gases, a unique interplay arises between phenomena known from condensed matter, few-body physics and chemistry. Similar to an electron in a solid, a quantum impurity in an atomic Bose-Einstein condensate is dressed by excitations from the medium, forming a polaron quasiparticle with modified properties. At the same time, the atomic impurity can undergo the chemical reaction of three-body recombination with atoms from the BEC, which can be resonantly enhanced due to universal three-body Efimov bound states crossing the continuum. As an intriguing example of chemistry in a quantum medium, we show that such Efimov resonances are shifted to smaller interaction strenghts due to participation of the polaron cloud in the bound state formation. Simultaneously, the shifted Efimov resonance marks the onset of a polaronic instability towards the decay into larger Efimov clusters and fast recombination.

References: [1] A. Christianen, J.I. Cirac, R. Schmidt, "Chemistry of a light impurity in a Bose-Einstein condensate", arXiv:2108.03174 [2] A. Christianen, J.I. Cirac, R. Schmidt, "From Efimov Physics to the Bose Polaron using Gaussian States", arXiv:2108.03175

A 23.2 Thu 11:00 A-H2

Formation of spontaneous density-wave patterns in DC driven lattices – an experimental study — •Henrik P. Zahn, Vijay P. Singh, Marcel N. Kosch, Luca Asteria, Lukas Freystatzky, Klaus Sengstock, Ludwig Mathey, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Driving a many-body system out of equilibrium induces phenomena such as the emergence and decay of transient states, which can manifest itself as pattern and domain formation. The understanding of these phenomena expands the scope of established thermodynamics into the out-of-equilibrium domain. Here, we observe the out-of-equilibrium dynamics of a Bose-Einstein condensate in an optical lattice subjected to a strong DC field, realized by strongly tilting the lattice. We observe the emergence of pronounced density wave patterns – which spontaneously break the underlying lattice symmetry – using a novel single-shot imaging technique with two-dimensional single-site resolution in three-dimensional systems, which also resolves the domain structure. Further, we investigate formation and decay time scales of the pattern formation as well as the role of tunnelling transverse to the tilt for the type of emerging pattern.

A 23.3 Thu 11:15 A-H2

Formation of spontaneous density-wave patterns in DC driven lattices - a theoretical study — •Lukas Freystatzky[1,2], Vijay Singh[1,3], Henrik Zahn[4], Marcel Kosch[4], Luca Asteria[4], Klaus Sengstock[1,2,4], Christof Weitenberg[2,4], and Ludwig Mathey[1,2,4] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Hanover, Germany — [4]Institut für Laserphysik, Universität Hamburg, Hamburg, Germany

We study the phenomenon of spontaneous density-wave patterns, which emerges in a Bose-Einstein condensate in an optical lattice subjected to a strong DC field, realized by strongly tilting the lattice. We use dynamical classical field simulations and analytical approaches to analyse the out-of-equilibrium dynamics of the system, which shows the emergence of pronounced density-wave patterns that spontaneously break the underlying lattice symmetry. This observation and the corresponding formation and decay time scales of the pattern formation are consistent with the measurements. We identify the dominant processes using Magnus expansion and describe the emergence of the density wave pattern in a perturbative approach.

A 23.4 Thu 11:30 A-H2

Exploring orbital extensions of the Fermi-Hubbard model with ultracold ytterbium atoms — •Giulio Pasqualetti[1,2,3], Oscar Bettermann[1,2,3], Nelson Darkwah Oppong[1,2,3], Immanuel Bloch[1,2,3], and Simon Fölling[1,2,3] — [1]Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

The Fermi-Hubbard model (FHM) represents a paradigmatic milestone in condensed-matter physics. In the last decades, neutral atoms in optical lattices have become a powerful platform for investigating its properties in a clean and well-controlled environment. However, experiments have so far mostly explored the single-orbital limit of the FHM.

Here, we explore orbital extensions of the FHM with ultracold ytterbium atoms. The electronic ground state of neutral ytterbium possesses a SU(N) symmetry, which allows the study of the FHM with larger spin multiplicity. Moreover, a metastable electronic state known as the clock state can serve as a completely independent orbital degree of freedom, enabling the study of the mass-imbalanced FHM utilizing state-dependent potentials. In our experiment, we probe these orbital extensions of the FHM in different dimensionalities, investigating their spectroscopic properties, their thermodynamics, and dynamic response.

A 23.5 Thu 11:45 A-H2

Quantum thermodynamics: Heat leaks and fluctuation dissipation — •Oleksiy Onishchenko[1], Daniël Pijn[1], Janine Hilder[1], Ulrich Poschinger[1], Raam Uzdin[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Fritz Haber Center for Molecular Dynamics, The Hebrew University, Jerusalem, Israel

Quantum thermodynamics focuses on extending the notions of heat and work to microscopic systems, where the concepts of non-commutativity and measurement back-action play a role [1]. In this work, we show a novel way to test the unitary functioning of a quantum processor by detecting heat leaks [2]. We also observe the first experimental signatures of operator non-commutativity on work fluctuations, as suggested theoretically [3]. Our experimental system consists of one or multiple Ca+ ion qubits held in a microstructured Paul trap. We initialize qubits in a statistical mixture of |0> and |1>, thus emulating thermal states. For the heat leak test, we reveal the amount of non-unitary evolution of the system qubits by measuring only in the computational basis and without accessing the environment. For the quantum work measurement, we set the operation and measurement bases to be non-commuting, and then evaluate the resulting work distribution.

[1] Sai Vinjanampathy and Janet Anders, Contemporary Physics 57, 545-579 (2016).

[2] D. Pijn et. al., arXiv:2110.03277v1 (2021).

[3] M. Scandi et. al., Physical Review Research 2, 023377 (2020)

A 23.6 Thu 12:00 A-H2

Methods for atom interferometry with dual-species BEC in space — •Jonas Böhm[1], Maike D. Lachmann[1], Baptist Piest[1], Ernst M. Rasel[1], and the MAIUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, U Bremen — [3]DLR RY Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenoptik, JGU Mainz — [6]FBH, Berlin

Atom interferometry is a promising tool for precise measurements, e.g. for quantum tests of the weak equivalence principle. As the sensitivity scales with the squared time atoms spend in the interferometer, this recommends low expansion velocities of the atomic ensembles. Hence, conducting these experiments in microgravity with Bose-Einstein-Condensates (BEC) is of great interest. The sounding rocket mission MAIUS-1 demonstrated the first creation of a BEC and matter wave interferences in space [1,2]. With the follow-up missions MAIUS-2 and -3, we extend the apparatus by another species to perform atom interferometry with ^{87}Rb and ^{41}K, paving the way for implementing and testing the methods of dual-species interferometers on board of space stations or satellites. In this contribution, the manipulation of BECs using Raman double-diffraction processes to form (asymmetric) Mach-Zehnder-type interferometers, e.g. for inertial sensing, are presented for a compact, robust, and autonomously operating setup that generates ^{87}Rb and ^{41}K BECs with a high repetition rate.

[1] D. Becker, et al., Nature 562, 391-395 (2018). [2] M.D. Lachmann, H. Ahlers, et al., Ultracold atom interferometry in space. Nat Commun 12, 1317 (2021).

A 24: Precision spectroscopy of atoms and ions III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H3

Invited Talk A 24.1 Thu 10:30 A-H3

Spectroscopy of a Highly Charged Ion Clock with Sub-Hz Uncertainty — •Lukas J. Spiess[1], Steven A. King[1], Peter Micke[1,2], Alexander Wilzewski[1], Tobias Leopold[1], Erik Benkler[1], Nils Huntemann[1], Richard Lange[1], Andrey Surzhykov[1], Robert Müller[1], Lisa Schmöger[2], Maria Schwarz[2], 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

Modern optical clocks are the most accurate metrological devices ever built. So far, such systems were only based on neutral and singly charged atoms. Potential further candidates are highly charged ions (HCI) which are intrinsically less sensitive to several types of external perturbations [1]. In previous work, we have demonstrated quantum logic spectroscopy of a HCI [2], enabling the first ever clock-like spectroscopy of these species.

We will present the first sub-Hz accuracy measurement of an optical transition in a HCI. The transition frequency of the 441 nm line in Ar^{13+} is compared to the electric octupole transition frequency in $^{171}Yb^{+}$. Measurements were performed for the two isotopes ^{40}Ar and ^{36}Ar which yields the isotope shift at sub-Hz accuracy and provides input for theoretical studies.

[1] M. G. Kozlov et al., Rev. Mod. Phys. **90** (2018)

[2] P. Micke et al., Nature **578** (2020)

A 24.2 Thu 11:00 A-H3

Tailored Optical Clock Transition in $^{40}Ca^{+}$ — •Lennart Pelzer[1], Kai Dietze[1], Johannes Kramer[1], Fabian Dawel[1], Ludwig Krinner[1], Nicolas Spethman[1], Victor Martinez[2], Nati Aharon[3], Alex Retzker[3], Klemens Hammerer[2], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Theoretische Physik, Appelstraße 2, 30167 Hannover 30167 Hannover, Germany — [3]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

Optical clocks based on single trapped ions are often impeded by long averaging times due to the quantum projection noise limit. Longer probe time would improve the statistical uncertainty, but currently, phase coherence of clock laser systems is limiting probe times for most clock candidates. We propose pre-stabilization of the laser to a larger $^{40}Ca^{+}$ ion crystal, offering a higher signal-to-noise ratio. We engineer an artificial optical clock transition with a two stage continuous dynamical decoupling scheme, by applying near-resonant rf dressing fields. The scheme suppresses inhomogeneous tensor shifts as well as the linear Zeeman shift, making it suitable for multi-ion operation. This tailored transition has drastically reduced magnetic-field sensitivity. Even without any active or passive magnet-field stabilization, it can be probed close to the second-long natural lifetime limit of the $D_{5/2}$ level. This ensures low statistical uncertainty. In addition, we show a significant suppression of the quadrupole shift on a linear five-ion crystal by applying magic angle detuning on the rf-drives.

A 24.3 Thu 11:15 A-H3

Towards continuous superradiance driven by a thermal beam of Sr atoms for an active optical clock — •Francesca Famà, Camila Beli Silva, Sheng Zhou, Stefan Alaric Schäffer, Shayne Bennetts, and Florian Schreck — Institute of Physics, University of Amsterdam

Continuous superradiant lasers have been proposed as next generation optical atomic clocks for precision measurement, metrology, quantum sensing and the exploration of new physics [1]. A superradiant laser consists of phase-synchronized atoms showing an enhanced single atom emission rate, allowing direct lasing on narrow clock transitions [2]. Despite pulsed superradiance having been demonstrated [3-4], steady-state operation remains an open challenge. Here we describe our machine aimed at validating a proposal [5] for a rugged superradiant laser operating on the 1S0-3P1 transition of 88Sr using a thermal collimated continuous atomic beam. The elegance of this approach is that a single cooling stage and a low finesse cavity appear sufficient to fulfill the requirements for continuous superradiance. Expected performances are up to 1 μW output power with a reduced output linewidth of 2π x 8 Hz and a sensitivity to frequency drift due to cavity-mirrors fluctuations suppressed by two orders of magnitude. Such a device promises a compact, robust and simple optical frequency reference, ideal for a wide range of industrial and scientific applications. [1] Chen, Chi.Sci.Bull. 54, 3,(2009). [2] Dicke, Phys.Rev. 93, 99 (1954). [3] Norcia et al., Sci.Adv. 2, e1601231(2016). [4] Schaffer et al., Phys.Rev.A 101, 013819(2020). [5] Liu et al., Phys.Rev.Lett. 125, 253602(2020).

A 24.4 Thu 11:30 A-H3

Investigation of frequency shifts induced by thermal radiation for an ^{88}Sr^{+} optical clock — •Martin Steinel[1], Hu Shao[1], Thomas Lindvall[2], Melina Filzinger[1], Richard Lange[1], Burghard Lipphardt[1], Tanja Mehlstäubler[1,3], Ekkehard Peik[1], and Nils Huntemann[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]VTT Technical Research Centre of Finland, National Metrology Institute VTT MIKES, P.O. Box 1000, 02044 VTT, Finland — [3]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

To realize transition frequencies in optical clocks with high accuracy, a careful investigation of all frequency shifts is required. For most systems operated at room temperature, the AC Stark shift induced by thermal radiation is important. It shows a T^4-dependence, and is proportional to the differential polarizability of the states. For an ion in a radiofrequency (rf) trap, it is challenging to determine the effective temperature T of blackbody radiation, if the trap assembly is heated by rf-losses. Temperature sensors and infrared cameras can be employed to determine T from FEM simulations. Because of the low thermal conductivity of our trap assembly, we expect large uncertainties from such investigations. Thus, we determine the frequency shift from thermal radiation by measuring the clock transition frequency of a single ^{88}Sr^{+} ion at three different trap drive powers using our ^{171}Yb^{+} clock as the reference. Using the known polarizability of ^{88}Sr^{+}, we find a temperature uncertainty of only 4 K and determine the ratio of the unperturbed transition frequencies with 6×10^{-17} fractional uncertainty.

A 24.5 Thu 11:45 A-H3

Two-color grating magneto-optical trap for narrow-line laser cooling — •Saskia Anna Bondza[1,2], Christian Lisdat[1], Stefanie Kroker[3,4,1], and Tobias Leopold[2] — [1]1Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]2DLR-Institute for Satellite Geodesy and Inertial Sensing c/o Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Technische Universität Braunschweig, Institut für Halbleitertechnik, Hans-Sommer-Str. 66, 38106 Braunschweig — [4]LENA Laboratory for Emerging Nanometrology, Langer Kamp 6, 38106 Braunschweig, Germany

We present for the first time design and operation of a two-color grating magneto-optical trap (gMOT) optimized for cooling and trapping of ^{88}Sr atoms on the first and second cooling transition. We trap 10^6 ^{88}Sr atoms on the $^1S_0 \rightarrow {}^1P_1$ transition at 461 nm with a linewidth of 30.2 MHz that are initially cooled to few mK and subsequently transferred to the second cooling stage on the narrow line $^1S_0 \rightarrow {}^3P_1$ transition at 689 nm with a linewidth of 7.48 kHz where they are further cooled to a temperature of 5 μK. We reach a transfer efficiency of 25%. We outline general design considerations for two-colour cooling with a gMOT transferable to other atom species. These results present an important step in further miniaturization of quantum sensors based on cold alkaline-earth atoms.

A 24.6 Thu 12:00 A-H3

ARTEMIS - HITRAP: Status of the beamline — •Khwaish Kumar Anjum[1,2], Patrick Baus[3], Gerhard Birkl[3], Manasa Chambath[1,4], Kanika Kanika[1,5], Jeffrey Klimes[1,5,6], Wolfgang Quint[1,5], and Manuel Vogel[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [2]Dept. of Applied Physics, Delhi Technological University, New Delhi, India — [3]Institut für Angewandte Physik, TU Darmstadt, Darmstadt, Germany — [4]Amrita Vishwa Vidyapeetham, Kollam, India — [5]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — [6]International Max Planck Research School for Quantum Dynamics in Physics, Chemistry and Biology, Heidelberg, Germany

In ARTEMIS (AsymmetRic Trap for measurement of Electron Magnetic moment in IonS), at HITRAP, we aim to perform the g-factor measurements of medium to heavy highly charged ions. It serves as a test of QED in strong fields and we do this using laser-microwave double-resonance spectroscopy. Currently, we are in the process of attaching the cold valve to ARTEMIS which will mark the completion of the beamline. This connects the experiment to the HITRAP facility and the EBIT, an offline ion source, and is on schedule for the planned beamtime of May 2022. Alongside this, in-situ production and analysis of Ar13+ ions are being successfully carried out (up to a few weeks). As of 2021, we have completed the individual assembly of the parts of the beamline connecting ARTEMIS to the HITRAP facility and have received ions in the final Faraday cup of the vertical beamline.

A 25: Ultracold Atoms and Molecules I (joint session Q/A)

Time: Thursday 10:30–12:30 Location: Q-H10

A 25.1 Thu 10:30 Q-H10

Optical bench system for the BECCAL ISS quantum gas experiment — •Jean Pierre Marburger[1], Faruk Alexander Sellami[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and THE BECCAL TEAM[1,3,4,5,6,7,8,9,10,11] — [1]Institut für Physik, JGU, Mainz — [2]ILP, UHH, Hamburg — [3]HUB — [4]FBH — [5]LUH — [6]ZARM — [7]Universität Ulm — [8]DLR-SC — [9]DLR-SI — [10]DLR-QT — [11]OHB

The DLR-NASA BECCAL multi-user experimental facility is intended for the study of quantum gases in the microgravity environment of the ISS. In this talk, we present a stable optical bench system that enables frequency stabilization, as well as efficient light distribution and manipulation for this facility. In contrast to a lab-based setup, this system needs to withstand the mechanical loads during launch, and be mechanically stable under varying temperature conditions on the ISS over a timeframe of many years. To this end, we use and expand upon an optical toolkit based on the glass-ceramic Zerodur, which has a negligible coefficient of thermal expansion. This toolkit has already been successfully deployed in the scope of the sounding rocket missions KALEXUS, FOKUS, MAIUS-1, and will be used for the upcoming MAIUS-2/3 missions.

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 25.2 Thu 10:45 Q-H10

Rapid generation of all-optical ^{39}K Bose-Einstein condensates — •Alexander Herbst, Henning Albers, Vera Vollenkemper, Knut Stolzenberg, Sebastian Bode, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

Ultracold potassium is a promising candidate for fundamental research and quantum sensing applications as it offers multiple broad Feshbach resonances at small magnetic fields. These can be used to control the atomic scattering length and therefore allow, e.g., for the suppression of phase diffusion or the generation of solitons. To apply this technique the magnetic field must be kept as an external degree of freedom thus necessitating optical trapping. However, compared to their magnetic counterparts, optical traps suffer from slower evaporative cooling. This poses a major challenge if the experiment requires a high repetition rate. We investigate the production of all-optical ^{39}K BECs under different scattering lengths in a time-averaged crossed optical dipole trap. By tuning the scattering length in a range between 75 a_0 and 350 a_0 we demonstrate a trade off between evaporation speed and final atom number and decrease our evaporation time by a factor of five while approximately doubling the atomic flux. To this end, we are able to produce fully condensed ensembles with 5×10^4 atoms within 850 ms evaporation time at a scattering length of 234 a_0 and 1.5×10^5 atoms within 4 s at 160 a_0, respectively. We analyze the flux scaling with respect to collision rates and describe routes towards high-flux sources of ultra-cold potassium for inertial sensing.

A 25.3 Thu 11:00 Q-H10

Optical dipole trap in microgravity - the PRIMUS-project — •Marian Woltmann[1], Christian Vogt[1], Sven Hermann[1], and The PRIMUS-Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]Institut für Quantenoptik, LU Hannover

The application of matter wave interferometry in a microgravity (μg) environment offers the potential of largely increased interferometer times and thereby highly increased sensitivities in precision measurements, e.g. of the universality of free fall. While most μg-based cold atom experiments use magnetic trapping on an atom chip, we develop an optical dipole trap as an alternative source for matter wave interferometry in weightlessness. Solely using optical potentials offers unique advantages like improved trap symmetry, trapping of all magnetic sublevels and the accessibility of Feshbach resonances. Equipping a 50W trapping laser at a wavelength of 1064nm we implement a cold atom experiment for use in the drop tower at ZARM in Bremen, offering 4.7s of microgravity time. We demonstrated Bose-Einstein condensation of Rubidium in a compact setup on ground while now focusing on a fast, efficient preparation in microgravity using painted optical potentials. Within this talk we will report on the current status and latest results of the experiment. The PRIMUS-Project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 2042.

A 25.4 Thu 11:15 Q-H10

Compact and Robust Laser System for Cold Atom Experiments in BECCAL on the ISS — •Tim Kroh[1], Victoria A. Henderson[1], Jean Pierre Marburger[2], Faruk Alexander Sellami[2], Esther del Pino Rosendo[2], André Wenzlawski[2], Matthias Dammasch[3], Ahmad Bawamia[3], Andreas Wicht[3], Patrick Windpassinger[2], Achim Peters[1,3], and THE BECCAL TEAM[1,2,3,4,5,6,7,8,9,10,11] — [1]HUB, Berlin — [2]JGU, Mainz — [3]FBH, Berlin — [4]DLR-SC — [5]DLR-SI — [6]DLR-QT — [7]IQ & IMS, LUH — [8]ILP, UHH — [9]ZARM, Bremen — [10]IQO, UULM — [11]OHB

BECCAL (Bose-Einstein Condensate–Cold Atom Laboratory) is a cold atom experiment designed for operation on the ISS. This DLR and NASA collaboration builds upon the heritage of sounding rocket and drop tower experiments as well as NASA's CAL. Fundamental physics with Rb and K BECs and ultra-cold atoms will be explored in this multi-user facility in microgravity, providing prolonged timescales and ultra-low energy scales compared to those achievable on earth. Matching the complexity of the required light fields to the stringent size, weight, and power limitations presents a unique challenge for the laser system design, which is met by 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. The design of the BECCAL laser system will be presented, alongside the requirements, concepts, and heritage which formed it. This work is supported by DLR with funds provided by the BMWi under grant numbers 50 WP 1433, 1702, 1703, 1704, 2102, 2103, and 2104.

A 25.5 Thu 11:30 Q-H10

Few-Body Physics in Spherical Shell Traps — C. Moritz Carmesin[1] and •Maxim A. Efremov[2,1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89069 Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), 89081 Ulm, Germany

With the recent progress in cold atom physics in microgravity [1–5] it is feasible to trap atoms in spherical shell-shaped traps. We start our analysis from exploring both bound and scattering states of two identical particles in spherical shell traps. Due to the non-separability of the center-of-mass and relative motions, we have solved the 6-dimensional Schrödinger equation numerically. Moreover, we have derived analytical models for the effective interaction between the particles for small and large shell radii, where the latter features quasi-two-dimensional dynamics in curved space.

[1] D. C. Aveline et al., Nature 582,193 (2020).
[2] K. Frye et al., EPJ Quantum Technol. 8, 1 (2021).
[3] N. Lundblad et al., npj Microgravity 5, 30 (2019).
[4] R. A. Carollo et al., arXiv:2108.05880
[5] A. Wolf et al., arXiv:2110.15247

A 25.6 Thu 11:45 Q-H10

A lattice model for traid anyons — •Sebastian Nagies[1], Botao Wang[1], Nathan Harshman[2], and André Eckardt[1] — [1]Institute of Theoretical Physics, Technical University Berlin, Berlin — [2]Department of Physics, American University, Washington DC, USA

Hard-core two-body interactions in two dimensions leave the configuration space of particles not simply connected. This gives rise to anyons exhibiting fractional exchange statistics governed by the braid group. Recently it was pointed out that hardcore three-body interactions in one dimension leave similar defects in configuration space. This allows for novel exchange statistics described by the traid group, for which the Yang-Baxter relation no longer holds. Here we propose a lattice model realizing a specific abelian representation of this traid group. Our model uses bosons with number-dependent hopping phases to generate alternating bosonic and fermionic exchange phases. By combining numeric simulations with analytic derivation in the continuum limit, we find interesting ground state density distributions and energies that differ greatly from bosons, fermions and braid anyons. We define new traid anyon operators satisfying non-local commutation relations, and predict distinctive traid anyon quasi-momentum distributions. We discuss their possible relation with Haldane's exclusion statistics.

A 25.7 Thu 12:00 Q-H10

Reservoir-engineered shortcuts to adiabaticity via quantum non-demolition measurements — •Raphael Menu[1], Josias Langbehn[2], Christiane Koch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

The preparation of a quantum state via a slow tuning of the parameters of the system lies at the heart of the concept of adiabatic quantum computing. Yet, the realization of such types of computation requires a wide time-window over which dissipation effects may occur, ultimately leading to errors. Here, we propose a protocol that achieves fast adiabatic Landau-Zener dynamics by coupling a spin to an external system. The coupling realizes a quantum non-demolition (QND)Hamiltonian, where the external system acts as a meter. When the meter's decay rate is the largest frequency scale of the dynamics, the QND coupling induces an effective dephasing of the spin in the adiabatic basis and the spin dynamics is described by a quantum adiabatic master equation. We show, however, that adiabaticity can be maximized in the non-adiabatic limit when the coupling with the meter tends to suppress diabatic transitions via effective cooling processes. We investigate the protocol efficiency in terms of non-Markovianity measures for the spin-meter dynamics and qualitatively discuss the spectral gap of the incoherent dynamics. We finally show that the protocol is robust against imperfection in the implementation of the QND Hamiltonian.

A 25.8 Thu 12:15 Q-H10

Engineering of Feshbach Resonances by a Floquet Drive — •Christoph Dauer, Axel Pelster, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany

Feshbach resonances are a common tool in order to control the scattering length in ultracold quantum gases [1]. In this talk we discuss how time-periodic driving enables to induce novel resonances that are fully controllable by the parameters of the drive [2,3]. A theory allowing a deeper understanding of these driving induced resonances within the Floquet picture is given. Our method is capable of describing resonance positions and widths for general inter-particle potentials. We demonstrate our results on an experimentally relevant example.

[1] C. Chin et al., Rev. Mod. Phys. 82, 1225 (2010)
[2] D.H. Smith, Phys. Rev. Lett. 115, 193002 (2015)
[3] A.G. Sykes et al., Phys. Rev. A 95, 062705 (2017)

A 26: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 14:00–15:45 Location: A-H1

A 26.1 Thu 14:00 A-H1

Ion-Rydberg interactions observed by a high-resolution ion microscope — •Moritz Berngruber, Nicolas Zuber, Viraatt Anasuri, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Center for Integrated Quantum Science and Technology (IQST)

In this talk, we present the latest experimental results on spatially resolved ion-Rydberg-atom interaction studied with our high-resolution ion microscope. The apparatus provides a highly tunable magnification, ranging from 200 to over 1500, a spatial resolution better than 200 nm and a depth of field of more than 70 μm. These properties and the excellent electric field compensation enable the observation of ion-Rydberg-interaction in cold bulk quantum gases. The direct spatial imaging method allows for in-situ images of a new type of long-range Rydberg-atom-ion molecule in rubidium, which arises from a binding mechanism that is based on the interaction between the ionic charge and a flipping induced dipole of a Rydberg atom [1].

In addition, the ion microscope also allows for spectroscopic studies of the vibrational level structure. Moreover, the good temporal resolution of the detector enables the observation of dynamic phenomena during the interaction process which compared to traditional molecules are slowed down by many orders of magnitude.

[1] Zuber, N., et al. "Spatial imaging of a novel type of molecular ions." arXiv preprint arXiv:2111.02680 (2021).

A 26.2 Thu 14:15 A-H1

Chiral Rydberg States of Laser Cooled Atoms — •Stefan Aull[1], Steffen Giesen[2], Markus Debatin[1], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Institut für Physik, 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. Following a well established procedure for circular Rydberg state generation and subsequent manipulation with taylored radio frequency pulses under the influence of a magnetic field, the necessary superposition with correspondingly set phases can be prepared. Enantio-selective excitation using photo-ionization circular dichroism is under theoretical and experimental development.

A 26.3 Thu 14:30 A-H1

Coherent delocalization in a frozen Rydberg gas — •Matthew Eiles, Ghassan Abumwis, Christopher Wächtler, and Alexander Eisfeld — Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str. 38 01187 Dresden

The long-range dipole-dipole interaction can create delocalized states due to the exchange of excitation between Rydberg atoms. We show that even in a random gas many of the single-exciton eigenstates are surprisingly delocalized, composed of roughly one quarter of the participating atoms. We identify two different types of eigenstates, one which stems from strongly-interacting clusters and one which extends over large delocalized networks, and show how to excite and distinguish them via appropriately tuned microwave pulses. The extent of delocalization can be enhanced by degeneracies in the atomic states which be controllably lifted using the Zeeman splitting provided by a magnetic field.

A 26.4 Thu 14:45 A-H1

From Highly Charged to Neutral Microplasma — •Mario Grossmann, Julian Fiedler, Jette Heyer, Markus Drescher, Klaus Sengstock, Philipp Wessels-Staarmann, and Juliette Simonet — The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

By combining an ultracold quantum gas of ^{87}Rb with strong-field ionization in femtosecond laser pulses, we investigate the dynamics of highly charged to neutral microplasmas.

Our experimental setup enables us to detect ions and electrons separately and resolve their kinetic energies.

We locally ionize an ultracold target with densities of up to $10^{20}\mathrm{m}^{-3}$ within a micrometer sized focus. This allows creating initially strongly coupled plasmas with ion temperatures below 40 mK and a few hundred to thousand charged particles.

The excess energy of the electrons can be tuned via the wavelength of the ionizing laser pulse resulting in initial electron temperatures from 5800 K to 65 K. This directly impacts the neutrality of the plasma:

High excess energies yield a highly charged plasma with rapid electron cooling whereas low excess energies trigger a neutral plasma with greatly increased lifetimes. Below the ionization threshold we observe ultrafast excitation of Rydberg states.

The small number of particles permits us to compare our results to molecular dynamics simulations that grant access to the non-equilibrium plasma dynamics on picosecond timescales.

A 26.5 Thu 15:00 A-H1

Non-equilibrium Spin Dynamics using the Discrete Truncated Wigner Approximation — •Neethu Abraham[1,2] and Sebastian Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India — [2]Department of Physics, Indian Institute of Science Education and Research, Tirupati, Andhra Pradesh 517 507, India

Approximate simulation methods play a crucial role in the efficient numerical computation of quantum dynamics in many body spin systems, since the exponentially increasing dimension of their Hilbert space cannot be treated exactly. We have investigated the realm of applicability of a very recently developed phase space method, based on the Monte Carlo sampling of the discrete Wigner function: the discrete truncated Wigner approximation (DTWA). Using the DTWA, we show that an aggregate of Rydberg atoms immersed in a background of detector atoms can serve as a quantum simulating platform for various many body physics problems. Decoherence in the excitation transport induced by the interactions with the background atoms can be controlled by altering the distance between the aggregate and detector atoms. This may allow for an experimental platform to examine energy transport subject to an environment.

We were also able to look at quench dynamics in condensed matter spin systems using essentially the same techniques due to the mathematical similarities between the Hamiltonians of these two systems. We explore the possible supremacy of DTWA over other methods, such as tDMRG, for the study of Domain Wall melting in a 2D spin lattice.

A 26.6 Thu 15:15 A-H1

Quantum simulations with circular Rydberg atoms — •Christian Hölzl, Aaron Götzelmann, Alexander Buhl, Achim Scholz, Moritz Wirth, and Florian Meinert — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

Highly excited low-l Rydberg atoms in configurable mircotrap arrays have recently proven highly versatile for studying quantum many-body spin systems with single particle control. I will report on the advances of a new project pursuing to harness high-l circular Rydberg atoms for quantum simulation. When stabilized against black body radiation (BBR) in a suitable cavity structure, circular Rydberg states promise orders of magnitude longer lifetimes compared to their low-l counterparts and thus provide an appealing potential to strongly boost coherence times in Rydberg-based interacting atom arrays. To maintain excellent high-NA optical access we exploit a novel approach using an indium tin oxide (ITO) capacitor, capable of surpressing the parasitic microwave BBR even in a non-cryogenic environment while beeing transparent to visible light.

A 26.7 Thu 15:30 A-H1

Phonon dressing of a facilitated one-dimensional Rydberg lattice gas — •Matteo Magoni, Paolo P. Mazza, and Igor Lesanovsky — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We study the dynamics of a one-dimensional Rydberg lattice gas under facilitation conditions which implement a so-called kinetically constrained spin system. Here an atom can only be excited to a Rydberg state when one of its neighbours is already excited. Once two or more atoms are simultaneously excited mechanical forces emerge, which couple the internal electronic dynamics of this many-body system to the external vibrational degrees of freedom in the lattice. This electron-phonon coupling results in a so-called phonon dressing of many-body states which in turn impacts on the facilitation dynamics.

In our theoretical study we focus on a scenario in which all energy scales are sufficiently separated such that a perturbative treatment of the coupling between electronic and vibrational states is possible. This allows to analytically derive an effective Hamiltonian for the evolution of clusters of consecutive Rydberg excitations in the presence of phonon dressing [1]. We analyse the spectrum of this Hamiltonian and show, by employing Fano resonance theory, that the interaction between Rydberg excitations and lattice vibrations leads to the emergence of slowly decaying bound states that inhibit fast relaxation of certain initial states. We supplement our analysis by providing detailed experimental considerations on the validity of the approximations used.

[1] M. Magoni et al., arXiv: 2104.11160 (2021)

A 27: Ultracold Atoms and Molecules II (joint session Q/A)

Time: Thursday 14:00–15:30 Location: Q-H10

Invited Talk A 27.1 Thu 14:00 Q-H10

Self-bound Dipolar Droplets and Supersolids in Molecular Bose-Einstein Condensates — •Tim Langen — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany

I will discuss the prospects of exploring quantum many-body physics with ultracold molecular gases.

On the theory side, I will present a numerical study of molecular Bose-Einstein condensates with strong dipole-dipole interactions. We observe the formation of self-bound droplets, and explore phase diagrams that feature a variety of exotic supersolid states. In all of these cases, the large and tunable molecular dipole moments enable the study of unexplored regimes and phenomena, including liquid-like density saturation and universal stability scaling laws for droplets, as well as pattern formation and the limits of droplet supersolidity.

On the experimental side, I will discuss progress in molecular laser cooling towards the ultracold regime. I will further present a realistic approach to realize both the collisional stability of ultracold molecular gases and the independent tunability of their contact and dipolar interaction strengths using a combination of microwave and DC electric fields.

Taken together, these results provide both a blueprint and a benchmark for near-future experiments with bulk molecular Bose-Einstein condensates.

A 27.2 Thu 14:30 Q-H10

Single-beam laser cooling using a nano-structured atom chip — •Hendrik Heine[1], Joseph Muchovo[1], Aaditya Mishra[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, Callinstr. 36, D-30167 Hannover, Germany

Matterwave interferometry with Bose Einstein Condensates (BEC) promises exciting prospects in inertial sensing and research on fundamental physics both on ground and in space. BECs can be efficiently created using atom chips and compact setups have already been shown. However, for transportable or space applications further reduction in complexity is desired in order to lower size, weight, and power demands.

I will present a nano-structured atom chip with results on magneto-optical trapping and sub-Doppler cooling using only a single beam of light. This reduces the overall complexity and promises greater long-term stability. We demonstrate state-of-the-art performance and magnetic trapping with the atom chip.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

A 27.3 Thu 14:45 Q-H10

Real-Time detection and feedback cooling of the secular motion of an ion — •Hans Dang[1,2], Martin Fischer[1], Atish Roy[1], Lakhi Sharma[1], Markus Sondermann[1,2], and Gerd Leuchs[1,2,3,4] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nürnberg (FAU), Department of Physics, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada — [4]Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia

We report on the direct observation of the secular motion of a single ion by imaging it onto a knife-edge using a deep parabolic mirror. The unique misalignment functionals of the phase front of the light collected by the mirror together with its high collection efficiency[1] allow us to detect the motion in a time shorter than the coherence time of the harmonic motion of the ion. Using a known oscillation amplitude to calibrate the detection the temperature of the ion can be extracted from the rms voltage of the measured signal. By applying the phase-shifted and amplified signal to one of the compensation electrodes of the ion trap it is possible to dampen the amplitude of the harmonic oscillation and hence cool the ion. Prospects of expanding the detection to all three motional modes simultaneously will be discussed.

[1] R. Maiwald *et al.*, Physical Review A **86**, 043431 (2012)

A 27.4 Thu 15:00 Q-H10

Surface charge removal in a microstructured electrostatic trap for cold polyatomic molecules — •Jindaratsamee Phrompao, Michael Ziemba, Florian Jung, Martin Zeppenfeld, Isabel Rabey, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Cold polar molecules are an excellent platform to explore fascinating research areas in both physics and chemistry, such as cold collisions, cold chemistry, and tests of fundamental physics. Motivated by these applications, techniques in the field are advancing rapidly with the overall goal of producing dense and cold molecular samples. To achieve these, electric trapping provides long trapping times and deep confinement of the molecules. In our electrostatic trap [1], we combine two parallel microstructured capacitor plates and a surrounding ring electrode to provide a tunable homogeneous electric control field and transverse confinement, respectively. By combining the various electrodes, polar molecules are confined within a boxlike potential. However, the trap depth is limited by high-voltage breakdown and surface charge accumulation, which possibly also induces early breakdown.

In this talk, we will present induced removal of charges by applying UV light and heating to test samples. We find that heating these to more than $200°C$ can remove the charge almost completely, but the characteristics are not reproducible. In contrast, charge removal by shining in UV light is more reliable and capable of providing rapid and complete charge removal.

[1] B.G.U. Englert et al., Phys. Rev. Lett. 107, 263003 (2011)

A 27.5 Thu 15:15 Q-H10

Creating an ensemble of cooled and trapped formaldehyde molecules in their ortho ground state — •Maximilian Löw, Martin Ibrügger, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Direct cooling methods to produce polar molecules in the ultracold regime have improved significantly in recent years. Optoelectrical Sisyphus cooling is one of the most promising techniques in this field providing a large number of electrically trapped molecules at sub-millikelvin temperatures [1]. However, this method is not applicable to molecules in their absolute ground state.

Cooled ground state molecules can still be obtained by first applying Sisyphus cooling to formaldehyde (H_2CO) molecules in the rotational states $|J=3,K_a=3,K_c=0\rangle$ and $|4,3,1\rangle$. Afterwards, they are transferred to their ortho ground state $|1,1,0\rangle$ by optical pumping via a vibrational transition. In a proof-of-principle experiment we thereby obtained trapped ground state molecules with a temperature of 65 mK and trapping times of several seconds. Colder temperatures should be easily achievable in the future.

As molecules in this state are stable against inelastic two-body collisions this fulfills an important requirement for evaporative or sympathetic cooling of formaldehyde in e.g. a microwave trap which takes us one step further on the envisioned road towards quantum degeneracy.

[1] A. Prehn *et al.*, *Phys. Rev. Lett.* **116**, 063005 (2016).

A 28: Interaction with VUV and X-ray light

Time: Thursday 16:30–18:30 Location: P

A 28.1 Thu 16:30 P

An XUV and soft X-ray split-and-delay unit for FLASH2 — •Matthias Dreimann[1], Dennis Eckermann[1], Felix Rosenthal[1], Sebastian Roling[2], Frank Wahlert[2], Sven Eppenhoff[2], Marion Kuhlmann[3], Sven Toleikis[3], Rolf Treusch[3], Elke Plönjes-Palm[3], and Helmut Zacharias[1] — [1]Center for Soft Nanoscience, WWU Münster, 48149 Münster, Germany — [2]Physikalisches Institut, WWU Münster, 48149 Münster, Germany — [3]Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

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 covering the whole spectral range of FLASH2 from 30 eV up to 1800 eV. Using wavefront beam splitting and grazing incidence mirrors a sub-fs resolution with a relative pulse delay of $-5\,ps \leq \Delta\tau \leq +18\,ps$ is achieved. Two different mirror coatings are required to cover the complete spectral range and thus, a design that is based on a three dimensional beam path was developed. This allows the choice between different sets of mirrors with either coating for the fixed branch. A Ni coating allows a total transmission above T > 0.50 for photon energies between hν = 30 eV and 650 eV at a grazing angle of a $\vartheta_{variable}$ = 1.8° in the beam path with variable delay. With a Pt coating a transmission of T > 0.06 is possible for photon energies up to hν = 1800 eV. In the fixed beam path at a grazing angle of ϑ_{fixed} = 1.3° a transmission of T > 0.61 with a Ni coating and T > 0.23 with a Pt coating is possible.

A 28.2 Thu 16:30 P

Analysis of x-ray single-shot diffractive imaging using the propagation multislice method — •Paul Tuemmler, Björn Kruse, Christian Peltz, and Thomas Fennel — Institut für Physik, Universität Rostock

Single-shot wide-angle x-ray scattering has enabled the three-dimensional characterization of free nanoparticles from a single scattering image [1,2,3]. Key to this method is the fact, that the scattering patterns contain information of density projections on differently oriented projection planes. Wide-angle scattering typically requires XUV photon energies where absorption and attenuation cannot be neglected in the description of the scattering process [4,5]. The multislice Fourier transform (MSFT) method, which provides a fast scattering simulation within the Born approximation, can be extended to also include these propagation effects. In this presentation the performance of conventional MSFT and propagation MSFT will be discussed and compared to exact results obtained from Mie theory. As a first application, selective resonant scattering from core shell systems is explored.

[1] I. Barke , Nat. Commun. 6, 6187 (2015).
[2] K. Sander , J. Phys. B 48, 204004 (2015).
[3] C. Peltz , Phys. Rev. Lett. 113, 133401 (2014).
[4] D. Rupp , Nat. Commun. 8, 493 (2017).
[5] B. Langbehn , Phys. Rev. Lett. 121, 255301 (2018).

A 28.3 Thu 16:30 P

Coherent population transfer techniques for the ^{229}Th nuclear clock candidate — •Tobias Kirschbaum and Adriana Pálffy — Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

The ^{229}Th nucleus posses a metastable first excited state, i.e., an isomer, at around 8.19 eV. This state should be accessible via VUV light and presents a radiative lifetime of a few hours. These unique properties make ^{229}Th a promising candidate for a nuclear clock with excellent accuracy [1]. However, due to the relatively large uncertainty on the isomeric state energy, efficient laser manipulation with VUV light has proven cumbersome so far.

Here, we investigate theoretically an alternative to populate the isomeric state by indirect excitation via the second excited nuclear state at 29.19 keV. We make use of quantum optics schemes to achieve the population transfer via Stimulated Raman adiabatic passage (STIRAP) or two π-pulses. The coherent x-ray pulses that we consider are generated by x-ray lasers or using UV pulses at the Gamma Factory in combination with relativistic acceleration of the nuclei in a storage ring. The two scenarios are discussed in view of experimental feasibility.

[1] E. Peik *et al.*, Quantum Sci. Technol. **6**, 034002 (2021).

A 29: Ultra-cold atoms, ions and BEC (joint session A/Q)

Time: Thursday 16:30–18:30 Location: P

A 29.1 Thu 16:30 P

Quantum degenerate Fermi gas in an orbital optical lattice — •Yann Kiefer — Luruper Chaussee 149, 22761 Hamburg

Spin-polarized samples and spin mixtures of quantum degenerate fermionic atoms are prepared in selected excited Bloch bands of an optical chequerboard square lattice. For the spin-polarized case, extreme band lifetimes above 10 s are observed, reflecting the suppression of collisions by Pauli*s exclusion principle. For spin mixtures, lifetimes are reduced by an order of magnitude by two-body collisions between different spin components, but still remarkably large values of about one second are found. By analyzing momentum spectra, we can directly observe the orbital character of the optical lattice. The observations demonstrated here form the basis for exploring the physics of Fermi gases with two paired spin components in orbital optical lattices, including the regime of unitarity. Furthermore access to a broad Feshbach resonance enables to study the role of interaction and pairing of ultracold molecular orbital optical lattices.

A 29.2 Thu 16:30 P

non-equilibrium dynamics of a bose-einstein condensate populating higher bands of an optical lattice — •josé vargas[1,3] and andreas hemmerich[1,2,3] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

We present the realization of diverse experiments on non-equilibrium dynamics of a Bose-Einstein condensate populating higher bands of a bipartite square optical lattice. We experimentally investigate single- and many-body phenomena such as Bloch oscillations along different paths over each addressable Brillouin zones, and Josephson oscillations in the second Bloch band of the lattice. In addition, by exciting the atomic sample into different initial quasi-momenta of the lattice, we study instabilities of the system together with the characterization of re-condensation dynamics towards the energy minimum of the Bloch band.

A 29.3 Thu 16:30 P

Optically trapping single ions in a high-focused laser beam — •Wei Wu[1], Fabian Thielemann[1], Joachim Welz[1], Pascal Weckesser[1,2], Daniel Hönig[1], Amir Mohammadi[1], Thomas Walker[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

Ions stored in Paul traps are well suited to design few-particle systems with high-fidelity control over electronic and motional degrees of freedom and individual addressability., alongside long-range interactions. It is challenging, however, to extend this control to two- or higher-dimensional systems. This is partly due to the existence of driven motion, which intrinsically leads to decoherence and heating. Ions confined in optical traps, on the other hand, constitute a system which is free of driven motion but still benefits from long-range interaction. For example, ions in optical traps could be used to study and control quantum structural phase transitions from 1D (linear) to 2D (zigzag) crystals. Additionally, optical traps offer scalability, flexibility and nanoscale potential geometries which are not easily accessible with Paul traps. Optical traps for ions also feature state-dependent trapping due to the different potentials seen by the ion when in different electronic states. In this poster, we present a method to deterministically prepare a single ion or string of ions, making use of state dependent potentials in optical traps to eject selected ions from the trap.

A 29.4 Thu 16:30 P

Feshbach Resonances in a hybrid Atom-Ion System — •Joachim Welz[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 interaction rate between particles to be tuned with the perspective to even switch them off. 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]. By immersing a single Ba ion in an ultracold cloud of Li, we demonstrate the enhancement of both two-body and three-body interactions through changes in the ion's internal and motional energy. This 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 29.5 Thu 16:30 P

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

We present the progress towards constructing a dipolar quantum gas microscope. This new apparatus combines the long-range interactions found in dipolar quantum gases with the single-site resolution of a quantum gas microscope, allowing for detailed studies of quantum phases in strongly correlated systems. Fermionic atoms trapped in optical lattices can model the behaviour of electrons in complex solid materials. By implementing a quantum gas microscope, microscopic details such as site occupation and site correlations will be observable, providing new insights into elusive quantum phases. We plan to do this using dysprosium atoms trapped in an ultraviolet optical lattice with a lattice spacing of about 180 nm. Combined with the long-range dipole interaction, the short lattice spacing will significantly increase the nearest-neighbour interaction strength to be on the order of 200 Hz (10 nK). This will allow us to study the regime of strongly interacting dipolar Bose- and Fermi-Hubbard physics where even next-nearest-neighbour interactions could be visible.

A 29.6 Thu 16:30 P

Compact device for painting blue-detuned time-averaged optical potentials for space application — •Kai Frye[1,2], Marius Glaeser[1], Christian Schubert[1,2], Waldemar Herr[1,2], Ernst Rasel[1], and 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

The Bose-Einstein and Cold Atom Laboratory (BECCAL) will be a multi-user and -purpose facility onboard the International Space Station. It will provide ultacold ensembles of Rb and K atoms for experiments on fundamental research and sensor applications. For this, BECCAL will support the confinement of atoms in optical flat-bottom traps of arbitrary shapes.

Here, we present a design of a compact and robust setup for creation of blue-detuned time-averaged optical potentials. We utilize a dual-axis acousto-optical deflector and characterize the setup in terms of efficient use of light power, light extinction in the center of the optical trap and smoothness of the potential.

BECCAL is supported 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. Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany*s Excellence Strategy * EXC-2123 QuantumFrontiers * 390837967.

A 29.7 Thu 16:30 P

Trapping Ions And Ion Coulomb Crystals In Optical Lattices — •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, Deutschland — [2]Leibniz-Universität, Hannover, Deutschland

Optically trapped ion Coulomb crystals are an interesting platform for quantum simulations due to the long range of the Coulomb interaction as well as the state dependence of the optical potential. Optical lattices expand the possible application of this platform by trapping the ions in seperate potential wells as well as giving optical confinement along the axis of the beam. In the past we reported the succesfull 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 Poster, we present recent advancements in trapping of Ba138+ ions in an one dimensional optical lattice at a wavelength of 532nm and report the first successfull trapping of small ion coulomb crystals ($N \leq 3$) in a lattice. We compare trapping results between the lattice and a single-beam optical dipole trap and investigate the effect of axial electric fields on the trapping probability of a single ion to demonstrate the axial confinement of the ion by the lattice structure. Additionally we show preliminary results on the measurement of the vibrational modes of a single ion in the optical lattice.

A 29.8 Thu 16:30 P

Vortex motion quantifies strong dissipation in a holographic superfluid — Paul Wittmer[1,2], Christian-Marcel Schmied[2,3], •Martin Zboron[3], Thomas Gasenzer[1,2,3], and Carlo Ewerz[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

Gauge-gravity duality establishes a connection between strongly correlated quantum systems and higher-dimensional gravitational theories at weak coupling. In general, finding the quantitative parameters of the quantum system thus described is challenging. We numerically simulate dynamics of generic vortex configurations in the holographic superfluid in two and in three spatial dimensions and match to these the corresponding dynamics resulting from the dissipative Gross-Pitaevskii equation. Excellent agreement between the vortex core profiles and their trajectories in both frameworks is found, both in two and three dimensions. Comparing our results to phenomenological equations for point- and line-like vortices allows us to extract friction parameters of the holographic superfluid. The parameter values suggest the applicability of two-dimensional holographic vortex dynamics to strongly coupled Bose gases or Helium at temperatures in the Kelvin range, effectively enabling experimental tests of holographic far-from-equilibrium dynamics.

A 29.9 Thu 16:30 P

Accordion lattice set-up for trapping Dysprosium ultra-cold gases in two dimensions — •Valentina Salazar Silva, Jianshun Gao, Karthik Chandrashekara, Joschka Schöner, Christian Gölzhäuser, Lennart Hoenen, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold quantum gases offer an excellent platform to study few- and many-body quantum phenomena with a remarkable level of control.

At the new group of Quantum Fluids in Heidelberg we are designing a novel experimental set-up focused on highly magnetic dysprosium atoms, with the aim to study the effect of competing long- and short-range interactions at the many-body level and in lower dimensional settings. With our unique combination of 2D and 3D magneto-optical traps, magnetic field coils, and various optical traps, we intend to achieve large quantum degenerate samples and to be able to adjust their confinement geometry and their interaction properties at will.

In order to achieve a 2-dimensional sample in the main experimental chamber, we plan to implement a dynamical optical trap - the accordion lattice. The interference pattern of two laser beams at a shallow angle, theta, creates a spatially periodic potential. Varying theta allows us to adjust both the fringe spacing and the confinement strength in the modulated direction. This scheme makes it possible to achieve a 2D regime with high efficiency and tuneability. At the Erlangen 22 conference, I will present the design and implementation of this accordion lattice.

A 29.10 Thu 16:30 P

Towards simulation of lattice gauge theories with ultracold ytterbium atoms in hybrid optical potentials — •Tim Oliver Hoehn[1,2], Etienne Staub[1,2], Guillaume Brochier[1,2], Clara Zoe Bachorz[1,2,3], David Gröters[1,2], Bharath Hebbe Madhusudhana[1,2], Nelson Darkwah Oppong[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München — [2]Munich Center for Quantum Science and Technology, München — [3]MPI für Quantenoptik, Garching

Gauge theories play a fundamental role for our understanding of nature, ranging from high-energy to condensed matter physics. Their formulation on a regularized periodic lattice geometry, so-called lattice gauge theories (LGTs), has proven invaluable for theoretical studies. However, as numerical simulations are limited in their capability to simulate, e.g., the real-time dynamics, there have been sustained efforts to develop quantum simulators for LGTs. We report on our recent progress on constructing a novel experimental platform for ytterbium atoms, which employs optical lattices and optical tweezers to engineer and probe LGTs. In contrast to other experimental realizations, this approach allows for a robust and scalable implementation of local gauge invariance. A central component enabling this favorable property are optical tweezer potentials operated at the tune-out wavelengths for the ground and clock state of ytterbium. Notably, optical potentials generated from light at these wavelengths could also find applications for digital quantum computation. We present our efforts towards precisely determining these wavelengths experimentally.

A 29.11 Thu 16:30 P

Investigating ultracold chemical processes with NaK molecules — •Jakob Stalmann, Jula Simone Morich, Kai Konrad Voges, and Silke Ospelkaus — Institute of Quantum Optics, Leibniz University Hannover

Ultracold ground-state molecular quantum gases yield highly complex and mostly unknown scattering behavior, ranging from the formation of long-lived collisional complexes to subsequent chemical reactions, photo-excitation or spontaneous spin relaxation.

Here, we present our approach for the detection of such quantum chemical reaction pathways by state-selective product ionization and VMI mass spectroscopy [1] with ultracold $^{23}Na^{39}K$ ground-state molecules. The chemically stable, lightweight NaK molecule is ideally suited for such investigations. Alongside deeper studies of ultracold collisions and reaction pathways, this approach will allow us to develop and implement new quantum control techniques for chemical reactions.

[1] Phys. Chem. Chem. Phys., 2020,22, 4861-4874

A 29.12 Thu 16:30 P

A moveable tuneout optical dipole trap for ultracold ^{6}Li in a ^{133}Cs BEC — •Robert Freund, Binh Tran, Eleonora Lippi, Michael Rautenberg, Tobias Krom, Manuel Gerken, Lauriane Chomaz, and Matthias Weidemüller — Physikalisches Institut, Ruprecht Karls University of Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is an interesting system which can be used to study different few- and many-body phenomena. By immersing fermionic ^{6}Li impurities into a ^{133}Cs Bose-Einstein Condensate (BEC) the energy spectrum of quasiparticles namely Bose polaron can be mapped out. The large mass imbalance between Caesium and Lithium atoms is expected to give a signature of 3-body Efimov effect in the polaron spectrum. In order to obtain a clear polaron signal the optimization of the overlap between the two species in space and momentum is crucial. The Lithium is going to be trapped in a tightly confined optical dipole trap with a beam waist of around 10 μm to adapt to the size of the BEC. Moreover the trap is translatable both to compensate for the gravitational sag due to the large mass difference of the species and to store Lithium far away from Caesium during the preparation and cooling procedures. The trap runs at a tune-out wavelength of Caesium to reduce the influence of the trap on the potential landscape of the BEC as much as possible.

A 29.13 Thu 16:30 P

Towards Quantum Simulation of Light-Matter Interfaces with Strontium Atoms in Optical Lattices — •Valentin Klüsener[1,2], Jan Trautmann[1,2], Dimitry Yankelev[1,2], Annie J. Park[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]MCQST, Schellingstr. 4, 80799 München, Germany — [3]LMU, Schellingstr. 4, 80799 München, Germany

In the last two decades, quantum simulators based on ultracold atoms in optical lattices have successfully emulated strongly correlated condensed matter systems. With the recent development of quantum gas microscopes, these quantum simulators can now control such systems with single-site resolution. Within the same time period, atomic clocks have also started to take advantage of optical lattices by trapping alkaline-earth-metal atoms such as Sr, and interrogating them with unprecedented precision and accuracy. Here, we report on progress towards a new quantum simulator that combines quantum gas microscopy with optical lattice clock technology. We have developed in-vacuum buildup cavities with large mode volumes that will be used to overcome the limits to system sizes in quantum gas microscopes. In addition, we present precision spectroscopy of the ultra-narrow magnetic quadrupole transition $^1S_0 - {}^3P_2$ in Sr, which enables spatially selective addressing in an optical lattice. By combining these techniques with state-dependent lattices, we aim to emulate strongly-coupled light-matter-interfaces.

A 29.14 Thu 16:30 P

Magnetic-field-coils and 3D-MOT for novel dysprosium quantum gas experiment — •Joschka Schöner, Lennart Hoenen, Jianshun Gao, Christian Gölzhäuser, Karthik Chandrashekara, Valentina Salazar Silva, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut, Heidelberg, Germany

Ultra-cold atoms are one of the major platforms to study novel quantum phenomena due to their outstanding level of controllability. Highly magnetic atoms like Dysprosium show a long-range, anisotropic dipolar interaction, comparable in strength to the short-range contact interaction. These interactions can be precisely tuned by controlling the direction and strength of the applied magnetic fields.

At our new Quantum Fluids group in Heidelberg we aim to produce ultracold quantum gases of Dy to study exotic physical phenomena like supersolidity, topological ordering, and out-of-equilibrium physics emerging from competing dipolar and contact interactions and restricting the system to 2D. Our novel experimental platform relies on transferring Dy atoms from a 2D- to a 3D-MOT before loading them into an accordion lattice combined with an in-plane trap of tailorable geometry and a highly controllable magnetic-field environment.

I will report on our 3D-MOT and coil setup. The latter is made of 5 pairs of coils used to generate (1) gradient fields for the MOT, (2) homogeneous magnetic fields at the required strengths and orientations with fast response times. This is central to our quest to realize the promise of the outstanding level of controllability of the ultra-cold atom platform to investigate novel quantum phenomena.

A 29.15 Thu 16:30 P

Dipolar Supersolid States of Matter with Dysprosium — •Kevin Ng[1], Jan-Niklas Schmidt[1], Jens Hertkorn[1], Mingyang Guo[1], Sean Graham[1], Paul Uerlings[1], Ralf Klemt[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart — [2]MIT-Harvard center for Ulatracold Atoms, Research Laboratory of Electronics, and Department of Physics, MIT

Ultracold dipolar gases are an established platform to realize exotic states of matter due to the anisotropic and long-range dipolar interaction between atoms. Recently, supersolid states of matter which have both a superfluid nature and crystal-like periodic density modulation have been realized with ultracold dysprosium.

With a self-organized array of dipolar quantum droplets in one dimension, we demonstrate supersolidity of the droplet array from the coherent nature of these droplets and have observed the low energy goldstone mode that exists as a consequence of the systems superfluidity. We map out the elementary excitations of droplet arrays in one and two dimensions and study in-situ the density fluctuations at the superfluid-supersolid phase transition. A peak in the extracted static structure factor identifies the transition region and allows us to connect the crystallization mechanism of the droplet array to the emergence of low-lying angular roton modes. Furthermore, we theoretically predict supersolid phases beyond droplets in two dimensions at higher densities, where density saturation favours honeycomb and stripe phases.

A 29.16 Thu 16:30 P

Towards dark energy search using atom interferometry in microgravity — •Magdalena Misslisch[1], Holger Ahlers[2], Maike Lachmann[1], and Ernst Rasel[1] — [1]Institute of Quantum Optics, Hanover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) Institut für Satellitengeodäsie und Inertialsensorik, Hanover, Germany

Dark energy is estimated to represent around 70 % of the universe energy budget, yet its nature remains unknown. A possible solution for this problem is the proposed scalar chameleon field whose effects are hidden from usual high density probe particles due to a screening effect.

The project DESIRE (Dark energy search by atom interferometry in the Einstein-Elevator) aims to detect chameleon dark energy by atom interferometry in micrograviy. In this experiment multi-loop interferometry with Rb-87 Bose-Einstein condensates will be performed to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity [1]. Atoms traverse a periodic test mass designed in cooperation with the JPL while accumulating the signal within a multi-loop interferometer over several seconds. To reach these long interaction times the experiment will be performed in microgravity in the Einstein-Elevator, an active drop tower in Hanover.

[1] Sheng-wey Chiow und Nan Yu. "Multiloop atom interferometer measurements of chameleon dark energy in microgravity" doi: 10.1103/PhysRevD.97.044043, 2018

A 29.17 Thu 16:30 P

Excitation Spectra of Homogeneous Ultracold Fermi Gases — •René Henke, Hauke Biss, Niclas Luick, Jonas Faltinath, Lennart Sobirey, Thomas Lompe, Markus Bohlen, and Henning Moritz — Institute of Laserphysics, University of Hamburg, Luruper Chaussee 149, Gebäude 69, 22761 Hamburg, Germany

Understanding the origins of unconventional superconductivity has been a major focus of condensed matter physics for many decades. While many questions remain unanswered, experiments have found that the systems with the highest critical temperatures tend to be layered materials where superconductivity occurs in two-dimensional (2D) structures. However, to what extent the remarkable stability of these strongly correlated 2D superfluids is related to their reduced dimensionality is still an open question. In our experiment, we use dilute gases of ultracold fermionic atoms as a model system to directly observe the influence of dimensionality on strongly interacting fermionic superfluids. This poster presents our most recent work, where we measured the superfluid gap of a strongly correlated quasi-2D Fermi gas over a wide range of interaction strengths and compares the results to recent measurements in 3D Fermi gases as well as theoretical predictions.

A 29.18 Thu 16:30 P

RF and MW coils for experimental quantum simulators — •Hüseyin Yildiz, Tobias Hammel, Maximilian Kaiser, Keerthan Subramanian, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

To manipulate the spin degree of ultracold atoms we apply radio frequency (RF) and microwave (MW) magnetic fields. In current experiments it is challenging to realize magnetic field amplitudes that realize sufficiently large Rabi frequencies. It is therefore a major challenge to optimize magnetic field coil designs.

We present optimized and frequency-variable RF and MW coils for the excitation of different states in the Paschen-Back regime of ultracold Lithium-6 atoms and molecules. Fast and controlled changes in resonance frequency of RF and MW coils enable more flexible sequences and shorter sequence times.

A 29.19 Thu 16:30 P

A new apparatus for trapping single strontium atoms in arrays of optical microtraps — Tobias Kree, •Felix Rönchen, Jonas Schmitz, and Michael Köhl — Physikalisches Institut Bonn

We present the design and implementation of the vacuum system featuring a custom designed titanium vacuum chamber with optical access along six different axes. The apparatus offers space to incorporate two high-NA objectives (NA $>$ 0.65) to manipulate and read out atoms cooled to the motional ground state. One of the two objectives is characterized and currently being installed. In addition we describe the sequence of cooling steps we implemented to rapidly cool thermal Strontium atoms to microkelvin temperatures. To produce optical dipole traps we set up and characterized a liquid-crystal based spatial light modulator. We are able to produce highly uniform one-, two- and three-dimensional geometries of hundreds of optical foci. The system will be integrated into the main experiment in the upcoming months. In the future the experiment will be used as a quantum simulator profiting from the powerful combination of high imaging efficiency and arbitrary arrangements of single atoms.

A 29.20 Thu 16:30 P

Quantum simulation of many-body non-equilibrium dynamics in tilted 1D fermi-hubbard model. — •Bharath Hebbe Madhusudhana[1,2], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Ludwig-Maximilians-Universitat Munchen, Germany — [2]Max-Planck-Institut fur Quantenoptik, Garching, Germany

Thermalization of isolated quantum many-body systems is deeply related to redistribution of quantum information in the system. Therefore, a question of fundamental importance is when do quantum many-body systems fail to thermalize, i.e., feature non-ergodicity. A useful test-bed for the study of non-ergodicity is the tilted Fermi-Hubbard model. Here we experimentally study non-ergodic behavior in this model by tracking the evolution of an initial charge-density wave over a wide range of parameters, where we find a remarkably long-lived initial-state memory [1]. In the limit of large tilts, we identify the microscopic processes which the observed dynamics arise from. These processes constitute an effective Hamiltonian and we experimentally show its validity [2]. We show that in these simulations, our experiment surpasses the present-day computational limitation with $L_{exp} =$ 290 lattice sites and evolution times up to 700 tunneling times. We use our experiment to benchmark a new efficient numerical technique to solve for the dynamics of many-body systems [3].

[1.] Sebastian Scherg et al. Nature Communications 12 (1), 1-8 [2.] Thomas Kohlert et al. arXiv:2106.15586 [3.] Bharath Hebbe Madhusudhana et. al. PRX Quantum 2, 040325.

A 29.21 Thu 16:30 P

Tunable Beyond-Ising Interactions in Tweezer Arrays by Rydberg Dressing — Lea Steinert, •Philip Osterholz, Arno Trautmann, and Christian Gross — Physikalisches Institut, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

We report on a new experimental platform leveraging the long coherence times of a spin-1/2 encoded in the potassium-39 ground-state manifold and the tunability and versatility of interactions between atoms excited to Rydberg-states. We utilize an SLM to prepare an arrangement of optical tweezers, each occupied by a single atom. By off-resonantly coupling to the Rydberg manifold via a single photon transition, we are able to map tuneable angular- and distance-dependent XYZ-type interactions onto the spin-1/2 system. This approach paves the way not only to novel types of quantum magnets but together with the fast cycling time of ~1s it holds the promise to enable the measurement of new entanglement witnessing observables.

A 29.22 Thu 16:30 P

Multiloop functional renormalization group study of the Fermi polaron problem — •Marcel Gievers — Max Planck Institute for Quantum Optics, Garching, Germany

Imbalanced mixtures of strongly correlated fermions have been investigated both theoretically and experimentally for several decades. A single impurity immersed in a Fermi gas is subject to a transition from a bound molecule of two different fermion species to a so-called Fermi polaron where the impurity forms a quasiparticle with the surrounding fermions. We study the Fermi polaron problem theoretically in three dimensions in an experimentally more realistic setup where there is a finite density of the impurity particles. For this, we apply multi-loop functional renormalization group (mfRG) which is an extension of the conventional functional renormalization group equivalent to the diagrammatic parquet formalism. With this elaborate numerical method, we aim to provide more reliable theoretical predictions such as the lifetime of the polaron.

A 30: Precision Measurements and Metrology II (joint session Q/A)

Time: Thursday 16:30–18:30 Location: P

A 30.1 Thu 16:30 P

Experimental and theoretical investigations for an all optical coherent quantum noise cancellation scheme — •Bernd Schulte[1,2], Jonas Junker[1,2], Mariia Matiushechkina[1,2,3], Roman Kossak[1,2], Nived Johny[1,2], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics and Institute for Gravitational Physics, Hannover, Germany — [2]Quantum Frontiers — [3]PhoenixD

Optomechanical detectors can and have been used successfully for the ultra-precise measurement of weak forces. The sensitivity of such detectors is limited by the standard quantum limit (SQL) which is defined by the shot noise of the probe beam and the quantum radiation pressure back action noise. To surpass the SQL Tsang and Caves suggested a scheme [1] with an anti-noise (ancilla cavity) path which is coupled to the measurement device (meter cavity) to destructively interfere the radiation pressure back action noise. In this scheme the anti-noise path contains a two-mode squeezer and a beam splitter interaction. To achieve perfect coherent quantum noise cancellation (CQNC), exact matching of the respective coupling strengths is required. Additionally, the linewidths of the ancilla cavity and mechanical oscillator needs to be matched and the ancilla cavity needs to be sideband-resolved. Our group has conducted a detailed analysis of the proposed method under experimentally feasible conditions and has shown that even for non-perfect matching one can surpass the SQL [2].

[1] M. Tsang and C. Caves, Phys. Rev. Lett. 105, 123601, (2010)
[2] M. H. Wimmer et al, Phys. Rev. A 89, 053836 (2014)

A 30.2 Thu 16:30 P

Towards magneto-optical trapping of Zinc — •Marc Vöhringer Carrera, David Röser, and Simon Stellmer — Physikalisches Institut, University of Bonn, Germany

In the pursuit of increasingly precise time and frequency standards, optical lattice clocks belong to the prime candidates. Among the various approaches and elements currently under investigation, it remains unclear which element will eventually turn out to be the most suitable for the numerous applications.

We investigate the element Zinc as a potential candidate for an optical lattice clock. This study is motivated by various favorable properties of Zinc, including a very low sensitivity to black-body radiation shifts [1]. Its core advantage however is the possible derivation of its clock transition frequency as the fifth harmonic of 1547.5 nm [2], lying in the telecom C-band, thus allowing convenient frequency transfer via optical fibers.

To construct an optical lattice clock based on Zinc, many challenges lie ahead. One of them is the construction of a 214 nm laser system for the first cooling stage, as well as the implementation of a two-stage MOT. We report on progress from the lab regarding these challenges.

[1] Dzuba et al., J. Phys. B 52, 215005 (2019)
[2] Büki et al., Appl. Opt. 60, 9915-9918 (2021)

A 30.3 Thu 16:30 P

Current status of the Al^+ ion clock at PTB — •Fabian Dawel[1,2], Johannes Kramer[1,2], Marek B. Hild[1,2], Steven A. King[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1,2], Stephan Hannig[1,2], Kai Dietze[1,2], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Since 1967 time is defined via a hyperfine transition in caesium-133. Optical clocks offer advantages over microwave clocks in terms of statistical and systematic uncertainties. A particularly promising candidate is the $^1S_0 \rightarrow {}^3P_0$ transition of $^{27}Al^+$. The advantageous atomic properties resulting in small uncertainties in magnetic, electric and black-body shifts. Here we report on the design and operation of the $^{27}Al^+$ clock at PTB. In our clock implementation, Al^+ is co-trapped with $^{40}Ca^+$ in a linear Paul trap. The working principle of quantum logic spectroscopy and a lifetime-limited excitation rabi cycle on the Al^+ logic transition is demonstrated. We will present an evaluation of systematic frequency shifts using the more sensitive Ca^+ as a proxy. All investigated shifts have an uncertainty below 10^{-18}. We will show measurements of the ac-Zeeman shift of our trap and unveil first measurements on the Al^+ clock transition with a power-broadened linewidth of 48 Hz.

A 30.4 Thu 16:30 P

Towards testing Local Lorentz Invariance in a Coulomb crystal of $^{172}Yb^+$ ions — •Kai C. Grensemann[1], Chih-Han Yeh[1], Laura S. Dreissen[1], Henning A. Fürst[1,2], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover,Welfengarten 1, 30167 Hannover, Germany

We report on our recent progress towards testing Local Lorentz Invariance on a Coulomb crystal of $^{172}Yb^+$ ions. The F-state of $^{172}Yb^+$ is highly sensitive to low-energy Lorentz violation (LV) and the ion offers excellent experimental controllability [1]. While the Earth rotates, the quantization axis of our setup probes different directions in space. Thus, a potential LV would manifest itself in a modulation of the energy splitting between Zeeman sublevels throughout the sidereal day. However, the octupole transition to the F-state strongly suffers from a large AC-Stark shift of a few 100 Hz and a first order Zeeman sensitivity [2]. Therefore, to achieve efficient excitation of all ions, spatial homogeneity of the laser beam's intensity and the magnetic field is needed. We address these challenges with simulations and experimentally, using ions as precise quantum sensors. In addition, we will discuss robust dynamical decoupling schemes [3] that make the measurement insensitive to slowing magnetic field and intensity fluctuations.

[1] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [2] H. A. Fürst et al., *Phys. Rev. Lett.* **125**, 163001 (2020). [3] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018).

A 30.5 Thu 16:30 P

Uncertainty Characterization of an In^+ Single Ion Clock — •Moritz von Boehn[1], Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Nishant Bhatt[1], Jonas Keller[1], Oleg Prudnikov[3], Valera I. Yudin[3], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany — [3]Institute of Laser Physics SB RAS, Novosibirsk, Russia

Nowadays optical ion clocks achieve fractional frequency uncertainties on the order of 10^{-18} and below. Due to its low systematic shift sensitivities, $^{115}In^+$ is a promising candidate to go beyond this uncertainty level. Moreover, it has favorable properties for scaling to multiple clock ions, such as a transition for direct state detection [1]. We present the first clock operation in our setup using an $^{115}In^+$ ion sympathetically cooled by an $^{172}Yb^+$ ion in a linear Paul trap and its uncertainty characterization at the 10^{-17} level.

The In^+ ion's residual thermal motion causes a time dilation frequency shift. A way to further decrease the resulting frequency uncertainty is via a reduced final temperature of the cooling process. We report on our progress towards direct laser cooling of indium. Indium offers a narrow intercombination line $^1S_0 \leftrightarrow {}^3P_1$ ($\gamma = 360\,\mathrm{kHz}$), enabling temperatures close to the motional ground state. Cooling on this transition could sufficiently decrease the time dilation related frequency uncertainty, to allow for overall systematic uncertainties at the 10^{-19} level [2]. [1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012). [2] J. Keller et al., *PRA* **99**, 013405 (2019).

A 30.6 Thu 16:30 P

Characterization of a Laser System for a Rubidium Two-

Photon Frequency Reference — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Klaus Döringshoff[1,2], and Markus Krutzik[1,2] — [1]Institut f. Physik - Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik

Global navigation satellite systems and deep space navigation require precise clocks with stringent requirements on size, weight and power budgets. Besides advanced RF clocks, optical clocks are envisioned for application in next generation GNSS. Laser spectroscopy of atomic vapor in conjunction with optical frequency combs may provide such compact, high precision frequency standards with fractional instabilities comparable to optical state-of-the-art GNSS systems.

Rubidium offers narrow linewidth two-photon transition at 778 nm from 5S to 5D, which can be detected via monochromatic fluorescence at 420 nm. In this poster, we present a two-photon Rubidium frequency reference featuring an extended cavity diode laser applied to a heated and magnetically shielded vapor cell. With this setup we achieved a fractional frequency instability of $7 \cdot 10^{-13}$. Recent spectroscopy results will be presented as well as considerations for the most suitable transition within the Manifold. We further report on details of the lasers system including power stabilization and suppression of residual amplitude modulation.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971.

A 30.7 Thu 16:30 P

Frequency stability of a cryogenic silicon resonator with crystalline mirror coatings — •Jialiang Yu[1], Thomas Legero[1], Fritz Riehle[1], Daniele Nicolodi[1], Sophia Herbers[1], Chun Yu Ma[1], Dhruv Kedar[2], Eric Oelker[3], Jun Ye[2], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado, USA — [3]University of Glasgow, UK

The state-of-the-art performance of ultra-stable lasers is limited by various noise contributions like Brownian thermal noise of the optical coatings. In our 21 cm long optical resonator at 124 K, made from single-crystal silicon with low noise $Al_{0.92}Ga_{0.08}As/GaAs$ crystalline mirror coatings, we have investigated a new type of noise associated with the birefringence of these coatings.

To elucidate its nature we have expanded our set-up to lock two independent laser frequencies to two polarization eigenmodes of the resonator, separated by 200 kHz. The observed anti-correlated fluctuations allowed us to cancel the birefringence noise by taking their mean, resulting in an instability below $3.5 \cdot 10^{-17}$. We investigated spatial noise correlations by observing the fluctuations of the difference frequency between TEM_{00} and TEM_{01} modes, and find that local noise like Brownian thermal noise of the coating is below 10^{-17}, consistent with previous estimates. However, there is significant excess noise; most likely from the coating's semiconducting properties.

A 30.8 Thu 16:30 P

PTB's transportable Al^+ ion clock - concept and current status — •Constantin Nauk[1], Benjamin Kraus[1,2], Stephan Hannig[1,2], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks provide significantly lower fractional systematic and statistical frequency uncertainties compared to state-of-the-art microwave atomic clocks. A particularly promising candidate for high-accuracy applications is $^{27}Al^+$ as its $^1S_0 \rightarrow {}^3P_0$ transition is relatively insensitive towards external electromagnetic fields, especially to black body radiation. However, direct laser cooling of $^{27}Al^+$ is more than challenging. Instead, the clock ion can be cooled sympathetically by a co-trapped and well-controllable $^{40}Ca^+$ ion, which additionally allows state detection of the Al^+ ion via quantum logic spectroscopy.
Besides its design, we present the current status of our transportable ion quantum logic optical clock towards fractional frequency uncertainties on the order of 10^{-18} and review compact and robust breadboarding for UV laser systems.

A 30.9 Thu 16:30 P

Decreasing ion optical clock instability by multi-ion operation — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Jonas Keller[1], Nishant Bhatt[1], Moritz von Boehn[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The statistical uncertainty of single-ion clocks is fundamentally limited by quantum projection noise which can be reduced by scaling up the number of ions [1]. We are working on a demonstration of a multi-ion clock using $^{115}In^+$ clock ions, sympathetically cooled by $^{172}Yb^+$ in a linear segmented Paul trap. This trap is optimized for multi-ion operation and offers e. g. low axial micromotion for spatially extended linear Coulomb crystals and low heating rates [2]. We discuss sympathetic cooling of mixed-species crystals and its dependence on the cooling ion positions. To ensure reproducible conditions in the presence of decrystallizing background gas collisions, we experimentally implement crystal ordering sequences and characterize their reliability. Chains up to 10 In^+ ions can be ordered with reliabilities >90%. We show multi-ion spectroscopy results with a fixed crystal configuration, obtained by conditionally triggering such sequences when required.

[1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)

A 30.10 Thu 16:30 P

Towards a miniaturized, all diode laser based strontium lattice clock demonstrator — •Christoph Pyrlik[1,5], Vladimir Schkolnik[1,5], Ronald Holzwarth[2], Robert Jördens[3], Enrico Vogt[4], Andreas Wicht[5], Markus Krutzik[1,5], and the SOLIS1G team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin — [2]Menlo Systems GmbH, Bunsenstr. 5, 82152 Martinsried — [3]QUARTIQ GmbH, Rudower Chaussee 29, 12489 Berlin — [4]Qubig GmbH, Balanstr. 57, 81541 München — [5]Ferdinand Braun Institut gGmbH, Gustav-Kirchhoffstraße 4, 12489 Berlin

SOLIS1G is a joint project targeting to develop critical technologies for future space-born optical lattice clocks and verify these by operating a miniaturized, all diode laser based strontium lattice clock demonstrator.

We will report on the current design of the SOLIS1G clock and give an overview on the technological concepts to be developed towards reducing the size, weight and power budget such as micro-integrated laser and distribution modules, compact optical modulators, miniaturized physics package and robust frequency combs.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WM2151 and DLR50RP2190B.

A 30.11 Thu 16:30 P

Active optical clocks: Towards continuous superradiance on the clock transition of strontium — •Sheng Zhou, Francesca Famà, Camila Beli Silva, Stefan Alaric Schäffer, Shayne Bennetts, and Florian Schreck — Institute of Physics, University of Amsterdam

Active optical clocks based on superradiance have been proposed to directly obtain light with the stability of an atomic transition [1]. This approach decouples clock performance from limitations in ultrastable resonators, and could dramatically reduce limitations due to cavity pulling and required averaging times.

Superradiant pulses have been experimentally demonstrated on the 1S0-3P0 'mHz' transition of 87Sr [2]. However, continuous operation is needed to achieve state-of-the-art performance.

We will describe a continuous superradiant laser using the mHz clock transition of strontium. Our approach is based on loading a cold atomic beam [3] of 3P0 excited atoms into a moving magic lattice propagating along the mode of a bow-tie cavity. In this way, large numbers of atoms can be loaded along the cavity mode while maintaining low atomic densities and long lifetimes [5]. Using the fluxes from [3] and [4], an estimation of emitted powers of 0.3 pW for 87Sr and 9 pW for 88Sr should be possible with our setup.

[1] Meiser et al., PRL 102, 163601 (2009). [2] Norcia et al., Phys. Rev. X, 8, 021036 (2018). [3] Chen et al., Phys. Rev. Applied 12, 044014, (2019). [4] Escudero et al., Phys. Rev. Research 3, 033159 (2021). [5] Cline et al., E08.09, DAMOP (2021).

A 30.12 Thu 16:30 P

Correlation spectroscopy on a $^{40}Ca^+$ two ion system for optical atomic clocks — •Kai Dietze[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1,2], Fabian Dawel[1,2], Johannes Kramer[1,2], Nicolas Spethmann[1,2], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch Technische

Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Time and Frequency are the most accurately determined physical quantities. Though for optical clocks based on trapped ions like $^{40}Ca^+$ the reachable statistical uncertainty is limited by the interrogation time due to decoherence processes and a low signal-to-noise ratio (SNR). Both can be significantly enhanced by employing correlated interrogation techniques within a decoherence-free subspace (DFS) of multiple ions. We utilize Bell-states of opposing magnetic quantum numbers to create a two-particle state whose phase evolution is independent of the ambient magnetic field. Using a pair of fully entangled ions the SNR of this measurement technique can even surpass the standard-quantum-limit (SQL). In our experiments, the correlation of both ions within a Ramsey-interferometer is used to disseminate the differential phase evolution against our clock laser. We present measurements showing the preparation of entangled and correlated two-ion states, demonstrating the increased interrogation time as well as first results showing the potential of the correlation spectroscopy used in an optical atomic clock.

A 30.13 Thu 16:30 P

Proceedings on Ultrastable Cryogenic Cavities and Ring-Cavities used as Spectral Pre-Filters — •Erich Günter Leo Pape, Marc Kitzmann, and Achim Peters — Humboldt Universität zu Berlin, AG QOM, Newtonstr. 15, 12489 Berlin, Germany

Cryogenic Cavities: We present our new cryogenic sapphire cavities in order to reach relative frequency stability of $10^{-16}\,\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ towards a modern Michelson Morley experiment testing for possible Lorentz violations.

Filter Cavity: We present our new triangular ring cavity used as a spectral prefilter in double pass. We stabilize the cavity to a laser with a piezo ring actuator while using the tilt lock method.

A 30.14 Thu 16:30 P

2D phase sensitivity beyond the shot-noise limit in an SU(1,1) interferometer. — •Ismail Barakat[1], Klaus Mantel[2], Mahmoud Kalash[1], Norbert Lindlein[1], and Maria Chekhova[2] — [1]University of Erlangen-Nuremberg,Institut für Optik, Information und Photonik, Staudtstraße 7/B2 91058 Erlangen,Germany — [2]1Max-Planck Institute for the Science of Light, Staudtstr. 2, Erlangen D-91058, Germany

2D phase measurements are necessary for characterizing rough and smooth surfaces. In classical interferometry, these measurements are always bounded by the shot-noise limit (SNL). To overcome the SNL, we use a wide-field SU(1,1) interferometer where spatially multimode bright squeezed vacuum is sensing the phase. This non-linear interferometer promises to enhance the overall phase sensitivity in quantum and optical metrology and in imaging. The 2D phase is extracted using the N-steps phase shifting interferometry algorithm. We compare the obtained 2D phase values with the SNL and use the repeatability as a measure of precision for the extracted phase maps. We also test the 2D phase sensitivity by sensing the strain applied to an optical surface.

A 30.15 Thu 16:30 P

Measuring small coefficients of thermal expansion with Fabry-Perot resonators — •Nina Meyer, Maryam Ghazi Zahedi, Tobias Ohlendorf, Uwe Sterr, and Thomas Legero — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Materials with small coefficients of thermal expansions (CTEs) are needed for industrial and scientific applications as in extreme-ultraviolet lithography, in telescopes or ultra-stable resonators [1]. Such materials, like Zerodur and Corning ULE glass, show a very small CTE of about $10^{-8}\,\mathrm{K}^{-1}$, with zero crossing near room temperature. CTE measurements based on two-beam Michelson interferometers for measuring length have reached $10^{-9}\,\mathrm{K}^{-1}$ uncertainties [2].

In this poster, we present a multiple-beam approach based on a Fabry-Perot resonator, consisting of a test-material spacer and two optically contacted reflecting endcaps in a temperature-controlled vacuum chamber. We discuss a refined uncertainty budget taking the temperature homogeneity of the spacer and the impact of the CTE mismatch between the end caps and the spacer into account [3]. This allows us to determine the CTE with uncertainties in the range of $10^{-9}\,\mathrm{K}^{-1}$.

[1] F. Riehle, Meas. Sci. Technol. **9**, 1042−1048 (1998).
[2] R. Schödel, Meas. Sci. Technol. **19**, 084003 (2008).
[3] T. Legero et al., J. Opt. Soc. Am. B **27**, 914-919 (2010).

A 30.16 Thu 16:30 P

Towards a continuous wave superradiant Calcium Laser — •David Nak and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland

Superradiant Lasers are suitable as narrow light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1].

At present, the setup is being extended by an incoherent repumping mechanism, which will allow continuous wave operation.

[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

A 31: Ultra-cold atoms, ions and BEC IV (joint session A/Q)

Time: Friday 10:30–12:15 Location: A-H1

Invited Talk A 31.1 Fri 10:30 A-H1

Cavity-enhanced optical lattices for scaling neutral atom quantum technologies — •Jan Trautmann[1,2], Annie J. Park[1,2], Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, 85748 Garching, Germany — [2]MCQST, 80799 München, Germany — [3]LMU, 80799 München, Germany

We present a solution to scale up optical lattice experiments with ultracold atoms by an order of magnitude compared to the state-of-the-art. We utilize power enhancement in optical cavities to create two-dimensional optical lattices with large mode waists using low input power. We test our system using high-resolution clock spectroscopy on ultracold Strontium atoms trapped in the lattice. The observed spectral features can be used to locally measure the lattice potential envelope and the sample temperature with a spatial resolution limited only by the optical resolution of the imaging system. The measured lattice mode waist is 489(8) μm and the trap lifetime is 59(2) s. We observe a long-term stable lattice frequency and trap depth on the MHz level and the 0.1% level. Our results demonstrate that large, deep, and stable two-dimensional cavity-enhanced lattices can be created at any wavelength and can be used to scale up neutral-atom-based quantum simulators, quantum computers, sensors, and optical lattice clocks.

[1] A. J. Park, J. Trautmann, N. Šantić, V. Klüsener, A. Heinz, I.Bloch, and S. Blatt. Cavity-enhanced optical lattices for scaling neutral atom quantum technologies, arXiv:2110.08073, (2021).

A 31.2 Fri 11:00 A-H1

Ionic Polarons in a Bose-Einstein condensate — •Luis Ardila — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

The versatility and control of ultracold quantum gases opened up a plethora of theoretical predictions on polaronic physics using ultracold quantum gases, resulting in several experimental realizations. In his talk, we will discuss ionic polarons 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 a charged impurity 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. Recent experiments on ionic impurities in quantum gases are promising platforms to study ionic polarons. Our work paves the way to understand how ions coupled a quantum gas which may be important for future applications in quantum technologies.

A 31.3 Fri 11:15 A-H1

An Artificial Bosonic Atom in One Spatial Dimension — •Fabian Brauneis[1], Timothy Backert[1], Simeon Mistakidis[2], Mikhail Lemeshko[3], Hans-Werner Hammer[1,4], and Artem Volosniev[3] — [1]Technische Universität Darmstadt, Department of Physics, Institut für Kernphysik, 64289 Darmstadt, Germany — [2]ITAMP, Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA 02138 USA — [3]Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria — [4]ExtreMe Matter Institute EMMI and Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

We study an analogue of an atom realized by a one-dimensional Bose gas. Repelling bosons ("electrons") are attracted to an impurity, the "nucleus". The interplay between the attractive impurity-boson and repulsive boson-boson interaction leads to a crossover between different states of the system when the parameters are varied. For a non-interacting Bose gas, an arbitrary number of bosons can be bound to the impurity. In contrast, if they are impenetrable, the bosons fermionize and only one boson is bound. This observation implies that there is a critical number of bosons that can be bound to the impurity for finite values of the boson-boson interaction strength. We discuss the three resulting states of the system - bound, transition and scattering - within the mean-field approximation. In particular, we calculate the critical particle number supporting a bound state. To validate our mean-field results, we use the flow equation approach.

A 31.4 Fri 11:30 A-H1

Pattern formation and symmetry breaking in a periodically driven 2D BEC — •Nikolas Liebster, Celia Viermann, Maurus Hans, Marius Sparn, Elinor Kath, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, Heidelberg, Deutschland

Dynamical pattern formation is a ubiquitous phenomenon in nature, and has relevance in many fields in physics. The emergence of these patterns, as well as how symmetries are broken, remains an open field of research in quantum physical systems. By periodically driving the scattering length in a 2D potassium-39 Bose-Einstein condensate, we use parametric resonance to non-linearly populate specific momentum modes of trapped condensates. We show the emergence of randomly oriented standing waves with D4 symmetry and investigate these structures in real and momentum space, showing the growth of both primary and secondary momentum modes. Finally, we investigate the effects of trapping geometries on the formation of patterns on the condensate.

A 31.5 Fri 11:45 A-H1

Quantum gas magnifier for sub-lattice-resolved imaging of 3D quantum systems — Luca Asteria, Henrik P. Zahn, •Marcel N. Kosch, Klaus Sengstock, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Imaging is central for gaining microscopic insight into physical systems, but direct imaging of ultracold atoms in optical lattices as modern quantum simulation platform suffers from the diffraction limit as well as high optical density and small depth of focus. We introduce a novel approach to imaging of quantum many-body systems using matter wave optics to magnify the density distribution prior to optical imaging, allowing sub-lattice spacing resolution in three-dimensional systems. Combining the site-resolved imaging with magnetic resonance techniques for local addressing of individual lattice sites, we demonstrate full accessibility to local information and local manipulation in three-dimensional optical lattice systems. The method opens the path for spatially resolved studies of new quantum many-body regimes including exotic lattice geometries.

A 31.6 Fri 12:00 A-H1

Resetting many-body quantum systems — •Gabriele Perfetto, Federico Carollo, Matteo Magoni, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We consider closed quantum many-body systems subject to stochastic resetting. This means that their unitary time evolution is interrupted by resets at randomly selected times. The study of the non-equilibrium stationary state that emerges from the combination of stochastic resetting and coherent quantum dynamics has recently raised significant interest. The connection between this non-equilibrium stationary state, an effective open dynamics and non-equilibrium signatures of quantum phase transitions is, however, not fully understood.

In the talk we provide a unified understanding of these phenomena by combining techniques from quantum quenches in closed systems and semi-Markov processes. We discuss as an application the paradigmatic quantum Ising chain. We show that signatures of its ground-state quantum phase transition are visible in the steady state of the reset dynamics as a sharp crossover.

Our findings show that stochastic resetting can be exploited to generate many-body quantum stationary states where incoherent effects, such as heating, can be hindered. These stationary states can be then used in quantum simulator platforms for sensing applications.

[1] G.Perfetto *et al.*, Phys. Rev. B **104**, L180302 (2021)

A 32: Precision spectroscopy of atoms and ions IV (joint session A/Q)

Time: Friday 10:30–12:00 Location: A-H2

Invited Talk A 32.1 Fri 10:30 A-H2

High-resolution DR spectroscopy with slow cooled Be-like Pb^{78+} ions in the CRYRING@ESR storage ring — •Sebastian Fuchs[1,2], Carsten Brandau[1,3], Esther Menz[3,4,5], Michael Lestinsky[3], Alexander Borovik Jr[1], Yanning Zhang[6], Zoran Andelkovic[3], Frank Herfurth[2], Christophor Kozhuharov[3], Claude Krantz[3], Uwe Spillmann[3], Markus Steck[3], Gleb Vorobyev[3], Regina Hess[3], Volker Hannen[7], Dariusz Banaś[8], Michael Fogle[9], Stephan Fritzsche[4,5], Eva Lindroth[10], Xinwen Ma[11], Alfred Müller[1], Reinhold Schuch[10], Andrey Surzhykov[12,13], Martino Trassinelli[14], Thomas Stöhlker[3,4,5], Zoltán Harman[15], and Stefan 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]UPMC Paris — [15]MPIK

Dielectronic recombination (DR) collision spectroscopy is a very successful tool for studying the properties of ions. Due to its versatility and the high experimental precision, DR spectroscopy plays an important role in the physics program of the SPARC collaboration. CRYRING@ESR is particularly attractive for DR studies, since its electron cooler provides an ultra-cold electron beam promising highest experimental resolving power. Here, we report on the first DR experiment with highly charged ions in the heavy-ion storage ring CRYRING@ESR of the international FAIR facility in Darmstadt. The recent results are well in accord with our expectations and the theory.

A 32.2 Fri 11:00 A-H2

Theory of the $^3He^+$ magnetic moments and hyperfine splitting — •Bastian Sikora, Zoltán Harman, Natalia S. Oreshkina, Igor Valuev, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In an external magnetic field, the ground state of the $^3He^+$ ion is split into four sublevels due to hyperfine and Zeeman effect. The bound electron's g-factor, the ground-state hyperfine splitting as well as the shielded magnetic moment of the nucleus can be determined by measurements of transition frequencies between these sublevels [1,2].

We present the theoretical calculation of the nuclear shielding constant, the ground-state hyperfine splitting and the bound-electron g-factor. The nuclear shielding constant is required to extract the magnetic moment of the bare nucleus with unprecedented precision, enabling new applications in magnetometry. Furthermore, one can extract the nuclear Zemach radius from the experimental hyperfine splitting value. The theoretical uncertainty of the bound-electron g-factor is dominated by the uncertainty of the fine-structure constant, allowing in principle an independent determination of α in future.

[1] A. Mooser et al., J. Phys.: Conf. Ser. 1138:012004 (2018)
[2] A. Schneider et al., submitted (2021)

A 32.3 Fri 11:15 A-H2

Path integral formalism of Dirac propagators for atomic physics — •Sreya Banerjee and Zoltán Harman — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

The very basic building blocks of perturbative calculations in atomic structure and collision theory are Green's functions. We extend this study of Green's functions, in the nonperturbative regime, using Feynman's path integral approach. As a first step, we derive the free Dirac propagator followed by the derivation of the Dirac-Coulomb Green's function (DCGF) in spherical coordinates, using this formalism.

For the free relativistic Dirac particle, the effective Hamiltonian for the iterated Dirac equation is constructed. The corresponding Green's function is expanded into partial waves in spherical coordinates. The radial part of this Green's function is then converted into a path integral, through reparametrisation of the paths by local time rescaling, followed by a one-to-one mapping of the radial variable with the local time parameter. This yields a closed form of the Green's function. Following the same procedure, the DCGF is diagonalised in Biedenharn's basis into a radial path integral, the effective action of which is similar to that of the non-relativistic hydrogen atom. We convert the radial path integral from Coulomb type to that of an isotropic harmonic oscillator through coordinate transformation along with local time rescaling. As such, an explicit path integral representation of the DCGF is obtained, along with the energy spectrum of the bound states.

A 32.4 Fri 11:30 A-H2

Progress of the Laser Resonance Chromatography project — •EunKang Kim[1,2], Elisabeth Rickert[1,2,3], Elisa Romero Romer[1,2,3], Harry Ramanantoanina[1,2], Michael Block[1,2,3], Mustapha Laatiaoui[1,2], and Philipp Sikora[1] — [1]Department Chemie, Johannes Gutenberg-Universität, Fritz-Strassmann Weg 2, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, Staudingerweg 18, 55128 Mainz, Germany — [3]GSI, Planckstraße 1, 64291 Darmstadt, Germany

Optical spectroscopy of superheavy elements is experimentally challenging as their production yields are low, half-lives are very short, and their atomic structure is barely known. Conventional spectroscopy techniques such as fluorescence spectroscopy are no longer suitable since they lack the sensitivity required in the superheavy element research. A new technique called Laser Resonance Chromatography (LRC) could provide sufficient sensitivity to study super-heavy ions and overcome difficulties associated with other methods. In this contribution, I will explain the LRC technique and the progress that we made towards LRC experiments. This work is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

A 32.5 Fri 11:45 A-H2

CREMA-Measuring the Ground State Hyperfine splitting of 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 33: Rydberg Systems (joint session Q/A)

Time: Friday 10:30–11:45 Location: Q-H14

A 33.1 Fri 10:30 Q-H14

Trapped Rydberg Ions in Motional States for Quantum Computation and Sensing — •Jonas Vogel[1], Alexander Schulze-Makuch[1], Marie Niederländer[1], Bastien Gely[2], Arezoo Mokhberi[1], and Ferdinand Schmidt-Kaler[1,3] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]ENS Paris-Saclay, 91190 Gif-sur-Yvette, France — [3]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

Cold and controlled atoms and ions are currently of great interest for applications in quantum information processing, simulation and sensing. Excitation of trapped ions to their Rydberg states offers a unique opportunity for combining advantages of precisely controllable trapped-ion qubits with long-range and tunable Rydberg interactions [1]. Intrinsically large polarizabilities of Rydberg states result in enhanced electric field sensitivity to generate entanglement in sub-μs timescales [2]. Here, we present two-photon spectroscopy on high lying Rydberg states of $^{40}Ca^+$ ions for precise determination of the second ionization energy as well as principal quantum number scaling for blackbody induced ionization and depopulation rates [3]. We introduce a model to simulate the transition lineshape and study phonon number induced frequency shifts. Finally, we excite large coherent states of motion to extract the Rydberg state polarizability, a prerequisite for using Rydberg ions as electric field sensors.

[1] Mokhberi et al., Adv. At., Mol., Opt. Phys. Ch.4, 69 (2020)
[2] Vogel et al., Phys. Rev. Lett. 123, 153603 (2019)
[3] Andrijauskas et al., Phys. Rev. Lett. 127, 203001 (2021)

A 33.2 Fri 10:45 Q-H14

Structure and dynamics of cesium long-range Rydberg molecules — •Michael Peper, Ali-Dzhan Ali, Martin Trautmann, and Johannes Deiglmayr — Leipzig University, Department of Physics and Geosciences, 04103 Leipzig, Germany

Long-range Rydberg molecules (LRMs) are exotic bound states of a Rydberg atom and a ground-state atom within its orbit. Because their structure is very sensitive to the elastic electron–ground-state-atom scattering phase shifts, precision measurements and accurate theoretical modelling may provide a unique possibility to test quantum scattering theories for such systems at extremely low collision energies [1]. A detailed understanding of the structure of LRMs is also a prerequisite for the proposed creation of ultracold neutral plasmas with equal-mass charges via photoassociation (PA) and stimulated charge-transfer of LRMs [2,3].

In this talk I will present recent results on the modelling of experimental PA spectra using an accurate Hamiltonian [4] and optimized scattering phase shifts. I will discuss in detail the characterization of molecular decay processes and the role of Stark-facilitated excitation of Rydberg atoms at molecular PA resonances.

[1] M. Peper, J. Deiglmayr, Phys. Rev. Lett. 126, 013001 (2021) [2] M. Peper, J. Deiglmayr, J. Phys. B 53, 064001 (2020) [3] F. Hummel *et al.*, New J. Phys. 22, 063060 (2020) [4] M. Eiles, C. Greene, Phys. Rev. A 95, 042515 (2017)

A 33.3 Fri 11:00 Q-H14

Hamiltonian Engineering of a many-body Rydberg-spin system — •Sebastian Geier[1], Nithiwadee Thaicharoen[1,2], Clément Hainaut[1,3], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], David Grimshandl[1], Gerhard Zürn[1], Matthias Weidemüller[1], Pascal Scholl[4], Hannah J. Williams[4], Guillaume Bornet[4], Loic Henriet[5], Adrien Signoles[5], Florian Wallner[4], Daniel Barredo[4], Thierry Lahaye[4], and Antoine

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Using time-periodic driving, we present how a naturally given many-body Hamiltonian of a quantum system can be transformed into an effective target Hamiltonian. We demonstrate such Floquet engineering with a Rydberg-spin system in different spatial geometries. Applying a sequence of spin manipulations, we change the interaction parameters of the effective XYZ Hamiltonian. In a 3D disordered configuration with hundreds of spins, we explore the conservation laws associated to engineered symmetries. In complementary experiments, we apply the engineering to a 1D array of ordered atoms and benchmark the technique for the case of two atoms. Furthermore, we explore the transport behavior of a domain wall state for tunable XXZ Hamiltonians.

A 33.4 Fri 11:15 Q-H14

Controlled Dephasing and Unequal Time Correlations in Rydberg Qubits — •Andre Salzinger[1], Kevin T. Geier[2,3], Titus Franz[1], Sebastian Geier[1], Nithiwadee Thaicharoen[4], Annika Tebben[1], Clément Hainaut[5], Robert Ott[3], Martin Gärttner[1], Gerhard Zürn[1], Philipp Hauke[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut Heidelberg — [2]University of Trento — [3]Institut für Theoretische Physik Heidelberg — [4]Chiang Mai University — [5]Université Lille

Engineering open system dynamics relies on restricted degrees of freedom of a larger system. Equivalently, master equations can be derived by averaging over realisations of stochastic processes. We present experimental results for qubit rotations subjected to random phase walks, which are sampled from 1D Brownian motion. The observed realisation average follows a Lindblad description with decay parameter γ given by the variance of sampled phase walks. We use this controlled dephasing in a linear-response scheme to extract the unequal-time anticommutator in an ensemble of driven two-level systems by coupling to an ancilla level. This acts as a first benchmark for future measurements in many-body systems far from equilibrium, where unequal-time commutator and anticommutor probe fluctuation-dissipation relations.

A 33.5 Fri 11:30 Q-H14

Quantum transport enabled by non-adiabatic transitions — Ajith Ramachandran[1], Alexander Eisfeld[2], •Sebastian Wüster[1], and Jan-Michael Rost[2] — [1]Indian Institute of Science Education and Research, Bhopal — [2]Max Planck Institute for the Physics of Complex Systems, Dresden

Quantum transport of charge or energy in networks with discrete sites is a core feature of diverse prospective quantum technologies, from molecular electronics over excited atoms to photonic metamaterials. In many of these examples, transport can be affected by motion of the sites or coupling to phonons.

The Born-Oppenheimer surfaces of the hybrid Rydberg chain with side-unit (Fano-Anderson chain), are shown to inherit characteristics from both constituents: A dense exciton band from the regular chain with added avoided crossings or conical intersections. Using time dependent quantum wave packets, we demonstrate that these features enable a setting in which only a mobile, symmetric side unit permits quantum transport on the regular chain, while transport is blocked without motion or for a distorted side unit [1]. This provides an example for functional synthetic Born-Oppenheimer surfaces with possible uses for temperature sensing in molecular electronics, through the sensitive linkage between molecular motion and quantum transport [2].

[1] A. Ramachandran, A. Eisfeld, S. Wüster, J. M. Rost; ArXiv (2022).

[2] A. Ramachandran, M. Genkin, A. Sharma, A. Eisfeld, S. Wüster, J. M. Rost; PRA 104 (2021) 042219.