Q 76: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 11:00–13:00 Location: N 1

Invited Talk Q 76.1 Fri 11:00 N 1

Toolbox for of Rydberg state engineering in trapped ions — •Robin Thomm, Vinay Shankar, Natalia Kuk, and Markus Hennrich — Department of Physics, Stockholm University

Trapped Rydberg ions offer a novel approach that combines the advantages of deep, state independent confinement and excellent external and internal control found in trapped ions with the scaling of key atomic properties, such as polarizability and interaction strengths, of Rydberg states. By coherently moving between different Rydberg states in a controlled manner, one could tune these parameters to maximize effects like inter-ion coupling and minimize adverse effects. We demonstrate such control of Rydberg S and P states coupled by microwave radiation. We show Rabi oscillations on the nanosecond timescale with 96% fidelity and demonstrate adiabatic transfer between different dressed states on the sub-microsecond timescale, fast enough for multiple transfer operations within the lifetime of the short-lived Rydberg states. The techniques developed pave the way for more sophisticated quantum simulation and sensing applications, especially for Rydberg experiments with longer ion strings where ground state cooling is difficult to achieve, or where different Rydberg states are desired.

Q 76.2 Fri 11:30 N 1

Hybrid van Hove approach to mixed quantum-classical gases — •Maja Maschke[1,2] and Sebastian Ulbricht[1,2] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, Braunschweig, Germany — [2]Fundamental Physics for Metrology, Physikalisch-Technische Bundesanstalt PTB, Braunschweig, Germany

In cold matter physics, the search for effective approximation schemes is a constant one due to the difficulty of many-particle calculations at the fully quantum level. One set of such schemes are semi-classical approaches in which one sector of a quantum system is treated classically. Historically, such hybrid theories have often been proposed adhoc, rather than being derived from a set of first principles. Recently, an axiomatic approach to mixed quantum-classical systems based on a Hilbert space formulation of classical mechanics due to van Hove has been proposed [1]. To date, the consistency of this novel approach was demonstrated at the few-particle level only. In this talk, we extend this work to many-particle systems and discuss its applicability to cold bosonic gases. We will demonstrate how to derive a mean field theory of an interacting hybrid gas at finite temperature featuring a quantum ground state (BEC) and a classical thermal cloud. We present a quantitative analysis of the critical temperature and the condensate fraction and compare our self-consistent numerical approach to the well-established ZNG theory. Our results mark a successful consistency check for the hybrid van Hove-formalism and illustrate to which extent a purely classical description of the thermal cloud is sufficient.

[1] M. Reginatto et al 2025 J. Phys.: Conf. Ser. 3017 012037

Q 76.3 Fri 11:45 N 1

Observation of a structural transition in dipolar (super)solids — •Karthik Chandrashekara, Jianshun Gao, Christian Gölzhäuser, Lily Platt, Wyatt Kirkby, Manon Ballu, and Lauriane Chomaz — Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

Spontaneous formation of spatially nonuniform, periodic structures from homogeneous backgrounds is well known in classical systems and has analogues in quantum matter, where interactions can generate such patterns even at equilibrium. Dipolar Bose gases provide a striking example: long-range, anisotropic dipole-dipole interactions stabilized by quantum fluctuations yield ordered crystalline phases that may remain superfluid, first observed in one-dimensional geometries and later in planar systems. For a planar dipolar Bose gas with transverse dipole orientation, extended mean-field theory predicts triangular droplet, stripe, and honeycomb-like structures. Transitions from unmodulated to these modulated states are generally first order except at a critical point allowing a continuous transition. Tilting the dipoles from the plane normal alters these boundaries, broadening the stripe region and introducing new critical points. Varying the scattering length can thus drive transitions to triangular droplet or stripe phases depending on the density and angle. Here, we experimentally explore the phase diagram of a dipolar gas in a surfboard-shaped trap using interaction ramps and control of dipole tilts. We observe the formation of crystalline phases, including a tilt-induced stripe-like (super)solid, and investigate the structural transitions between the morphologies.

Q 76.4 Fri 12:00 N 1

Localized to Delocalized: Radial Eigenmodes in a Tapered Ion Trap — •Moritz Göb[1], Manika Bhardwaj[1], Bogomila Nikolova[2], Bernd Bauerhenne[1], Peter Ivanov[2], and Kilian Singer[1] — [1]Experimentalphysik 1, Universität Kasssel — [2]Center for Quantum Technologies, Department of Physics, St. Kliment Ohridski University of Sofia

The tapered ion trap, originally proposed for the single ion heat engine [1], exhibits position-dependent radial confinement [2]. Investigating the motional resonances of two- or three-ion crystals in this trap reveals distinct eigenmode characteristics differing from those in linear ion traps.

At weak axial confinement, the inter-ion coupling is minimal, resulting in localized modes where each ion oscillates at a distinct frequency. In contrast, stronger axial confinement leads to the emergence of delocalized eigenmodes, akin to those observed in linear ion traps.

This presentation will explore the implications of these findings for quantum optics and quantum information applications, highlighting the potential benefits of tapered ion traps in these fields.

[1] J. Roßnagel, S.T. Dawkins, K. N. Tolazzi, O. Abah, E. Lutz, F. Schmidt-Kaler, K. Singer, Science 352, 325 (2016).

[2] B. Deng, M. Göb, M. Masuhr, J. Roßnagel, G. Jacob, D. Wang, K. Singer, Quantum Sci. Technol. 10, 015017 (2025).

Q 76.5 Fri 12:15 N 1

Dark Energy search using atom interferometry in microgravity — •Sukhjovan Singh Gill[1], Magdalena Misslisch[1], Charles Garcion[1], Alexander Heidt[2], Ioannis Papadakis[3], Christoff Lotz[2], Sheng-Wey Chiow[4], Nan Yu[4], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut für Transport- und Automatisierungstechnik, Leibniz Universität Hannover, Germany — [3]Institut für Physik, Humboldt Universität zu Berlin, Germany — [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA

The nature of dark energy is one of the biggest quests of modern physics and is required to explain the accelerated expansion of the universe. In the chameleon theory, a scalar field is proposed that is hidden by a screening effect in the vicinity of bulk masses, thereby making the model consistent with observations. The DESIRE project studies the chameleon field model using BEC of ^{87}Rb atoms as a source in a microgravity environment. The Einstein-Elevator at Leibniz University Hannover provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon fields shaped by a changing mass density. This work will further constrain thin-shell models for dark energy by several orders of magnitude. The BEC is transported via Bloch oscillations from the atom chip to the test-mass to perform atom interferometry.

Q 76.6 Fri 12:30 N 1

Quantum Simulation of Excitons in Ultracold Dipolar Fermi Gases in Optical Lattices — •Florian Hirsch[1], Oriana Diessel[2], Rafal Oldziejewski[3], and Richard Schmidt[1] — [1]Institute for Theoretical Physics, Heidelberg University, Heidelberg, Germany — [2]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138, US — [3]Max-Planck- Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Ultracold atoms have emerged as a powerful platform for simulating condensed matter phenomena, offering insights into effects difficult to analyze in detail in solid-state systems. Inspired by the progress on the study of exciton physics in atomically thin semiconductors, we investigate the formation of analogs of excitons in cold atomic systems. Using dipolar Fermions in a hexagonal optical lattice with an energy offset between trigonal sublattices, we predict the existence of cold atomic excitons and show that cold atoms allow to study excitons across the whole interaction range, from weak interactions when electron mass models can be applied to flat band models at strong interactions. We demonstrate how these excitons can be observed using lattice modulation spectroscopy, and we show that both time-of-flight spectroscopy and high-resolution quantum gas microscopy can be used to map out the exciton wavefunction. Establishing the core idea of quantum simulation of semiconductor physics, this work lays the foundation for simulating complex electronic states found in semiconductors, including trions, polarons, exciton insulators and condensates.

Q 76.7 Fri 12:45 N 1

Spin-resolved microscopy of an SU(N) Fermi-Hubbard system — •Leonardo Bezzo[1], Carlos Gas-Ferrer[1], Sandra Buob[1], Antonio Rubio-Abadal[1], and Leticia Tarruell[1,2] — [1]ICFO, Castelldefels (Barcelona), Spain — [2]ICREA, Barcelona, Spain

Quantum-gas microscopes have provided direct access to the phases of the Fermi-Hubbard model. For SU(2) systems, they have brought microscopic insight into the complex competition between interactions, quantum magnetism, and doping. Alkaline-earth(-like) fermions extend this spin-1/2 paradigm by giving access to SU(N) Fermi-Hubbard models, with rich phase diagrams to be unveiled. Despite its fundamental interest, a microscopic exploration of SU(N) quantum systems has remained elusive. We report the realization of a quantum-gas microscope for fermionic ^{87}Sr. Our fluorescence imaging scheme, based on cooling and detection on the narrow intercombination line at 689 nm, enables spin-resolved single-atom detection. By combining it with an optical pumping protocol, we are able to detect the 10 spin states occupation in a single experimental run, a crucial capability for probing site-resolved magnetic correlations. Moreover, we characterize the fundamental inelastic photon scattering processes that limit the site-resolved fidelity of our imaging protocol, and demonstrate an extension of our method that allows us to reach fidelities $> 96\%$ for systems up to SU(8). These results establish ^{87}Sr quantum-gas microscopy as a powerful approach to study exotic magnetism in the SU(N) Fermi-Hubbard model, and provide a new detection tool with potential applications to quantum simulation, computation, and metrology.