Q 51: Ultra-cold Atoms, Ions and BEC III (joint session A/Q)

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

Invited Talk Q 51.1 Thu 11:00 N 1

Quantum-enabled active matter at the atomic scale — •Sabrina Burgardt[1], Julian Fess[1], Silvia Hiebel[1], Alexander Guthmann[1], Aritra K. Mukhopadhyay[2], Sangyun Lee[3], Michael te Vrugt[3], Benno Liebchen[2], Hartmut Löwen[4], Raphael Wittkowski[5,6], and Artur Widera[1] — [1]Department of Physics and State Research Center OPTIMAS, RPTU University Kaiserslautern-Landau, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany — [2]Institute for Condensed Matter Physics, Technical University of Darmstadt, Hochschulstraße 8, 64285 Darmstadt, Germany — [3]Institute of Physics, Johannes-Gutenberg University Mainz, Staudingerweg 9, 55128 Mainz, Germany — [4]Institute of Theoretical Physics II: Soft Matter, Heinrich-Heine University Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany — [5]Department of Physics, RWTH Aachen University, Forckenbeckstr. 50, 52074 Aachen, Germany — [6]DWI – Leibniz Institute for Interactive Materials, Forckenbeckstr. 50, 52074 Aachen, Germany

Active particles, which are able to extract energy from their local environment and convert it into motion, have been widely studied in robotics, biology, and soft matter science. So far, it is unclear whether activity can be realized on the much smaller scale of individual quantum systems. Here, we experimentally demonstrate that optically trapped ^{133}Cs atoms are able to extract energy via nonreciprocal quantum-mechanical spin-exchange interactions from a thermal cloud of ^{87}Rb atoms and convert this energy into active motion. It is found that the quantum-enabled activity has significant effects on the in-trap dynamics. We quantitatively reproduce the experimental findings with numerical Monte-Carlo collision simulations and with an active Langevin model for the motion of the ^{133}Cs atoms. Our results open the door to combining effects of quantum mechanics and activity, allowing to design novel exotic far-from-equilibrium systems.

Q 51.2 Thu 11:30 N 1

In-situ observation of density-wave ordering in strongly interacting Fermi gases — •Zeyang Xue, Gaia S. Bolognini, Tabea Bühler, Aurélien Fabre, Kyuhwan Lee, Timo Zwettler, Giulia D. Pace, Victor Helson, and Jean-Philippe Brantut — Institute of Physics and Center for Quantum Science and Engineering, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

We study quantum many-body phenomena of strongly correlated fermions. Our setup includes atoms cooled to the degenerate regime and a high-finesse optical cavity. The atoms inside the cavity combine the short-range contact interaction between atoms with the cavity-mediated long-range interaction induced by atoms exchanging photons of the cavity mode. When the strength of the long-range interaction exceeds a critical threshold, the system undergoes a phase transition into a density-wave ordered state. The talk focuses on the first in-situ observation of density-wave ordering. The local density-wave information is extracted by a high-resolution microscope with a numerical aperture of 0.39. We obtain direct information about the phase transition order parameter by quantifying the density-wave modulation contrast. We further investigate the correlation between atomic and photonic signatures of the density-wave ordering phase transition by recording the amplitude and phase of the photonic signal through heterodyne detection. We anticipate further experimental implementations enabled by the high-resolution microscope. For instance, a digital micromirror device (DMD) to apply arbitrary trapping potentials to atoms.

Q 51.3 Thu 11:45 N 1

Time resolved formation dynamics of a heavy Fermi polaron — •Tobias Krom[1], Michael Rautenberg[1], Eugen Dizer[2], Richard Schmidt[2], Olivier Bleu[2], Tilman Enss[2], Lauriane Chomaz[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, University of Heidelberg — [2]Institute for Theoretical Physics, University of Heidelberg

We study the decoherence of ^{133}Cs impurities within a Fermi sea (3D) of ^{6}Li. As we show, this interacting system of impurities and a degenerate Fermi sea can be well described by the quasiparticle picture introduced by Landau's Fermi liquid theory [1]. The behavior of these emerging quasiparticles scales with the Fermi sea characteristics which allows for complementary studies on different systems. While in metals the Fermi Energy is a few electron volts and its corresponding shortest reaction time τ_F is on the order of 100 attoseconds, ultracold atoms experiments provide much more accessible timescales in the microsecond regime [2].

The chosen combination of atomic species provides the highest mass ratio of 22.2 which can be realized with alkali atoms. Due to this, current quasiparticle theory models cannot fully predict the dynamics, making this experiment a perfect testbed for state-of-the-art polaron theories [3,4].

[1] G. Baym and C. Pethick, Landau Fermi Liquid Theory, 1991
[2] M. Cetina et al 2015 Phys. Rev. Lett. 115, 135302
[3] R. Schmidt et al 2018 Rep. Prog. Phys. 81 024401
[4] Chen et al 2025 Phys. Rev. Lett. 135, 193401

Q 51.4 Thu 12:00 N 1

Spectroscopic structure of the heavy Fermi polaron — •Michael Rautenberg[1], Tobias Krom[1], Eugen Dizer[2], Olivier Bleu[2], Richard Schmidt[2], Tilman Enss[2], Lauriane Chomaz[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Heidelberg University — [2]Institut für Theoretische Physik, Heidelberg University

I am going to present our latest spectroscopic measurements on the structure of the heavy Fermi polaron. In our experiment, this system is realized by a few heavy Caesium (^{133}Cs) impurities immersed in a deeply degenerate Fermi gas of much lighter Lithium (^{6}Li) atoms.

While Fermi polarons - quasiparticles formed by impurities dressed by the excitations of a surrounding Fermi sea - are interesting in their own right, the large mass ratio in the Li-Cs system additionally enables addressing questions about the fate of quasiparticles close to the infinitely heavy impurity limit. At this point, Landau's quasiparticle picture [1] breaks down and the system is best described by a new state that is fully orthogonal to the Fermi sea without the impurity - a phenomenon dubbed "Anderson orthogonality catastrophe" [2].

Using tuneable impurity-bath interactions close to a magnetic Li-Cs Feshbach resonance, we can investigate both ground and excited states of the polaron using spectroscopy between two Cs hyperfine states. A careful comparison to different theoretical models sheds light onto the effects of finite temperature and finite mass of the heavy Fermi polaron.

[1] L. D. Landau, Phys. Z. Sowjetunion, 3:644 (1933)
[2] P. W. Anderson, Phys. Rev. Lett. 18, 1049-1051 (1967)

Q 51.5 Thu 12:15 N 1

Determination of the dissipative response of a circularly driven atomic erbium quantum Hall system — •Franz Richard Huybrechts[1], Arif Warsi Laskar[2], and Martin Weitz[1] — [1]University of Bonn, Germany — [2]IIT Guwahati, India

Cold atomic gases are an attractive system for studying topological states and phases. We examine the dissipative response of a synthetic erbium quantum Hall system to two different circular shaking modes. The dissipative response of a quantum Hall system to such a drive is linked to the transport properties, and associated with topological states. In our experiment, the quantum Hall geometry is realised in the two-dimensional state space consisting of one spatial dimension and one synthetic dimension. The latter is encoded in the Zeeman quantum number of erbium atoms in the electronic ground state. Our measurements provide evidence for a difference in the excitation rates between left- and right-handed driving. We will report on the current status of this experiment.

Q 51.6 Thu 12:30 N 1

Exploring dynamic properties of finite-temperature Bose-Einstein condensed bubbles in microgravity — •Brendan Rhyno[1], Timothé Estrampes[1,2], Charles Garcion[1], Zain Mehdi[3], Abel Beregi[4], Jean-Baptiste Gerent[4], Nathan Lundblad[4], Kuei Sun[5], Smitha Vishveshwara[6], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover — [2]Université Paris-Saclay — [3]Australian National University — [4]Bates College — [5]Washington State University — [6]University of Illinois at Urbana-Champaign

Since the first observation of ultracold bosonic bubbles with the Cold Atom Lab (CAL) aboard the International Space Station, interest in the structure and properties of Bose-Einstein condensate (BEC) bubbles has grown steadily. Motivated by ongoing CAL operations and upcoming microgravity experiments using the Einstein-Elevator at the

Leibniz University of Hannover, we discuss our efforts to model the dynamic properties of quantum bubbles. Starting from an initial thermal state, we develop a formalism to compute n-point correlation functions while varying the shell radius and thickness, utilizing an isotropic 'bubble trap' potential. In the ultra-dilute limit, we study nonequilibrium expansions and contractions of the system in the vicinity of the BEC phase transition. In the ultra-thin spherical-shell limit, we develop Bogoliubov techniques for computing nonequilibrium correlators. We conclude by highlighting the relevance of our results to ongoing experimental efforts.

Q 51.7 Thu 12:45 N 1

Towards a dual-species dipolar quantum gas microscope — •Gerard Solà Berga[1], Clemens Ulm[1,2], Eva Casotti[1,2], Andrea Litvinov[1], Manfred J. Mark[1,2], and Francesca Ferlaino[1,2] — [1]Institute for Quantum Optics and Quantum Information Austrian Academy of Sciences, Innsbruck, Austria — [2]Institute for Experimental Physics, University of Innsbruck, Innsbruck, Austria

Ultracold atoms in optical lattices have been established as a powerful toolbox for quantum simulation, enabling the study of many-body physics and strongly correlated condensed matter. In the last decade, single-site imaging and addressing of these lattice-confined atoms has been achieved by the experimental realization of quantum gas microscopes. Until 2023, quantum gas microscopes utilized atomic species with a negligible magnetic moment, which interact exclusively via short-range contact interaction. The addition of long-range interactions in a lattice leads to new exotic phases of matter, such as the Haldane insulator, an interaction-induced topological phase.

Here, we report on the progress towards a quantum gas microscope utilizing the highly dipolar species erbium and dysprosium, which will allow the study of both single- and dual-species physics on the single-atom level. With this new setup, we aim to probe extended Bose- and Fermi-Hubbard models, entering a new quantum simulation framework, beyond the capabilities of conventional short-range interaction setups.