Q 16: Ultracold Matter III – Fermions (joint session Q/A)

Time: Tuesday 11:00–13:00 Location: P 2

Q 16.1 Tue 11:00 P 2

Quantum gas microscopy of three-flavor Hubbard systems — •Jan Deppe[1], Jirayu Mongkolkiattichai[2], Liyu Liu[2], Sohail Dasgupta[3], Kaden R. A. Hazzard[3], and Peter Schauss[1,2] — [1]Institute for Quantum Physics, University of Hamburg — [2]University of Virginia — [3]Rice University

This talk will highlight our recent published results at our quantum gas microscope. We demonstrate site- and flavor-resolved imaging of three-component Fermi gases in the Hubbard regime. Extending beyond the SU2 case, three-flavor systems allow access to a wide range of novel exotic quantum phases relevant for models of quantum chromodynamics in lattices. Using the three lowest hyperfine states of Li 6, we realize a balanced mixture in a 2D square lattice with individually tunable interactions for all three flavor pairs.

Our measurements reveal the formation of three-flavor Mott insulators, flavor-selective localization, and selective pairing, observed at temperatures approaching the tunneling scale. Flavor-resolved detection enables reconstruction of pairing correlations, including both onsite and nearest-neighbor contributions, and allows us to directly detect triply occupied sites (triplons), which remain stable despite strong interactions. By exploiting full interaction control via Feshbach resonances, we map out the phase diagram of the three-flavor Fermi system, identifying regimes of flavor-selective pairing, competing attractive pairing, and the Mott-insulating regime.

Finally, it will shortly present the relocation of the experiment from Charlottesville, USA, to Hamburg, Germany and its current state.

Q 16.2 Tue 11:15 P 2

Spectroscopy of excitons and spin-waves in an optical superlattice — •Johannes Obermeyer[1,2], Petar Bojović[1,2], Si Wang[1,2], Marnix Barendregt[1,2], Dorothee Tell[1,2], Immanuel Bloch[1,2,3], and Titus Franz[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Ludwig-Maximilians-Universität, München, Germany

In our quantum gas microscope, we load a balanced spin mixture of fermionic Li-6 atoms into a single plane of a 3D optical superlattice. Our precise individual control of the long and short lattice amplitudes allows to create bound doublon-holon (Mott exciton) and spinon excitations via lattice amplitude modulation. Depending on the structure of the superlattice, excitations of s-, p- and d-orbital kind are possible. Further, through controlled quenches of a Mott insulator state with Heisenberg spin interactions, we can access dynamical correlation maps of bimagnon-like bound states using time-resolved measurements.

Q 16.3 Tue 11:30 P 2

Quantum engine and thermometry in the BEC-BCS crossover — •Felix Lang, Alexander Guthmann, Louisa Kinesberger, Eleonora Lippi, and Artur Widera — RPTU University Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Heat engines have become an integral part of our lives, as they allow us to turn heat into physical work. Quantum heat engines can run at higher efficiencies than their classical counterparts [1]. Our platform uses ultracold quantum gases of ^{6}Li in a harmonic trap along the crossover from a Bardeen-Cooper-Schrieffer (BCS) superfluid to a Bose-Einstein condensate (BEC) allowing us to utilize quantum statistics of fermions and bosons to perform work in a thermodynamic engine cycle.

In this talk, we present experimental results on the engine's efficiency over a large parameter space spanned by temperature and interaction strength. A key component of our analysis is thermometry based on the virial expansion of the Fermi gas. Our results demonstrate a versatile route toward exploring quantum thermodynamics in strongly interacting many-body Fermi systems.

[1] Koch, J. et al. A quantum engine in the BEC-BCS crossover. Nature 621, 723-727 (2023)

Q 16.4 Tue 11:45 P 2

Observation of an integer quantum Hall state of six fermions — •Johannes Reiter, Paul Hill, Maciej Galka, and Selim Jochim — Physikalisches Institut, Univeristät Heidelberg, Deutschland

Integer and fractional quantum Hall states underpin the understanding of topological phases of matter featuring exotic macroscopic properties such as the quantization of the transverse resistivity and emergence of robust edge currents. Expanding upon our deterministic preparation of a spinful two-particle Laughlin state [PRL 133, 253401], we present the recent observation of an integer quantum Hall state of six rapidly rotating fermions confined in a tight optical tweezer. Momentum-space imaging of the many body density reveals the hallmark uniform flattening of the particle density distribution. Through a differential time-of-flight measurement in anisotropically shaped traps, we extract the 2D current density indicative of the non-zero angular momentum in quantum Hall states. This novel technique allows direct determination of the angular momentum otherwise impossible to obtain from a density measurement without prior assumptions of the state's composition.

Our results not only demonstrate the scalability of our atom-by-atom assembly technique of quantum hall states, but also introduce a new method to directly measure angular momentum, opening new avenues for probing the microscopic kinematics of topological phase transitions.

Q 16.5 Tue 12:00 P 2

Local shielding of ground state wavefunctions during imaging of lithium-6 — •Daniel Dux, Tobias Hammel, Maximilian Kaiser, Finn Lubenau, Tim Schiffer, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Heidelberg, Germany

We present a technique to locally shield ^{6}Li atoms during spin-resolved fluorescence detection. By overlapping selected regions of the system with a laser beam tuned near the $2P \leftrightarrow 3S$ excited-state transition at 813 nm, we induce substantial light shifts of the D2 imaging transition due to the diverging polarizability close to the resonance. This shift strongly suppresses fluorescence from illuminated atoms while leaving the wavefunction unaffected, enabling selective shielding and thus local readout of the surrounding system.

We combine this shielding method with our novel free-space imaging scheme, which provides simultaneous, single-atom, spin-resolved detection. Together, these capabilities allow us to interrogate chosen subsets of the system while protecting others from measurement backaction. Integrating both modules into our modular experimental platform, the Heidelberg Quantum Architecture [1], we realize deterministically prepared few-body systems with programmable local readout.

[1]: T. Hammel, M. Kaiser, et al., Modular quantum gas platform, Phys. Rev. A **111**, 033314

Q 16.6 Tue 12:15 P 2

Ytterbium quantum gases under the microscope — •Philipp Lunt[1,2], Riccardo Panza[2], Sandra Sbernardori[2], Fabrizio Barbuio[2], Alessandro Muzi Falconi[2], Matteo Marinelli[2], and Francesco Scazza[2] — [1]Universität Heidelberg, Physikalisches Insitut, Im Neuenheimer Feld 226 — [2]ArQuS Laboratory, CNR Edificio Q2, Trieste, Italy

In this talk, I will present the realization of a single-atom resolved quantum gas of ultracold ytterbium atoms under the microscope. This system provides a unique platform for exploring fermionic quantum many-body physics at the single-atom level, featuring a long-lived metastable state ideal for coherent qubit encoding and the simulation of multi-orbital models. Central to this work is a fast, high-fidelity, and low-loss single-atom imaging technique that enables atom re-use in quantum processors and atomic clocks [1,2].

[1] O. Abdel Karim et al 2025 Quantum Sci. Technol. 10 045019 [2] A. Muzi Falconi et al https://arxiv.org/abs/2507.01011 (2025)

Q 16.7 Tue 12:30 P 2

Overcoming Atom Loss During Cooling Utilizing Two-Photon Repumping for Ytterbium — •Michael Huber[1,2], René Villela[1,2], Er Zu[1,2], Ronen Kroeze[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität — [2]Max-Planck-Institut für Quantenoptik

Neutral ytterbium atoms provide a clock state pair whose precise state-dependent control enables a novel approach to quantum simulation and computation. Enhanced, state-selective control can be realized by leveraging magic and tune-out wavelengths. Additionally, these states enable direct access to the 3D ground state via resolved sideband cooling. However , imperfect repumping efficiency during cooling leads to a non-negligible population accumulating in the anti-trapped 3P2 state, causing losses. Here, we demonstrate a method to suppress this loss channel by implementing a coherent two-photon transition from 3P0 to 3P1. We report a laser-stabilization scheme in which we use a high finesse cavity transferring the stability from the clock laser to the two-photon-repumping lasers. This approach provides robust control of the repumping dynamics and substantially mitigates losses during ground state cooling.

Q 16.8 Tue 12:45 P 2

Bound state in the continuum realized in ultracold gases — •Eleonora Lippi, Alexander Guthmann, Louisa Marie Kienesberger, Felix Lang, and Artur Widera — Department of Physics and Research Center OPTIMAS, RPTU University Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Quantum mechanical interaction potentials typically support either bound molecular states or unbound scattering states. An interesting exception are bound states in the continuum (BICs), localized quantum states with energies well above the molecular dissociation threshold that have no wavefunction overlap with free scattering states. In 1985, Friedrich and Wintgen (FW) proposed a mechanism to realise such BICs in quantum systems through the interference of two Feshbach resonances. Although BICs have largely been realised in classical systems, an unambiguous quantum-mechanical realisation based on the FW mechanism has so far remained elusive. In this talk, we present our experimental observations of the FW-BIC in an ultracold Li-6 atomic gas. This is achieved through the interference of two tunable Feshbach resonances induced by Floquet engineering, implemented via strong magnetic-field modulation that generates additional Feshbach scattering resonances with controllable positions and widths [1]. We support our observation by full coupled-channel calculations. Additionally, by an effective non-Hermitian Hamiltonian, we interpret the state as a dark-scattering state, in analogy to electromagnetically-induced transparency.

[1] Guthmann, A. et al., Sci. Adv.11, eadw3856 (2025)