Q 65: Ultra-cold Atoms, Ions and BEC V (joint session A/Q)

Time: Friday 14:30–16:30 Location: HS 1010

Q 65.1 Fri 14:30 HS 1010

Pairing dome from an emergent Feshbach resonance in a strongly repulsive bilayer model — •Hannah Lange[1,2,3], Lukas Homeier[1,3], Eugene Demler[4], Ulrich Schollwöck[1,3], Annabelle Bohrdt[3,5], and Fabian Grusdt[1,3] — [1]LMU Munich, Germany — [2]MPI for Quantum Optics, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Germany — [4]ETH Zurich, Switzerland — [5]University of Regensburg, Germany

A key to understanding unconventional superconductivity lies in unraveling the pairing mechanism of mobile charge carriers in doped antiferromagnets, giving rise to an effective attraction between charges even in the presence of strong repulsive Coulomb interactions. In this talk, I will consider a mixed-dimensional t-J ladder, a system that has recently been realized with ultracold atoms [1], and show how it can be extended with a nearest neighbor Coulomb repulsion. With repulsion turned off, the system features tightly bound hole pairs and large binding energies (closed channel). When the repulsion strength is increased, a crossover to more spatially extended, correlated pairs of individual holes (open channel) can be observed. In the latter regime, we still find robust binding energies that are strongly enhanced in the finite doping regime. The effective model in the strongly repulsive regime reveals that the attraction is mediated by the closed channel, in analogy to atomic Feshbach resonances between open and closed channels [2].

[1] Hirthe et al., Nature 2023

[2] Lange et al., arXiv:2309.15843, 2309.13040

Q 65.2 Fri 14:45 HS 1010

ARPES spectroscopy of an extended Majumdar-Ghosh model — •Simon M. Linsel[1,2], Nader Mostaan[1,2,3], Annabelle Bohrdt[2,4], and Fabian Grusdt[1,2] — [1]LMU Munich, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]Université Libre de Bruxelles, Brussels, Belgium — [4]University of Regensburg, Germany

Experimental and numerical spectroscopy have revealed novel physics in anti-ferromagnets, in particular in frustrated and doped systems. The Majumdar-Ghosh (MG) model has an analytically known spin-disordered ground state of dimerized singlets as a result of magnetic frustration. Here we study the single-hole angle-resolved photoemission spectroscopy (ARPES) spectrum of an extended MG model, where we introduce a spin-density interaction that is experimentally accessible with ultracold molecules. We report a bound spinon-holon ground state and clear signatures of a spinon-holon molecule state and polarons in the ARPES spectrum at different magnetizations. We also apply a Chevy ansatz to gain analytical insights into the molecule spectrum. Our results provide new insights into the physics of dopants in frustrated t-J models.

Q 65.3 Fri 15:00 HS 1010

In-Situ Observation of Antibunching at the Single-Atom Level in a Continuous Fermi Gas — •Tim de Jongh, Maxime Dixmerias, Joris Verstraten, Cyprien Daix, Bruno Peaudecerf, and Tarik Yefsah — Laboratoire Kastler Brossel, Paris, France

Fermionic systems adhere to Pauli Exclusion, one of the most fundamental principles of quantum mechanics that prevents identical fermions from occupying the same quantum state. This leads to an antibunching of particles which manifests itself in density-density correlations and sub-Poissonian number fluctuations. Here we present the direct, in situ observation of antibunching at the single-atom level. Using a newly developed Lithium 6 quantum gas microscope devoted to the study of continuous many-body systems, we probe both the density correlations and number fluctuations in an ultracold two-dimensional, non-interacting Fermi Gas in continuous space. For these highly degenerate gases, we observe distinct antibunching behavior in the density correlations as well as a clear suppression of the number fluctuations in the gas. The ability to distinguish the quantum fluctuation (zero temperature) contribution and the thermal contribution, allows us to use the fluctuation-dissipation theorem to extract the temperature of these samples from the number fluctuations, offering a direct thermometry method for single-atom imaging techniques. These results represent the first application of a quantum gas microscope to a many-body system in continuous space and offer the perspective to probe strongly interacting Fermi gases in free space at an unprecedented length scale.

Q 65.4 Fri 15:15 HS 1010

Towards Probing Heat Transport in an Anharmonic Ion Chain — •Moritz Göb[1], Bo Deng[1], Lea Lautenbacher[2], Giovanni Spaventa[2], Daqing Wang[1,3], Martin B. Plenio[2], and Kilian Singer[1] — [1]Institut für Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany — [2]Institut für Theoretische Physik und IQST, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany — [3]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Trapped ions are a versatile platform, which is well suited for probing thermodynamics down to a single atom [1]. We have indentified nonlinear dynamics that results in a Duffing-type resonance that can be used to improve sensing of very small forces [2]. Motivated by these results we present how the experimental setup has relevance in the context of resource theory and how the special features of the tapered ion trap can be exploited to implement a model system for heat transport [3].

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

[2] B. Deng, M. Göb, B. A. Stickler, M. Masuhr, K. Singer, and D. Wang, Amplifying a zeptonewton force with a single-ion nonlinear oscillator, PRL 131, 153601 (2023).

[3] M. Lostaglio, An introductory review of the resource theory approach to thermodynamics, Rep. Prog. Phys. 82 114001 (2019).

Q 65.5 Fri 15:30 HS 1010

Optimal time-dependent manipulation of Bose-Einstein condensates — •Timothé Estrampes[1,2], Alexander Herbst[1], Annie Pichery[1,2], Gabriel Müller[1], Dennis Schlippert[1], Ernst M. Rasel[1], Éric Charron[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France

Quantum sensing experiments benefit from fast Bose-Einstein Condensate (BEC) generation with small expansion energies. Here, we theoretically find the optimal BEC collimation parameters with painted optical potentials to experimentally achieve 2D expansion energies of 438(77) pK taking advantage of the tunable interactions by driving Feshbach resonances and engineering the collective oscillations. Based on these findings and corresponding simulations, we propose a scenario to realize 3D expansion energies on ground below 16 pK, going beyond the experimental state of the art in microgravity [A. Herbst et al., arXiv:2310.04383 (2023)].

Furthermore, we report on current theoretical studies of the dynamics of space single- and dual-BEC experiments including applications in NASA's Cold Atom Lab aboard the International Space Station or the sounding rocket mission MAIUS-2, paving the way for next-generation quantum sensing experiments, including tests of fundamental physics such as Einstein's equivalence principle.

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Q 65.6 Fri 15:45 HS 1010

Magnetic polarons beyond linear spin-wave theory: Mesons dressed by magnons — •Pit Bermes and Fabian Grusdt — LMU Munich & MCQST, Munich, Germany

When a mobile impurity is doped into an antiferromagnet, its movement will distort the surrounding magnetic order and yield a magnetic polaron. The resulting complex interplay of spin and charge degrees of freedom gives rise to very rich physics and is widely believed to be at the heart of high-temperature superconductivity in cuprates. Recent experimental realizations of the doped Fermi-Hubbard model in ultra-cold quantum gases allowed to probe the local structure of the polarons. Drawing from experimental insights, we present a new quantitative theoretical formalism to describe these quasiparticles in the strong coupling regime. Based on the phenomenological parton description and geometric string picture, we construct an effective Hamiltonian with weak coupling to the spin-wave excitations in the background, making the use of standard polaronic methods possible.

We apply our formalism to calculate beyond linear spin-wave spectra, analyze the pseudogap expected at low doping and resolve the difference between hole an electron doping on local correlations.

Q 65.7 Fri 16:00 HS 1010

A fluid of 10 ultracold fermions — •Lars Helge Heyen[1], Giuliano Giacalone[1], and Stefan Floerchinger[2] — [1]Universtität Heidelberg, Deutschland — [2]Friedrich-Schiller-Universität Jena, Deutschland

Recent experiments in heavy-ion collisions have challenged our understanding of the applicability of fluid dynamics by showing typical signatures of collective flow with only a small number of final state particles. Motivated by this, we investigate fluidlike behavior in a system of few ultracold fermions. Our key observable is the inversion of the shape of the cloud after release from an anisotropic harmonic trap. This elliptic flow is shown to persist down to as low as 10 particles. I discuss ongoing efforts to understand these experimental observations.

Q 65.8 Fri 16:15 HS 1010

Anisotropic and Non-Additive Interactions of Rydberg Impurities in Bose-Einstein Condensates — •Aileen A.T. Durst[1,2], Seth T. Rittenhouse[3,2], Hossein R. Sadeghpour[2], and Matthew T. Eiles[1] — [1]Max-Planck-Institute for the Physics of Complex Systems, Germany — [2]ITAMP, Harvard & Smithsonian, USA — [3]United States Naval Academy, USA

The interaction between a highly electronically excited atomic impurity and surrounding BEC atoms is typically characterised by a scattering length which can rival or even surpass the average interparticle spacing. The significance of this interaction depends on the density: when the average distance between Bosons is smaller than the scattering length, the system exhibits a rich absorption spectrum which extends typical polaron physics. However, within a dense bath, the absorption spectrum consists only of a single broad Gaussian, indicating an almost classical response. The scattering length and interaction strength of a Rydberg impurity can be altered by changing the principal quantum number. Additionally, the electronic angular momentum of the impurity can be changed in order to control the nature of the interaction potential, which becomes anisotropic when the spherical symmetry is broken. In free space, this manipulation leads to the emergence of (2l+1) degenerate electronic potential energy surfaces, introducing additionally non-additive interactions. Our investigation delves into the impact of these non-additive and anisotropic interactions on the absorption spectrum of a Rydberg impurity within an ideal BEC.