Q 57: Quantum Gases II

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

Q 57.1 Thu 16:30 P

An algebraic geometric study of the solution space of the 1D Gross-Pitaevskii equation — •David Reinhardt[1], Matthias Meister[1], Dean Lee[2], and Wolfgang P. Schleich[1] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]Michigan State University, Facility for Rare Isotope Beams and Department of Physics and Astronomy, East Lansing, Michigan, USA

The stationary solutions of the Schrödinger equation considering box or periodic boundaries show a clear correspondence to solutions found for the non-linear Gross-Pitaevskii equation commonly used to model Bose-Einstein condensates. However, in the non-linear case there exists an additional class of solutions for periodic boundaries first identified by L.D. Carr et al. [1]. These nodeless complex symmetry breaking solutions have no corresponding counterpart in the linear case. To examine how these solutions behave in the limit of vanishing non-linearity we consider an algebraic geometric picture. Therefore, we treat both equations in the hydrodynamic framework, resulting in a first-order differential equation for the density determined by a quadratic polynomial in the linear case and by a cubic polynomial in the non-linear case, respectively. Our approach allows for a clear geometric interpretation of the solution space in terms of the nature and location of the roots of these polynomials.

[1] L.D. Carr, C.W. Clark, W.P. Reinhardt, Phys. Rev. A 62, 063610 & 063611 (2000)

Q 57.2 Thu 16:30 P

Emerging long-range magnetic phenomena in a quantum gas coupled to a cavity — •Nicola Reiter, Rodrigo Rosa-Medina, Fabian Finger, Francesco Ferri, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Dissipative and coherent processes are at the core of the evolution of many-body systems. Their interplay can lead to new phases of matter and complex non-equilibrium dynamics. However, probing these phenomena microscopically in a setting of controllable coherent and dissipative couplings proves challenging.

We realize such a system using a ^{87}Rb spinor Bose-Einstein condensate (BEC) strongly coupled to a single optical mode of a lossy cavity. Two transverse laser fields incident on the BEC allow for cavity-assisted Raman transitions between different motional states of two neighboring spin levels. Adjusting the drive imbalance controls coherent dynamics and dissipation, with the appearance of a dissipation-stabilized phase and bistability. By characterizing the properties of the underlying polariton modes, we give a microscopic interpretation of our observations.

Moreover, we realize dynamical superradiant currents in a spin-textured lattice in momentum space. Real-time, frequency-resolved measurements of the leaking cavity field allow us to locally resolve individual tunneling events and cascaded dynamics. Together, our results open new avenues for investigating spin-orbit coupling in dissipative settings and dynamical gauge fields in driven-dissipative settings.

Q 57.3 Thu 16:30 P

Observation of unconventional many-body scarring in a quantum simulator — •Guo-Xian Su[1], Hui Sun[1], Ana Hudomal[2], Jean-Yves Desaules[2], Zhao-Yu Zhou[1], Bing Yang[3], Jad Halimeh[4], Zhen-Sheng Yuan[1], Zlatko Papić[2], and Guoxian Su[1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Im Neuenheimer Feld 226 — [3]Department of Physics, Southern University of Science and Technology, Shenzhen, China — [4]INO-CNR BEC Center and Department of Physics, University of Trento, Via Sommarive 14, I-38123 Trento, Italy

Quantum many-body scarring has recently opened a window into novel mechanisms for delaying the onset of thermalization, however its experimental realization remains limited to the $\mathbb{Z}_2$ state in a Rydberg atom system. Here we realize unconventional many-body scarring in a Bose–Hubbard quantum simulator and extend scarring to the unit-filling state. Our measurements of entanglement entropy illustrate that scarring traps the many-body system in a low-entropy subspace. Further, we develop a quantum interference protocol to probe out-of-time correlations, and demonstrate the system's return to the vicinity of the initial state by measuring single-site fidelity. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments, and it allows to explore its relation to constrained dynamics in lattice gauge theories, Hilbert space fragmentation, and disorder-free localization.

Q 57.4 Thu 16:30 P

Investigation of Josephson vortices in coaxial ring-shaped Bose-Einstein condensates — •Dominik Pfeiffer[1], Ludwig Lind[1], Daniel Derr[1], Gerhard Birkl[1], Nataliia Bazhan[2], Yelyzaveta Nikolaieva[2], Anton Svetlichnyi[2], and Alexander Yakimenko[2] — [1]Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Physics, Taras Shevchenko National University of Kyiv, Kyiv 01601, Ukraine

Josephson vortices (JV) attract considerable interest due to their perspectives for application in ultra-sensitive rotation sensors and quantum information processing systems. Remarkably, Josephson vortices, being extensively investigated for decades, have not yet been demonstrated experimentally in atomic BECs. The first direct observation of rotational JVs in bosonic junctions now appears as a realistic goal. We investigate the generation of JVs between two coaxial toroidal BECs coupled in a coplanar and in a vertically stacked system. In both systems we generate counter-rotating flows and demonstrate the formation of the JVs. Our results open up a way to the first direct experimental observation of rotational JVs in atomic BECs. We present experimental schemes for the creation of two coupled coaxial rings in a coplanar system based on optical dipole potentials and ultra cold-atoms. Utilizing a digital micromirror device, arbitrary topological charges can be accessed and imprinted onto the coaxial rings. We investigate the feasibility of these techniques to create the desired states, atom distributions, and dynamic behavior.

Q 57.5 Thu 16:30 P

Hole pairing in Fermi-Hubbard ladders systems observed with a quantum gas microscope — •Thomas Chalopin[1], Sarah Hirthe[1], Dominuk Bourgund[1], Petar Bojović[1], Annabelle Bohrdt[3], Fabian Grusdt[2], Eugene Demler[4], Immanuel Bloch[1,2], and Timon Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, 80799 München, Germany — [3]Harvard University, Cambridge, MA 02138, USA — [4]ETH Zurich, 8093 Zurich, Switzerland

The Fermi-Hubbard model is an iconic model of solid state physics that is believed to capture the intricate physics of strongly correlated phases of matter such as High-Tc superconductivity. Such a state of matter supposedly achieved upon doping a cold antiferromagnetic Mott insulator. Pairing of dopants (holes), in particular, is considered to be a key mechanism for the occurrence of unconventional superconductivity.

Here, I will present our experimental observation of hole pairing due to magnetic order in a Fermi-Hubbard-type system in our Lithium quantum-gas microscope. We engineer mixed-dimensional*Fermi-Hubbard ladders in which an offset suppresses the tunneling along the rungs, while it enhances spin exchange and singlet formation, thus drastically increasing the binding energy. We observe that holes preferably sit on the same rung in order to maintain magnetic ordering, i.e. singlets on the other rungs of the ladder. We furthermore find indications for repulsion between pairs when there is more than one pair in the system.

Q 57.6 Thu 16:30 P

Exploration of spin imbalanced few fermion systems in position and momentum space — •Sandra Brandstetter, Carl Heintze, Keerthan Subramanian, Marvin Holten, Philipp Preiss, and Selim Jochim — Physics Institute, University of Heidelberg, Germany

Recent advances in the preparation of ultracold few-fermion systems combined with a spin resolved TOF imaging technique with single particle resolution, have led us to the first observation of Cooper pairs of interacting atoms [1]. However, the exploration of correlations in real space has so far remained elusive, owing to the small system size, which we can't resolve with our optical imaging setup.

In this poster we present the addition of a matter wave microscopy scheme [2], enabling us to access the spatial distribution of our atoms. While it is too small to resolve with our imaging setup, we can magnify it using a combination of two T/4 evolutions in traps with different trapping frequencies.

Additionally, we have recently achieved the preparation of imbalanced systems with different number of particles in the two spin states. Combining this with our access to both the momentum and real space correlations, we aim to explore open questions on the nature of the phase diagram and pairing in spin imbalanced systems [3,4].

[1] M. Holten, et al. arXiv:2109.11511 (2021).
[2] L. Asteria et al. Nature 599, 571*575 (2021).
[3] R. Schmidt and T. Enss. Phys. Rev. A 83 (2011)
[4] Felipe Attanasio et al. 2021. arXiv: 2112.07309 (2021)

Q 57.7 Thu 16:30 P

Towards fast, deterministic preparation of few-fermion states — •Maximilian Kaiser, Tobias Hammel, Micha Bunjes, Armin Schwierk, Matthias Weidemüller, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

Measurements of higher-order correlations in quantum systems, e.g. for the tomography of complex quantum states, requires large data sets. This demand stands in contrast to typical cycle times of 10 seconds or more in traditional experiments with ultracold quantum gases.

We report on the ongoing development of an apparatus for fast, experimental quantum simulations using ultracold Lithium-6 with envisioned cycle times of less than 1 second. Within each run, few-fermion states are being prepared in a sequence based upon [1]. The resulting high data output will especially be key for iteration-intensive research in the future.

[1] Deterministic Preparation of a Tunable Few-Fermion System - F.Serwane et Al., Science Vol. 332 (2011)

Q 57.8 Thu 16:30 P

Realizing a superlattice for studying topological systems with interacting fermions — •Nick Klemmer, Janek Fleper, Jens Samland, Andrea Bergschneider, and Michael Köhl — Physikalisches Institut, University of Bonn, Bonn, Germany

Quantum simulation of the Hubbard model using ultracold atoms in optical lattices has been essential for studying strongly correlated matter. Optical superlattices, mostly realized by a superposition of two trapping wavelengths, have enabled the emulation of more complex systems. For instance, on our experiment we used an out-of-plane superlattice to study magnetic correlations in a coupled-bilayer Hubbard model [1].

In our experiment, we prepare atoms in a few-layer stack of two-dimensional lattices. Currently, we are setting up an in-plane superlattice that provides us with a chain of double wells with tunable coupling strengths. For characterizing and stabilizing the superlattice phase, we have implemented a bichromatic Michelson interferometer. This will allow us to deterministically prepare atoms in the superlattice with any desired energy tilt of the double wells. Combined with the control over the scattering length we will investigate interacting topological systems and study transport properties in time-dependent superlattices.

[1] Gall, Wurz, et al., Nature 589, 40-43 (2021)

Q 57.9 Thu 16:30 P

Realization of the symmetry-protected Haldane phase in Fermi-Hubbard ladders — •Petar Bojović[1], Pimonpan Sompet[1,2], Sarah Hirthe[1], Dominik Bourgund[1], Thomas Chalopin[1], Joannis Koepsell[1], Guillaume Salomon[1,3], Julian Bibo[4], Ruben Verresen[5], Frank Pollmann[4], Christian Gross[1,6], Immanuel Bloch[1,7], and Timon Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Research Center for Quantum Technology, Chiang Mai University, Chiang Mai, — [3]Institut für Laserphysik, Universität Hamburg, Hamburg — [4]Department of Physics, Technical University of Munich, Garching — [5]Department of Physics, Harvard University, Cambridge — [6]Physikalisches Institut, Universität Tübingen, Tübingen — [7]Fakultät für Physik, Ludwig-Maximilians-Universität, München

The Haldane antiferromagnetic spin-1 chain constitutes a paradigmatic model of a quantum system which holds a symmetry-protected topological phase. Here, we experimentally realize the Haldane phase using Fermi-Hubbard ladders in an ultracold quantum gas microscope. Site-resolved potential shaping allows us to create tailored spin-1/2 geometries which permit the exploration of such a topological chain and its comparison to a trivial configuration. We use spin- and density-resolved measurements to probe edge and bulk properties of the system, revealing a non-local string order parameter and localized spin-1/2 edge states We furthermore investigate the robustness of the topological phase upon the onset of density fluctuations by tuning the Hubbard interaction.

Q 57.10 Thu 16:30 P

Modulation Transfer Spectroscopy in Atomic Lithium-6 — •Leo Walz, Tobias Hammel, Maximilian Kaiser, Selim Jochim, and Matthias Weidenmüller — Physikalisches Institut, Heidelberg, Germany

Good experimental control and imaging of ultracold quantum gasses is in many parts achieved through precisely tuned laser pulses, often with a frequency specifically detuned to an atomic transition or directly on resonance. This requires active frequency stabilization of the laser system.

This poster shows the implementation of a modulation transfer spectroscopy setup to exploit the strong dispersive property of atomic transitions on modulated laserlight within the Doppler-free saturation regime. Modulation transfer through degenerate four-wave mixing leads to a zero baseline error signal with a steep signal slope at the zero crossing, that is centered on the atomic transition. Further optimization guided by theory from [1] leads to a fast and high fidelity error signal well suitable for external laser locking. With this setup, frequency deviations on a scale of 1/10th to the natural linewidth are resolvable. In this regime, the leading contribution to frequency noise comes from pressure fluctuations through acoustic noise in the lab.

[1] Tilman Preuschoff, Malte Schlosser, and Gerhard Birkl Opt. Express 26, 24010-24019 (2018)