Q 28: Fermionic Quantum Gases I (joint session Q/A)

Time: Wednesday 11:00–13:00 Location: HS 1199

Q 28.1 Wed 11:00 HS 1199

Bulk-boundary correspondence for anomalous Floquet topological insulators: winding number and micromotion area — •Luca Asteria[1,2], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut for Quantum Physics, Hamburg University — [2]Hamburg Centre for Ultrafast Imaging — [3]Center for Optical Quantum Technologies, Hamburg University

Driven Floquet systems can realize topological phases with no static counterparts. So-called anomalous Floquet topological insulators (AFTIs) break the bulk-boundary correspondence based on the Chern number. The winding number, which predicts the number of edge modes instead, is calculated from the time evolution operator of the bulk states within one driving period. While in non-driven system the Chern number also predicts the quantization of the transversal Hall conductance in the systems bulk, for AFTIs so far, no dynamical bulk observable directly connected to the winding number was identified. Here we show that the winding number is directly connected to such an observable, namely the area enclosed by an initially localized particle during a Floquet period. In particular, in the associated fine-tuning limit of the Floquet protocol, we show that the winding number is exactly given by this area in units of half the unit cell area. Such a direct real-space detection of anomalous topology could be realized in several quantum simulation platforms. We also show how, by choice of the associated fine-tuning protocol, the number and the speed of coexisting edge modes could be arbitrarily tuned, which may be of relevance for quantum information and communication applications.

Q 28.2 Wed 11:15 HS 1199

Bosonization analysis for a ring of SU(N) fermions with a single impurity — •Andreas Osterloh[1], Wayne Chetcuti[1], Juan Polo[1], and Luigi Amico[1,2] — [1]Technology Innovation Institute, Masdar City & Yas Island, P.O. box 9639 Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia Ettore Majorana, Via S. Sofia 64, 95127 Catania, Italy

We are using a bosonization analysis for handling a ring lattice carrying SU(N) fermions. Similar as for bosons, the impurity results in a boundary sine-Gordon field theory. Their effect on the charge and SU(N)-spin parts of the fields is analyzed and the charge-current is calculated. Its interconnection with the observed fractionalization results is discussed in detail.

Q 28.3 Wed 11:30 HS 1199

Heidelberg Quantum Architecture: Fast and modular programmable quantum simulation — •Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physikalisches Institut, Heidelberg, Germany — [2]MPQ, Garching, Germany

Heidelberg Quantum Architecture (HQA) is a new ^{6}Li quantum gas experiment providing a fast, versatile, and expandable platform for programmable quantum simulation. In this talk, we report on the realization of these characteristics in our new ^{6}Li experiment and first experimental findings.

Key components of the experiment are easily exchangeable optical modules, which include tweezers, a Digital Mirror Device, optical dipole traps, a tuneable 2D confinement and single atom and spin resolved imaging. Our broad and easy to expand toolbox will enable experimental cycles of up to 10Hz in the near future and allow for fast data collection and on-demand quantum simulation.

The current status of the experiment features a 2D-MOT with loading rates of larger than 10^8atoms/s loaded into a 3D-MOT. From there the atoms are loaded via two optical dipole traps into a tweezer, in which we can rapidly evaporate down to degeneracy.

Q 28.4 Wed 11:45 HS 1199

Emergence of a collective excitation in a mesoscopic Fermi gas — •Johannes Reiter, Philipp Lunt, Paul Hill, Maciej Galka, and Selim Jochim — Physikalisches Institut, Univeristät Heidelberg, 69120 Heidelberg, Deutschland

Understanding the elementary excitations of strongly interacting many-body systems in terms of the independent motion of individual particles and their collective behaviour constitutes a pervasive problem in many fields ranging from nuclear physics to cold atoms [1,2].

In this talk, we present the spectroscopic observation of the emergence of the radial quadrupole mode from the confinement dominated excitation spectrum in a mesoscopic Fermi gas trapped in an optical tweezer. By systematically tuning the interparticle interactions across the BEC-BCS crossover we investigate the stability of the mode against single particle excitations and showcase the measurement of its coherent properties. Finally, we discuss the prevailing competition between the confinement and interaction energy delineating constraints on the manifestation of collective behaviour in finite-size quantum systems.

[1] B. Mottelson, Science 193 (4250), 287-294 (1976) [2] S. Giorgini et al., Rev.Mod.Phys. 80, 125 (2008)

Q 28.5 Wed 12:00 HS 1199

Observation of pairing in a strongly correlated few-fermion system — •Carl Heintze, Sandra Brandstetter, Karen Wadenpfuhl, Philip Lunt, Keerthan Subramanian, Marvin Holten, Maciej Galka, and Selim Jochim — Universität Heidelberg

Strong correlations and entanglement are crucial for many phenomena of modern physics as high temperature superconductivity and the expansion of the early universe. They pose a challenging task for theorists and experimentalists. We address this problem with few body systems of up to 12 particles. They are large enough to build up complex correlations but are experimentally well controlled, allowing us to extract microscopic observables as atom-atom correlations [1]. We work with quasi 2D systems which are prepared in their quantum mechanical ground state with fixed atom number. We use two different matterwave magnification techniques to measure the momentum or position of every single particle in a spin-resolved way. Recently we observed hydrodynamic behaviour in an expanding few particle system accompanied by the formation of atom pairs [2]. As a next step we aim to gain a deeper understanding of pairing by studying real space correlations in the trapped system. Additionally, we want to use RF-spectroscopy to extract the energy spectrum [3]. In the future we want to measure the contact, prepare repulsively interacting systems and observe interference of identical few body systems.

[1] Holten et al. Nature 606 (2022) [2] Brandstetter et al. arXiv: 2308.09699v1 [cond-mat.quant-gas] [3] Wenz et al. Science 342 (2013)

Q 28.6 Wed 12:15 HS 1199

Realisation of a two-particle Laughlin state with rapidly rotating fermions — •Paul Hill[1], Philipp Lunt[1], Johannes Reiter[1], Maciej Galka[1], Philipp Preiss[2], and Selim Jochim[1] — [1]Physikalisches Institut Heidelberg — [2]Max-Planck-Institut für Quantenoptik

The fractional quantum Hall (FQH) effect features remarkable states that due to their strongly correlated nature and exotic topological properties have stimulated a rich body of research going far beyond the condensed matter community, where the effect was originally discovered. One fundamental class of FQH states is described by the celebrated Laughlin wavefunction, which accounts for a large number of plateaus in the Hall resistivity and already exhibits interesting anionic, fractionally charged quasi-particle excitations.

Here we present the direct realisation of the two-particle Laughlin wavefunction by rapid rotation of two interacting spinful fermions in a tight optical tweezer. We owe this result to our newly established experimental tools allowing us to precisely shape and modulate our optical potentials using coherently interfering laser fields.

Our observations reveal distinctive features of the Laughlin wavefunction, including a ground state distribution in the center-of-mass motion, a vortex distribution in the relative motion, correlations in the relative angle of the two particles, and the suppression of interparticle interactions. This achievement represents a significant step towards scalable experiments, enabling the atom-by-atom assembly of fermionic fractional quantum Hall states in quantum simulators.

Q 28.7 Wed 12:30 HS 1199

Imaging strongly correlated states of the Fermi-Hubbard model — •Petar Bojović[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Si Wang[1,2], Titus Franz[1,2], Johannes Obermeyer[1,2], Timon Hilker[1,2], and Immanuel Bloch[1,2,3] — [1]Max Planck Institute of Quantum Optics — [2]Munich Center for Quantum Science and Technology — [3]Ludwig Maximilian University

The Fermi-Hubbard model is a simple yet powerful model that captures much of the essential physics of high-Tc superconductors. It is naturally realized in our Quantum Gas Microscope, where we load fermionic 6Li atoms into optical lattices and conduct site-resolved measurements of their spin and density. Our experiment serves as a powerful tool to explore quantum phases of a Fermi Hubbard diagram.

An example is the pseudogap phase, which exists above the superconducting transition temperature and is suggested to result from preformed dopant pairs. Our experiment allows us to calculate two-point and multi-point correlation functions between spins and/or dopants and explore the phase diagram. Higher-order correlators directly reveal intriguing features about the interaction of dopants or excitations with the antiferromagnetic background.

Here, I will present measurement of multi-point spin and charge correlators as a function of doping and temperature. We observe significant higher order correlations at low temperature and close to half filling, signaling the emergence of strongly correlated states. This formalism opens a new outlook to the characterization of the real-space and low temperature states of the Fermi-Hubbard model.

Q 28.8 Wed 12:45 HS 1199

Exploring stripe phase in Fermi-Hubbard model with a quantum gas microscope — •Si Wang[1,2], Dominik Bourgund[1,2], Thomas Chalopin[1,2], Petar Bojović[1,2], Titus Franz[1,2], Sarah Hirthe[4], Immanuel Bloch[1,2,3], and Timon Hilker[1,2] — [1]Max-Planck Institute of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Ludwig Maximilian University of Munich, Munich, Germany — [4]ICFO - The Institute of Photonic Sciences, Castelldefels, Spain

The Fermi-Hubbard model is crucial for understanding physics in quasi 2D layers of high-Tc cuprate superconductors. Investigating the profound connection between d-wave superconductivity and stripes, essential elements in cuprate ordered phases, promises valuable insights. In the isotropic Fermi-Hubbard model, the interplay between the kinetic energy of the dopants and the magnetic energy of the AFM spin order governs the system and reduces the energy scale for stripe order well beyond the reach of state-of-the-art cold-atom quantum simulators. To address this, we engineered a mixed-dimensional system, selectively suppressing particle tunneling along one direction while maintaining 2D spin interactions. This innovative approach tilts the balance in the competition between kinetic and magnetic energies, and thus elevates characteristic energy scales for collective effects, allowing us to observe signatures of stripes in our quantum simulator. Notably, recent discoveries indicate that mixed-dimensional systems can exhibit a distinct manifestation of high-Tc superconductivity, emphasizing the significance of our research endeavors in advancing this field.