Q 56: Quantum Gases: Fermions II

Time: Thursday 14:30–16:30 Location: F342

Q 56.1 Thu 14:30 F342

Hartree-Fock-Bogoliubov Variational Approach for BCS Superfluidity — •Nikolai Kaschewski and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

The established theory for the BCS-BEC crossover is based on formulating the underlying many-body problem with the functional integral and on performing a Hubbard-Stratonovich transformation in the Bogoliubov channel [1,2]. A saddle-point approximation reveals then that the whole BCS-BEC crossover can only be described once Gaussian fluctuations around the saddle point are taken into account, which turns out to be numerically quite demanding.

Here we tackle this many-body problem from another point of view. To this end we work out a variational approach for the underlying Hamilton operator in canonical field quantization, which includes not only the Bogoliubov but also the Hartree and the Fock channel. We determine the first beyond mean-field corrections and compare their results for the density profiles in the BCS regime with the corresponding ones of the functional integral theory.

[1] C. A. Sá de Melo, M. Randeria, and J. R. Engelbrecht, Phys. Rev. Lett. **71**, 3202 (1993).

[2] J. R. Engelbrecht, M. Randeria, and C. A. R. Sá de Melo, Phys. Rev. B **55**, 15153 (1997).

Q 56.2 Thu 14:45 F342

Correlations in ultracold few-fermion systems revealed by matterwave microscopy — •Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Marvin Holten, Philipp Lunt, Luca Bayha, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Germany

The ability to image individual quantum particles has provided unprecedented access to microscopic correlations in few and many-body ultracold quantum systems. Recent advances in momentum space microscopy of continuous systems have revealed how Pauli blocking leads to fermionic antibunching and formation of cooper pairs in mesoscopic 2D fermi gases in the vicinity of a phase transition precursor.

Microscopy is inherently limited by optical resolution and this prevents direct imaging in position space when interparticle spacing is smaller than the resolution limit. Here we circumvent this limit by magnifying the many-body wavefunction using matterwave techniques prior to imaging the system thereby giving us access to particle correlations in position space. We use this technique to probe correlations in two paradigmatic models consisting of an equal or unequal number of spin components. A spin-balanced system shows a tendency towards short distance correlations with increasing interaction strengths. The opposite limit of a strongly interacting single impurity in a Fermi gas is also explored which is prepared using radio frequency transfer with motional state resolution. As the interaction strength in the system is increased the impurity preferentially binds to one of the majority atoms as revealed by higher-order correlations.

Q 56.3 Thu 15:00 F342

A mesoscopic fluid of 10 fermions — •Sandra Brandstetter, Philipp Lunt, Carl Heintze, Jonas Herkel, Marvin Holten, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

A striking manifestation of collective behaviour is the emergence of hydrodynamics, the effective description of a system as a fluid. In addition to classical systems, hydrodynamic expansion has been observed in different many-body quantum systems, ranging from heavy ion collisions to ultracold quantum gases. However the emergence of hydrodynamics in the mesoscopic limit is still unexplored. Our cold atom experiment opens up new pathways starting from the smallest scales with deterministic control over the atom number and interaction strength. We observe the inversion of the initial aspect ratio after an interacting expansion - a signature of hydrodynamics - in a system comprised of only 10 particles.

We prepare few fermionic 6Li atoms in 2 different spin states in the ground state of an elliptical 2D trap. A sudden switch off of the confining potential in radial direction leads to an expansion in a 2D plane, which we perform at different interaction strengths. Our spin and single atom resolved imaging technique allows us to study correlations of any order between atoms. Two different matterwave magnification techniques provide access to momentum or real space at different times during the expansion, such that we can directly observe the inversion of the aspect ratio.

Q 56.4 Thu 15:15 F342

Full phase aberration correction - from the source to the atoms — •Paul Hill, Philipp Lunt, Johannes Reiter, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Heidelberg, Deutschland

Using light to engineer a broad class of potential landscapes for ultracold atoms has enabled numerous breakthroughs in the field of analog quantum simulation [1]. Especially, trapping and manipulation of individual particles requires light patterns of exquisite precision saturating the diffraction limit of high NA optics. Characterizing and eliminating wavefront errors in an optical setup is therefore a key factor for experimental success, but usually proves to be challenging or can only be done for parts of the setup.

Here, we present a method to measure the entirety of aberrations acquired in an optical setup with a Spatial Light Modulator (SLM), from the source plane to the atoms. This method relies on a type of Phase Shift Interferometry (PSI) [2] where we use a double well pattern sensitive to the phase aberrations present in the light path. Imaging the fluorescence signal of only 100 atoms trapped in this double well potential is sufficient to retrieve the relevant phase information, which is then used to cancel aberrations on the SLM. This allows critical components, including our vacuum window, to be mapped out that are usually inaccessible to aberration correction.

[1] W Hofstetter and T Qin 2018 J. Phys. B: At. Mol. Opt. Phys. 51 082001

[2] Philip Zupancic et al. Opt. Express 24, 13881-13893 (2016)

Q 56.5 Thu 15:30 F342

Dark state transport in a strongly interacting Fermi gas — Mohsen Talebi, •Simon Wili, Philipp Fabritius, Jeffrey Mohan, Meng-Zi Huang, and Tilman Esslinger — Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Laser-induced coherence of atomic states can dramatically alter the properties of an atomic medium. For example, a three-level system in a lambda configuration can be transparent to a resonant laser when another laser drives the other resonance. This is known as electromagnetically induced transparency (EIT). Another feature is the so-called dark state: The system driven by two lasers has an eigenstate which is a superposition of the two ground states. While the amplitudes of this superposition, described by a mixing angle, depend on the optical fields, the energy of this state does not, hence it is dark. EIT and dark states have various applications, such as slow light, stimulated rapid adiabatic passage (STIRAP), and photonic quantum memory. Here we study transport of a Fermi gas with two strongly-interacting spins, one of which is subject to an auxiliary lambda system. We create a particle current flowing through a one-dimensional channel connecting two superfluid reservoirs. A localized laser beam addressing a transition of the lambda system in the channel suppresses fast particle transport, while a second beam fulfilling the EIT condition can revive the fast transport. Hence we demonstrate a current that comprises a dark state for the first time in a strongly-interacting fermionic system. As in our system the pairing interaction depends on the mixing angle, this work paves the way for local and temporal engineering of fermionic pairing.

Q 56.6 Thu 15:45 F342

Exploring doped antiferromagnets with a Quantum Gas Microscope — Petar Bojovic[1,2], Sarah Hirthe[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Si Wang[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

We use our quantum gas microscope of fermionic ^{6}Li atoms loaded into the optical lattices to realize and study magnetic phases of the Fermi-Hubbard model with single-site spin and density resolution. In this talk, I will present our recent implementation of highly stable and tunable optical bichromatic superlattices, which provide the flexibility to test promising cooling protocol and reach novel phases of matter. I will furthermore discuss how we use a digital micromirror device (DMD) for potential shaping on individual sites and create tailored geometries [1, 2]. In such microscopically engineered systems, we can investigate interaction mechanisms in hole- or doublon- doped anti-ferromagnets and probe the formation of magnetically induced bound pairs among dopants.

[1] P. Sompet, S. Hirthe, D. Bourgund et al., Nature 606, 484-488 (2022)
[2] S. Hirthe et al., arXiv: 2203.10027 (2022)

Q 56.7 Thu 16:00 F342

Feshbach molecules in an optical orbital lattice — •Max Hachmann, Yann Kiefer, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We experimentally study strongly interacting degenerate Fermi gases exposed to an optical lattice. Previous studies focussed on the case, where only the lowest Bloch band is populated, such that the orbital degree of freedom is excluded. We report our experimental findings studying ultracold Feshbach molecules of fermionic 40K atoms selectively prepared in the second Bloch band of a bipartite optical square lattice, covering a wide range of interaction strengths including the regime of unitarity. Binding energies and band relaxation dynamics are measured by means of a method resembling mass spectrometry. The longest lifetimes arise for strongly interacting Feshbach molecules at the onset of unitarity with values around 300ms for the lowest band and 100ms for the second band. In the case of strong confinement in a deep lattice potential, we observe bound dimers also for negative values of the s-wave scattering length, extending previous findings for molecules in the lowest band. Our work prepares the stage for orbital BEC-BCS crossover physics.

Q 56.8 Thu 16:15 F342

Thermometry for trapped fermionic atoms in the BCS limit — •Sejung Yong, Sian Barbosa, Artur Widera, and Axel Pelster — Physics Department and Research Center OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Germany

Measuring the temperature of an interacting fermionic cloud of atoms in the BCS limit represents a delicate task. In the literature temperature measurements have so far been only suggested in an indirect way, where one sweeps isentropically from the BCS to the BEC limit. Instead we suggest here a direct thermometry, which relies on measuring the column density and comparing the obtained data with a Hartree-Fock-Bogoliubov mean-field theory combined with a local density approximation. In case of an attractive interaction between two-components of ^{6}Li atoms trapped in a tri-axial harmonic confinement we show that minimizing the error within such an experiment-theory collaboration turns out to be a reasonable criterion for determining the temperature. The findings are discussed in view of various possible sources of errors.