Q 35: Quantum Gases (Fermions) I

Time: Wednesday 14:00–16:15 Location: S HS 037 Informatik

Group Report Q 35.1 Wed 14:00 S HS 037 Informatik

Beyond particle transport at an atomic quantum point contact: thermoelectric effects and spin control — Martin Lebrat, •Philipp Fabritius, Samuel Häusler, Dominik Husmann, Jeff Mohan, Tilman Esslinger, and Laura Corman — Departmen of Physics, ETH Zurich, 8093 Zurich, Switzerland

In this talk, we report on a few remarkable transport properties of lithium-6 atoms through a quantum point contact (QPC) precisely defined by a set of optical potentials. The versatility of cold-atom techniques allows us to directly measure heat or spin currents and to tune interatomic interactions.

In a first experiment performed with a unitary Fermi gas close to the superfluid transition, we probe the thermoelectric effects induced by a temperature difference accross the QPC. We show that the system evolves towards a non-equilibrium steady state, associated with a reduced heat diffusion and a strong violation of the Wiedemann-Franz law. In a second experiment performed with weakly interacting atoms, we locally lift the spin degeneracy of atoms inside the QPC using an optical tweezer tuned very close to atomic resonance. We observe quantized, spin-polarized transport that is robust to dissipation and sensitive to interaction effects on the scale of the Fermi length.

These results open the way to the quantum simulation of efficient thermoelectric and spintronic devices with cold atoms.

Q 35.2 Wed 14:30 S HS 037 Informatik

Transverse magnetization effect of the spin-imbalanced Hofstadter-Hubbard model — •Bernhard Irsigler, Jun-Hui Zheng, Mohsen Hafez-Torbati, and Walter Hofstetter — Institut für Theoretische Physik, Frankfurt am Main, Germany

We spin-imbalance the fermionic, time-reversal invariant Hofstadter-Hubbard model through a population difference between two spin states. In the strongly interacting regime, where the system can be described by an effective spin model, we find an exotic spin structure by means of classical Monte-Carlo calculations. Remarkably, this spin structure exhibits a finite transverse net magnetization perpendicular to the magnetization induced by the population imbalance. We further investigate effects of quantum fluctuations within the dynamical mean-field approximation and obtain a rich phase diagram including ferromagnetic, anti-ferromagnetic, and ferrimagnetic phases, where the latter emerges from strong interaction induced quantum entanglement.

Q 35.3 Wed 14:45 S HS 037 Informatik

Degenerate Fermi gases of polar molecules with tilted dipoles — •Vladimir Veljić[1], Axel Pelster[2], and Antun Balaž[1] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Research Center OPTIMAS and Department of Physics, Technische Universität Kaiserslautern, Germany

A recent experimental realization of an ultracold quantum degenerate gas of $^{40}\mathrm{K}^{87}\mathrm{Rb}$ molecules [1] opens up a new chapter in exploring strongly dipolar Fermi gases. This includes the deformation of the Fermi surface (FS) for polarized systems, where the electric dipoles have a preferential orientation. Compared to atomic magnetic species [2,3], this effect is significantly increased in ultracold Fermi gases of polar molecules, and the stability of the system is expected to strongly depend on its geometry. Here we generalize a previous Hartree-Fock mean-field theory [2] for the Wigner function, which now takes into account that the cloud shape in the ground state is determined not only by the trap frequencies, but also by the dipoles' orientation. We calculate the corresponding FS deformation for an arbitrary orientation of the dipoles, demonstrating the great promise for the exploration of polarized degenerate molecules.

[1] L. De Marco, G. Valtolina, K. Matsuda, W. G. Tobias, J. P. Covey, and J. Ye, arXiv:1808.00028 (2018).
[2] V. Veljić, A. R. P. Lima, L. Chomaz, S. Baier, M. J. Mark, F. Ferlaino, A. Pelster, and A. Balaž, New J. Phys. **20**, 093016 (2018).
[3] V. Veljić, A. Balaž, and A. Pelster, Phys. Rev. A **95**, 053635 (2017).

Q 35.4 Wed 15:00 S HS 037 Informatik

A few-body approach to pairing correlations in a two-dimensional Fermi gas — •Ralf Klemt, Jan Hendrik Becher, Ram-Janik Petzold, Philipp M. Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Strong pairing correlations are, in combination with a shell structure, the central mechanism leading to the structure of atomic and nuclear matter but are also key to understanding the nature of strongly correlated fermionic many-body-phases as seen for example in the framework of the BEC-BCS crossover.

In this talk, I present recent experimental efforts on realizing and probing deterministic few-body states of fermionic ^6Li in a two-dimensional geometry. In the presence of strong interactions, it was theoretically shown [1] that such a system features signatures which can be interpreted as the few-body precursor of a normal to superfluid transition. As a consequence, in this superfluid phase strong pairing correlations at the "Fermi-surface", reminiscent of Cooper-pairing in many-body systems, are present.

We will characterize such few-body systems by probing the excitation spectrum of the pairing mode as well as by directly observing single particle resolved spin-spin correlations in momentum space. However, the unique opportunity to directly observe all relevant correlations will also help bridging the gap toward the understanding of strongly interacting fermionic 2D systems in the many-body limit.

[1] J. Bjerlin et al., PRL. 116, 155302 (2016)

Q 35.5 Wed 15:15 S HS 037 Informatik

Diverging exchange force for ultracold fermionic atoms — •Christian Schilling[1] and Rolf Schilling[2] — [1]Clarendon Laboratory, University of Oxford — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz

The Pauli exclusion principle $0 \leq n_k \leq 1$ is a kinematical constraint on fermionic occupation numbers which strongly shapes the behavior and the properties of fermionic quantum systems on all length scales. We demonstrate that this fundamental restriction can also be interpreted dynamically: the fermionic exchange symmetry manifests itself in the one-fermion picture in the form of an "exchange force" which repulsively diverges on the boundary of the allowed region, preventing fermionic occupation numbers n_k from leaving their domain $0 \leq n_k \leq 1$. Moreover, for translationally invariant one-band lattice models (e.g. ultracold atoms in an optical lattice), we exploit the *ab initio* knowledge of the natural orbitals (momentum states) and discover the exact one-matrix functional $\mathcal{F}(\vec{n})$ for smaller cluster systems (such as the Hubbard square). Remarkably, $\mathcal{F}(\vec{n})$ turns out to be strongly shaped by Pauli's exclusion principle and its recently found generalization.

Q 35.6 Wed 15:30 S HS 037 Informatik

High-Contrast Interference of Ultracold Fermions — •Jan Hendrik Becher, Philipp M. Preiss, Ralf Klemt, Vincent Klinkhamer, Andrea Bergschneider, and Selim Jochim — Physics Institute, Heidelberg University, Germany

Many-body interference between indistinguishable particles induces strong correlations rooted in quantum statistic. Such correlations have been studied with few photons but are thus limited to massless, non-interacting systems. Using deterministically prepared fermionic atoms in optical tweezers, such experiments can be extended to a higher particle number and further correlations can be induced by tuning the interactions over a wide range.

In our experiment we assemble mesoscopic fermionic quantum systems from independently prepared optical tweezers. We combine the full control of the system with a single-atom, spin-resolved imaging scheme that allows us to extract momentum correlation functions up to third order.

I will present recent measurements on momentum correlations between three independently prepared, identical fermions. The observed correlations are purely induced by quantum statistics and are a consequence of the particles' indistinguishability. We measure and analyze two and three-body density correlations after time-of-flight and find that even non-interacting, identical fermions exhibit intrinsic three-body correlations that cannot be predicted from measured two-body correlation functions.

Q 35.7 Wed 15:45 S HS 037 Informatik

Pairing on the BEC side of a fermionic system — •Manuel Jäger[1], Thomas Paintner[1], Daniel Hoffmann[1], Wladimir Schoch[1], Wolfgang Limmer[1], Michele Pini[2], Pierbagio Pieri[2], Giancarlo Strinati[2], Cheng Chin[3], and Johannes Hecker Denschlag[1] — [1]Universität Ulm, Institut für Quantenmaterie, Deutschland — [2]University of Camerino, School of Science and Technology, Physics Division, Italy — [3]University of Chicago, James Franck Institute, USA

We investigate the pair formation in a two-component fermionic system on the BEC side of unitarity. For a given interaction strength and temperature a thermodynamic equilibrium between unbound fermions and preformed pairs forms. Especially in the vicinity of unitarity, such a strongly interacting many-body system is still not fully understood.

In order to investigatge this system experimentally, we use a 50-50 mixture of the two lowest ^{6}Li Zeemann states and set their interaction strength by adjusting the scattering length with the help of the Feshbach resonance at 832 G. We then determine the fraction of paired atoms at different temperatures and interaction strengths using optical spectroscopy. The results are compared with a classical calculation, a self-consistent t-matrix approach and a thermal equilibrium model based on quantum statistics and mean field interaction.

The measurements and the calculations agree quite well, indicating that even at interaction parameters up to $(k_F a)^{-1} = 0.5$ the fermionic many-body system can be still viewed as dominantly consisting of a mix of atoms and molecules.

Q 35.8 Wed 16:00 S HS 037 Informatik

Quantum scale anomaly and spatial coherence in a 2D Fermi superfluid — •Marvin Holten[1], Luca Bayha[1], Nicolò Defenu[2], Antonia Klein[1], Puneet Murthy[1], Philipp Preiss[1], Tilman Enss[2], and Selim Jochim[1] — [1]Physics Institute, University of Heidelberg, Germany — [2]Institute for Theoretical Physics, Heidelberg University, Germany

Quantum anomalies are violations of a classical symmetry in the corresponding quantized version of the theory. They appear in quantum field theories when a cut-off has to be introduced to regularize some divergent physical quantity. Quantum anomalies are typically associated with high energy physics only and their influence on experimental observables in other fields is difficult to discern.

In this talk, we report a striking manifestation of a quantum scale anomaly in the breathing mode dynamics of a 2D Fermi superfluid of ultracold atoms. In two independent measurements we have studied both the breathing frequency and the position and pair momentum distribution of the cloud during one breathing mode cycle.

While the atom distributions exhibit self-similar evolution in the weakly interacting BEC and BCS limits, we found a significant violation in the strongly interacting regime. The signature of scale-invariance breaking is enhanced in the first-order coherence function. In particular, the power-law exponents that characterize long-range phase correlations in the system are modified due to this effect, indicating that the quantum anomaly has a significant influence on the critical properties of 2D superfluids.