Q 14: Ultra-cold atoms, ions and BEC II (with A)

Time: Monday 14:00–16:00 Location: F 428

Q 14.1 Mon 14:00 F 428

Observing the Drop of Resistance in the Flow of a Superfluid Fermi Gas — •David Stadler, Sebastian Krinner, Jakob Meineke, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich

The ability of particles to flow with very low resistance is a distinctive character of a superfluid or superconducting state and led to its discovery in the last century. While the particle flow in liquid Helium or superconducting materials is essential to identify superfluidity or superconductivity, an analogous measurement has not been performed with superfluids based on ultracold Fermi gases. Here we report on the direct measurement of the conduction properties of strongly interacting fermions, and the observation of the celebrated drop of resistance associated with the onset of superfluidity. We observe variations of the atomic current over several orders of magnitude by varying the depth of the trapping potential in a narrow channel, which connects two atomic reservoirs. We relate the intrinsic conduction properties to thermodynamic functions in a model-independent way, making use of high-resolution in-situ imaging in combination with current measurements. Our results show that, similar to solid-state systems, current and resistance measurements in quantum gases are a sensitive probe to explore many-body physics. The presented method is closely analogous to the operation of a solid-state field-effect transistor. It can be applied as a probe for optical lattices and disordered systems, and paves the way towards the modeling of complex superconducting devices.

Q 14.2 Mon 14:15 F 428

Ultracold fermions in two and three dimensions — •Igor Boettcher[1], Sebastian Diehl[2,3], Jan Pawlowski[1,4], and Christof Wetterich[1] — [1]Institut fuer Theoretische Physik, Universitaet Heidelberg — [2]Institut fuer Theoretische Physik, Universitaet Innsbruck — [3]IQOQI, Innsbruck — [4]ExtreMe Matter Insitute EMMI, GSI Darmstadt

The increasing experimental advances in realizing ultracold atom ensembles constitute an unprecedented possibility for testing and constraining predictions from quantum field theory. Key observables in equilibrium are the equation of state and the phase diagram of the system. I will present results on the BCS-BEC crossover of two-component ultracold fermions in both two and three dimensions, obtained with the Functional RG. We aim at quantitative precision. For this purpose we incorporate renormalization effects like the Contact, which is related to the high energy behavior of the momentum distribution of particles, and study its influence on the thermodynamics. The two-dimensional case is particularly interesting due to strong quantum fluctuations and can be realized in experiment with highly anisotropic traps.

Q 14.3 Mon 14:30 F 428

A SU(N) symmetric Fermi degenerate gas of ytterbium for lattice many-body physics — •F. Scazza, C. Hofrichter, P. C. De Groot, M. Höfer, C. Schweizer, E. Davis, I. Bloch, and S. Fölling — MPI für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching and Ludwig-Maximilians-Universität, Schellingstrasse 4, 80799 München, Germany

Ytterbium and other alkaline-earth-like atoms have some peculiar properties compared to alkali atoms which make them very attractive in the context of quantum simulation with ultracold atoms, especially in the presence of periodic potentials such as optical lattices.

Ytterbium possesses a metastable excited state which can be used to implement state-dependent optical lattices, enabling the simulation of new complex types of many-body Hamiltonians, e.g. the Kondo lattice model. In addition, the high nuclear spin of the fermionic ^{173}Yb, which is highly decoupled from the electronic state, gives rise to an enlarged SU(N) symmetry of the many-body Hamiltonian.

We describe preparation and detection of the nuclear and electronic spin state populations of a degenerate Fermi gas of Yb in the “magic lattice”, used for coupling to the $^3P_0$ metastable state via a narrow line “clock” laser on the doubly forbidden clock transition.

Q 14.4 Mon 14:45 F 428

Two-component few-fermion mixtures in a one-dimensional trap — •Ioannis Brouzos and Peter Schmelcher — Zentrum für Optische Quantentechnologien, Universität Hamburg

We explore a few-fermion mixture consisting of two components which are repulsively interacting and confined in a one-dimensional harmonic trap. Different scenarios of population imbalance ranging from the completely imbalanced case where the physics of a single impurity in the Fermi-sea is discussed to the partially imbalanced and equal population configurations are investigated. For the numerical calculations the multi-configurational time-dependent Hartree (MCTDH) method is employed, extending its application to few-fermion systems. Apart from numerical calculations we generalize our Ansatz for a correlated pair wave-function proposed in [1] for bosons to mixtures of fermions. From weak to strong coupling between the components the energies, the densities and the correlation properties of one-dimensional systems change vastly. The numerical and analytical treatments are in good agreement with respect to the description of this crossover. We show that for equal populations each pair of different component atoms splits into two single peaks in the density while for partial imbalance additional peaks and plateaus arise for very strong interaction strengths. The case of a single impurity atom shows rich behaviour of the energy and density as we approach fermionization, and is directly connected to recent experiments.

[1] I. Brouzos and P. Schmelcher, PRL 108, 045301 (2012).

Q 14.5 Mon 15:00 F 428

Measurements on first and second sound in a unitary Fermi gas — •Leonid A. Sidorenkov[1,2], Meng Khoon Tey[1,2], Rudolf Grimm[1,2], Yan-Hua Hou[3], Lev Pitaevskii[3,4], and Sandro Stringari[3] — [1]Institut für Quantenoptik und Quanteninformation (IQOQI), Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria — [2]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [3]Dipartimento di Fisica, Universitá di Trento and INO-CNR BEC Center, 38123 Povo, Italy — [4]Kapitza Institute for Physical Problems RAS, 119334 Moscow, Russia

We report on the propagation of first- and second-sound-like excitations in a highly elongated Fermi gas with unitarity-limited interactions around the critical temperature for superfluidity. Our measurements on first sound are in excellent agreement with calculations based on the recently measured equation of state (EoS) of the unitary Fermi gas for the whole temperature range explored. Given the available knowledge of thermodynamic quantities from the EoS, we investigate second-sound-like excitations in the unitary Fermi gas, and their connection to the superfluid hydrodynamics. Observation of these second-sound-like excitations offers, in analogy to superfluid helium, a direct access to the local superfluid density. This quantity cannot be obtained in EoS measuremens and requires additional knowledge of the elementary excitation spectrum of the unitary Fermi gas.

Q 14.6 Mon 15:15 F 428

Attractive atom-dimer interaction on the repulsive side of a ^{6}Li-^{40}K Feshbach resonance — •Michael Jag[1,2], Matteo Zaccanti[1], Marko Cetina[1], Rianne Lous[1], Dmitri Petrov[3], Jesper Levinsen[4], Florian Schreck[1], and Rudolf Grimm[1,2] — [1]IQOQI, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [2]Inst. für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [3]LPTMS, CNRS, Université Paris Sud, Orsay, France — [4]Cavendish Laboratory, Cambridge, UK

Mass imbalance in strongly interacting mixtures of ultracold fermions is predicted to lead to new pairing phenomena and quantum phases. We investigate a mass-imbalanced ^{6}Li-^{40}K Fermi-Fermi mixture in the regime of strong interactions on the repulsive side of an interspecies Feshbach resonance. We find that, for a sufficiently strong repulsive s-wave interaction, the ^{40}K atoms and the ^{6}Li^{40}K dimers interact attractively, which is in strong contrast to the mass-balanced case. This surprising behavior is related to the existence of a $\uparrow\uparrow\downarrow$ trimer state in $\uparrow\downarrow$ Fermi-Fermi mixtures with a mass ratio $m_\uparrow/m_\downarrow > 8.2$. For lower mass ratios (i.e. $m_{\mathrm{K}}/m_{\mathrm{Li}} = 6.64$) this trimer state turns into a p-wave atom-dimer scattering resonance. Here, we present our experimental results on interactions in a resonantly interacting atom-dimer mixture. Employing radio-frequency spectroscopy over a range of temperatures and interaction strengths, we confirm the presence of a strong attraction on the repulsive side of a Feshbach resonance, in good agreement with theory.

Q 14.7 Mon 15:30 F 428

Towards optical trapping of a single Ba^+ ion — •Michael Zugenmaier, Thomas Huber, Alexander Lambrecht, Julian Schmidt, and Tobias Schaetz — Albert-Ludwigs Universität Freiburg

In 2010 our group demonstrated the trapping of an Mg^+ ion in an optical dipole trap [1,2]. The lifetime in the optical potential was limited by heating due to photon recoils out of the optical field, detuned by only $7000\,\Gamma$ (depth $\sim$40 mK).

We are setting up a new experiment to trap a Ba^+ ion in a far off-resonance dipole trap. At first the Ba^+ ion is trapped and cooled in a linear Paul trap. The Ba^+ ion will then be transferred into an optical dipole trap which will be provided by a focussed laser at 532 nm. Using a far-detuned trapping laser of enhanced power features a comparable depth of the potential ($\sim$20 mK) while minimizing the photon scattering rate and will result in longer trapping durations.

The results of this experiment will be our first step towards the trapping of a Ba^+ ion and Rb atoms in one common trap. Combining the optically trapped ion with atoms in the same optical trap might allow us sympathetically cool the ion and to enter the regime of ultracold chemistry, where quantum phenomena are predicted to dominate.

[1] Ch. Schneider et al., Nat. Phot. 4, 772-775 (2010)
[2] M. Enderlein et al., Phys. Rev. Lett. 109, 233004 (2012)

Q 14.8 Mon 15:45 F 428

A single ion coupled to an optical fibre cavity — •Matthias Steiner[1], Hendrik-Marten Meyer[1], Christian Deutsch[2], Jakob Reichel[2], and Michael Köhl[1] — [1]Department of Physics, University of Cambridge, Cavendish Laboratory, Cambridge, United Kingdom — [2]Laboratoire Kastler-Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France

The development of an efficient ion-photon interface is a major challenge which needs to be overcome to realize large scale ion-based quantum networks. Such an interface could consist of a single ion coupled to a high finesse optical cavity. Existing ion-cavity systems operate in a regime, where the coupling of light and ion is smaller than the excited state decay rate[1]. In order to enhance the coupling, smaller cavity mode volumes must be used.

We report on the realization of a combined trapped-ion and optical cavity system, in which a single Yb^+ ion is confined by a micron-scale ion trap inside a 230 μm-long optical fibre cavity. We characterize the spatial ion-cavity coupling and measure the ion-cavity coupling strength using a cavity-stimulated Λ-transition [2]. Owing to the small mode volume, the coherent coupling strength between the ion and a single photon exceeds the natural decay rate of the dipole moment. Our results demonstrate that stable trapping of single ions in close vicinity of dielectric surfaces does not impose fundamental problems, even at room temperature.

[1] G. R. Guthöhrlein et al., Nature, 414, (2001).
[2] M. Steiner et al, arXiv:1211.0050.