Q 32: Fermionic Quantum Gases II (joint session Q/A)

Time: Wednesday 14:30–16:30 Location: Aula

Q 32.1 Wed 14:30 Aula

Exact one-particle density matrix for SU(N) fermionic matter-waves in the strong repulsive limit — •Andreas Osterloh[1], Wayne Chetcuti[1], Juan Polo[1], and Luigi Amico[1,2] — [1]Technology Innovation Institute, Masdar City and Yas Island, P.O. box 9639Abu Dhabi, UAE — [2]Dipartimento di Fisica e Astronomia Ettore Majorana, Via S. Sofia 64, 95127 Catania, Italy

We consider a gas of repulsive N-component fermions confined in a ring-shaped potential, subject to an effective magnetic field. For large repulsion strengths, we work out a Bethe ansatz scheme to compute the two-point correlation matrix and then the one-particle density matrix. Our results holds in the mesoscopic regime of finite but sufficiently large number of particles and system size that are not accessible by numerics. We access the momentum distribution of the system and analyse its specific dependence of interaction, magnetic field and number of components N. In the context of cold atoms, the exact computation of the correlation matrix to determine the interference patterns that are produced by releasing cold atoms from ring traps is carried out.

Q 32.2 Wed 14:45 Aula

Universal Entropy Transport in Fermionic Superfluids across the BEC-BCS Crossover — Jeffrey Mohan, •Simon Wili, Philipp Fabritius, Mohsen Talebi, Meng-Zi Huang, and Tilman Esslinger — ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

Particle transport between two superfluids is often associated with reversible, entropy-free supercurrents, such as in the Josephson and fountain effects. However, this only applies to weakly-coupled superfluids in the linear response regime. Here, we experimentally investigate particle and entropy flow within a ballistic channel, strongly coupling two superfluids across the BEC-BCS crossover. Our observations reveal large currents of both particles and entropy. While these currents depend on the channel's geometry, the entropy transported per particle appears constant across different geometries. Instead, it is influenced by the interaction strength and reservoir degeneracy. This suggests that the non-equilibrium currents flowing through the channel inherit the universal equilibrium properties from the reservoirs. Moreover, when distinguishing advective and diffusive entropy currents, we find that the Wiedemann Franz law, which describes the relation of these currents in Fermi liquids, is strongly violated at unitarity but partially restored on the BCS side. The present observations raise fundamental questions about transport in strongly interacting, non-equilibrium Fermi systems.

Q 32.3 Wed 15:00 Aula

Unravelling Interaction and Temperature Contributions in Unpolarized Trapped Fermionic Atoms in the BCS Regime — •Sejung Yong, Sian Barbosa, Jennifer Koch, Felix Lang, Axel Pelster, and Artur Widera — Physics Department and Research Center OPTIMAS, Kaiserslautern-Landau, Germany

In the BCS limit density profiles for unpolarized trapped fermionic clouds of atoms are largely featureless. Therefore, it is a delicate task to analyze them in order to quantify their respective interaction and temperature contributions. Temperature measurements have so far been mostly considered 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-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 analyzing in detail measured densities and, thus, for ultimately determining the sample temperatures. The findings are discussed in view of various possible sources of errors.

[1] S. Yong, S. Barbosa, J. Koch, F. Lang, A. Pelster, and A. Widera, arXiv:2311.08853

Q 32.4 Wed 15:15 Aula

A quantum engine in the BEC-BCS crossover — •Jennifer Koch[1], Keerthy Menon[2], Eloisa Cuestas[2,3], Sian Barbosa[1], Eric Lutz[4], Thomás Fogarty[2], Thomas Busch[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]OIST Graduate University, Onna, Japan — [3]Enrique Gaviola Institute of Physics, Córdoba, Argentina — [4]Institute for Theoretical Physics I, University of Stuttgart, Germany

Heat engines convert thermal energy into mechanical work both in the classical and quantum regimes. However, quantum theory offers genuine nonclassical forms of energy, different from heat, which so far have not been exploited in cyclic engines to produce useful work. In this talk, I will discuss a recently realized quantum many-body engine fuelled by the energy difference between fermionic and bosonic ensembles of ultracold particles that follows from the Pauli exclusion principle [1]. We employ a harmonically trapped superfluid gas of ^{6}Li atoms close to a magnetic Feshbach resonance, which allows us to effectively change the quantum statistics from Bose-Einstein to Fermi-Dirac by tuning the gas between a Bose-Einstein condensate of bosonic molecules and a unitary Fermi gas (and back) through a magnetic field. The talk will focus on the quantum nature of such a Pauli engine. Additionally, I will present the pressure-volume diagram of the new kind of engine and show how the engine behaves after multiple cycles. Our findings establish quantum statistics as a useful thermodynamic resource for work production. [1] J. Koch et al., Nature 621, 723 (2023)

Q 32.5 Wed 15:30 Aula

A generalized formalism to describe multi-channel Hartree-Fock-Bogoliubov interactions in fermionic systems — •Nikolai Kaschewski[1], Axel Pelster[1], and Carlos A. R. Sá de Melo[2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]School of Physics, Georgia Institute of Technology, Atlanta, USA

A simplified description of fermionic systems relies on the Hartree-Fock-Bogoliubov (HFB) approximation, where the interaction is decomposed into distinct channels. However, an major issue with this procedure is that the separation between the channels is somewhat arbitrary. In some cases, only one interaction channel is considered, e.g the pairing channel in the BCS theory and the BCS-BEC crossover, or in other cases, two different interaction channels are artificially separated like in the Jellium model. In this talk, we present a generalized self-consistent theory by using weighting parameters for each channel. Our approach removes the arbitrariness of channel separation and provides a minimization principle for the optimal partitioning. We present this formalism for any type of spatially non local potentials without memory and derive the respective HFB self-consistency equations on a mean-field level and show how inter-channel interactions arise. We illustrate the power of our technique with a simple example before showing on a formal level how to include pairing, density, and exchange fluctuations simultaneously without miscounting or double-counting states.

Q 32.6 Wed 15:45 Aula

The role of particle-hole interactions and effective ranges in homogeneous Fermi fluids — Nikolai Kaschewski[1], Axel Pelster[1], and •Carlos A. R. Sá de Melo[2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]School of Physics, Georgia Institute of Technology, Atlanta, USA

The standard theoretical method for studying fermionic superfluidity is based on the description of interactions in terms of pairing and on the identification of a superfluid order parameter. Only particle-particle (pp) processes are included that form Cooper pairs which then perform Bose-Einstein condensation. Particle-hole (ph) processes are only sparsely considered. One example are the ph fluctuations of Gor'kov and Melik-Barkhudarov that lowers the condensation temperature [1]. On this poster, we present a self-consistent mean-field theory for BCS superfluidity that includes pp and ph processes simultaneously through a weighted partitioning of states that produce and inhibit pairing. We obtain non-perturbative corrections due to ph scattering, which require an effective range expansion [2] in order to get physical results. The theory generalizes the BCS mean field theory, makes connections to effective-range mean-field effects [3]. Our preliminary results set the stage for the simultaneous exploration of fluctuations in the pp and ph channels [1] in the BCS-BEC crossover.

[1] L.P. Gor'kov, T.K. Melik-Barkhudarov, Sov. Phys. JETP **13**, 1018 (1961) [2] H. A. Bethe, Phys. Rev. **76**, 38 (1949) [3] S. Mal and B. Deb, J. of Phys. B **55**, 035301 (2022)

Q 32.7 Wed 16:00 Aula

Topological pumping induced by interactions — KONRAD VIEBAHN[1], ANNE-SOPHIE WALTER[1], ERIC BERTOK[2], •ZIJIE ZHU[1], MARIUS GÄCHTER[1], ARMANDO A. ALIGIA[3], FABIAN HEIDRICH-MEISNER[2], and TILMAN ESSLINGER[1] — [1]Institute for Quantum Electronics & Quantum Center, ETH Zurich, 8093 Zurich, Switzerland — [2]Institute for Theoretical Physics, Georg-August-Universität Göttingen, 37077 Göttingen, Germany — [3]Instituto de Nanociencia y Nanotecnologia CNEA-CONICET, Centro Atomico Bariloche and Instituto Balseiro, 8400 Bariloche, Argentina

A topological 'Thouless' pump represents the quantised motion of particles in response to a slow, cyclic modulation of external control parameters. The Thouless pump, like the quantum Hall effect, is of fundamental interest because it links physically measurable quantities, such as particle currents, to geometric properties which can be robust against perturbations and thus technologically useful. Here we observe a Thouless-type charge pump in which the particle current and its directionality inherently rely on the presence of strong interactions. Experimentally, we utilise fermionic atoms in a dynamical superlattice which traces a pump trajectory that remains trivial in the non-interacting limit. Remarkably, the transferred charge in the interacting system is half of its usual value in the non-interacting case, in agreement with matrix-product-state simulations. Our experiments suggest that Thouless charge pumps are promising platforms to gain insights into interaction-driven topological transitions and topological quantum matter.

Q 32.8 Wed 16:15 Aula

Kapitza-Dirac scattering of strongly interacting Fermi gases — •MAX HACHMANN[1], YANN KIEFER[1,2], and ANDREAS HEMMERICH[1] — [1]Universität Hamburg, Hamburg, Deutschland — [2]ETH, Zürich, Schweiz

We experimentally probe properties of interacting spin-mixtures of fermionic (40K) atoms by studying their interaction with light. An elementary scattering scenario is resonant Bragg diffraction, also referred to as Bragg spectroscopy, where matter is diffracted from a onedimensional (1D) optical standing wave. A Feshbach resonance is used to tune the interactions across the entire BEC-BCS crossover regime, including the point of unitarity. With the preparation schemes available in our experiment, the scattering lengths can be dynamically tuned, such that either repulsively bound molecular dimers (Feshbach molecules) or pairs of unbound fermions can be studied. To benchmark our scattering protocol, we apply it to a sample of spin-polarized non-interacting fermionic atoms and study the dynamical behaviour. In this case, a simple model using a time-dependent Schrödinger equation yields surprisingly accurate results, well matching the experimental observations. For spin-mixtures in the unitarity regime, the higher order diffraction peaks are observed to disappear with no conclusive theoretical description presently available.