Stephanie Reimann
(Lund University)

Quantum gases in a low-dimensional confinement – from few-body properties to the mean-field regime

The talk will review recent work on bosonic or fermionic quantum gases in a low-dimensional confinement from different perspectives, setting emphasis on the transition from the few-body limit to the mean-field regime.

For a weakly interacting Bose gas rotating in a harmonic trap, the exact quantum states reveal significant structure not captured by the Gross-Pitaevskii approach, providing deepened insight into beyond-mean-field properties [1]. Fermionic systems reveal a surprisingly similar behavior than their bosonic counterparts when set rotating, showing similar vortex patterns for repulsive interactions as they for example occur in dipolar gases.

For fermions with attractive interactions, pairing may lead to a superfluid-like state even in the few-body limit. In this case, a table-top few-body precursor of the Higgs mode can be found [2]. The lowest monopole mode frequency depends non-monotonically on the interaction strength, with a minimum in the crossover region that deepens with increasing particle number, and vanishes at the quantum phase transition point to the normal phase. This mode mainly consists of coherent excitations of time-reversed pairs, and can be selectively excited by modulating the interaction strength.

Finally, I will comment on some very recent ideas to explore the quantum-thermodynamic properties of few-body systems [3]. The Szilard engine is a more than eight decades old thought experiment that has become a paradigm for describing information-to-work conversion in thermodynamic systems. Conceptually, the engine transforms heat isothermally into work, using information about a single particle's location on either side of a moving piston. While Landauer's principle was recently verified experimentally for a single classical particle, it is still a mystery how the fundamental relations between work, heat and information, as captured in the Szilard engine, are altered by quantum effects and correlations. In recent work we could demonstrate [4] that a quantum Szilard engine containing many bosons with attractive interactions is significantly boosting the information-to-work conversion. Using an ab initio approach to the full quantum-mechanical many-body problem, we show that the average work output dramatically increases for a larger number of bosons. We find that the highest overshoot occurs at a finite temperature, demonstrating how thermal and quantum effects conspire to enhance the conversion efficiency between information and work. The predicted effects occur over a broad range of interaction strengths and temperatures. We anticipate that the interacting quantum many-body Szilard cycle may serve as a new prototype to study the fundamental, and hitherto largely unexplored, relations between correlations, information and thermal fluctuations for a wide range of quantum many-body systems.

[1] *Rotating Bose-Einstein condensates: Closing the gap between exact and mean-field solutions,* J.C. Cremon, A.D. Jackson, E.O. Karabulut, G.M. Kavoulakis, B.R. Mottelson, and S.M. Reimann, Phys. Rev. A 91, 033623 (2015).

[2] *Few-Body Precursor of the Higgs Mode in a Fermi Gas*, J. Bjerlin, S.M. Reimann and G.M. Bruun, Phys. Rev. Lett. 116, 155302 (2016).

[3] *Supremacy of the quantum many-body Szilard engine with attractive bosons,* J. Bengtsson, M. Nilsson Tengstrand, A. Wacker, P. Samuelsson, M. Ueda, H. Linke, and SM. Reimann,
arXiv:1701.08138 (2017).

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19. Mai 2017, 14:00 Uhr

Universität Stuttgart, NWZ II, Raum 2.136
Pfaffenwaldring 57, 70569 Stuttgart