The nature of superfluidity in the cold atomic unitary Fermi gas

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The two-species cold atomic Fermi gas system provides a well-defined and clean system for which the interaction strength can be tuned experimentally to describe a crossover between a Bose-Einstein condensate (BEC) and the Bardeen-Cooper-Schrieffer (BCS) regime. Of particular interest is the unitary limit for which the interaction is strongest and characterized by an infinite scattering length.

The nature of superfluidity in the unitary gas remains incompletely understood. In particular, a pseudogap phase, in which the gap is non-zero above the critical temperature, was proposed but its existence is still debated both theoretically and experimentally. We implemented finite-temperature auxiliary-field quantum Monte Carlo (AFMC) methods for the canonical ensemble to study the nature of superfluidity of the unitary gas in both a harmonic trap and in a periodic box (describing a homogeneous gas).

(i) *Superfluidity in the finite-size trapped unitary gas.* We used AFMC methods in the framework of the configuration-interaction (CI) shell model [1] to study the thermodynamics of the finite-size cold atom condensate [2]. We performed the first ab initio calculations of the energy-staggering pairing gap, the condensate fraction and the heat capacity in a trapped cold atom system. We observed clear signatures of the superfluid phase transition in these quantities. However, we found no signatures of a pseudogap effect in the energy-staggering pairing gap.

(ii) *Superfluidity in the homogenous unitary gas.* We have used AFMC methods on a spatial lattice to study the cold atom Fermi gas at unitarity [3]. We present the first quantum Monte Carlo calculation of the heat capacity as a function of temperature and compare it with the recently measured lambda peak. We have also calculated the condensate fraction, pairing gap, and the spin susceptibility as a function of temperature. We find no evidence of a pseudogap phase above the critical temperature for superfluidity.

[1] For a recent review of AFMC, see Y. Alhassid, Ch. 9 in a review book *Emergent Phenomena in Atomic Nuclei from Large-Scale Modeling: a Symmetry-Guided Perspective*, edited by K.D. Launey, World Scientific (2017), arXiv:1607.01870.

[2] C.N. Gilbreth and Y. Alhassid, Phys. Rev. A **88**, 063643 (2013).

[3] S. Jensen, C.N. Gilbreth and Y. Alhassid, in preparation (2017).