Cold atomic Fermi gases in two dimensions: superfluidity and pseudogap effects in the strongly interacting regime

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Cold atomic Fermi gases are of great interest in diverse areas of physics because they provide a well-defined paradigm of strongly interacting Fermi systems. We discuss the strongly interacting regime of the crossover between the Bose-Einstein condensate (BEC) and the Bardeen-Cooper-Schrieffer (BCS) limits of the two-species Fermi gas with attractive contact interaction in two (2D) spatial dimensions [1]. The physics of a 2D system is different than the corresponding 3D system in that a two-particle bound state exists for arbitrarily weak interactions and the superfluid phase transition is of the Berezinskii-Kosterlitz-Thouless (BKT) type, characterized by the algebraic decay of correlations in the superfluid regime.

The 2D BEC to BCS crossover and the BKT transition have been intensively studied in recent experiments and theoretical work. Of particular interest is a pseudogap regime in which pairing correlations persist above the critical temperature. Many of the theories used are based on uncontrolled approximations. We use controlled auxiliary-field quantum Monte Carlo (AFMC) methods in the canonical ensemble on a discrete lattice that are accurate up to statistical errors [2,3]. Systematic errors associated with the discreteness of the lattice are eliminated by extrapolating to the continuum limit [4].

We determined the critical temperature by finite-size scaling of the condensate fraction and observe signatures of pseudogap (or spin gap) in the temperature dependence of the spin susceptibility and of the free energy gap.

Another observable of interest is the contact, a fundamental property of quantum many-body systems with short-range correlations that measures the pair correlation at short distances. We find that the 2D contact increases rapidly as the temperature decreases below the critical temperature for superfluidity, as was found for the 3D unitary Fermi gas [4].

[1] S. Ramachandran, S. Jensen, and Y. Alhassid, to be published (2022).

[2] S. Jensen, C. N. Gilbreth, and Y. Alhassid, Phys. Rev. Lett. 124 (2020) 090604.

[3] For a recent review of AFMC, see Y. Alhassid, in *Emergent Phenomena in Atomic Nuclei from Large-Scale Modeling: a Symmetry-Guided Perspective*, edited by K.D. Launey, (World Scientific, Singapore, 2017), Ch. 9, pp. 267 - 298.

[4] S. Jensen, C. N. Gilbreth, and Y. Alhassid, Phys. Rev. Lett. 125 (2020) 043402.