

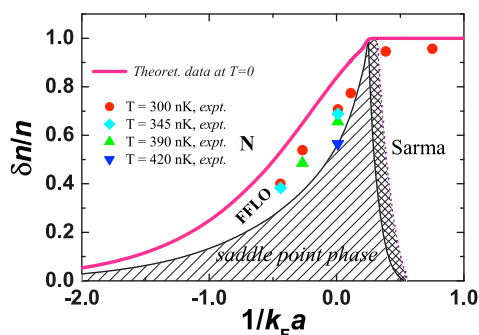
Spin-polarized superfluid Fermi gases

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Recently, three experiments, reported in Science and Nature[1, 2, 3], have studied the properties of spin-polarized ultra-cold Fermi gases. This very new area has attracted a great amount of interest in widely varying fields ranging from condensed matter, atomic, molecular and optical physics, to particle and astro physics. An experimental program in ultra-cold fermionic ${}^6\text{Li}$ near a Feshbach resonance is underway at the SUT node of ACQAO. The work described here provides theoretical support for possible experimental investigations of new forms of superfluidity near the Feshbach resonance.

Since the usual BCS pairing requires an equal number of atoms in each spin state, the presence of spin population imbalance leads to some exotic forms of pairing, such as the finite-momentum paired Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state, the breached pairing or Sarma superfluidity, and phase separation. However, the true ground state of spin-polarized fermionic superfluidity remains elusive and has been the subject of debate for decades. Motivated by these significant experimental developments, we have studied the phase diagram and thermodynamics of the ground state and vortices in spin-polarized Fermi gases.



Firstly, by using a mean-field approach we propose a phase diagram at zero temperature for a spin-polarized Fermi gas at the BCS-BEC crossover. We construct the phase boundary of superfluid-to normal transitions and compare it with measurements by Zwierlein et al. The agreement is qualitatively good. We also include quantum fluctuations using NSR theory. We determine the transition temperature at fixed chemical potential imbalance, and give the finite-temperature phase diagram[4, 5].

We also consider trap effects by using both the Bogoliubov-de Gennes equations and the local density approximation at finite temperature. We find that a bimodal structure emerges in the density profile of the minority spin state at finite temperature, as observed in experiments. The superfluid transition temperature as a function of the population imbalance is determined, and is shown to be consistent with recent experimental measurements[6].

Next, we have analyzed the effects of creating superfluid vortices, and show that this results in a core of trapped normal fermions, which can be visualized experimentally using phase-contrast imaging[7]. Finally, we have treated the exactly soluble one-dimensional case, obtained the complete phase-diagram which demonstrates the existence of an exotic FFLO phase, and shown for the trapped case that there is an experimentally accessible signature via a collective mode frequency measurement[8].

References

- [1] M. W. Zwierlein *et al.*, Science **311**, 492 (2006).
- [2] G. B. Partridge *et al.*, Science **311**, 503 (2006).
- [3] M. W. Zwierlein *et al.*, Nature (London) **442**, 54 (2006).
- [4] Hui Hu and Xia-Ji Liu, Phys. Rev. A **73**, 051603(R) (2006).
- [5] Xia-Ji Liu and Hui Hu, Europhys. Lett. **75**, 364 (2006).
- [6] Xia-Ji Liu, Hui Hu, and P. D. Drummond, to appear, Phys. Rev. A (2007).
- [7] Hui Hu, Xia-Ji Liu, Peter D. Drummond, arXiv: cond-mat/0607179, to appear, Phys. Rev. Lett. (2007).
- [8] Hui Hu, Xia-Ji Liu, Peter D. Drummond, arXiv: cond-mat/0610448, to appear, Phys. Rev. Lett. (2007).