Strong Correlation Physics in Trapped Cold Atom Systems

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Introduction

During the last 15 years or so a new frontier of condensed matter research has emerged in trapped atomic or molecular systems. It was initiated by technological advances in trapping large numbers of atoms and molecules using magnetic fields and lasers, and cooling them to astonishingly low temperatures. This allowed for a long-awaited scientific breakthrough in 1995, namely the observation of Bose-Einstein condensation (BEC, first predicted in 1924) in alkali atom gases. This work, which was awarded Nobel prize in physics six years later (2001), lead to an explosion of interest and activities in trapped cold atom system, especially the many-particle collective behavior due to inter-atomic interactions; "cold atoms" become one of the hottest fields of research in condensed matter physics. Of particular interest is the strong correlation physics in these systems; our group have done some work using sophisticated theoretical methods in this area.

Results and Discussion

We have made substantial progress in the following directions.

- We have studied the nature superfluid-insulator transition (SIT) of a mixture of bosonic and fermionic atoms on an optical lattice. We find that the critical properties of particle-hole symmetric SIT with dynamical exponent z=1 is modified when fermions are present; it either becomes a fluctuation-driven first order transition or a different second-order transition. On the other hand the more generic particle-hole asymmetric (with z=2) SIT is stable against coupling with fermions. We also discuss pairing interaction between fermions mediated by quantum critical fluctuations near SIT [1].
- Supersymmetry is assumed to be a basic symmetry of the world in many high energy theories, but none of the super partners of any known elementary particle has been observed yet. We have shown that supersymmetry can also be realized and studied in ultracold atomic systems with a mixture of bosons and fermions, with properly tuned interactions and single particle dispersion. We further show that in such non-releativistic systems supersymmetry is either spontaneously broken, or explicitly broken by a chemical potential difference between the bosons and fermions. In both cases the system supports a sharp fermionic collective mode or the so-called Goldstino, due to supersymmetry. We have also proposed methods to detect the Goldstino mode experimentally [2].
- We considered two-species of fermions in a rotating trap that interact via an s-wave Feshbach resonance, at total Landau level filling factor two (or one for each species). We show that the system undergoes a quantum phase transition from a fermion integer quantum Hall state to a boson fractional quantum Hall state as the pairing interaction strength increases, with the transition occurring near the resonance. The effective field theory for the transition is shown to be that of a (emergent) massless relativistic bosonic field coupled to a Chern-Simons gauge field, with the coupling giving rise to semionic statistics to the emergent particles [3].

Conclusions

Trapped cold atom systems offer exciting opportunities to study strong correlation physics in interacting many-body systems. Our group is beginning to make significant contribution to this new and fast-evolving research field.

Acknowledgements

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References

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[2] Yu, Y., and Yang, K., http://arxiv.org/abs/0707.4119.
[3] Yang, K., and Zhai, H., http://arxiv.org/abs/0709.2934.