Quantum phases in a small-scale Bose-Fermi system

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In recent years, the possibility to address ultracold atoms in single sites of optical lattices and to create mixtures of bosons and fermions drew the attention to the study of small, inhomogeneous systems with complex inter-species interactions [1]. The study of such two- or three-dimensional systems enables understanding of basic physics of more complicated systems, such as interaction-dependent properties of ground states (e.g., frustrations) and the role of symmetry breaking in transitions between different quantum phases. Small, strongly correlated systems may also lend themselves to the process of controlled quantum state preparation and manipulation making it potentially useful in quantum information, quantum-limited measurements, and atomtronics.

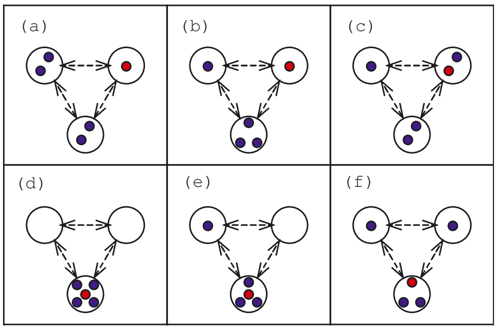

Fig. 1: Schematics of the on-site state configurations of four bosons (blue circles) and one fermion (red circle), contributing to the lowest energy band. The panels (a), (b), (c), and (f) correspond to repulsive inter-species interaction and (d), (e), and (f) to inter-species attraction.

In this work we consider a minimal finite two-dimensional lattice model, namely a three-site ring of a Bose-Fermi ultracold mixture. Such a three-site system may be realized experimentally by engineering magnetic microtraps on an atomic chip, or by combining a harmonic potential with a triangular or Kagome lattice, as suggested in [2]. With the small number of atoms, this system lends itself to the Bose-Fermi-Hubbard model solvable by means of direct diagonalization. We consider the ground state of the system and investigate how the admixture of fermions leads to various phases, depending on the filling factor and inter-species interaction strength.

By examining the tunneling correlations and particle fluctuations in the system, we have found that the system admits mobile and insulating states that are analogous to the superfluid and Mott-insulator states in infinite lattices. The novel insulating states identified in this small-scale system for both commensurate and incommensurate filling of bosons, are purely due to the inter-species interactions, and can be controlled by controlling the interaction strengths and the number of fermions injected into the system. [3]. These unusual insulating phases are connected to the existence of macroscopic self-trapping states in the mean-field regime [4].

References

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