Orbital physics in optical lattices: From strong correlations to twisted superfluidity

Abstract:

Orbital physics plays a significant role for a vast number of important phenomena in complex condensed matter systems such as high-Tc superconductivity and unconventional magnetism. The interaction in strongly correlated bosonic systems promotes particle to higher orbital states, which has been mostly neglected in favor for single-band Hamiltonians. In this regard, optical lattices offer an ideal testing ground to study many-particle problems with widely tunable parameters.

I will discuss multi-orbital and density-induced tunneling which have significant impact on the phase diagram of bosonic atoms in optical lattices [1]. Off-site interactions lead to density-induced hopping, so-called bond-charge interactions, which can be identified with an effective tunneling potential. In addition, interaction-induced higher-band processes give rise to strongly modified tunneling, on-site, and bond-charge interactions. Using an extended occupation-dependent Hubbard model, the phase diagram is derived which substantially deviates from the single-band Bose-Hubbard predictions leading to strong changes of the superfluid to Mott-insulator transition point.

In contrast, phenomena in superfluids are commonly well described by the lowest orbital and a real order parameter. I will report on the observation of a novel multi-orbital superfluid phase in hexagonal lattices with a complex order parameter [2]. In this unconventional superfluid, the local phase angle of the complex order parameter is continuously twisted between neighboring lattice sites. The observed quantum phase transition to this twisted superfluid phase is consistent with theoretical phase diagrams and reveal new aspects of orbital superfluidity in bosonic spin mixtures.

[1] Dirk-Sören Lühmann, Ole Jürgensen, and Klaus Sengstock, arXiv:1108.3013 (2011).
[2] Parvis Soltan-Panahi, Dirk-Sören Lühmann, Julian Struck, Patrick Windpassinger, and Klaus Sengstock, Nature Physics, doi:10.1038/nphys2128 (2011).