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Higher orbital physics and artificial gauge fields with ultracold quantum gases

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Recently the physics of quantum gases in higher orbitals attracted a lot of attention, theoretically and experimentally. We report on studies of a new type of superfluid described by a complex order parameter, resulting from an interaction-induced hybridization of the two lowest orbitals for a binary spin-mixture. As a main result we observe a quantum phase transition between the normal superfluid and this unconventional superfluid phase, where the local phase angle of the complex order parameter is continuously twisted between neighboring lattice sites [1]. In addition we discuss new experimental work on the creation of artificial gauge potentials for neutral atoms in 1D and 2D lattices, which do not rely on the internal structure of the atoms. Via a time-dependent driving of the optical lattice we have full control over amplitude and phase of the complex valued hopping parameters. In a 2D triangular lattice, we demonstrate the realization of gauge invariant staggered fluxes [2]. Our system consists of an array of tubes filled with bosonic atoms having a well-defined local phase. The phase distribution obtained in presence of large amplitude staggered fluxes – where frustration plays a key role - obeys two fundamental symmetries, the discrete Ising symmetry (Z2) and a continuous global phase symmetry (U(1)). Via the full control of the staggered gauge fields [3], we are able to break the Ising symmetry on purpose which means lifting the degeneracy of the two possible Ising states, in analogy to a longitudinal homogenous magnetic field in the standard Ising-Spin model. The measurements reveal "textbook like" magnetization curves with the well known dependence on both, the external magnetic field and the temperature. We observe a thermally driven phase transition from an ordered Ising (ferromagnetic) to an unordered (paramagnetic) state. Future directions to combine orbital physics and gauge fields will be discussed.

[1] Soltan-Panahi et al., Nature Physics 8, 75 (2012)
[2] Struck et al., Science 333, 996 (2011)
[3] Struck et al., PRL 108, 225304 (2012)