Matteo Rizzi

Universität Mainz

Exploring topological phases with cold atoms & tensor networks

Abstract: Understanding the robustness of topological phases of matter in the presence of strong interactions, and synthesising novel strongly-correlated topological materials, lie among the most important and difficult challenges of modern theoretical and experimental physics. The synthetic Creutz-Hubbard ladder is a paradigmatic model that provides a neat playground to address these challenges, including the generation of flat bands as well as of non-doubled Dirac dispersion relations.

In [1], we present a theoretical analysis of the competition between correlated topological phases and orbital quantum magnetism in the regime of strong interactions at half-filling. We predict topological quantum phase transitions for weak and intermediate interactions with different underlying conformal field theories (CFTs), i.e. Dirac versus Majorana CFTs.

In [2], we study the response of an interacting system of Dirac-Weyl fermions confined in a one-dimensional (1D) ring: we show that tuning of interactions leads to a unique many-body system that displays either a suppression or an enhancement of the Drude weight—the zero-frequency peak in the ac conductivity—with respect to the non-interacting value. Both studies are furthermore confirmed and extended by extensive numerical simulations based on matrix product states (MPS) and binary Tree Tensor Networks (bTTN). Moreover we propose how to experimentally realize this model in a synthetic ladder, made of two internal states of ultracold fermionic atoms in a one-dimensional optical lattice.

If time allows, we briefly overview another recent work of ours [3], where bTTN are applied to a 2D Harper-Hofstadter Hamiltonian for hard-core bosons (within reach of state-of-the-art experiments): we show that this supports a topological phase realizing the $\nu = 1/2$ fractional quantum Hall effect on the lattice. We address the robustness of the ground state degeneracy and of the energy gap, measure the many-body Chern number, and characterise the system using Green functions, showing that they decay algebraically at the edges of open geometries, indicating the presence of gapless edge modes. Our results provide extensive evidence that FQH states are within reach of state-of-the-art cold atom experiments.