PhD thesis project

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Quantum magnetism of ultracold fermions in optical lattices

We offer an experimental PhD project in the field of ultracold atoms. Our project relies on the operation of a quantum simulator, i.e., an experiment manipulating a complex quantum system with well controlled physical parameters, that can be seen as emulating models for a range of quantum systems untractable to direct theoretical study.

Our quantum simulator is designed for the study of strongly correlated degenerate fermions. This is a category of systems prone to rich phenomena such as quantum magnetism, exotic conduction regimes, and many-body entanglement. Primarily a condensed matter topic, such systems are now explored in new settings by quantum simulators such as our experiment. In our case, we produce dilute degenerate gases of fermionic strontium 87 atoms, using laser cooling techniques, and confine them onto a periodic structure created by interfering laser beams: an optical lattice potential. There, we specifically aim at exploring generalizations of the Heisenberg model of antiferromagnetism to large spins, using the large spin (9/2) of our atoms. We can actually constrain the system to realize both situations analogous e.g. to those encountered by electrons (of spin ½) in crystalline materials, and novel situations that have no known equivalent system yet but for which novel magnetic phases are expected, with connections to magnetic frustration and spin liquids.

The aim of this thesis is to explore the dynamics of many-body correlations. This ranges from detecting the dynamical evolution of a classical spin ordering up to detecting the growth of purely quantum correlations (entanglement). In a first set of experiments, we will exploit the narrow optical lines of strontium to prepare deterministically low-energy spin textures, such as a classical alternate ordering of spins. These will the be the starting point for i) out-of-equilibrium studies of magnetism, and ii) adiabatically driven approaches onto the strongly entangled ground state of the Heisenberg Hamiltonian. A second set of experiment, at a later stage in the thesis, will be to implement dissipative engineering tools on our quantum simulator: laser-induced photoassociation losses, which, in the Fermi Hubbard model, actually are expected to drive the system towards strongly correlated spin states. This scheme highlights promises of quantum simulators to engineer quantum correlated states in a manner robust to decoherence.

The project is a team effort on an experimental apparatus. The work will include technological developments on the machine, such as the installation of a high-resolution (1.2µm) imaging system with close to single-atom detectivity. The project is globally strongly connected to a second experiment in our group (quantum magnetism with dipolar chromium atoms), and theory activities in our group (P. Pedri). We are furthermore in a close collaboration with two theoretical groups supporting the routes towards creating quantum correlated states on our system: T. Roscilde, ENS Lyon, for adiabatic schemes; and L. Mazza, LPTMS, for dissipative engineering schemes.

Group webpage and recent publications : http://www-lpl.univ-paris13.fr/gqm/

Methods and techniques: Laser-cooled ultracold atoms: lasers, optics, optomechanics, electronics