Sujet de Thèse : **Investigating novel phases of matter with dipolar atoms loaded in optical lattices.**

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Loading quantum gases in periodic potentials made of optical lattices has allowed the ultracold atoms community to study the properties of quantum correlated systems. This is particularly interesting since the strong correlations in quantum systems are such that these systems are often intractable by classical computers. Thanks to the excellent degree of control in the cold atom experiments, these systems have thus become a prominent platform to realize quantum simulators relevant for quantum many-body physics. Amongst these systems, atoms interacting by dipole-dipole interactions are particularly interesting since the interaction is long-range and thus couples each atom to its many neighbors, thus offering a natural arena to study quantum many-body physics.

Our project focuses on the properties of chromium quantum gases, which interact strongly with each other through dipolar interactions due to the large electronic spin of this strongly magnetic atom. The long-range character of dipolar interactions ensures coupling of atoms loaded in different sites of an optical lattice (as we have shown in [1]), and can give rise to novel quantum phases and properties. We have recently studied the growth of entanglement in these spin systems after preparation in an out of equilibrium, uncorrelated initial state [2].

The aim of this thesis is to experimentally prepare and characterize novel phases and phenomena that arise due to the long-range character of the interaction. To this aim, we have recently setup a bichromatic optical lattice system, which creates an array of double potential wells. The bichromatic lattice was realized by combining standing waves using 532 nm and 1064 nm light.

During the thesis, we plan to explore two scenarios. In a first experiment, we plan to measure the spin of the atoms independently in the right wells and in the left wells, by making use of an energy tilt between the two sub-lattice sites. Measuring the spin state of atoms in every other site constitutes a bi-partite measurement, which is known to offer efficient ways to characterize entanglement in a large pure system.

In a second scenario, we will use the double-well lattice system to artificially create a checkerboard configuration where only every other site contains one atom. We will the study the stability of the phase after the double-well lattice system is transformed into a regular lattice. We envision that the artificially created checkerboard pattern will be stabilized because long-range interactions should prevent the atoms to occupy neighboring sites. We will also investigate whether supersolid behavior is then possible at low lattice depth, by testing whether superfluidity can coexist with the created checkerboard-like pattern.

[1] A. de Paz et al, Phys. Rev. Lett. 111, 185305 (2013)
[2] S. Lepoutre et al., Nature Communications, 10, 1714 (2019)

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