Sujet de Thèse : **Quantum correlations of dipolar atoms loaded in optical lattices.**

Laboratoire de Physique des Lasers
Directeur de Thèse Bruno Laburthe-Tolra, LPL, Laboratoire de Physique des Lasers
bruno.laburthe-tolra@univ-paris13.fr
01 49 40 33 85
co-direction : Laurent Vernac

Loading quantum gases in periodic potentials made of optical lattices has allowed many groups in 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.

Our group focuses on the magnetic properties of chromium quantum gases, which are quite original as high spin S=3 chromium atoms interact with each other through dipolar interactions. 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 characterize the dynamical growth of entanglement in this scenario, by using new experimental tools that will be developed in close collaboration with theoretical studies.

First, we plan to characterize the quantum fluctuations of the collective spin of the sample. The spin is measured by monitoring the population of the 7 different Zeeman states by means of a Stern-Gerlach separation in a magnetic field gradient. To measure quantum fluctuations, we will change the imaging system based on absorption imaging, in order to reduce the technical noise in our experiment, and perform shot noise limited measurements. This first part of the thesis will involve setting-up, charactering and optimizing a new laser which has recently been purchased by the group.

In addition, we will implement bichromatic optical lattices, which will create an array of double potential wells. In this system, the spin of the atoms can be measured independently in the right wells and in the left wells, because a controlled energy tilt can be applied 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. The bichromatic lattice will be realized by combining standing waves using 532 nm and 1064 nm light. The experiment will be performed in a regular lattice, and the bichromatic lattice that we will build will be used for measurement purpose only: we will use a combination of band excitations spectroscopy (which can resolve odd and even sites), and Stern-Gerlach measurements to perform bi-partite-measurements.

Our first experiments to investigate the growth of quantum correlations will be realized at large lattice depths, where each atom is pinned to a lattice site, and transport is forbidden. We then plan as well to study the growth of entanglement as a function of the lattice depth, and of the lattice filling. These controls will allow us reaching regimes where spin interactions and transport both come into play. Such a competition may lead to exotic magnetic and transport properties, as has been experimentally shown in a number of solid-state devices. As these phenomena correspond to theoretically open questions which are intractable with classical computers, our experiment should then reveal its potentiality as a quantum simulator.

[1] Nonequilibrium Quantum Magnetism in a Dipolar Lattice Gas , A. de Paz et al, Phys. Rev. Lett. 111, 185305 (2013)
[2] Out-of-equilibrium quantum magnetism and thermalization in a spin-3 many-body dipolar lattice system, S. Lepoutre et al., Nature Communications, 10, 1714 (2019)