Sujet de Thèse : **Adiabatic preparation of correlated states in a SU(N) Fermi lattice gas.**

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-encadrement : Martin Robert-de-Saint-Vincent

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. For example, loading atoms with fermionic statistics and s=1/2 in an optical lattice realizes the Hubbard model which is relevant to the quest to understand high-Tc superconductivity. Furthermore, atoms can carry a larger spin that s=1/2, so that the experiments with ultra-cold atoms can study situations beyond what has been achieved in condensed matter. These experiments can thus enlarge our comprehension of the appearance of collective phenomena in quantum systems.

Our experiments will be performed on many-body systems made of large-spin particles, which are expected to display many novel phenomena compared to the s=1/2 case. We will focus on our Strontium (Sr) machine which has been producing quantum degenerate Fermi gases since 2019. The inter-particle interactions of fermionic Sr atoms (with purely nuclear spin F=9/2) are short-ranged and independent of the spin projections of the colliding particles. This results in a SU(N) symmetry in the spin sector, and a wealth of new ordered and disordered quantum phases depending on the number of populated spin states N (≤10 for F=9/2) and the lattice geometry. Our aim is to study the conditions for the emergence of antiferromagnetic ordering when tuning the number of spin states. To do so our approach is to take profit of the narrow lines of Strontium (which can be used as clock transitions), that allow manipulating the spin of the atoms with little dissipation. We shall design original protocols and prepare alternating-spin textures, in order to study the low-energy behavior of our system.

The first step in the PhD program will be to load a polarized Fermi gas into the lattice structure. We shall then build a spin-dependent optical lattice using the strontium inter-combination line. Our set-up insures that the periodicity of this spin-dependent potential is close to half that of the optical lattice. Therefore, it will be possible to prepare alternating spin textures in the optical lattice, in a robust fashion. The first main result in the thesis will be to verify this approach, that in principle creates the lowest energy state of the system in presence of the spin-dependent potential.

The second main stage of the PhD will be dedicated to the adiabatic suppression of the spin-dependent potential. We will be able to verify whether the many-body state follows adiabatically this dynamical evolution, by reversing the whole scheme. The most interesting regime for many-body physics is when the spin-dependent energy is close to the super-exchange energy. We anticipate a phase transition between a glass state and a quantum anti-ferromagnet. The breakdown of adiabaticity will allow to precisely measure where this transition occurs.

The third step of the PhD (second year) will be to investigate the magnetic properties that are dynamically obtained when the spin-dependent potential is reduced as slowly as possible, to zero. Using the same laser system that is used to realize the spin-dependent potential, we can also probe the spin structure factor at twice the lattice periodicity. Therefore, this tool also allows to characterize the growth of anti-ferromagnetic correlations. This can be performed either in the original measurement basis, or after performing a global rotation of the spins, which can easily be performed by applying a homogeneous transverse magnetic field. Thus, all components of the alternate spin can be measured, including those not deterministically controlled in the initial preparation procedure, and it can be verified whether the collective spin approaches zero as expected for the ground state of the quantum SU(2) anti-ferromagnet at unit-filling.

The last step of the PhD, assuming the previous ones will have been successful, is to generalize these studies to more than two spin states. Then, our studies will allow investigating the most salient features of the SU(N) quantum magnets from a unique perspective. We thus expect that our approach will offer a new paradigm to generate, detect and manipulate entanglement in novel original large spin many-body quantum systems away from equilibrium, even in situations in which the equilibrium low-energy physics remains inaccessible in practice.