CONTRATS DOCTORAUX 2025
PROJET QUANTEDU

Sujet de thèse – Laboratoire de Physique des Lasers

Title: **Spin manipulations in a degenerate Fermi gas of strontium atoms**
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Ultracold atoms, produced by laser cooling techniques, offer a platform to explore quantum collective effects in the regime of quantum degeneracy. We perform experiments with degenerate Fermi gases of strontium 87 atoms – an exotic fermionic system, in that its spin-9/2 degree of freedom encompasses a large number (10) of Zeeman sublevels. This is both an opportunity to explore novel many-body effects (for example, antiferromagnets with a novel mechanism for frustration), and a “technological” opportunity to use quantum objects with a large internal Hilbert space, as a resource for quantum simulation, computation, or sensing.

We have developed original methods to manipulate and measure the atomic spins. We want now to demonstrate the production of quantum correlated states, by engineering either Hamiltonian or dissipative terms acting on the atoms. The Hamiltonian terms are best described by the Fermi-Hubbard model, for which the ground state is a quantum antiferromagnet. The dissipative control is counter-intuitive: it is a novel insight that couplings to an environment, typically destroying the manifestations of quantum physics, will in specific cases actually produce and stabilize quantum states with many-body correlations. This exciting point means that quantum phenomena may be harvested for quantum simulation or quantum sensing (clocks, atom interferometers) in a more robust manner than formerly thought.

Our methods rely on the original spectroscopic properties of strontium: narrow optical lines, relevant to optical atomic clocks, that we use to engineer highly selective spin manipulations. We will introduce a dissipation that selectively extracts pairs of atoms in spin-antisymmetric two-body wavefunctions. This results from photoassociation, controlled by laser, and the Pauli principle, that prevents identical fermions from being in the vicinity of each other. The effect is expected to pump the remaining atomic ensemble towards spin-symmetric entangled states. This effect can be harvested to stabilize quantum states in quantum simulation or computation schemes (e.g., stabilizing ferromagnetic states), or to produce states of interest to metrology. In particular, the stabilized states fully exclude the possibility of atoms meeting at short range, and thus suppress interaction shifts in an atom interferometer such as an optical atomic clock.

Thanks to the use of an atom with a large spin F=9/2, exotic collective states will be at reach beyond those usually drawn on a Bloch sphere. Our objectives in the years of this PhD will be to characterize these states, test their interest for metrology (e.g. optical clocks desensitized to interaction shifts), and explore new schemes to manipulate the quantum correlations and symmetries of the collective spin state.

The project is built in strong connection with two other experiments in our group (quantum magnetism with dipolar chromium atoms; superradiant optical clock with strontium atoms), and in-house theory activities (P. Pedri). We are furthermore closely collaborating with theoretical groups, in particular L. Mazza, LPTMS, on dissipative dynamics, and T. Roscilde, ENS Lyon, on Hamiltonian dynamics.

Group webpage: https://gqm.lpl.univ-paris13.fr/