M2 Internship / PhD offer

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Spin manipulations in a degenerate Fermi gas of strontium atoms

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. Our experiment will now enter a new phase, where collective effects are evidenced. We want 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 indeed 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.

The implementation of our ideas will rely on the original spectroscopic properties of strontium: narrow optical lines, relevant to optical atomic clocks, and that in our case we use to engineer highly selective spin manipulations. In particular, we will in the short term 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.

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; superradiance 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/

Possibility to go on with a PhD ? YES
Envisaged fellowship ? Ecole Doctorale, DIM Quantip