PhD Position

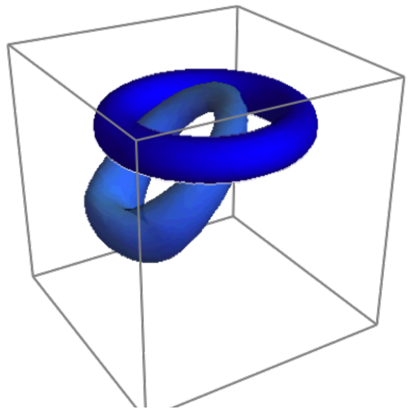
Quantum control of Rydberg states for metrology of classical fields

Laboratoire Kastler Brossel, Collège de France, Paris
Cavity Quantum Electrodynamics group (www.cqed.org)

Supervisors:
Michel Brune (michel.brune@lkb.ens.fr)
Sébastien Gleyzes (gleyzes@lkb.ens.fr)

Thesis possibility after internship: **YES**
Funding: **EU ITN grant (if eligible)**

Scientific context:



Wavefunction of the Schrödinger cat state of the Rydberg atom. The electron is in a quantum superposition of two classical trajectories (dark blue and light blue) with very different electric dipole, making the state highly sensitive to the electric field.

Rydberg atoms are highly excited atomic levels for which the electron is far away from the nucleus and only sees the 1/r-potential of the atomic core. The spatial extension of the electron wavefunction, thousands of time larger than that of ground state atoms, make them of great interest to be used as a quantum probe of the electric or magnetic field. Starting with the atom in a semi-classical states for which the wavefunction is localized along one of the Kepler orbit [1] one can use a combination of microwave and radiofrequency pulses to induce non-classical dynamics that drive the electron in very non-classical states [2], similar to Schrödinger cats, quantum superpositions of two classically distinct classical orbits. Since the electron is at the same time on two trajectories with very different electric dipoles, the relative phase of the quantum superposition is extremely sensitive to the electric field, making these states ideally suited for quantum metrology. It is possible to reach a sensitivity much below the Standard Quantum Limit (SQL), defined as the best sensitivity that can be achieved using classical methods. We have demonstrated recently that we could reach an electric field sensitivity corresponding to the detection, in one second, of a single elementary charge at a distance of 0.7 mm [3].
However, in our previous experiments, the evolution of the atom was restricted to a subspace of the Rydberg manifold, and the states that we prepared were sensitive to both electric and magnetic field variations, leading to uncontrolled sources of decoherence.

[1] A. Signoles, E.K. Dietsche, A. Facon, D. Grosso, S. Haroche, J.-M. Raimond, M. Brune et S. Gleyzes, Coherent transfer between low-angular momentum and circular Rydberg states, Phys. Rev. Lett. 118, 253603 (2017).
[2] A. Signoles, A. Facon, D. Grosso, I. Dotsenko, S. Haroche, J.-M. Raimond, M. Brune et S. Gleyzes, Confined quantum Zeno dynamics of a watched atomic arrow, Nature Physics 10, 715–719 (2014)
[3] A. Facon, E. K. Dietsche, D. Grosso, S. Haroche, J.-M. Raimond, M. Brune et S. Gleyzes, A sensitive electrometer based on a Rydberg atom in a Schrödinger cat state, Nature, 532, 262 (2016)

PhD Thesis:

The purpose of the PhD thesis will be to extend this work to prepare quantum states of the Rydberg atom that allow us to perform Heisenberg limited measurement of either the electric field or the magnetic field separately. To do so, we will no longer restrict the evolution of the atom to a subspace of the Stark levels, but explore the full Rydberg manifold. In close collaboration with the team of Christiane Koch at the University of Kassel, we will use optimal control to generate faster and more elaborate schemes in order to efficiently prepare the state of the probe atom, in a way that will be more immune to the electric noise of the environment. These methods should drastically improve the measurement bandwidth of our Rydberg probe. Combined with trapping techniques, this will open the way to using the atom as a quantum sensor to characterize more complex systems, like solid-state device.