PhD Position

Quantum simulations with laser-trapped circular Rydberg atoms

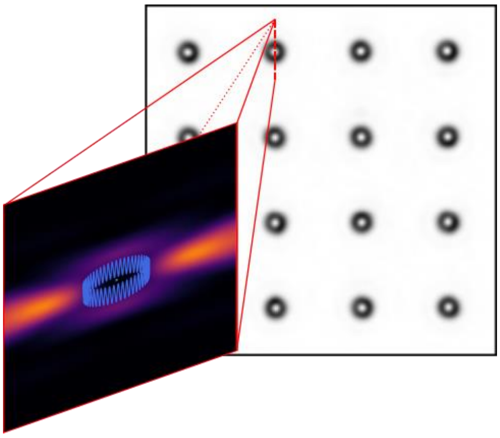
Laboratory: Laboratoire Kastler Brossel
Location: Collège de France, Paris **Website:** www.cqed.org

Supervisors:
Clément Sayrin (clement.sayrin@lkb.ens.fr), Michel Brune (michel.brune@lkb.ens.fr)

Thesis possibility after internship: YES **Funding:** YES

Scientific context:

The dynamics of a quantum system, particularly in condensed matter, can be utterly complex, due to the huge size of its Hilbert space. **Quantum simulation** aims at emulating these dynamics with a simpler system, of which all parameters are under control and on which all relevant observables can be measured. Quantum simulation is the focus of an intense activity, particularly with cold atoms. **Rydberg atoms**, i.e. atoms excited to high-principal-quantum-number levels, are particularly well suited to the quantum simulations of interacting spins. They can be prepared from arrays of single atoms, laser-trapped in optical tweezers. The strong dipole-dipole or van der Waals interactions between Rydberg atoms, even at a few microns, then enable the quantum simulation of interacting spins.



Individual circular Rydberg atoms are trapped in an array of optical bottle beams.

Existing experiments, however, are limited by the few-100µs lifetime of the laser-accessible Rydberg levels, and by the fact that the Rydberg atoms have not been laser-trapped. Quantum simulations are, thus, limited to a few microseconds, corresponding to a few interaction cycles only. We propose to explore an alternate, promising route, using **circular Rydberg atoms** [1], namely Rydberg atoms with maximal orbital momentum. These levels show a natural lifetime of a few 10ms, can be laser-trapped in light intensity minima with no reduction of their lifetime, and still benefit from the strong interactions of ''usual'' Rydberg levels. By preparing a defect-free array of laser-trapped circular Rydberg atoms, we will be able to bring quantum simulations in unprecendented regimes: Our platform will enable the simulation of long long-term dynamics of the system, such as thermalization after a quench of the Hamiltonian.

PhD Thesis:

The building blocks of the experiment have been recently demonstrated in a former version of the experimental setup: preparation of circular Rydberg atoms out of a gas of cold atoms [2] and 2D laser-trapping of the circular-Rydberg atoms [3]. We have since then developed a room temperature setup where we can prepare large arrays of laser-trapped Rubidium atoms in their ground states and where we should in the near future demonstrate laser-trapping of circular Rydberg atoms in optical tweezers. In parallel, a cryogenic setup, necessary to benefit from the long lifetime of the circular levels, has been developed and will be assembled in the coming months.

During the PhD work, **the proposed quantum simulator will be realized and operated** in the cryogenic environment. On the way towards genuine quantum simulations, we will develop novel tools to optically and selectively manipulate or detect the circular atoms of the array. Collaborations with theoretical teams will be developed to identify the condensed-matter or more general problems best suited to our platform. The PhD student will actively participate to all these tasks. Quantum simulations of the dynamics of interacting spins in regimes beyond the reach of numerical simulations is the main objective of the proposed thesis.

References:

[1] T. L. Nguyen *et al.*, PRX 8, 011032 (2018)
[2] T. Cantat-Moltrecht *et al.*, PRR 2, 022032(R) (2020)
[3] R. Cortiñas *et al.*, PRL 124, 1123201 (2020)