PhD Position

Quantum simulation with circular Rydberg atoms in optical tweezers

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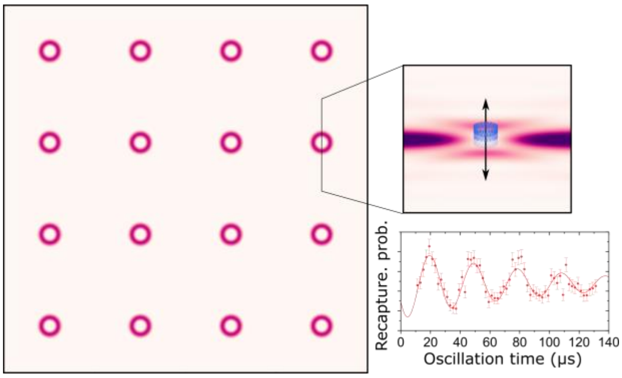
Scientific context:

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 **Rydberg atoms**, i.e., atoms excited to high-principal-quantum-number levels. They can be prepared from arrays of single atoms, laser-trapped in optical tweezers. The strong interactions between Rydberg atoms, even a few microns apart, then enable the quantum simulation of interacting spins.



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

Existing experiments are limited by the few-100µs lifetime of the laser-accessible Rydberg levels and by the fact that the Rydberg atoms are not laser-trapped. Quantum simulations are, thus, limited to a few microseconds, corresponding to a few interaction cycles only. We propose to lift these limitations by laser-trapping, in a cryogenic environment, individual **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.

We have recently demonstrated the most fundamental building blocks of this project. In a UHV chamber operated at room-temperature [2], we prepare defect-free arrays of laser-trapped Rubidium atoms in their ground states. We can then laser trap the atoms promoted to circular Rydberg atoms in an array of hollow optical tweezers, so-called optical bottle beams (see Figure).

PhD Thesis:

To fully benefit from the long lifetimes of the circular Rydberg atoms, we need to transfer the existing setup to a cryogenic environment. We will make use of an operating He cryostat inside which we have prepared circular Rydberg atoms out of a gas of cold atoms [3] and laser-trapped them in two dimensions [4].

During the PhD work, **the proposed quantum simulator will be realized and operated** in this 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] B. Ravon et al., in preparation (2022)
[3] T. Cantat-Moltrecht *et al.*, PRR 2, 022032(R) (2020)
[4] R. Cortiñas *et al.*, PRL 124, 1123201 (2020)