Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

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Thesis possibility after internship: YES
Funding: YES

Quantum simulation with Strontium circular Rydberg atoms

Summary

Rydberg atoms arrays are one of the most promising platforms for quantum simulation. Ground-state atoms trapped in optical tweezers are arranged in an arbitrary geometry before being transferred into low-angular momentum Rydberg states using laser pulses. Once in a Rydberg level, the atoms interact with each other by dipole-dipole coupling, making it possible to simulate the dynamics of arbitrary Hamiltonians. However, the relatively short lifetime (in the 100 μs range) of low-angular momentum Rydberg atoms currently limits either the number of atoms or the duration of the simulation in order to ensure that none of the atom decays during the experiment.

To overcome this issue, we propose to build a quantum simulator based on circular states of strontium. Circular Rydberg atoms have a much longer lifetime (on the 10 ms range), opening the way to the study of quantum dynamics on a much longer time scale [1]. As an alkaline-earth element, strontium atoms possess two valences electrons, leaving an optically active ionic core once one of the electrons is promoted to a Rydberg state. The ionic core transitions can be used to trap the Rydberg atom, or to cool its motion [2]. This opens very exciting prospects for quantum simulation, where the atomic motion can be the limiting factor preventing observation of the long-term dynamics of the system. Furthermore, our group has recently demonstrated that the electrostatic coupling between the two valence electrons induces an energy shift of the ionic core levels that depends on the state of the Rydberg electron [3]. This opens the way to implement a quantum non demolition measurement of the circular state using the ionic core fluorescence in order to optically detect a Rydberg atom, with very interesting perspective for both quantum simulation and quantum metrology.

Project

The purpose of the proposed PhD work is to join our ongoing efforts to build a new experimental platform for manipulating arrays of circular strontium atoms in a cryogenic environment. Our team has recently succeeded in trapping individual ground-state strontium atoms in optical tweezers. The next steps are to transfer strontium atoms into the circular state and recapture them using tweezers tuned close to the optical transition of the ionic core. We will then demonstrate that it is possible to measure the state of the Rydberg atom using selective fluorescence of the second valence electron. During their master's internship, the student will participate the integration of the setup in a new cryogenic environment and set up a new laser system to improve the fidelity of the preparation of the circular state.

[1] T. L. Nguyen *et al*, Towards Quantum Simulation with Circular Rydberg Atoms, Phys. Rev. X **8**, 011032 (2018)
[2] L. Lachaud *et al*, Slowing Down a Coherent Superposition of Circular Rydberg States of Strontium, Phys. Rev. Lett. **133**, 123202 (2024)
[3] A. Muni *et al*, Optical coherent manipulation of alkaline-earth circular Rydberg states, Nat. Phys. **18**, 502 (2022)

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: YES Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: YES