Master in Photonics – "PHOTONICS BCN"
Master ERASMUS+ "EuroPhotonics"

MASTER THESIS PROPOSAL

Dates: April 2021 - September 2021

Laboratory: Ultracold Quantum Gases group
Institution: ICFO – The Institute of Photonic Sciences
City, Country: Castelldefels (Barcelona), Spain

Title of the master thesis: Towards degenerate Fermi gases of strontium atoms

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Keywords: ultracold atoms, quantum optics, atomic physics, degenerate Fermi gases, Bose-Einstein condensates, cooperative effects in atom-photon scattering

Summary of the subject:

In recent years, ultra-cold atomic gases have emerged as a novel platform for the study of quantum many-body systems. Exploiting these gases, it is possible to synthesize quantum matter of highly controllable properties (interactions, dimensionality, potential landscape, etc.) in table-top experiments [1]. In our group, we use them to explore experimentally collective phenomena originally studied in condensed-matter physics, such as superfluidity, supersolidity or magnetism, and to realize completely new types of many-body systems of potential use for modern quantum technologies.

On the one hand, ultracold quantum gases allow us to realize the cleanest quantum "materials" that can be studied in the laboratory. To this end, quantum degenerate gases are trapped in the periodic potential created by interfering laser beams, so-called optical lattices. Replacing the electrons by atoms and the crystalline structure of solids by a crystal of light enable us to "synthesize" artificial materials of highly-tunable properties and in parameter regimes inaccessible in solid-state platforms. Our goal is to exploit these systems to solve long-standing problems of condensed matter physics, an approach that can be seen as an analogue version of a quantum computer and is named "quantum simulation" following the original vision of Richard Feynman [1, 2].

On the other hand, periodically ordered arrays of atoms coupled to resonant light constitute a new type of quantum light-matter interface where collective effects in atom-photon scattering could be exploited as a new many-body resource to improve existing quantum technologies. In particular, more powerful quantum memories, atomic clocks of improved accuracy, could potentially be created exploiting such many-body effects. [3].

Our group is currently setting-up at ICFO a new experimental apparatus specifically adapted to these goals. As atomic species we use strontium, an alkali-earth atom with two electrons in its outer shell. Strontium has both fermionic and bosonic isotopes, which make it ideal for quantum simulation, and a rich optical spectrum with narrow transitions well suited to realize quantum light-matter interfaces. Whereas we have recently succeeded in creating laser-cooled strontium clouds, several experimental steps still need to be implemented before reaching quantum degeneracy and performing the planned quantum simulation and quantum optics experiments.

We propose a very experimental internship, during which the candidate will work together with the team (two PhD students and two postdocs) on the final construction stages of the experimental apparatus and the achievement of quantum degeneracy. This will provide him/her the unique opportunity of contributing to the production of the first degenerate Fermi gas in Spain. Specifically, the candidate will be in charge of fully developing a subpart of the experimental apparatus. Depending on his/her specific skills and interests, and on the advancement of the experiment, possible projects include the setup of frequency stabilized lasers for the laser cooling and manipulation of strontium, the generation and stabilization of magnetic fields for manipulating the atomic energy levels, and the design, construction and characterization of a high-resolution imaging and manipulation system.

For further information, references, and a list of former Bachelor and Master projects completed in the group, please consult www.qge.icfo.es

[1] I. Bloch, J. Dalibard, and S. Nascimbène, Nature Physics **8**, 267 (2012).
[2] T. Esslinger, Annu. Rev. Condens. Matter. Phys. **1**, 129 (2010).
[3] A. Asenjo-Garcia, M. Moreno-Cardoner, A. Albrecht, H. J. Kimble, and D. E. Chang, "Exponential Improvement in Photon Storage Fidelities Using Subradiance and "Selective Radiance" in Atomic Arrays", Phys. Rev. X **7**, 031024 (2017).

Additional information:

* Required skills: We are looking for candidates with a good background in quantum optics, and atomic physics, and a strong motivation for setting up and conducting challenging experiments in a team. Previous experimental experience in optics, electronics, and programming would be very beneficial.
* Miscellaneous: The project will be carried out in a team of 4-5 people. The candidate will have his/her own project, but will participate in all group activities in order to maximize the learning experience. He/she will be trained in a broad range of cutting-edge experimental techniques (optics, electronics, ultra-high vacuum technology, and computer control).