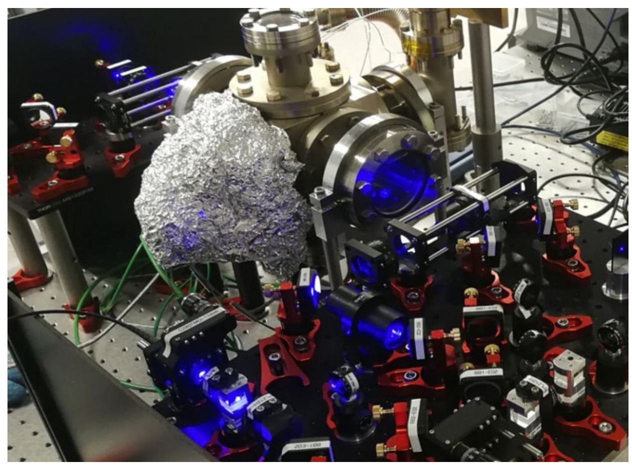
- **Name and affiliation of supervisor:** Supervisor: Leticia Tarruell, ICFO; Co-supervisor: Antonio Rubio, ICFO
- **Project title:** Characterization and transverse laser cooling of a strontium atomic source
- **Project description:**

Ultracold atomic gases have emerged in the last two decades as a highly versatile platform for the study of quantum many-body physics. Their control, which uses external magnetic fields and laser-based optical potentials, allows one to tune the dimensionality of the system, its interactions, and bring it to the strongly interacting regime. This has enabled the realization of fundamental models of condensed-matter physics such as the Hubbard model, originally conceived for the description of correlated electrons in solids.

In our lab at ICFO, we work with degenerate quantum gases of atomic strontium. Strontium belongs to the earth-alkaline elements and displays many exciting properties for its use in the quantum simulation of Hubbard models. For example, it features a fermionic isotope, strontium-87, with a nuclear spin of $I = 9/2$, i.e., with 10 different spin states. This allows the study of so-called SU(N) quantum magnetism, which extends beyond the SU(2) magnetism of pure electrons in solids.

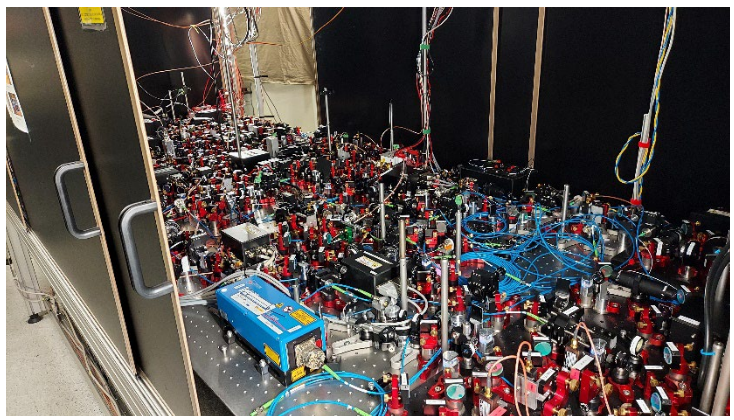


A central element of the experimental apparatus in such labs is the atomic source. It is desirable to have a high-flux atomic source, since it allows to cool and trap large atomic clouds. Designing such a source for strontium is challenging, since it must operate at temperatures above 500 ºC, and requires nozzles based on microcapillary arrays.

In this project, a master student will perform an in-depth characterization of the properties of an atomic beam coming from an already built atomic source. This will involve the experimental study of the system via laser spectroscopy as well as the theoretical modelling of the atomic flux. The student will acquire experimental skills on optical laser setups, ultra-high vacuum and atomic physics. The improvements realized in the project will later be introduced to the main experiment, where they will provide an excellent starting point for the preparation of ultracold quantum gases of strontium.

- **Name and affiliation of supervisor:** Supervisor: Leticia Tarruell, ICFO; Co-supervisor: Ramón Ramos, ICFO
- **Project title:** Exploring supersolidity in a spin-orbit coupled mixture of potassium Bose-Einstein condensates
- **Project description:**

Ultracold atomic gases have become an ideal platform for exploring novel quantum phases of matter thanks to the excellent control that they provide over the system. This allows one to engineer complex quantum many-body systems described by Hamiltonians that are perfectly well defined, and whose parameters (interatomic interactions, dispersion relation of the particles, system geometry, etc.) can be tuned experimentally almost at will. One intriguing phase that has fascinated physicist for decades is the supersolid: a counterintuitive quantum state of matter that spontaneously breaks translational invariance, developing crystalline structure like a solid, while simultaneously displaying frictionless flow like a superfluid.



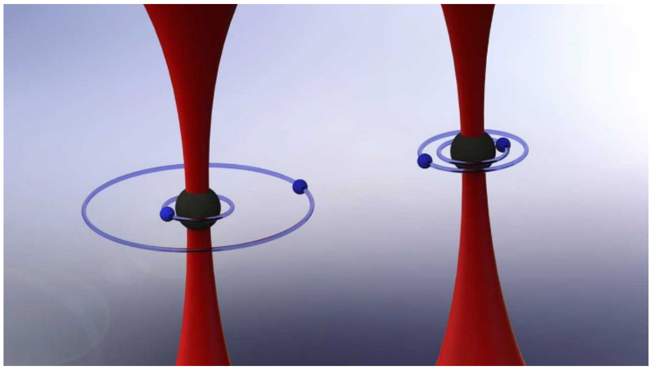
Our group at ICFO is currently attempting to realize this phase in one of its laboratories. The idea is to use a mixture of Bose-Einstein condensates, where interactions can be broadly tuned by controlling the external magnetic field, and subject them to a synthetic spin-orbit coupling obtained by dressing the atoms with light. Supersolidity has been predicted in this system for a certain range of parameters, but a complete characterization of the phase and of its intriguing excitation spectrum is still lacking.

The goal of this project will be to support the observation and characterization of supersolidity in our experiment. The master student will integrate into the potassium team and will actively participate in the main experiment. Depending on the experimental circumstances, the student will develop subprojects such as magnetic field monitoring and stabilization, the development of an improved laser source for Raman dressing, the correction of aberrations in the imaging system, or the contribution to the operation of the experiment and the analysis of the data. During this time, the student will develop experimental and theoretical skills in laser cooling, atomic physics, laser sources, optics and electronics.

- **Name and affiliation of supervisor:** Supervisor: Leticia Tarruell, ICFO
- **Project title:** A new experimental apparatus for quantum simulation and computing with arrays of trapped Rydberg atoms
- **Project description:**

The last years have seen the emergence of a new platform for quantum technologies based on ultracold neutral atoms. It consists of arrays of single atoms trapped using optical tweezers, which allows one to arrange them with almost arbitrary geometries. The atom positions are fixed by the traps, but they can be made to interact by exciting them to Rydberg states. Rydberg atom arrays are becoming a competitive platform for digital quantum computing. Compared to trapped ions or superconducting qubits, the setups are relatively simple, the geometry and connectivity can be adjusted quite easily, and there is a clear roadmap to scale up their size. Moreover, these systems constitute an ideal platform for the quantum simulation of spin Hamiltonians, which can be used to solve both fundamental physics problems and to address practical optimization tasks.

In our group at ICFO, we are just starting the design and construction of a new Rydberg atom array experiment for quantum simulation. As atomic species we will use strontium, which is an alkali-earth atom with two valence electrons in its outer shell. This brings several technical advantages, such as better cooling and detection efficiencies, easier excitation to the Rydberg state, and the possibility to trap the Rydberg states with the non-excited electron. Our long-term plan is to use our atom arrays to address hard quantum problems of quantum magnetism, and to exploit them to realize lattice gauge theories originally proposed in the high-energy physics context.



In this project, the master student will join a completely new laboratory and will have the opportunity to participate in the design and construction of the experimental apparatus from the very beginning, together with a PhD student. Depending on the advancement of the project, possible tasks are the construction of a laser system for the laser cooling of strontium, the frequency stabilization of various lasers on the strontium atomic transitions, the design, construction and test of magnetic field coils, the design, assembly and test of electrodes to control the external electric fields, etc. This will be a very experimental project, during which the student will be exposed to a broad range of atomic physics concepts and experimental techniques (optical laser setups, ultra-high vacuum, spectroscopy, electronics, etc.) by joining an emergent research field.