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International Master in Photonics

## **MASTER IN PHOTONICS – “PHOTONICS BCN” ERASMUS+ “EUROPHOTONICS”**

### **MASTER THESIS PROPOSAL**

**Dates: April - September 2019**

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

**Title of the master thesis: Experimental quantum many-body physics with ultracold atoms**

**Name of the master thesis supervisor: Leticia Tarruell**

Email address : [leticia.tarruell@icfo.es](mailto:leticia.tarruell@icfo.es)

Phone number : 935542254

Mail address : ICFO, Av. Carl Friedrich Gauss, 3, 08860 Castelldefels (Barcelona)

**Keywords : ultracold atoms, quantum optics, atomic physics, Bose-Einstein condensates, cooperative atom-photon scattering**

**Summary of the subject (maximum 1 page) :**

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. In our group, we use them to explore experimentally collective phenomena originally studied in condensed-matter physics, such as superfluidity, superconductivity or magnetism.

Our group has currently a fully operational quantum gas apparatus. There, we have recently focused on the study of ultra-dilute quantum liquids obtained from mixtures of potassium Bose-Einstein condensates [1,2]. These liquids are eight orders of magnitude more dilute than liquid helium, and form droplets that are self-bound in the absence of any external confinement. Their existence is a direct manifestation of quantum fluctuations in very weakly interacting systems, which makes them ideal testbeds for understanding the role of quantum correlations in quantum many-body physics. We are currently pursuing the study of these liquids, exploring how the behaviour of the system is modified when, instead of using a mixture of two Bose-Einstein condensates, each of the particles is put in a coherent superposition of two internal atomic states.



At the end of 2018, we started the design and construction of a second experimental apparatus. In this new project, we aim at exploring many-body systems made of atoms and photons. To this end, we plan to realize closely-spaced arrays of strontium atoms trapped in optical tweezers and coupled to resonant light. This new type of quantum light-matter interface opens interesting possibilities for the realization of improved quantum memories and atomic clocks, exploiting cooperative effects on the atom-photon scattering [3]. Furthermore, it constitutes a new platform for realizing quantum spin models and strongly interacting photon “gases”.

We offer Master thesis projects on the two experiments. They will be focused on the design and development of a sub-system to be integrated in the main experimental apparatus. Interested candidates should contact Leticia Tarruell as soon as possible to define the exact project. For further information, references and a list of former Bachelor and Master projects please consult [www.qge.icfo.es](http://www.qge.icfo.es)

- [1] C. R. Cabrera, L. Tanzi, J. Sanz, B. Naylor, P. Thomas, P. Cheiney, L. Tarruell, “Quantum liquid droplets in a mixture of Bose-Einstein condensates”, [Science 359, 301-304 \(2018\)](#)
- [2] P. Cheiney, C. R. Cabrera, J. Sanz, B. Naylor, L. Tanzi, L. Tarruell, “Bright soliton to quantum droplet transition in a mixture of Bose-Einstein condensates”, [Phys. Rev. Lett. 120, 135301 \(2018\)](#)
- [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, atomic physics or condensed-matter physics, and a strong motivation for setting up and conducting challenging experiments in a team of three to four people.

\* Miscellaneous: We offer training in a broad range of cutting-edge experimental techniques (from optics, electronics, ultra-high vacuum technology and computer control to quantum state engineering), as well as in theoretical atomic, quantum, statistical, and condensed matter physics. The candidate will have his/her own project, but will participate in all group activities in order to maximize the learning experience.