Master 2: ***International Centre for Fundamental Physics***

INTERNSHIP PROPOSAL

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Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: Doctoral school

Correlations between individual atoms in the critical regime of the Mott transition

Many-body quantum states and dynamics can in principle be characterized by measuring all correlation functions between individual particles. In practice, accessing correlations at the single particle level turns out difficult and only a few platforms – such as trapped ions, superconducting qbits or quantum gases – offer this possibility. In our lab, we are pursuing this line of research with an original approach consisting in measuring correlations between individual atoms in the momentum (or velocity) space. To do so, we have built a dedicated apparatus that produces Bose-Einstein condensates of metastable Helium atoms [1]. Our detection method is based on the special properties of metastable Helium atoms: the large internal energy (20 eV) stored in the metastable state allows for reconstructing the three-dimensional momentum coordinates of individual atoms [2].

By loading atoms into a 3D optical lattice (a standing light wave along the 3 directions of space) one creates a periodic potential for the atoms and, effectively realizes a crystal of light. This is the starting point to implement a series of many-body Hamiltonians inspired by solid-state physics. Doing so, we investigate the Bose-Hubbard phase diagram, which exhibits a quantum phase transition from a superfluid state to the Mott insulator. Using our quite unique probe we have recently studied two-body and three-body correlations in the Mott insulator state [3] and in strongly interacting superfluids [4], far from the Mott transition.

During the internship, the candidate will investigate the critical regime of the Mott transition, where multi-particle correlations are expected, although no observation was reported so far. A central objective is to unveil the presence of many-body correlations whose statistics is non-Gaussian. This aim touches upon fascinating questions one may ask about the realization of a quantum phase transition in an experiment: what is the role of the inhomogeneous trap, the finite size of the system and the non-zero temperature on the properties of the critical regime? is it possible to extract information on entanglement from the measurement of many-body correlations?

The apparatus is currently running with the bosonic species Helium-4 but we have started building the lasers to cool the fermionic species Helium-3. Being able to load fermions into the 3D lattice will open novel and fascinating scientific perspectives. This new direction will be at the center of a PhD thesis following the internship.

[1] Q. Bouton, R. Chang, L. Hoendervanger, F. Nogrette, A. Aspect, C. Westbrook and D. Clément, **Phys. Rev. A 91**, 061402(R) (2015).
[2] H. Cayla, C. Carcy, Q. Bouton, R. Chang, G. Carleo, M. Mancini and D. Clément, **Phys. Rev. A 97** 061609(R) (2018).
[3] C. Carcy, H. Cayla, A. Tenart, A. Aspect, M. Mancini, D. Clément, **Phys. Rev. X 9** 041208 (2019).
[4] H. Cayla, S. Butera, A. Tenart, G. Hercé, M. Mancini, A. Aspect, I. Carusotto, D. Clément, to appear in **Phys. Rev. Lett.** (2020).

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: NO