Spécialité de Master « Optique, Matière, Paris »

Stage de recherche (4 mois minimum, à partir de début mars)

Proposition de stage

Responsable du stage /			
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Lieu du stage / *internship place*: Institut d'Optique Graduate School			

Momentum correlations between individual atoms across the Mott transition

In principle, many-body quantum states and dynamics can be investigated and characterized by measuring all correlation functions between individual quantum particles. In practice, accessing correlations at the single particle level turns out extremely difficult and only a few platforms – trapped ions, superconducting qbits or quantum gases – offer the possibility of a controlled experimental implementation. In our lab, we are pursuing this line of research with an original approach consisting in measuring correlations between individual atoms in the momentum (velocity) space. To do so, we have built an apparatus that produces Bose-Einstein condensates of metastable Helium atoms with a high-duty cycle of 6 seconds [1]. We have implemented a unique detection method 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]. This detection method provides a unique probe of interacting quantum gases, as illustrated by our investigation of the phenomenon of quantum depletion [3].

To attack open research questions on many-body physics inspired by solid-state physics, we have recently installed a 3D optical lattice on the experiment. An optical lattice consists in a standing light wave that creates a periodic potential for the atoms, effectively realizing a crystal of light for the quantum gas. By loading Bose-Einstein condensates in the 3D lattice we have shown to measure the momentum distributions of strongly interacting lattice superfluids and monitored the superfluid-to-normal phase transition [4].

During the internship, the candidate will participate to the investigation of a many-body quantum phase transition: the superfluid-to-Mott transition. In the quantum critical regime of the Mott transition, large two-particle correlations are expected in the momentum space but there has been no direct observation reported so far. These correlations (two particles with opposite momenta) originate from the quantum depletion in the superfluid state and particle-hole excitations in the Mott state. Our goal is to observe and characterize them (amplitude and shape of the correlation functions). In addition, the candidate will be offered the possibility to set up a new optical table whose aim is to provide the laser beams to laser cool the fermionic species Helium-3. The apparatus has been running only with the bosonic species Helium-4 so far but 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] F. Nogrette, D. Heurteau, R. Chang, Q. Bouton, C. I. Westbrook, R. Sellem and D. Clément, **Rev. Scient. Instrum. 86**, 113105 (2015).
[3] R. Chang, Q. Bouton, H. Cayla, C. Qu, A. Aspect, C. Westbrook and D. Clément, **Phys. Rev. Lett. 117,** 235303 (2016).
[4] H. Cayla, C. Carcy, Q. Bouton, R. Chang, G. Carleo, M. Mancini and D. Clément, In preparation (2017).

Ce stage pourra-t-il se prolonger en thèse ? *Possibility of a PhD* **? : Yes**			
Si oui, financement de thèse envisagé/ *financial support for the PhD***: Doctoral school or ANR Funding**			
Lumière, Matière, Interactions	**X**	Lasers, Optique, Matière	**X**