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 in the quantum critical regime of the Mott transition

Many-body quantum states and dynamics can in principle be characterized by measuring all correlation functions between individual quantum particles. In practice, accessing correlations at the single particle level turns out difficult and only a few platforms – 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 (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]. This unique probe allows us to investigate interacting quantum gases, as illustrated by our work on the quantum depletion [3].

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 for the quantum gas. This is the starting point to implement a series of many-body Hamiltonians inspired by solid-state physics. Doing so, we have investigated the Bose-Hubbard phase diagram in momentum space, from the superfluid-to-normal phase transition [4] to the quantum phase transition towards the Mott insulator [in preparation].

During the internship, the candidate will investigate the quantum critical regime of the Mott transition, where 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. The candidate will also be offered the possibility to work with one-dimensional gases to measure the celebrated contact of 1D bosons. In collaboration with theory colleagues we have characterized the contact in different regimes of interaction and temperature [5]. The experimental testing of these predictions on our apparatus should be rather straightforward.

The apparatus is running with the bosonic species Helium-4 but we are currently 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] 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, **Phys. Rev. A 97** 061609(R) (2018).
[5] H. Yao, D. Clément, A. Minguzzi, P. Vignolo and L. Sanchez-Palencia, **arXiv preprint** 1804.04902 (2018).

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**