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Observation of pairs of atoms at opposite momenta in the quantum depletion of an interacting Bose gas

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Antoine Ténart [a], Gaétan Hercé [a*], Jan-Philipp Bureik [a], Alexandre Dareau [a], David Clément [a]

a. Laboratoire Charles Fabry, Institut d'Optique Graduate School,91120 Palaiseau, France

* email : gaetan.herce@institutoptique.fr

Quantum fluctuations play a central role in the properties of quantum matter. In non-interacting ensembles, they manifest as fluctuations of non-commuting observables, quantified by Heisenberg inequalities. In the presence of interactions, additional quantum fluctuations appear, from which many-body correlations and entanglement originate. In the context of many-body physics, the Bogoliubov theory provides us with an illuminating microscopic picture of how this occurs for weakly-interacting bosons, with the appearance of the quantum depletion formed by pairs of bosons with opposite momenta [1,2]. This conceptually simple example yet lacks experimental confirmation. Exploiting the single particle resolution of our metastable Helium detector [3-5], we report the direct observation of pairs of atoms with opposite momenta in the depletion of an equilibrium interacting Bose gas. We show that the pair correlation signal rapidly drops as temperature rises, as expected for the quantum depletion. A quantitative study of the atom-atom correlations, both at opposite and close-by momenta, allows us to fully characterise the quantum correlations in the interacting Bose gas. Our results demonstrate how an equilibrium many-body quantum state acquires specific correlations - those of two-mode squeezed states here - as a result of the interplay between quantum fluctuations and interactions. In addition, the measured amplitudes of the correlation signals reveal sub-poissonian number differences between modes at opposite momenta, an important step towards characterising entanglement in equilibrium many-body quantum states.

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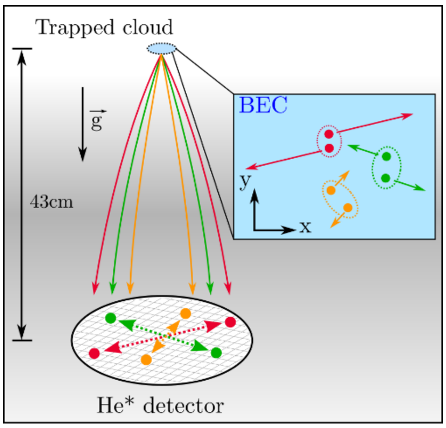

Figure 1 : Schematics of the experiment. A gas of weakly-interacting 4He* atoms is released from a lattice trap and undergoes a free fall towards the He* detector where atoms are detected individually. The inset depicts the many-body ground state which contains a BEC (uniform light blue color) and the quantum depletion made of pairs of atoms with opposite momenta (colored circles). When the trap is abruptly switched off, the many-body ground state is projected onto the momentum basis and the atom pairs fall onto the He* detector with opposite momenta (atoms from the BEC are not shown on the detector).