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Strongly-interacting Bose gases and the fate of the Bogoliubov's pairs at large interactions

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A cornerstone in the description of quantum fluids is the Bogoliubov theory used to explain the emergence of superfluidity in ensembles of weakly-interacting bosons. At the microscopic level, this theory predicts that interactions deplete the condensate through the formation of pairs of bosons with opposite momenta, known as quantum depletion. Exploiting the capability to detect individual metastable Helium atoms in momentum space [1], we confirmed this microscopic prediction and reveal linearised quantum fluctuations induced by interactions at equilibrium [2].
Introduced in the context of liquid Helium, Bogoliubov's theory is yet inapplicable when interactions deplete too strongly the condensate and the linearisation of quantum fluctuations is no longer valid. This prompts the question of what happens to the Bogoliubov's pairs and how to describe interacting Bose gases in a regime where the condensate is strongly depleted.
Varying the amplitude of a 3D optical lattice [3], we studied momentum-correlated subsets of atoms in the strongly-interacting regime. We observed a non-monotonic variation of the number of Bogoliubov's pairs as a function of interactions [4], which is further confirmed by numerical simulations on the model of quantum rotors. We introduce a simple microscopic picture supporting our observations, a BBGKY-type hierarchy of momentum-correlated subsets, and provide new insights into the description of strongly-interacting bosons.

[1] H. Cayla et al. Physical Review A 97, 061609(R) (2018); A. Tenart et al. Physical Review Research 2, 013017 (2020).
[2] A. Tenart et al. Nature Physics 17, 1364 (2021).
[3] C. Carcy et al. Physical Review Letters 126, 045301(2021).
[4] In preparation (2023).

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