Measurement of the condensate order parameter statistics across the Mott transition

Géraud Dupuy,[1] Paul Paquiez,[1] Maxime Allemand,[1] Thomas Chalopin,[1] David Clément,[1] Adam Rançon,[2] Nicolas Dupuis,[3] and Tommaso Roscilde[4]

[1] *Université Paris-Saclay, Institut d Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127, Palaiseau, France*
[2] *Univ. Lille, CNRS, UMR 8523, PhLAM Laboratoire de Physique des Lasers Atomes et Molécules,F-59000 Lille, France*
[3] *Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, LPTMC, F-75005 Paris, France*
[4] *Univ Lyon, Ens de Lyon, CNRS, Laboratoire de Physique, F-69342 Lyon, France*

Transversally to all domain of physics, phases transitions display sharp modification of macroscopic aspects of a system under variation of environmental parameters. Since the middle of the twentieth century, the Ginzburg-Landau theory bridges these macroscopic properties of the system, notably the spontaneous symmetry breaking, and its microscopic behaviour, through the introduction of an order-parameter, switching from a zero average value in the disordered phase to a non-zero one in the ordered phase.

Our experiment puts helium-4 metastable atoms in optical lattices, such that it implements a Bose-Hubbard hamiltonian featuring a Superfluid to Mott insulator transition [1]. In this work, we monitor the condensate order parameter across the Mott transition. More precisely, we measure the full statistics [2] of the square root of the atom number with zero momentum, thanks to a single-atom-resolved detection in momentum space [3].

We observe marked differences between the ordered phase, the disordered phase, and the transition regime, in line with the Ginzburg-Landau paradigm. The fluctuations of the order parameter significantly increase on approaching the transition and, we show that their statistics are non-gaussian in this regime, from measuring non-zero high order cumulants. Finally, we emphasize the fact that our experiment is performed in a non-homogeneous trap, of finite size. A system that is currently difficult to address both theoretically and numerically, and where critical physics are often considered to not play a role.

[1] C. Carcy, et al. (2021). Certifying the Adiabatic Preparation of Ultracold Lattice Bosons in the Vicinity of the Mott Transition. Physical Review Letters. 126.

[2] G. Hercé, et al. (2023). Full counting statistics of interacting lattice gases after an expansion: The role of condensate depletion in many-body coherence. Physical Review Research. 5.

[3] M. Allemand, et al. (2024). Tomography of a Spatially Resolved Single-Atom Detector in the Presence of Shot-to-Shot Number Fluctuations. PRX Quantum. 5.