PhD Position

Topological phase transition in a 2D Bose gas

Laboratory

Laboratoire Kastler Brossel. Collège de France. Paris

Contacts

Jérôme Beugnon (beugnon@lkb.ens.fr)
Sylvain Nascimbene (sylvain.nascimbene@lkb.ens.fr)
Jean Dalibard (dalibard@lkb.ens.fr)

Scientific context

Dimensionality plays an important role in phase transitions. For instance, conventional phase transitions can not happen in one or two dimensions. However, a superfluid phase can still appear in a two-dimensional Bose fluid at low temperature. The 2016 Nobel prize was awarded to M. Kosterlitz and D. Thouless who developed (after a preliminary work of V. Berezinskii) the theoretical framework to explain this unconventional "topological" phase transition. Its topological nature can be understood from a microscopic point of view: above a critical temperature topological defects (vortices) proliferate in the sample whereas they are bound in vortex/anti-vortex pairs in the low temperature phase.

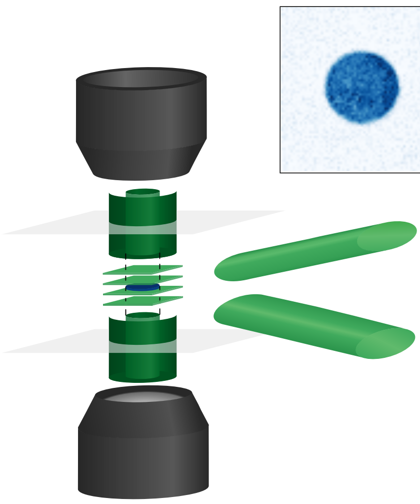

FIGURE 1 – *Schematic of the current experimental setup: we load atoms (in blue) into a single node of a vertical optical lattice. The in-plane confinement is realized by imaging the front of a spatial light modulator (not shown here) thanks to the top microscope objective. We realize flat-bottom potentials with arbitrary shape like a disk here. The top right inset shows an absorption image of a uniform atomic cloud loaded in such a potential. This image is obtained with the bottom microscope objective with a typical resolution of 1 μm.*

Our team has a long-standing expertise on the physics of 2D Bose gases which includes the experimental observation of this BKT phase transition [1] and the measurement of the equation of state of this system [2]. More recently we developed new experimental techniques (see figure 1) to realize flat bottom optical potentials enabling the realization of uniform gases. Uniform gases, contrary to commonly used gases in harmonic potentials, offer the possibility to study the emergence of long-range order. This opportunity has been recently used in our team to study the dynamics of the Bose-Einstein condensation in a uniform gas [3, 4].

Thesis project

In this thesis we plan to merge our expertise on the BKT phase transition and the manipulation of uniform gases to provide new insights on this topological phase transition. First we will aim at characterizing the equilibrium state of the system across the transition. We will develop interferometric methods (either using microwave fields or optical fields) to measure the first order correlation function of the cloud [5] and investigate the emergence of phase coherence in the system. The main goal of this study will be to show the absence of true long-range order through the algebraic decay of the correlation function. Second we will focus on the dynamical crossing of this phase transition. After quench cooling the cloud, we will measure its coherence properties and we will detect the possible formation of topological defects in the superfluid phase. This study should reveal the strong differences between this transition and conventional ones.

This thesis can be preceded by an internship before summer 2017.

[1] Z. Hadzibabic, P. Krüger, M. Cheneau, B. Battelier, and J. Dalibard. Berezinskii–Kosterlitz–Thouless crossover in a trapped atomic gas. *Nature*, 441(7097) :1118–1121, 2006.

[2] S.P. Rath, T. Yefsah, K.J. Günter, M. Cheneau, R. Desbuquois, M. Holzmann, W. Krauth, and J. Dalibard. Equilibrium state of a trapped two-dimensional Bose gas. *Phys. Rev. A*, 82 :013609, Jul 2010.

[3] L. Corman, L. Chomaz, T. Bienaimé, R. Desbuquois, C. Weitenberg, S. Nascimbène, J. Dalibard, and J. Beugnon. Quench-induced supercurrents in an annular Bose gas. *Phys. Rev. Lett.*, 113 :135302, Sep 2014.

[4] L. Chomaz, L. Corman, T. Bienaimé, R. Desbuquois, C. Weitenberg, S. Nascimbene, J. Beugnon, and J. Dalibard. Emergence of coherence via transverse condensation in a uniform quasi-two-dimensional Bose gas. *Nature Communications*, 6, Jan 2015.

[5] N. Navon, A.L. Gaunt, R.P. Smith, and Z. Hadzibabic. Critical dynamics of spontaneous symmetry breaking in a homogeneous Bose gas. *Science*, 347(6218) :167–170, Jan 2015.