Bose-Einstein condensates under rotation

V. Bretin, F. Chevy, P. Rosenbuch and J. Dalibard

Laboratoire Kastler Brossel, Département de physique de l'Ecole Normale Supérieure,
24 rue Lhomond, 75005 Paris, France
Tel +33 1 44 32 33 07, Fax +33 1 44 33 34 34
E-mail: vincent.bretin@lkb.ens.fr

Bose-Einstein condensates exhibit very unusual properties especially when driven under rotation. This comes out of the theory as a consequence of the mean field approximation, under which the condensate part of the atomic cloud is fully described by a single-particle wave function. For instance, the velocity field derived from this formalism has the property of being irrotational, which prevents any motion such as solid body rotation. Instead, when the condensate is driven by a rotating potential, phase singularities appear, known as vortices [1].

In the experiment, we produce condensates of ^{87}Rb in a Ioffe-type magnetic trap, leading thus to cigar-shaped atomic clouds with axial symmetry. Once the condensate has grown, we superimpose for an adjustable time a rotating potential generated by a red-detuned laser beam to the harmonic potential of the magnetic trap (see figure 1). Then, we release the cloud for a 25 ms free fall, after which an absorption image is taken with a resonant laser beam.

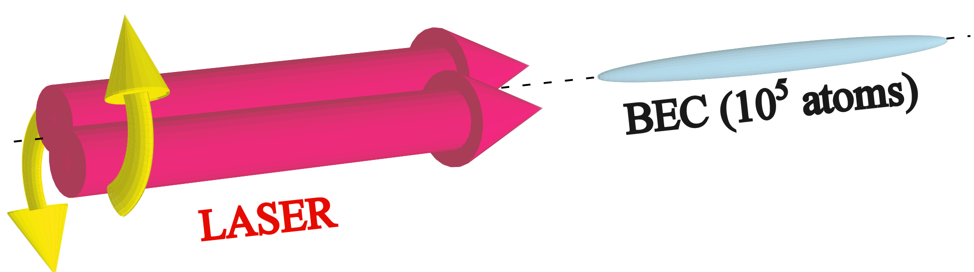

Figure 1: Scheme for creating a rotating potential for the atoms: a red-detuned laser generates an elliptic spot which is put under rotation.

By making various choices for the rotation frequency Ω with respect to the transverse trapping frequency $\omega_\perp$, we have pointed out different regimes for the condensate (figure 2):

- for $\Omega \sim \omega_\perp/\sqrt{2}$, a non-linear resonance is strongly excited [2]. For low amplitudes, this resonance is connected to the surface mode $m = 2$, which is known to be resonant at $\Omega = \omega_\perp/\sqrt{2}$. After a long enough time, quantized vortices show up within the condensate and eventually arrange into a regular Abrikosov lattice [3].

- for $\Omega \sim \omega_\perp$, the center of mass motion is unstable due to the centrifugal force. One would expect the atomic cloud to explode as a consequence of this single-particle instability. Although this statement proved right for a non-condensed cloud, a condensate was observed to spiral away without exploding. This is a situation where repulsive interactions help maintaining particles together [4].

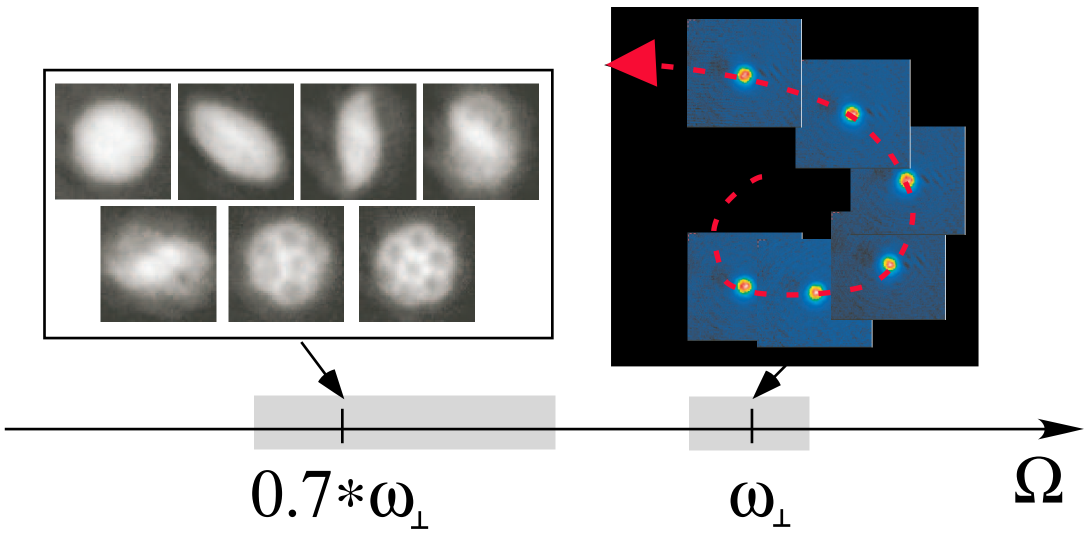

Figure 2: Different regimes for a Bose-Einstein condensate placed in a rotating potential at frequency Ω. Around the $m = 2$ quadrupolar resonance, a strong non-linear resonance is excited. It constitutes the first step to vortex nucleation. For $\Omega \sim \omega_\perp$, the condensate spirals away keeping a constant radius and a constant aspect ratio.

[1] K.W. Madison *et al.*, Phys. Rev. Lett. **84**, 806 (2000)
[2] A. Recati *et al.*, Phys. Rev. Lett. **86**, 377 (2001)
[3] K.W. Madison *et al.*, Phys. Rev. Lett. **86**, 4443 (2001)
[4] P. Rosenbuch *et al.*, cond-mat/0201568