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Supersonic rotation of a superfluid : a long-lived dynamical ring

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Superfluidity is a rich quantum dynamical phenomenon with striking manifestations such as the existence of a critical velocity for the creation of excitations and the appearance of quantized vortices when set into rotation, as observed in liquid helium and in dilute Bose-Einstein condensates. The particular case of a quantum gas rotating at an angular frequency Ω has especially attracted a lot of theoretical and experimental interest. Indeed, it presents a strong analogy with a quantum system of charged particles in a uniform magnetic field, relevant for condensed matter problems such as type II super-conductors or the quantum Hall effect. In a superfluid quantum gas confined in a harmonic trap of radial frequency ω_r, for rotation rates $\Omega \lesssim \omega_r$ a dense triangular array of singly charged vortices establishes. In the limit $\Omega \simeq \omega_r$ the ground state of the system reaches the atomic analog of the lowest Landau level (LLL) relevant in the quantum Hall regime. However, reaching the situation $\Omega \geq \omega r$ is impossible in a purely harmonic trap because the radial effective trapping in the rotating frame vanishes due to the centrifugal potential, leading to the loss of the atoms.This high rotation regime requires an anharmonic trap to counteract the centrifugal effect. A crucial point of this new situation is that a hole grows at the trap center above a critical rotation frequency, leading to an annular density profile. Moreover, the velocity of the atomic flow is expected to be supersonic, i.e., exceeding by far the speed of sound. We will present in this talk the first experimental realization of such a superfluid annular flow stabilized by its own angular momentum [1], as shown in Fig.1. This dynamical ring is a very long-lived quasi-two-dimensional stable structure that persists over more than a minute. We measure rotation frequencies corresponding to a linear supersonic velocity of Mach 18 with respect to the peak speed of sound. We perform the spectroscopy of elementary excitations of the ring and observe the quadrupole-like modes predicted by the diffuse vorticity approach [2]. We observe that once the ring is formed, the mode frequencies disagree with this simplified approach.

[1] Y. Guo et al., Phys. Rev. Lett. **124**, 025301 (2020).
[2] M. Cozzini et al., Phys. Rev. Lett. **94**, 100402 (2005).

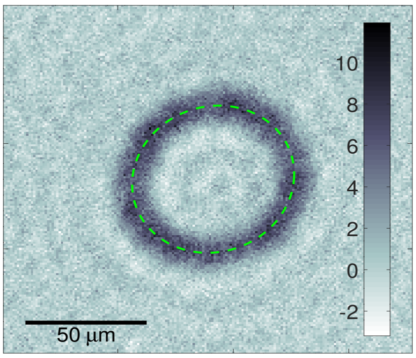

Figure 1 : Dynamical ring rotating at Mach 15, observed from the vertical direction.