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Quantized vortices and sound velocities across the superfluid-supersolid phase transition in a dipolar Bose gas

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Supersolidity has recently been discovered in ultra-cold dipolar Bose gases. This intriguing state of matter is characterized by the spontaneous and simultaneous breaking of phase and translational symmetry, resulting in the non-intuitive coexistence of superfluid and crystalline features.

One of the fundamental characteristics of superfluidity is the existence of quantized vortices. However, their experimental detection in dipolar supersolids remains challenging due to vortices localizing in regions of reduced density caused by the presence of droplets, thereby inhibiting their observability. In this study, we propose an approach for the nucleation and observation of quantized vortices in harmonically trapped dipolar Bose gas. The method is based on quenching the s-wave scattering length across the superfluid-supersolid phase transition. Starting from a slowly rotating, vortex-free configuration in the superfluid phase, quenching into the supersolid phase drives the vortex nucleation, due to the significantly reduced critical angular velocity in the supersolid phase. Once a vortex is created, it remains stable as the condensate is brought back to the superfluid phase, where it can be readily observed. These results may have a significant impact on ongoing experiments, offering a method of probing the superfluid nature of dipolar supersolids.

Another key feature linked to supersolids is the emergence of Goldstone modes, stemming from the spontaneous breaking of continuous symmetries. Our investigation focuses on dipolar supersolids in a ring configuration, where two phonon modes are present. We induce their excitation by abruptly removing an applied periodic modulation proportional to $\cos(\varphi)$, where φ is the azimuthal angle, and explore the resulting oscillations of the gas, by solving the extended Gross-Pitaevskii equation. The obtained longitudinal sound velocities are then analyzed employing the hydrodynamic theory of supersolids at zero temperature. This approach enables the determination of the layer compressibility modulus, as well as the superfluid fraction, in agreement with the Leggett estimate of the non-classical moment of inertia. This analysis provides a framework for an experimental determination of the relevant parameters of the hydrodynamic theory of supersolids.

These results are detailed in the related papers:
[1] M. Sindik, A. Recati, S. M. Roccuzzo, L. Santos, and S. Stringari, Creation and robustness of quantized vortices in a dipolar supersolid when crossing the superfluid-to-supersolid transition, Phys. Rev. A 106, L061303 (2022).
[2] M. Sindik, T. Zawislak, A. Recati, and S. Stringari, Sound, superfluidity and layer compressibility in a ring dipolar supersolid, In preparation (2023).

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