Supersolid Symmetry Breaking from Compressional Oscillations in a Dipolar Quantum Gas[1]

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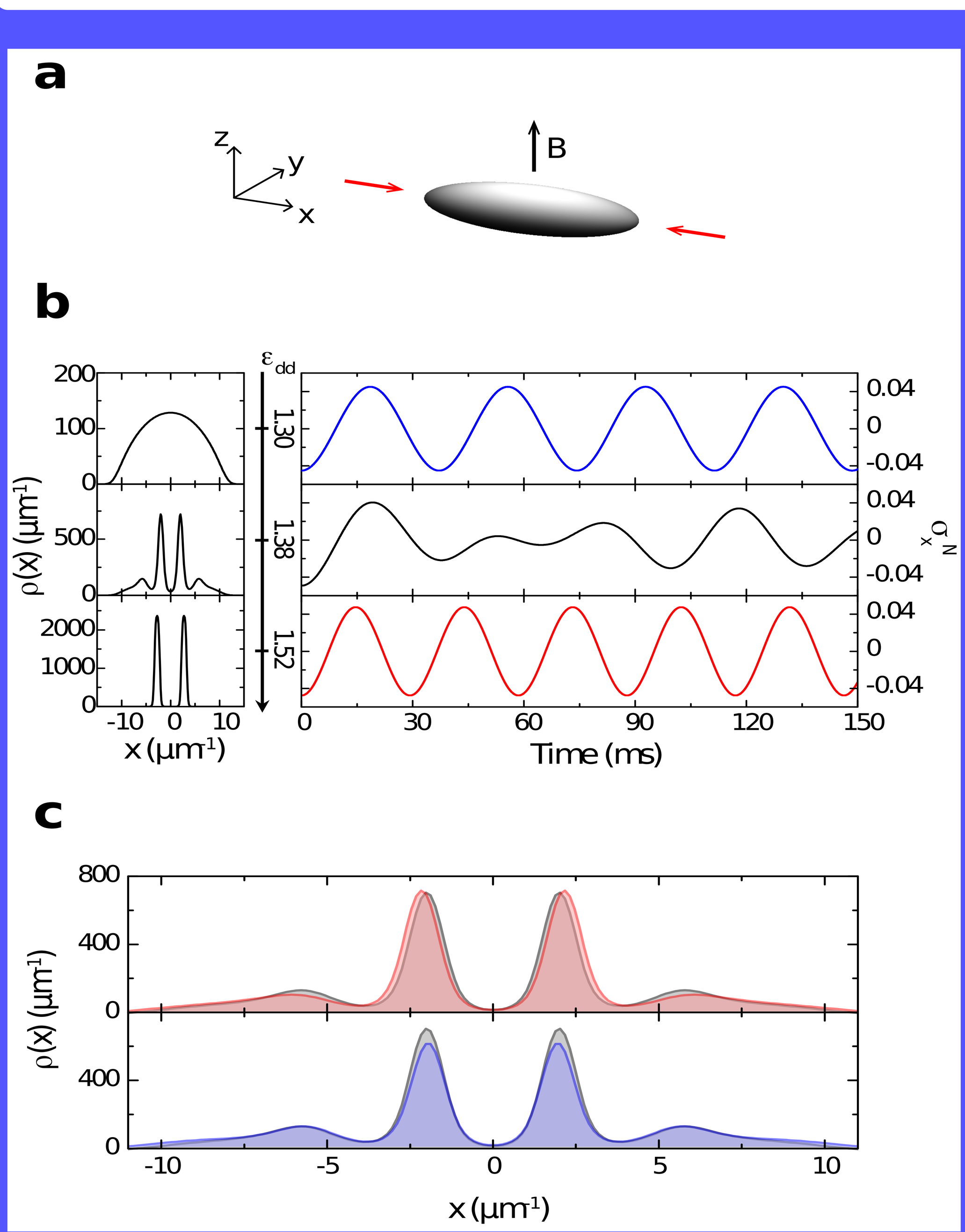
Abstract

We investigate, both theoretically and experimentally, the manifestation of Supersolid Spontaneous Symmetry Breaking in a dipolar Bose Einstein Condensate (BEC) confined in a harmonic trap by revealing **two distinct compressional oscillation modes**. One of such oscillations reveals the **superfluid** nature of our system, the other instead is a manifestation of its **solid** character.

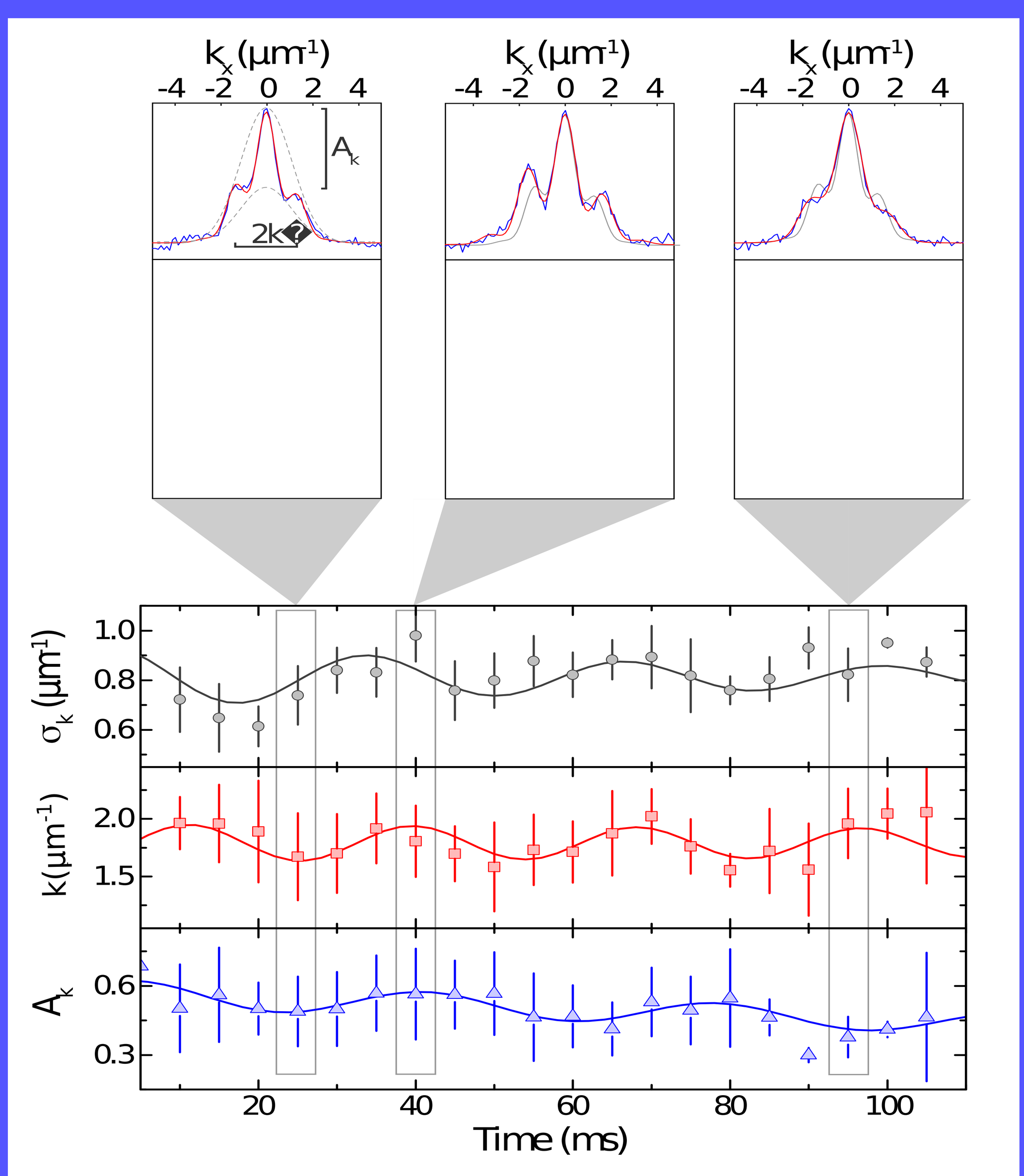
Doubling the axial compressional oscillations

We observe, in both theory and experiment, that the formation of the supersolid manifests through the appearence of **two distinct compressional modes** in the harmonically trapped dipolar quantum gas, reflecting the **two gapless Goldstone excitations** in the homogeneous system.

The higher frequency mode is associated with an oscillation of the periodicity of the emerging lattice, the lower frequency one characterizing the supefluid oscillations



Doubling of the axial breathing mode in the dipolar supersolid: theory. a) Geometry of the system: the axial breathing of the BEC leads mainly to a variation of the width along the x direction (arrows). b) Theoretical calculations of the stationary in-trap density distributions along the x direction (left) and of the time-dependent oscillations (right) in its normalized width. Three representative cases are shown: standard BEC (top row), supersolid regime (middle row), and droplet crystal regime (bottom row). c) Different frames of the time evolution representative of the character of the two modes: upper panel (lower panel) shows the lattice deformation (amplitude modulation) associated with the higher (lower) frequency.



Doubling of the axial breathing mode in the dipolar supersolid: experiment. Experimental oscillation modes in the supersolid regime, obtained by monitoring the width of the distributions in momentum space (top panel, gray), the spacing of the side peaks (middle panel, red) and the modulation amplitude (bottom panel, blue). The insets show samples of the experimental false-color distributions in the k_x-k_y plane and the related fits of $n(k_x,k_y)$ with a two-slit model to measure k and A_k; grey lines show the fit to the first distribution, for comparison. Error bars represent the standard deviation of 4-8 measurements.

Conclusions and perspectives

The **bifurcation** of the lowest compressional mode of a harmonically-trapped dipolar supersolid gives evidence of the **simultaneous breaking of two continuous symmetries**, in analogy with the gapless Goldstone modes predicted for a homogeneous supersolid. Although the existence of two Goldstone modes is a manifestation of superfluidity, our work does not exhaust the assessment of superfluidity in supersolid dipolar gases. The study of other important consequences of superfluidity, like the occurrence of **permanent currents**, the reduction of the **moment of inertia**, as well as the existence of **quantized vortices**, will be developed in future works.

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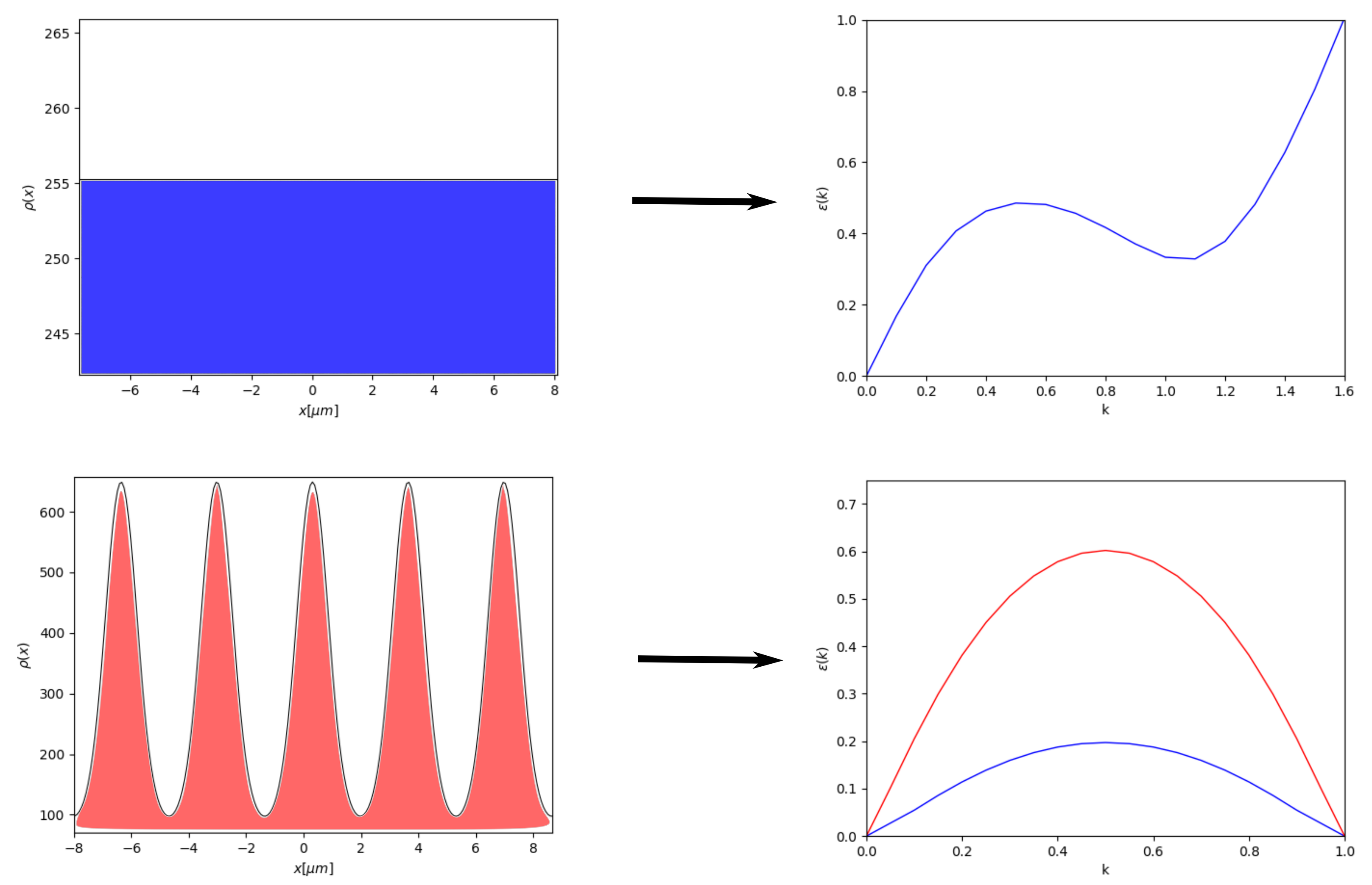
Theoretical background

A supersolid is a paradoxical phase of matter possessing the apparently incompatible properties of **crystalline order and superfluidity**.

Supersolid behaviour has been recently predicted to occur in a dipolar quantum gas confined in a tubular geometry[2], and observed experimentally in a harmonically trapped system[3,4,5].

The formation of the Supersolid is triggered by the reduction of the so-called **roton minimum**, a local minimum in the energy-momentum dispersion relation.

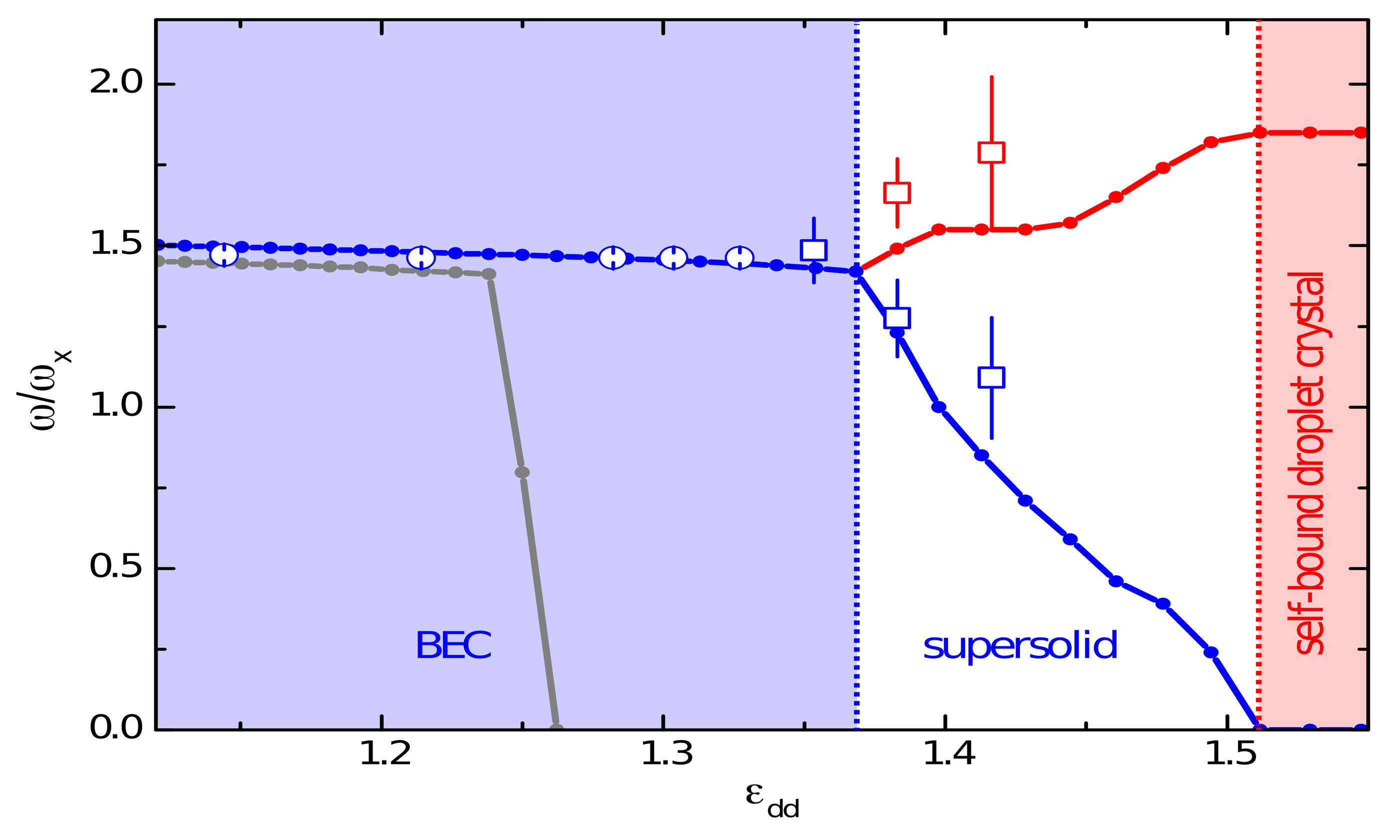
A fundamental property of the Supersolid is the appereance of **two gapless Goldstone modes** in the excitation spectrum, associated with the spontaneous breaking of two continuous symmetries: the breaking of phase invariance at the origin of **superfluidity**, and the breaking of translational symmetry due to the emerging **lattice crystal.**



Axial mode frequencies across the phase transitions

We study the frequency of the modes as function of the the strength of the dipole-dipole interaction, quantified by the parameter ε_{dd}.

As ε_{dd} is increased, the higher frequency approaches the value characteristic of a solid phase of incoherent droplets. The lower frequency instead becomes smaller and smaller until it disappears.



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