Supersolidity with Bose-Einstein condensates

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Supersolidity is a paradoxical state of matter featuring both the crystalline order of a solid and the dissipationless flow typical of a superfluid. The realization of this state of matter requires the breaking of two continuous symmetries, the phase invariance of a superfluid and the translational invariance to form the crystal [1]. Proposed for Helium almost 50 years ago [2], experimental verification of supersolidity remained elusive [3].
Here we report on the realization of such a supersolid state of matter [4]. This state is realized by coupling a Bose-Einstein condensate (BEC) to the modes of two crossed optical cavities. Self-organization to individual cavities only breaks a discrete spatial symmetry and realizes a 'lattice supersolid'. By equally coupling the BEC to both modes we enhance the symmetry of the system to a continuous one and observe simultaneous self-organization to the two cavities. We reveal the high ground state degeneracy of the new supersolid state by measuring the crystal position over many realizations through the light fields leaking from the cavities (Fig.1a).
Using cavity-enhanced Bragg-spectroscopy we measure the excitation spectrum at the superfluid to supersolid phase transition (Fig.1b). In the supersolid phase we detect a Higgs (gapped) and a Goldstone (gapless) branch.

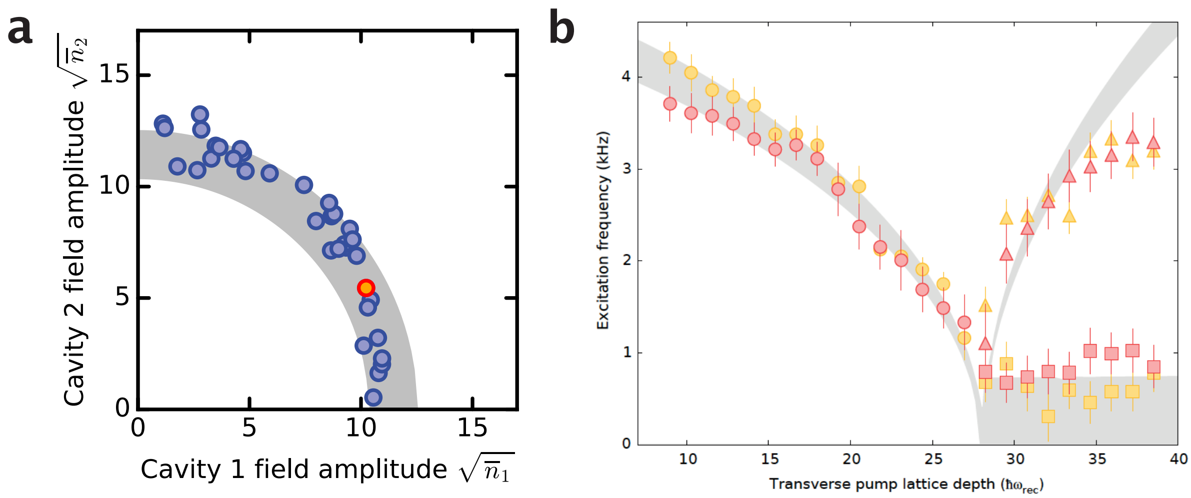

Fig. 1: a Measurement of the high ground state degeneracy of the two cavities self-organized ground state as measured from their light field amplitudes upon multiple realizations. **b** Excitation spectrum of the system across the superfluid to supersolid phase transition. After a critical transverse pump power we enter the supersolid phase, where we observe a Higgs and a Goldstone branch.

References

[1] Boninsegni, M. Prokof'ev, N. V. Supersolids: what and where are they? (2012)
[2] Morales, A. Can a solid be superfluid?, SIF-Società Italiana di Fisica, Prima Pagina, (2017).
[3] Kim, D.Y. and Chan, M.H.W. Absence of supersolidity in solid helium in porous Vycor glass. Phys. Rev. Lett. **109**, 155301 (2012).
[4] Leonard, J. Morales, A. Zupancic, P. Esslinger, T. Donner, T., Supersolid formation in a quantum gas breaking a continuous translational symmetry. Nature **543**, 87-90 (2017).

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