From Cavity Opto-Mechanics to Quantum Phase-Transitions

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Ultracold gases coupled to high-finesse optical cavities provide a novel approach to cavity opto-mechanics [1,2]. In these mesoscopic systems, the ground state of the mechanical oscillator is naturally prepared by the initial cooling of the atomic gas. In our experiment, a Bose-Einstein condensate is trapped inside an optical cavity and dispersively coupled to a single mode of the optical cavity. A collective density excitation of the condensate serves as a mechanical oscillator strongly coupled to the cavity field. We observe optical bistability already below the single photon level and a strong back-action dynamic, in quantitative agreement with a cavity opto-mechanical model. With this experiment we approach the strong coupling regime of cavity opto-mechanics, where a single excitation of the mechanical oscillator significantly influences the cavity field.

Extending the system to a two-dimensional geometry allowed us to observe the Dicke quantum phase transition [3]. In this configuration, the cavity is pumped by a standing wave field which crosses the cavity axis transversely. At a sufficiently strong pump strength we observe the sudden emergence of a density wave in the ground state of the system, which is associated with a spontaneously broken symmetry. The observations are quantitatively captured by the Dicke model (or Tavis-Cummings model), which describes the interaction of N two-level atoms with a single cavity mode.

[1] K. W. Murch, K. L. Moore, S. Gupta, D. M. Stamper Kurn, Nature Physics **4**, 561 (2008).
[2] F. Brennecke, S. Ritter, T. Donner, T. Esslinger, Science **322**, 235 (2008)
[3] K. Baumann, C. Guerlin, F. Brennecke, T. Esslinger, Nature **464**, 1301 (2010).