Exploring strongly correlated matter with multimode cavity QED

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Abstract: We introduce an experiment aimed at incorporating traditionally soft condensed matter physics involving emergent, compliant lattices into an ultracold atomic physics setting. We describe how Bose-Einstein condensates in multimode cavity QED can give rise to spontaneously emergent dynamical lattices with rigidity and topological defects, generating supersmctic and superglass phases.

Externally imposed optical lattices have given experimental cold atoms physics access to a wide variety of hard condensed matter phenomena. Here we introduce an experiment to create a fully emergent and dynamical optical potential with a transversely pumped BEC in a degenerate multi-mode optical resonator. The emergent potential is the result of a spontaneously broken quasi-continuous symmetry, and the resulting crystalline state is therefore compliant, unlike traditional lattices or spontaneous self organization of an atomic cloud in a single mode resonator [1].

The crystallization transition is weakly first order and of the Brazovskii universality class known from classical soft condensed matter physics [2]. Competition between coupling to the degenerate field modes gives rise to domain formation and topological defects in a stripe-like smectic ordered state. As in the single mode case [1], superfluidity is preserved across the self-organization transition, so the resulting crystalline state in the multi-mode case is a fully emergent supersmectic [2, 3]. For three-dimensional clouds, the coupling to the resonator modes is naturally frustrated, giving rise to a superfluid glassy state: a superglass.

FIG. 1. a) Schematic representation of a transversely pumped two dimensional BEC cloud in a degenerate near concentric resonator above the crystallization transition. Different portions of the cloud couple maximally to different field modes and patches of crystalline order nucleate in these different modes. The different lattices are incommensurate, resulting in topological defects at the interfaces between them. The phase transition from the uniform cloud to the ordered state is driven by constructive interference between the scattered light from all of the atoms, so atoms organize at every other lattice site where the field modes are in phase. Superfluidity is preserved across the transition so the site occupations fluctuate with Poissonian statistics with alternating average of zero and one, indicated by the red dots [2]. b) Schematic representation of two transversely pumped planar BECs in a near-concentric resonator. Neighboring regions along the cavity axis couple to modes with different parity parity in the two clouds. Hence in-plane and out-of-plane ordering are mutually frustrated. The result is a superglass arising due to the frustrated cavity-mediated interactions [2].