Quantum Crystals of Matter and Light

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The coupling of a quantum gas to the field of an optical high-finesse cavity can be employed to induce global-range atom-atom interactions. If these are sufficiently strong, such a many-body system undergoes a structural phase transition. Introducing a 3D optical lattice to this system, the collisional short-range interactions can be brought to competition with these global-range interactions and – at the same time – with the zero-point motion of the particles. We explore a rich phase diagram hosting four distinct phases – a superfluid, a lattice supersolid, a Mott insulator and a charge density wave.

In a different experiment, we couple a superfluid cloud of atoms simultaneously to two intersecting optical cavities. This arrangement leads to symmetry enhancement and the resulting system exhibits a continuous spatial U(1)-symmetry. The combination of two continuous symmetries – the gauge symmetry of the superfluid and the spatial symmetry – is a prerequisite for a supersolid state of matter, which we explore in our experiments.