

A cavity-microscope for micrometer-scale control of atom-photon interactions

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Cavity quantum electrodynamics studies the strong interaction between matter and the electromagnetic field of an optical cavity. This enhanced interaction enables fast, sensitive, and minimally destructive measurements of atomic systems, and provides a platform for quantum simulation of models in which atoms interact by exchanging photons over long distances. The naturally emerging all-to-all coupling between atoms in cavity systems creates opportunities for simulating strongly correlated quantum models.

I will describe the construction and operation of a cavity-microscope device that enables spatial shaping of interatomic interactions within a cloud of ultracold ⁶Li atoms. The system integrates an optical cavity with a pair of high-numerical-aperture lenses into a single device. This configuration allows the projection of arbitrary trapping potentials and the imprinting of designed spatial patterns of atom-cavity coupling.

This technology opens new possibilities for analog quantum simulations of programmable systems with all-to-all interactions. I will report on the observation of the superradiant phase transition of a Fermi gas in a cavity under tight confinement, and on the development of optical techniques that can tightly focus the interaction region allowing for high resolution probing of the atomic cloud. I will also present an experimental way to randomize cavity-mediated interactions. Such interactions can qualitatively modify the behavior of the system and enable the exploration of models of holographic quantum matter, including the Sachdev-Ye-Kitaev model.

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