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Real-time arrangement of atoms into a low-entropy state using high-resolution optical tweezers

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Designing and assembling highly complex quantum systems from their individual constituents provide an important milestone in quantum information science and quantum many-body physics. Cavity QED provides a means for efficient light-matter quantum interfaces, where the internal states of individual atoms can encode the information of the material system, whereas the cavity vacuum can act as the bosonic channel that mediates effective spin-spin interaction. Here, we investigate a new regime of cavity QED, which we call many-body QED. In this regime, the optical strong coupling of the light-matter interaction competes with the internal atom-atom interaction in the form of Rydberg excitations.
In our research group, we are pursuing an approach of introducing Rydberg excitations into a spatially regularized array of neutral atoms in an ultra-high-finesse optical cavity. A critical element required for this vision is the capability to resolve and identify Rydberg excitations, as well as to perform the real-time arrangement of atoms into a low-entropy state. We discuss how to do the trapping and manipulation of single neutral atoms in reconfigurable arrays of optical traps with micrometer resolution. This method is based on employing a Texas Instruments Digital Micro-Mirror Device (DMD) as a dynamical holographic phase-amplitude modulator with about 20 kHz update rate. The desired arrangement of traps (the Fourier transform of the mask) is produced in the focal plane of a microscope objective with NA of about 0.5, with a new phase-amplitude algorithm based upon superpixel techniques. We are trying to show how to perform high-precision modulations on laser beam profiles to create arbitrary potential landscapes or prepare the initial atomic states at the individual quanta level. In addition, we are trying to demonstrate a robust scheme to measure and compensate wavefront distortions of laser systems in-situ using a DMD as a holographic spatial light modulator. Our technique can be employed for resolving and trapping ultracold atoms in optical lattices, trapped ions, NV centers or other small, localized and fluorescent objects. We discuss the limitations of the technique and the scope for technical improvements.

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