A Rydberg superatom for cavity QED applications

Sébastien Garcia*[1], Julien Vaneecloo[1], and Alexei Ourjoumtsev*[1]

[1]Jeunes Équipes de l'Institut de Physique du Collège de France – Collège de France, CNRS : USR3573 – France

Abstract

We present the first building blocks for cavity QED applications with a single Rydberg superatom. Our experimental platform is made of a small (5 μm rms) and cold (2 μK) rubidium ensemble strongly coupled to a medium-finesse resonator. The system is probed in a ladder electromagnetically induced transparency scheme (EIT) to map Rydberg excitations onto photons. The Van der Waals interactions between Rydberg atoms are converted into strong optical nonlinearities such that the propagation of photons through the cavity becomes very dependent on the Rydberg population. For sufficiently strong interactions, one excitation is enough to blockade the presence of any other Rydberg excitation in the cloud and the atomic ensemble can then be seen as a single Rydberg superatom strongly coupled to the cavity. We have demonstrated this Rydberg blockade mechanism at the single-photon level by observing strong anti-bunching in transmission of the resonator.

We have implemented a coherent control of the Rydberg superatom via a two-photon Rabi driving between the ground and the collective singly-excited Rydberg state, observing a collective enhancement of its frequency. The state of the superatom can be optically detected via the cavity transmission with a 94% efficiency, in par with results recently obtained in free-space and cavity-assisted experiments but with a significantly weaker residual transmission, making this system analogous to a single-excitation-controlled optical transistor with a weak leakage current.

Finally, we demonstrated that our coupled system induces pi phase shift on the light reflected off of the cavity dependent on the superatom's state, allowing us to detect the latter with a 90% efficiency. This pi phase rotation, together with the coherent control and the single-shot state detection, is a key ingredient for the implementation of an efficient controlled-phase gate or for the deterministic generation of optical "Schrödinger's kitten" states, without the need for a low-volume high-finesse cavity.

*Speaker