An Intracavity Rydberg Superatom for Quantum Engineering of Light

Alexei Ourjoumtsev
Julien Vaneecloo, Sébastien Garcia

JEIP, UAR 3573 CNRS, Collège de France, PSL University, 11, place Marcelin Berthelot, 75005 Paris, France

alexei.ourjoumtsev@college-de-france.fr

We demonstrate a new approach for creating deterministic photon-photon interactions for optical quantum engineering, based on a single-ended medium-finesse optical cavity containing a mesoscopic atomic ensemble. This ensemble is made transparent by a laser beam mapping intracavity photons into Rydberg polaritons. The transparency vanishes when the cloud, acting as a single collective two-level superatom with an enhanced coupling to light, is driven from the ground to a Rydberg state. We observe collectively-enhanced Rabi oscillations between these states and optically discriminate them in a single shot with a 95% efficiency. Most importantly, we show that a change between the two internal states of the superatom induces a π phase rotation on the light reflected off the cavity. These ingredients form a complete set of tools for implementing deterministic photonic entangling gates and for generating highly non-classical light without the need for a low-volume high-finesse cavity.

References

[1] J. Vaneecloo, S. Garcia, A. Ourjoumtsev, arXiv: 2111.09088, Phys. Rev. X in press (2022).

Figures

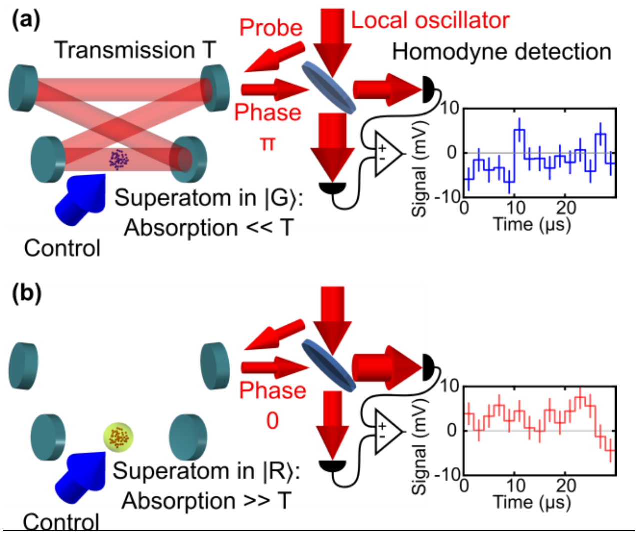

Figure 1: Optical π phase rotation conditional on the state of a two-level Rydberg superatom. A small Rydberg-blockaded cloud of cold Rb atoms, acting as a two-level superatom with a ground state |G⟩ and a Rydberg state |R⟩, is strongly coupled to a single-ended optical cavity. (a) When the superatom is in |G⟩, the control beam (blue) creates electromagnetically-induced transparency (EIT) and converts probe photons into dark Rydberg polaritons. In this case, the absorption of the cloud being much smaller than the transmission T of the resonator's input/output coupling mirror, the system is optically overcoupled. The probe field is then reflected with a phase π, measured with a homodyne detector in our experiment. The inset shows a single-shot homodyne trace with 2μs binning, where errorbars correspond to standard errors. (b) When the superatom's state is coherently rotated to |R⟩, the strong Rydberg blockade destroys the EIT and makes the system optically undercoupled: the probe field is then reflected with a phase 0, leading to a sign flip of the homodyne signal. The homodyne trace in the inset shows a quantum jump from |R⟩ back to |G⟩ around t=25μs.