Cavity Protected Multifrequency Polaritons in a Cold Atomic System

Pierre-Antoine Bourdel*[1], Mohamed Baghdad[2], Sylvain Schwartz[3], Ferri Francesco , Romain Long[1], and Reichel Jakob[1]

[1]Laboratoire Kastler Brossel – CNRS : UMR8552, École normale supérieure [ENS] - Paris, Sorbonne Universités, UPMC, CNRS, Collège de France, Collège de France – France

[2]LENS – Italy

[3]ONERA (DPHY) – ONERA (DPHY) – France

Abstract

Controlling and characterizing entanglement in large quantum systems is an exciting challenge of modern physics. Along this line, we have built a CQED (Cavity Quantum Electrodynamics) platform where cold rubidium atoms are strongly coupled to a fiber-based Fabry-Perot cavity under a high-numerical aperture lens. The cavity is used to create collective interactions between the atomic qubits, and generate multiparticle entanglement, while the microscope is meant to allow for single-qubit manipulation and readout.
Increasing the number of qubits of a quantum system without decreasing its coherence is one of the main achievments necessary to fulfil the promises of quantum technologies. Indeed, systems with many qubits are often inhomogeneous in frequency and subjected to decoherence. In inhomogeneous light-matter coupled systems, all eigenstates have a photonic component, contrary to homogeneous systems for which only the two polaritons have a photonic component. Therefore, the distribution of the photonic excitation among the eigenstates is a way to apprehend coherence.

In our experiment, frequency inhomogeneity comes from the strong position-dependent light-shift induced by our trapping intra-cavity lattice. Thus we can tune the amount of inhomogeneity by changing the depth of this lattice. By tuning the number of atoms, and thus the collective coupling to the cavity, and by measuring an experimental quantity quantity analog to the photonic weight distribution, we observed a smooth transition between two different regimes:

- For low collective couplings, the photonic weight is distributed among many eigenstates, because of the frequency inhomogeneity.

- For higher collective couplings, the photonic weight is held by the sole two polaritons, and the coherence is retrieved in spite of the inhomogeneities. This is a "cavity protection" effect, as theoretically described in [1, 2, 3] and previously experimentally observed in [4,5].

To our knowledge, this is the first experiment that finely characterizes this transition with a mesoscopic number of qubits (a few tens to hundreds), leveraging the strong coupling of each individual atom.

*Speaker

Finally, using the high sensitivity of the light-shifted atomic frequency to the 1560nm dipole light power, we modulate the polariton frequencies very efficiently. We thus demonstrate a frequency modulated Rabi splitting, which increases the number of available frequencies of the coupled system while preserving its coherence thanks to cavity protection. Such spectral shaping of the polaritons could have applications for quantum memories and quantum communications.

R. Houdré *et al.*, PRA 53(4) (1996)

Z. Kurucz *et al.*, PRA 83, 053852 (2011)

I. Diniz *et al.*, PRA 84, 063810 (2011)

S. Putz *et al.,* Nat. Phys., **10**(10) (2014)

T. Zhong *et al.,* Nat. Commun., 8, 14107 (2017)