A new interconnection platform for neutral atom arrays

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Advances in the manipulation of arrays of individual Rydberg atoms have demonstrated the potential of the latter for quantum information [1]. However, actual applications in quantum computing will require millions of logical qubits, themselves encoded on tenths of single atoms. The number of atoms in a single array will reach a limit (on the order of 10^4), defined by the available laser power, the field of view offered by high-NA optics or the resolution of spatial light modulators defining the geometry of the array. This limit calls for the development of distributed quantum processing, which requires quantum interconnections. Our proposal for this necessary development is a platform that will allow the connection of atomic processors through an intracavity Rydberg superatom.

By coupling an atomic cloud to a medium-finesse cavity and driving it to a highly excited state, we can achieve a collective two-level system called a superatom [2]. The main advantage of such a platform is that the collective coupling of the atomic cloud to the cavity bypasses the challenges for a high-finesse cavity and the high sensitivity of Rydbergs atoms to nearby dielectric surfaces. In our group, the coherent mapping of the state of the superatom onto a free-propagating photonic qubit has been demonstrated [3].

Building on this scheme, we propose trapping an array of atoms, via optical tweezers, next to the atomic cloud within the cavity mode. The aim is to entangle the individual atom with the superatom, then map the superatom onto a free-propagating light mode. This will result in an entangled single-atom single-photon state, forming a building block to distribute entanglement between distant single-atom arrays.

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[2] J. Vaneecloo, S. Garcia, A. Ourjoumtsev, Intracavity Rydberg superatom for optical quantum engineering : Coherent control, single-shot detection, and optical π phase shift, Phys. Rev. X 12, 021034 (2022).

[3] V. Magro et al, Deterministic freely propagating photonic qubits with negative Wigner functions, Nat. Photon. 17, 688-693.