PhD Thesis Defense EMANUELE DISTANTE 'A Quantum Light-Matter Interface with Rydberg Polaritons in a Cold Atomic Ensemble'

EMANUELE DISTANTE

March 24, 2017

Friday March 24, 15:30. ICFO Auditorium

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Quantum Photonics with Solids and Atoms

ICFO-The Institute of Photonic Sciences

Nonlinear optics at the single-photon level enables deterministic photon-photon interaction, a long-standing goal in quantum photonics science. Besides its implication in fundamental aspects of physics, this would unlock several applications in quantum information science. A relevant exemple are deterministic Bell state measurements which find a prominent application in long-distance quantum communications using quantum repeater architecture. Toward this goal, we built a highly nonlinear system based on Rydberg excited states of a cold atomic ensemble and electromagnetically induced transparency (EIT).

Our work first focuses on the storage of weak coherent light pulses in the atomic ensemble analyzing the resulting nonlinear response of the medium. Then we demonstrate storage and retrieval of a paired single photon by coupling the Rydberg ensemble with a second remote cold atomic based quantum memory.
Our set-up is based on magneto-optically trapped 87Rb atoms cooled down to temperature of 50 to 100 uK , with a cloud density of 10 ^(10) cm^(-3). Using EIT, light pulses are slowed down, stored as Rydberg collective atomic excitation and retrieved. We characterize EIT, slow-light and light-storage on a variety of Rydberg states, from the 26S up to the 80S. Depending on the state, the typical storage efficiency observed is of the order of few percents at a storage time of ~200 ns while the typical 1/e coherence time is of ~2us.

By studying the optical response at different mean probe photon number, we have examined the Rydberg induced nonlinearity in EIT, slow-light and stored-light case for different Rydberg states. In particular we have measured the nonlinear Rydberg induced dephasing of a stored collective Rydiberg state. For few microseconds storage time we have measured nonlinear response at the order of tens of photons. Our results show that light-storage enhances the nonlinear response of the atomic ensemble when compared to the slow light case, this possibly facilitating photonic quantum information processing using Rydberg excited atoms.

Finally, we have used a separated cold atomic quantum memory to generate pair of correlated single photons. One photon of the pair is stored as single collective Rydberg atomic excitation and we show that non-classical correlations between the two photons and the single-photon statistic persist after the retrieval from the Rydberg ensemble. This result marks an important step towards deterministic photon-photon interactions. At the same time, linking a quantum memory with a highly nonlinear system may enable deterministic distribution of entanglement over long-distance using quantum repeaters.

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