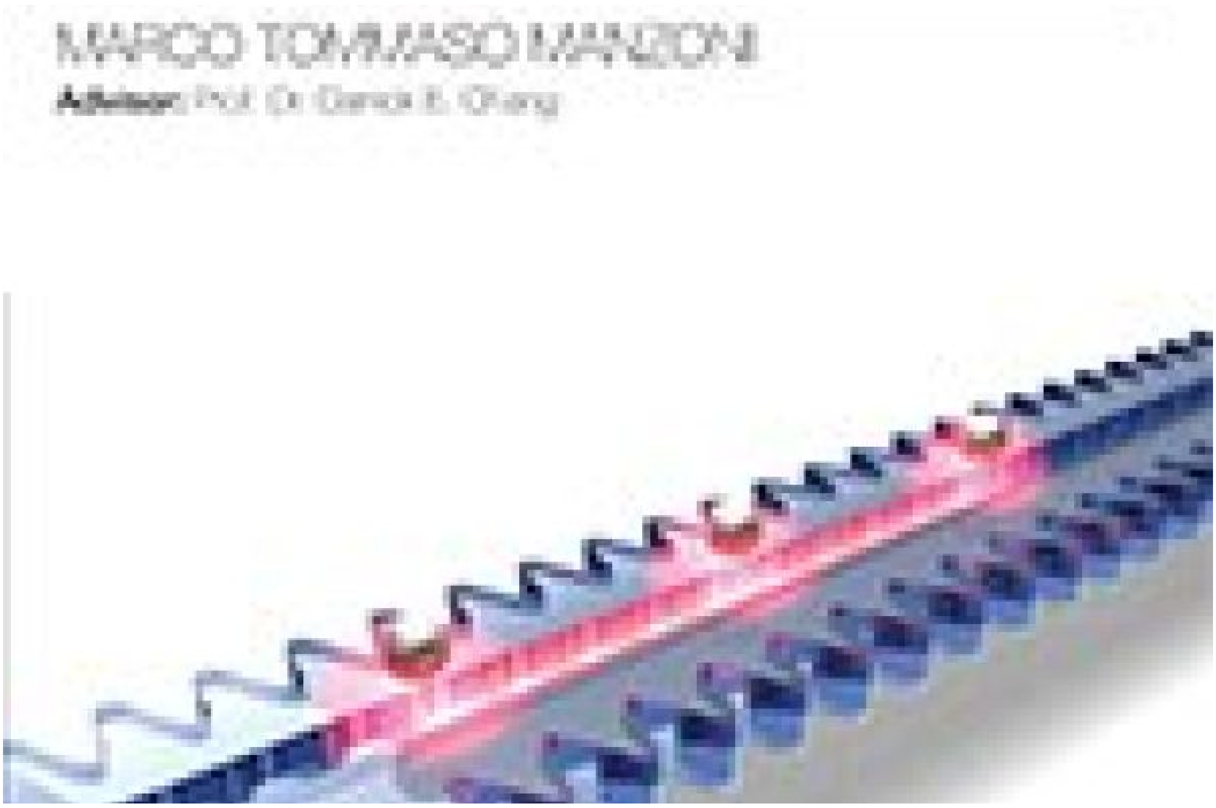

PhD Thesis Defense MARCO MANZONI 'New Systems for Quantum Nonlinear Optics'

MARCO MANZONI

October 19, 2017

Thursday October 19, 11:00. ICFO Auditorium

MARCO MANZONI

Theoretical Quantum-Nano Photonics

ICFO-The Institute of Photonic Sciences

Photons travelling through free space do not interact with each other. This characteristic makes them perfect candidates to carry quantum information over long distances. On the other hand, processing the information they encode requires interaction mechanisms. In recent years, there have been growing efforts to realize strong, controlled interactions between photons by making them interact with individual atoms, which are intrinsically nonlinear objects. This, and the efforts to understand the phenomena that can emerge, have spawned the new field of ``quantum nonlinear optics."

A number of approaches have been pursued to attain near-deterministic atom-photon interactions, including the use of cavities (CQED), of atomic ensembles, and more recently of dielectric nanostructures able to confine light without defocusing, thus enabling the interaction with atoms trapped in the proximity of the structures. While for the CQED case powerful theoretical tools have been developed to treat the interactions of photons, in the case of atomic ensembles, either in free space or coupled to nanophotonic structures, there is a general lack of theoretical methods beyond the linear regime. This relative lack of understanding also implies that there could be rich new physical phenomena that have thus far not been identified. The overall goal of this thesis is to explore these themes in greater detail.

In Chapter 2 of this thesis we develop a new formalism to calculate the properties of quantum light when interfaced with atomic ensembles. The method consists of using a ``spin model" that maps a quasi one-dimensional (1D) light propagation problem to the dynamics of an open 1D interacting spin system, where all of the photon correlations are obtained from those of the spins. The spin dynamics can be numerically solved using the toolbox of matrix product states (MPS), thus providing a technique to study strongly interacting photons in the true many-body limit.
In Chapter 3 we investigate the possibility of creating exotic phases of matter using the recently realized photonic crystal waveguide (PCW)-atoms interface. In particular, we examine the consequences that arise from the strong interatomic forces mediated by the exchange of band gap photons, whose strengths also depend strongly on the internal atomic states ("spins"). Taking one realistic model, we show that "quantum crystallization" can occur, in which the emergent spatial orders of atoms depend intricately on the spin correlations.

In Chapter 4 we investigate the possibility of implementing second-order nonlinear quantum optical processes with graphene nanostructures, as a more robust alternative to the use of atomic systems. We quantify the second-order nonlinear properties, showing that the tight confinement of surface plasmons (SP) in graphene gives rise to extraordinary interaction strengths at the single-photon level. Finally, we predict that opportunely engineered arrays of graphene nanostructures can provide a second harmonic generation efficiency comparable with that of state-of-the-art nonlinear crystals, with the high Ohmic losses of graphene serving as the fundamental limitation for deterministic processes.

In Chapter 5 we investigate a new paradigm for quantum memories of light based upon ordered atomic arrays. In particular, we show that the strong constructive interference in optical emission can give rise to a significantly enhanced atom-light interface, as compared to a standard, disordered atomic ensemble. In the case of a single, 2D atomic layer, we find the impressive result that a memory realized with 16 atoms can have the same storage efficiency as an atomic ensemble with optical depth larger than 100.

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Thesis Director: Prof Dr. Darrick Chang