Winterschool 2019
Abstracts selected for presentation

Giuseppe Baio

University of Strathclyde

Optomechanical self-structuring of cold atoms with structured light

Recent experimental works in cold atoms have provided several examples of self-organization including density (optomechanical) or magnetic ordering. In the first case, the atomic bunching due to dipole forces provides positive feedback leading to multimode spontaneous symmetry breaking and pattern formation.In this work we extend previous studies of transverse optomechanical self-organization in cold atomic clouds allowing the pump field to have a structured phase profile. We predict a wide range of drifting modulation instabilities induced by the pump orbital angular momentum (OAM). This effect leads to the formation of tunable rotating ring lattices and, more generally, to the propagation of coupled light-matter perturbations. Macroscopic transport processes are also investigated in the limit of strong momentum damping, providing an analogy with several soft-matter systems.The formation of spatial structures carrying OAM represents a novel platform to probe rotational effects in cold or ultracold matter, such as persistent currents or the appearance of turbulent regime

Stefano Grava

ICFO

Light propagation in three-dimensional atomic lattices

The response of a dense gas to light seems quite complex a priori due to multiple emission/reabsorption through the ensemble. To reduce the complexity, the standard theoretical approach is to assume that atoms interact with the optical field independently such that the system is simply characterized by a linear susceptibility, proportional to the linear response of a single, isolated atom and to the density of atoms.; ; However this assumption is neglecting the possible collective behavior associated with wave interference and multiple scattering of light. ; Second, the susceptibility derived from the assumption is generically complex, describing absorption, whereas "losses" are simply photons emitted in unwanted modes.; ; To study collective interference effects, here, we aim to investigate the optical response of a 3D optical lattice of atoms. We discuss how to calculate both the linear optical response for a finite system, through a â€œspin modelâ€� formalism, and for an infinite system via optical band structure. For a sub-wavelength lattice, we show that the susceptibility becomes purely real, as the lattice prevents coherent scattering of light into any diffraction orders. We furthermore investigate the scaling of the effective refractive index with atomic density, and its deviation from the independent-atom result.

Roberta Palacino

University of St Andrews

Collective Effects with Multimode Cavity QED

Cavity QED offers a platform to engineer strong matter-light interactions enabling the exploration of the states of quantum matter. Previous studies have focused on single or few mode cavities and have unveiled and characterised exotic forms of quantum matter-light. However such configurations are restricted to those where the mean-field approximation is adequate, and do not allow for inhomogeneties or quantum fluctuations. As such, all phase transitions in such models can be fully described by mean field theory, with mean-field critical exponents. Such limitations can be overcome using a multimode cavity, allowing for tunable and yet strong local atom-atom interaction, combined with intrinsic inhomogeneous character, given by the very large number of spatially structured modes interacting with the atomic ensemble. This is expected to alter the nature of the phase transitions and provides the opportunity to investigate out-of-equilibrium physics beyond mean-field theory. We consider such a system in order to study theoretically spin-spin self organization processes associated to the U(1) symmetry breaking in engineered Dicke model

Rui Lin

ETH Zurich

Steady state, limit cycle, and chaos in a blue-detuned cavity-BEC system

We numerically study a weakly-interacting, harmonically-trapped boson gas coupled to a high-finesse optical cavity. The bosons self-organise into a lattice when the driving laser is strong enough. When the cavity is blue-detuned, previous mean-field analysis predicts limit cycle and chaotic behaviours in the system. In our study, we confirm these behaviours numerically and give them a more profound analytic understanding. On top of that, more interesting phenomena are observed in the steady self-organised region. First, going beyond mean-field, we observe a subdivision into a superfluid phase and a Mott insulator phase. Second, contrary to intuition, the self-organisation is accompanied by an increase in the energy in a certain parameter region. Third, the lattice sites are split into dimers and fork-like density distributions are observed. Such splitting clearly manifests itself in the momentum space, especially in the Mott phase, and in principle can be observed in experiments. These unusual behaviours can be attributed to the competing components of the cavity-induced effective potential.

Lewis Ruks

Okinawa Institute of Science and Technology

Nanofiber-mediated optical binding between atoms

We consider the effects of an optical nanofiber on the collective interaction between two atoms with internal and center-of-mass degrees of freedom. The presence of the guided modes of the fiber affects the collective decay rates, dipole-dipole interaction coefficients, and the optical forces on the atoms. Using a Greenâ€™s function approach we find that the optical binding potential between the atoms oscillates with an amplitude that remains non-zero with increasing distance between them along the fiber axis.; The dynamics of this atom-light system displays known phenomena such as infinite distance atom-atom interactions and collective chiral spontaneous emission, but also holds the potential to reveal new regimes induced by particular choices of driving field, which can be potentially used in probing and trapping protocols for few atom systems. The theory presented is for two atoms close to a nanofiber, but completely generalizes to n atoms in the presence of arbitrary dielectric

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