Scientific Report for Exchange Grant under the ESF programme POLATOM

Title of the grant: Exploring the Dicke model in cold atoms, ions and semiconductors

Duration of the visit: Aug 1st 2011 – Aug 31st 2011

Visitor: Prof. Tilman Esslinger, ETH Zürich

Host: Prof. Michael Köhl, University of Cambridge

Purpose of the visit

The purpose of the visit was to develop a deeper understanding of the Dicke model in the context of cold atoms, ion and semiconductors experiments. Particular emphasis was put on the recent experimental demonstration of the Dicke phase transition with cold atoms. A second direction, which developed during the visit, was to create a link between the physics of graphene and the realisation of a honeycomb optical lattice for an atomic Fermi gas.

The Dicke model is a fundamental concept to describe the interaction between matter and light and has found applications in a variety of fields, including quantum optics, spin physics and quantum information processing. The Dicke model considers the coupling of an ensemble of two-level systems to a single mode of the electromagnetic field. In a generalized form it is used to describe Bose-Einstein condensation of cavity polaritons [1]. Recently, the Dicke quantum phase transition, predicted by Hepp and Lieb [2], could be experimentally observed in a Bose-Einstein condensate coupled to a high-finesse optical cavity [3]. In this setting, a transverse pump field induces a dispersive coupling between a density excitation in the Bose-Einstein condensate [4], i.e. a phonon, and the field mode of an ultra-high finesse cavity.

Description of the work carried out during the visit

During the visit I worked on one of the central questions of the experimental realisation of the Dicke model, which is the role of quantum fluctuations and dissipation. I had important interactions and discussions with Prof. Ben Simons, Dr. Jonathan Keeling (St. Andrews) and Dr. Joe Bhaseen on the semi-classical description of the Dicke model and the resulting phase diagram for the experimental situation. The description developed by J. Keeling, B. Simons and J. Bhaseen takes into account an overall AC-Stark shift which has so far been neglected. This leads to new phases in the region where the pump field approaches a cavity resonance. Specifically we discussed the non-linearity in these new phases and the possible influence for the creation of non-classical states of light. The work of J. Keeling et al. will soon be published.

Main results and projected publications

Concerning quantum fluctuations and dissipation in the experimental realisation of the Dicke model we identified two decay mechanisms as being relevant for the experimental system. The first decay mechanism is the cavity decay, i.e. the loss of photons out of the cavity [5]. This increases the fluctuations in photon number in the normal phase in the vicinity of the phase transition to the superradiant phase. The second mechanism is the decay of spin excitations. This is a result of the coupling of the effective spin to other momentum modes. For the case of a Bose-Einstein condensate these other momentum modes have negligible population and therefore this decay results in a reduction of the fluctuations. Our results on the fluctuations in the experimental realisation of the Dicke model will soon be ready for publication.

During my stay in Cambridge I had several discussions with Prof. Michael Koehl in which we addressed the question, how one can how one could realize Dicke models using ions in optical cavities and how one can extend the Dicke model to a multimode Dicke model. New possibilities of a multimode Dicke model entering the realm of spin glass physics have recently been discussed in a proposal by Subir Sachdev.

Part of the time, I worked on honeycomb lattices for ultracold atoms. In particular, I developed an atom optical understanding of the Dirac points in this novel optical lattice, which we could experimentally realize at ETH Zurich. I had several fruitful discussions with Nigel Cooper on the semi-classical motion of atoms in a honeycomb lattice. This led to a proposal on how to measure the effect of the Berry-phases in the semi-classical motion of the atoms.

Together with my group at ETH Zurich we are preparing publications on the fluctuations of the cavity field in the Dicke model below threshold. We further prepare a manuscript on the realisation of a honeycomb lattice for fermionic atoms. Both publications will profit from the ESF grant. A publication together with Nigel Cooper is projected, if the semiclassical motion in the honeycomb lattice can be measured in the experiment.

I would very much like to acknowledge the hospitality of the Physics Department of the University of Cambridge and its uniquely inspiring and creative atmosphere.

Tilman Esslinger Zurich, 29. September 2011

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