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Purpose of the visit

The purpose of my visit was to discuss with Prof. Lewenstein and the other members of his group about few important topics of collaboration.

At present, a common field of research is the study of degenerate samples of bosonic atoms (Bose-Einstein condensates) in the weak coupling regime. Already in this regime the physics of those systems turns out to be very rich, giving rise, among others, to collective excitations, energetic and dynamicl instabilities in presence of a periodic potential, and the formation of solitons. On one hand, this field still offers interesting directions to be investigated, on the other hand interactions can bring the system far away from the weak coupling regime, where a wide area of new phenomena appears.

As I will go to describe in more detail in the following, the purpose of my visit was to discuss some specific research directions in both regimes.

Description of the work carried out during the visit

During my visit in Hannover, the discussion has been focused on three main subjects:

1) Entanglement of solitons:

In this first project, we consider an ultracold gas of bosons in the weak interaction regime. In that case, the non linear Schrödinger equation (Gross-Pitaesvkii equation) for the order parameter is a good description for the state of the system. In this regime, the behaviour of this coherent atomic system shows strong analogies with the propagation of light in non linear optics. In particular it is well know that the non linear Gross-Pitaevskii equation supports solitonic solutions, which in the case of attractive self-focusing interactions correspond to a positive density variation propagating without dispersion. As recently studied, solitons can be manipulated with a very high degree of control, and in particular can be split. The idea is to exploit this kind of systems in order to achieve entanglement of two macroscopic objects, in analogy to what already performed experimentally on Cesium gas samples entangled via the interaction with a pulse of light.

2) Ultracold atoms in optical lattices:

In recent year is has been possible to propose and sometimes realise experimentally with ultra cold gases in trapping potentials situations well known in solid state and condensed matter physics. Most striking examples of this trend have been for instance the obvservation of the superfluid-Mott insulator transition in three dimensional optical lattices and the creation of fermionised bosons (Tonks gas). However, one can go even beyond this: cold atomic samples do not only provide a good testing ground for systems existing in traditional condensed matter, but also provide a new kind of matter due to the tunability of the parameters of the system. In fact, contrary to condensed matter systems, where usually the parameters are given by nature, in trapped atomic samples one can tune them by changing the trapping potentials, the interaction between particles, the external couplings. These features can be exploited and should be investigate deeply. Although efforts have been already made in several directions (e.g. strong correlated, low dimensional and disordered systems), many directions are still open, including the whole field of the dynamics which has not yet been deeply studied in many of the previously mentioned cases.

2a) Lattices of dipolar bosonic atoms

In particular, we want to consider a lattice of dipolar bosons. This system is characterised by three tunable parameters: the tunneling rate (tunable through the lattice strength), the dipole force (tunable through the dipole moment, and especially through the orientation angle of the dipoles) and the on-site interaction (tunable through the lattice strength and especially through the orientation angle of the dipoles). There are reasons to believe that this systems shows a lot of almost degenerate stationary states, making it in this respect similar to a disordered system. This will be the main point of our investigation, and its connection to possible applications, as neural network or the creation of a quantum memory.

3b) Non abelian gauge fields in optical lattices

The study of particles in magnetic fields is a widespread area of research since the very early days. Still it is a problem which attracts lots of interest. In systems of ultracold neutral atoms, magnetic field can be simulated for instance by rotations. This idea lead to famous proposals on how to create for cold bosons the same conditions present in the fractional quantum Hall effect. More recently, it has been proposed how to create an artificial magnetic field for atoms in optical lattices by using laser-induced hopping, which generate a phase for a particle going around a close path in the lattice. As an extension of this idea, we want to engeneer a non abelian gauge field in an optical lattice, by introducing more internal states and state-dependent tunneling. The study of this system involves three steps, first the solution of the single particle problem, presently under study in Hannover, then the case of weak interactions and finally the strongly correlated regime.

Future collaboration with host institution

The topics explained above constitute the basis of a long term collaboration between me and Prof. Lewenstein. In fact, I am planning to join his group in a few months, after he has moved to the ICFO in Barcelona.

Projected publications/article resulting or to result from my grant

As explained above, the collaboration with Prof. Lewenstein is supposed to go on in the near future, and will for sure give rise to common publications.