Mesoscopic Phenomena in Quantum Gases

Dr. Minguzzi Anna, CNRS - LPMMC, Maison des Magisteres, 25 Rue des Martyrs, BP 166, 38042 Grenoble- France

Prof. Hekking Frank, Université Joseph Fourier, CNRS - LPMMC, Maison des Magisteres, 25 Rue des Martyrs, BP 166, 38042 Grenoble- France

Dr. Citro Roberta, Department of Physics "E.R. Caianiello", University of Salerno, Via S. Allende 84081 Baronissi (Sa)-Italy

Keywords relating to the proposed workshop topic

mesoscopic physics, quantum gases, atomtronics, quantum phase transitions, quantum coherence, quantum dynamics

Abstract

The aim of the proposed thesis is to propose new directions in quantum gases, focussing on challenges at the interface between theoretical condensed matter physics and the physics of atomic gases.

Ultracold atomic gases are novel quantum fluids which have become available thanks to a remarkable experimental progress in the last fifteen years. Originally belonging to the community of atomic physics, where powerful cooling and trapping techniques were developed, the field of quantum gases is now rapidly growing in many directions. In particular, the last years have witnessed a formidable experimental and theoretical effort towards the understanding of the effects of interactions and correlations in the quantum degenerate regime, aiming at the realisation of long-sought (as well as novel) many-body systems. Major advances in this direction call for the development of techniques originally used for other correlated systems belonging to the domain of condensed matter and mesoscopic physics.

The interest of quantum gases is the possibility of tuning the interactions, the geometry and even the disorder strengths. This allows to explore (and even design) new quantum phases which were not

accessible in conventional condensed matter systems. The purity of the samples and optical access allows measuring several observables both in space and time domain (density profiles, momentum distribution, excitation spectrum, dynamic structure factor, interference pattern, noise distribution and higher order correlations). Recent directions include the study of low-dimensional strongly interacting systems, such as quasi two-dimensional and one-dimensional configurations, experimentally realized by trapping atoms in the minima of a light standing wave. Traps with nontrivial topology, such as ring traps and rotating lattices have also been recently realized, and optical lattices with complex geometries such as triangular, kagome, or checkerboard lattices, are within experimental reach. In addition to regular trapping, a considerable effort has been devoted to the application of tunable disorder potentials, realized either with so-called laser speckles or with a two-color lattice with incommensurate periodicity. These issues are close to those studied within the context of mesoscopic systems.

Fundamental open questions that are important for atomic gases in the mesoscopic regime concern anomalously strong fluctuations of measurable physical quantities and out-of-equilibrium phenomena. Below, we discuss a few examples.

New quantum phases. Progress in the ability to manipulate the interaction strength and the dimensionality as well as to realize traps with nontrivial topology in ultracold atomic gases is stimulating interest in the search for new quantum phases. Examples are the Bose glass and Mott insulator phases found for bosons in a disordered lattice.

Application to quantum information. A fascinating perspective for atoms localized in the nodes of an optical potential is that they can be viewed as a natural quantum register that opens powerful possibilities for quantum computing. This possibility could have tremendous technological interest not only in quantum computation but also in the more general context of rapidly advancing atom-chip technologies. Here integration and miniaturization have proven to be the key to the development of fundamental science into a robust technology.

Out-of equilibrium quantum transport. The possibility to control the coherent quantum dynamics of strongly interacting atomic systems out of equilibrium, has given rise to the growing field of «atomtronics» based on the atomic realization of basic components of quantum circuits. It offers the opportunity of investigating fundamental problems of coherent quantum transport in a cold-atom setup, which enjoys the very weak coupling of the system to the environment and hence the long coherence times. Of particular interest is the possibility to study time-dependent non-equilibrium phenomena such as the response of the system after a «quantum quench» or the onset of novel steady states under continuous driving of the system.

In conclusion, it is to be expected that more and more experiments on cold atomic gases will probe the mesoscopic regime. There is therefore a clear need of forming new young researchers in the field. The candidates will be introduced to different theoretical techniques (such as bosonization and renormalization group techniques, Keldysh Green's function approach etc.) to deal with non-equilibrium effects in the context of low-dimensional and correlated models for cold atomic systems. A strong interaction between the theoretical group in Grenoble and Salerno is foreseen.