Over several decades physicists were developing ever more powerful methods of cooling and trapping of neutral atoms. Nanokelvin temperatures are achieved. As a result, the condensation of rubidium and sodium dilute gases in 1995 has initiated a new area of physics: physics of quantum gases. It is a truly interdisciplinary subject with contributions from statistical physics, quantum optics, atomic physics and condensed matter physics. Perhaps the most important aspect of ultra cold gases is the macroscopic manifestation of quantum features. Moreover: well controlled experiments with only a single copy of the system are possible. Experiment with a large number of atoms in a trap as well as experiments with atoms distributed in tiny wells of optical lattices are available. Thus studying a few atoms in a trap is also of importance. We have cold bosons and cold fermions. We witness here an exemplary interplay between experimental and theoretical results. My group at the Center for Theoretical Physics, since 1995, has been involved in the theoretical effort.
Over last three years we have been expanding our studies of the quantum gases with MAESTRO grant. The research program proposed here is a logical expansion emerging from the most recent results. We plan to continue our work in several interrelated directions:

1. Better understanding of the quantum measurement of ultra cold gases.

Problem of quantum measurement is one of the most controversial topics of quantum theory. Usually stressed is a somewhat mysterious role of the decoherence caused by the interaction of the tiny quantum system with the environment. A detection and a measurement of the BEC is special. The quantum system is not small. We have a single quantum system consisting of even million atoms. In practice the detection is made with the help of light. We are going to develop a microscopic model of the BEC measurement which is based on the fundamental aspects of quantum optics.

2. Continued research on the role of dipolar interactions in quantum gases.

We pioneered research on the role of long range dipolar (magnetic) forces in the condensate. We plan to continue this research inspired by the recent discovery of fragmentation of the dipolar condensate in Stuttgart, in the group of Tilman Pfau. We will start by looking for the minimal energy states of the set of trapped dipoles using rules of classical mechanics. Then a much more complicated quantum version of the problem will be solved. We are going to use Monte Carlo methods.

3. Further study of a few atom systems with dipolar interactions.

Many years ago we have found exact energy levels of a pair of atoms in a trap and interacting by a contact potential. Now, we have just found the solution of the corresponding problem of two dipolar atoms in a trap. It opens access to the dynamics of the system. Next will solve the two dipolar atom problem in the presence of external magnetic field. It is more complicated since the external magnetic field breaks the spherical symmetry. In this case only one component of the angular momentum is conserved. In all these systems there is a coupling between atomic spins and the orbital angular momentum the relative motion. It is a microscopic model of the Einstein de Haas effect.

4. Study of dynamics of multicomponent Fermi gas.

Experiments with ultra cold fermions are also available now in many laboratories. We have also started working on the two fermi mixtures. Our effort is directly related to the experimental program of G. Roati in Florence. In the new paper we studied the ground state of a two component Fermi gas. We use hydrodynamic formulation of the density functional approximation. We stress importance of often neglect, so called, gradient corrections to the well known Thomas-Fermi model. We discovered a sequence of two quantum phase transitions with the symmetric and then also asymmetric separation of the components. As the next step we shall study the dynamics. Of immediate interest is the process in which initially the components are separated by a barrier. As in the planned experiment we shall remove the barrier to see how the components diffuse into each other. A little known but powerful method of pseudo Schrödinger equation representation of the hydrodynamic equation will be used to streamline the numerics.