

Research project objectives

In 2015 the group of researchers from University of Stuttgart led by Tilman Pfau observed, to their surprise, quantum droplets of Dysprosium atoms. These are self-bound very dilute objects which can freely levitate in space in a gradient of magnetic field compensating for the gravity. In contrast to all known ultracold atomic systems, the quantum droplets do not need any external potential to provide their stability. This project is devoted to theoretical studies of these unusual objects.

Quantum droplets are totally new systems of not known properties. They are unique macroscopic objects and their stability is determined by quantum correlations and fluctuations. Energy of quantum fluctuations strongly depends on density of states which, in turn, depends on the space dimensionality. Therefore physical properties of droplets depend on the system geometry. We plan to investigate mainly droplets formed in bose-bose mixtures. We want to gain knowledge about their static and dynamic properties such like: stability diagram, excitation spectrum, collective excitations, vortices and solitons in droplets, coherence and collisions of droplets. We plan to study dynamic of creation of droplets, their thermal properties but also expect to discover new self-bound ultracold systems.

Research project methodology

Stability of droplets is related to beyond mean-field effects. In order to account for these effects the extended Gross-Pitaevskii equation was suggested. A term describing energy of Bogoliubov vacuum is incorporated into the mean field description assuming a local density approximation. It allows to study droplets within well established formalism based on the time dependent Gross-Pitaevskii equation. In a case of a two component mixture droplets can be described by a set of two coupled equations. Extended Gross-Pitaevskii equation will be the working horse of our studies. The equations will be solved numerically. We know from our previous experience that one of the most effective numerical approaches is the method based on the Fast Fourier Transform. The method allows to switch from the position to the momentum representation to determine different components of the evolution operator.

Expected impact of the research project on the development of science

We expect that our studies of fundamental properties of droplets will have a significant influence on quantum simulations. Quantum droplets should enrich a tool-box of quantum engineers. They provide a unique possibilities of controlling very subtle effects beyond the mean field approximation - quantum fluctuations and correlations. They should also bench-mark all models accounting for quantum fluctuations. Quantum droplets because of their coherence and superfluid character can find applications in interferometry and precision measurements. Because of their excitation spectrum, they might be also a very useful coolants for other quantum systems.