Quantum critical points of cold atomic gases

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There are classical and quantum phase transitions. The best known examples of classical phase transitions include the solid↔liquid↔gas transitions of H_2O, the ferromagnet↔paramagnet transition of iron, and the lambda transition of ^{4}He. These phase transitions can be induced by the change of the thermodynamic parameters of the system such as temperature or pressure.

By contrast, the quantum phase transitions are induced by the change of the external field acting on the system. For example, such a field could be the magnetic field interacting with electrons in solids or the laser field interacting with atoms in optical traps. Unlike their classical counterparts, quantum phase transitions are best visible at zero absolute temperature.

Both quantum and classical phase transitions have been studied in the condensed matter community. These studies have provided deep insights into physics of superfluids, superconductors, and various magnetic materials. A new promising playground for the studies of quantum phase transitions has recently emerged in the cold atom community after the spectacular creation of strongly interacting samples of cold atoms. It was then proposed that the easy-to-control cold atom systems can used for the simulation of challenging models from condensed matter physics.

Despite the fact that these results have been met with great interest, the experimental progress in the studies of quantum phase transitions in cold atom setups has been *moderate*. Among other things, this is caused by the difficulties in measuring the observables characterizing quantum phase transitions in those systems.

We have recently proposed the approach, which allows for finding the critical points and exponents of cold atomic systems. The goal of this project is to comprehensively study it. Quantum critical points provide the value of the external field at which the system goes from one phase to another. Critical exponents quantify how fast the properties of the system change near the critical point. The approach that we will study allows for getting these quantities from the images of the spatial distribution of atoms. Such images are taken in nearly all experiments with cold atoms.

Our goal is to find out how accurately one can obtain the critical points and exponents of Bose-Hubbard-like models from our approach. The Bose-Hubbard-like models describe physics of the simplest strongly interacting systems that can be simulated with cold atoms. Realization of this goal should allow for making substantial progress in the detailed studies of quantum phase transitions.

This is important, because the studies of quantum phase transitions provide fundamental insights into rich physics of some of the most complicated quantum systems that we know. They also contribute a lot to understanding of the properties of numerous materials of technological importance such as high-temperature superconductors. One of the key obstacles to progress in the field of quantum phase transitions is our inability to efficiently solve the models describing strongly interacting systems. This problem may be fixed by the quantum simulation of condensed matter models in cold atomic gases. The studies that we have proposed should bring physicists significantly closer to the realization of this goal. This provides motivation for research described in this project.