# Abstract

In this habilitation-thesis a collection of 14 experiments is presented. In these experiments we have developed and used novel techniques to control ultracold gases on the quantum level.

In brief, Bose-Einstein condensates (BEC) and degenerate Fermi gases of laser-cooled alkali atoms are subjected to specially designed optical and magnetic fields. The fields influence in a coherent way the behavior, properties and dynamics of the gases. On this basis we developed tools to prepare, coherently manipulate, and analyze pre-defined quantum states. With this high level of control, it was possible to investigate interesting physics phenomena, and we were able to achieve several breakthroughs in the field of ultracold atoms.

Highlights of our experimental results include the demonstration of phase engineering of a BEC wavefunction where we created solitons in a BEC and studied their propagation. In another experiment we constructed a spatially resolved matter wave interferometer with which we mapped out the phase distribution on a condensate. Illuminating the BEC with a periodic pattern, i.e. an optical lattice, allowed us to study solid states physics phenomena. In a second set of experiments we demonstrated optically tuning of the interaction between atoms with optical Feshbach resonances. Employing either magnetically tunable Feshbach resonances or laser radiation, we were able to produce ground state molecules in well defined quantum states. This led to the production of the first molecular BEC. By tuning the coupling of atom pairs in a Fermi gas of atoms, we could for the first time investigate the so-called BEC-BCS crossover which describes the continuous change from a BEC superfluid to a Bardeen-Cooper Schrieffer (BCS) superfluid.

Due to the excellent control on the quantum level, the developed cold atom techniques open up intriguing prospects for future applications and experiments. They represent a general tool box to investigate fundamental physical phenomena in a pure and undisturbed environment. In the future, cold atoms might serve as a testing ground for fundamental theories or as quantum simulators for complex systems.