Abstract

This thesis reports on detailed studies of collective oscillations of an ultracold gas of fermionic ^{6}Li atoms. A key feature for our experiments is the tunability of particle-particle interactions. This is realized in the vicinity of a broad magnetic Feshbach resonance. The Feshbach resonance also has the effect that there exists a stable bosonic molecular ^{6}Li$_2$ state on the repulsive interaction side of the resonance. These molecules can form a Bose-Einstein condensate (BEC). On the other side of the resonance fermionic atoms form Cooper pairs and the system can enter a superfluid Bardeen-Cooper-Schrieffer (BCS) state. There is a smooth crossover between the limits of a molecular BEC and a superfluid fermionic quantum gas in the BCS state. This BEC-BCS crossover is an interesting model system for other fields of physics, e.g. neutron stars or high-temperature superfluidity. Our experiments allow for measurements in this crossover regime.

Collective oscillations are a useful tool to study the properties of many-body systems. In this thesis, we present different low-energy collective oscillation modes. We focus on radial modes of a cigar-shaped gas cloud, as these are suited best for measurements in our experimental setup. In particular, we give a theoretical description of the radial compression mode, the radial quadrupole surface mode and the radial scissors mode.

We conduct precision measurements of the frequency of the radial compression mode. This probes the equation of state of the system and allows for a detection of beyond mean-field effects. The experimental results fully agree with theoretical predictions in the unitarity and in the BEC limit. High precision results in the strongly interacting BEC regime allow for a detailed quantitative analysis of theoretical models and favor quantum Monte Carlo theory over mean-field BCS theory.

The radial quadrupole surface mode is not affected by the equation of state of the system. Therefore we use this mode to determine if the gas is in the hydrodynamic or in the collisionless regime. We examine frequency and damping of this mode, along with its expansion dynamics. Our results show the transition between the collisional regimes in the BEC-BCS crossover.

We present first results on the radial scissors mode that show the way to future experiments. A detailed characterization of the temperature dependence of this mode together with studies of rotating systems open up possibilities to test superfluidity. This enables us to study superfluidity at temperatures of a few ten percent of the Fermi temperature. In this way our experiments with ultracold gases in the BEC-BCS crossover regime are connected to theories of high-temperature superconductivity.