Summary

In this thesis we present our experimental study of the dynamics of an ultracold Fermi gas at finite temperature in the presence of unitarity limited interactions. We trap fermionic ^{6}Li in a single focused laser beam and tune the interactions using a Feshbach resonance. At finite temperature the cloud is made up of a superfluid component coexisting with a noncondensed part. In the presence of unitarity limited interactions both obey the Euler equations describing hydrodynamic behavior. However, whereas the superfluid is hydrodynamic due to its long range order, the noncondensed state is hydrodynamic due to the very short collision times in comparison to the trap frequency. Thus, the former is quantum hydrodynamic and the latter collisional hydrodynamic. Moreover, on resonance the crossover from collisional hydrodynamic to near-collisionless is at a temperature much higher than the condensation critical temperature. Distinguishing experimentally between the two regimes is difficult. It is the purpose of this thesis to study the finite temperature dynamics of the cloud and the effect of the coexisting hydrodynamic fluids primarily in the unitarity limit.

In a first set of experiments we used collective modes to study the finite temperature dynamics of the cloud. Using the scissors mode excitation we are able to map the temperature versus interaction strength phase diagram and identify the crossover from hydrodynamic to near-collisionless dynamics. We find a large temperature region above the critical temperature where the noncondensed state shows collisional hydrodynamic behavior. To further study the temperature dependence of the collisional hydrodynamic state above the critical temperature on resonance we compare different collective modes. The experimental data showing the transition from hydrodynamic to near-collisionless behavior as a function of temperature is compared to a theoretical model that can include both pairing correlations and Pauli blocking. We find that both elements are necessary to properly describe the observed change of dynamics.

In subsequent experiments we study rotational properties of the cloud. By means of a rotating ellipse we introduce angular momentum into the noncondensed component. The measurement of the precession angle of the quadrupole mode excitation allows us to determine the precession frequency of the cloud, which relates to its angular momentum. The dissipation of the angular momentum can be fitted to a model, which gives the collision time that one uses to quantify how hydrodynamic the cloud is. We find that on resonance the noncondensed state is most hydrodynamic and shows very long lifetimes of the angular momentum. Next we measure the total angular momentum of the cloud to obtain the moment of inertia (MOI). The presence of the superfluid quenches the MOI of the noncondensed component. Hence, by measuring the temperature dependence of the MOI on resonance we are able to estimate a critical temperature

In the context of interference experiments of two molecular BECs also the deep hydrodynamic state of the cloud is observed. In these set of experiments we observe that close to the unitarity limit the two colliding clouds do not penetrate each other, but rather collide hydrodynamically.

As a first step to study the effect of the two hydrodynamic fluids in the context of second sound, we develop the experimental and analytical tools to excite and analyze adiabatic higher order collective modes. It has been theoretically suggested that they may offer a route to measuring entropy waves, that is to say, second sound. Introducing a repulsive laser beam perpendicular to the axial direction of the cigar shape cloud and a camera to image the axial density profile, we observe collective modes up to third order in the zero temperature limit. We recover the wave form and oscillation frequency of each mode.