Ultracold Fermi gases and Molecular Bose-Einstein condensates

Supervisor: Dr Chris Vale

In the cold molecules lab we have several research programs underway which use ^{6}Li gas cooled to quantum degeneracy. We have the only such system in the southern hemisphere which can create fermionic superfluids and Bose-Einstein condensates of molecules. Our primary research goals are to study the various types of superfluidity which can occur in these macroscopic quantum systems. Superfluidity is the remarkable property of flow without resistance, a striking example of which is high temperature superconductivity, where electrical current can flow with zero resistance or dissipation. Systems of ultracold atoms offer new prospects for understanding these macroscopic quantum effects because of the unprecedented levels of control we can achieve in cold atom experiments. This, combined with the ability to image cold atom clouds in fine detail using laser light, means we can tailor and probe these superfluids in ways never before imagined. We currently have PhD projects to offer studying the following aspects of superfluidity.

Bragg scattering:
We have recently shown how Bragg scattering of particles from a cold atomic cloud can be used to observe pairing in fermionic superfluids. These pairs form in a strongly interacting system where correlations between particles lead to dramatic dynamical effects. We next want to characterise how these correlations build up as the temperature of a gas gets lower and lower. Investigating the nature and temperature dependence of these quantum correlations will form the basis of this PhD project.

Lower dimensional superfluids
Lower dimensional (< 3D) systems can display features which differ dramatically from their 3D counterparts. For instance, high temperature superconductivity occurs in quasi-2D structures for reasons which still defy theoretical understanding. We have recently developed a 2D trap for fermionic atoms which will be applied to realise a 2D superfluid. This PhD project will explore superfluidity in these systems specifically examining the critical properties and pairing that occurs in 2D systems.

Dipolar quantum gases
Nearly all cold atom experiments to date have utilised the simplest possible form of scattering interaction between particles, ie. spherically symmetric s-wave scattering. It has recently become possible to prepare gases of ultracold molecules which possess a permanent electrical dipole moment. The goal of this project is to produce such a dipolar gas to be used for studies of fundamental questions in condensed matter physics. Long range anisotropic interactions exist in dipolar systems and these give rise to a host of new quantum many body phases which relate closely to some of the big questions in condensed matter.