Quantum Phase Transitions and the BCS-BEC Evolution with Population Imbalance

Carlos Sá de Melo
School of Physics, Georgia Institute of Technology, Atlanta, USA
carlos.sademelo@physics.gatech.edu
https://www.physics.gatech.edu/user/carlos-sa-de-melo

In these two lectures I will describe a couple of examples of exotic quantum phase transitions that emerge in the context of ultra-cold atoms, when Fermi mixtures are subject to population (spin) imbalance. I will focus on the emergence of superfluid phases of these mixtures with changing attractive interactions.

In the first lecture, I will introduce the problem of the evolution from BCS to BEC superfluids as interactions are tuned for population (spin) balanced system of fermions of equal mass, and show that a simple crossover between weak and strong coupling superfluid phases occurs. However, when population (spin) imbalance is present, new superfluid phases with topological structure emerge, and quantum phase transitions take place as interactions are tuned. Prototypical examples are equal-mass Fermi systems, such as ^{6}Li-^{6}Li or ^{40}K-^{40}K mixtures, where connections to known condensed matter systems involving electrons can be made.

In the second lecture, I will discuss the more exotic problem of a mixture of fermions with unequal masses, where interactions between them, as well as the populations of each type of fermion can be tuned. In this case, the prototypical example is the Fermi mixture ^{6}Li-^{40}K, which does not have an easy connection to known condensed matter systems. I will discuss the quantum phases that emerge and show that the mass differences lead to an asymmetric phase diagram along the axis of population imbalance. I will conclude that the mass anisotropy can stabilize uniform superfluid phases when light fermions are in excess.

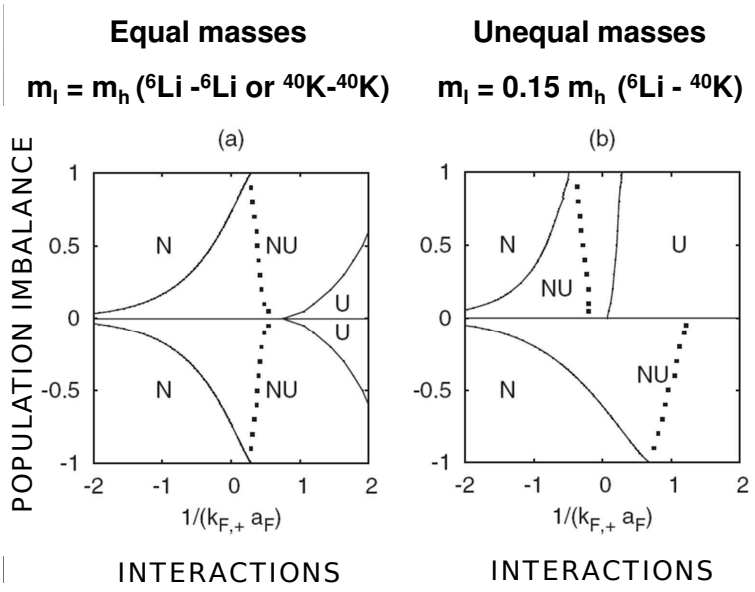

Figure 1: Zero temperature phase diagrams of population (spin) imbalance versus interactions (scattering length) for equal and unequal mass Fermi mixtures. The normal phase is denoted by N, the uniform superfluid phase is denoted by U, and non-uniform phases are denoted by NU. In (a) the masses of fermions are the same, while in (b) the mixture has lighter fermions with mass m_l and heavier fermions with mass m_h. Examples of such mixtures are ^{6}Li-^{6}Li or ^{40}K-^{40}K for equal masses and ^{6}Li-^{40}K for unequal masses.