Inhomogeneous Superfluid Phases in Resonantly Interacting ^{6}Li-^{40}K Mixtures

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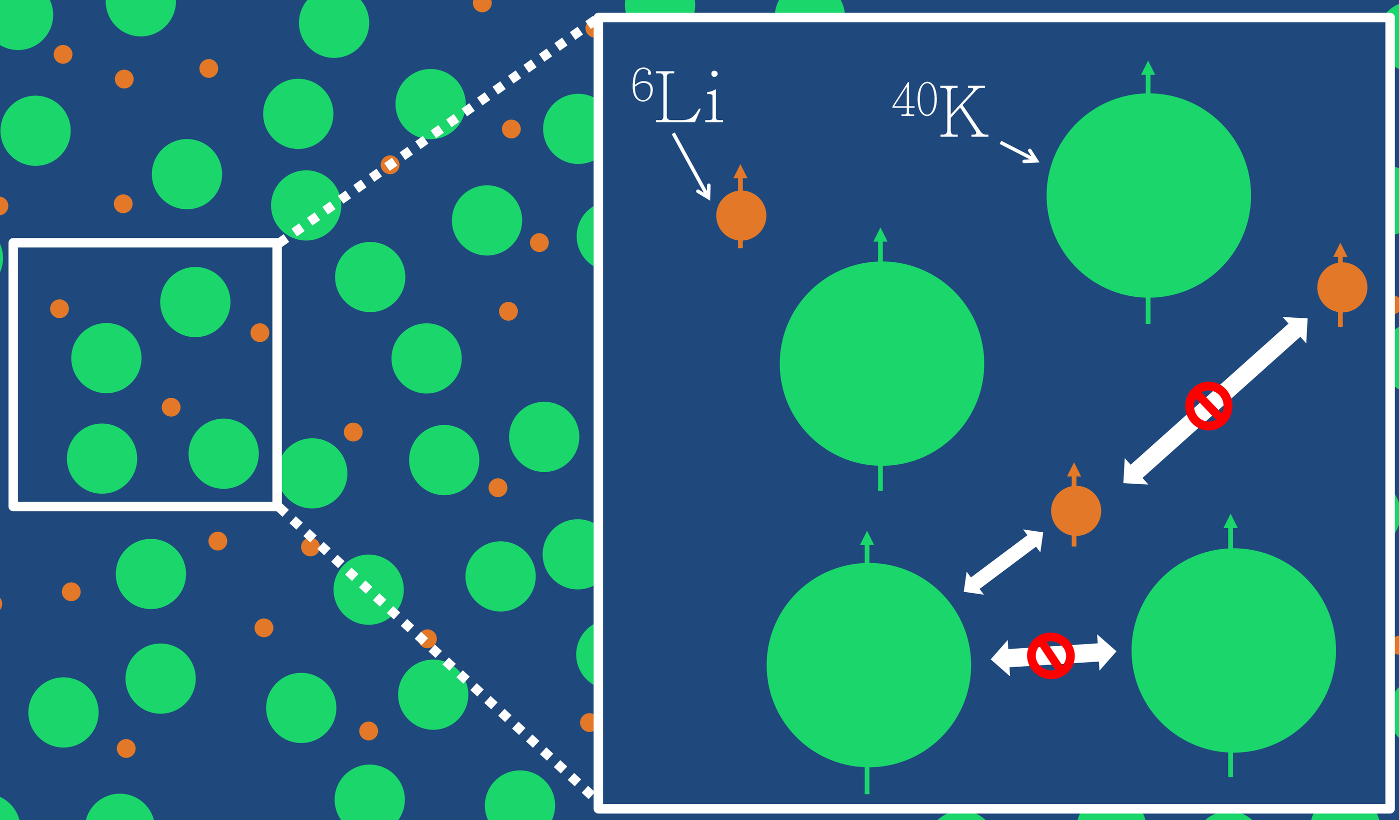
Mass Imbalance

We study mixtures of ^{6}Li and ^{40}K atoms. The large difference in mass between the atoms has a huge effect on the phase transitions present in this mixture.

$$\frac{m_K}{m_{Li}} = 6.7$$



Interactions

At low temperatures only *s*-wave collisions occur between atoms. Between fermions *s*-wave interactions can only exist for different particles.

In the mixtures of ^{6}Li and ^{40}K atoms we study, all atoms are in the same spin state. Therefore only atoms of different species interact. The interaction is short-range and attractive. In the presence of an attractive interaction fermions can form Cooper pairs. In this mixture a Cooper pair consists of one ^{6}Li and one ^{40}K atom.

Population Imbalance

We study mixtures where the densities of the two atomic species are not equal. This means a non-zero polarization

$$P = \frac{n_{Li} - n_K}{n}$$

with $n = n_{Li} + n_K$.

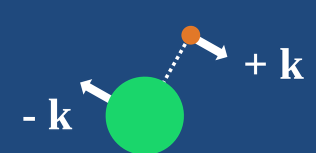
The polarization on this poster is

$$P \approx 0.2.$$

Phase Transitions

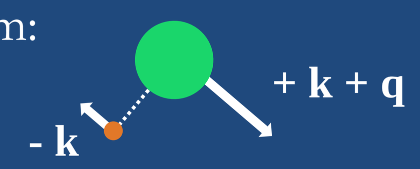
Because of the Pauli exclusion principle not all fermions in a gas can occupy the ground state. As a consequence, Bose-Einstein condensation can not occur. However, in the presence of an attractive interaction fermions can form Cooper pairs. Cooper pairs can Bose-Einstein condense. We studied this phase transition in a Fermi gas with a mass and population imbalance. We found that exotic superfluids can form in ^{6}Li-^{40}K mixtures.

In the case of equal densities the Cooper pairs have zero effective momentum:

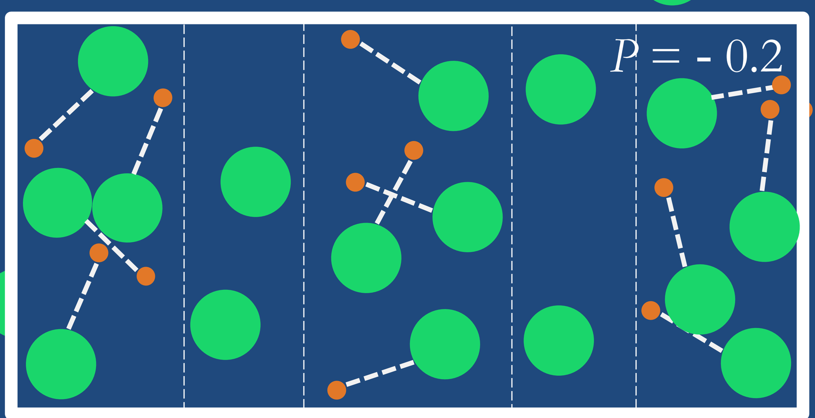


This results in a position-independent superfluid density, *i.e.*, a homogeneous superfluid.

For a majority of ^{40}K we find that a phase transition occurs to a superfluid where the Cooper pairs have nonzero momentum:

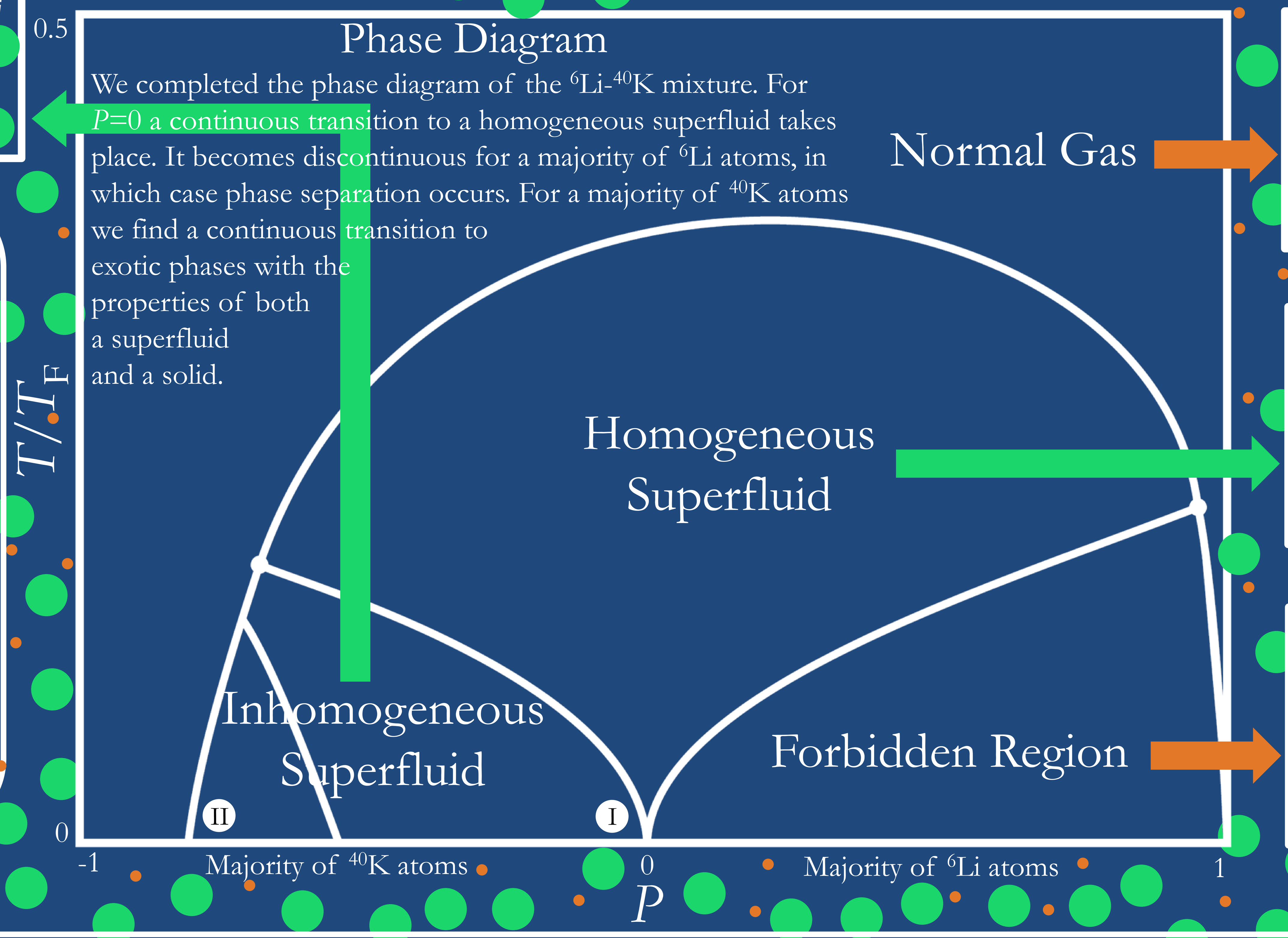


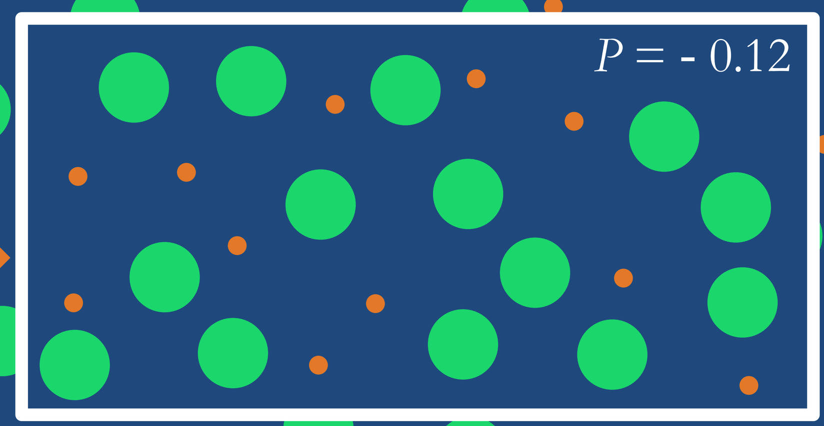
This results in a position-dependent superfluid density, which means that the superfluid now also has properties of a solid phase.

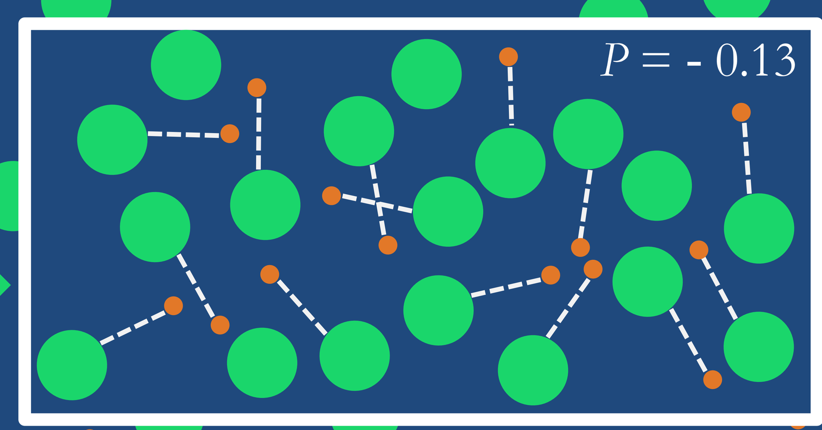


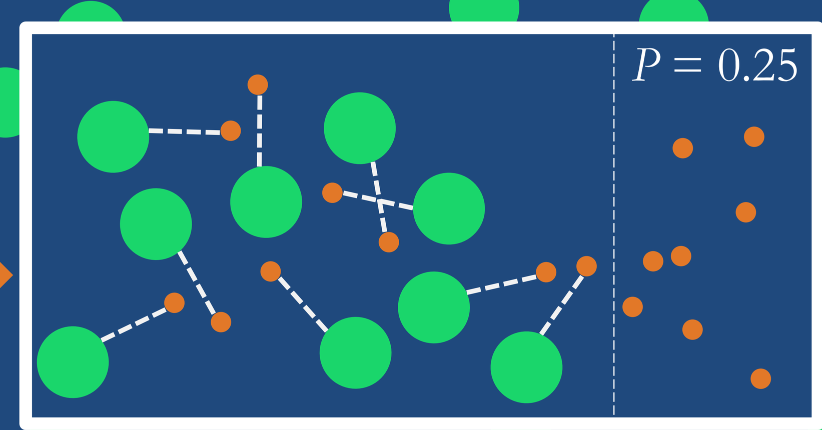
Phase Diagram

We completed the phase diagram of the ^{6}Li-^{40}K mixture. For P=0 a continuous transition to a homogeneous superfluid takes place. It becomes discontinuous for a majority of ^{6}Li atoms, in which case phase separation occurs. For a majority of ^{40}K atoms we find a continuous transition to exotic phases with the properties of both a superfluid and a solid.



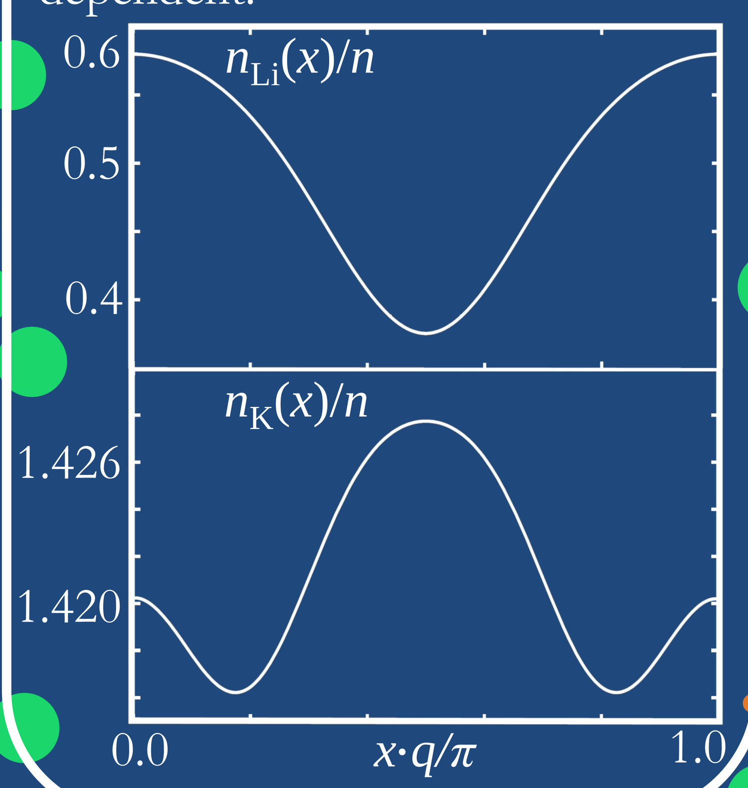






Densities

In the inhomogeneous superfluid the atomic densities are position dependent.

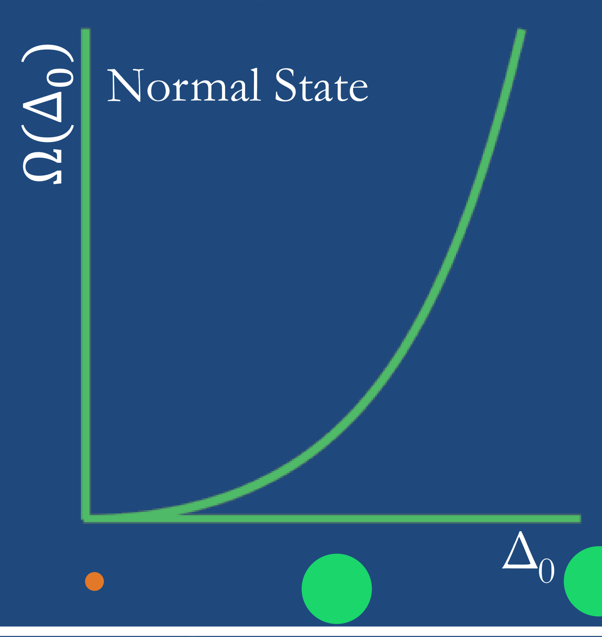


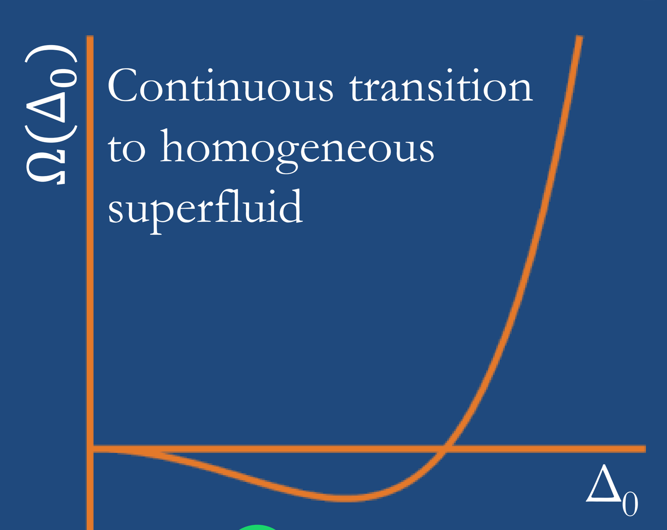
Landau Theory of Phase Transitions

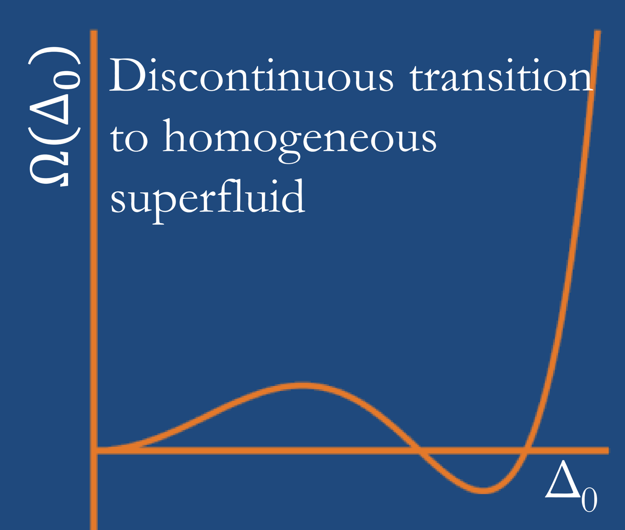
We determine the phase transitions in the ^{6}Li-^{40}K mixture by studying its free energy as a function of the order parameter. For the transition to a superfluid the order parameter Δ describes the condensate of Cooper pairs. The role of the free energy is played here by the thermodynamic potential Ω, which can be calculated in a mean-field approximation after making an Ansatz for Δ. A global minimum of Ω at $\Delta = 0$ means that there is no condensate, the gas is in the normal state. If the global minimum is located at a nonzero value of Δ there is a condensate of Cooper pairs and a phase transtition has occurred. The minimum can shift from zero in a continuous or a discontinuous fashion.

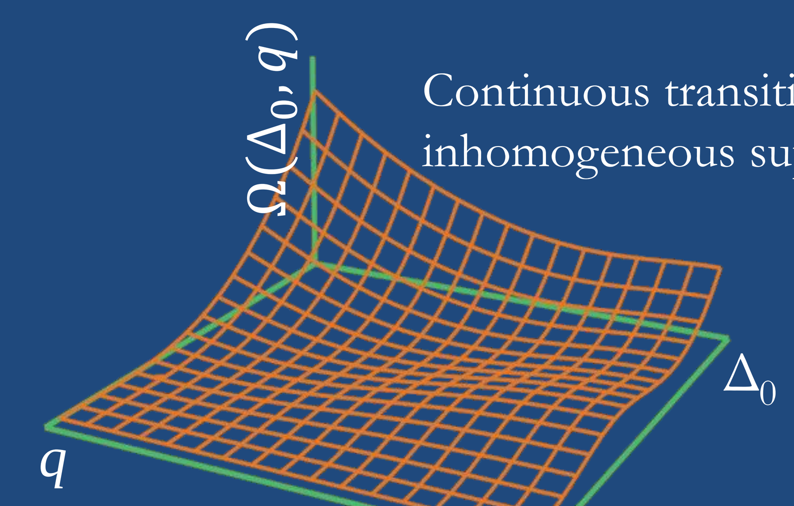
To describe the transition from a gas of fermions to a homogeneous superfluid of condensed Cooper pairs we assume a position-independent order parameter, $\Delta(\mathbf{x}) = \Delta_0$. By minimizing the resulting thermodynamic potential we find both the continuous and discontinuous transitions from the normal state to the homogeneous superfluid.

To describe the exotic superfluids we assume a Cooper pair with nonzero momentum, $\Delta(\mathbf{x}) = \Delta_0 \cos(x \cdot q)$ (I) and $\Delta(\mathbf{x}) = \Delta_0 [\cos(x \cdot q) + \cos(y \cdot q) + \cos(z \cdot q)]$ (II). The thermodynamic potential now also depends on momentum and had to be minimized with respect to both Δ_0 and q.









Continuous transition to inhomogeneous superfluid

http://arxiv.org/pdf/1212.5450.pdf

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