we can get the pseudogap equation

The Fermi energy is defined as $E_F = E_0 + k^2/(2M)$, where $k = (\hbar^2m^2)1/2$ is the Fermi momentum and $M = (m + m)/2$ is the average mass of $^{6}$Li and $^{40}$K.

**Results**

![Figure 1](image1.png)  
**Figure 1**: $T$-$p$ phase diagram of $^{6}$Li-$^{40}$K mixture in a homogeneous case on the BCS side under the interaction $1/\xi = 0.1$. Here "PS" and "FFLO" indicate pseudogapped normal state and phase separation, respectively. The superfluid density of Fermi state $\sigma_{\text{Sarma}}(n_\uparrow)$ is calculated by the mean field theory.

![Figure 2](image2.png)  
**Figure 2**: Phase diagram of $^{6}$Li-$^{40}$K as in Fig. 1 except that $1/\xi = 0.5$. The conventions follow that in Fig. 1.

![Figure 3](image3.png)  
**Figure 3**: Phase diagram of $^{6}$Li-$^{4}$K at unitary.

![Figure 4](image4.png)  
**Figure 4**: Phase diagram of $^{6}$Li-$^{4}$K in the BEC regime.

![Figure 5](image5.png)  
**Figure 5**: Phase diagram of $^{6}$Li-$^{4}$K in the $p$ vs $1/\xi$p plane for $T = 0.001T_c$ when $p = 0$. Inset shows the FFLO wave vectors $q$ along different phase transition lines.

![Figure 6](image6.png)  
**Figure 7**: $T$-$p$ phase diagram of the FFLO phases in Fermi-Fermi mixtures under different mass ratios at unitarity. The regions surrounded by solid lines indicate the stable FFLO superfluid against phase separation, while the dashed lines give the unstable ones. We just show three unstable regions of representative mass ratios for guide.

**Conclusions**

We have studied the exotic FFLO states for Fermi-Fermi mixtures in a homogeneous case with both population and mass imbalances, using a pairing fluctuation theory. From our numerical results we know that in order to find a stable FFLO state in 3D Fermi gas systems in experiments, one may take large mass ratios of Fermi-Fermi mixtures, such as $^{6}$Li-$^{4}$K, $^{6}$Li-$^{3}$He and $^{6}$Li-$^{7}$Be.

Looking for Fulde-Ferrell-Larkin-Ovchinnikov states in Fermi-Fermi mixtures

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**Introduction**

FFLO states which were first predicted by Fulde and Ferrell (1964) (FF) and Larkin and Ovchinnikov (1964) (LO) in an s-wave superconductor under the presence of a Zeeman field almost fifty years ago, have attracted enormous attentions in condensed matter physics (Casalbuoni et al., 2004), including heavy fermion superconductors (Radovan et al., 2004; Kerenzi et al., 2004) and ultra-cold Fermi gases (Liao et al., 2010). In the original prediction of Fulde and Ferrell, Cooper pairs have finite momenta $\mathbf{q}$ and the order parameter is $\Delta(\mathbf{r}) = \Delta_0 e^{i\mathbf{q}\cdot\mathbf{r}}$, while Larkin and Ovchinnikov considered a more complicated pairing state with a sinusoidal variation of the order parameter, for example, $\Delta(\mathbf{r}) = \Delta_0 e^{i\mathbf{q}\cdot\mathbf{r}} \cos(\mathbf{Q}\cdot\mathbf{r})$. In recent years, ultra-cold Fermi gases have provided a good opportunity to investigate these exotic superfluid states, because of their easy controllability in interactions, population imbalances as well as mass independent features (Chen et al., 2005; Bloch et al., 2008; Radoshko et al., 2010). Although there are many theoretical results studying FFLO states in 3D equal-mass Fermi gas systems, both in a homogeneous case (Sheehy et al., 2006; Hu et al., 2006; Yoshida et al., 2007; He et al., 2007) and in a trap (Machida et al., 2006; Zhang et al., 2007; Kinnunen et al., 2006), these exotic states still have not been observed experimentally for their small region in phase space and a very low temperature acquired. For these reasons, some theoretical physicists switch the attentions to different mass systems (Gubbels et al., 2009; Baarsma et al., 2010, 2012) or equal-mass systems with a spin-orbit (SO) coupling (Liu et al., 2013; Zhang et al., 2013). In Refs. Gubbels et al. (2009) and Baarsma et al. (2010, 2012), Strom and coworkers studied the superfluid or LO state in a homogeneous $^{6}$Li-$^{40}$K mixture. But even the simplest isomorphic superfluid state, i.e. the FFLO state, has not been investigated in this kind of system before. In fact, this is an interesting subject in ultra-cold Fermi-Fermi mixtures and needs to be studied in detail.

**Theoretical Formalism**

We have studied the exotic FFLO states for Fermi-Fermi mixtures, where momentum $k = q$ pairs with $k - q$ and the Cooper pairs have a nonzero center-of-mass momentum $\mathbf{q}$. The dispersion relations of such pairs are $\varepsilon_{\mathbf{k}+\mathbf{q}} = \varepsilon_{\mathbf{k}-\mathbf{q}} + \Delta_0 e^{i\mathbf{q}\cdot\mathbf{r}}$, and the self-energy is (Chen et al., 2005) $\Sigma(\mathbf{k}) = \sum_q G(q)|\Delta(q-K)|^2/k = \sum_q G(q)|\Delta(q-K)|^2/\xi_q$. So the total T-matrix $\mathbf{T}(\mathbf{q})$ contains a contribution from paired condensates $\rho_{\mathbf{q},\uparrow}(\mathbf{q})$, $\rho_{\mathbf{q},\downarrow}(\mathbf{q})$, where $\rho_{\mathbf{q},\uparrow}(\mathbf{q}) = -\Delta_0^2/\xi_q$, $\rho_{\mathbf{q},\downarrow}(\mathbf{q}) = 0$, and $\xi_q = (\omega_q, \mathbf{q})$ are four vector notations, $\omega_q = (\omega_q, \mathbf{a})$, $\varepsilon_q = (\varepsilon_q, \mathbf{a})$ and even Matsubara frequencies (Fetter and Walecka, 1971) (where $\omega_q + \varepsilon_q = 0$). In our treatment of BCS-BEC, at finite $T$, the total T-matrix $\mathbf{T}(\mathbf{q})$ contains a contribution from paired condensates $\rho_{\mathbf{q},\uparrow}(\mathbf{q})$, $\rho_{\mathbf{q},\downarrow}(\mathbf{q})$, where $\rho_{\mathbf{q},\uparrow}(\mathbf{q}) = -\Delta_0^2/\xi_q$, $\rho_{\mathbf{q},\downarrow}(\mathbf{q}) = 0$, and $\xi_q = (\omega_q, \mathbf{q})$ are four vector notations, $\omega_q = (\omega_q, \mathbf{a})$, $\varepsilon_q = (\varepsilon_q, \mathbf{a})$ and even Matsubara frequencies (Fetter and Walecka, 1971) (where $\omega_q + \varepsilon_q = 0$).

The Thouless criterion (Thouless, 1960) implies that $\rho_{\mathbf{q},\uparrow}(\mathbf{q})$ is dominated by the vicinity of $Q = 0$, so $\rho_{\mathbf{q},\uparrow}(\mathbf{q})$ is approximated by $\rho_{\mathbf{q},\uparrow}(\mathbf{q}) = -\Delta_0^2/\xi_Q = -\Delta_0^2/\xi_0$. For the self-energy $\Sigma(\mathbf{k}) = \sum_{\mathbf{q}} G(q)|\Delta(q-K)|^2/\xi_q$, the $\xi_q$ can be divided into two parts, $\Sigma_q(\mathbf{k}) = \Sigma_{\xi_q}(\mathbf{k}) + \Sigma_{\xi_0}(\mathbf{k})$, where $\Sigma_{\xi_q}(\mathbf{k}) = \sum_{\mathbf{q}} G(q)|\Delta(q-K)|^2/\xi_q$ and $\Sigma_{\xi_0}(\mathbf{k}) = -\Delta_0^2/\xi_0$. For the Dyson’s equation $G^{-1}_q(\mathbf{k}) = G^{-1}_{\xi_q}(\mathbf{k}) + G^{-1}_{\xi_0}(\mathbf{k})$, we can write down the full Green’s function:

**References**

- [Ref1](http://example.com)
- [Ref2](http://example.com)
- [Ref3](http://example.com)