Induced *p*-wave superfluidity in asymmetric Fermi gases

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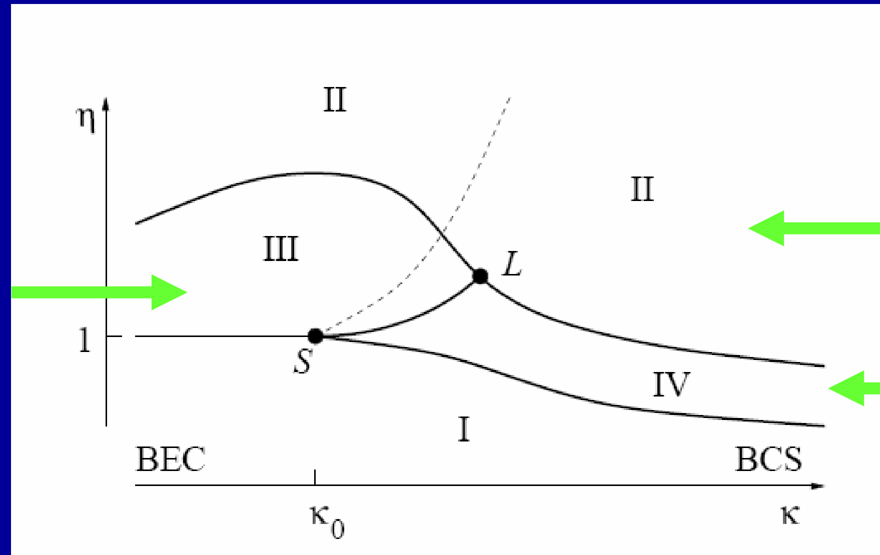
BEC + Normal Fermi gas
= gapless superfluid

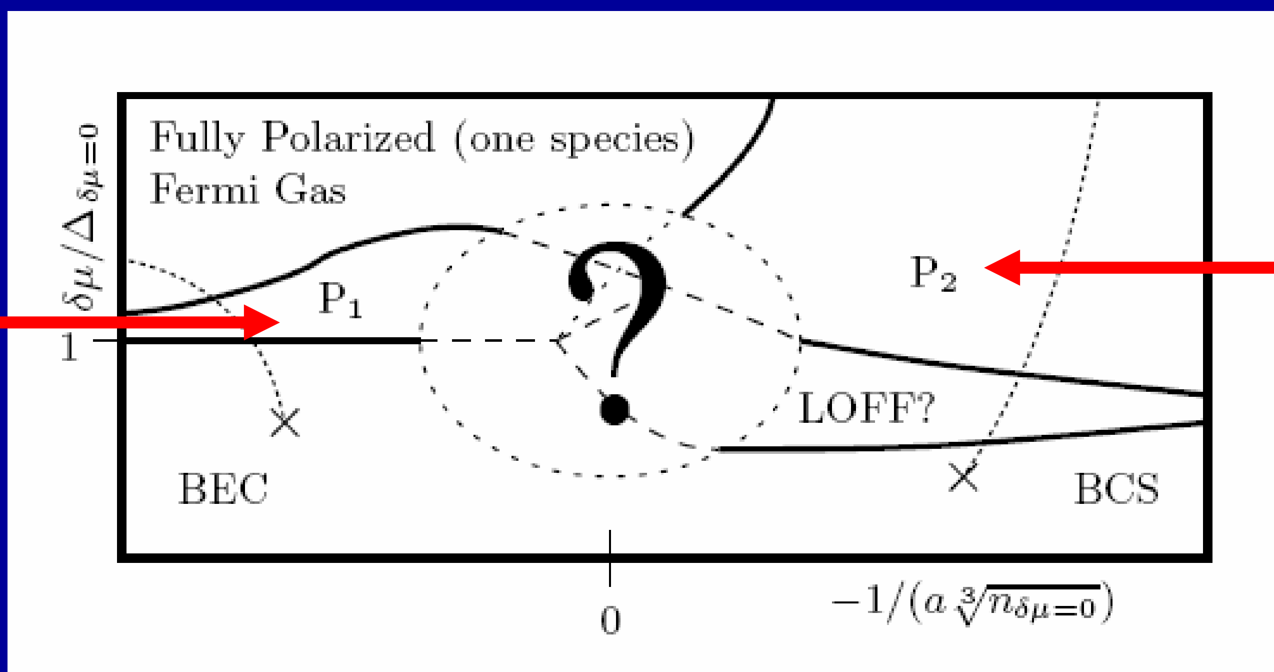


Normal Fermi gas

LOFF, DFS

Son and Stephanov, PRA 74, 013614 (2006)

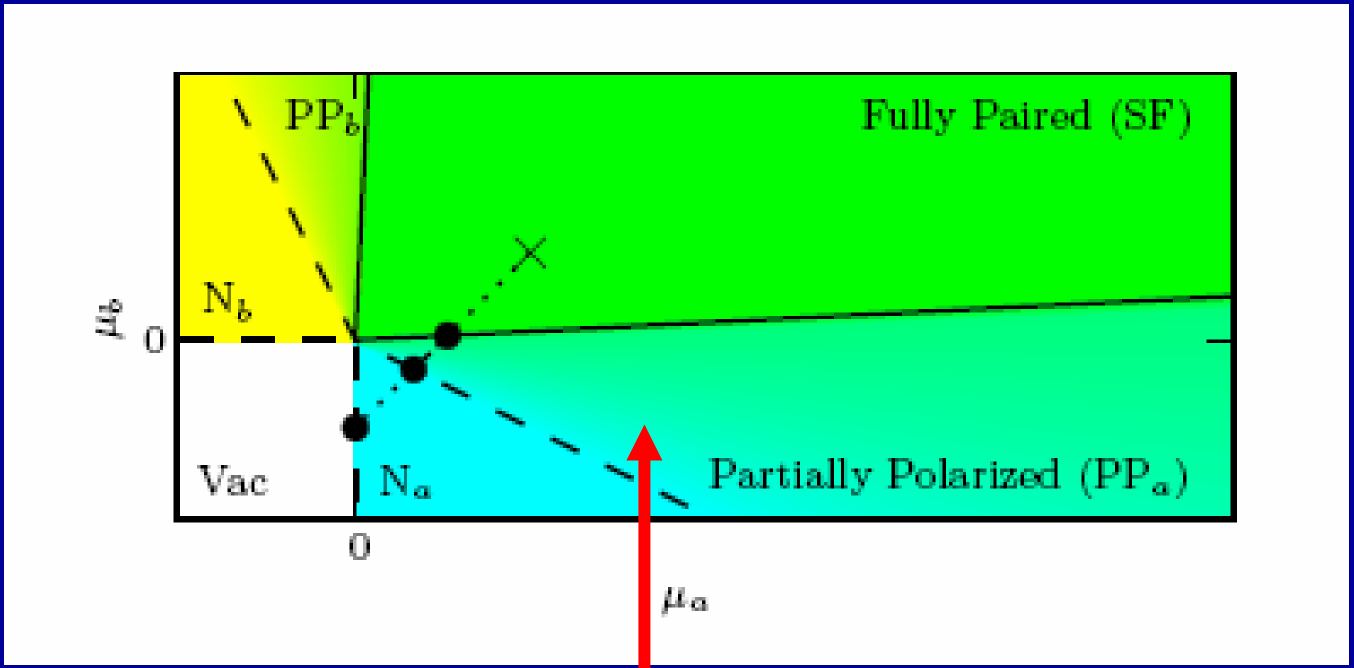
BEC + p-wave
superfluids



2 p-wave
superfluids

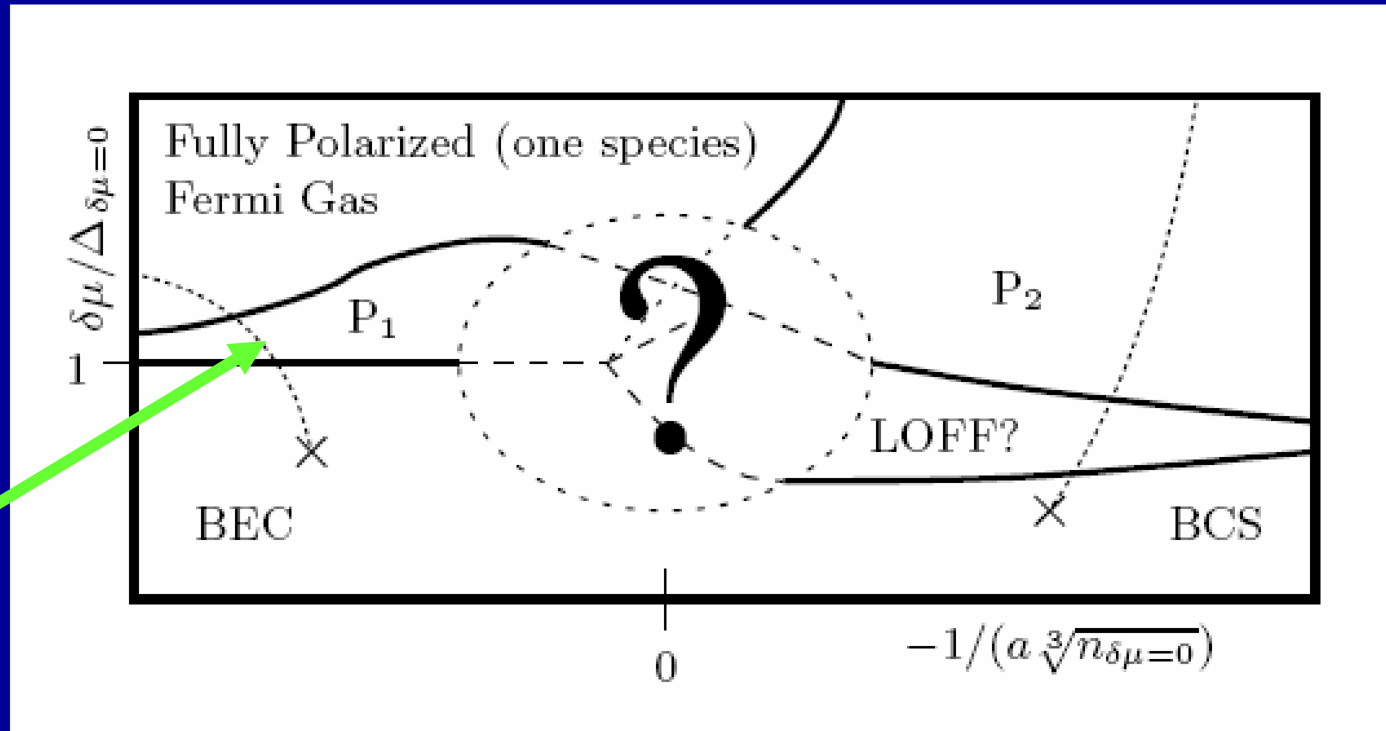
Bulgac, Forbes, Schwenk, PRL 97, 020402 (2006)

What we think is going on at unitarity?



The existence of the partially polarized phase is required by the strong constraints imposed by *ab initio* calculations and some experimental data

Bulgac and Forbes, cond-mat/0606043, PRA 75, 031605(R) (2007)
Chevy, PRA, 74, 063628 (2006)

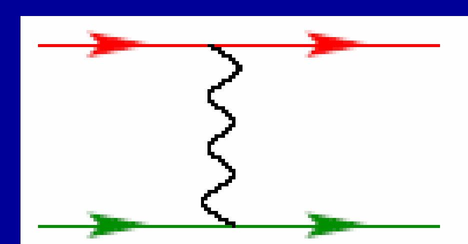


BEC regime

➢ all minority (spin-down) fermions form dimers and the dimers organize themselves in a Bose superfluid

➢ the leftover/un-paired majority (spin-up) fermions will form a Fermi sea

➢ the leftover spin-up fermions and the dimers coexist and, similarly to the electrons in a solid, the leftover spin-up fermions will experience an attraction due to exchange of Bogoliubov phonons of the Bose superfluid



Mean-field energy density

$$\frac{E}{V} = \frac{3}{5}\frac{\hbar^2 k_F^2}{2m} n_f + U_{fb} n_f n_b + \frac{1}{2} U_{bb} n_b^2 + \varepsilon_2 n_b$$

$$U_{fb} = \frac{\pi\hbar^2 a}{m}\alpha_{fb} \approx \frac{\pi\hbar^2 a}{m} 3.6, \qquad U_{bb} = \frac{\pi\hbar^2 a}{m}\alpha_{bb} \approx \frac{\pi\hbar^2 a}{m} 1.2$$

$$n_b = \frac{n_\downarrow}{2}, \qquad n_f = n_\uparrow - n_\downarrow = \frac{k_F^3}{6\pi^2}, \qquad \varepsilon_2 = -\frac{\hbar^2}{ma^2}$$

Induced interaction between the un-paired spin-up fermions (Bardeen, Baym, Pines, 1967)

$$U_{ind}(q_0,\vec{q}) = U_{fb}^2 \frac{2n_b\varepsilon_{\vec{q}}}{q_0^2 - \varepsilon_{\vec{q}}(\varepsilon_{\vec{q}} + 2n_b U_{bb})}, \qquad \varepsilon_{\vec{q}} = \frac{q^2}{2m_b}, \qquad m_b = 2m$$

$$U_{ind}(0,\vec{q}) = -\frac{\pi\hbar^2 a}{m}\frac{\alpha_{fb}^2}{\alpha_{bb}}\frac{1}{1+\frac{q^2}{2m_b^2 c^2}}, \qquad m_b c^2 = U_{bb} n_b = \frac{2\pi\hbar^2 a\alpha_{bb} n_b}{m_b}$$

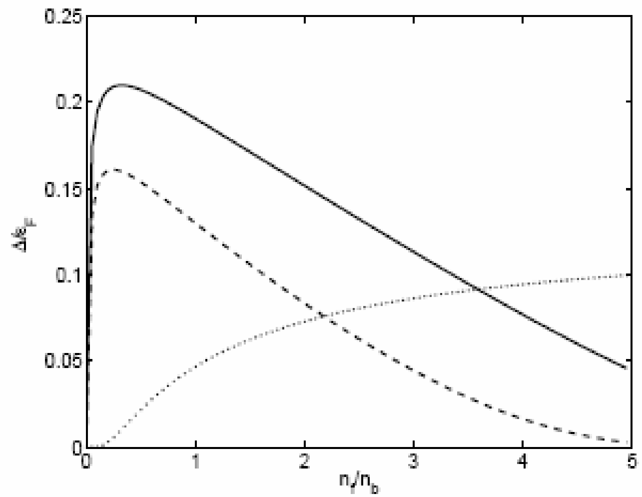


FIG. 1: The ratio Δ/ε_F ($\varepsilon_F = \hbar^2 k_F^2/2m$) as a function of n_f/n_b, for a fixed boson number density $n_b = 10^{13}\ cm^{-3}$ and $n_b a^3 = 0.064$ (solid line) and $n_b a^3 = 0.037$ (dashed line) respectively. The dots show the value of the gap in the case of p-wave paring for $n_b a^3 = 0.064$.

p-wave gap

Bulgac, Bedaque, Fonseca, cond-mat/030602
Bulgac, Forbes, Schwenk, PRL 97, 020402 (2006)

$$\Delta_p \sim \varepsilon_F \exp\left(-0.44\frac{n_b}{n_f}\right), \quad \text{if} \quad \frac{n_f}{n_b} \ll k_F a \ll 1$$

$$\Delta_p \sim \varepsilon_F \exp\left(-\frac{6\pi^2}{\alpha_{fb}^2 (k_F a)^2 \ln(x^2)}\frac{n_b}{n_f}\right), \quad \text{if} \quad \frac{n_f}{n_b} \gg k_F a, \quad x^2 = \left(\frac{\hbar k_F}{m_b c}\right)^2$$

$$\Delta_p\big|_{\max} \sim \varepsilon_F \exp\left(-\frac{5.6}{k_F a}\right), \quad \text{if} \quad \frac{n_f}{n_b} \approx 0.44 k_F a \ll 1$$

!!!

Induced interaction has however a strong momentum
and frequency dependence and BCS approximation might fail

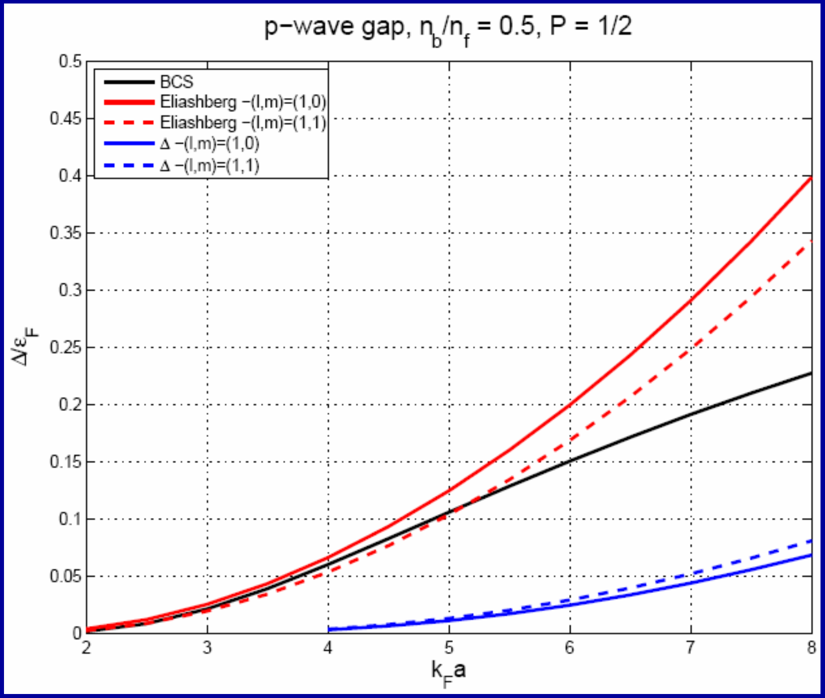
What happens at large couplings?

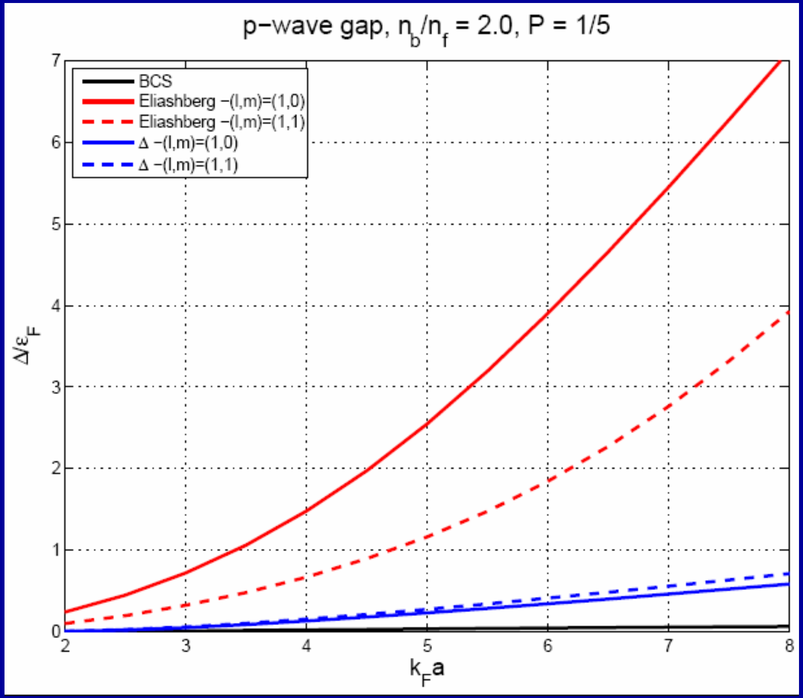
$$\Sigma(p) = [1 - Z(p)]p_0 + \chi(p)\sigma_3 + \phi(p)\sigma_1 = i\int \frac{d^4 q}{(2\pi)^4} G(p-q)U(q)$$

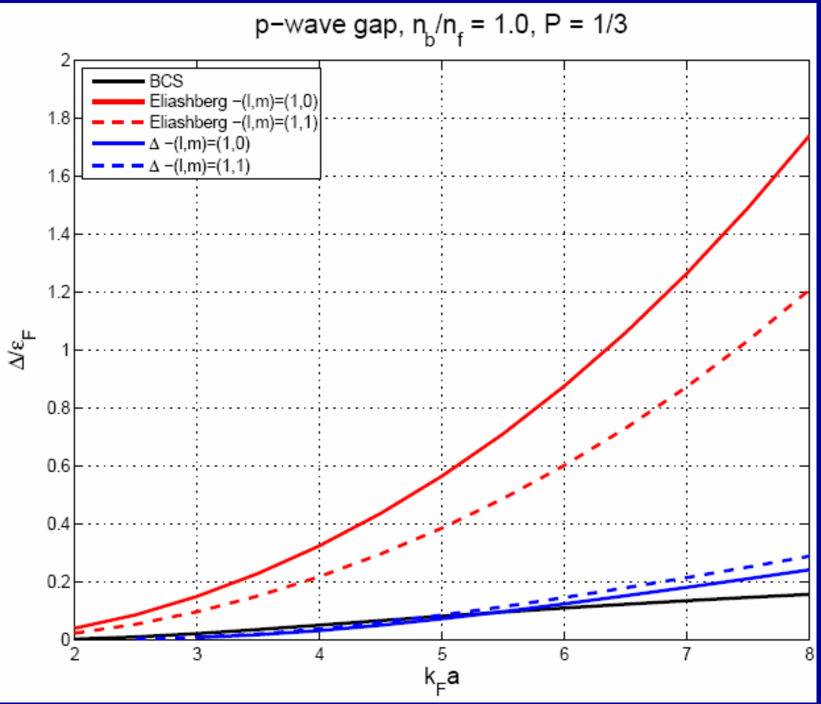
$$G_0(p) = \frac{1}{p_0 - \varepsilon(p)\sigma_3 - i\eta}$$

$$G(p) = \frac{1}{Z(p)p_0 - \varepsilon(p)\sigma_3 - \phi(p)\sigma_1 - i\eta}$$

$$p = (p_0, \vec{p}), \quad q = (q_0, \vec{q})$$







Calculations performed by Sukjin Yoon