Superfluid excitations of dipolar fermi gases

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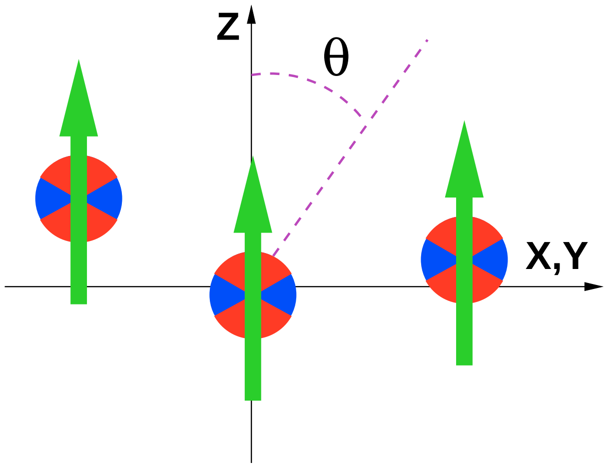
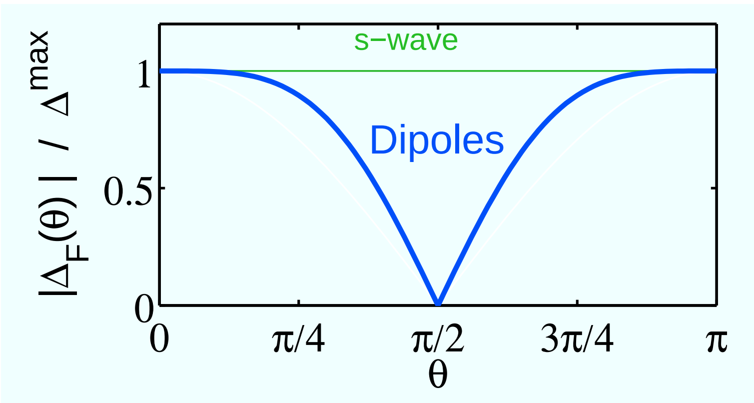
Uniform 3D dipolar Fermi gas



BCS pairing gap on Fermi surface has zeros



Baranov et al. PRA **66**, 013606 (2002)

- Cold: $T < T_c^{BCS}$
- static external field (E or B)
  $\Longrightarrow$ full polarisation
- single-species (spin polarised)
- dilute
  $\Longrightarrow$ Energy dominated by Fermi sea
- short-range interaction assumed negligible (Fermi exclusion, no p-wave resonances)
- Node structure like in *polar phase* of $^3\mathrm{He}$. (never experimentally realized)

Experimental prospects for superfluidity

$$T_c^{\mathrm{BCS}} = 1.44\, E_F \exp\left(-\frac{\pi}{2|a_D|k_F}\right); \qquad |a_D| = \frac{2m|\mathbf{d}|^2}{\pi^2\hbar^2}$$

Baranov et al., PRA **66**, 013606 (2002)

Comparison to RECENT VALUES

K.-K. Ni et al., arXiv:0808.2963

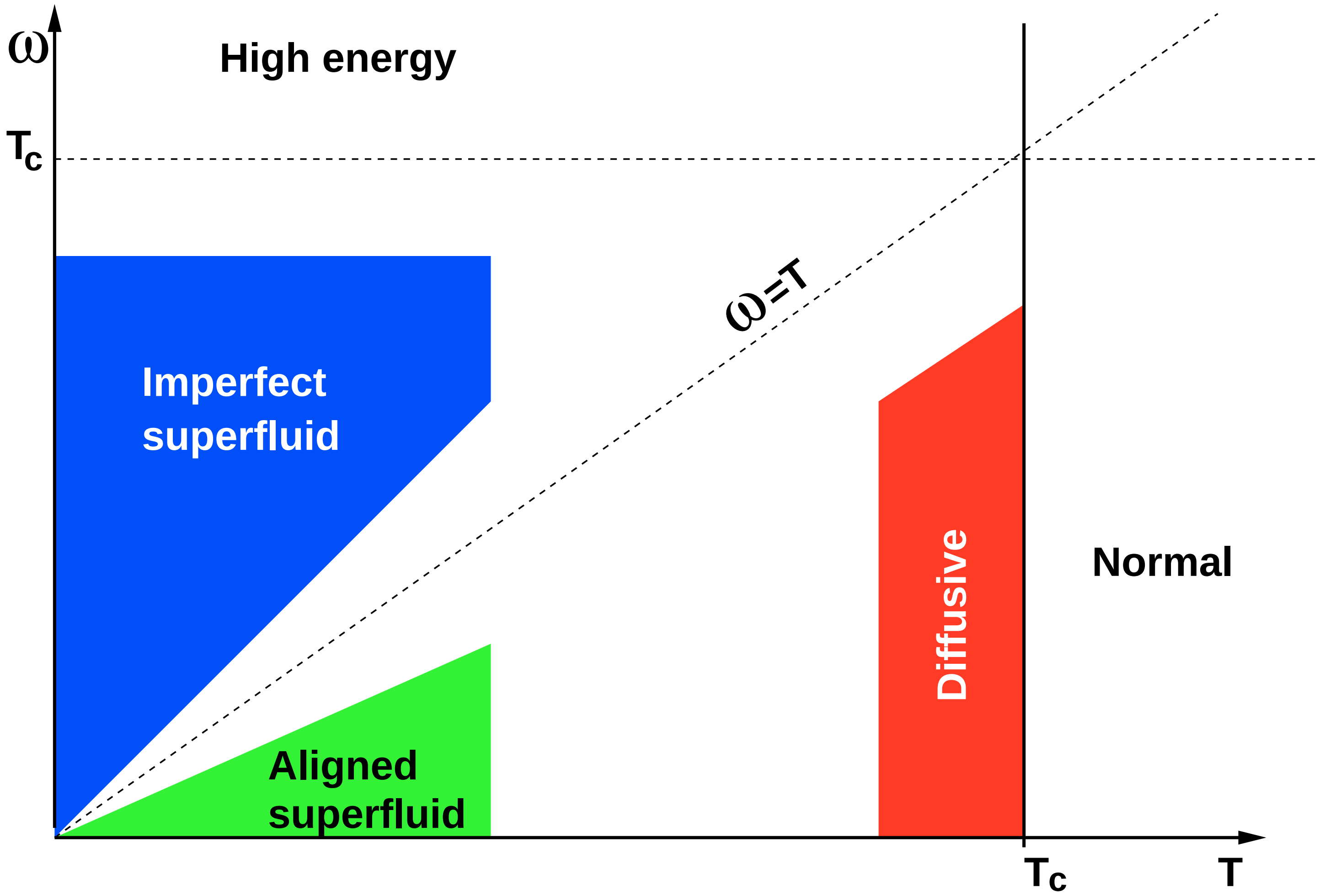
$$\begin{aligned} |\mathbf{d}| &= 0.566\,\mathrm{D} \\ n &\sim 10^{12}/\mathrm{cm}^3 \end{aligned} \Longrightarrow \boxed{T_c^{\mathrm{BCS}} \approx 1.6\mathrm{nK}}$$

small!
:–(

However, with $10\times$ more density (plausible?), one would have

$$\boxed{T_c^{\mathrm{BCS}} \approx 40\mathrm{nK} \sim T_F \qquad :-)}$$

Collective excitation regimes

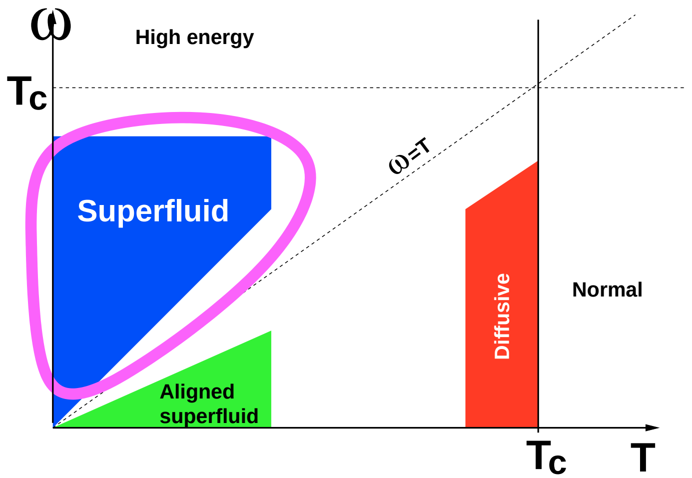


Weak Phase perturbations of the ground state order parameter

$$\Delta_0(x-y) \quad \rightarrow \quad \Delta(x,y) = \Delta_0(x-y)\; e^{2i\phi(x,t)}$$

Goldstone mode

Damped BCS superfluid regime

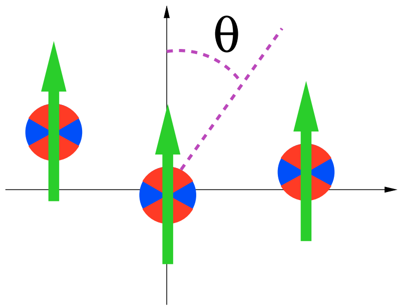


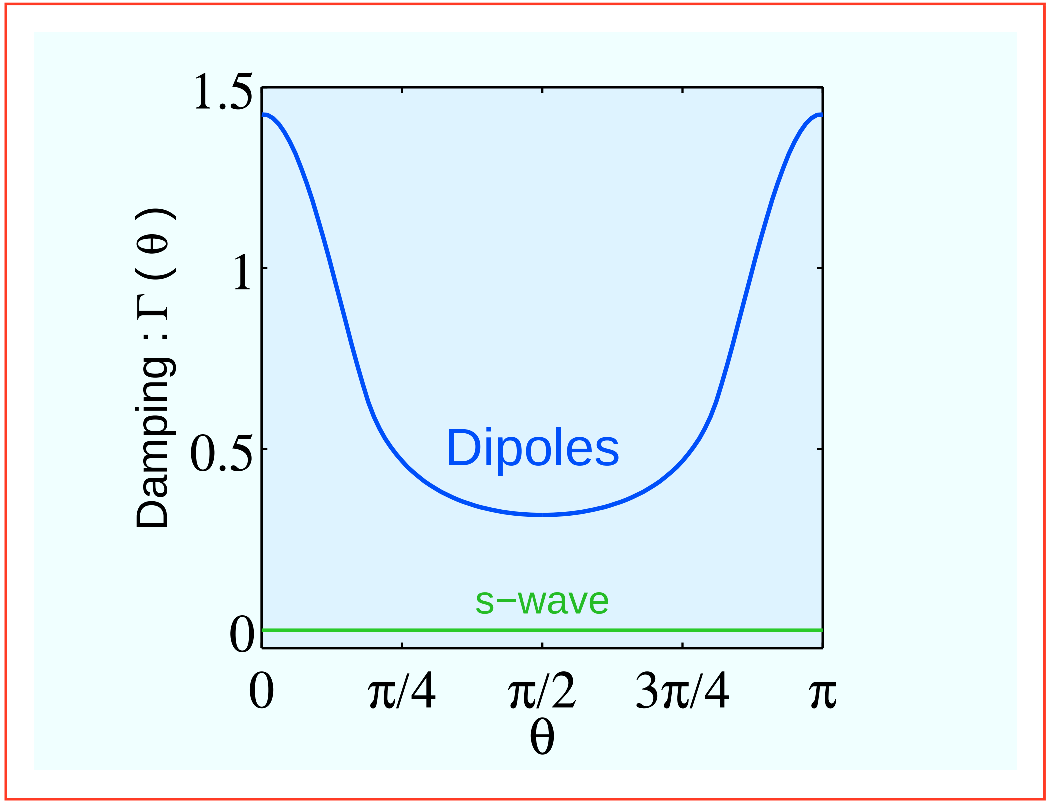
Anisotropic, nonzero damping

(no damping in s-wave BCS)

Beliaev process:

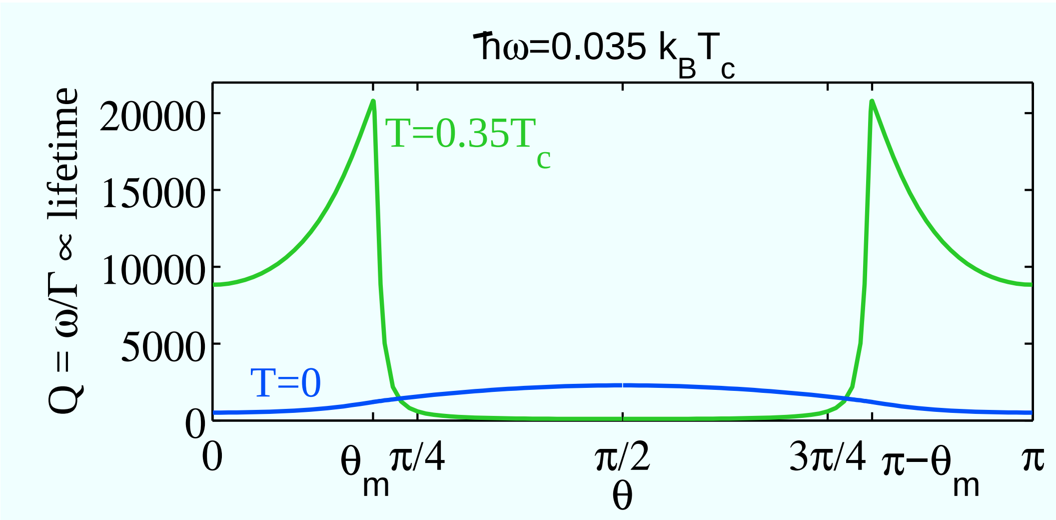
collective $\Longrightarrow$ $2\times$quasipart.

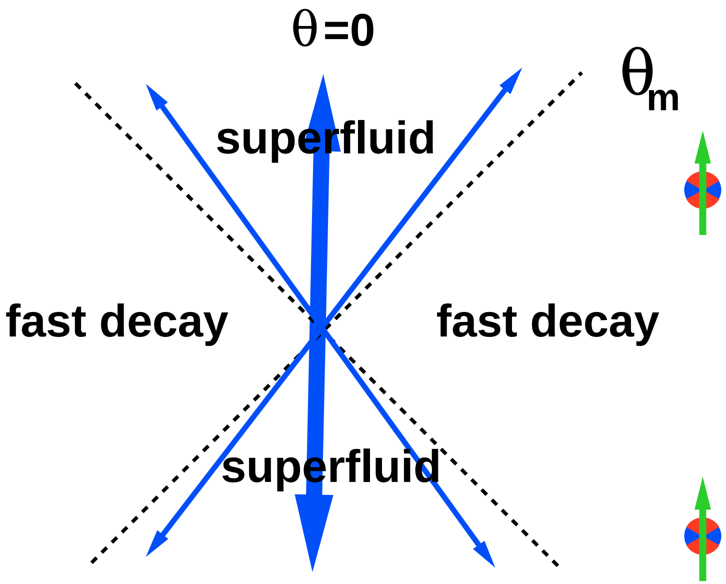




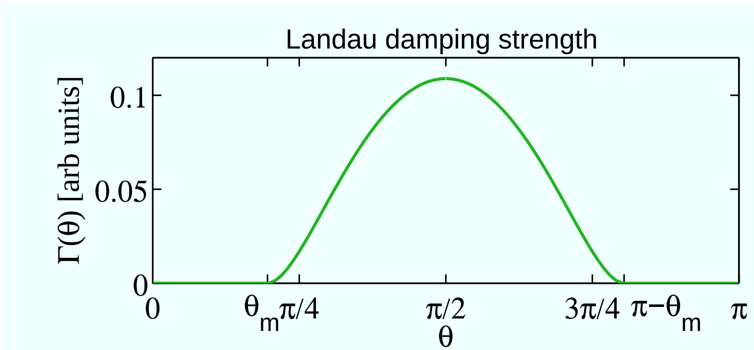
New “Aligned superfluid” regime

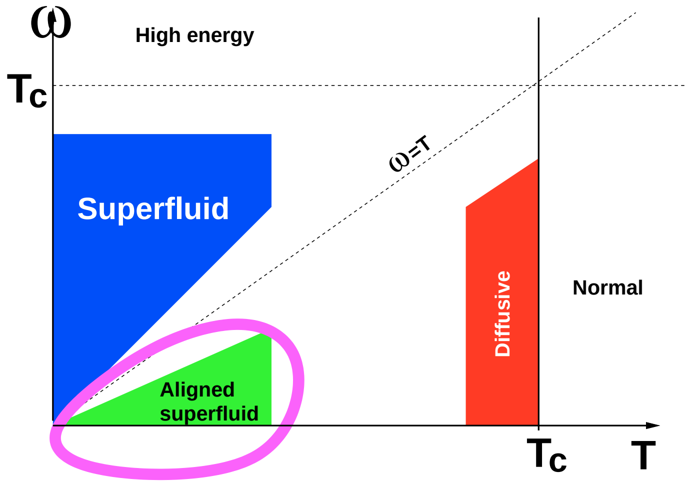
(No s-wave BCS analogue)





Strong Landau damping $\Gamma \propto \frac{1}{\omega}$



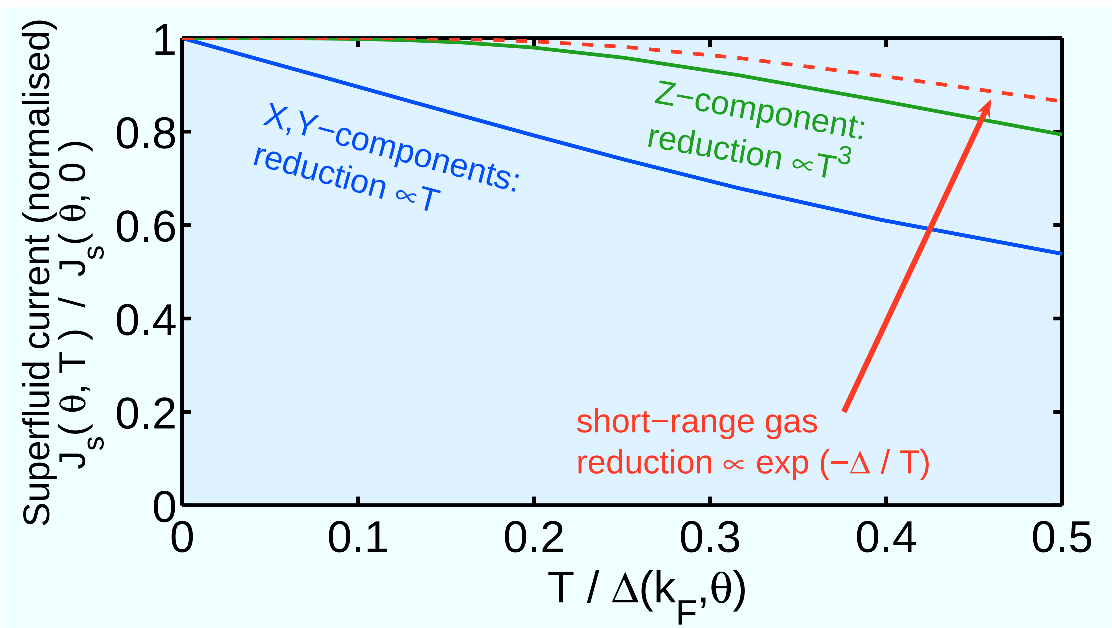


Deflected current response

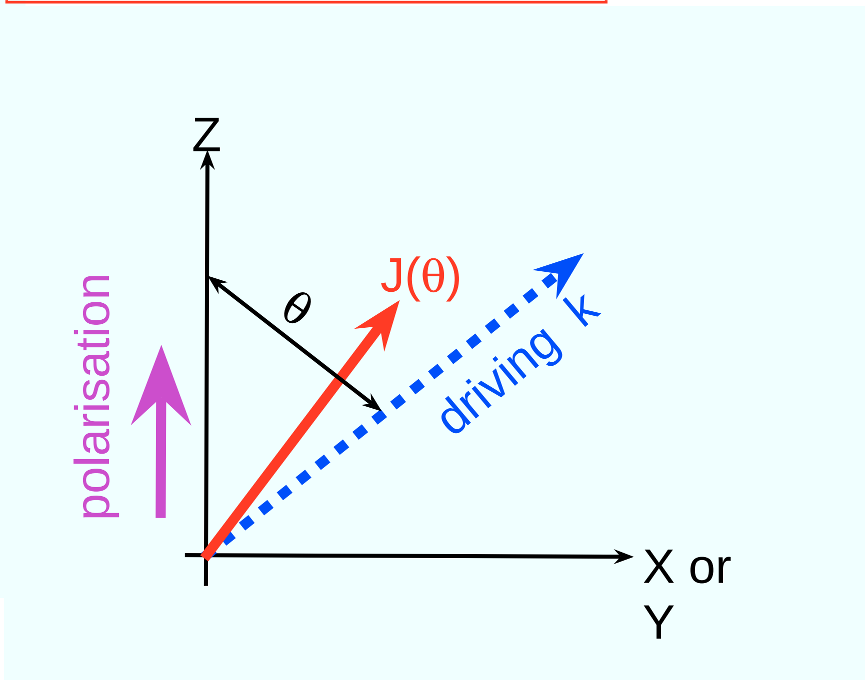
- Current response J_s to an EXTERNAL phase perturbation of the gap

$$\Delta(x,y,t) = \Delta_0(x-y)e^{2i\phi(x,t)}$$

- Strable driving frequency ω, wave-vector k, in direction θ.



Deflected current



Hamiltonian

$$\widehat{H} = \text{K.E.} + \frac{1}{2}\int d^3x\, d^3y \left\{ \widehat{\Psi}^\dagger_x \widehat{\Psi}_x\, V_D(x-y)\, \widehat{\Psi}^\dagger_y \widehat{\Psi}_y \right\}$$

Resulting effective BCS mean-field Hamiltonian

$$\widehat{H}_{\text{eff}} = \frac{1}{2}\int d^3x\, d^3y \left\{ \begin{array}{ll} \frac{\hbar^2}{m}\, \widehat{\Psi}^\dagger_x\, \nabla^2 \widehat{\Psi}_x\, \delta(x-y) & \textit{Kinetic} \\ \Delta^*(x-y)\, \widehat{\Psi}_x \widehat{\Psi}_y - \Delta(x-y)\, \widehat{\Psi}^\dagger_x \widehat{\Psi}^\dagger_y & \textit{BCS} \\ W(x-y)\, \widehat{\Psi}^\dagger_x \widehat{\Psi}_y & \textit{Hartree} \end{array} \right\}$$

Gap consistency equation

$$\Delta(x-y) = V_D(x-y) \left\langle \widehat{\Psi}_x \widehat{\Psi}_y \right\rangle_{\text{eff}}$$