Holographic model of the $S^{\pm}$ multiband superconductor

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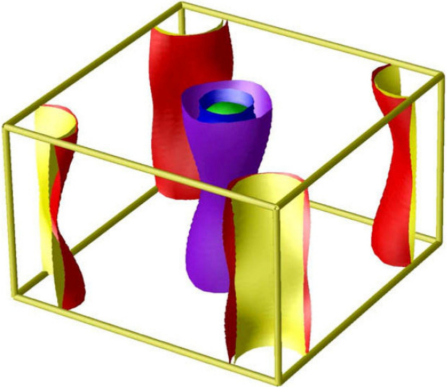
Multiband superconductors

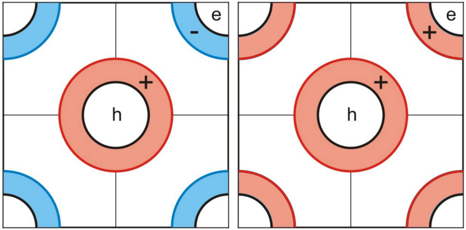
Most Fe-based superconductors have several Fermi surface sheets.



J. Paglione & R. L. Greene, Nature Physics 6, 645658 (2010)

$S^{\pm}$ order parameter

The condensates with different phases may appear on different Fermi surfaces (bands).



If signs of the isotropic condensates on two bands are opposite

$$\mathrm{sign}(\Delta_1) = -\mathrm{sign}(\Delta_2),$$

this is called $S^{\pm}$-order. It is suitable for spin fluctuation mediated mechanisms of superconductivity.

Holographic model

The idea of our work is to treat the two conduction bands as furnishing the fundamental representation of the global $U(2)$ group.

$$\begin{pmatrix} \Delta_1 \\ \Delta_2 \end{pmatrix} \in \mathcal{F}(U(2)_{\mathrm{band}})$$

Thus in the holographic model we anticipate $U(2)$ nonabelian gauge theory with fundamental scalar

$$S = \int d^3x dr \, \sqrt{-g} \left[-\frac{1}{4} tr(F_{\mu\nu}F^{\mu\nu}) - (D_\mu \phi)^\dagger (D_\mu \phi) + 2\phi^\dagger \phi \right],$$

Currents

We look for a solution using the ansatz

$$\phi(r) = \phi_0(r) \begin{pmatrix} \cos(\theta) \\ \sin(\theta) \end{pmatrix},$$

$$A = M(r) \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} dt + \Lambda(r) \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} dt,$$

In the second-quantized formalism these fields would be dual to the operators

$$\phi_\alpha \leftrightarrow \langle c_\alpha c_\alpha \rangle, \qquad M \leftrightarrow \langle c_1^\dagger c_1 + c_2^\dagger c_2 \rangle, \qquad \Lambda \leftrightarrow \langle c_1^\dagger c_2 + c_2^\dagger c_1 \rangle$$

Thus M corresponds to number of particles,
Λ – to interband current (μ and λ – corresponding potentials)

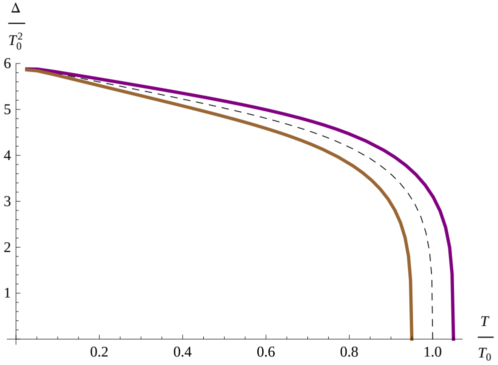
Condensation

In the black-hole background in this ansatz we observe condensation of the scalar at T_c

$$T_c \approx 0.118\sqrt{\rho_0\left(1 \pm \frac{\lambda}{\mu}\right)}$$

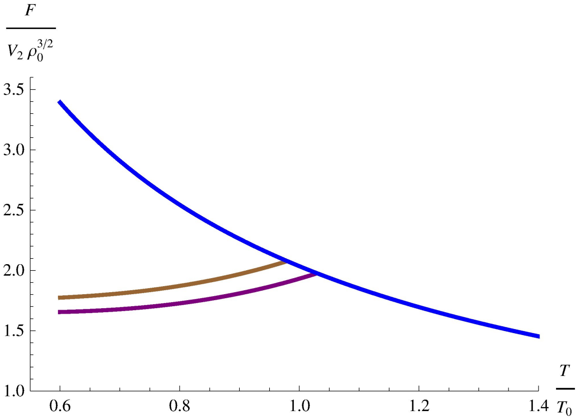
S^{++} – top sign,

$S^{\pm}$ – bottom sign



Free energy

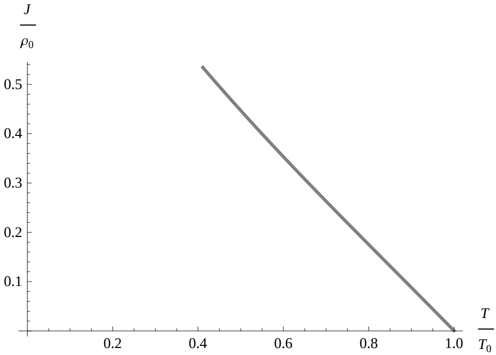
One can study the phase diagram of the material by calculating the free energy.



Purple curve – $S^{\pm}$ state, brown curve – S^{++}, blue curve – normal state

Interband current

Interestingly, even in the degenerate case the interband current is generated without the source.



And it affects the physical properties of material.

AC conductivity

In the case of electron-type and hole-type bands (with opposite charges) the electric field couples to the nonabelian part of the current.

$$J_\mu^{e.m.} \leftrightarrow A^3 \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},$$

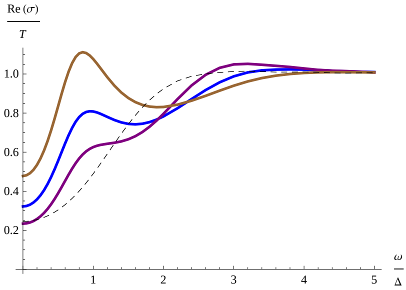
and equations of motion are

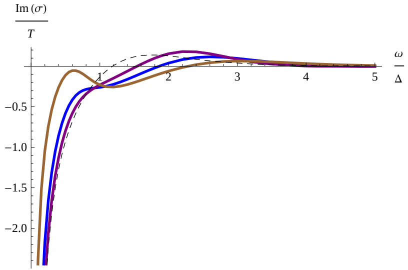
$$A_x^3: \quad \partial_r^2 A_x^3 + \frac{f'}{f}\partial_r A_x^3 + \left(\frac{\omega^2}{f^2} - \frac{\phi_0^2}{f} + 4\frac{\Lambda^2}{f^2}\right) A_x^3 + \frac{4i\omega\Lambda}{f^2} A_x^2 = 0,$$

$$A_x^2: \quad \partial_r^2 A_x^2 + \frac{f'}{f}\partial_r A_x^2 + \left(\frac{\omega^2}{f^2} - \frac{\phi_0^2}{f} + 4\frac{\Lambda^2}{f^2}\right) A_x^2 - \frac{4i\omega\Lambda}{f^2} A_x^3 = 0.$$

AC-conductivity

The result is

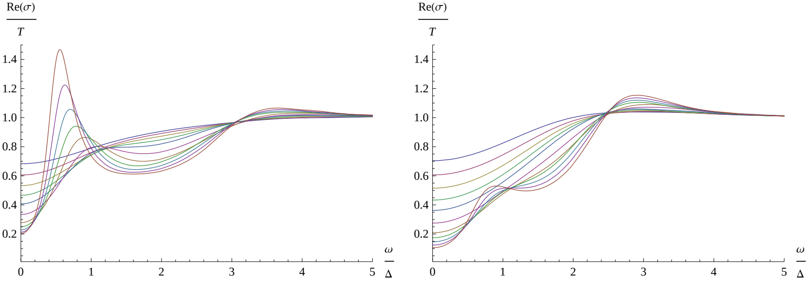




Purple curve – $S^{\pm}$ state, brown curve – S^{++}.
blue curve – degenerate case with $\lambda = 0$. Dashed curve – the ordinary one-band superconductor.
$\lambda = -0.05\mu$, $T \approx 0.8T_0$

The amplitude of the peak in mid-IR region is suppressed in the stable solution.

Temperature dependent features

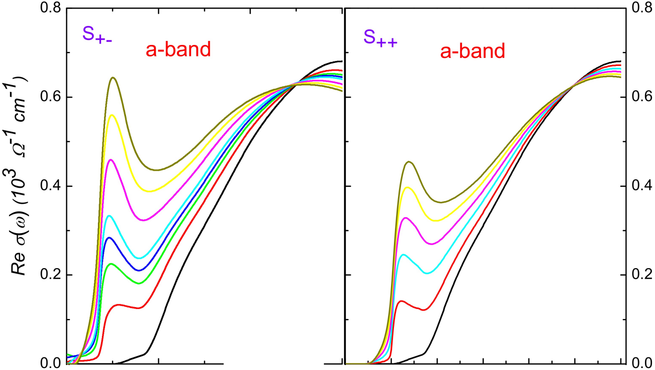


a) $\lambda = 0$ and b) $\lambda = -0.1\mu$ $\frac{T}{T_c} = 0.97, 0.96, 0.94, 0.92, 0.9, 0.87, 0.85, 0.81, 0.77, 0.74, 0.71$

The peak should be indeed related to the interband current.
There is isothermal point in the spectrum.

Eliashberg theory study

These pictures are surprisingly similar to the result of the Eliashberg theory calculation of Golubov et al.



D. V. Efremov, A. A. Golubov and O. V. Dolgov, New J. Phys. 15 013002 (2013)

Conclusions

The multiband holographic superconductor model is constructed by expoiting the $U(2)$ global symmetry

- It exhibits condensation in $S^{\pm}$ or S^{++} states, depending on the external perturbation.
- There is a generation of interband current in absence of the source.
- AC conductivity has a peak in mid-IR region, which is related to the interband current and is in accorance with the Eliashberg calculation.