Coexistence of two holographic vector order parameters: a possible view on ferromagnetic superconductivity

A. Amoretti, A. Braggio, N. Maggiore, N. Magnoli, D. Musso

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Outline

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  - Condensed matter motivations
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- The dual field theory: phase diagram
- The dual field theory: transport coefficients
- Conclusions

Motivations

Holographic motivations

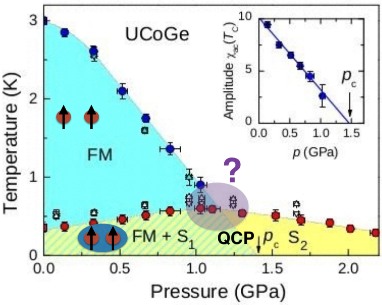
- Coexistence and competition of vector order parameters in holography
  Class.Quant.Grav. (2014) (Gauntlett)

Condensed matter motivations

- Ferromagnetic superconductors PRB (2005), Nature (2006)
  - Coexistence of ferromagnetism and superconductivity: UGe_2, URhGe, UIr, UCoGe (2011)
  - Strong interplay between the two orderings: UCoGe PRL (2012)

Motivations

UCoGe: phase diagram



- No BCS coupling: coexistence of ferromagnetism and superconductivity
- p-wave paring PRL (2011)
- strong interplay as an high pressure effect J. Phys. (2012)

- Itinerant ferromagnetism: how magnetic fluctuations can stimulate superconductivity? PRL (2013)

The gravitational Lagrangian

$$S = \int d^4x \left[\frac{1}{2\kappa_4^2} \left(R - \frac{\Lambda}{L^2} \right) - \frac{1}{4} F^a_{\mu\nu} F^{\mu\nu\ a} - \frac{1}{4} Y^a_{\mu\nu} Y^{\mu\nu\ a} + \frac{c}{2} F^a_{\mu\nu} Y^{\mu\nu\ a} \right]$$

$$F = dA + A^2, \qquad Y = dB + B^2,$$

c is a parameter which control the interaction between the two sector

Ansatz

- Probe approximation:

$$ds^2 = -h(r)dt^2 + \frac{dr^2}{h(r)} + \frac{r^2}{L^2}(dx^2 + dy^2), \qquad h(r) \equiv \frac{r^2}{L^2}\left(1 - \frac{r_h}{r}\right)$$

- Double p-wave (JHEP (2008) Gubser) ansatz for the vector fields:

$$A = \phi(r)\tau^3 dt + w(r)\tau^1 dx, \qquad B = \eta(r)\tau^3 dt + v(r)\tau^1 dx$$

- To have two well defined chemical potential in the normal we express the physics in term of the two combinations:

$$\bar{A} = \sqrt{\tfrac{1+c}{2}}\,(A - B) \text{ spin sector}$$

$$\bar{B} = \sqrt{\tfrac{1-c}{2}}\,(A + B) \text{ charged sector}$$

Symmetries

Normal phase symmetries

- $\bar{w}(r) = \bar{v}(r) = 0$
- the dual field theory has an $U(1) \times U(1)$ symmetry with two conserved charges defined by the two chemical potential:

$$\lim_{r\to\infty} \bar{\phi}(r) = \mu_{\bar{\phi}}$$
$$\lim_{r\to\infty} \bar{\eta}(r) = \mu_{\bar{\eta}}$$

- the black-brane solution is independent of c: the two sectors decouple.
- there are two conserved currents corresponding to the two sectors: the spin sector and the electric sector.

Symmetries

Condensed phase symmetries

- The sources of the two vector parameters are setted to zero:

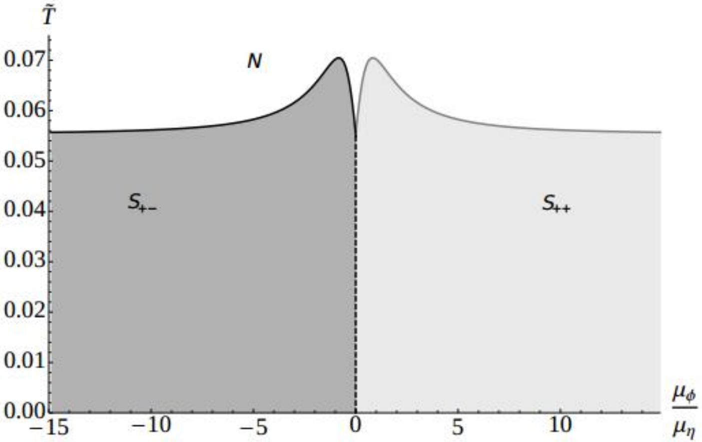
$$J_{\bar{w}} = \lim_{r\to\infty} \bar{w}(r) = 0 \text{ and } J_{\bar{v}} = \lim_{r\to\infty} \bar{v}(r) = 0$$

- The expectation values of the vector operators are non-zero:

$$\mathcal{O}_{\bar{w}} = \lim_{r\to\infty} -r^2 \bar{w}'(r) \neq 0 \text{ and } \mathcal{O}_{\bar{v}} = \lim_{r\to\infty} -r^2 \bar{v}'(r) \neq 0$$

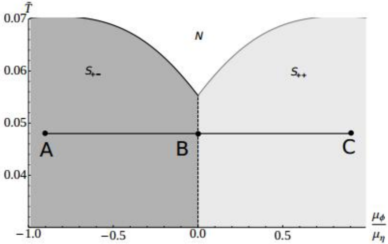
- The $U(1) \times U(1)$ symmetry of the normal phase is spontaneously broken and the two sector are coupled: one conserved gauge current (electric sector) and a non-conserved current in the adjoint (spin sector)

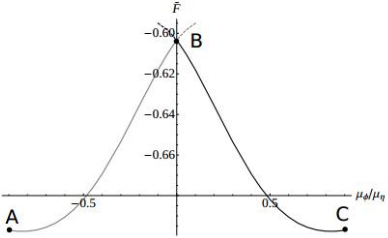
The phase diagram



The phase diagram

First order phase transition

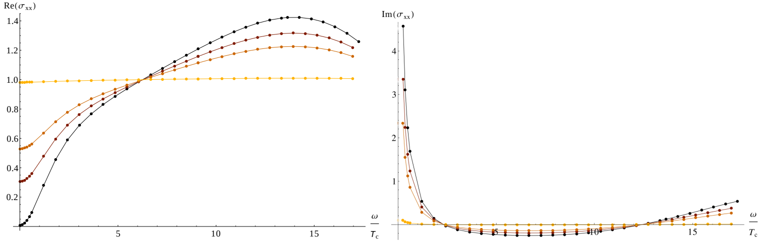




Transport Properties

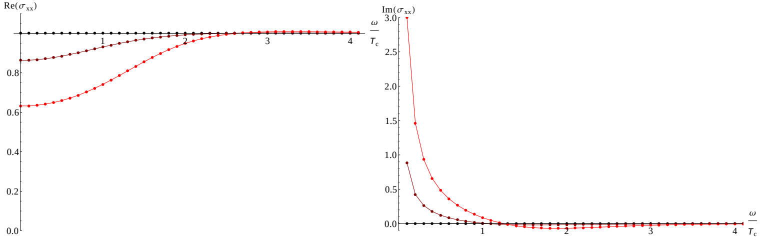
- We compute the transport coefficients using standard holographic techniques
- The electric conductivity σ is associated to the fluctuations of the the fields $\bar{B}$ (charged sector)
- The magnetic susceptibility is associated to the fluctuations of the fields $\bar{A}$ (spin sector)
- We have to distinguish the transport properties in the x direction (longitudinal sector) (where the two vector order parameter are aligned) and in the y direction (transverse sector)

Electric conductivity: Longitudinal sector



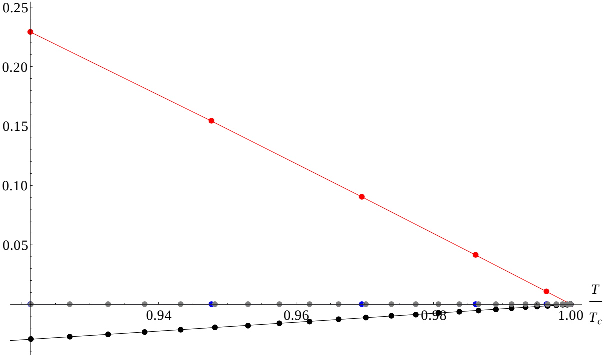
- An optical gap opens at the decreasing of the temperature
- Delta function at $\omega = 0$: superconductivity

Electric conductivity: Transverse sector



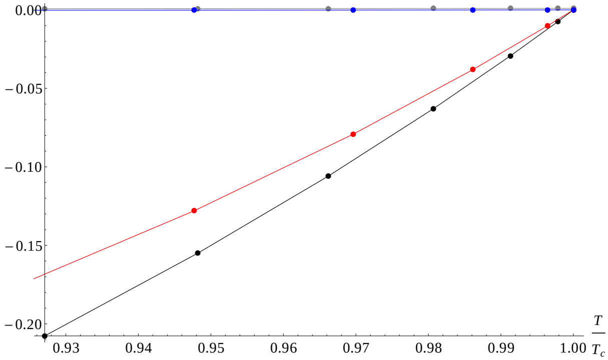
- The optical gap in the transverse sector is not completely closed: sign of anisotropic order parameter as usual in p-wave superconductivity

Magnetic susceptibility: Longitudinal sector



- ferromagnetic/diamagnetic behaviour depending on the sign of c

Magnetic susceptibility: Transverse sector



- always diamagnetic behaviour: sign of the anisotropy of the gap

Conclusions

- Coexistence of two vector order parameter:
  - strong interplay between the two sector
  - critical point of UCoGe
- Transport coefficient and strong interplay between the two orderings
- Anisotropic structure of the gap:
  - the optical gap in σ is not completely closed in the transverse sector
  - the transverse sector has always diamagnetic behaviour $\rightarrow$ $B_c^l >> B_c^t$