Towards nodal-antinodal dichotomy in high-Tc superconductors from the holographic perspective

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Quantum critical point

- Dense entanglement
- No quasiparticles (therefore no Fermi-liquid)
- Diagrammatic approach works poorly
AdS/CFT for High-T\textsubscript{c} superconductors

- Linear T-scaling of DC-conductivity

Davison, Schaalm, Zaanen, PRB 89 (2014)

It follows from hydrodynamic properties of systems with minimal viscosity proportional to the thermodynamic entropy

$$\rho_{DC}(T) = \frac{A\hbar}{\omega_p^2 m_e l^2} \frac{S_e(T)}{k_B}$$

T-linear resistivity in five overdoped cuprates (Legros et al. Nature Physics 2018)
AdS-CFT in High-Tc superconductors

- T-dependence of the Hall angle

Blake, Donos, PRL 114 (2015)

Hall angle can be naturally interpreted in terms of a two-constituent quantum liquid, with regular quasiparticles and the critical sector, which gives the dependence

\[ \tanh \theta_H = \sigma_{xy}/\sigma_{xx} \sim 1/T^2 \]
AdS-CFT in High-Tc superconductors

- Localization in two-dimensional CuO planes


The interaction-driven metal-insulator transition that causes anisotropic localization: current can flow along the plane but not in the direction orthogonal to them.
Nodal-antinodal dichotomy

Once the pseudogap sets in, the antinodal regions of the Fermi surface are gapped out, giving rise to Fermi arcs.

\[
\Delta_{SC}(k) = (\Delta_0/2) (\cos k_x a - \cos k_y a)
\]
Holographic setup

- We need finite chemical potential, therefore the background should be a deformed charged black hole (we need gauge field)
- Periodic structure is given by scalar fields
- Fermions are not coupled directly to gravity-matter equations
Holographic setup

• Consider system of coupled gravity-matter equations on periodic lattice
• Solve Dirac equations on the obtained background
• Study asymptotic behavior of spinors to obtain Green function
Einstein-Maxwell equations

\[ S = \frac{1}{16\pi G} \int d^4 x \sqrt{-g} \left[ R + \frac{6}{L^2} - \partial_\mu \phi \partial^\mu \phi - \partial_\mu \chi \partial^\mu \chi - \frac{1}{2} F^{\mu\nu} F_{\mu\nu} - 2V(\phi, \chi) \right] \]

\[ V(\phi, \chi) = -\left(\phi^2 + \chi^2\right)/L^2 \]

\[ \phi(x, z) \Big|_{z \to 0} = z\phi^{(1)}(x) + z^2 \phi^{(2)}(x) + \ldots \]

\[ \chi(x, z) \Big|_{z \to 0} = z\chi^{(1)}(x) + z^2 \chi^{(2)}(x) + \ldots \]

Crystal lattice is modeled by boundary conditions.

\[ \phi^{(1)}(x) = \cos(\theta)V_0 \cos(k_0 x) \]

\[ \chi^{(1)}(x) = \sin(\theta)V_0 \sin(k_0 x) \]
Dirac equations

\[ \Gamma^a \epsilon^\mu_a \left( \partial_\mu + \frac{1}{4} \omega_{ab\mu} \Gamma^{ab} - i q A_\mu \right) \zeta - m \zeta = 0 \]

Green function is given by spinor behaviour on the conformal boundary.

\[ \Psi_\alpha(x) = a_\alpha(x)(1 - r)^{-mL} \begin{pmatrix} 0 \\ 1 \end{pmatrix} + b_\alpha(x)(1 - r)^{mL} \begin{pmatrix} 1 \\ 0 \end{pmatrix} + ... \]

\[ \begin{pmatrix} b_1(x) \\ b_2(x) \end{pmatrix} = \int dx' \ G^R(\omega, k_x, k_y | x, x') \begin{pmatrix} a_1(x') \\ a_2(x') \end{pmatrix} \]

Spectral function \( A(\omega, k) = \text{Im} \ \text{Tr} \ G^R(\omega, k) \)
2 regimes

- Umklapp scattering due to interaction between Brillouin zones
- Anisotropy due to infrared physics captured by holographic approach
- The comparison can be achieved by different solutions of Einstein equations
Umklapp scattering

\[ \mu=2.3 \, k_0=0.7 \, \omega=1\times10^{-5} \]
Emergence of Fermi arcs

\[ \mu=2.3 \ k_0=2.2 \ \omega=1\times10^{-5} \]

[Graphs showing Fermi arcs with parameters]
Summary

• AdS-CFT correspondence allows to explain anisotropy of Fermi surfaces
• Anisotropy is related with strong correlations but not with one-particle scattering
• In the following we can consider modulations in 2 directions
• or include time into the equations, which would correspond to time-resolved ARPES