NORDITA

Coherent and incoherent transport in holographic models with dynamically broken translations

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Outline

1. **Dynamic translation symmetry breaking**
2. **Metal-insulator phase transition**
3. **Coherent and incoherent transport**
4. **Hydrodynamics of CDW and phase relaxation scale**
5. **Dynamics of the phase transition**

Motivation

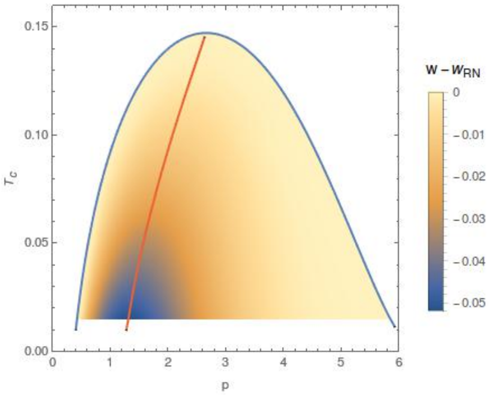
- Holography aims at describing non-Fermi liquid condensed matter
- Cuprate High Tc superconductors and strange metals are the systems of interest in nature
- Cuprate are doped Mott insulators, CDW plays important role
- Holographic models of CDW have few interesting features, which might be relevant to reality

Dynamic translation symmetry breaking

Dynamic TSB

Dynamic TSB is driven by an unstable mode in the spectrum at finite momentum

Donos, Gauntlett, Ooguri, Park



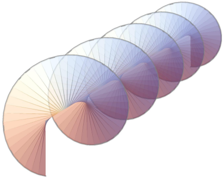
Helical model

One can consider a helical model

$$S = \int d^5x\sqrt{-g}\left(R - 2\Lambda - \frac{1}{4}F^2\right) - \frac{\gamma}{6}\int d^5x A \wedge F \wedge F$$

$$\omega_1 = dx,$$
$$\omega_2 = \cos(px)dy - \sin(px)dz,$$
$$\omega_3 = \sin(px)dy + \cos(px)dz.$$

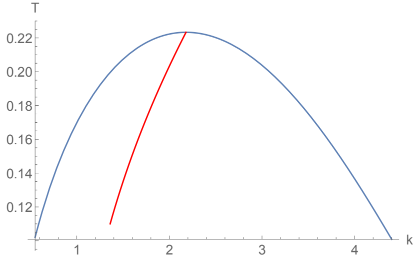
$$A = A_t dt + A_2\omega_2, \qquad A_t\Big|_{u\to 0} = \mu$$

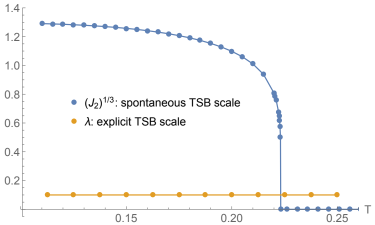


The unstable mode is: $\delta A_2 \sim \omega_2$

Helical model

Spontaneous symmetry breaking is driven by the instability at finite temperature and the **second order phase transition**





Periodic lattice model

The other model consists of Einstein Maxwell in 4D, supplimented with theta-term.

$$S = \int d^4x\sqrt{-g}\left(R - 2\Lambda - \frac{\tau(\psi)}{4}F^2 - \frac{1}{2}(\partial\psi)^2 - W(\psi)\right) - \frac{1}{2}\int \vartheta(\psi) F\wedge F$$

$$W(\psi) = -\psi^2 + \dots, \quad \tau(\psi) = 1 + \dots, \quad \vartheta(\psi) = \frac{c_1}{2\sqrt{6}}\psi + \dots$$

The instability is driven by theta-term

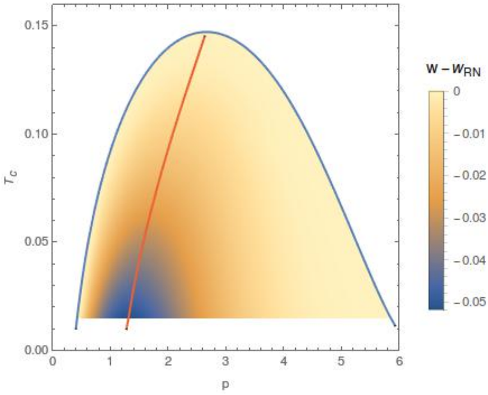
$$\frac{1}{2}\int \vartheta(\psi) F\wedge F \sim \psi \partial_x A_y \partial_z A_t \qquad (1)$$

The unstable mode is

$$\delta\psi \sim cos(ikx), \qquad \delta A_y \sim sin(ikx) \qquad (2)$$

Dynamic TSB

Same type of bell curve describes the dynamical phase transition



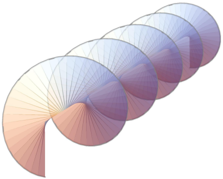
Metal-insulator transition

Explicit source

One can add a commensurate explicit source to the helical model

$$S = \int d^5x\sqrt{-g}\left(R - 2\Lambda - \frac{1}{4}F^2 - \frac{1}{4}W^2\right) - \frac{\gamma}{6}\int d^5x A\wedge F\wedge F - \frac{\kappa}{2}\int d^5x B\wedge F\wedge W, \qquad W = dB$$

$$\omega_1 = dx,$$
$$\omega_2 = \cos(px)dy - \sin(px)dz,$$
$$\omega_3 = \sin(px)dy + \cos(px)dz.$$



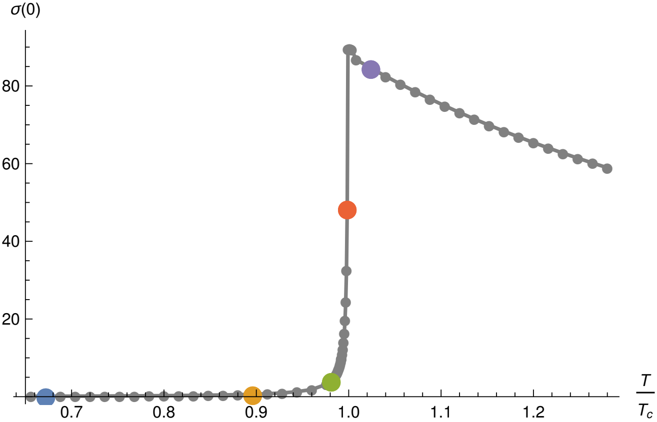
$$A = A_t dt + A_2\omega_2, \qquad A_t\Big|_{u\to 0} = \mu$$

$$B = B_t dt + B_2\omega_2, \qquad B_2\Big|_{u\to 0} = \lambda$$

This renders the conductivity finite

Helical model with explicit source

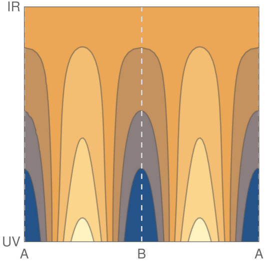
One observes a metal-insulator transition at critical temperature



Periodic lattice with explicit source

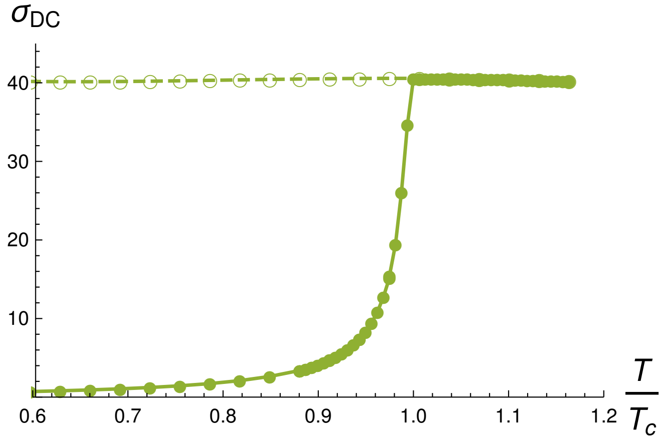
One can add an explicit potential to the periodic lattice model

$$\mu(x) = \mu_0 \left(1 + A\cos(kx)\right)$$



Periodic model with explicit source

The metal-insulator transition is similar

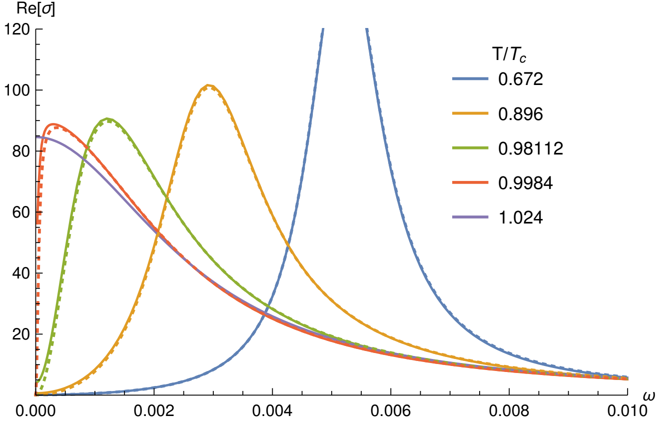


Coherent and incoherent transport

Gapping off coherent spectrum

One expects to gap out the coherent part of the spectrum

Helical model



Gapping off coherent spectrum

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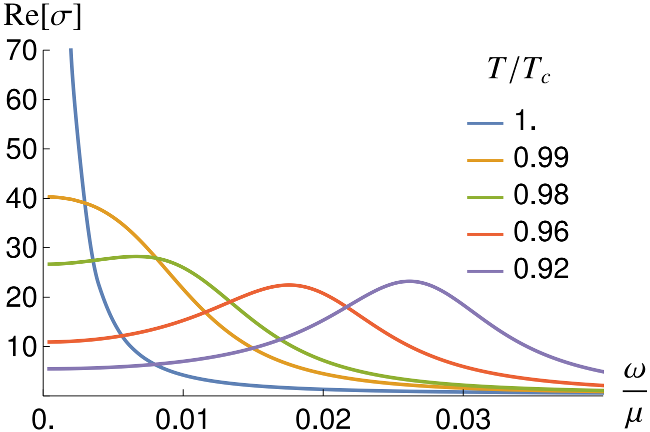
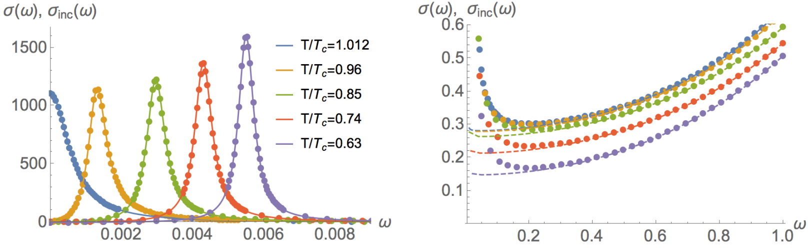
Periodic model



Incoherent remnant

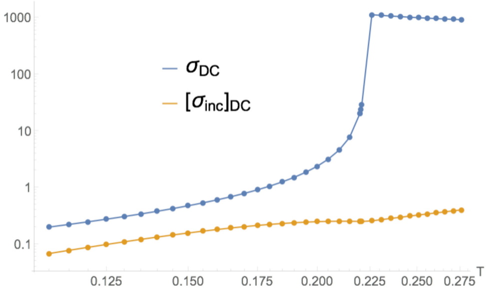
However, the DC conductivity stays finite, since is has an *incoherent contribution*



Phase relaxation scale

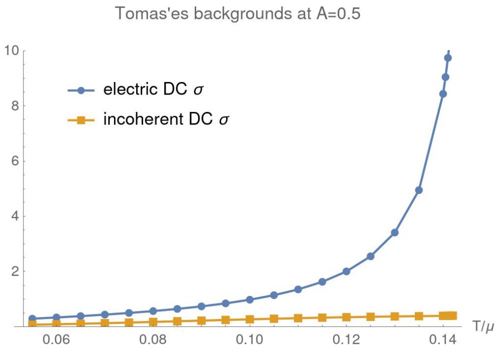
Coherent remnant

If one looks closely, one sees that the incoherent conducitivity doesn't take into account everything



Coherent remnant

Same happens in periodic model



Hydrodynamics of CDW and phase relaxation

$$\sigma(\omega) = \sigma_{inc}(\omega) + A_0 \frac{\Omega - i\omega}{(\Gamma - i\omega)(\Omega - i\omega) + \omega_0^2}, \qquad A_0 = \frac{\rho^2}{\mu\rho + sT}.$$

Γ – momentum relaxation rate, or explicit TSB measure
ω_0 – effective mass of the pinned Goldstone boson ($\omega \sim \Gamma \cdot \langle J_2 \rangle$)

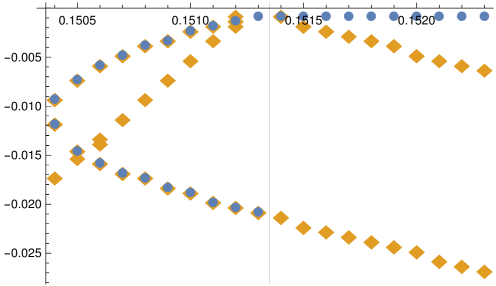
Explicit: $$\sigma_{DC} \sim \sigma_{inc} + \frac{A_0}{\Gamma}$$

Spontaneous: $$\sigma_{DC} \sim \sigma_{inc} + \frac{\Omega}{\omega_0^2}$$

Dynamics of phase transition

Coherent remnant

At critical T the behavior of QNMs reveal the nature of Omega mode



Coherent remnant

The coherent contribution gets suppressed by the explicit lattice