A Striped Holographic Superconductor

based on

R.Flauger, E.P. & S. Papanikolaou

1010.1775

Enrico Pajer

Cornell University, Ithaca

Cornell

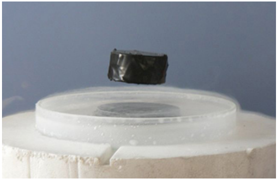
Nov 2010

Outline

Outline

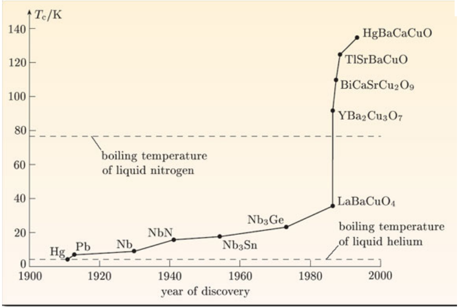
99 years of superconductivity

A century of history, six Nobel prizes, uncountable technological applications and still a lot to discover



- 1911, H. K. Onnes (Nobel '13) discovers SC in Hg at 4.2K
- 1933, W. Meissner, expulsion of magnetic field
- 1950, Landau-Ginzburg (Nobel '62 & '03) phenomenological theory
- 1957, Bardeen Cooper and Schrieffer (Nobel '72) microscopic theory
- 1962, B.D. Josephson (Nobel '73) effect
- 1986, Bednorz & Müller (Nobel '87) discover high-T_c in LBCO

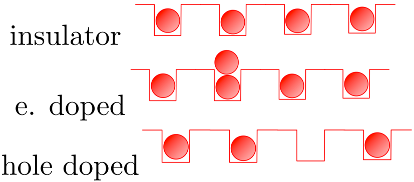
High T_c superconductors

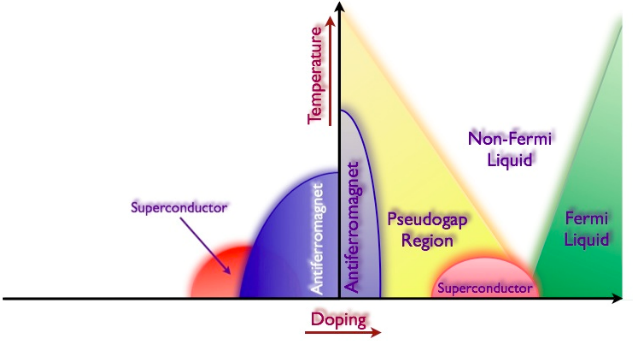


- T_c above liquid N and above the T_c allowed by BCS.
- The biggest family are the cuprates. Highest T_c is 135K.
- Other recently discovered families are iron-based and organic SC.
- Probably the most studied materials after the semiconductors.

Doping a Mott insulator

Cuprates are doped Mott insulators. Insulation is due to the strong Coulomb repulsion between electrons.





Ingredients of high T_c SC

- There are many peculiarities of the phase diagram of cuprates: pseudogap, strange metal, glassy phase ...
- We do not know which are crucial for high T_c and which are accidental.
- I will give a biased review of physical properties characterizing the cuprates.

Ingredients of high T_c SC

- There are many peculiarities of the phase diagram of cuprates: pseudogap, strange metal, glassy phase ...
- We do not know which are crucial for high T_c and which are accidental.
- I will give a biased review of physical properties characterizing the cuprates.

I will stress three ingredients

- Strong coupling
- Quantum criticality
- Inhomogeneity

The goal is to construct and study a simple computable model that accounts for these ingredients.

Strong coupling

- High T_c SC are not described by the weakly coupled BCS theory.

Strong coupling

- High T_c SC are not described by the weakly coupled BCS theory.
- The Hubbard model is believed to capture the physics of the cuprates

$$H = -\sum_{i,j,\alpha} t_{ij} c^\dagger_{i\alpha} c_{j\alpha} + \sum_i U_i c^\dagger_{i\uparrow} c_{i\uparrow} c^\dagger_{i\downarrow} c_{i\downarrow} - \mu \sum_{i.,\alpha} c^\dagger_{i\alpha} c_{i\alpha}$$

Strong coupling

- High T_c SC are not described by the weakly coupled BCS theory.
- The Hubbard model is believed to capture the physics of the cuprates

$$H = -\sum_{i,j,\alpha} t_{ij} c^{\dagger}_{i\alpha} c_{j\alpha} + \sum_{i} U_i c^{\dagger}_{i\uparrow} c_{i\uparrow} c^{\dagger}_{i\downarrow} c_{i\downarrow} - \mu \sum_{i.,\alpha} c^{\dagger}_{i\alpha} c_{i\alpha}$$

- Small doping: insulating and antiferromagnetic. The potential U wins over the kinetic term t.

Strong coupling

- High T_c SC are not described by the weakly coupled BCS theory.
- The Hubbard model is believed to capture the physics of the cuprates

$$H = -\sum_{i,j,\alpha} t_{ij} c^\dagger_{i\alpha} c_{j\alpha} + \sum_i U_i c^\dagger_{i\uparrow} c_{i\uparrow} c^\dagger_{i\downarrow} c_{i\downarrow} - \mu \sum_{i.,\alpha} c^\dagger_{i\alpha} c_{i\alpha}$$

- Small doping: insulating and antiferromagnetic. The potential U wins over the kinetic term t.
- Large doping: Fermi liquid. The kinetic term t wins over the potential U.

Strong coupling

- High T_c SC are not described by the weakly coupled BCS theory.
- The Hubbard model is believed to capture the physics of the cuprates

$$H = -\sum_{i,j,\alpha} t_{ij} c^\dagger_{i\alpha} c_{j\alpha} + \sum_i U_i c^\dagger_{i\uparrow} c_{i\uparrow} c^\dagger_{i\downarrow} c_{i\downarrow} - \mu \sum_{i.,\alpha} c^\dagger_{i\alpha} c_{i\alpha}$$

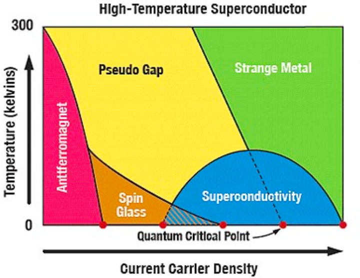
- Small doping: insulating and antiferromagnetic. The potential U wins over the kinetic term t.
- Large doping: Fermi liquid. The kinetic term t wins over the potential U.
- SC takes place in between, so no perturbation theory is possible.

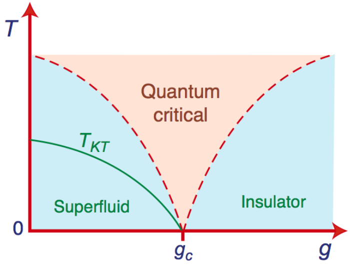
Quantum criticality

- A quantum phase transition is a phase transition at $T = 0$.
- Competition between potential and quantum fluctuations.
- The quantum critical point (QCP) has a scaling symmetry.

Quantum criticality

- A quantum phase transition is a phase transition at $T = 0$.
- Competition between potential and quantum fluctuations.
- The quantum critical point (QCP) has a scaling symmetry.





Is there a QCP beneath the SC dome leading to the strange metal phase?

Inhomogeneity

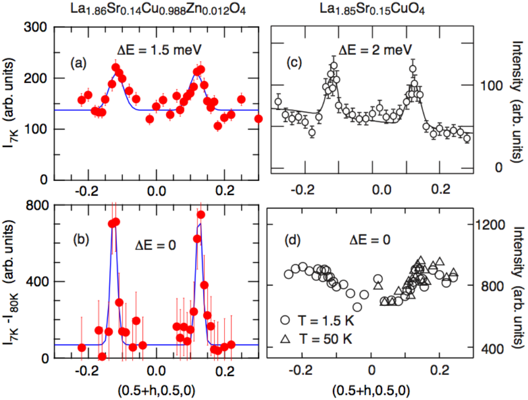
- Vast subject, I will present
  - theoretical
  - experimental
  - intuitive

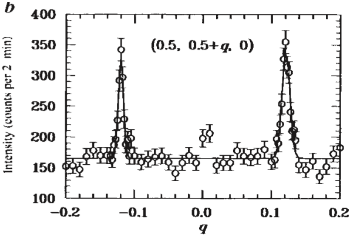
  evidence that inhomogeneity plays an important role in the cuprates.
- I focus on stripes (smectic order), but also other types of order exist (e.g. nematic).
- Charge density wave (CDW)

$$\langle \rho(\mathbf{r}, t) \rangle \equiv \bar{\rho} + \mathrm{Re}\left[e^{i\mathbf{Q}\mathbf{r}} \phi_{CDW}(\mathbf{r}, t) \right] \tag{1}$$

- Analogously SDW for spin modulations.

Experimental evidence I

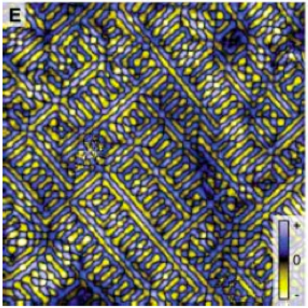


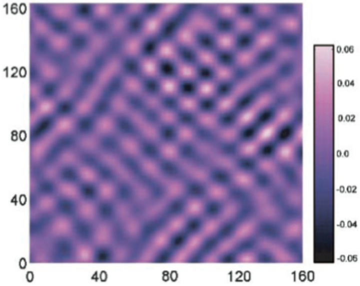


- Neutron scattering with varying momentum on the CuO plane [Kivelson et al] .
- The peaks indicate charge stripes.

- Neutron scattering on LaNdSrCuO at 11K.

Experimental evidence II

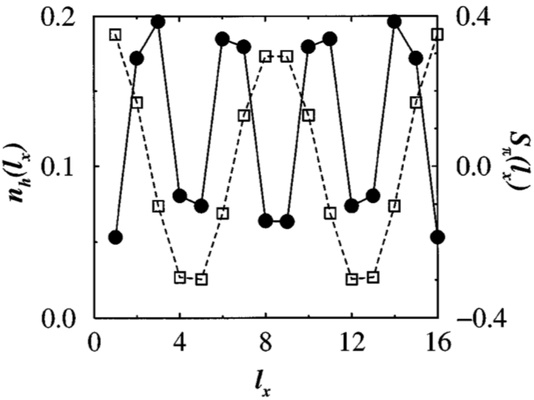




- Atomic-resolution tunneling-asymmetry imaging on CaNaCuOCl and BiSrDyCaCuO [Kohsaka et al]
- Local density of states in BiSrCaCuO at 8K via scanning tunneling spectroscopy [Howal et al '03]

Hubbard model

- Large number of numerical studies of Hubbard or t-J model.
- Stripes emerge [e.g. White & Scalapino] . Oscillating electron density.

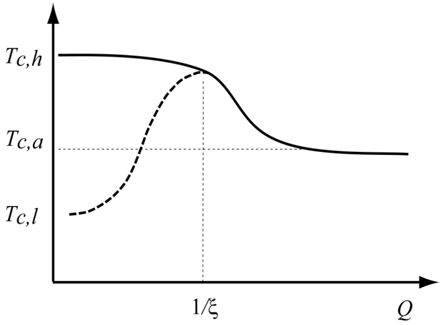


Optimal inhomogeneity [Martin, Podolsky & Kivelson '05; ...]

Weakly coupled BCS analysis of inhomogeneous Hubbard model

$$H = -\sum_{i,j,\alpha} t_{ij} c^\dagger_{i\alpha} c_{j\alpha} + \sum_i U_i c^\dagger_{i\uparrow} c_{i\uparrow} c^\dagger_{i\downarrow} c_{i\downarrow} - \mu \sum_{i.,\alpha} c^\dagger_{i\alpha} c_{i\alpha}$$

with $U_i = \bar{U} + U_Q \cos(Q r_i)$.

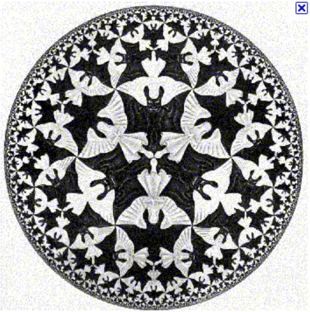


- Can one check this in a strongly coupled model?

Outline

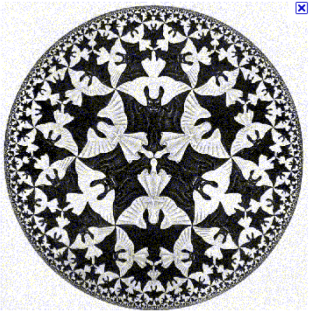
The correspondence

The AdS/CFT correspondence [Maldacena 97] relates certain strongly coupled CFT's to gravitational theories in one higher dimension on a weakly curved asymptotically AdS background (and vice versa).



The correspondence

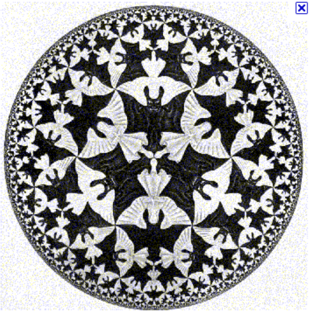
The AdS/CFT correspondence [Maldacena 97] relates certain strongly coupled CFT's to gravitational theories in one higher dimension on a weakly curved asymptotically AdS background (and vice versa).



- The CFT lives on the boundary while gravity is in the bulk.

The correspondence

The AdS/CFT correspondence [Maldacena 97] relates certain strongly coupled CFT's to gravitational theories in one higher dimension on a weakly curved asymptotically AdS background (and vice versa).



- The CFT lives on the boundary while gravity is in the bulk.
- The RG flow is geometrised by the bulk eom. Conformal symmetry is realized geometrically.

The AdS/CFT dictionary

$$Z[\phi_0] = \langle e^{-\int \phi_0 \mathcal{O}} \rangle_{CFT} = Z_{AdS} \sim e^{-S_{AdS}} \Big|_{b.c.\phi=\phi_0}$$

CFT	Gravity
Local operator $\mathcal{O}_\Delta$	field ϕ
dimension Δ	mass of ϕ
Source $\delta\mathcal{L} = \int \mathcal{O}_\Delta \phi_0$	non-normalizable profile $\phi_0 \neq 0$
vev $\langle \mathcal{O}_\Delta \rangle$	normalizable profile $\phi_1 \neq 0$

Solving the classical bulk eom one finds the relation between perturbation ϕ_0 and response ϕ_1

$$\phi(z \to 0) \simeq z^{d-\Delta}\phi_0 + z^{\Delta}\phi_1 + \dots$$

Ingredients of a holographic superconductor [Hartnoll et al 08]

Why	CFT	Gravity
QCP	Scaling	AdS
Temperature	Temperature	Black hole
Transport properties	Current J_μ	Gauge field A_μ
Phase transition	Order parameter	Charged scalar field Ψ
Cuprates	2+1	3+1

Einstein-Maxwell-scalar theory in 3+1

$$
\begin{aligned}
S &= \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G_N}\left(R+\frac{6}{L^2}\right)\right. \\
&\quad \left. -\frac{1}{4}F^{ab}F_{ab} - g^{ab}(D_a\Psi)^* D_b\Psi - V(|\Psi|)\right] ,
\end{aligned}
$$

A simple concrete choice

$$
V(|\Psi|) = -\frac{2}{L^2}|\Psi|^2 ,
$$

above BF bound.

Einstein-Maxwell-scalar theory in 3+1

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G_N}\left(R+\frac{6}{L^2}\right) -\frac{1}{4}F^{ab}F_{ab} - g^{ab}(D_a\Psi)^*D_b\Psi - V(|\Psi|)\right],$$

A simple concrete choice

$$V(|\Psi|) = -\frac{2}{L^2}|\Psi|^2\,,$$

above BF bound. Three symmetries by rescaling with weights

	x^a	L	q	$A_a dx^a$	Ψ	ds^2	G_N
α_1	1	0	0	0	0	0	0
α_2	0	1	-1	1	0	2	0
α_3	0	0	-1	1	1	0	-2

Probe limit and Schwarzschild AdS

Einstein equations are

$$G_{ab} - \frac{3}{L^2} g_{ab} = \frac{G_N}{q^2} T_{ab}\left(qA, q\Psi\right) \, .$$

The backreaction can be neglected in the probe limit

$$\frac{G_N}{q^2} \to 0 \quad \text{with} \quad qA, q\Psi \, \text{constant}$$

EE are solved by

$$ds^2 = \frac{L^2}{z^2}\left[-h(z)dt^2 + \frac{dz^2}{h(z)} + dx^2 + dy^2\right] \quad \text{with} \quad h(z) = 1 - \frac{z^3}{z_0^3} \, ,$$

with temperature $T = 3/(4\pi z_0)$.

Homogeneous ansatz

- Homogeneous and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.
- Can use three symmetries to fix e.g. $L = z_0 = q = 1$.
- Only two d.o.f. $A \equiv A_t$ and ψ:

$$\begin{aligned} hA_{zz} - \psi^2 A &= 0\,, \\ -h^2\psi_{zz} + 3z^2 h\psi_z + \left(hz - A^2\right)\psi &= 0\,. \end{aligned}$$

AdS boundary $z = 0$	Black hole horizon $z = z_0$
chemical potential: $A(0) = \mu$	regular: $A(z_0) = 0$
normalizable: $\psi(0) = 0$	regular: $\psi'(z_0) = -\psi(z_0)/3$

$\mu \neq 0$ breaks conformal invariance. The solution determines

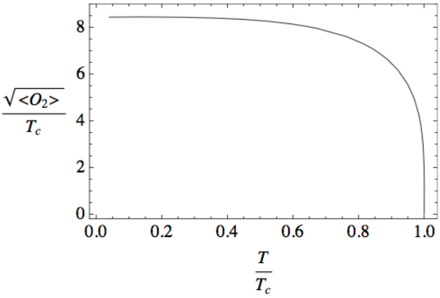
$$\begin{aligned} \partial_z A(0) &= \langle J_0 \rangle \equiv \rho \quad \text{charge density} \\ \partial_z \psi(0) &= \langle \mathcal{O}_2 \rangle \quad \text{order parameter} \end{aligned}$$

Normal state and instability

For high T, a simple stable solution is $\psi = 0$. The eom linearizes

$$\partial_z^2 A = 0 \Rightarrow A(z) = \mu\,(1 - z)\ .$$

- For low temperatures $\psi = 0$ is unstable [Gubser 08] .
- There is another solution $\psi \neq 0$, which is thermodynamically favored.
- The system is non-linear, we have mostly numerical solutions.



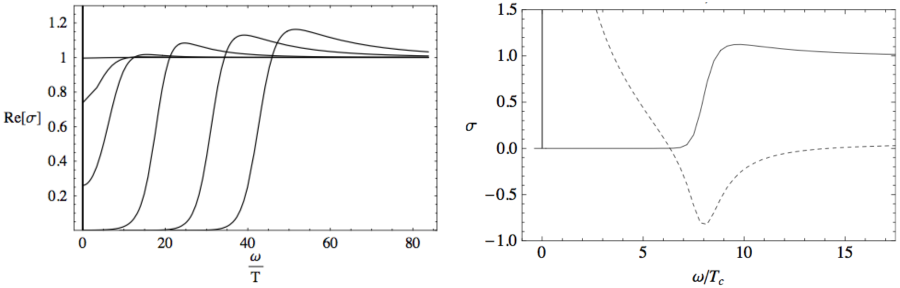
Conductivity

Perturb with a small electric field

$$h\partial_z \left(h\partial_z A_y\right) + \left(\omega^2 - \psi^2 h\right) A_y = 0\,,$$

and read the linear response. The optical conductivity

$$\sigma_y(\omega) \equiv \frac{J_y(\omega)}{E_y(\omega)} = -i\frac{A_y^{(1)}}{\omega A_y^{(0)}}\,,$$



Outline

Inhomogeneous ansatz

- Homogeneous only in y and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.

Inhomogeneous ansatz

- Homogeneous only in y and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.
- Again only two d.o.f. $A(z,x)$ and $\psi(z,x)$, but with $x-$dependence:

$$\begin{aligned} hA_{zz} - \psi^2 A + A_{xx} &= 0\,, \\ -h^2\psi_{zz} + 3z^2 h\psi_z - h\psi_{xx} + \left(hz - A^2\right)\psi &= 0\,, \end{aligned}$$

Inhomogeneous ansatz

- Homogeneous only in y and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.
- Again only two d.o.f. $A(z,x)$ and $\psi(z,x)$, but with $x-$dependence:

$$\begin{aligned} hA_{zz} - \psi^2 A + A_{xx} &= 0\,, \\ -h^2\psi_{zz} + 3z^2 h\psi_z - h\psi_{xx} + \left(hz - A^2\right)\psi &= 0\,, \end{aligned}$$

- Same boundary conditions as before: regularity at the horizon and normalizable ψ.

Inhomogeneous ansatz

- Homogeneous only in y and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.
- Again only two d.o.f. $A(z,x)$ and $\psi(z,x)$, but with $x-$dependence:

$$\begin{aligned} hA_{zz} - \psi^2 A + A_{xx} &= 0\,, \\ -h^2\psi_{zz} + 3z^2 h\psi_z - h\psi_{xx} + \left(hz - A^2\right)\psi &= 0\,, \end{aligned}$$

- Same boundary conditions as before: regularity at the horizon and normalizable ψ.
- Except we impose a modulated chemical potential

Inhomogeneous ansatz

- Homogeneous only in y and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.
- Again only two d.o.f. $A(z,x)$ and $\psi(z,x)$, but with $x-$dependence:

$$\begin{aligned} hA_{zz} - \psi^2 A + A_{xx} &= 0\,, \\ -h^2\psi_{zz} + 3z^2 h\psi_z - h\psi_{xx} + \left(hz - A^2\right)\psi &= 0\,, \end{aligned}$$

- Same boundary conditions as before: regularity at the horizon and normalizable ψ.
- Except we impose a modulated chemical potential
- This directly sources a charge density wave (CDW).

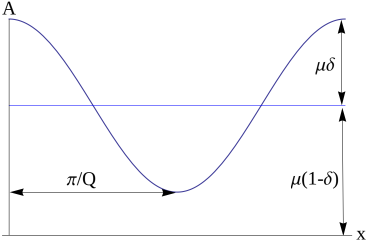
Inhomogeneous ansatz

- Homogeneous only in y and static $\Rightarrow A_{x,y,z} = 0$ and $\Psi = \psi z/\sqrt{2} \in \mathbb{R}$.
- Again only two d.o.f. $A(z,x)$ and $\psi(z,x)$, but with $x-$dependence:

$$\begin{aligned} hA_{zz} - \psi^2 A + A_{xx} &= 0\,, \\ -h^2\psi_{zz} + 3z^2 h\psi_z - h\psi_{xx} + \left(hz - A^2\right)\psi &= 0\,, \end{aligned}$$

- Same boundary conditions as before: regularity at the horizon and normalizable ψ.
- Except we impose a modulated chemical potential
- This directly sources a charge density wave (CDW).
- We study superconductivity in the presence of a CDW. In principle one could generate the inhomogeneity spontaneously.

Modulated chemical potential



$$A(0,x) = \mu\left[(1-\delta) + \delta\cos(Qx)\right]$$

- μ is the maximum chemical potential.
- δ controls the amplitude of the modulation.
- Q is the wavevector of the modulation.

Normal state CDW and instabilities

Again a simple solution at high T is $\psi = 0$. This gives a normal state with a CDW

$$\rho(x) = \mu \left[(1 - \delta) + \delta Q \coth(Q) \cos(Qx) \right] .$$

As T decreases (equivalently μ increases) there are various instabilities toward $\psi \neq 0$.

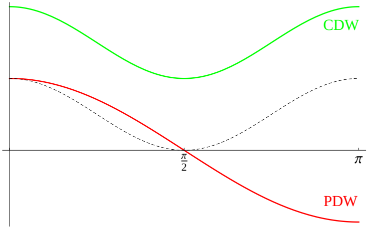
Normal state CDW and instabilities

Again a simple solution at high T is $\psi = 0$. This gives a normal state with a CDW

$$\rho(x) = \mu\left[(1-\delta) + \delta Q \coth(Q)\cos(Qx)\right] .$$

As T decreases (equivalently μ increases) there are various instabilities toward $\psi \neq 0$.

- Antiperiodic boundary conditions $\psi(z,0) = -\psi(2\pi/Q) \Rightarrow$ pair density wave PDW, i.e. the order parameter averages to zero.



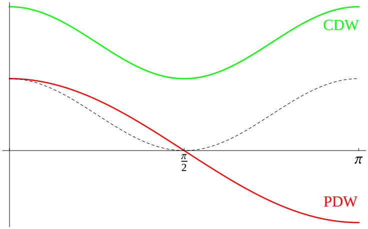
Normal state CDW and instabilities

Again a simple solution at high T is $\psi = 0$. This gives a normal state with a CDW

$$\rho(x) = \mu \left[(1-\delta) + \delta Q \coth(Q) \cos(Qx) \right] .$$

As T decreases (equivalently μ increases) there are various instabilities toward $\psi \neq 0$.

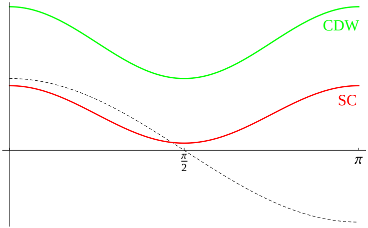
- Antiperiodic boundary conditions $\psi(z, 0) = -\psi(2\pi/Q) \Rightarrow$ pair density wave PDW, i.e. the order parameter averages to zero.
- PDW has been argued to explain LBCO and to be relevant for other cuprates [Berg et al 09]



Superconducting instability

Let us focus on periodic boundary conditions

$$\psi(z,0) = \psi(z, 2\pi/Q)$$

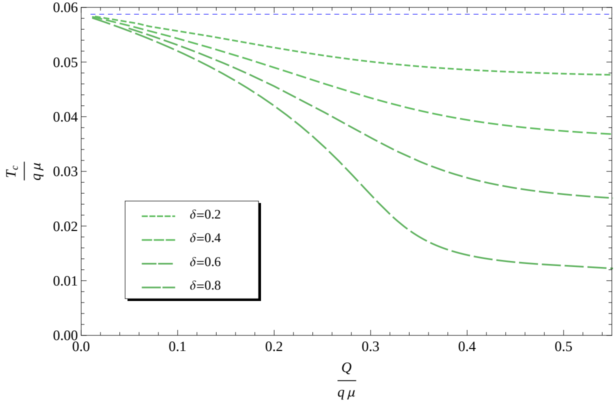


- The instability can be studied analytically in the limits $Q \to 0$ and $Q \to \infty$
- Or numerically by Fourier expanding

$$\psi(x,z) = \sum_{n=0}^{\infty} \psi_n(z) \cos(nQx)$$

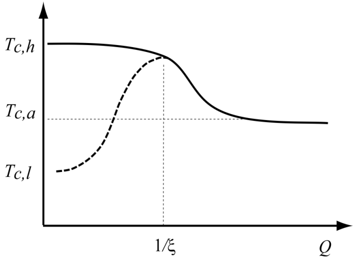
and truncating for large n.

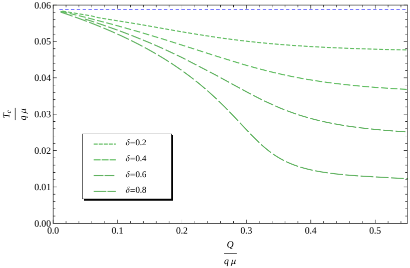
T_c of Q



- $T_c(0)$ is the same as a homogeneous system with $\mu_h = \mu$ because derivatives do not cost energy, so different x's decouple.
- $T_c(0)$ is the same as a homogeneous system with $\mu_h = \mu(1-\delta)$ because the oscillation is too fast.

A comparison with weakly coupled BCS





- Same qualitative behavior: asymptotics, inflection point.
- Quantitative different behavior for $q \to \infty$

$$\text{BCS}: \quad T_c(Q) - T_c(\infty) \sim \frac{1}{\log Q}$$

$$\text{holography}: \quad T_c(Q) - T_c(\infty) \sim e^{-Q}$$

- What happens with phase fluctuation?

Superconductivity in the presence of a CDW

We study numerically the full non-linear system

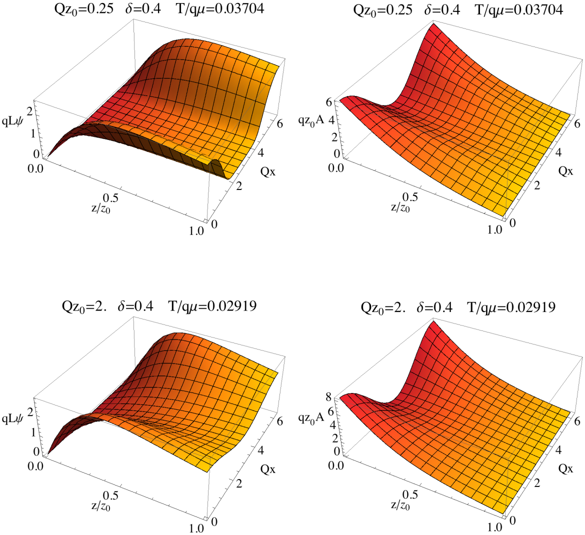
$$
\begin{aligned}
hA_{zz} - \psi^2 A + A_{xx} &= 0\,, \\
-h^2\psi_{zz} + 3z^2 h\psi_z - h\psi_{xx} + \left(hz - A^2\right)\psi &= 0\,,
\end{aligned}
$$

by Fourier expanding

$$
\begin{aligned}
\psi(x,z) &= \sum_{n=0}^{\infty} \psi_n(z)\cos(nQx)\,, \\
A(x,z) &= \sum_{n=0}^{\infty} A_n(z)\cos(nQx)\,,
\end{aligned}
$$

and truncating at some n.

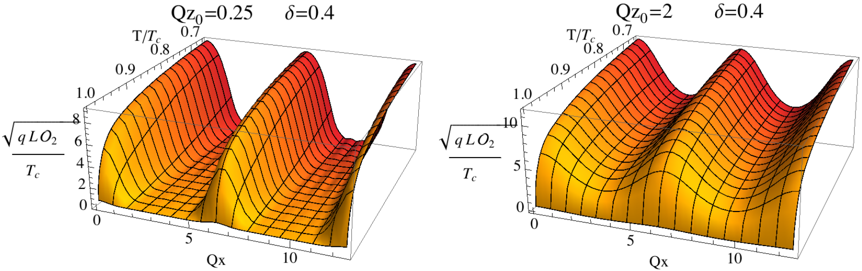
Bulk condensation with a CDW



- The stripes are more pronounced for $Q < 1$.
- For $Q < 1$ between the stripes ψ has not condensed yet.
- For $Q > 1$ the phase transition takes place almost everywhere at the same T.

Superconductivity with a CDW

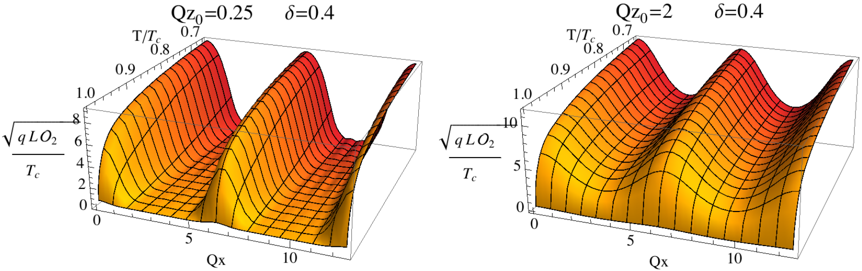
Read off the boundary order parameter:



- Superconducting stripes have emerged!

Superconductivity with a CDW

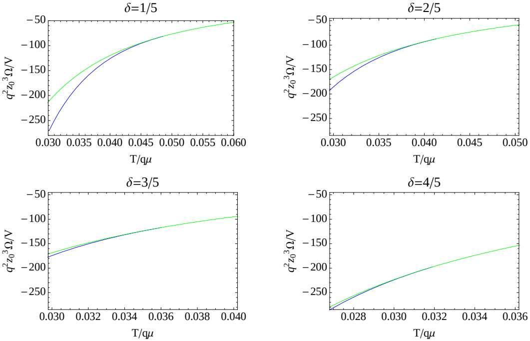
Read off the boundary order parameter:



- Superconducting stripes have emerged!
- Modulations persist for $Q > 1$ but the stripes are smoothed out.

Gran canonical potential

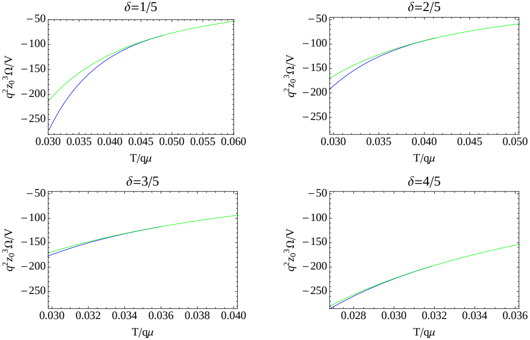
By the AdS/CFT dictionary: $\Omega = -TS_{\text{on-shell}}$



- Superconducting stripes have lower Ω than the normal state.

Gran canonical potential

By the AdS/CFT dictionary: $\Omega = -TS_{\text{on-shell}}$



- Superconducting stripes have lower Ω than the normal state.
- Striped superconductivity is thermodynamically favored. The more so for smaller δ.

Conductivity

- Perturb the system with a small electric field $E_{x,y}$ and read off the linear response.

Conductivity

- Perturb the system with a small electric field $E_{x,y}$ and read off the linear response.
- Due to the x-inhomogeneity, E_x excites almost all modes. σ_x, condutivity perpendicular to the stripe, is hard to compute.

Conductivity

- Perturb the system with a small electric field $E_{x,y}$ and read off the linear response.
- Due to the x-inhomogeneity, E_x excites almost all modes. σ_x, condutivity perpendicular to the stripe, is hard to compute.
- σ_x would tell us about proximity effects.

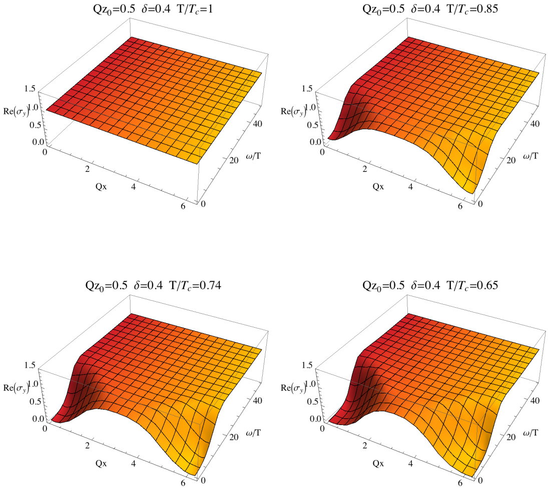
Conductivity

- Perturb the system with a small electric field $E_{x,y}$ and read off the linear response.
- Due to the x-inhomogeneity, E_x excites almost all modes. σ_x, condutivity perpendicular to the stripe, is hard to compute.
- σ_x would tell us about proximity effects.
- Since $\partial_y = 0$, there is nothing to contract E_y with. σ_y, conductivity along the stripe, is easy to compute.

$$h\partial_z \left(h\partial_z A_y\right) + h\partial_x^2 A_y + \left(\omega^2 - \psi^2 h\right) A_y = 0\,,$$

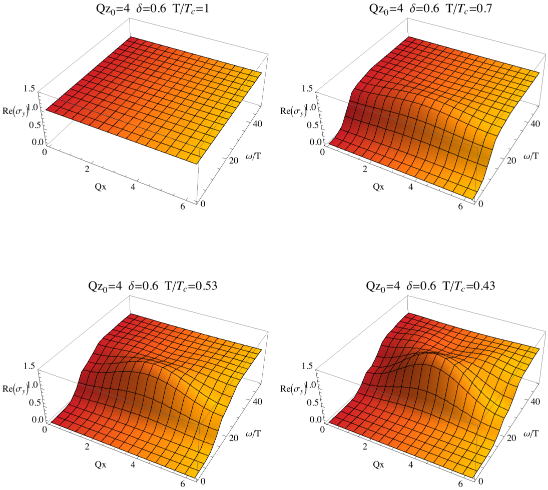
$$\sigma_y(\omega, x) \equiv \frac{J_y(\omega, x)}{E_y(\omega, x)} = -i\frac{A_y^{(1)}(x)}{\omega A_y^{(0)}(x)}\,,$$

y-conductivity for $Q < 1$



- On stripe conductivity $x = 0 + n2\pi/Q$ is like homogeneous conductivity. A gap opens up as T is decreased.
- In between stripes conductivity $x = \pi + n2\pi/Q$ is like normal state, i.e. constant.

y-conductivity for $Q > 1$



- Very different from the homogenous conductivity!
- A gap opens up everywhere at the same T.
- A interesting resonant pattern arises.

Outline

Conclusions

- Inhomogeneity is ubiquitous in high T_c superconductors.

Conclusions

- Inhomogeneity is ubiquitous in high T_c superconductors.
- The role of inhomogeneity at strong coupling can be studied via the AdS/CFT correspondence.

Conclusions

- Inhomogeneity is ubiquitous in high T_c superconductors.
- The role of inhomogeneity at strong coupling can be studied via the AdS/CFT correspondence.
- The striped holographic superconductor comes a step closer to real systems.

Conclusions

- Inhomogeneity is ubiquitous in high T_c superconductors.
- The role of inhomogeneity at strong coupling can be studied via the AdS/CFT correspondence.
- The striped holographic superconductor comes a step closer to real systems.
- $T_c(Q)$ is qualitatively similar but quantitatively different from the weakly coupled BCS case.

Conclusions

- Inhomogeneity is ubiquitous in high T_c superconductors.
- The role of inhomogeneity at strong coupling can be studied via the AdS/CFT correspondence.
- The striped holographic superconductor comes a step closer to real systems.
- $T_c(Q)$ is qualitatively similar but quantitatively different from the weakly coupled BCS case.
- Superconducting stripes are thermodynamically favored.

Conclusions

- Inhomogeneity is ubiquitous in high T_c superconductors.
- The role of inhomogeneity at strong coupling can be studied via the AdS/CFT correspondence.
- The striped holographic superconductor comes a step closer to real systems.
- $T_c(Q)$ is qualitatively similar but quantitatively different from the weakly coupled BCS case.
- Superconducting stripes are thermodynamically favored.
- We presented results for the conductivity along the stripes.

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?
- Compute the conductivity perpendicular to the stripes. Proximity effects?

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?
- Compute the conductivity perpendicular to the stripes. Proximity effects?
- Can we account for phase fluctuations? What is the optimal inhomogeneity?

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?
- Compute the conductivity perpendicular to the stripes. Proximity effects?
- Can we account for phase fluctuations? What is the optimal inhomogeneity?
- Realize the inhomogeneity spontaneously. What changes?

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?
- Compute the conductivity perpendicular to the stripes. Proximity effects?
- Can we account for phase fluctuations? What is the optimal inhomogeneity?
- Realize the inhomogeneity spontaneously. What changes?
- Study the holographic PDW [In progress] . Can one stabilize it?

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?
- Compute the conductivity perpendicular to the stripes. Proximity effects?
- Can we account for phase fluctuations? What is the optimal inhomogeneity?
- Realize the inhomogeneity spontaneously. What changes?
- Study the holographic PDW [In progress] . Can one stabilize it?

Future directions

It would be very interesting to:

- Understand the physics of the large Q conductivity. Where do the resonant patterns come from?
- Compute the conductivity perpendicular to the stripes. Proximity effects?
- Can we account for phase fluctuations? What is the optimal inhomogeneity?
- Realize the inhomogeneity spontaneously. What changes?
- Study the holographic PDW [In progress] . Can one stabilize it?