Killing the Fermi surface:

Some ideas on the strange metal, Fermi arcs and other phenomena

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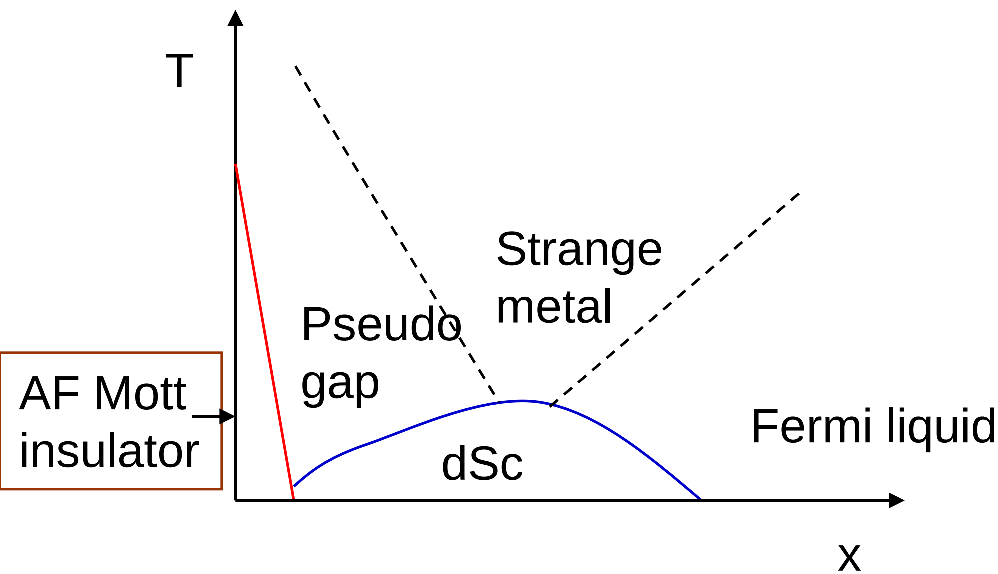
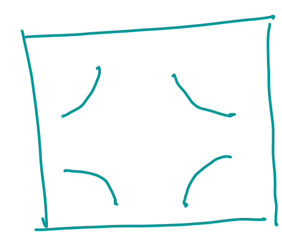
TS, ``Critical fermi surfaces and non-fermi liquid metals”, Phys Rev B, June 08

Some puzzles in the cuprates: finite-T phenomena



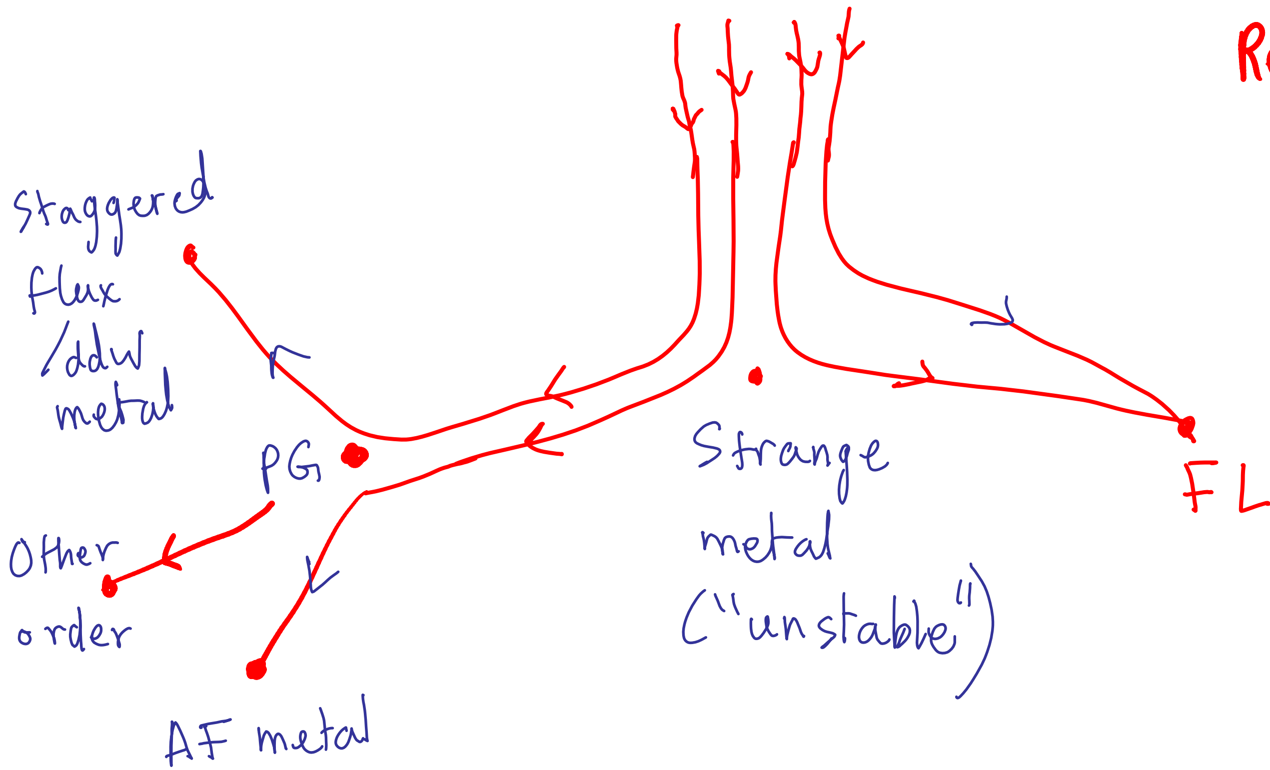
Strange metal: Unusual power laws in various quantities (e g transport)

Pseudo gap (PG): Fermi arcs that shrink in length as T ↘



HOW TO DESCRIBE THESE PHENOMENA?

A point of view



Renormalization flow as function of decreasing energy scale.

Rephrase question: description of (unstable) T=0 strange metal fixed point, and the PG fixed point??

This talk

Proposal for the strange metal fixed point and the crossovers to pseudogap & fermi liquid fixed points.

- Concept of "critical Fermi surface"
- Scaling theory – simple framework to think about many phenomena (at not too low-T)

- Useful analogies to other 'strange metal' systems: heavy fermion critical points, continuous Mott transitions.

- Loose resemblance with some ancient ideas (Varma et al., PWA) in hiTc.

Guidance by focusing on key question : fate of Fermi surface of "underlying normal" ground state as function of doping.

Fermi surface of ``underlying normal" ground state??

Overdoped : Large Fermi surface metal (Fermi liquid)

Underdoped : Apparently metallic

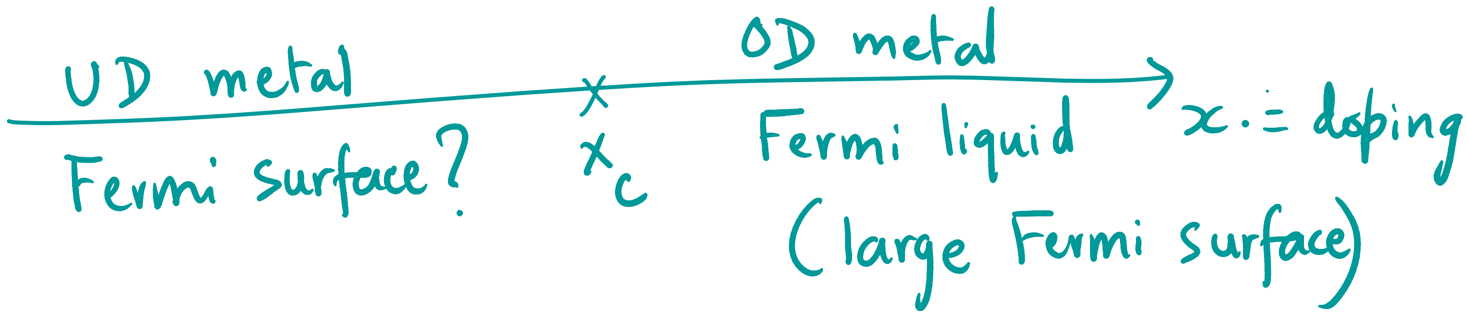
Existence/nature/size of Fermi surface under debate.

Small pockets likely - many theory proposals.

(Eg: natural in doped Mott insulators, ddw, ...)

Simple observations

Underdoped metal is <u>not</u> a large Fermi surface Fermi liquid



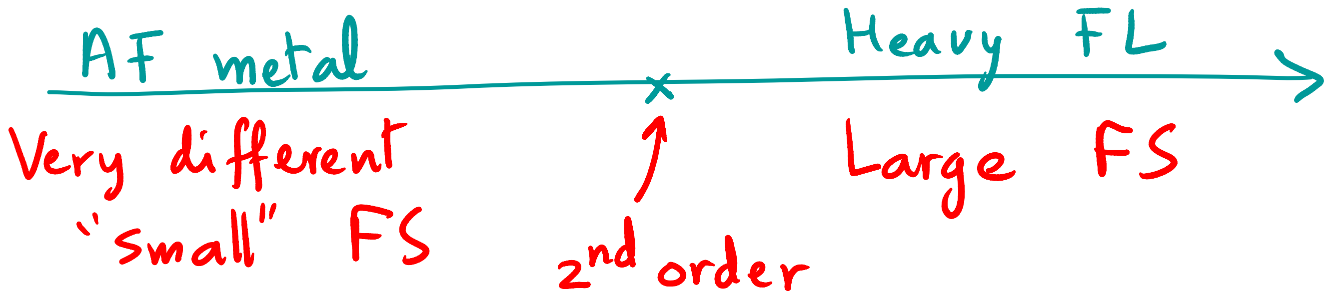
Large Fermi surface of OD metal needs to disappear below some doping x_c thru a quantum phase transition.

Proposal: Strange metal fixed point associated with a phase transition at x_c where <u>entire</u> large FS disappears <u>continuously</u>.

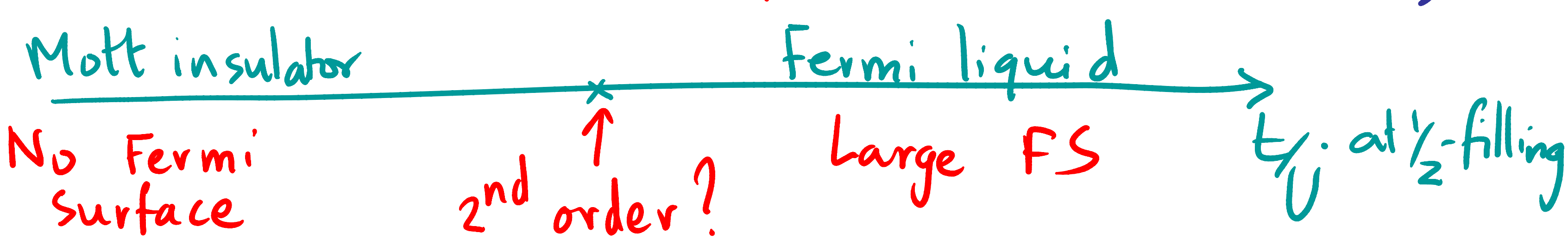
Possibly replaced by very <u>different</u> "small" Fermi surface in underdoped metal for $x < x_c$ (more discussion later, if time permits)

Other phase transitions where entire Fermi surfaces might disappear

1. Heavy fermion quantum critical points
($CeCu_{6-x}Au_x$, $YbRh_2Si_2$, 1-1-5, ...)



2. Continuous Mott transitions (eg: bandwidth controlled)



How might a Fermi surface disappear?

Can a Fermi surface disappear continuously through a 2nd order transition?

One route – quasiparticle weight Z vanishes continuously and everywhere on Fermi surface!

(à la Brinckman-Rice)

Concrete examples (TS, Sachdev, Vojta '04 ; TS '08)

Electronic structure at criticality: ``Critical Fermi surface"

Crucial question : Nature of electronic excitations right at quantum critical point when $Z = 0$?

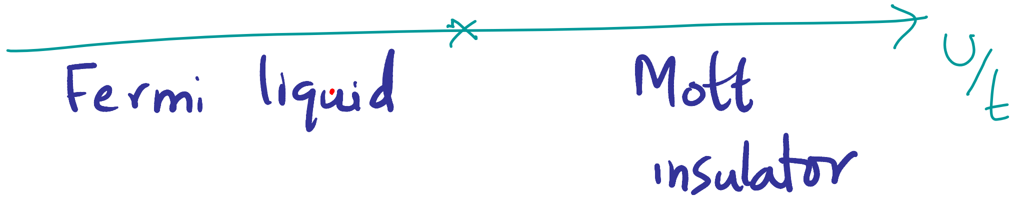
Claim : At critical point, Fermi surface remains sharply defined even though there is no Landau quasiparticle.

(TS '08)

"Critical Fermi surface".

Why a critical Fermi surface?

Mott transition example:



What is gap $\Delta(\vec{k})$ in electron spectral function $A(\vec{k},\omega)$?

Fermi liquid: $\Delta(\vec{k} \in FS) = 0$

Mott insulator: Sharp gap $\Delta(\vec{k}) \neq 0$ for all $\vec{k}$

Evolution of single particle gap

Approach from Mott

2^{nd} order transition to metal $\Rightarrow$ expect Mott gap

$\Delta(\vec{K})$ will close continuously

To match to Fermi surface in metal, $\Delta(\vec{K}) \to 0$
for all $\vec{K} \in FS$.

$\Rightarrow$ Fermi surface sharp at critical point.

But as $Z = 0$ no sharp quasiparticle.

$\Rightarrow$ Non-fermi liquid with sharp "critical" Fermi surface!

Why a critical Fermi surface?

Evolution of momentum distribution

Metal with Fermi surface

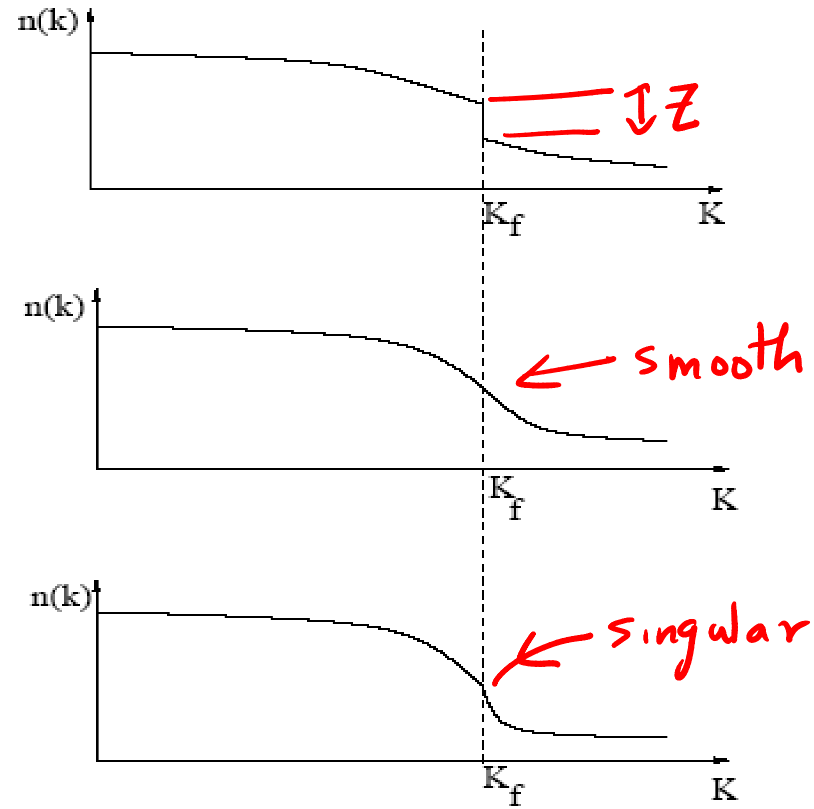
(a)

Phase where Fermi surface has disappeared

(b)

Critical point

(c)



n(k) continuous at k_F but is singular.

Killing a Fermi surface

Disappearance of Fermi surface through a continuous transition

At critical point

(a) $Z = 0$

(b) Fermi surface sharp

(Similar argument for proposed hiTc critical point, heavy fermion critical points, ...)

Some obvious consequences/questions

Critical Fermi surface ⇒ unusual criticality with phenomena different from familiar critical points.

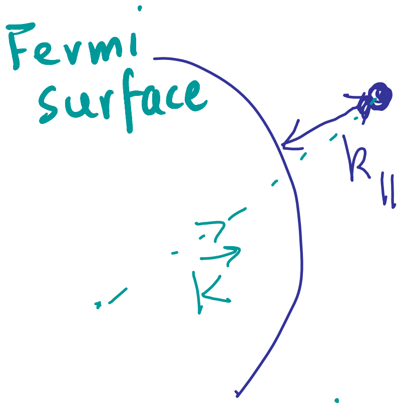
1. Structure of universal singularities/scaling phenomena ?

2. Calculational framework ?

Scaling phenomenology at a quantum critical point with a critical Fermi surface?

Critical Fermi surface: scaling for single particle physics

Right at critical point expect universal scale invariant singularity in $A_c(\vec{K}, \omega)$ for small ω, $k_{||}$



Scaling ansatz:

For every point θ on FS

$$A_c(\vec{K}, \omega, T) \sim \frac{1}{|\omega|^{\alpha/z}} F\left(\frac{\omega}{|k_{||}|^z}, \frac{\omega}{T}\right)$$

New possibility: angle dependent exponents

A priori must allow angle dependent exponents:

$$z = z(\theta), \quad \alpha = \alpha(\theta)$$

consistent with lattice symmetries.

Many interesting consequences!

. . . .

Leaving the critical point

Expect scale invariant spectrum is cut off

at $k_{\parallel} \sim \frac{1}{\xi}$, $\omega \sim \frac{1}{\xi^z}$ so that

$$A_c(\vec{k}, \omega) \sim \frac{1}{|\omega|^{\alpha/z}} F_1\left(\frac{\omega}{k_{\parallel}^z}, k_{\parallel}\xi\right)$$

Expect $\xi \sim |g-g_c|^{-\nu}$ but again

a priori must let $\nu = \nu(\theta)$

Approach from the Fermi liquid

If Fermi liquid physics is part of scaling function

$$Z \sim |\delta g|^{\nu(z-\alpha)} \qquad (\Rightarrow z(\theta) \geq \alpha(\theta))$$

$$v_F \sim |\delta g|^{\nu(1-z)}$$

$\Rightarrow$ Specific heat $C_v \sim T \int_{FS} \frac{1}{v_F} \sim T \int_{FS} |\delta g|^{-\nu(1-z)}$

If ν, z are θ-dependent, not a pristine power law

Asymptopia: Dominated by portion of FS with $\max(\nu(1-z))$

Critical 2Kf surface

2-particle response at finite q

Eg: $\chi''(q, \omega)$

Expect sharp $2K_f$ singularities associated with critical FS

$\Rightarrow$ $\chi''(q, \omega)$ has sharp critical singularities at entire surface in k-space (the $2K_f$ surface)

unlike at bosonic critical points

Separate scaling ansatz for q near $2k_f$ surface, small ω.

Implications of angle dependent exponents

(i) Different properties dominated by different portions of Fermi surface

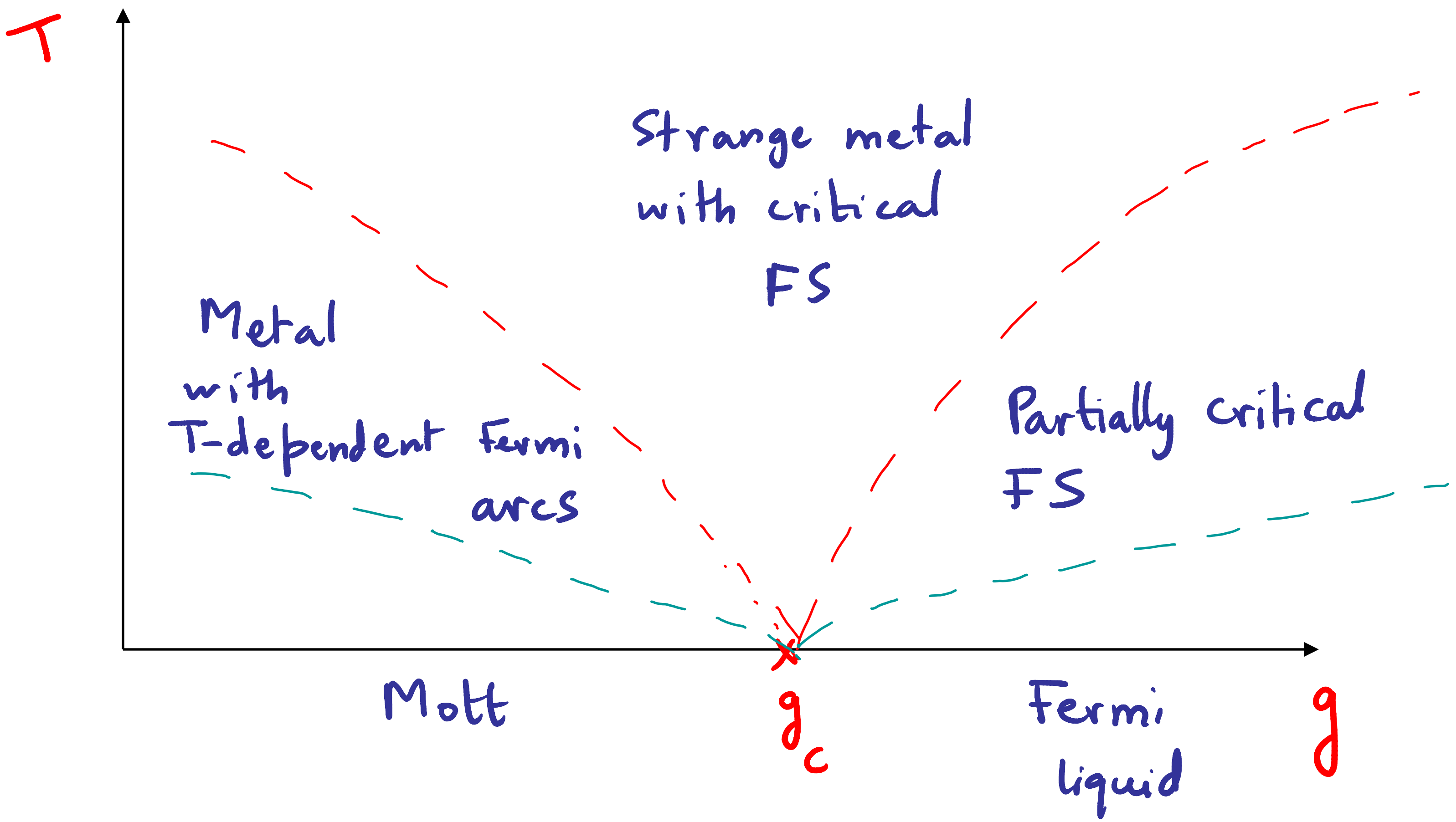
(ii) Different portions of Fermi surface will emerge out of criticality at different energy scales

Example: At Mott transition

Mott gap $\Delta(\theta) \sim |\delta g|^{z(\theta)\nu(\theta)}$.

$\Rightarrow$ Finite-T x overs richer than usual

Finite T crossovers



Application to proposed hiTc critical point

Approach x_c from OD side : no mass divergence $\Rightarrow$ $z = 1$ everywhere on FS.

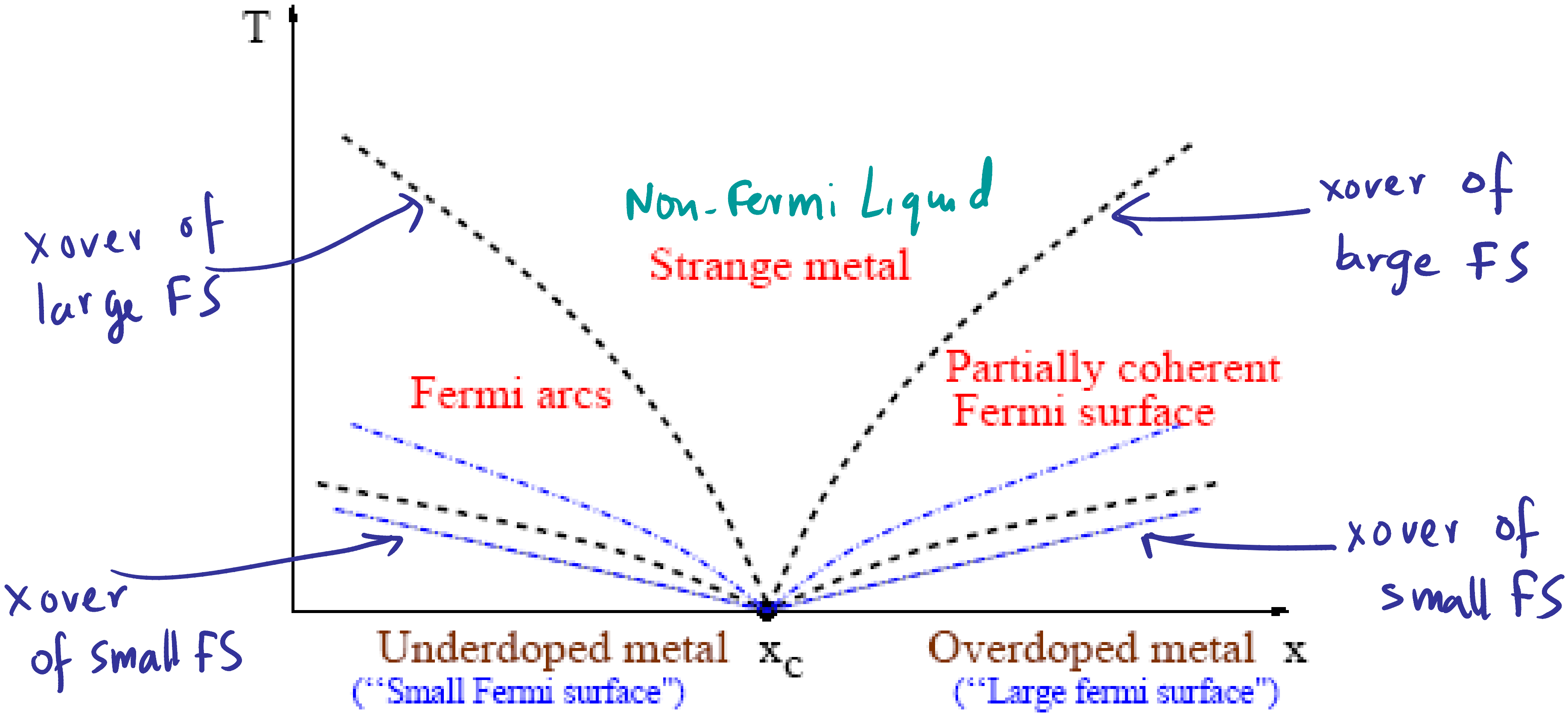
But can still have $\nu = \nu(\theta)$.

$\Rightarrow$ For $x < x_c$, gap on large Fermi surface

$$\Delta(\theta) \sim |x - x_c|^{\nu(\theta)}$$

$\Rightarrow$ Finite-T crossover from strange metal will again go through a PG regime with Fermi arcs.

Crossovers near proposed hiTc critical point



Transport scaling

Quasiparticle scattering rate in 0D Fermi liquid

$$\gamma \sim \xi T^2$$

If (in FL phase) this is also transport lifetime

then resistivity $\rho(T) \sim A T^2$

with $A \sim \xi \nearrow \infty$ as $x \to x_c$.

At criticality, expect $\xi \to 1/T$

$\Rightarrow \rho(T) \sim T$ in strange metal.

Summary

- Strange metal in cuprates: associate with quantum critical point where the entire large Fermi surface disappears.
- Concept of critical fermi surface to describe such a quantum critical point - unusual scaling phenomenology.
- Scaling hypotheses for various quantities
- Possibility of angle dependent exponents with interesting consequences (eg: metals with T-dependent Fermi arcs at intermediate temperature)