Title: Low energy field theories for non-Fermi liquids

Date: Apr 30, 2015 03:00 PM

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Abstract: In this talk, I will discuss some of the recent progress made on low energy effective field theories for non-Fermi liquids. Based on a dimensional regularization scheme, physical properties of various non-Fermi liquid states can be computed in controlled ways. I will emphasize novel features that arise due to the interplay between interaction and the presence of extensive gapless modes near Fermi surface. The examples include non-analytic expansion in coupling, emergent locality and UV/IR mixing.

Fates of quantum many-body states at T=0 are largely determined by the competition between kinetic energy and interaction

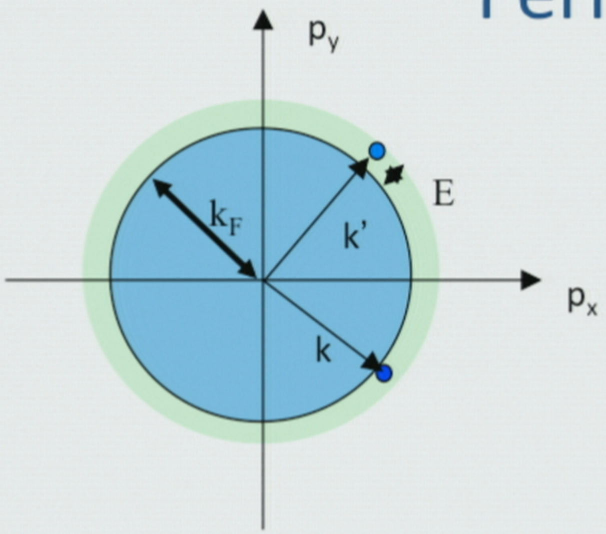
$$H = \sum_i \left(\frac{p_i^2}{2m} + V(r_i) \right) + \sum_{i \neq j} \frac{e^2}{|r_i - r_j|}$$

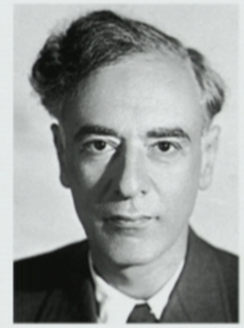
$$[x, p] \neq 0$$

- Kinetic term tends to delocalize particles
- Potential term promotes localization

Kinetic energy >> Interaction
Fermi Liquid

[Landau]



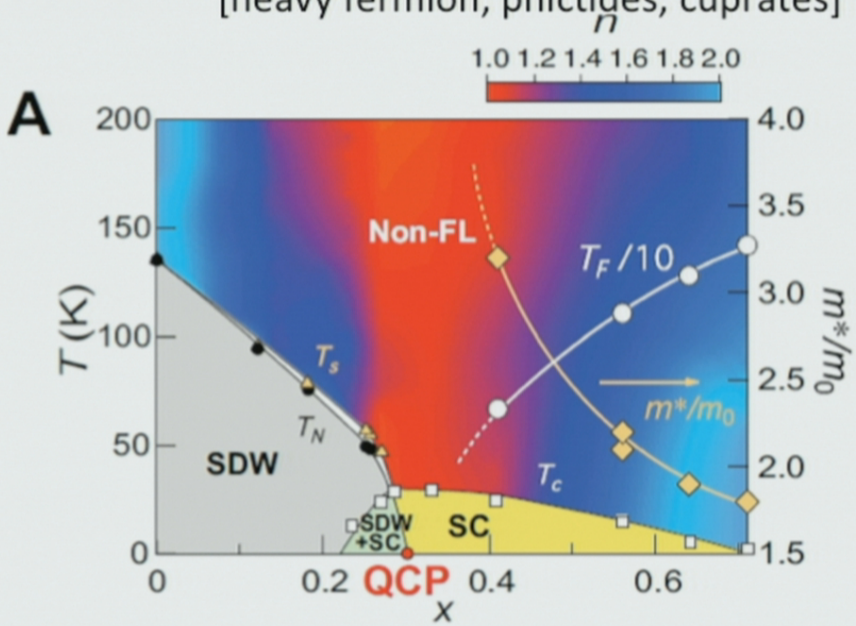


- Kinetic constraints set by the kinetic energy dominates over interactions
- Interactions only dresses electrons into coherent quasiparticles

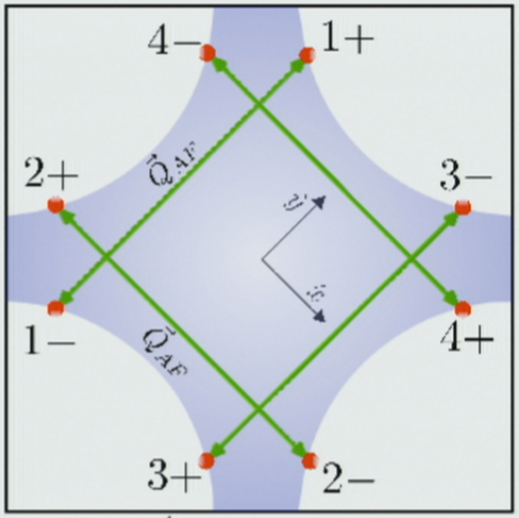
Exotic states can be realized at quantum critical points where neither K.E. nor Interaction dominates

Anti-Ferromagnetic quantum phase transitions in metals

[heavy fermion; pnictides; cuprates]



[Hashimoto et al. Science 336, 1554 (2012)]



Weak Coupling Approach (SDW) Minimal Theory in 2d

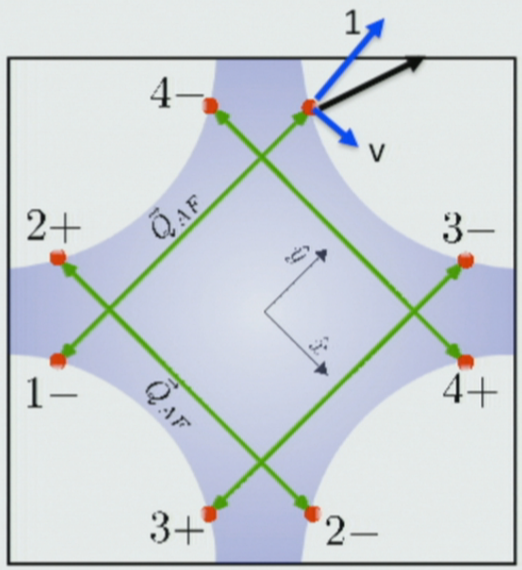
$$e_1^{\pm}(\vec{k}) = -e_3^{\pm}(\vec{k}) = vk_x \pm k_y$$

$$e_2^{\pm}(\vec{k}) = -e_4^{\pm}(\vec{k}) = \mp k_x + vk_y$$

$$\mathcal{S} = \sum_{l=1}^{4} \sum_{m=\pm} \sum_{\sigma=\uparrow,\downarrow} \int \frac{d^3k}{(2\pi)^3}\, \psi_{l,\sigma}^{(m)*}(k) \left[ik_0 + e_l^m(\vec{k}) \right] \psi_{l,\sigma}^{(m)}(k)$$
$$+\frac{1}{2} \int \frac{d^3q}{(2\pi)^3} \left[q_0^2 + c^2|\vec{q}|^2 \right] \vec{\Phi}(-q) \cdot \vec{\Phi}(q)$$
$$+g_0 \sum_{l=1}^{4} \sum_{\sigma,\sigma'=\uparrow,\downarrow} \int \frac{d^3k}{(2\pi)^3} \frac{d^3q}{(2\pi)^3} \left[\vec{\Phi}(q) \cdot \psi_{l,\sigma}^{(+)*}(k+q) \vec{\tau}_{\sigma,\sigma'} \psi_{l,\sigma'}^{(-)}(k) + c.c. \right]$$
$$+\frac{u_0}{4!} \int \frac{d^3k_1}{(2\pi)^3} \frac{d^3k_2}{(2\pi)^3} \frac{d^3q}{(2\pi)^3} \left[\vec{\Phi}(k_1+q) \cdot \vec{\Phi}(k_2-q) \right] \left[\vec{\Phi}(k_1) \cdot \vec{\Phi}(k_2) \right]$$

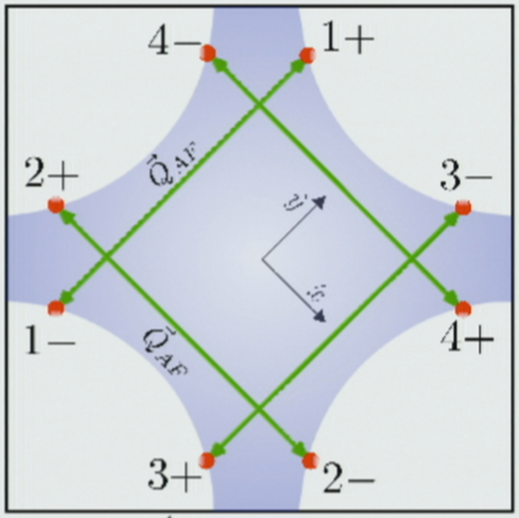
[Abanov, Chubukov]

Parameters of the theory



- v : Fermi velocity perpendicular to Q_{AF}
- c : boson velocity
- g : Yukawa coupling
- u : quartic boson coupling

- If v=0, hot spots connected by Q_{AF} are nested
- The four parameters can not be scaled away



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[Abanov, Chubukov]

Theoretical status (incomplete list)

- Hertz-Millis theory breaks down [Abanov, Chubukov]
- The theory flows to strong coupling regime even in the large N limit [Metlitski, Sachdev]
- The precise nature of the putative NFL state has not been understood due to a lack of control over the theory
- It is desired to introduce a different small parameter to control quantum fluctuations

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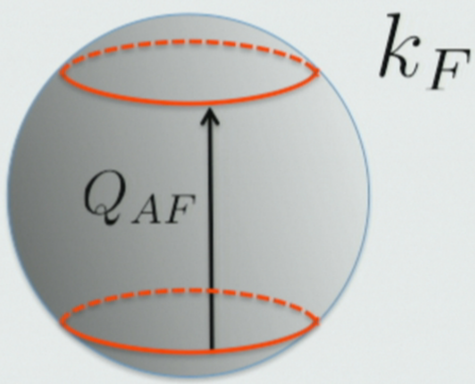
Strategy

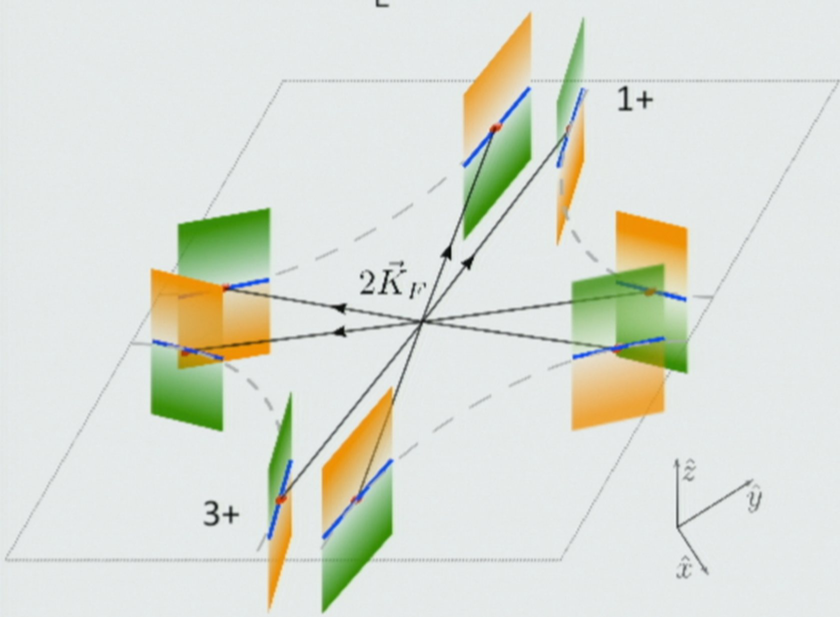
- Tune dimension as a tuning parameter
  - e.g. Epsilon-expansion for the Ising critical point
- The naïve extension of dimension introduce an additional scale



1 dimensional Fermi surface embedded in 3 dimensions

In 3d

$$H = (vk_x \pm k_y)\left[\psi^{(\pm)*}_{1,\sigma,j}\psi^{(\pm)}_{1,\sigma,j} - \psi^{(\pm)*}_{3,\sigma,j}\psi^{(\pm)}_{3,\sigma,j}\right] \mp k_z\left[\psi^{(\pm)*}_{1,\sigma,j}\psi^{(\pm)}_{3,\sigma,j} + h.c.\right]$$



P_z-wave CDW gaps out the 2d FS except for the line nodes at k_z=0

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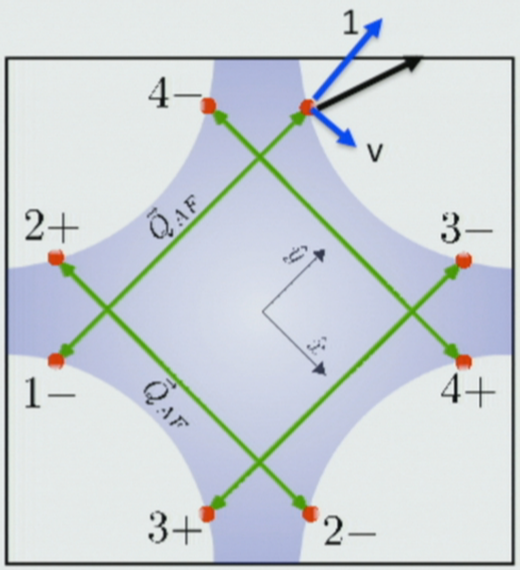

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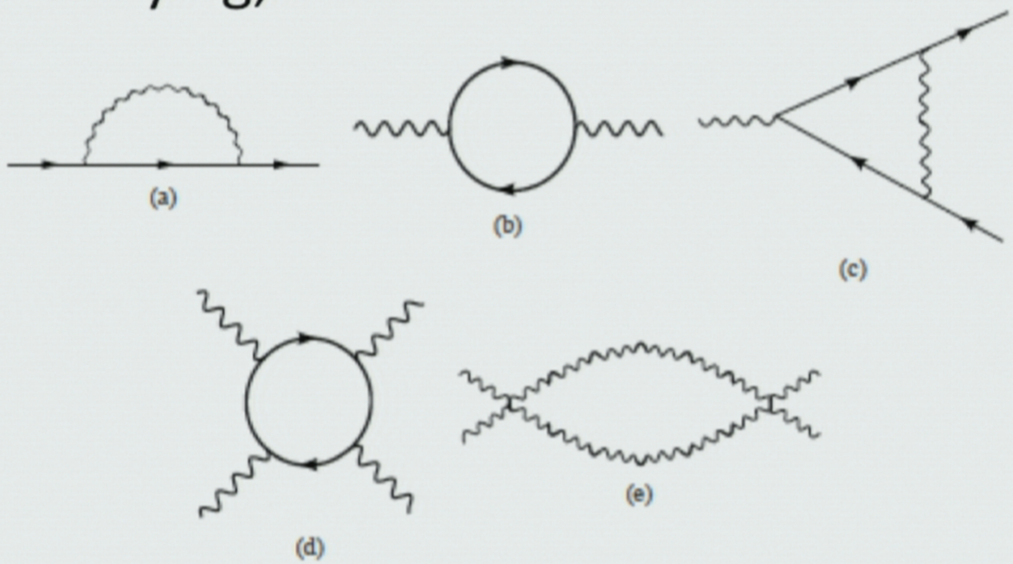
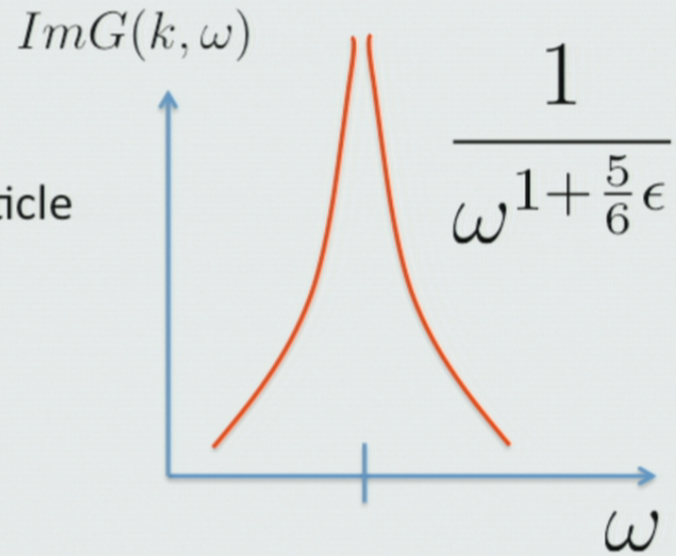
One-loop RG flow

- Yukawa coupling induces nesting : v ↘
- Nesting makes boson slower : c ↘
- Nested FS and slow boson screen more efficiently : g, u ↘



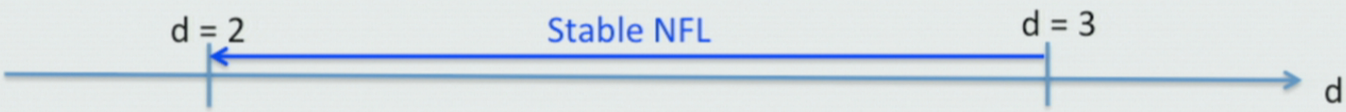
Physical Properties

Absence of quasiparticle at hot spots

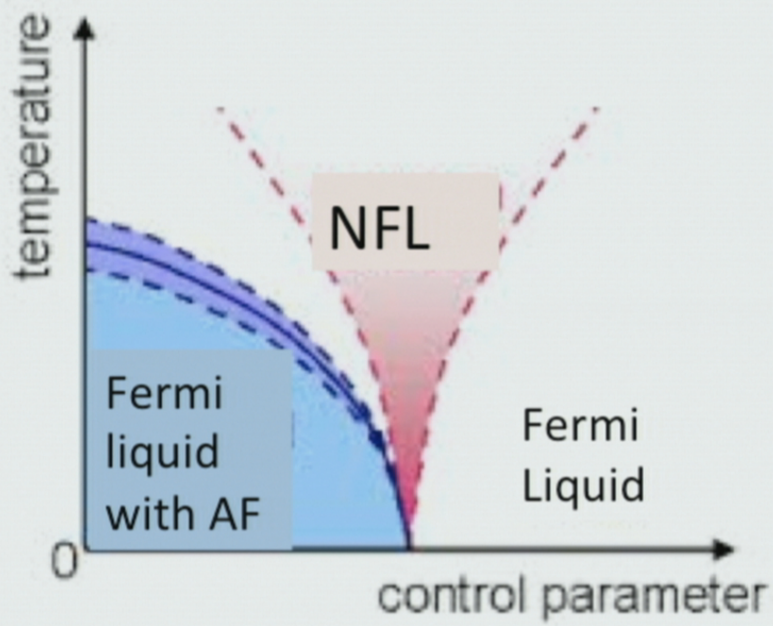


- Enhanced susceptibilities of **bond density wave order**, d-wave SC, Pair density waves

Fate in 2d



2d phase diagram



Summary

- Controlled access to the AF quantum critical point based on a dimensional regularization
- At low energies, FS is nested, boson becomes dispersionless, and interactions flow to zero
- The balance between screening and IR singularity results in a stable Quasi-Local Strange Metal
- CDW and SC fluctuations are enhanced (bond density order, d-wave SC, FFLO)