Typical-medium theories of Mott-Anderson transitions

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NATIONAL HIGH MAGNETIC FIELD LAB

Benasque, 8th International Workshop on Disordered Systems **Aug 26 - Sep 01, 2012**

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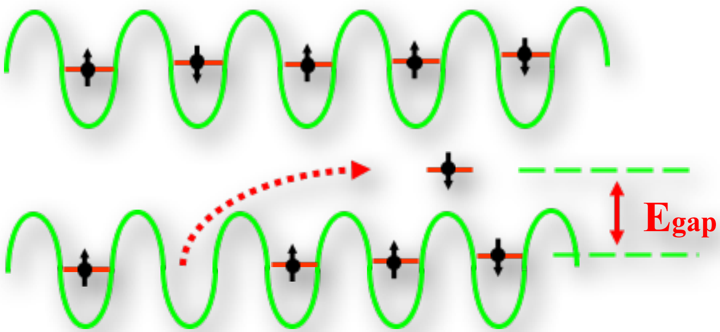
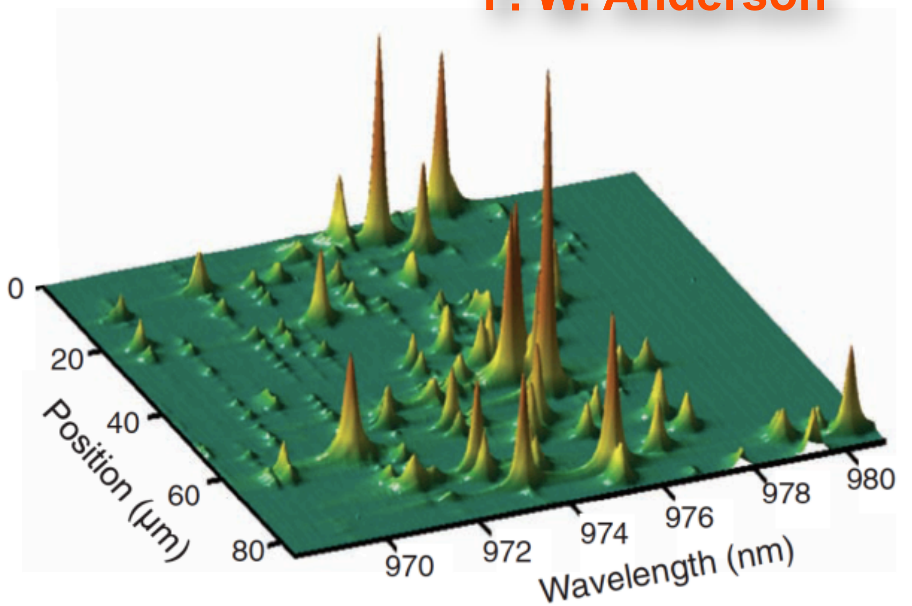
Mechanisms for Localization?

Sir Neville Mott

Friend or Foe???

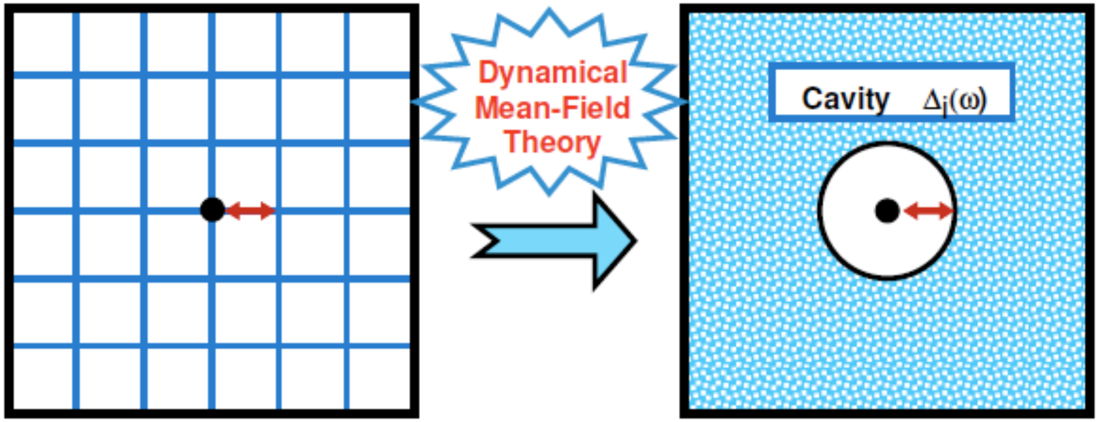
P. W. Anderson



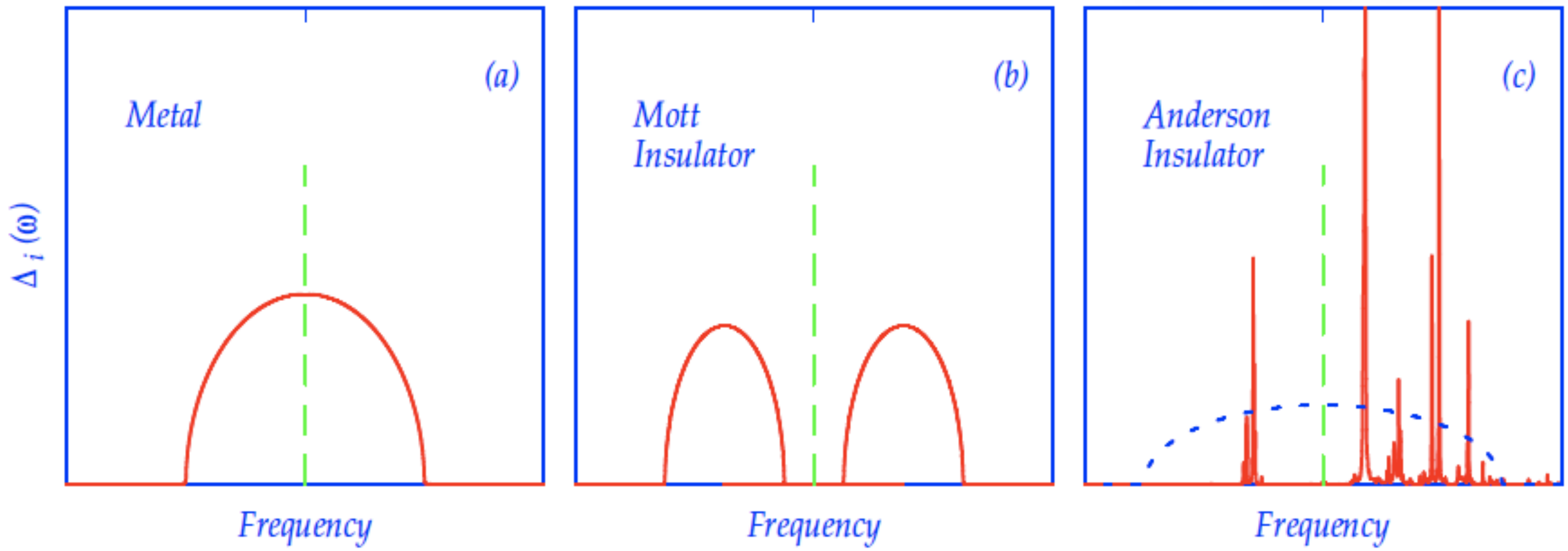


Order parameters??

Local (DMFT) perspective?
Fluctuating cavity field

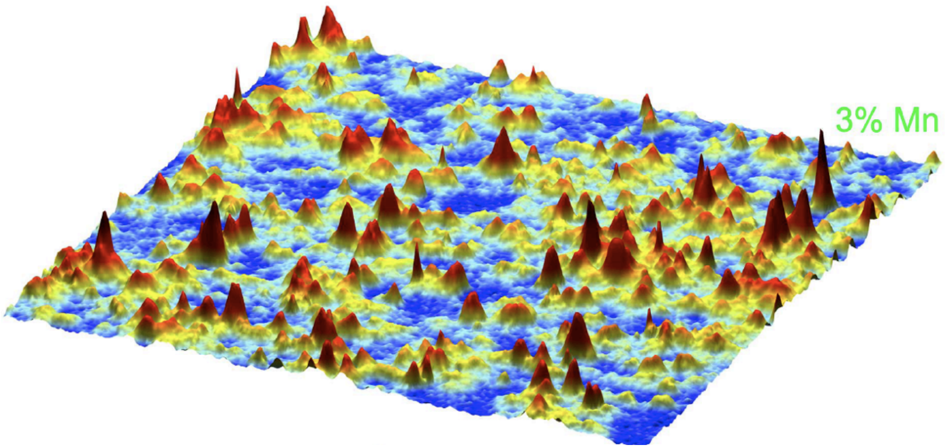


Bethe lattice simulation



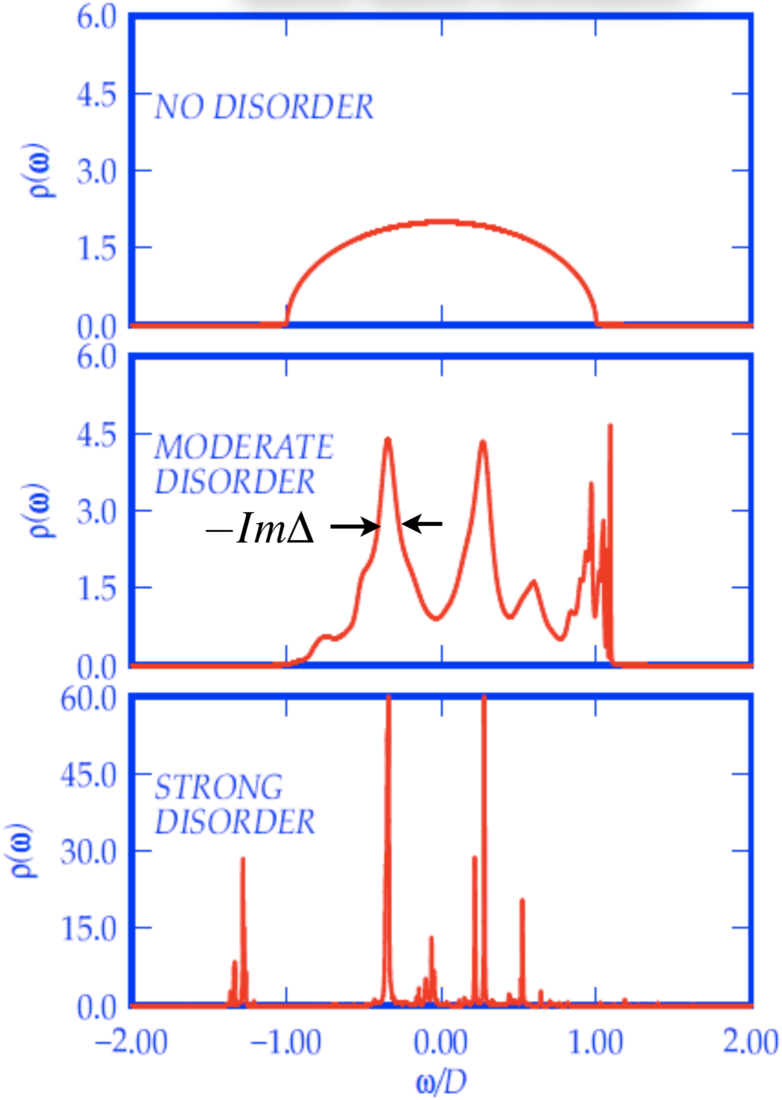
Can local spectrum recognize Anderson localization?

$$\rho_i(\omega) = \frac{1}{\pi} Im \frac{1}{\omega - \varepsilon_i - \Delta_i(\omega)}$$
$$= \sum_n \delta(\omega - \omega_n) |\psi_n(i)|^2$$

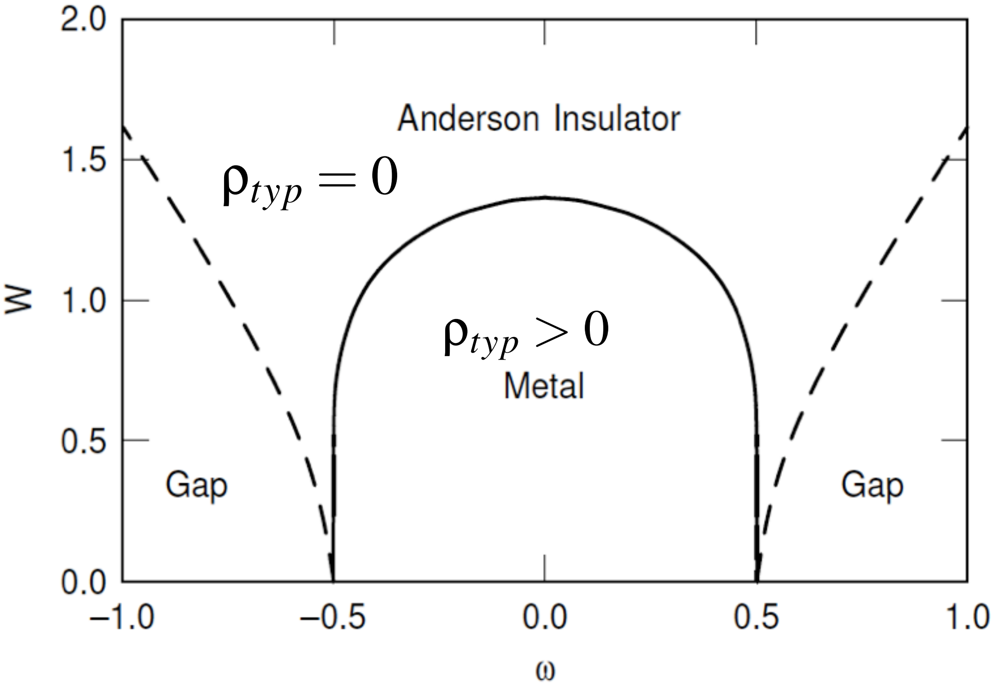


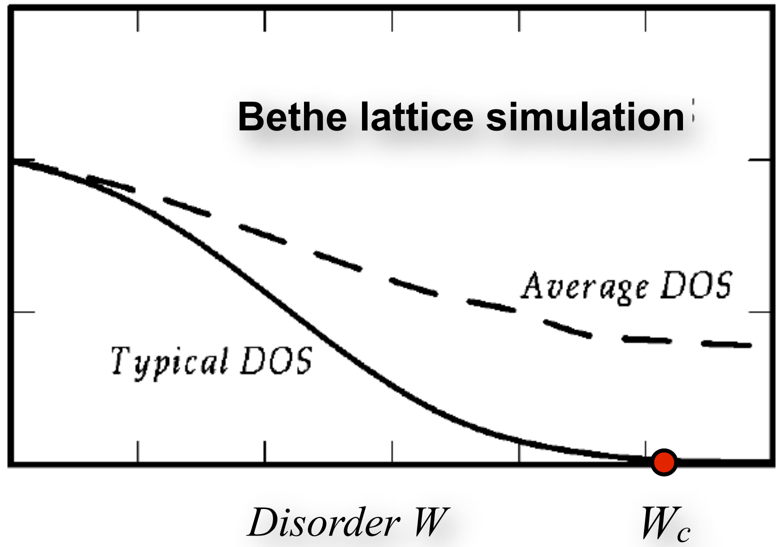
Yazdani, STM experiments GaMnAs
(close to localization)

Bethe lattice simulation



Typical DOS as order parameter for Anderson localization

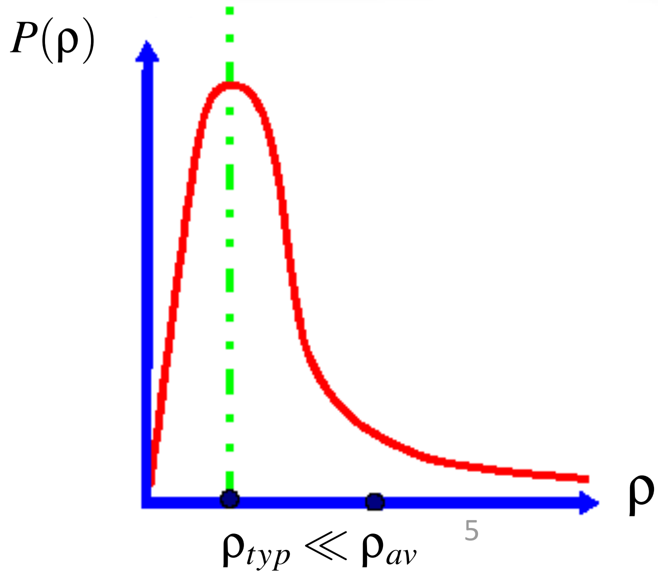




$$\rho_{av} = <\rho_i> \sim 1/W^2 \quad \text{(remains finite)}$$

$$\rho_{typ} = \exp\{<\ln \rho_i>\} \sim (W_c - W)^\beta$$

LOCAL order parameter



Typical Medium Theory for Anderson localization

V. Dobrosavljević, A. Pastor, and B. K. Nikolić, *Europhys. Lett.* **62**, 76–82, (2003)

Idea: **Localization: cavity function $\Delta_i(\omega)$ fluctuates**

DMFT (CPA) replaces it by average value (wrong)

TMT-DMFT: replace it by typical value (order parameter)

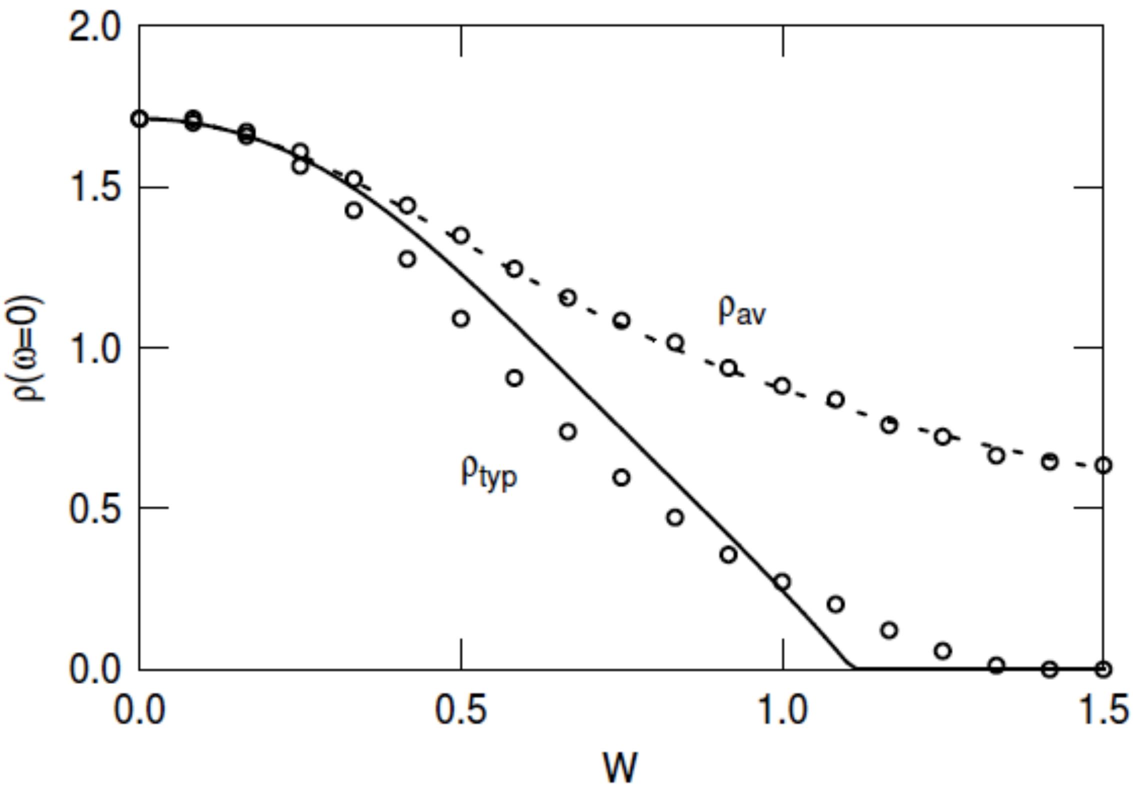
$$G(\omega, \varepsilon_i) = [\omega - \varepsilon_i - \Delta(\omega)]^{-1} \qquad \Delta(\omega) = \Delta_o(\omega - \Sigma(\omega))$$

$$\Delta_o(\omega) = \omega - 1/G_o(\omega). \qquad G_o(\omega) = \int_{-\infty}^{+\infty} d\omega' \, \frac{\rho_0(\omega')}{\omega - \omega'}$$

$$\rho_{\text{typ}}(\omega) = \exp\left\{ \int d\varepsilon_i \, P(\varepsilon_i) \, \ln \rho(\omega, \varepsilon_i) \right\} \qquad G_{\text{typ}}(\omega) = \int_{-\infty}^{+\infty} d\omega' \, \frac{\rho_{\text{typ}}(\omega')}{\omega - \omega'}$$

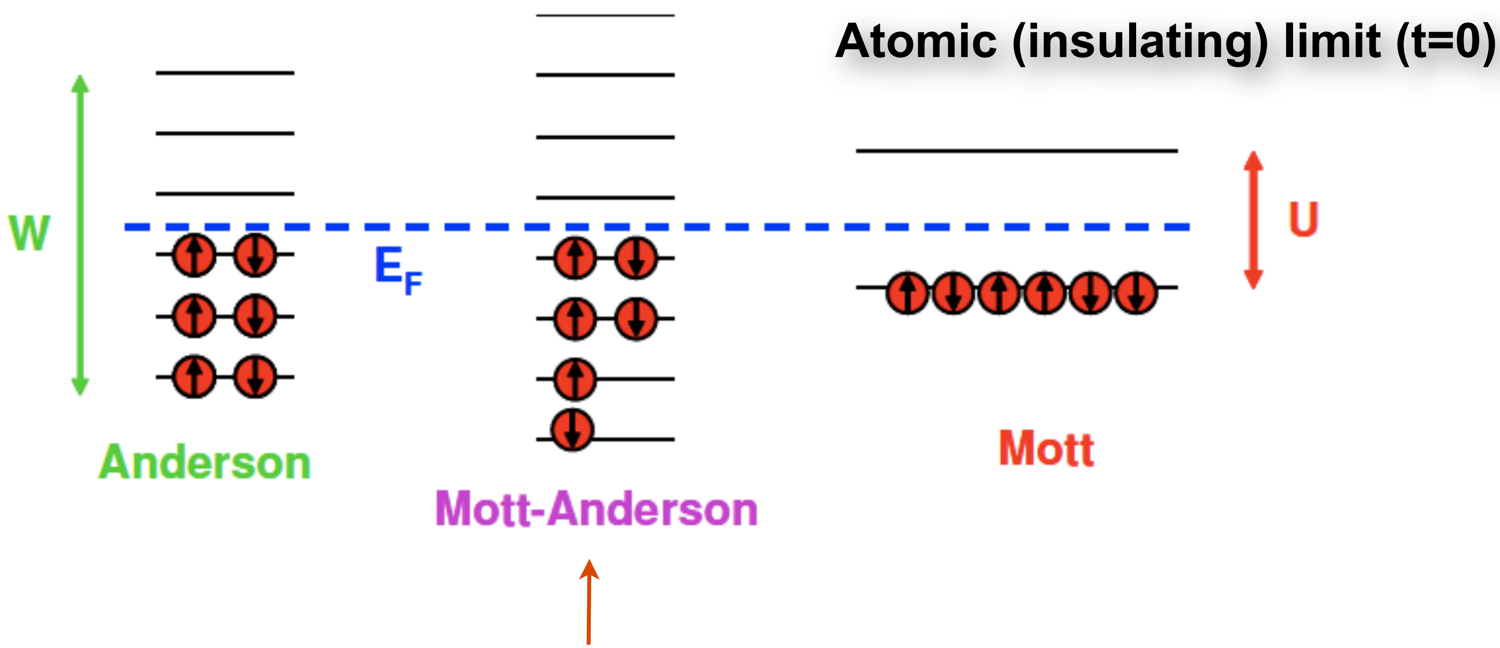
Self-consistency: $G_o(\omega - \Sigma(\omega)) = G_{\text{typ}}(\omega)$

TMT vs. exact 3D behavior



Excellent quantitative agreement with exact diagonalization in 3D

Challenges: Mott-Anderson Transitions

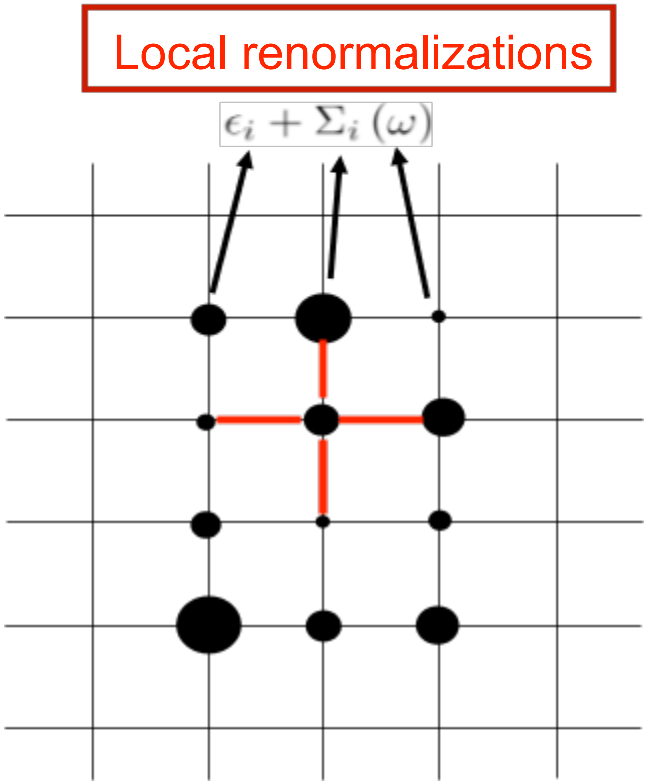


Two-Fluid behavior:
local moments (Mott) + Anderson-localized electrons

Mott-Anderson Transitions: order parameters

• Clean case (W=0): Mott metal-insulator transition at $U=U_c$, where $\boldsymbol{Z} \rightarrow 0$ (Brinkman and Rice, 1970).

• Fermi liquid approach in which each fermion acquires a quasi-particle renormalization and each site-energy is renormalized:



$$\Sigma_i(\omega) = \left(1 - Z_i^{-1}\right)\omega - \varepsilon_i + \bar{\varepsilon}_i / Z_i$$

Local moment formation: $Z_i \longrightarrow 0$

Orbitally (site) selective Mott transition?

"deconfinement", "fractionalization"

"Kondo" THEOREM: in any metal

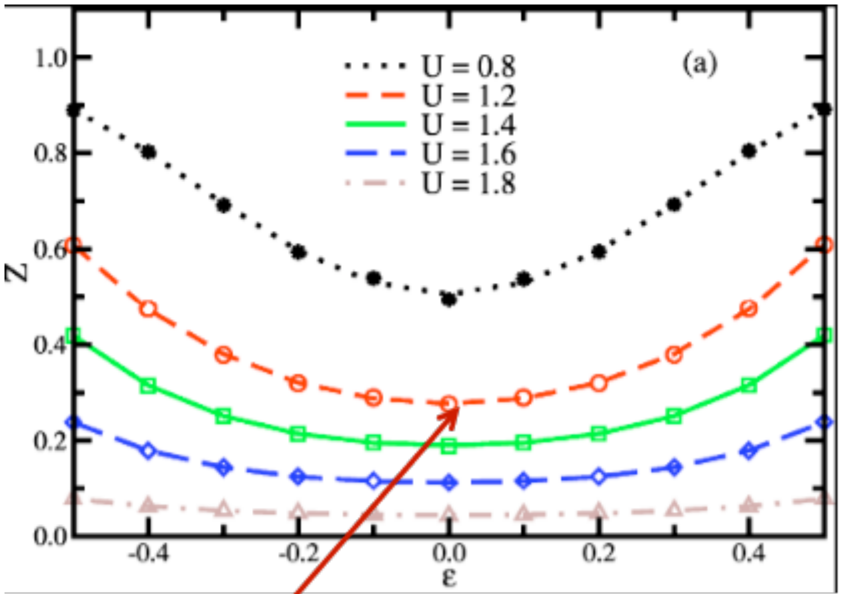
$Z_i \neq 0$ $\quad \rho_i \neq 0$ **(continuum spectrum)**

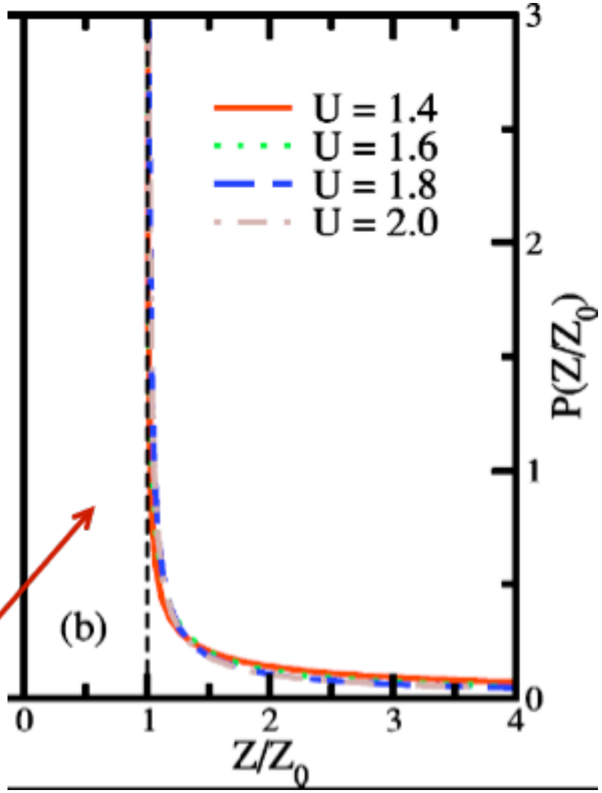
(exceptions on Friday)

Mott transition+weak disorder: results in D = ∞

(*D. Tanasković et al., PRL 2003*; *M. C. O. Aguiar et al., PRB 2005*)

- For $U \to U_c(W)$, all $\mathbf{Z}_i \to 0$ vanish (disordered Mott transition)
- If we re-scale all Z_i by $Z_0 \sim U_c(W)-U$, we can look at $P(Z_i/Z_0)$
- For $D = \infty$ (DMFT), $P(Z/Z_0)$ - **universal form** at U_c.

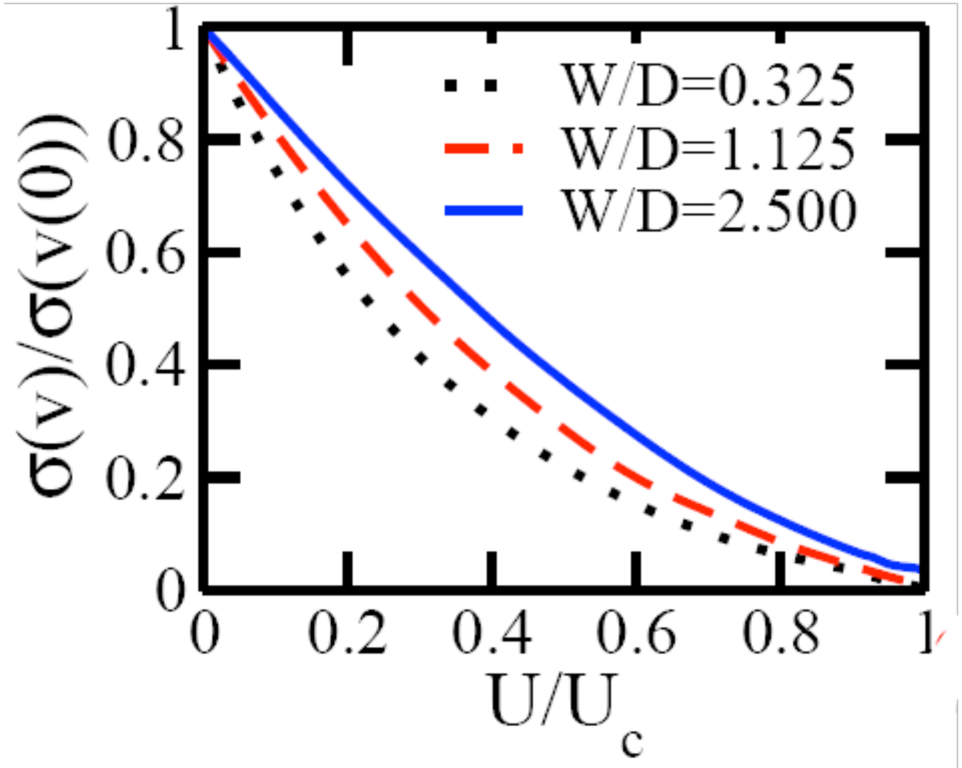




Spectroscopic signatures: disorder screening

- The effective disorder at the Fermi level is given by the distribution of: $v_i = \varepsilon_i + \Sigma_i(\omega = 0) = \bar{\varepsilon}_i / Z_i$

Width of the v_i distribution

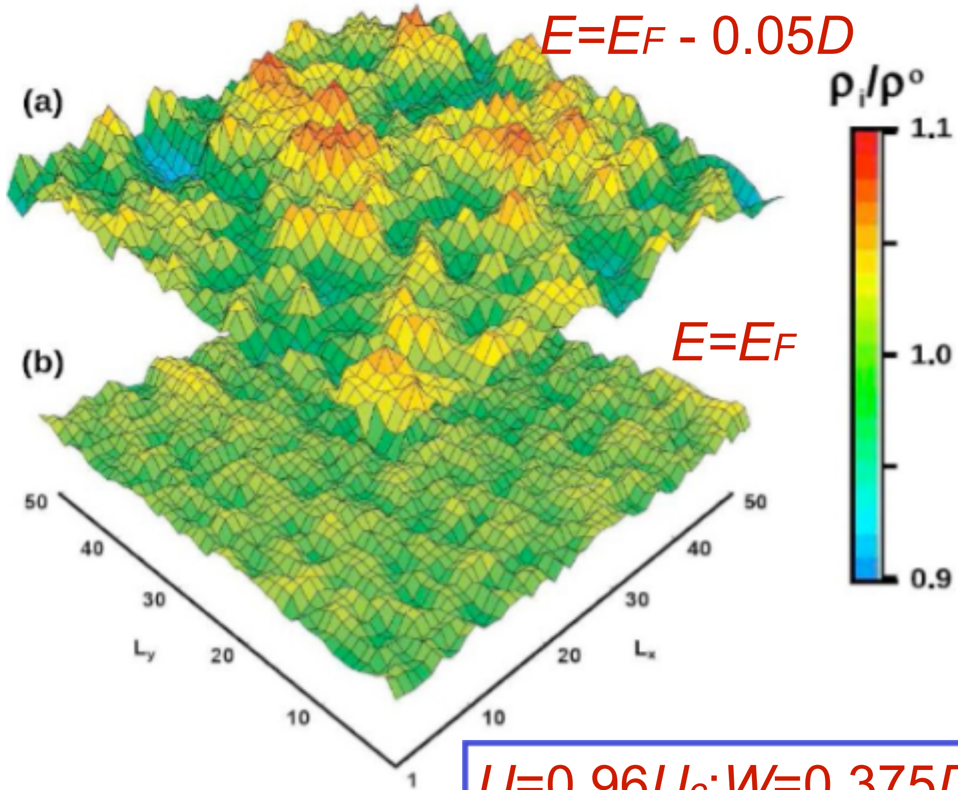


This quantity is strongly renormalized close to the Mott MIT

v_i is pinned to Fermi level (Kondo resonance)

Energy-resolved inhomogeneity!

- However, the effect is lost even slightly away from the Fermi energy:



$$v_i(\omega \neq 0) = \varepsilon_i + \Sigma_i(\omega \neq 0)$$
$$= v_i + \omega\left(1 - Z_i^{-1}\right)$$

The strong disorder effects reflect the wide fluctuations of Z_i

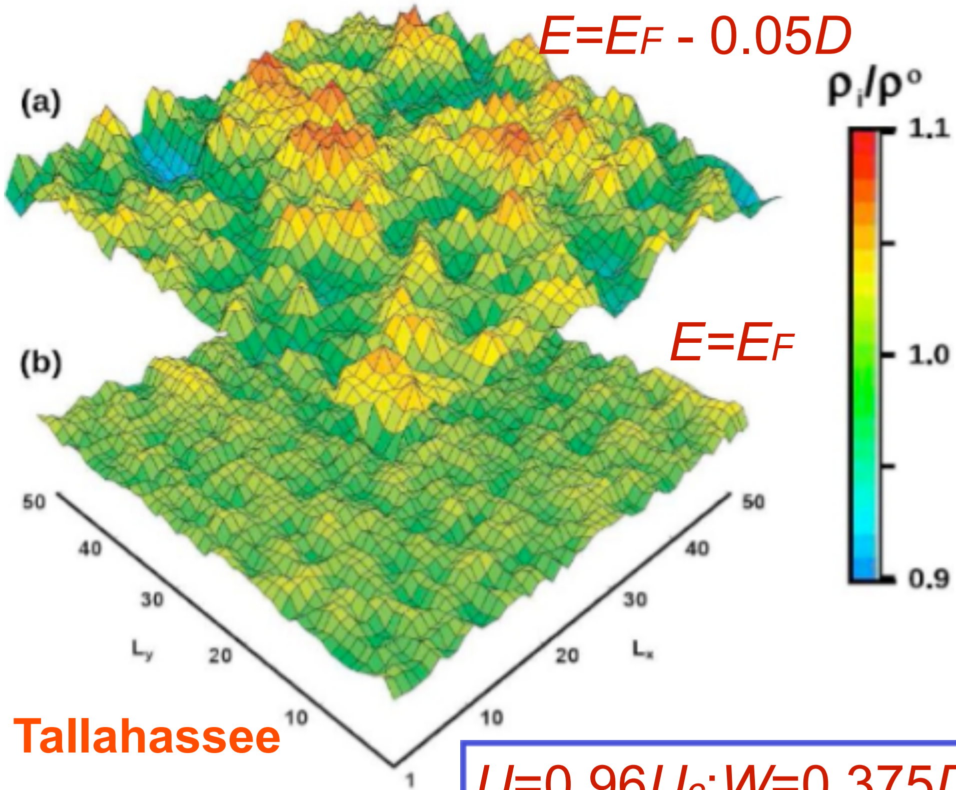
Similar to high-Tc materials, as seen by STM
Experiment: Seamus Davis (2005)
Theory: Garg, Trivedi, Randeria (2008))

U=0.96U_c;W=0.375D

Generic to the strongly correlated materials?

Energy-resolved inhomogeneity!

- However, the effect is lost even slightly away from the Fermi energy:



$$\begin{aligned} v_i(\omega \neq 0) &= \varepsilon_i + \Sigma_i(\omega \neq 0) \\ &= v_i + \omega\left(1 - Z_i^{-1}\right) \end{aligned}$$

The strong disorder effects reflect the wide fluctuations of Z_i

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Experiment: Seamus Davis (2005)
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Tallahassee

$U=0.96U_c; W=0.375D$

Generic to the strongly correlated materials?

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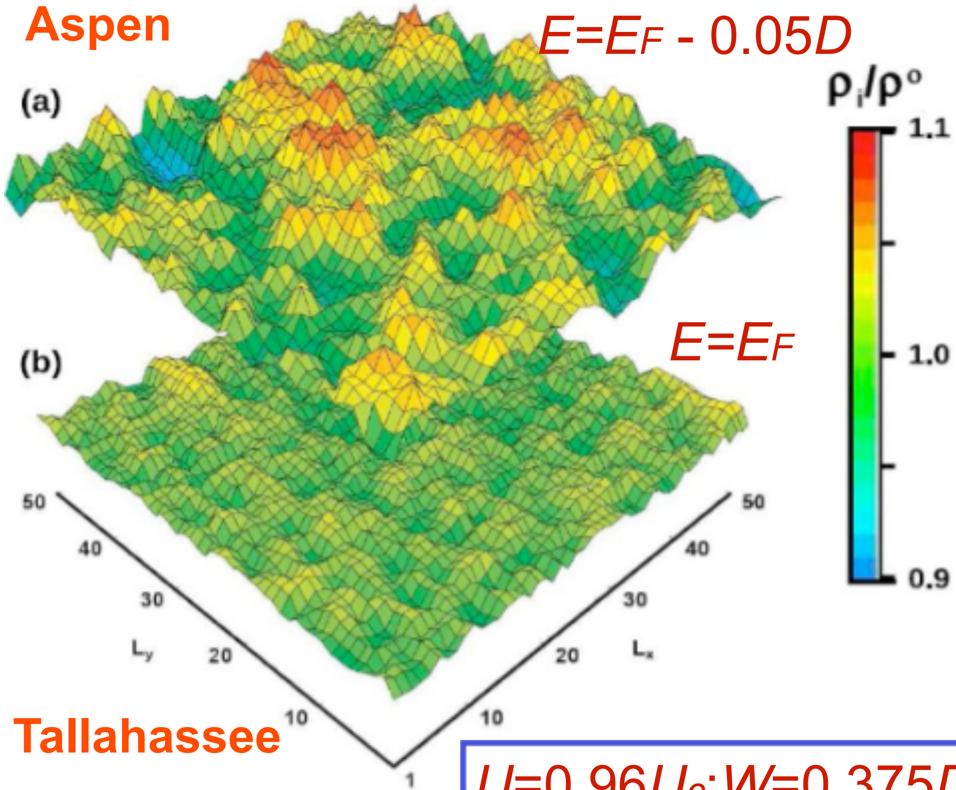

E=*E*F - 0.05*D*

E=*E*F

$$v_i(\omega \neq 0) = \varepsilon_i + \Sigma_i(\omega \neq 0)$$
$$= v_i + \omega\left(1 - Z_i^{-1}\right)$$

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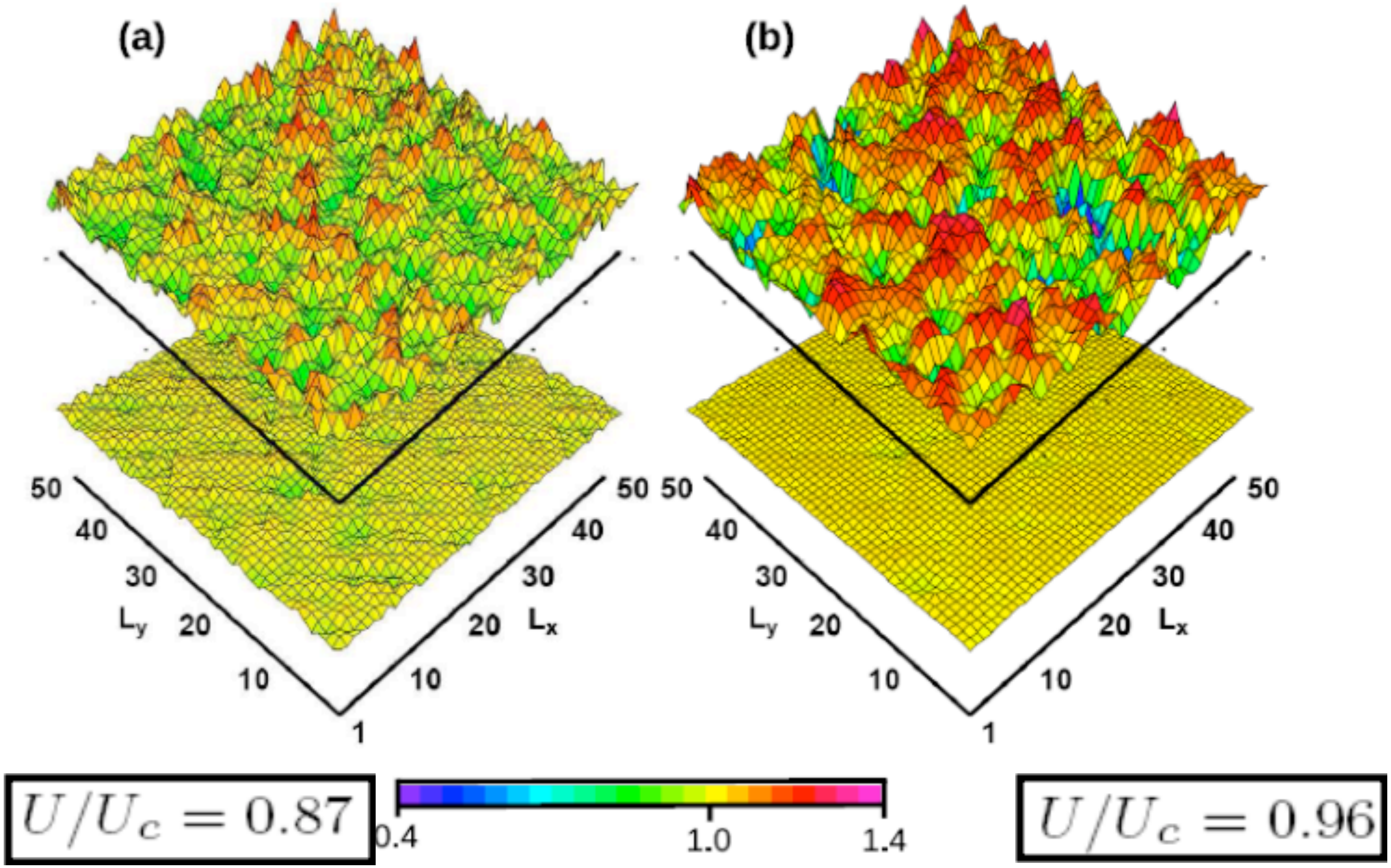
Generic to the strongly correlated materials?

Mottness-induced contrast

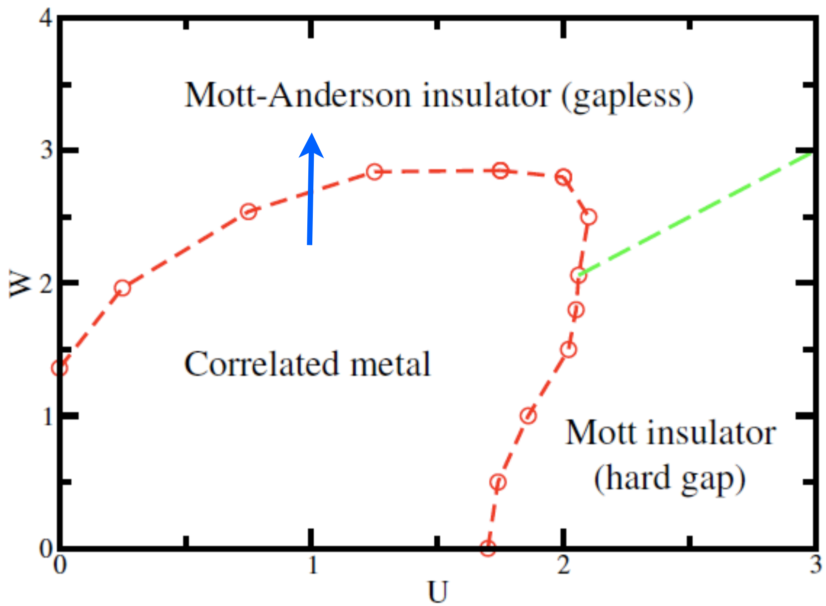


Generic feature of all Mott systems, not only high Tc cuprates?!

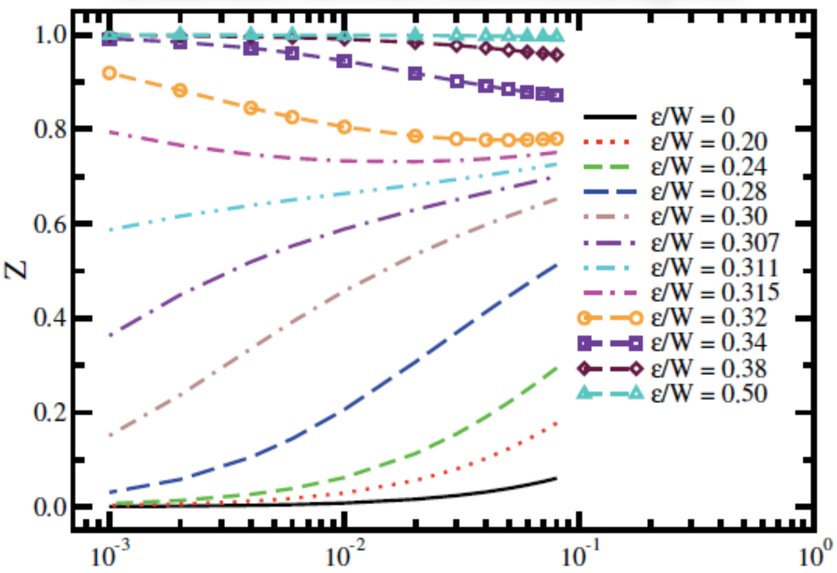
TMT-DMFT of Mott-Anderson transition

PRL 102, 156402 (2009) PHYSICAL REVIEW LETTERS week ending 17 APRIL 2009

Critical Behavior at the Mott-Anderson Transition: A Typical-Medium Theory Perspective



Disorder-driven (increasing W)



distance to transition

Only fraction of Z_i vanish - two fluid behavior!

Challenges: Spatial Fluctuations, Rare Events...
(missing from DMFT and even TMT-DMFT)

PRL 102, 206403 (2009) PHYSICAL REVIEW LETTERS week ending 22 MAY 2009

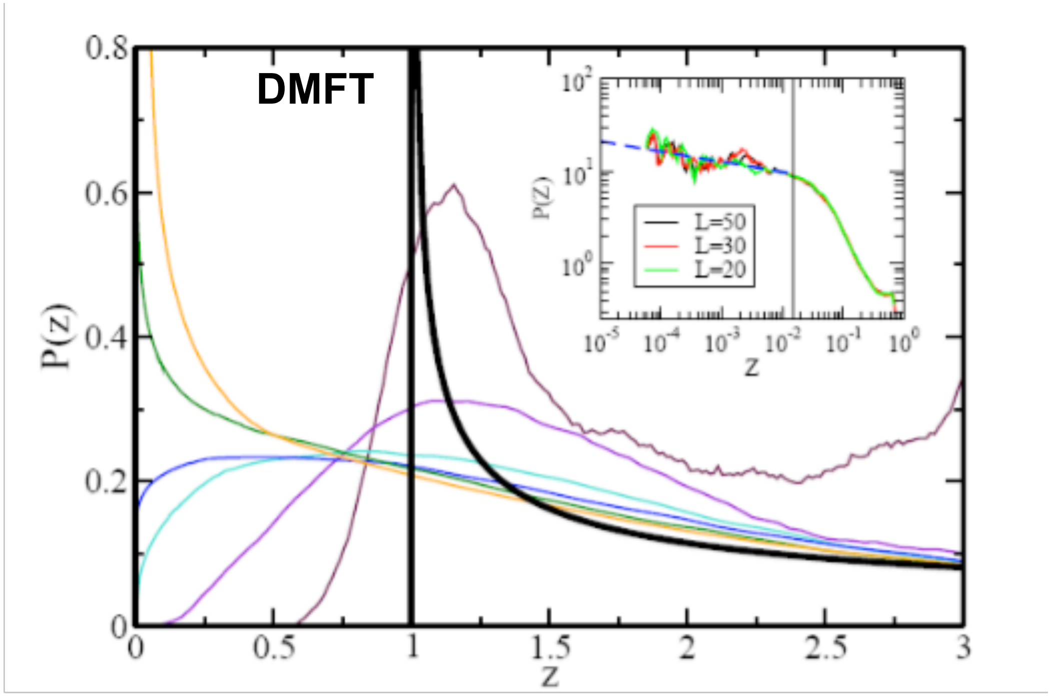
Electronic Griffiths Phase of the $d = 2$ Mott Transition

E. C. Andrade,[1,2] E. Miranda,[2] and V. Dobrosavljević[1]

- In D=2, the environment of each site ("bath") has strong **spatial fluctuations**
- **New physics**: **rare evens** due to fluctuations and spatial correlations

Distribution P(Z/Z_0) acquires a **low-Z tail**:

$$P(Z) \propto Z^{\alpha-1}$$



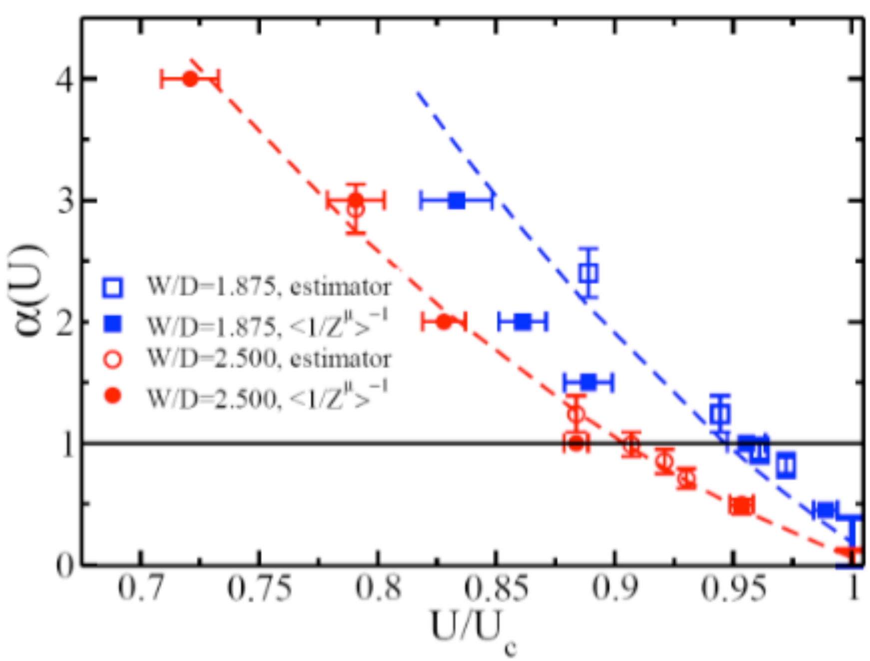
Results: Thermodynamics

- Remembering that the local Kondo temperature and $T_{Ki} \propto Z_i$

$$\chi_i(T) \sim \frac{1}{T + T_{Ki}} \Rightarrow \langle \chi(T) \rangle \sim \int dT_k \frac{T_K^{\alpha-1}}{T + T_K} \sim T^{\alpha-1}$$

Singular thermodynamic response

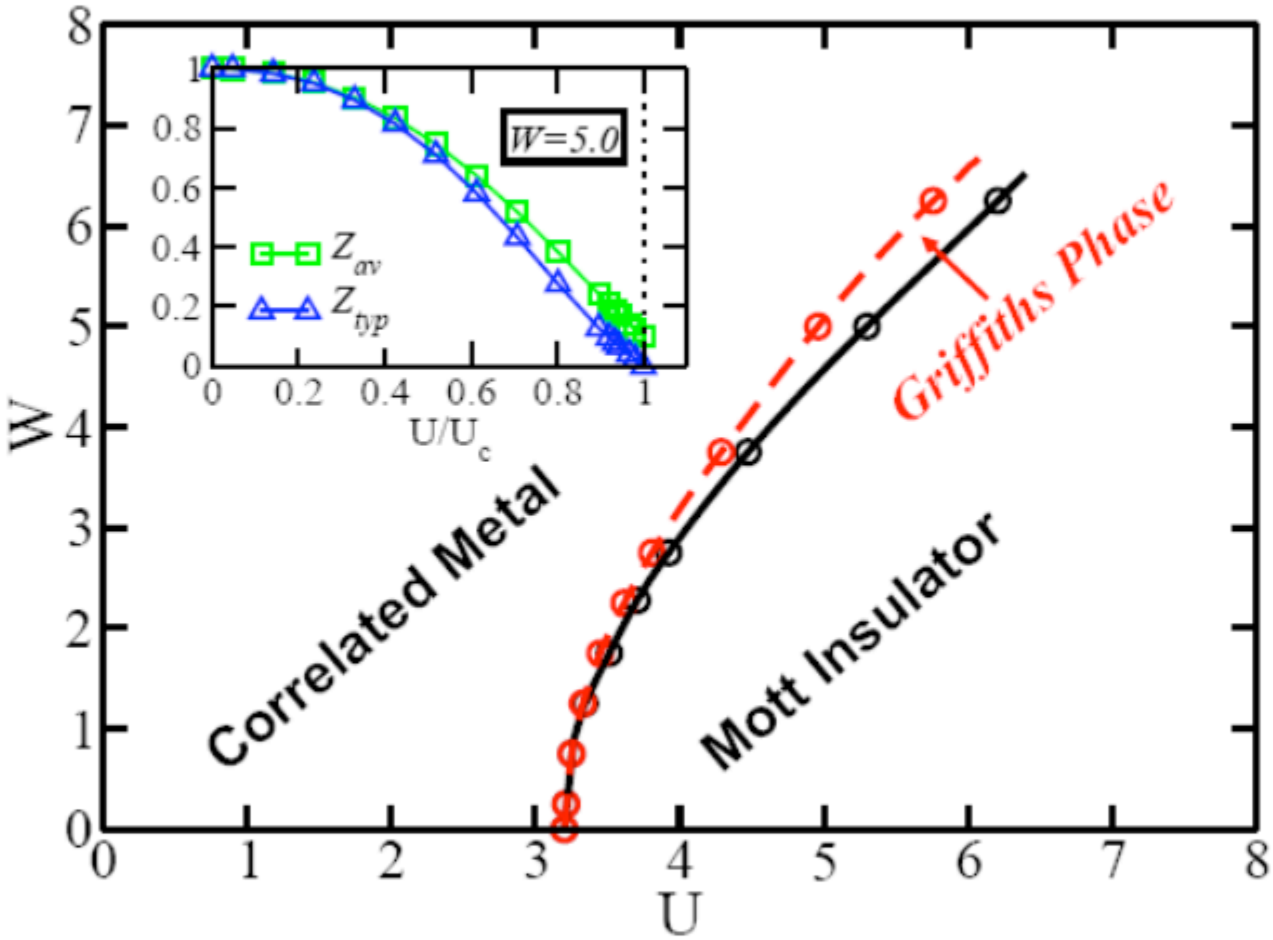
The exponent α is a function of disorder and interaction strength. **α=1** marks the onset of singular thermodynamics.



Quantum Griffiths phase

E. Miranda and V. D., Rep. Progr. Phys. **68**, 2337 (2005); T. Vojta, J. Phys. A **39**, R143 (2006)

Phase Diagram (U > W)



Z_{typ} = exp{ < ln Z> }

“Size” of the rare events?

$$\chi_i \sim Z_i^{-1}$$

Replace the environment of given site outside square by uniform (DMFT-CPA) effective medium.

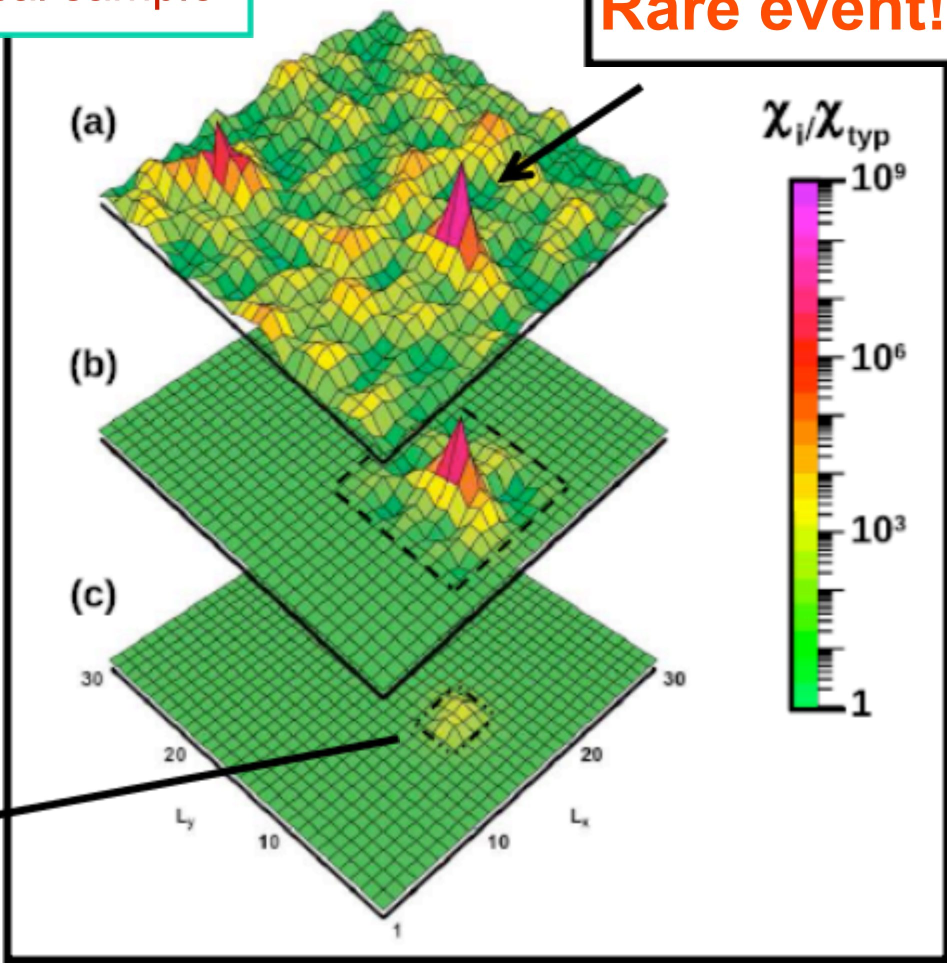
Reduce square size down to DMFT limit.

Rare evrents due to rare regions with weaker disorder

The rare event is preserved for a box of size *l* > 9: **rather smooth profile with a characteristic size.**

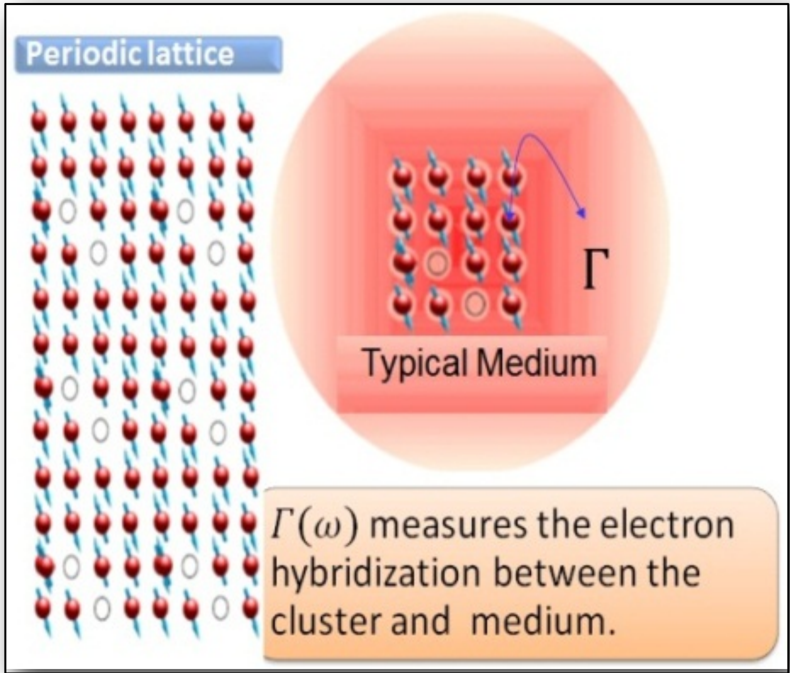
Typical sample

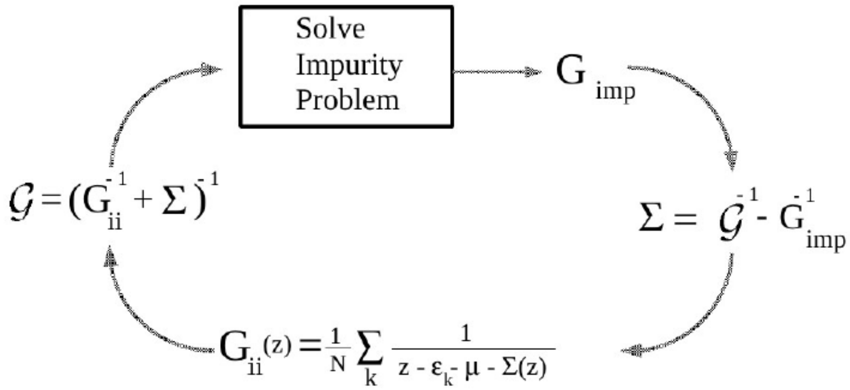
Rare event!

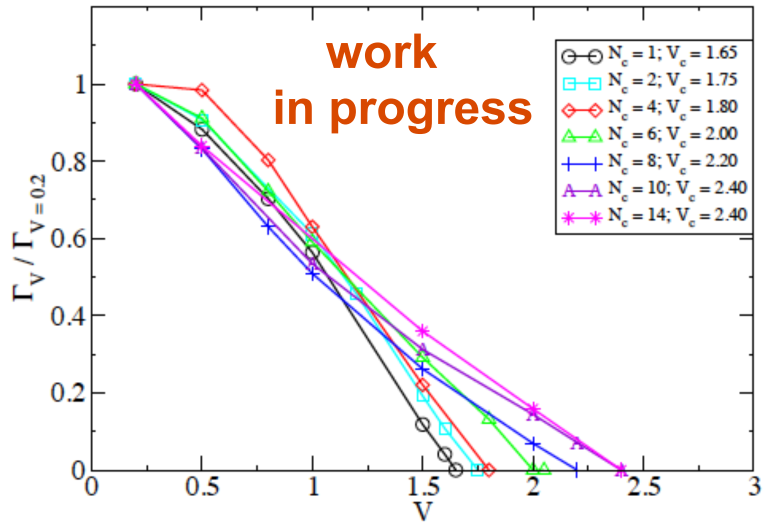


Nonlocal effects and inter-site correlations (DCA!!)

C. E. Ekuma, Z. Y. Meng, H. Terletska, J. Moreno, ***M. Jarrell****, and V. Dobrosavljević*







Cluster of size L embedded in a “typical” medium:
systematic corrections, nonlocal correlations

Current/Future Work: Challenges and Opportunities

Nonlocal effects and inter-site correlations (**DCA!!**)

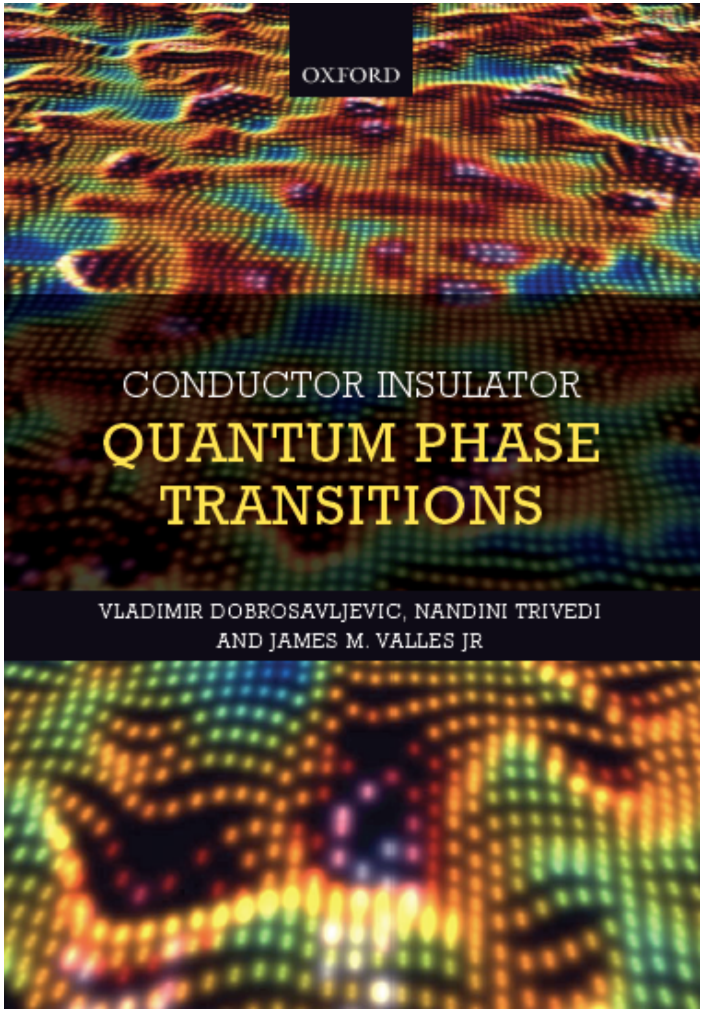
Finite-temperature coherence-incoherence crossovers

Metastability and glassy ordering (bosonic EDMFT)

Charge ordering (Wigner-Mott) and pseudogap phases

Realistic modeling of impurities and disorder

To learn more:



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