DMFT Approaches to Glassy Behavior of Electrons

2D MIT: Incoherent Fermi Liquid to Mott-Anderson Glass

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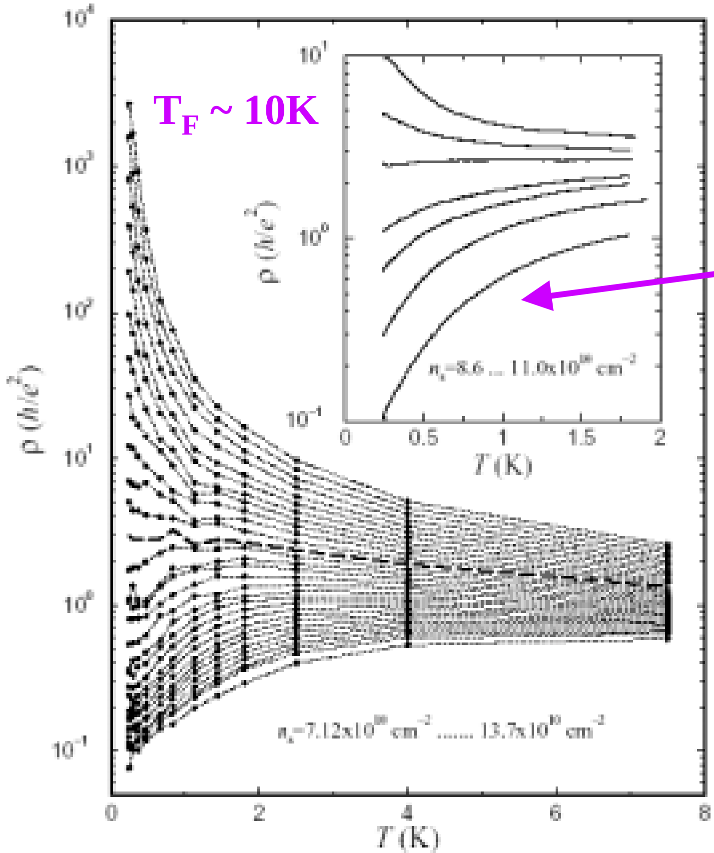
- **Physical picture:** Wigner crystal melting as **Mott transition**
- 2D MIT as a transition to a **Mott-Anderson glass**
- **Extended DMFT results:**
    - Correlation-enhanced **disorder screening**
    - **Mott-Anderson transition:** Mott physics survives disorder
    - **Electron glass behavior** in the vicinity of the (disordered) MIT

2D MIT: Distinct Experimental Features

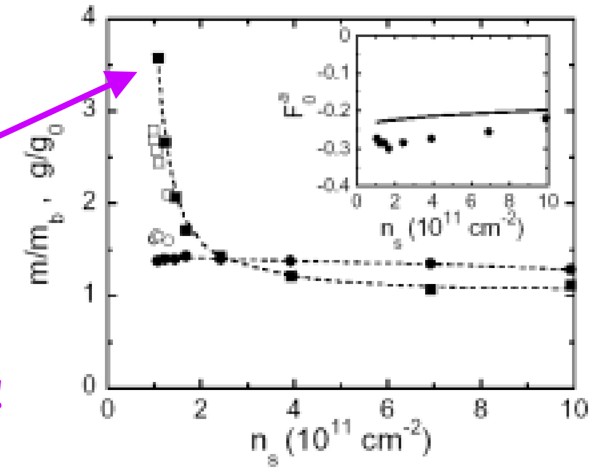
Drastic change of behavior near $n = n_c \sim 10^{11}$ cm^{-2}

NOTE: behavior seen up to **$T \sim 0.25\ T_F$; broad density range**

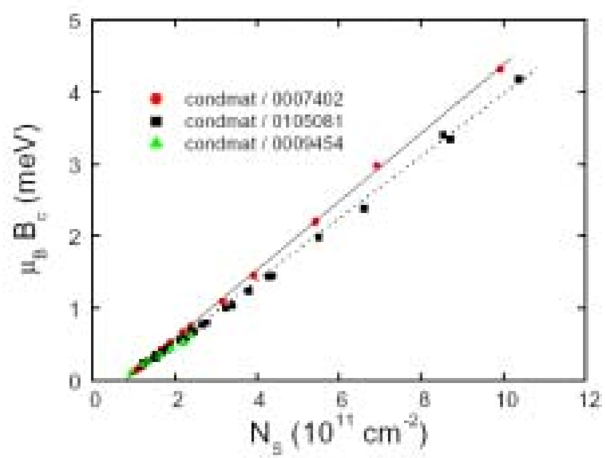


Mass enhanced

But **not** the g-factor



Large resistivity **drop!**



Metal destroyed by small parallel field near transition

Low density: $r_s \sim 10$
Close to **Wigner crystal?**

Experimental Puzzles:

- **From the metallic side:**

- Origin of small energy scale $T^* \sim T_F/m^* \sim (n-n_c)$
- Origin of small field scale $H^* \sim H_{sat} \sim (n-n_c)$
- Large T-dependence of resistivity

B) From the insulating side:

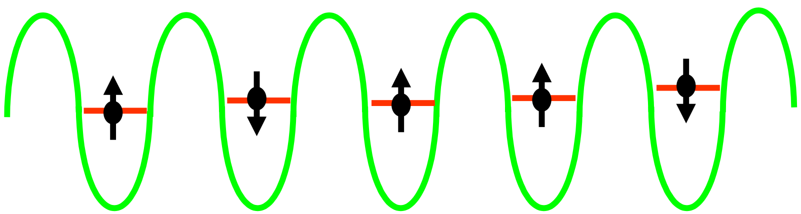
- Nature of the insulator?
- Origin of **glassy behavior** – disorder dependence (exp. by D. Popovic)

My claim: **all features: approach to Mott-Anderson transition**

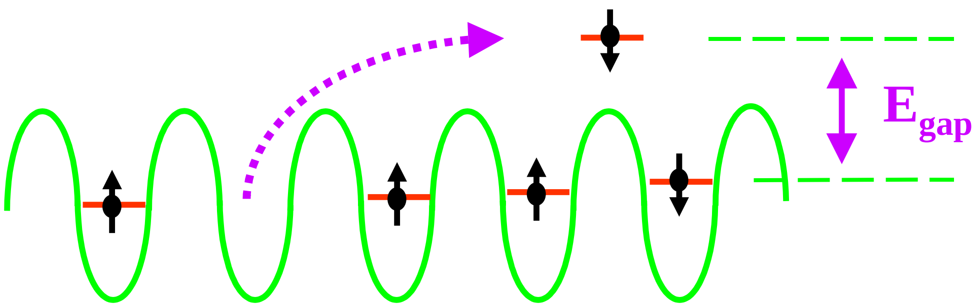
Physical picture: Wigner crystal melting as Mott transition

(Analogy with **He^3***; Spivak 2001)*

- **Wigner crystal ~ Mott insulator (magnet)**



- **Melting:** **Vacancy-Interstitial pair formation**
  (Phillips, Ceperley; 2001)

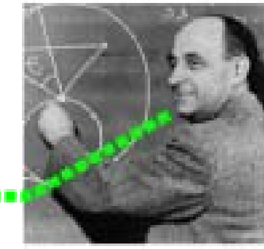


- **Model: disordered Hubbard model**

MIT – Mott transition + disorder

Dynamical Mean-Field Theory

-Physics Behind the Equations-

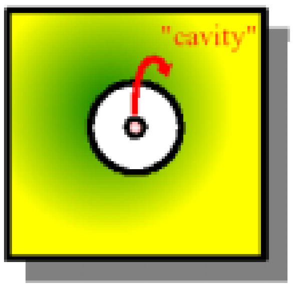


•**MIT - a dynamical phase transition (transport, not static order critical)**

What should be the order parameter?

-Go back to basic principles-

Use the Golden Rule !



•**Order parameter: escape (transition) rate from lattice site**

Transition rate: $\Delta(\omega) = t^2 \rho_c(\omega) \sim 1/\tau$ (**lifetime**)

•**Hubbard model**, **random** site energies (**Wigner crystal** ~ Mott insulator ➡ **correlated** metal)

$$H = \sum_{ij}\sum_{\sigma}(-t_{ij} + \varepsilon_i\delta_{ij})c^{\dagger}_{i,\sigma}c_{j,\sigma} + U\sum_i n_{i,\uparrow}n_{i,\downarrow}$$

•**Effective local dynamical theory**

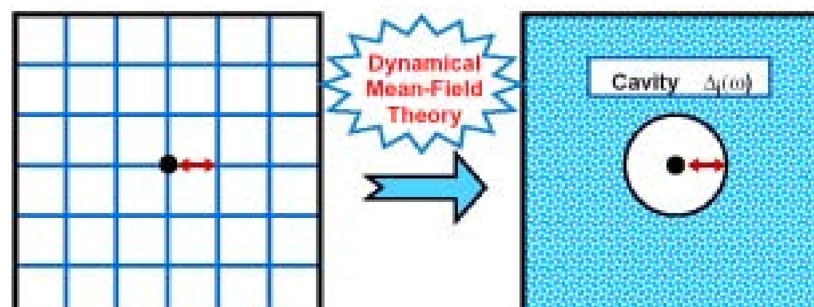
$$S_{eff}(i) = \sum_{\sigma}\int_0^{\beta} d\tau \int_0^{\beta} d\tau' c^{\dagger}_{i,\sigma}(\tau)[\delta(\tau-\tau')(\partial_\tau + \varepsilon_i - \mu) + \Delta_{i,\sigma}(\tau,\tau')]c_{i,\sigma}(\tau') + U\int_0^{\beta} d\tau\, n_{i,\uparrow}(\tau)n_{i,\downarrow}(\tau)$$

[**Anderson impurity model** in bath $\Delta_i(\tau,\tau')$]

$$\Delta_i(\omega) = \sum_{j=1}^{z} t_{ij}^2 < c_j^{\dagger}(\omega)c_j(\omega) > \sim \rho_j(\omega)$$

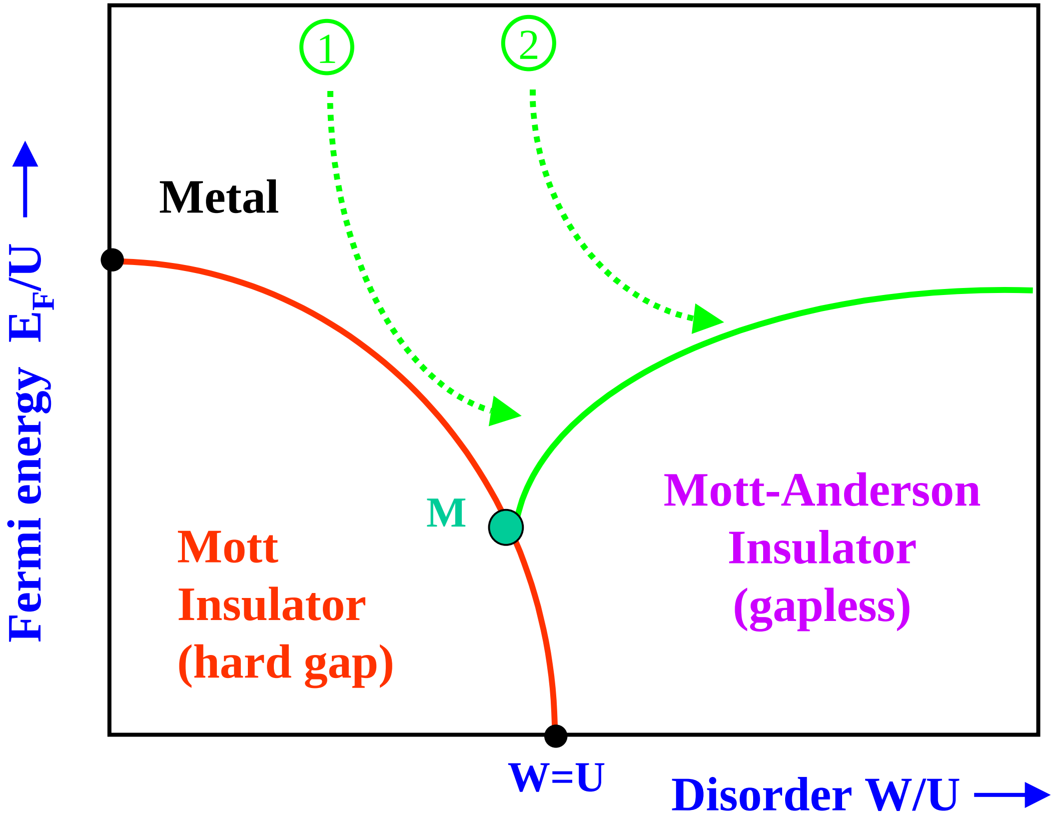
[self-consistency condition]

Local DOS



Integrate out all sites but one

Global Phase Diagram



① -**High mobility** samples:
Strong correlations;
$m^* >> m_e$; strong T-dep.

② -**Low mobility** samples:
Weaker correlations;
weak T-dependence

Physical trajectory: $E_F \sim n$; $U \sim n^{1/2}$; $W \sim$ const. ⇨ $(E_F/U) \sim (W/U)^{-1}$

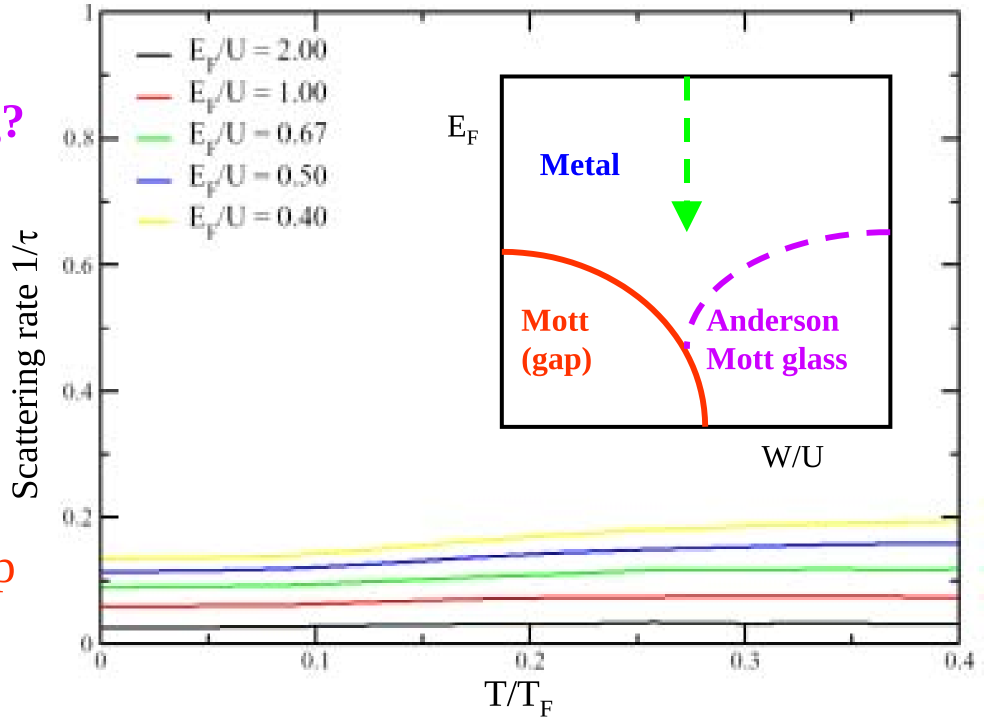
Disordered Metallic Phase: Correlation-Induced Screening of Randomness

(Zimanyi, Abrahams 1991; Tanaskovic, DeOliviera-Aguilar, VD, Kotliar; 2002)

Choose disorder W ~ U, reduce E_F *(ignore localization ~ CPA)*

- Resistivity **drop** at low T
$\Rightarrow$ **temperature-dependent screening?**
Altshuler & Maslov,
Das Sarma & Hwang,
Dolgopolov & Gold,
Herbut, Aleiner et al.

- **Hartree-Fock theory:**
weak T-dependence, only factor ~ 2 drop
(solve DMFT in H-F, similar as other's)

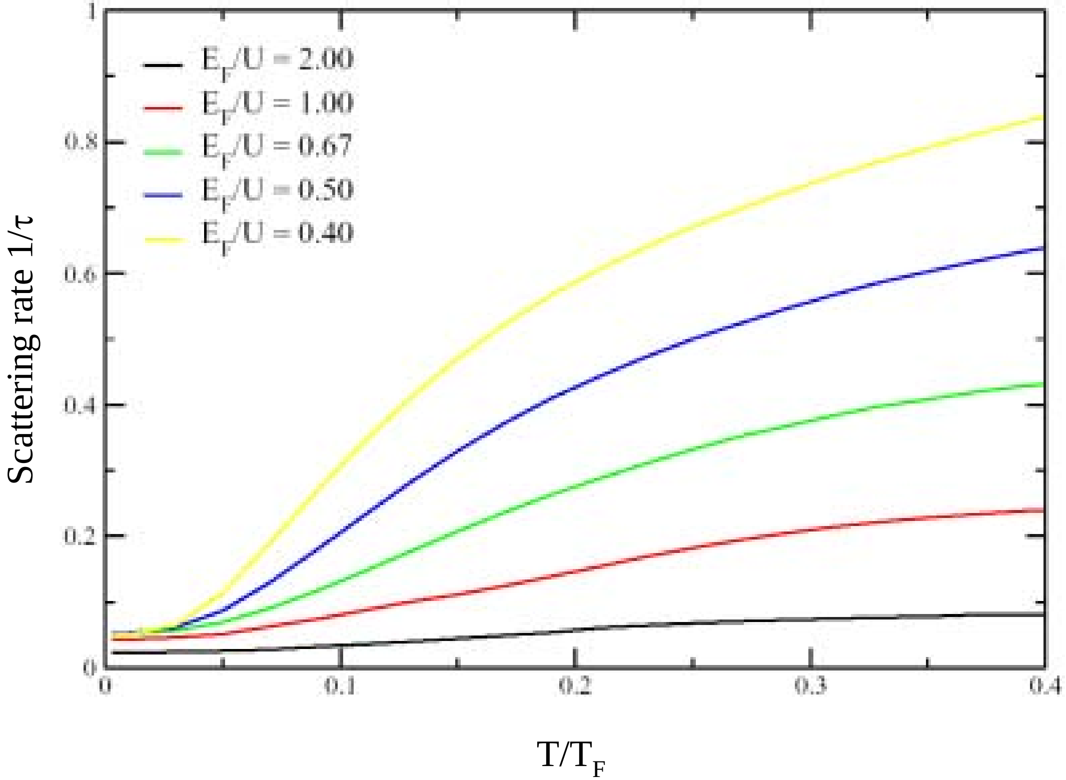


Full DMFT theory:

•Strong T-dependence,
factor > 10 drop!!!
(solve full DMFT
using IPT or slave bosons)

•Enhanced **screening** at low T
due to correlations
(approach to Mott transition)

•Strong **inelastic** scattering
at higher T



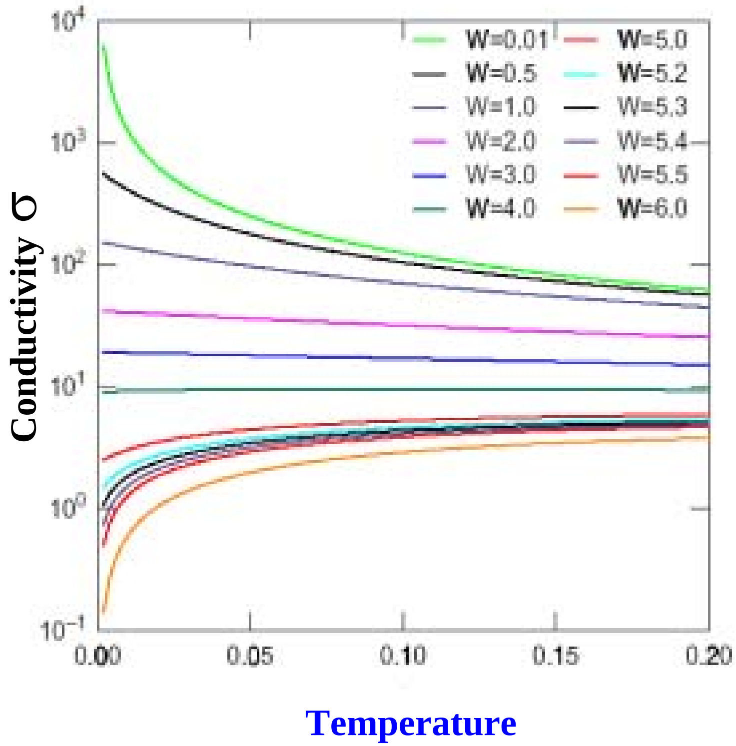
•**Incoherent** Fermi liquid (low $T^* \sim T_F/m^*$; **distribution** of **local** coherence scales)
(microscopic origin of decoherence?)

DMFT Picture of the Anderson-Mott Transition

(*DMFT + localization; V.D. & G. Kotliar, PRL 1997; in progress*)

Transition has character of **both** Mott and Anderson; **qualitatively different** then U=0

Anderson-like order parameter: conductivity



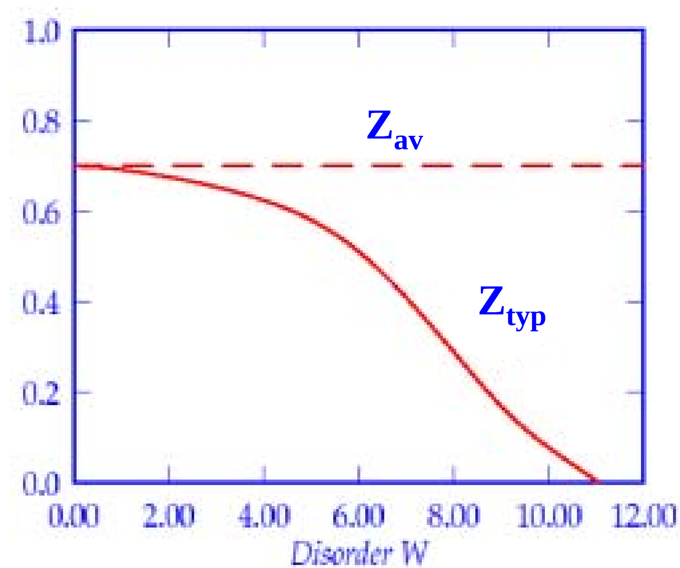
Mott-like order parameter:

Typical quasiparticle weight **Z ~ 1/m***

$$< Z_i >_{typ} = e^{<\ln Z_i>}$$

$T^* = T_F \ Z_{typ} \rightarrow 0$ } **Small energy scale**

Fraction of electrons turn into local moments

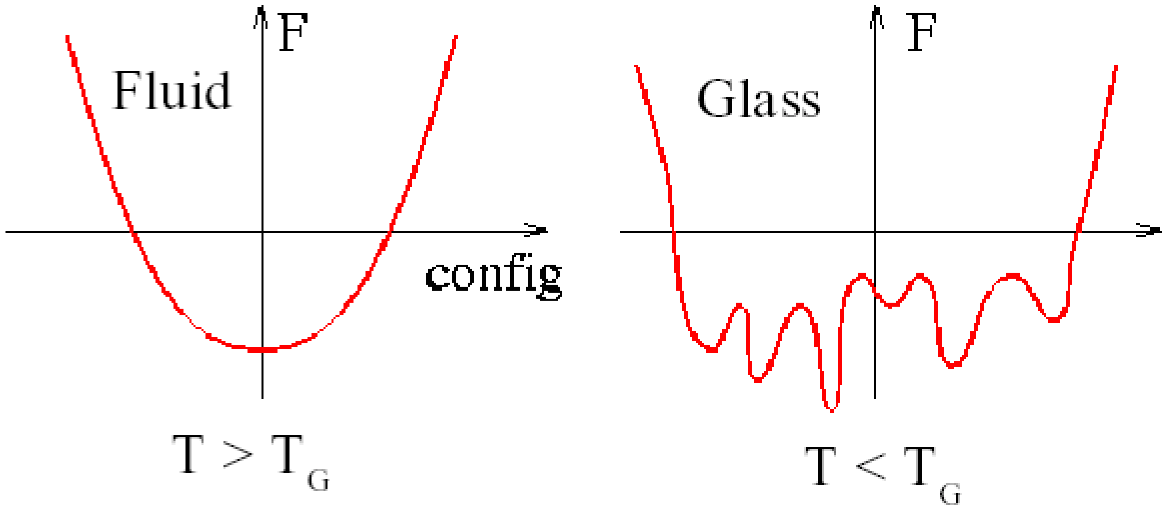


Glassy behavior of electrons near MIT

(Pastor, Tanaskovic, Dalidovich, V.D.; 1999-2002)

- **Coulomb repulsion: keep electrons apart (uniform density)**
- **Random potential: nonuniform density**
  - **--> "Frustration" !!! (can't make everyone happy)**
  - **--> Many metastable states of similar (free) energy**

- **Phase transition ? Emergence of (exponentially !!) many states at low T**
  - **--> Experimental signature: dynamics, slowing down**



Extended DMFT of the Electron Glass

(Inter-site interactions V_{ij})

Glassy behavior deep in the insulator (*Efros&Shklovskii*, *Pollak)*

Question: when does the glass melt?

Mobile electrons: ⇒ **quantum fluctuations MELT glass at T=0**

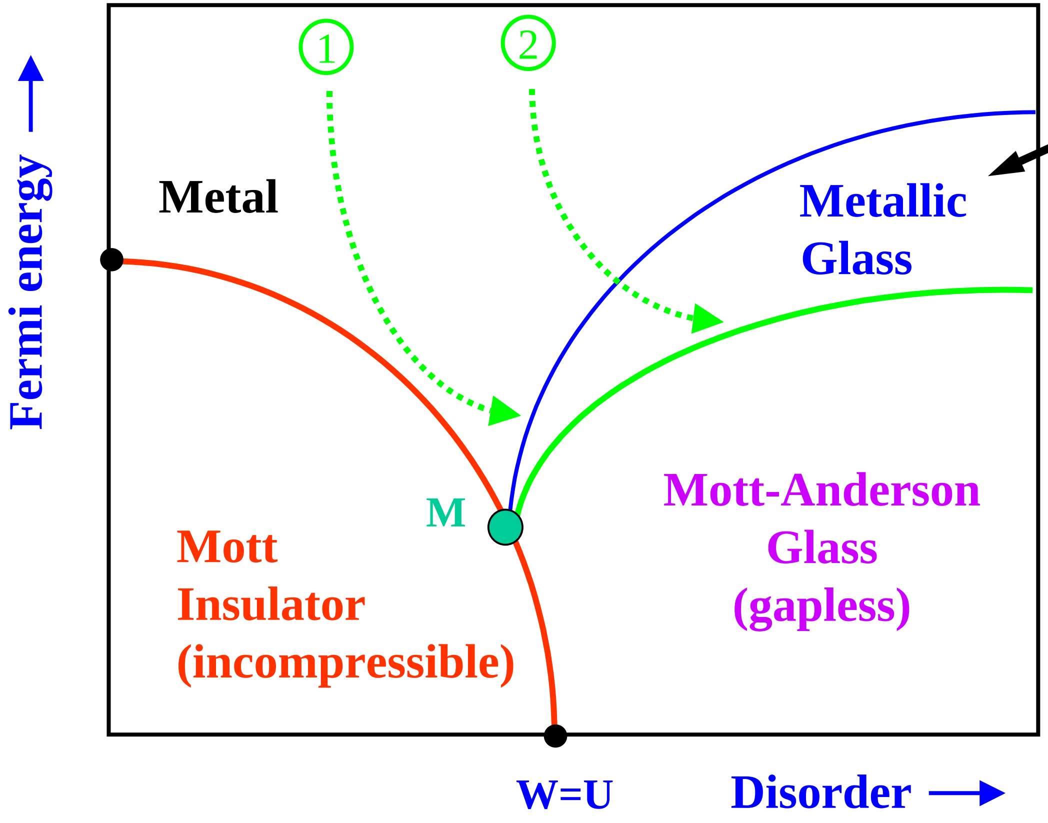
E-DMFT: "replica symmetry breaking" (Parisi scheme)

$$1 = V^2 \sum_j \left\langle \chi_{ij}^2 \right\rangle; \qquad \chi_{ij} = \frac{\partial n_i}{\partial \varepsilon_j}$$

Diverges at Anderson-like transition
Vanishes at Mott transition

Glassy behavior emerges before Mott-Anderson transition

history dependence, slow relaxation, aging



Metallic glass phase:

"replocon" modes:

- Non-Fermi liquid transport

$$\sigma(T) - \sigma(0) \sim T^{3/2}$$

- Hierarchical, correlated dynamics (scale invariant)

Conclusions:

- **New physical picture of 2D MIT:**

Wigner crystal melting + disorder = Mott-Anderson transition

- **Extended DMFT: order-parameter theory for Mott-Anderson transition**
- **Non-perturbative approach to strong correlations in disordered systems**
- **Metallic phase: enhanced disorder screening (low T) + inelastic scattering (high T)**
- **Microscopic origin of small energy (field) scales near MIT**
- **Predicts glassy behaviors of electrons close to MIT** *(as seen by exp. of D. Popovic)*