Is charge disorder alone sufficient to localize the Hubbard model?

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arXiv:1903.01049

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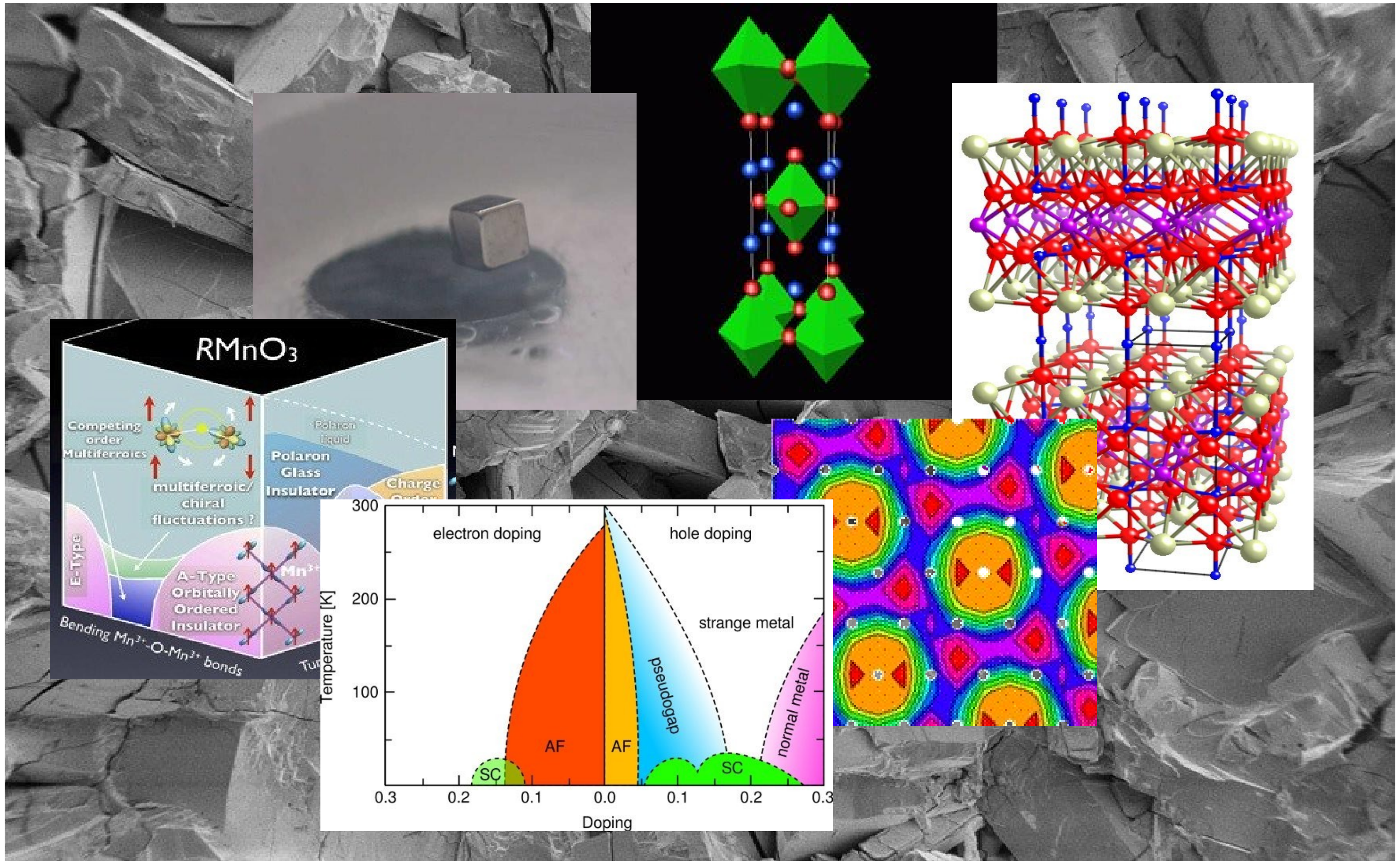
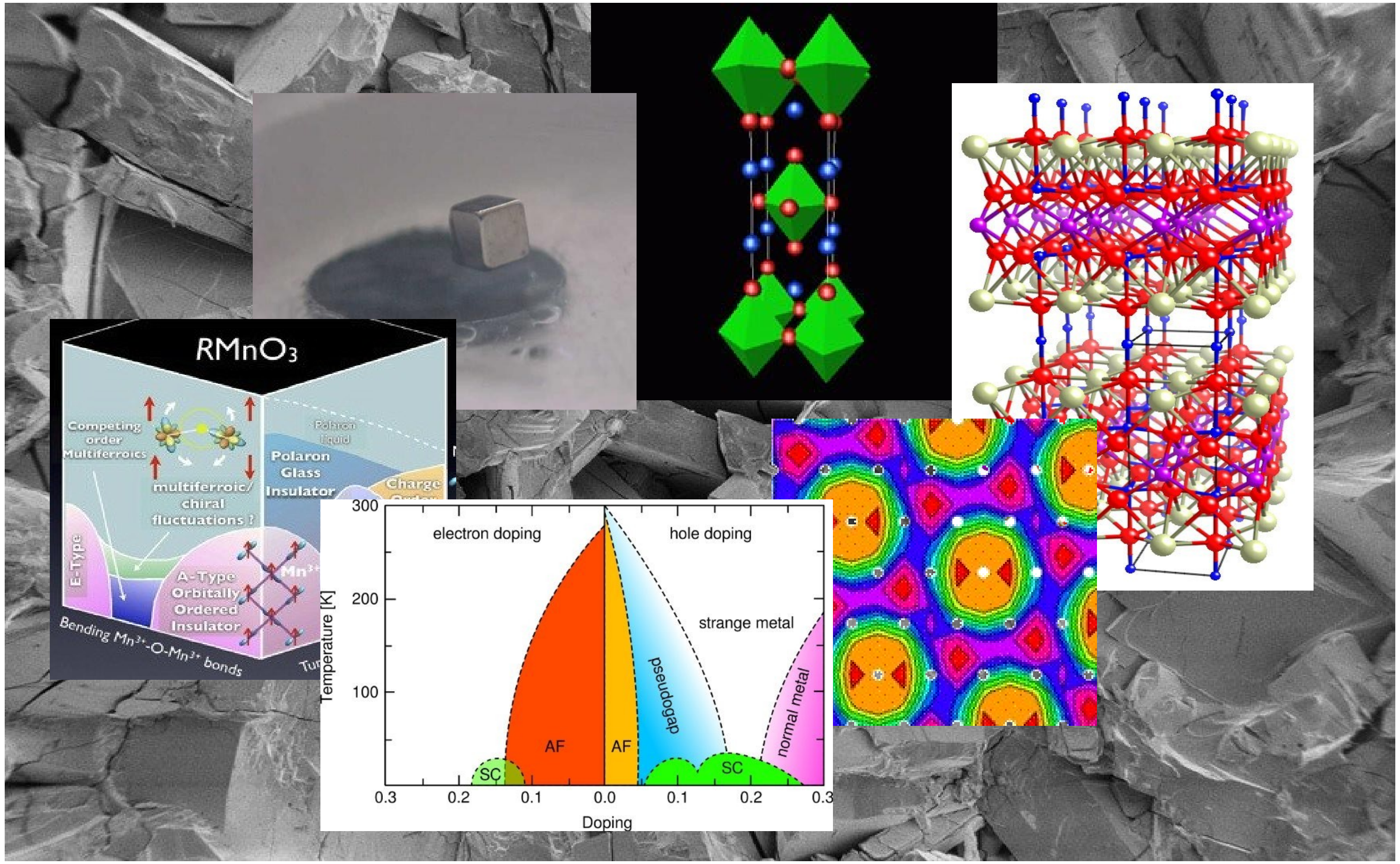


What does disorder do to strongly correlated systems?

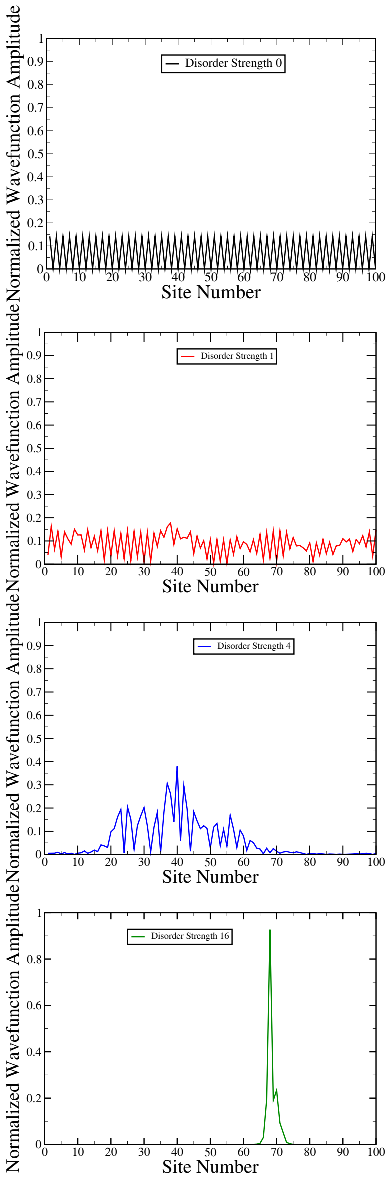


~~What does disorder do to strongly correlated systems?~~

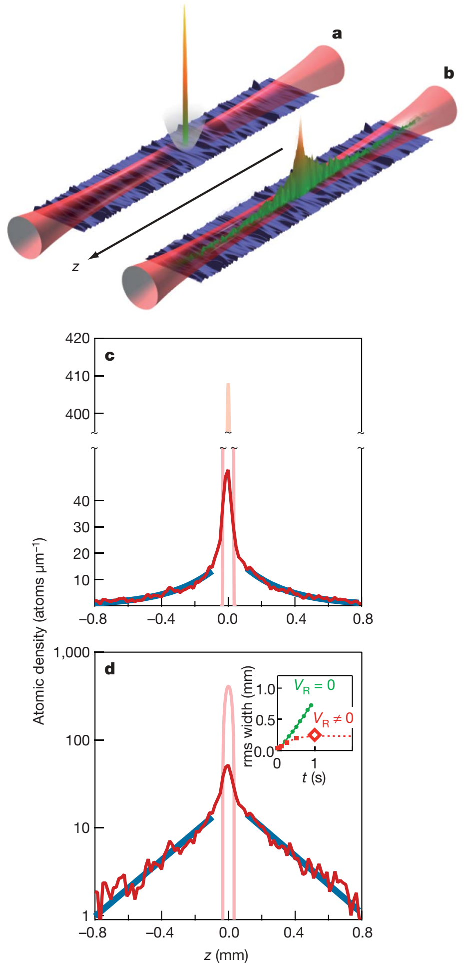
What do interactions do to disordered systems?

Anderson localization

amplitudes of sample wavefunctions



increasing disorder strength

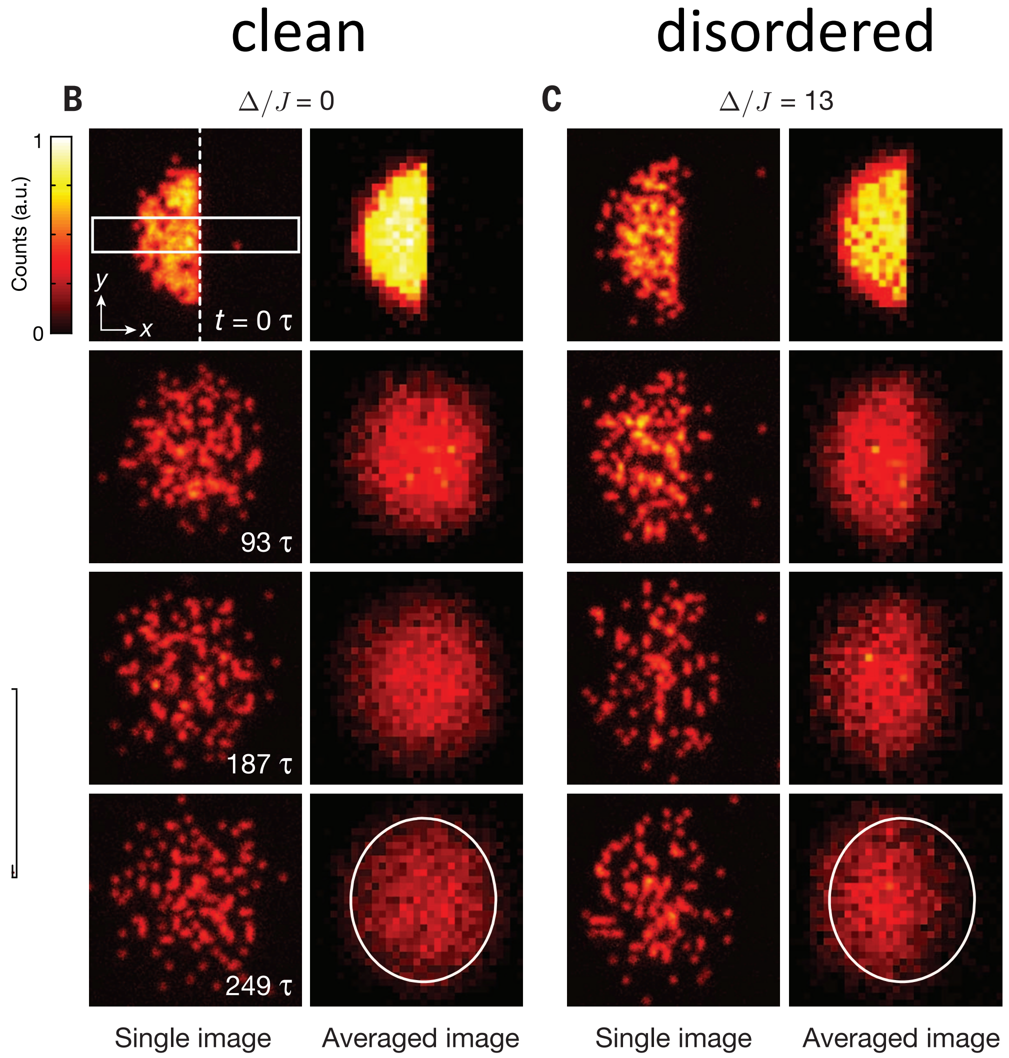


Billy, et al, Nature **453** 891 (2008)

Exponentially localized single-particle wavefunctions

Non-ergodic, memory of initial conditions

Many-body localization



Choi et al, Science **352** 1547 (2016)

Non-ergodic, memory of initial conditions

Exponentially localized conserved quantities: local integrals of motion (LIOM)

Standard model of many-body localization

$$H = \sum_{i=1}^{L} J \vec{S}_i \cdot \vec{S}_{i+1} + \sum_{i=1}^{L} h_i S_i^z$$

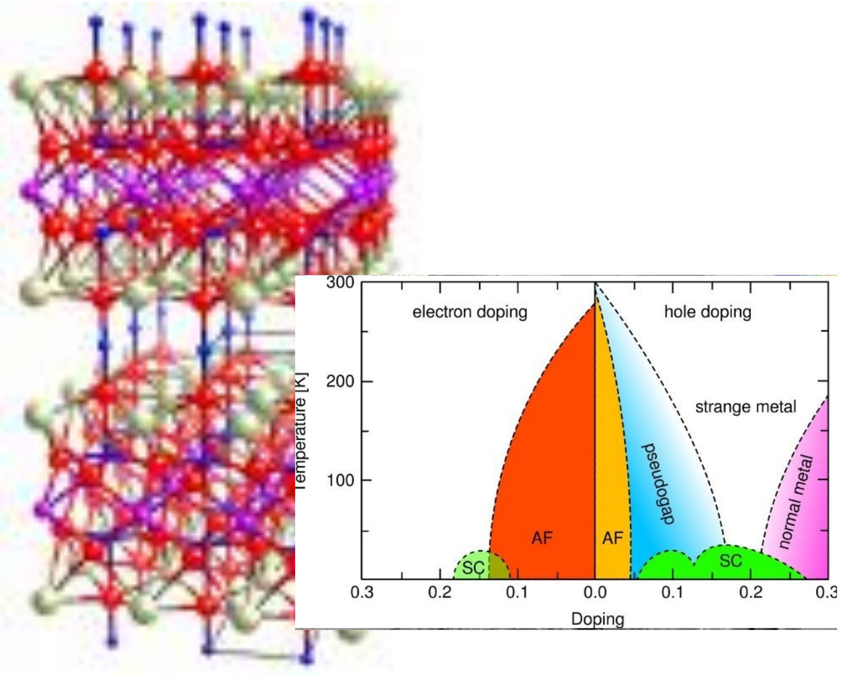
Hamiltonian in terms of local integrals of motion

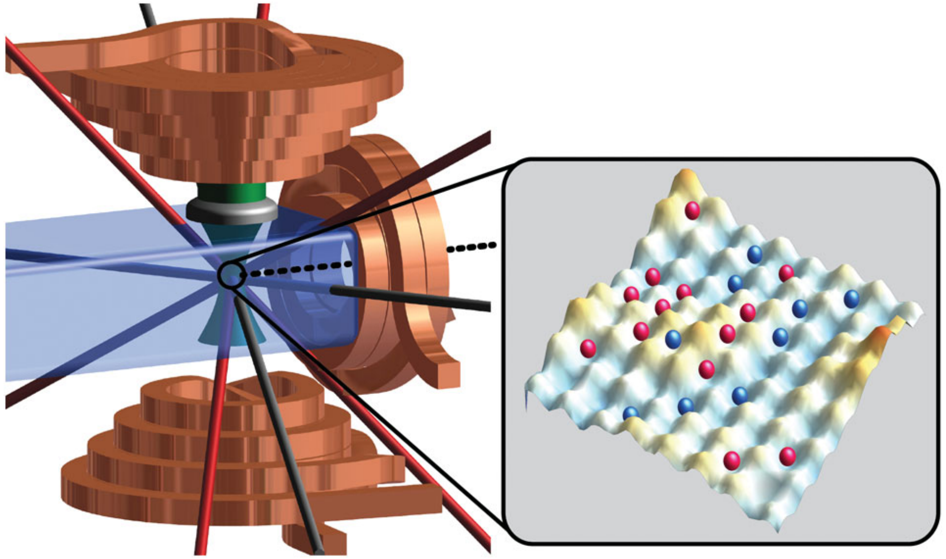
$$H = \sum_{i} h_i \tau_i^z + \sum_{i,j} J_{ij} \tau_i^z \tau_j^z + \ldots$$

Huse & Oganesyan PRB 90, 174202 (2014)

Hubbard model

$$H = -t_h \sum_{\langle i,j \rangle,\sigma} \left(c^\dagger_{i\sigma} c_{j\sigma} + c^\dagger_{j\sigma} c_{i\sigma} \right) + U \sum_i n_{i\uparrow} n_{i\downarrow}$$





Kondov PRL 2015

Hubbard model with charge and spin disorder

$$H = -t_h \sum_{\langle i,j\rangle,\sigma} \left(c^\dagger_{i\sigma} c_{j\sigma} + c^\dagger_{j\sigma} c_{i\sigma} \right) + U \sum_i n_{i\uparrow} n_{i\downarrow}$$

$$+ \sum_i \epsilon_i d_i + \sum_i h_i m_i$$

charge density

$$d_i = n_{i\uparrow} + n_{i\downarrow}$$

magnetization

$$m_i = n_{i\uparrow} - n_{i\downarrow}$$

$$\epsilon_i \in (-W_{ch}, W_{ch})$$

charge disorder

$$h_i \in (-W_{sp}, W_{sp})$$

spin disorder

Questions

Is disorder in just one of these channels sufficient to cause the full system to be localized?

Alternatively, does the degree of freedom without disorder delocalize the one which sees disorder?

Generally, to what extent is the level of localization in one channel related to the disorder in the other channel?

To what extent is the level of localization in one channel related to the disorder in the other channel?

Mondaini PRA 2015, Prelovsek PRB 2016, Mierzejewski PRB 2018, Kozarzewski PRL 2018, Zakrzewski PRB 2018, Yu 1803.02838, Protopopov 1808.05764

Almost all focus on disorder in just one channel.
Charge and spin-specific info just from dynamics.

Rest of talk: constructing charge/spin specific LIOM
-> measures of localization -> results

Message: Disorder in one channel influences localization in the other.

Charge/spin-specific local integrals of motion

integrals of motion

$$Q^\dagger H Q = D$$

O diagonal in Fock basis $\rightarrow$

$QOQ^\dagger$ diagonal in energy basis

local

O local, e.g. $n_{i\sigma}$

Q acts locally: choose Q close to the identity

charge and spin

$$\mathfrak{d}_i = Q\tilde{d}_i Q^\dagger \qquad \mathfrak{m}_i = Q\tilde{m}_i Q^\dagger$$

Measures of localization

single-site overlap

$$O_i^c = \frac{1}{N}\mathrm{Tr}(\tilde{d}_i \mathfrak{d}_i)$$

$$O_i^s = \frac{1}{N}\mathrm{Tr}(\tilde{m}_i \mathfrak{m}_i)$$

overlap vs distance

$$O_i^c(\ell) = \frac{1}{N}\mathrm{Tr}(\tilde{d}_{i\pm\ell} \mathfrak{d}_i)$$

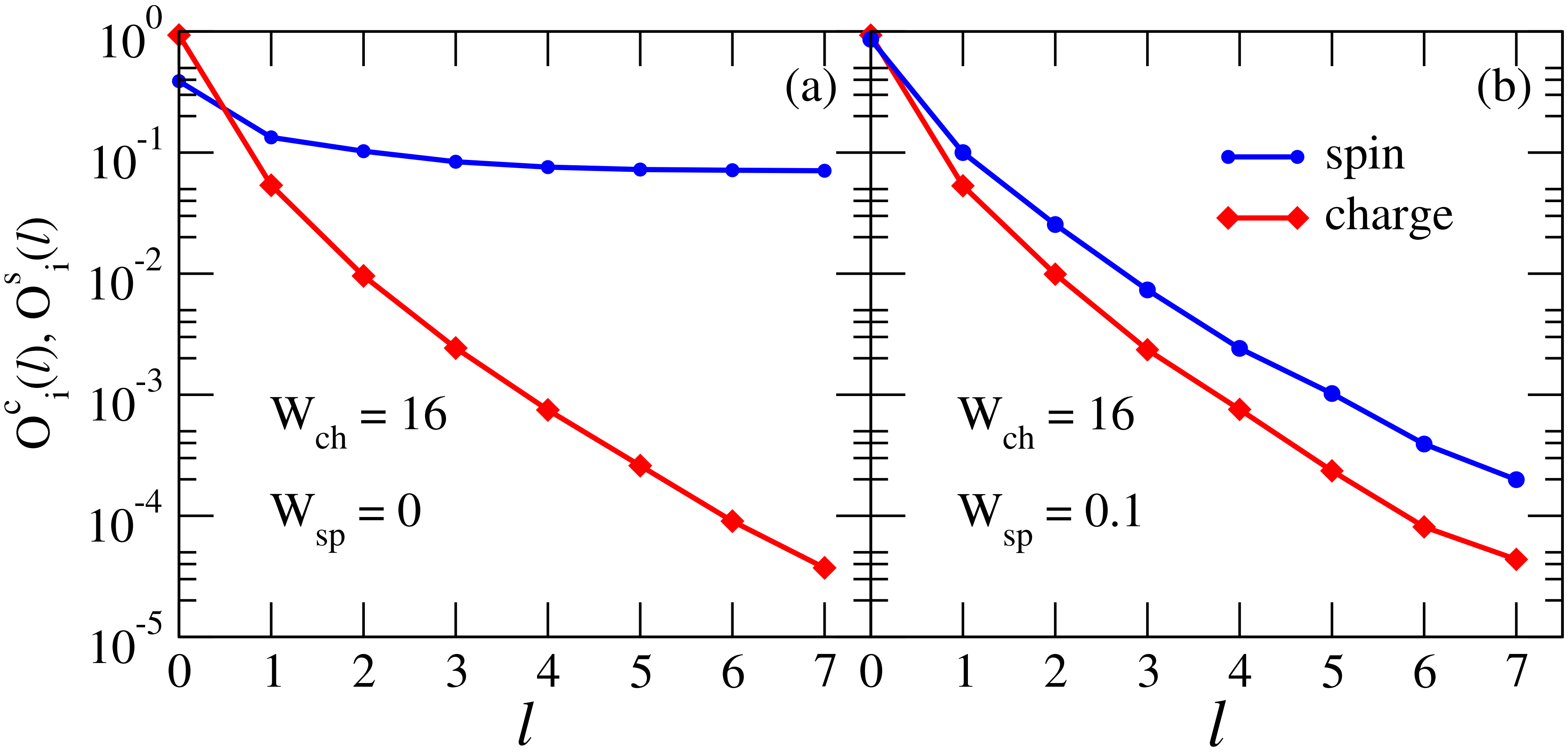
$$O_i^s(\ell) = \frac{1}{N}\mathrm{Tr}(\tilde{m}_{i\pm\ell} \mathfrak{m}_i)$$

local correlations

$$D(t) \ = \ D_0 \sum_i \langle\psi|(d_i(t) - \bar{d})(d_i(0) - \bar{d})|\psi\rangle$$

$$M(t) \ = \ M_0 \sum_i \langle\psi|m_i(t) m_i(0)|\psi\rangle$$

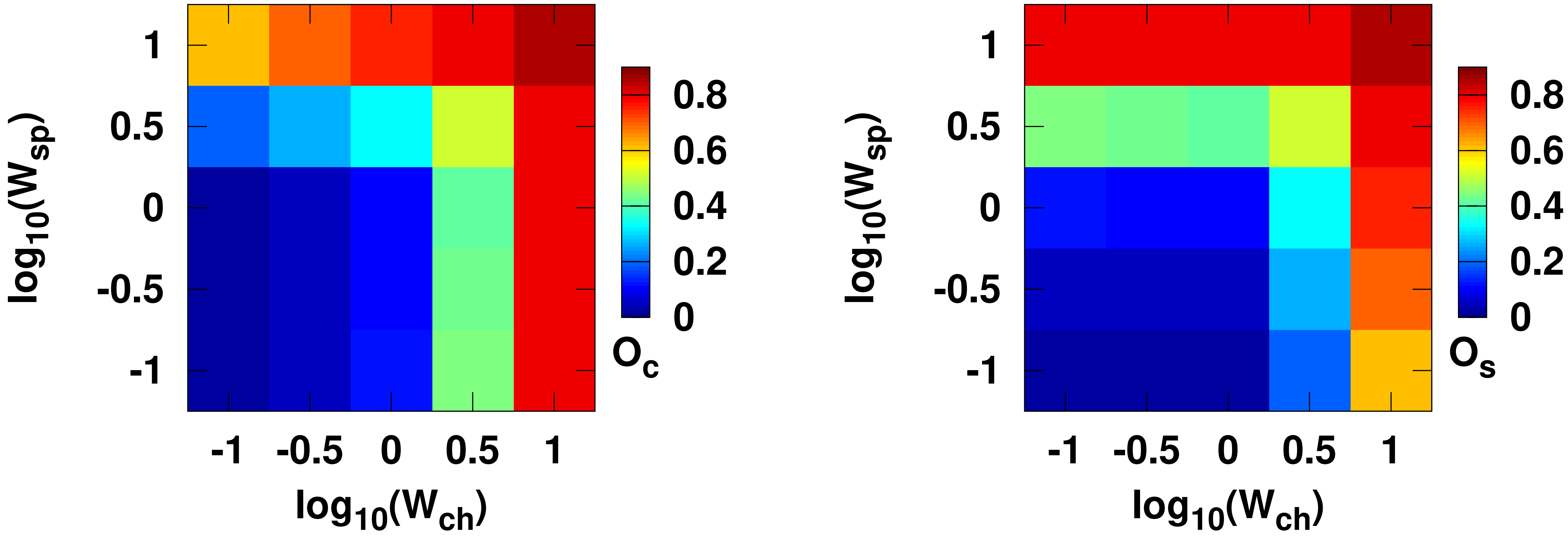
Strong charge disorder and very weak spin disorder



Zero spin disorder:
No localization of spin

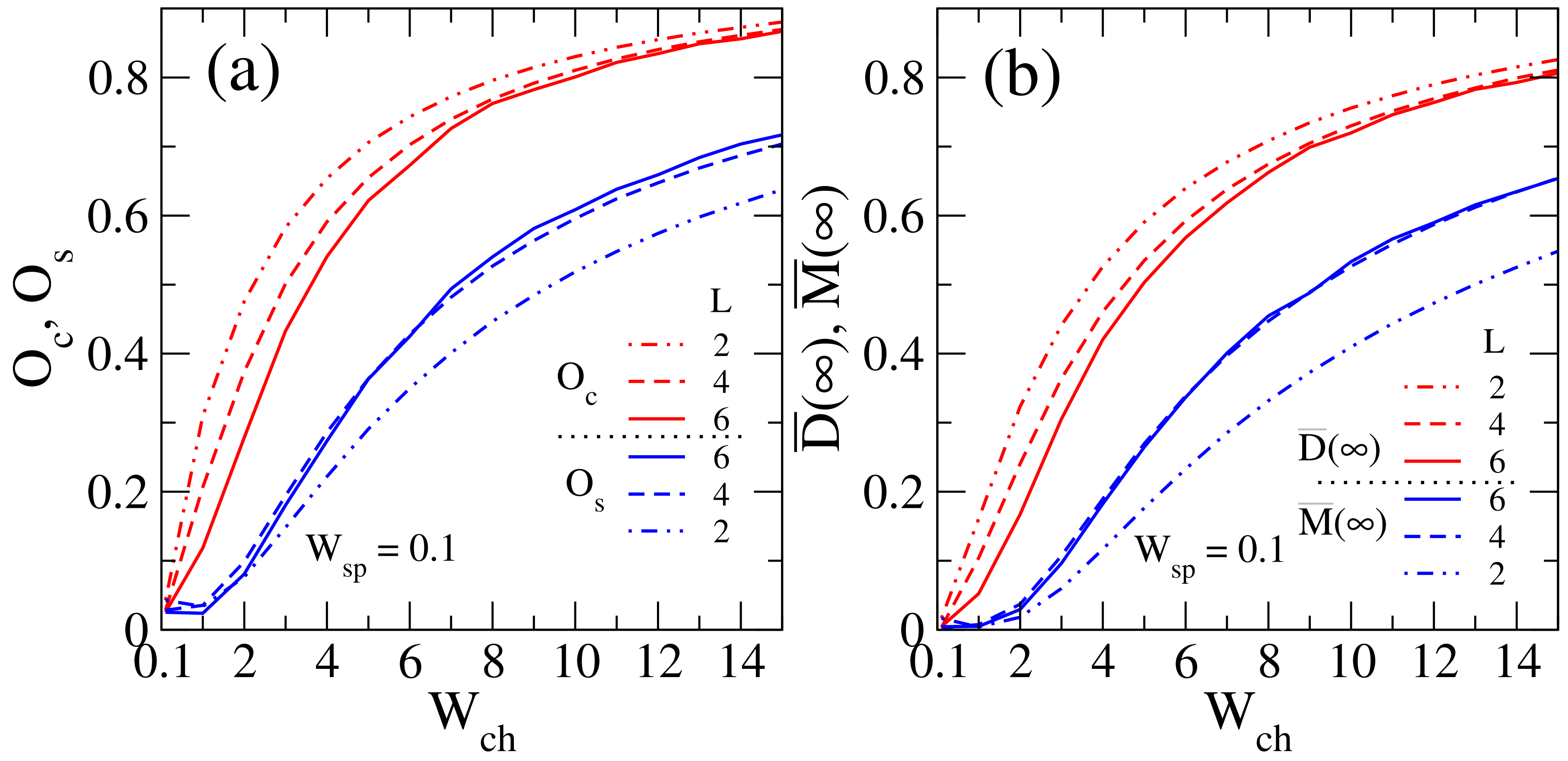
Very weak spin disorder:
Localization of spin is almost as strong as that of charge

Symmetry between charge and spin



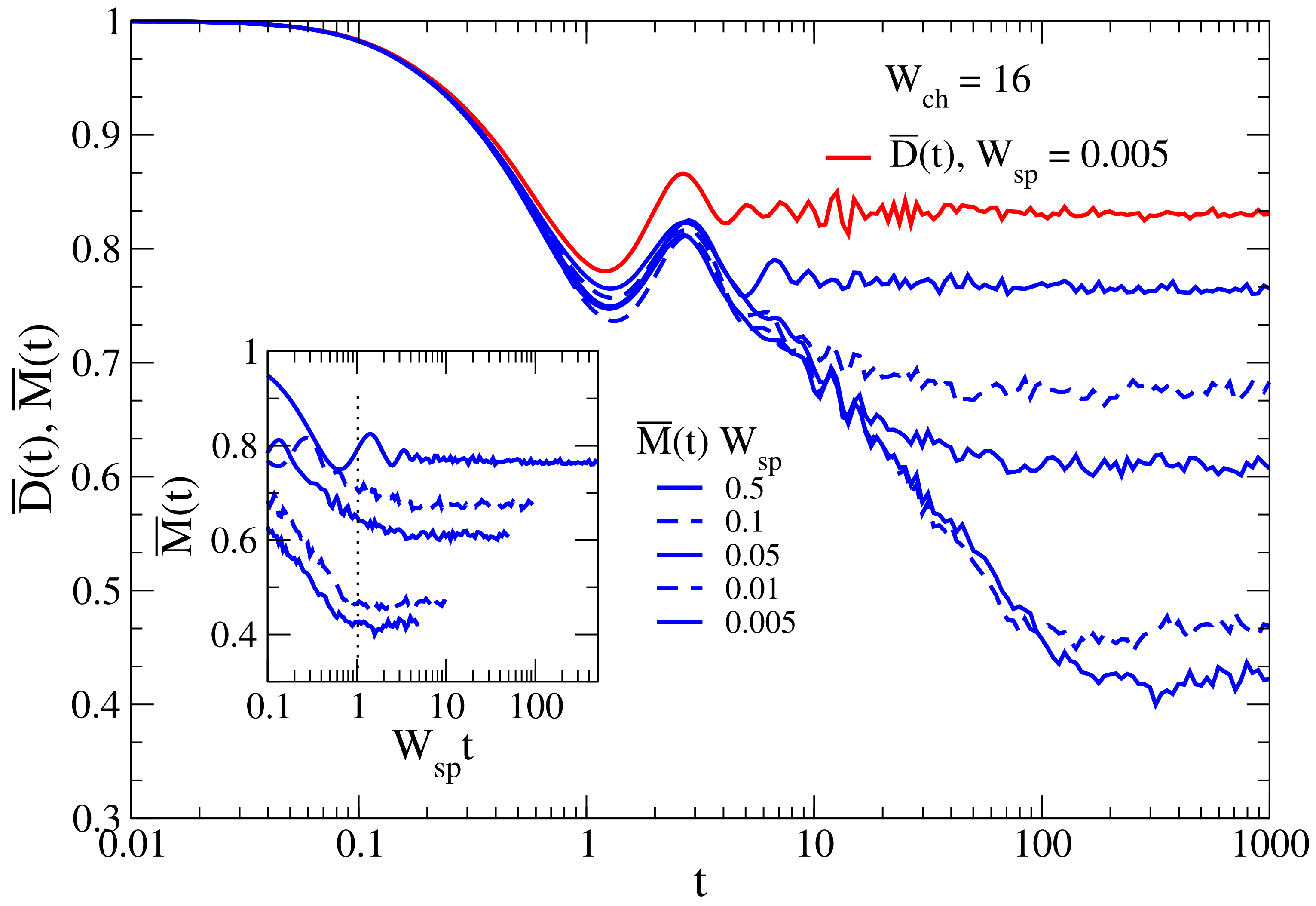
Can derive by particle-hole transformation in spin-down only: $U = \prod_i (c_{i\downarrow} + c_{i\downarrow}^\dagger)$

Comparing overlap and dynamical measures



Message: These show the same behavior

Time scales in the dynamics



Message:
Localization appears in the spin dynamics at time $t \propto 1/W_{sp}$

Summary

arXiv:1903.01049

Studied the Hubbard model with disorder in both charge and spin.

Constructed optimally local integrals of motion specific to charge/spin.

Localization in one sector depends on disorder in the other sector.

Symmetry between charge and spin response.

Time scale at which localization emerges in the less disordered channel is proportional to one over the disorder in that channel.