

EMERGENCE IN CORRELATED FERMIONS: FROM IMPURITY MODELS TO THE BULK

**ABHIRUP MUKHERJEE
RPC PRESENTATION 2022-2023**

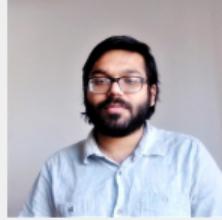
**EMERGENT PHENOMENA IN QUANTUM MATTER GROUP
DEPARTMENT OF PHYSICAL SCIENCES, IISER KOLKATA**

JULY 11, 2023

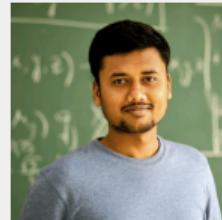




Siddhartha Lal



Anirban Mukherjee



Siddhartha Patra



A huge thanks to all my collaborators!
Thanks to IISER K and SERB for financial support.



Arghya Taraphder
IIT Kharagpur



N. S. Vidhyadhiraja
JNCASR Bangalore



LIST OF COMPLETED AND ONGOING PROJECTS

LIST OF PUBLICATIONS, PREPRINTS AND ONGOING PROJECTS

- ✓ Unveiling the Kondo cloud: Unitary RG study of the Kondo model.
2022 **Phys. Rev. B** 105, 085119.
A Mukherjee, **Abhirup Mukherjee**, N. S. Vidhyadhiraja, A. Taraphder, S Lal

- ✓ Frustration shapes multi-channel Kondo physics: a star graph perspective.
2023 **J. Phys.: Condens. Matter** 35 315601.
S Patra, **Abhirup Mukherjee**, A Mukherjee, N. S. Vidhyadhiraja, A Taraphder, S Lal

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- Kondo frustration via charge fluctuations: a route to Mott localisation.
2023 arXiv:2302.02328. **under review** at New Journal of Physics.
Abhirup Mukherjee, N. S. Vidhyadhiraja, A. Taraphder, S Lal
- Holographic entanglement renormalisation for fermionic quantum matter.
2023 arXiv:2302.10590. **under review** at Journal of HEP.
Abhirup Mukherjee, S Patra, S Lal

LIST OF PUBLICATIONS, PREPRINTS AND ONGOING PROJECTS

Currently in progress

- Development of auxiliary model-based method for studying bulk correlated systems.
 - Studies of the plateau-to-plateau transition in integer quantum hall systems.
-

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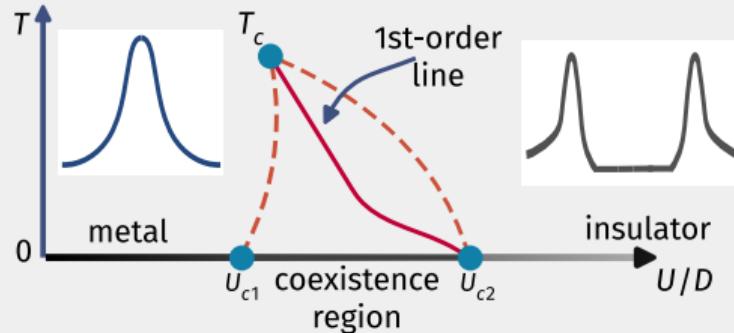
QUANTUM PHASE TRANSITION IN AN EXTENDED-SIAM

ABHIRUP MUKHERJEE, N. S. VIDHYADHIRAJA, A. TARAPHDER, SIDHARTH LAL

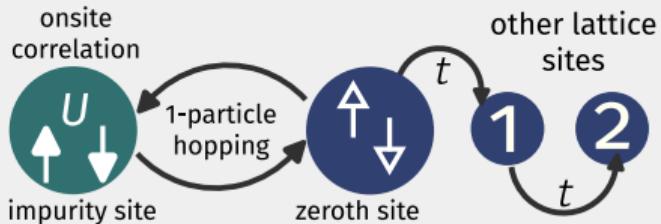
ARXIV:2302.02328. (2023)

SOME BROAD QUESTIONS

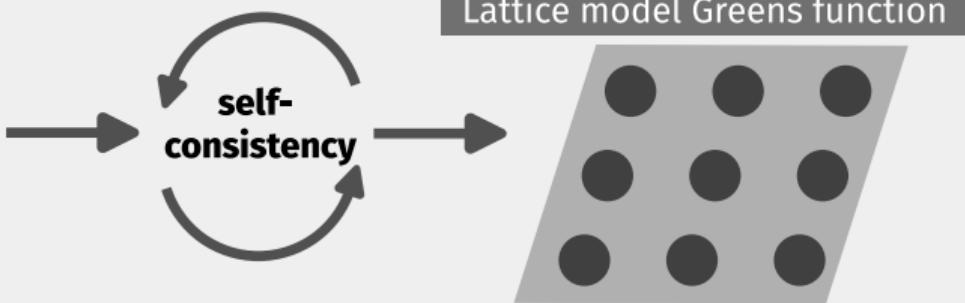
Dynamical mean-field theory shows **metal-insulator transition** for the Hubbard model in ∞ dimensions.



Single-impurity Anderson model

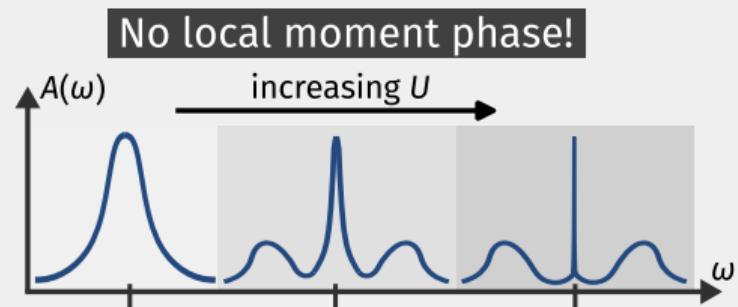
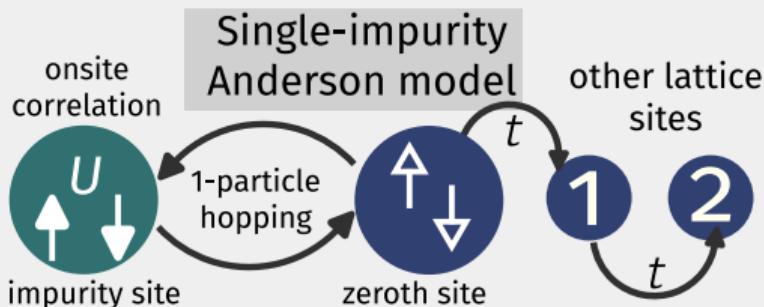
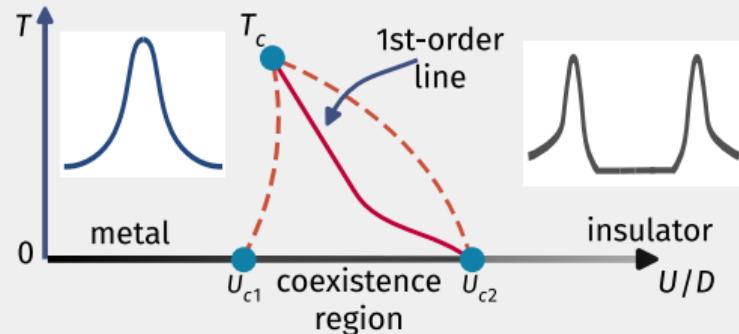


Lattice model Greens function



SOME BROAD QUESTIONS

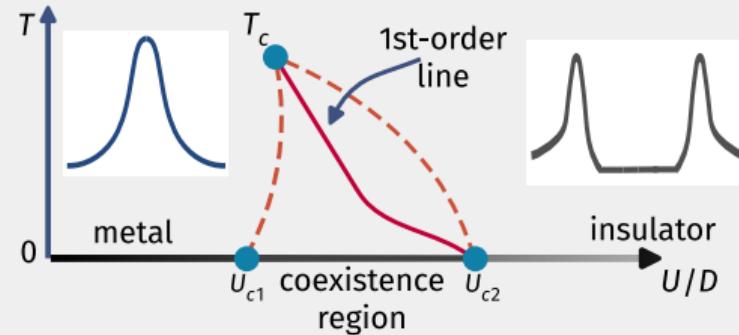
Dynamical mean-field theory shows **metal-insulator transition** for the Hubbard model in ∞ dimensions.



Standard Anderson model shows **no transition**, can't explain DMFT phase diagram.

SOME BROAD QUESTIONS

Dynamical mean-field theory shows **metal-insulator transition** for the Hubbard model in ∞ dimensions.

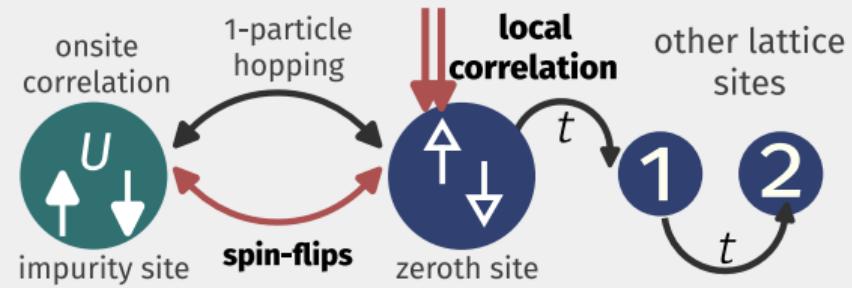


- Which impurity model is realised through self-consistency?
- What physics leads to U_{c1} and U_{c2} ?
- What is the state precisely at the $T = 0$ transition?

RESULTS

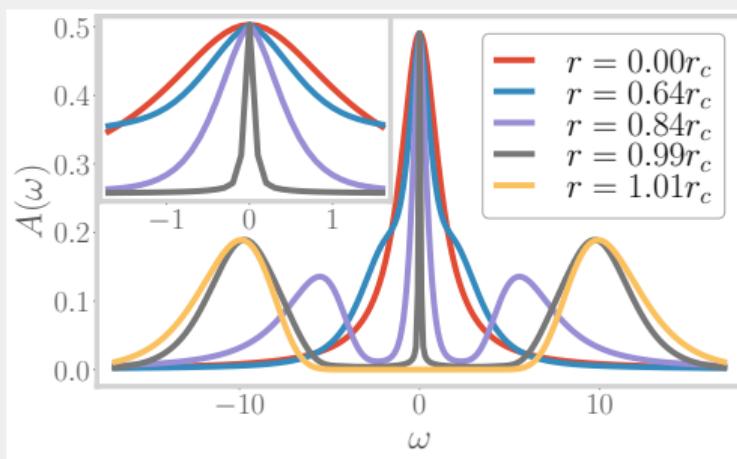
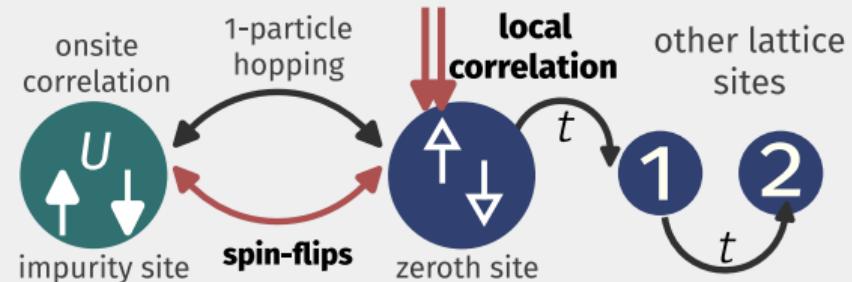
Phase **transition** occurs upon adding

- spin-flip correlation between impurity and bath
- **local correlation** on bath zeroth site



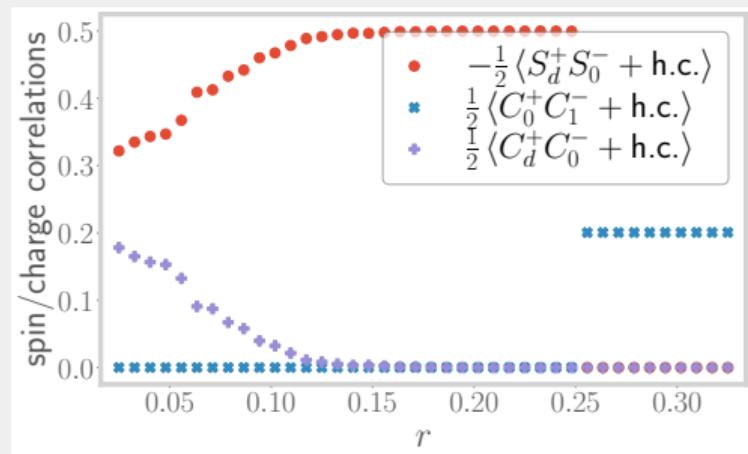
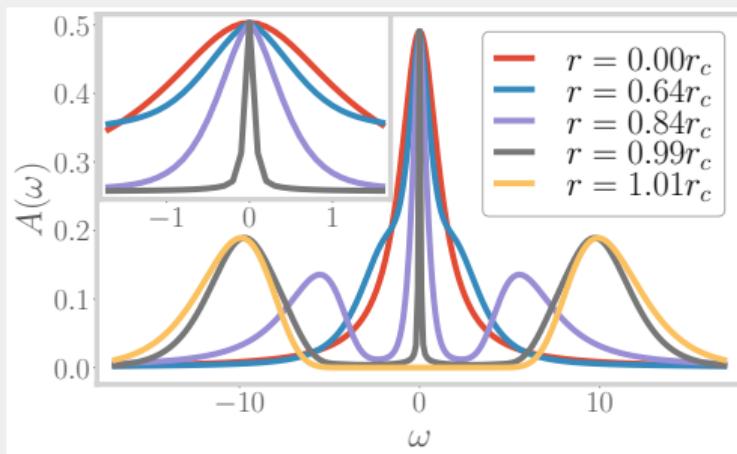
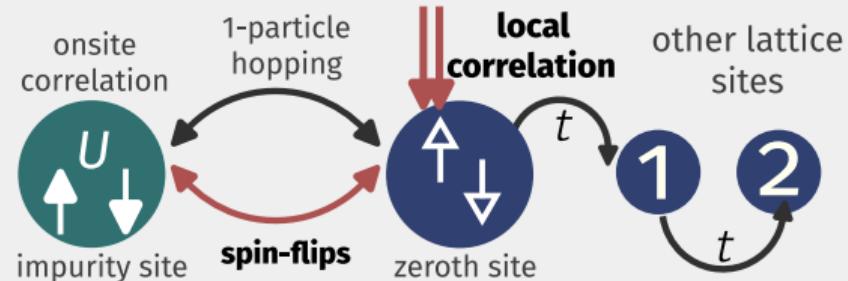
RESULTS

- Local spectral function shows gap.



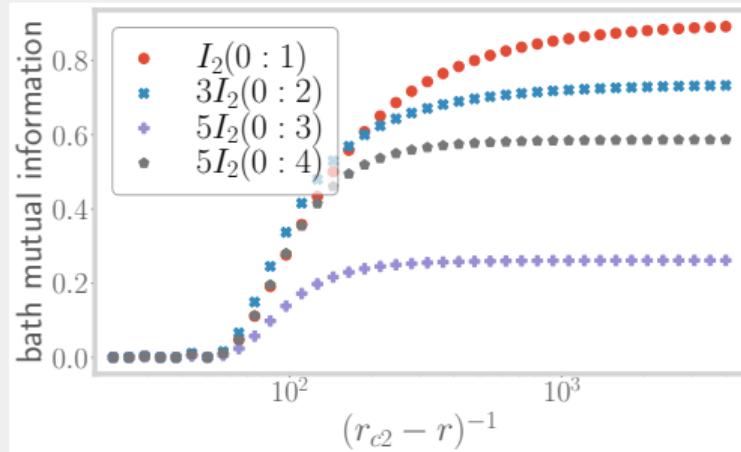
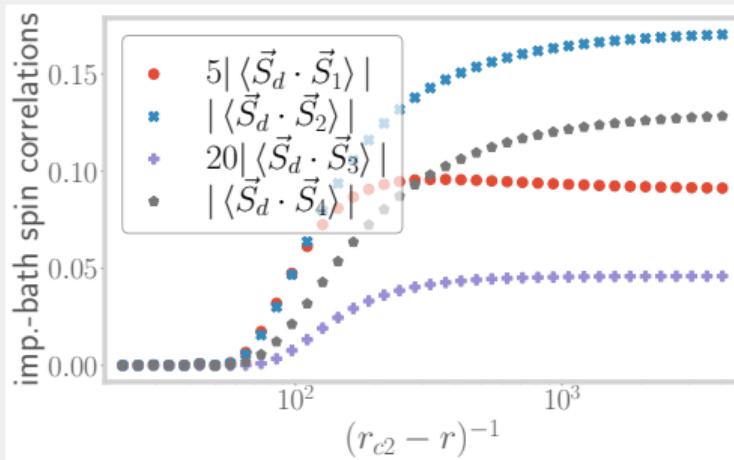
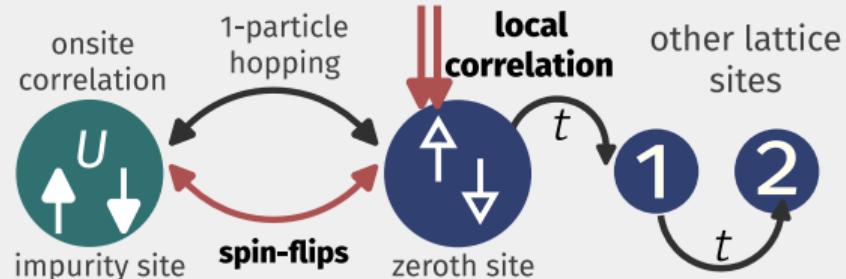
RESULTS

- Local spectral function shows gap.
- Spin correlations vanish, **pairing correlations** grow at the transition



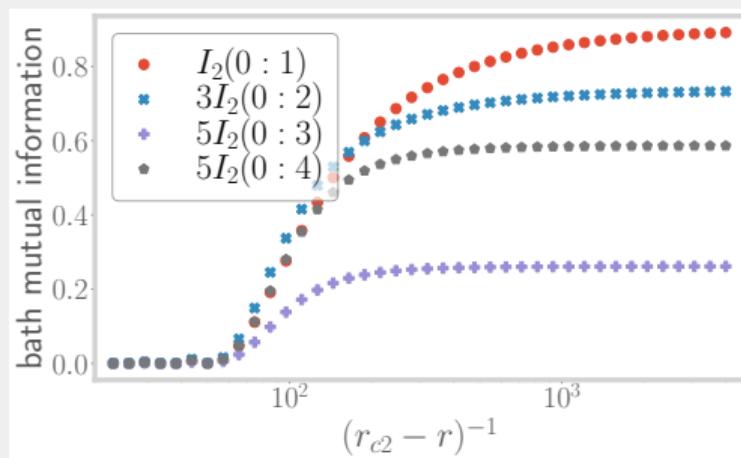
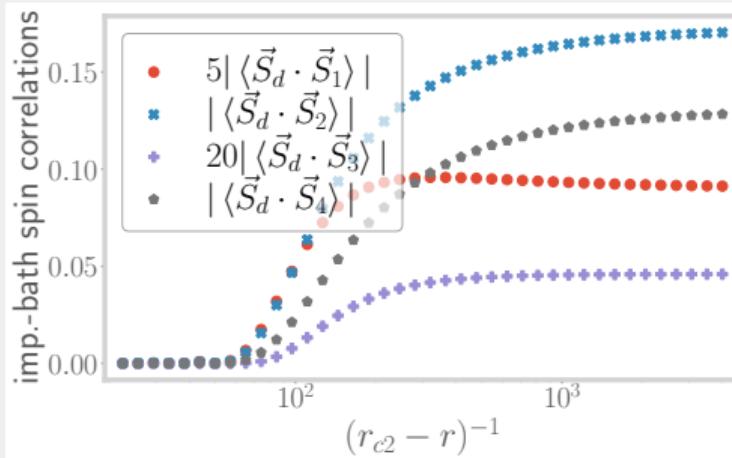
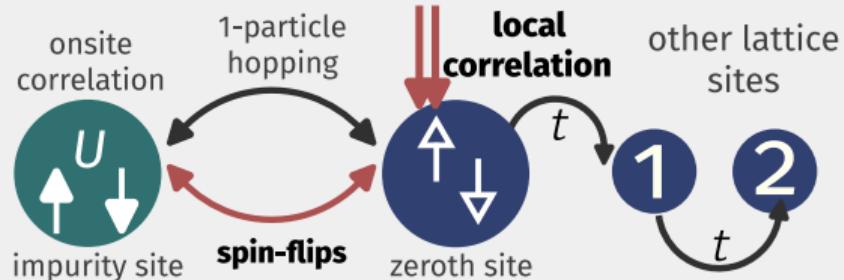
RESULTS

- Quantum critical point shows **long-ranged correlations**.



RESULTS

- Quantum critical point shows **long-ranged correlations**.
- Excitations at the QCP are non-Fermi liquid in nature.



HOLOGRAPHY OF ENTANGLEMENT IN 2D FREE FERMIONS

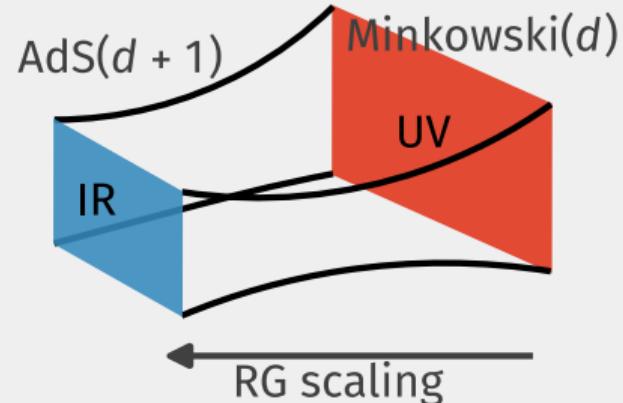
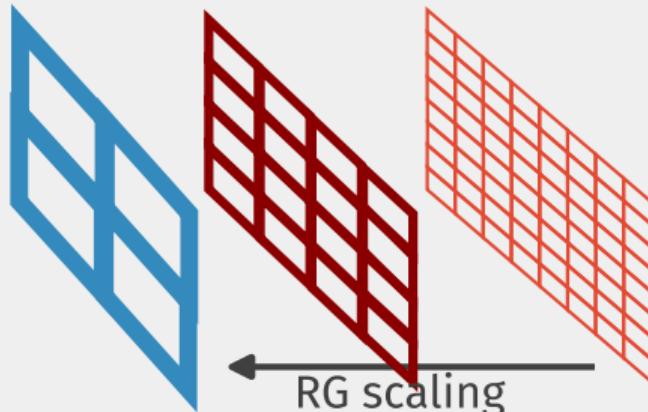
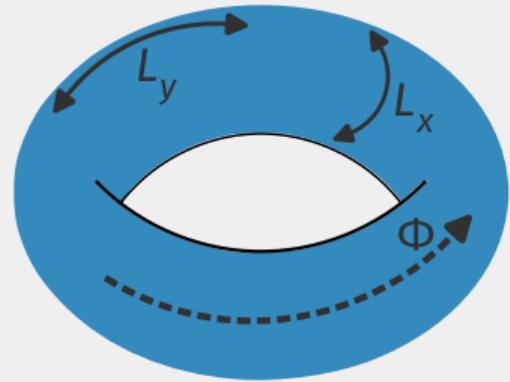
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ARXIV:2302.10590. (2023)

SOME BROAD QUESTIONS

We consider 2D electrons placed on a torus in a flux Φ .

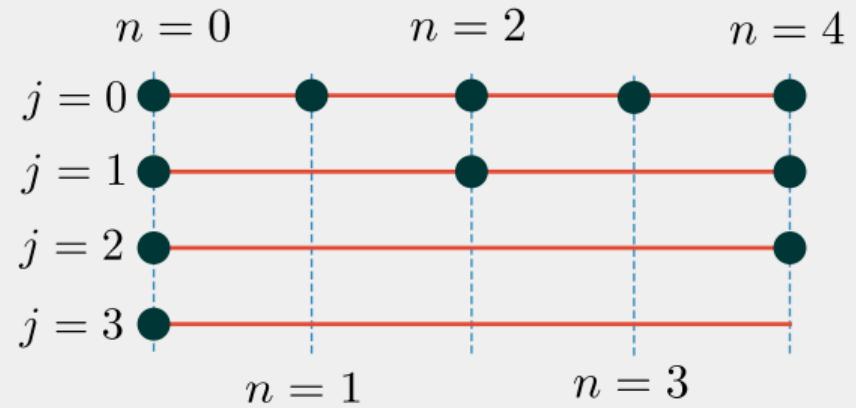
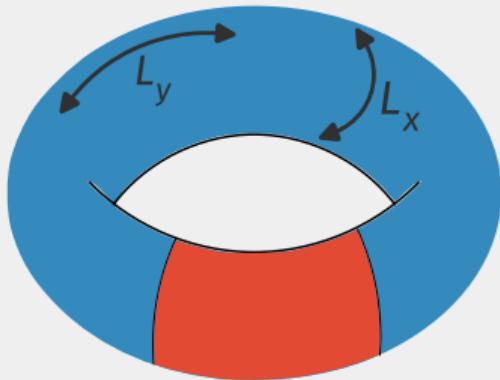
- Is the entanglement content of this system **holographic**?
- Is there any **topological** notion within the entanglement measures?



RESULTS

- Choose subsystem in real space (red region)
- Apply **coarse-graining transformations** in k -space

Evolution of subspace entanglement shows interesting properties.

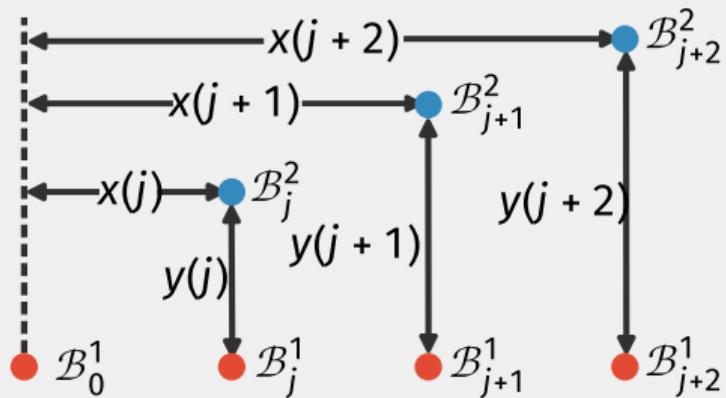


RESULTS

Use mutual information I_2 to define **distance**.

- Larger $I_2 \implies$ smaller distance
- Allows notion of **curvature** as well.

Coarse-graining transformations lead to **emergent** spatial dimension

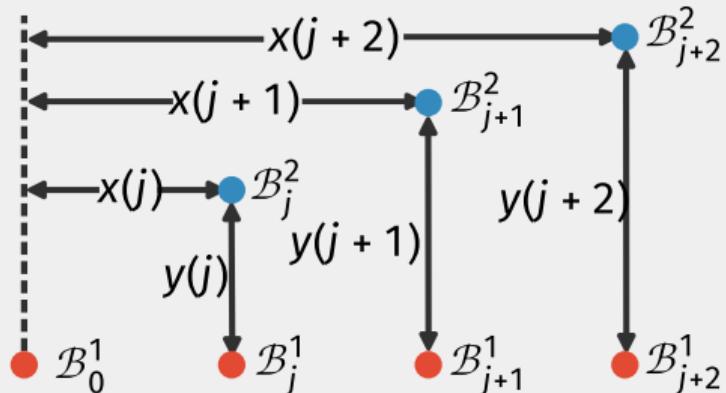


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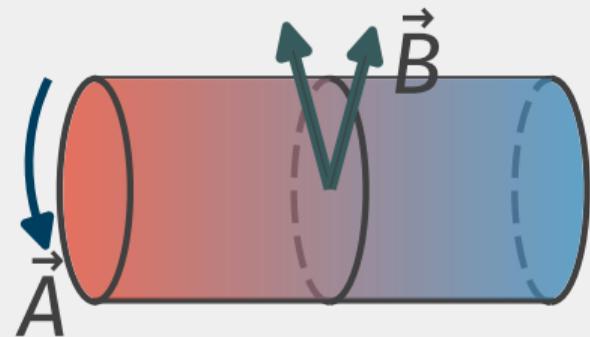


Other consequences:

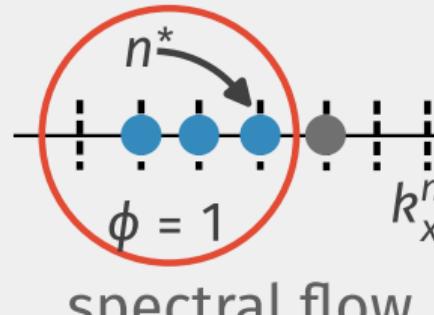
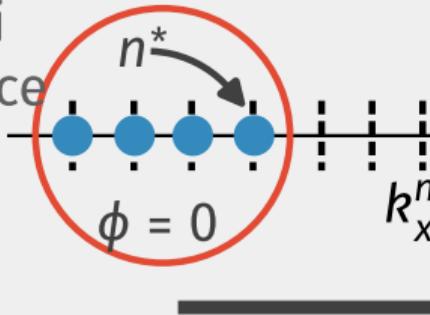
- **hierarchy** of entanglement exists along the RG
- hierarchy also present in **multipartite entanglement**

RESULTS

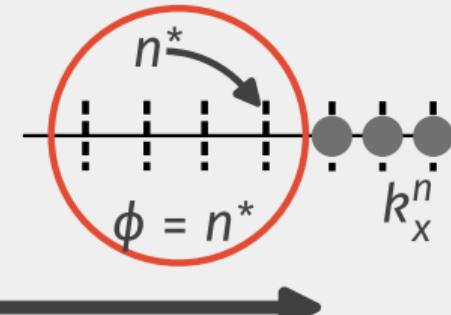
- By tuning flux, we relate Luttinger's volume to functions of entanglement
- Entanglement spectral flow is also related to Chern numbers in presence of magnetic field



Fermi surface



spectral flow

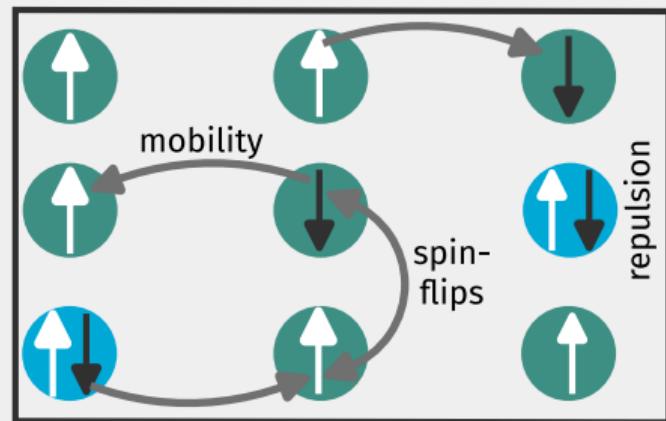


TILING A LATTICE WITH THE EXTENDED SIAM

ONGOING PROJECT

BROAD QUESTIONS

- Studying the Mott MIT on the 2D Hubbard-Heisenberg model
- Obtaining a momentum-space picture of the transition.
- Devising a method to tackle lattice models using impurity models



RESULTS

We use impurity model eigenstates (Hamiltonians) and **Bloch's theorem** to reconstruct full eigenstates (Hamiltonian):

$$|\Psi_{\vec{k}}\rangle \sim \sum_{\vec{R}_i} e^{i\vec{k}\cdot\vec{R}_i} |\psi_{\text{aux}}(\vec{R}_i)\rangle, \quad H \sim \sum_{\vec{R}_i} H_{\text{aux}}(\vec{R}_i)$$



RESULTS

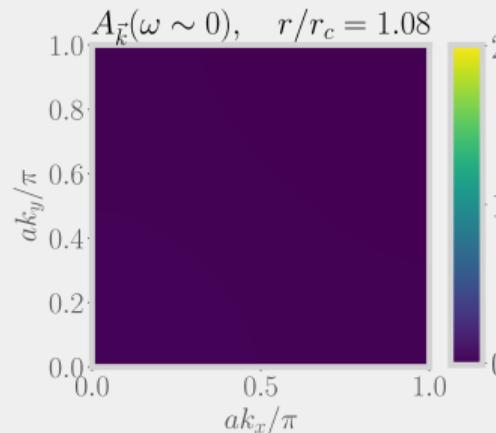
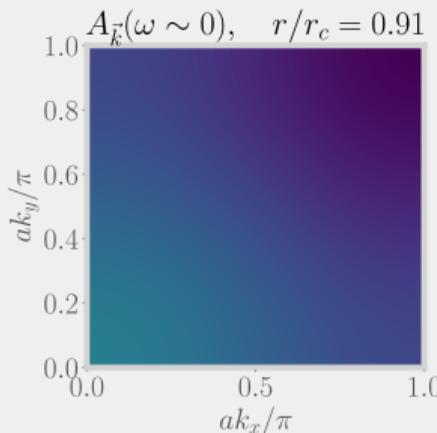
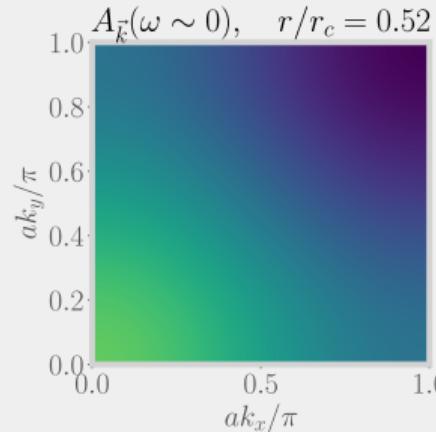
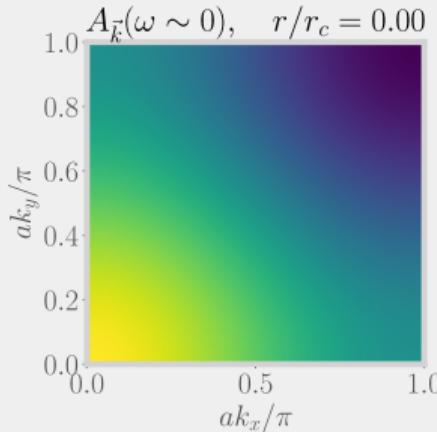
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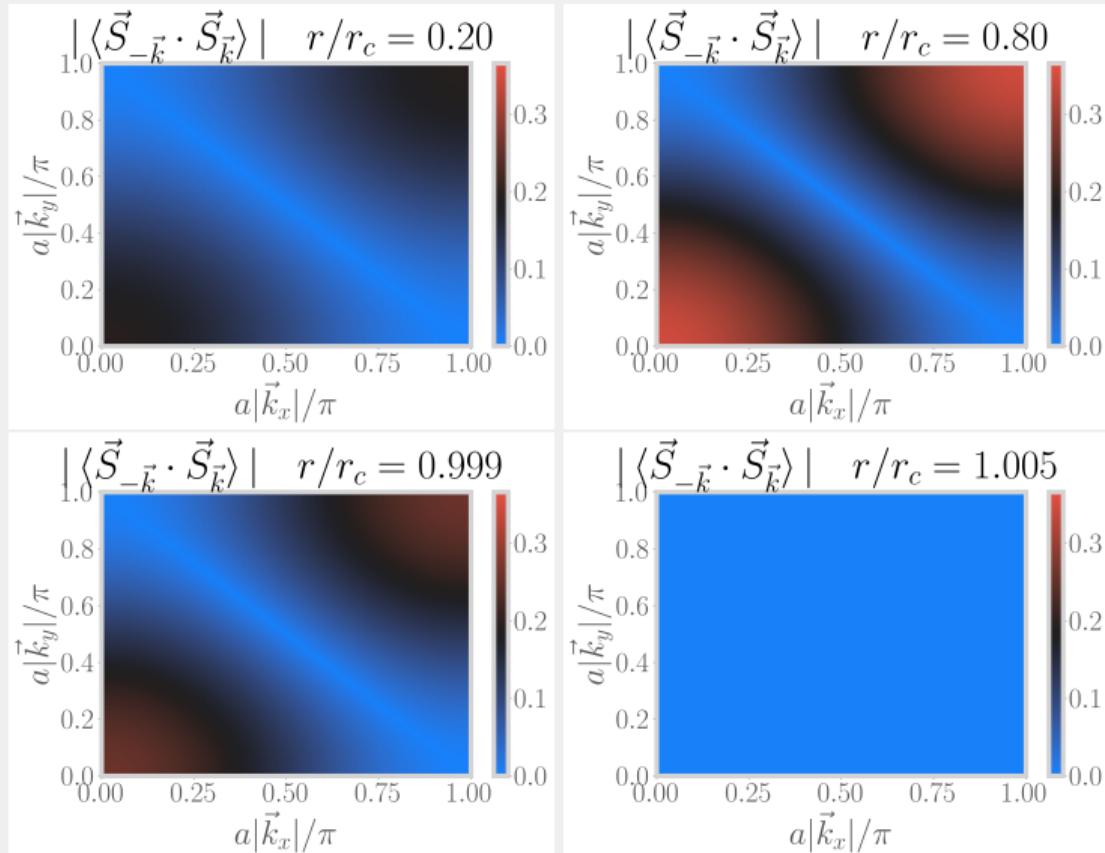
Allow us to **relate corresponding objects** between the impurity model and the lattice model

- Greens functions and self-energies
- Two-particle correlation functions
- entanglement measures

RESULTS: MOMENTUM SPACE SPECTRAL FUNCTION



RESULTS: MOMENTUM SPACE SPIN CORRELATIONS



SEARCH FOR PUNCTURED-CHERN TOPOLOGY AT IQHE TRANSITIONS

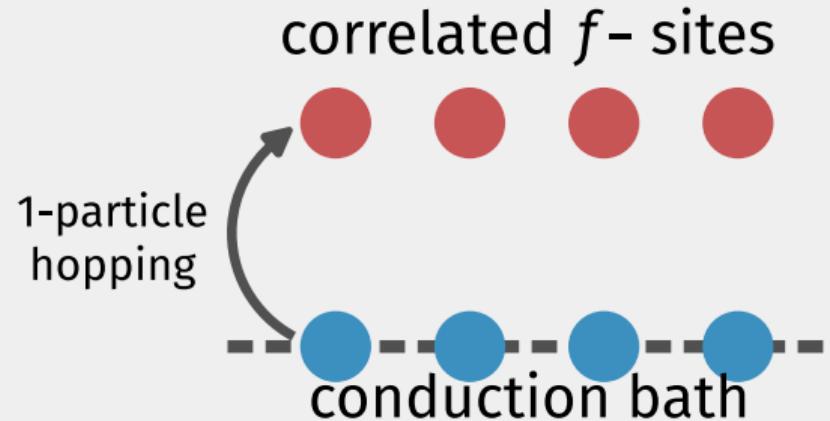
ONGOING PROJECT

BROAD QUESTIONS

FUTURE PLANS

Lattice models of impurities

- either directly or through the auxiliary model approach
- phase diagrams: strange metals and QCPs
- unconventional superconductivity



FUTURE PLANS

Fractional Chern insulators

- microscopic understanding of the FQHE ground states
- emergence of composite degrees of freedom and topological theories

FUTURE PLANS

Classification of RG flows in fermionic models

- growth of multipartite entanglement towards stable fixed points
- extending this to impurity models
- connections with the URG noise operator