Emergence in correlated fermions: From impurity models to the bulk

Abhirup Mukherjee

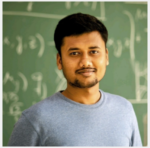
RPC Presentation 2022-2023

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

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

- ■ 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.

- ✓ 2022 **Phys. Rev. B** 105, 085119.

  A Mukherjee, **Abhirup Mukherjee**, ..., S. Lal
- ✓ 2023 **J. Phys.: Condens. Matter** 35 315601.

  S Patra, **Abhirup Mukherjee**, ..., S. Lal
- 2023 **arXiv:2302.02328**.

  Abhirup Mukherjee, ..., S. Lal
- 2023 **arXiv:2302.10590**.

  Abhirup Mukherjee, ..., S. Lal

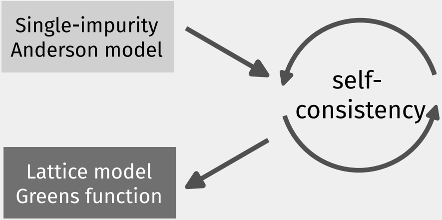
Quantum phase transition in an extended-SIAM

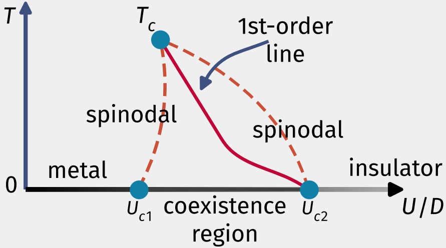
Abhirup Mukherjee, N. S. Vidhyadhiraja, A. Taraphder, Siddhartha Lal

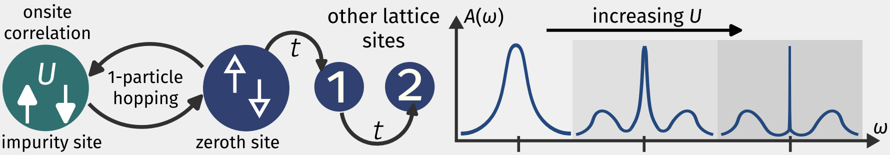
arXiv:2302.02328. (2023)

Broad questions

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







Holography of entanglement in 2D free fermions

Abhirup Mukherjee, Siddhartha Patra, Siddhartha Lal

arXiv:2302.10590. (2023)

Tiling the lattice with the extended SIAM

Ongoing project

Search for punctured-Chern topology at IQHE transitions

Ongoing project

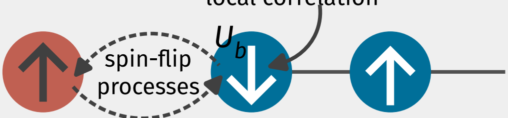
The extended-SIAM project

Abhirup Mukherjee, N. S. Vidhyadhiraja, A. Taraphder, S. Lal
arXiv:2302.02328. (2023)

WHAT IS THE NEW PHYSICS INGREDIENT?

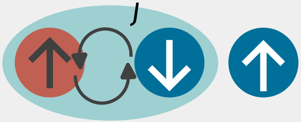
Add **local correlation** on bath (zeroth) site coupled to impurity

$$KE_{\text{bath}} + J\vec{S}_{\text{imp}} \cdot \vec{S}_{\text{bath}} - U_b \left(\vec{S}_{\text{bath}}\right)^2$$



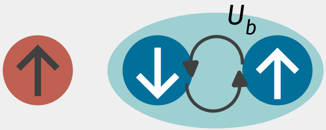
URG equations show that an **attractive** U_b frustrates the zeroth site.

$$\Delta J \sim J^2 + 4U_b J \implies \textbf{phase transition} \text{ at } J = -4U_b$$



singlet state (favour J)

OR



decoupled local moment (favour U_b)

Such a model sheds light on the Mott MIT in ∞-dimensions (as seen from DMFT).

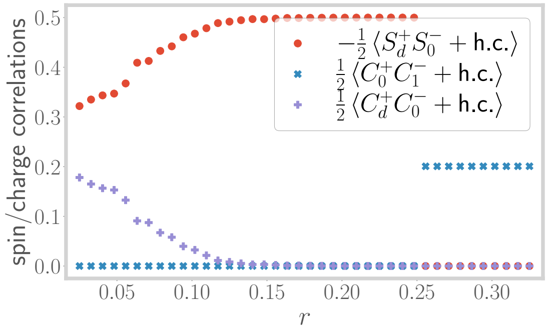
Georges et al. 1996.

Nature of the transition

Across the transition,

- impurity correlations vanish
- bath correlations become non-zero

Shows that **pairing correlations** in the bath are responsible for the transition.

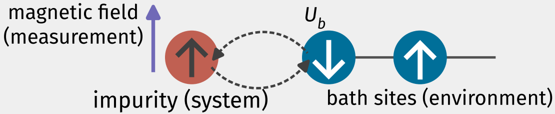


The state **precisely at the transition** is special:

- non-Fermi liquid excitations
- **fractional** impurity magnetisation and occupancy

Concluding remarks

- Our analyses often link entanglement measures with correlations, providing bridges between the worlds of condensed matter and quantum information.
- Models of Kondo breakdown can be used to study the effects of measurement on a system coupled to a bath.



- The Kondo model with attractive U_b term has applications in studying the physics of Mott transitions.


Thank you, all of you.

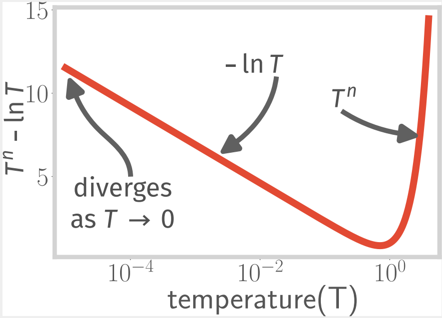
HOW TO EXPLAIN THE RESISTANCE MINIMUM & EVENTUAL SATURATION?

Second order perturbation theory in J gives:

$$\rho \sim T^n - \ln T$$

Explains the **non-monotonic** behaviour!

(Jun Kondo)

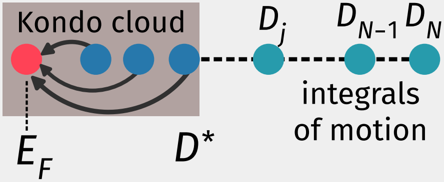


However, solution **diverges** at $T \to 0$!

Kondo 1964.

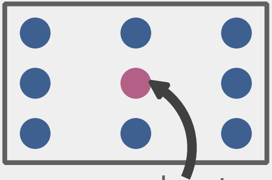
Unitary RG approach to impurity models

- Integrate out **high energy fluctuations** to reach strong-coupling low-energy theory
- Leads to **singlet ground state** and decoupled high-energy k–states
- Decoupling is carried out through **unitary transformations**



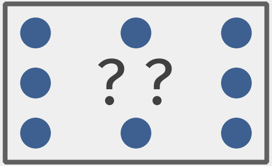
Mukherjee et al. 2020a; Mukherjee et al. 2020b.

- Entanglement entropy $S(A) \Longrightarrow$ quantifies how much **information is gained** about the rest of the system by measuring A



measure subsystem A

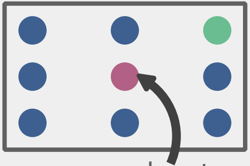
$$S(A) = \mathrm{Trace}\left(\rho_A \ln \rho_A\right)$$



gain information about rest

- Entanglement entropy $S(A) \Longrightarrow$ quantifies how much **information is gained** about the rest of the system by measuring A

- Mutual information $I_2(A : B) \Longrightarrow$ quantifies how much **information about subsystem A** is gained by measuring B



$$I_2(A : B) = S(A) + S(B) - S(A \cup B)$$

measure subsystem A

gain information about B