

INSIGHTS ON THE PSEUDOGAP IN 2D FROM AN IMPURITY MODEL

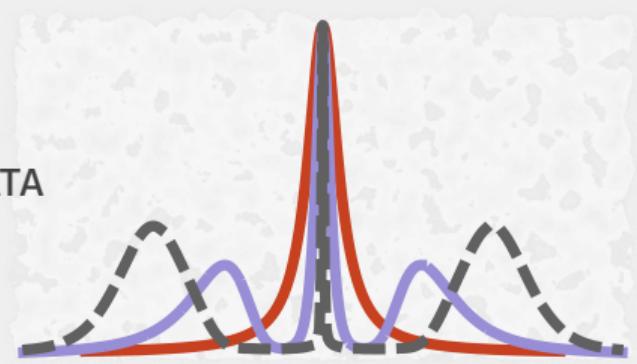
A NEW APPROACH TOWARDS CORRELATED LATTICE MODELS

ABHIRUP MUKHERJEE

DPS DAY '25

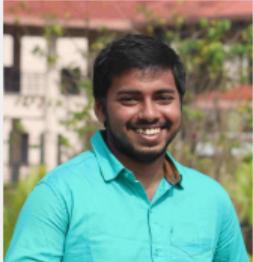
DEPARTMENT OF PHYSICAL SCIENCES, IISER KOLKATA

MARCH 19, 2025

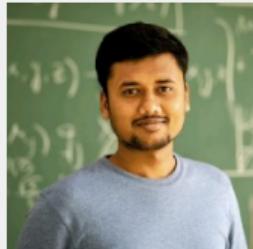




Prof. Siddhartha Lal



Debraj Debata



Siddhartha Patra
(Multiverse Computing)



Prof. Anamitra Mukherjee
(NISER Bhubaneshwar)



Prof. Arghya Taraphder
(IIT Kharagpur)



Prof. N. S. Vidhyadhiraja
(JNCASR Bangalore)

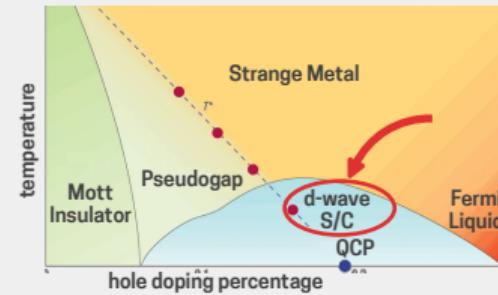
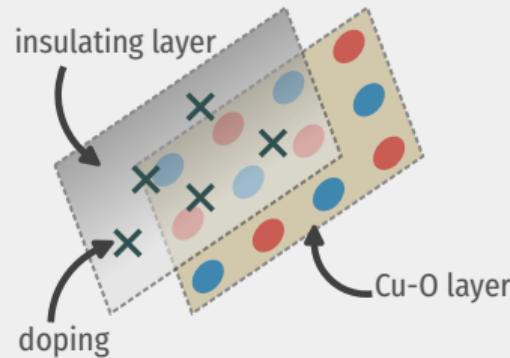


~~~~~  
**Financial support by IISER K and SERB is gratefully acknowledged.**  
~~~~~

THE ADVENT OF QUANTUM MATERIALS: CUPRATE SUPERCONDUCTORS

Consists of **Cu-O planes** that can be doped.

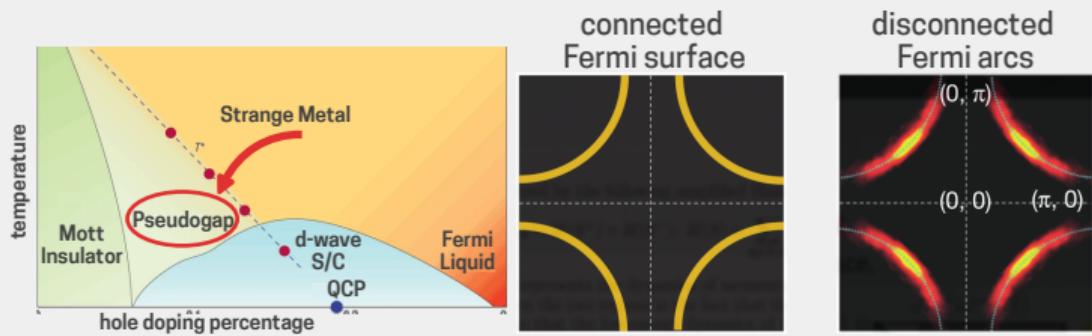
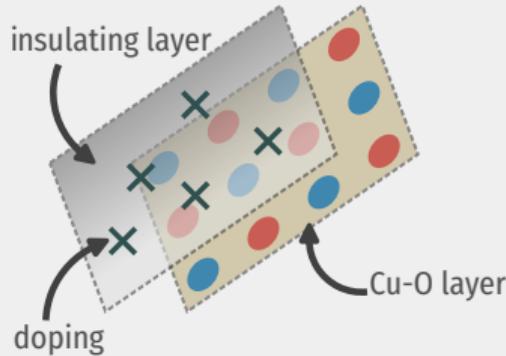
- **Unconventional** superconductivity,
borne out of electronic interactions.



THE ADVENT OF QUANTUM MATERIALS: CUPRATE SUPERCONDUCTORS

Consists of **Cu-O planes** that can be doped.

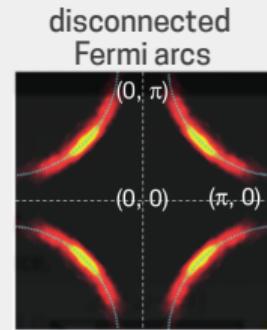
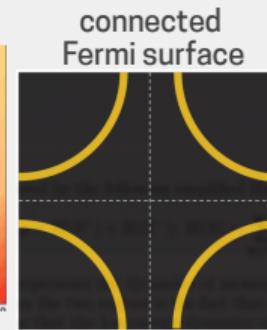
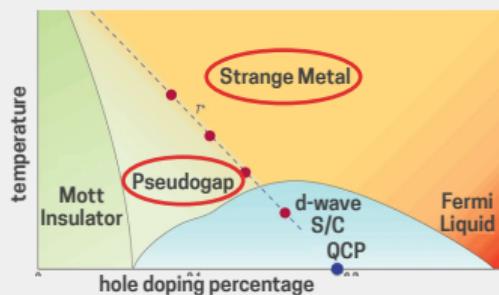
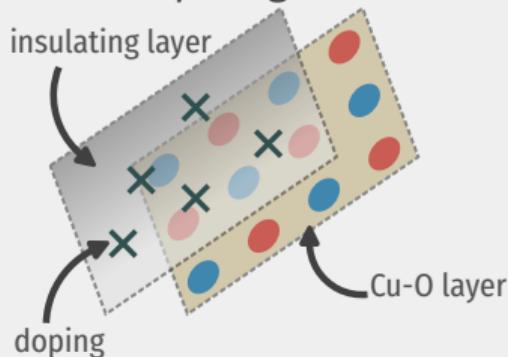
- **Unconventional** superconductivity, borne out of electronic interactions.
- **Pseudogap** phase has Fermi arcs and competing fluctuations



THE ADVENT OF QUANTUM MATERIALS: CUPRATE SUPERCONDUCTORS

Consists of **Cu-O planes** that can be doped.

- **Unconventional** superconductivity, borne out of electronic interactions.
- **Pseudogap** phase has Fermi arcs and competing fluctuations



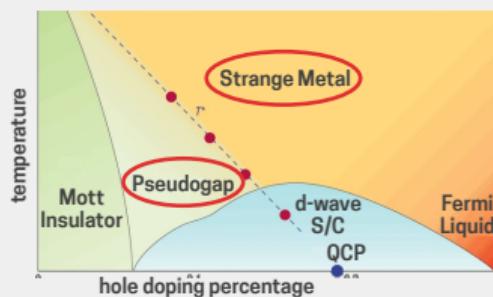
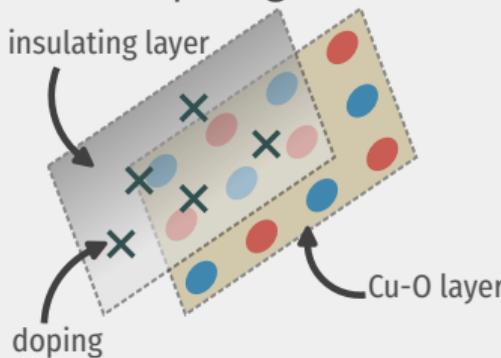
Effect of these phases at **half-filling**?

- * **Missing:** Microscopic understanding of the pseudogap phase
- * **Missing:** Simple and universal mechanism for strange metals

THE ADVENT OF QUANTUM MATERIALS: CUPRATE SUPERCONDUCTORS

Consists of **Cu-O planes** that can be doped.

- **Unconventional** superconductivity, borne out of electronic interactions.
- **Pseudogap** phase has Fermi arcs and competing fluctuations

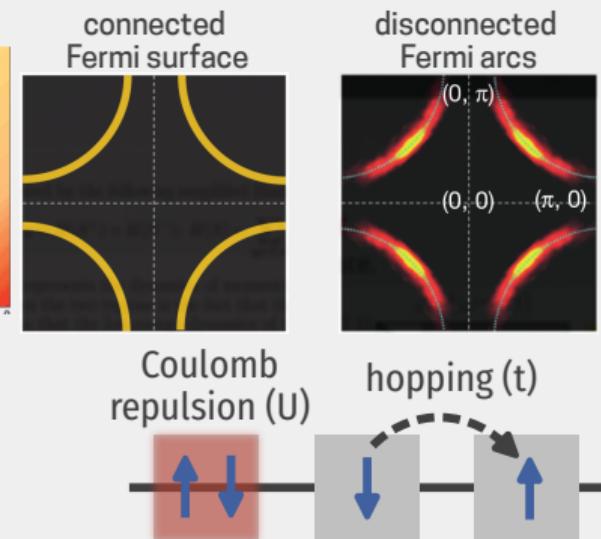


2D **Hubbard model** on square lattice

$$H = -t \sum_{\langle i,j \rangle, \sigma} (c_{i,\sigma}^\dagger c_{j,\sigma} + \text{h.c.}) + U \sum_i n_{i\uparrow} n_{i\downarrow}$$

Too hard to solve! Alternative approaches needed.

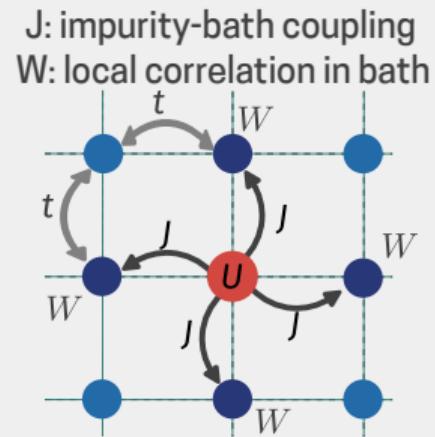
- * **Missing:** Microscopic understanding of the pseudogap phase
- * **Missing:** Simple and universal mechanism for strange metals



A BOTTOM-UP APPROACH: STARTING FROM AN IMPURITY MODEL

What is an Impurity Model?

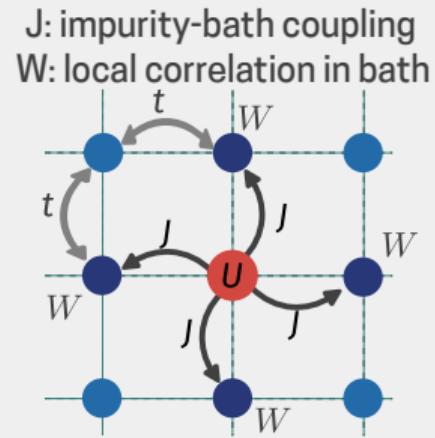
- Single **correlated site**, hybridising with conduction **bath**



A BOTTOM-UP APPROACH: STARTING FROM AN IMPURITY MODEL

What is an Impurity Model?

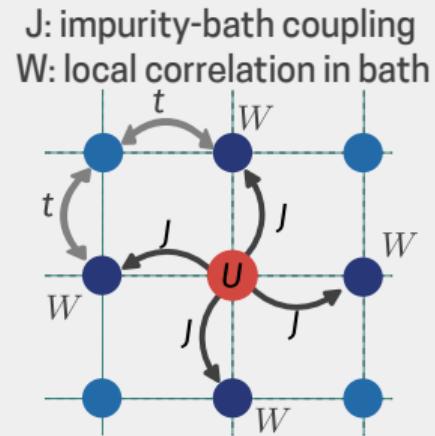
- Single **correlated site**, hybridising with conduction **bath**
- Impurity-bath hybridisation respects **C_4 symmetry** of 2D square lattice (**not s-wave** scattering, important!)



A BOTTOM-UP APPROACH: STARTING FROM AN IMPURITY MODEL

What is an Impurity Model?

- Single **correlated site**, hybridising with conduction **bath**
- Impurity-bath hybridisation respects **C_4 symmetry** of 2D square lattice (**not s-wave** scattering, important!)
- (Much!) **Simpler to solve** than Hubbard model, because of non-interacting conduction bath



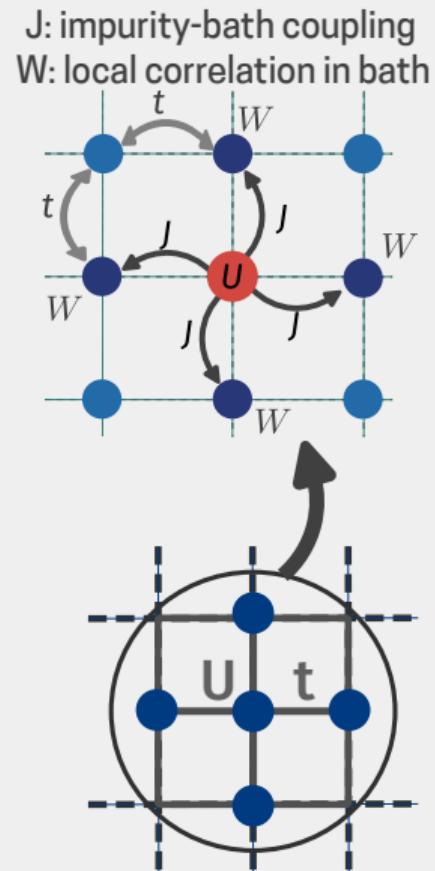
A BOTTOM-UP APPROACH: STARTING FROM AN IMPURITY MODEL

What is an Impurity Model?

- Single **correlated site**, hybridising with conduction **bath**
- Impurity-bath hybridisation respects **C_4 symmetry** of 2D square lattice (**not s-wave** scattering, important!)
- (Much!) **Simpler to solve** than Hubbard model, because of non-interacting conduction bath

Mapping to the Lattice Model

- Impurity model describes hopping into the correlated **local environment**.



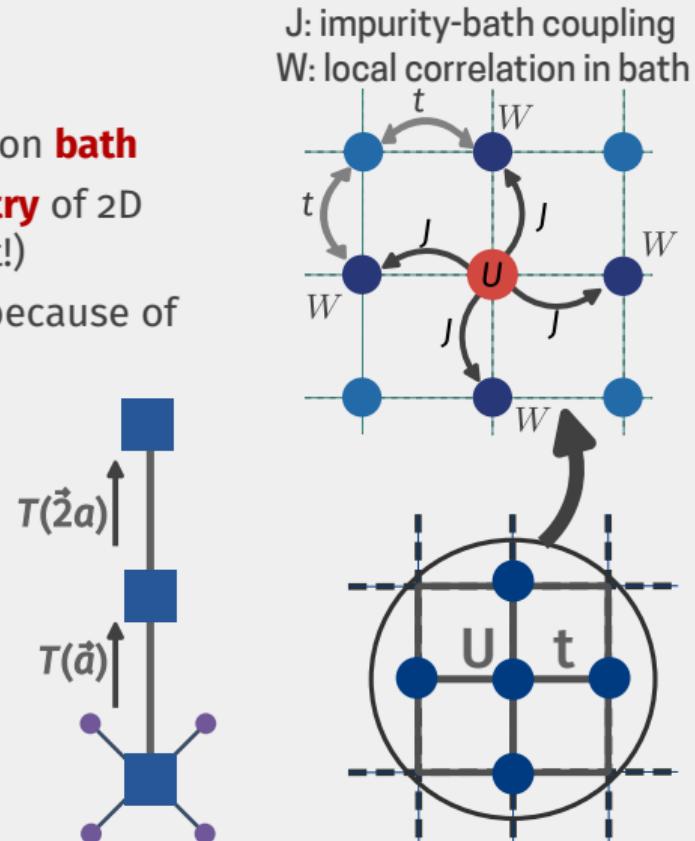
A BOTTOM-UP APPROACH: STARTING FROM AN IMPURITY MODEL

What is an Impurity Model?

- Single **correlated site**, hybridising with conduction **bath**
- Impurity-bath hybridisation respects **C_4 symmetry** of 2D square lattice (**not s-wave** scattering, important!)
- (Much!) **Simpler to solve** than Hubbard model, because of non-interacting conduction bath

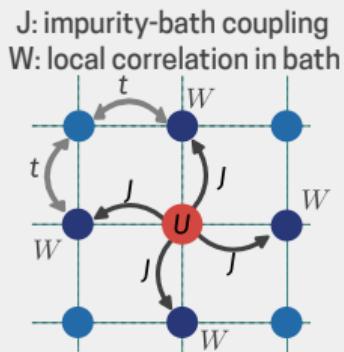
Mapping to the Lattice Model

- Impurity model describes hopping into the correlated **local environment**.
- **Translation** operator maps impurity model quantities to those on the lattice model (**Hubbard-Heisenberg** model)



MOMENTUM-SPACE RESOLVED IMPURITY PHASE TRANSITION

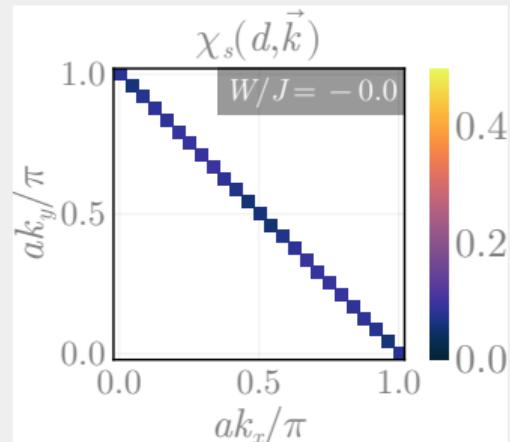
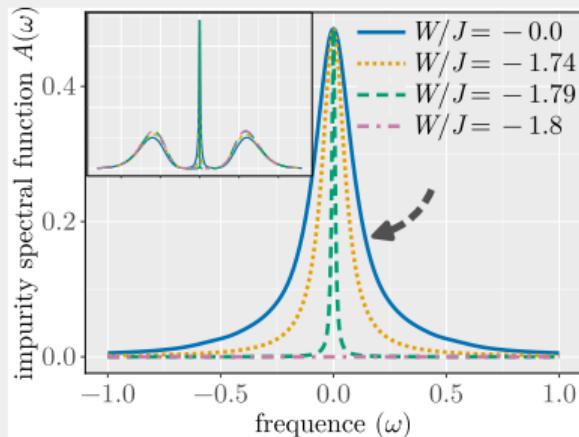
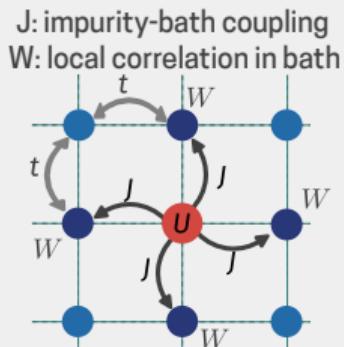
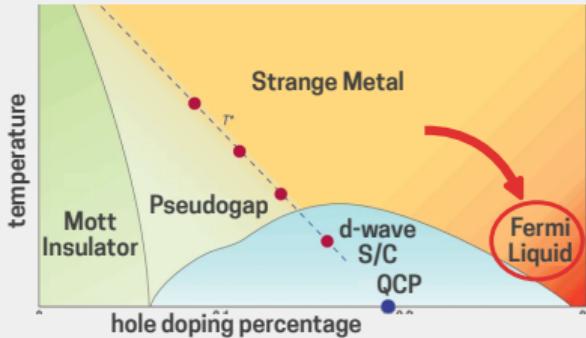
Increasing bath correlation W tunes the impurity model through three phases



MOMENTUM-SPACE RESOLVED IMPURITY PHASE TRANSITION

Increasing bath correlation W tunes the impurity model through three phases

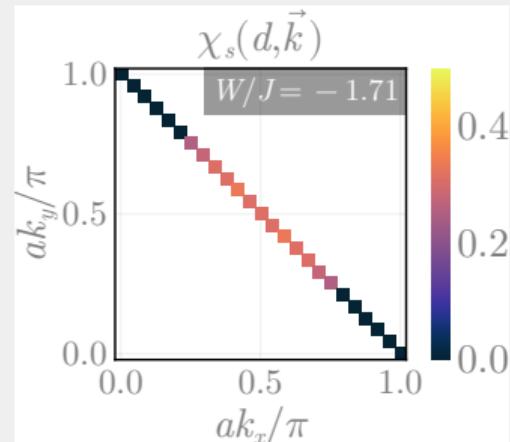
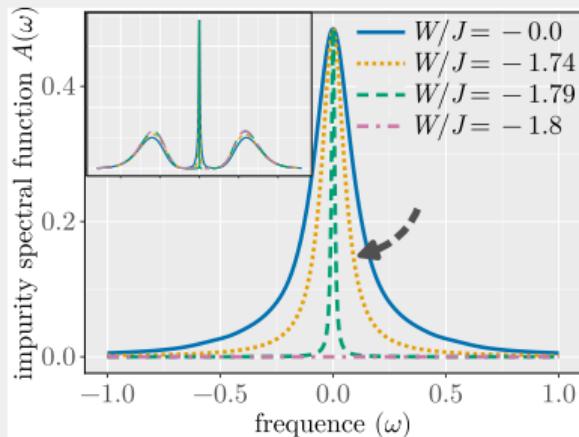
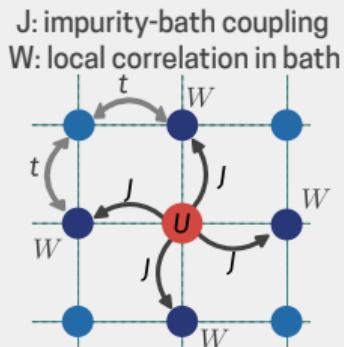
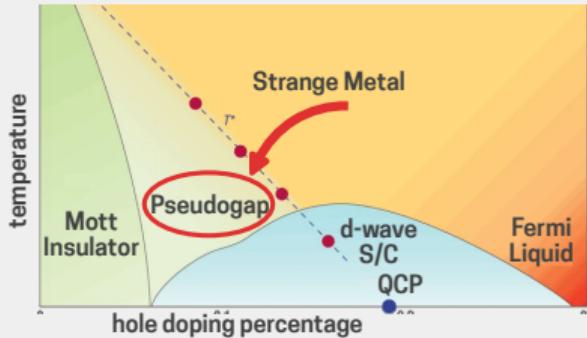
- Impurity **strongly coupled** to Fermi surface



MOMENTUM-SPACE RESOLVED IMPURITY PHASE TRANSITION

Increasing bath correlation W tunes the impurity model through three phases

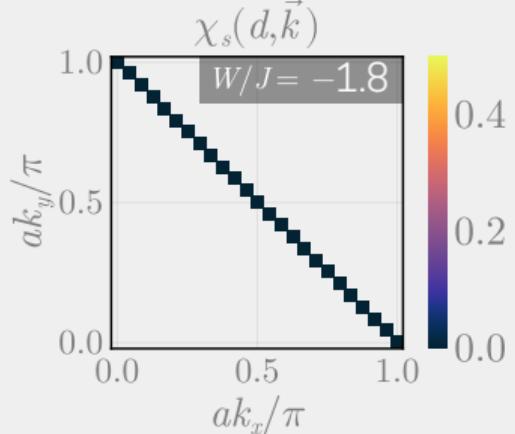
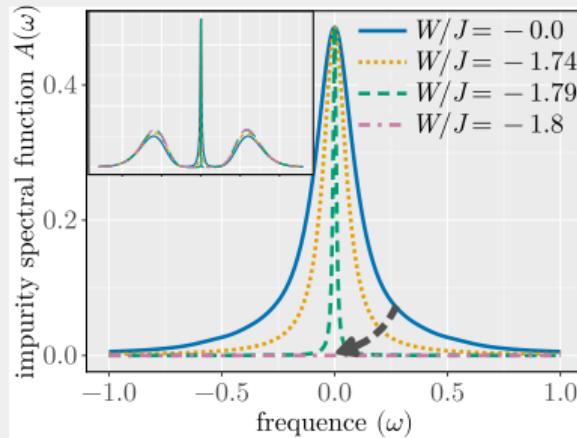
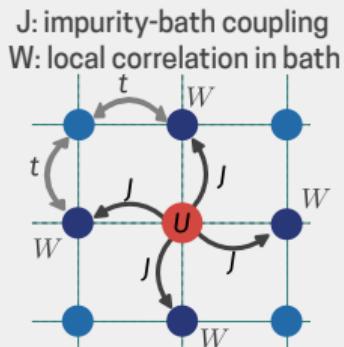
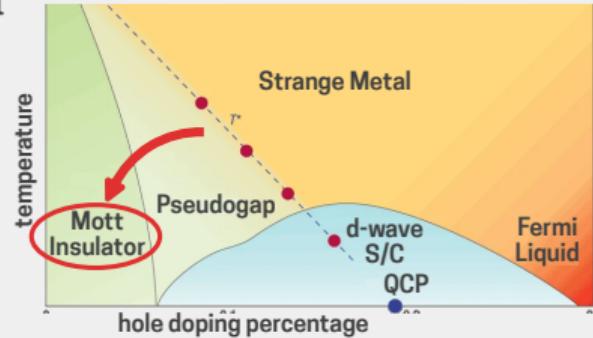
- Impurity **strongly coupled** to Fermi surface
- Impurity coupled **only to parts** of Fermi surface



MOMENTUM-SPACE RESOLVED IMPURITY PHASE TRANSITION

Increasing bath correlation W tunes the impurity model through three phases

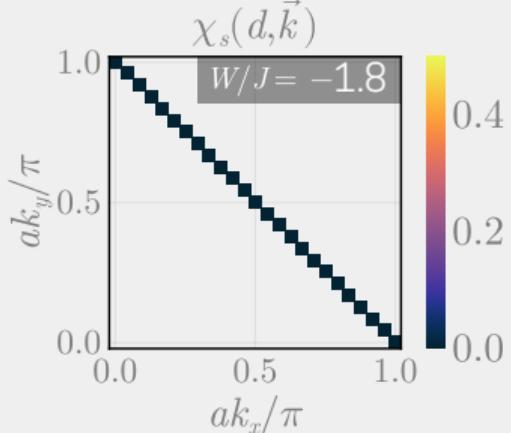
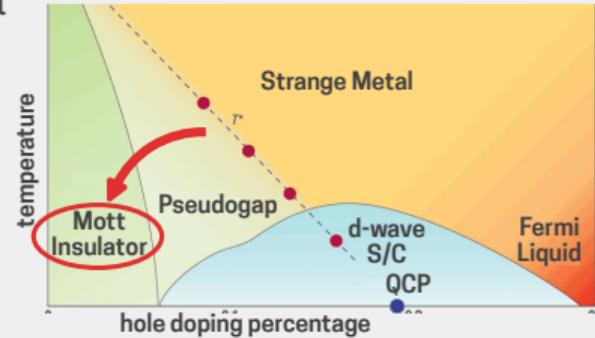
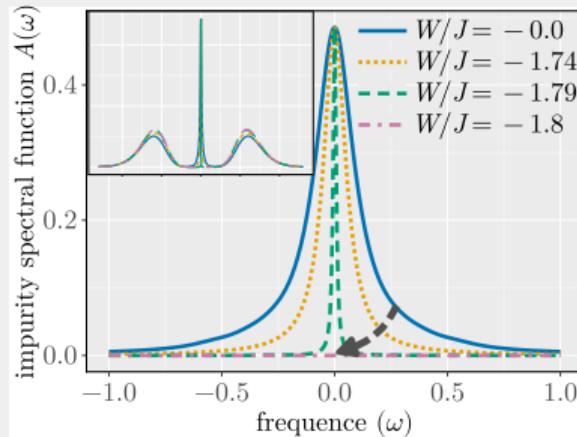
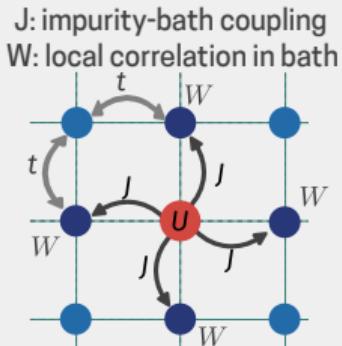
- Impurity **strongly coupled** to Fermi surface
- Impurity coupled **only to parts** of Fermi surface
- Impurity **decoupled** from the Fermi surface



MOMENTUM-SPACE RESOLVED IMPURITY PHASE TRANSITION

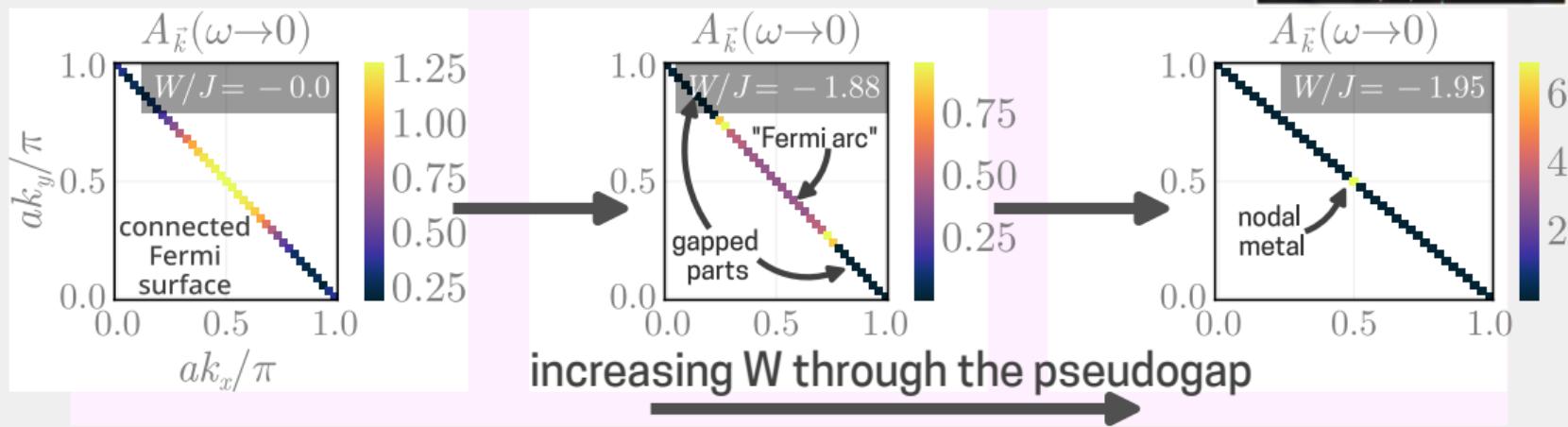
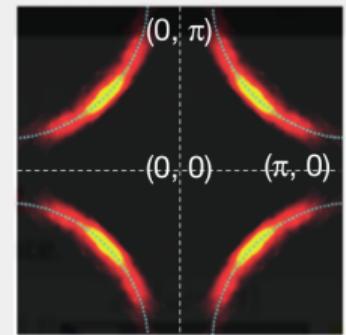
Increasing bath correlation W tunes the impurity model through three phases

- Impurity **strongly coupled** to Fermi surface
- Impurity coupled **only to parts** of Fermi surface
- Impurity **decoupled** from the Fermi surface
- Spectral function **sharpens** as Fermi surface decouples.



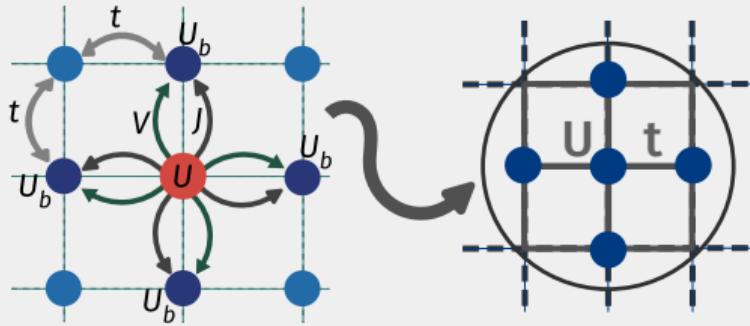
PSEUDOGAPPING TRANSITION ON THE LATTICE MODEL

- Map Greens functions from impurity model to **lattice model**.
- Momentum-space DOS reveals **partially gapped** Fermi surface.



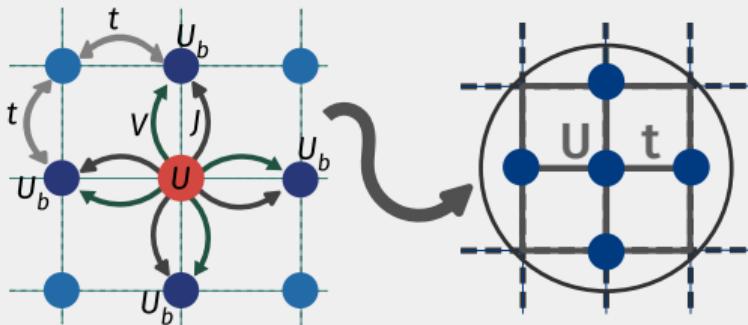
MAIN TAKEAWAYS

Our approach **simplifies** study of lattice models via appropriate **impurity models**.

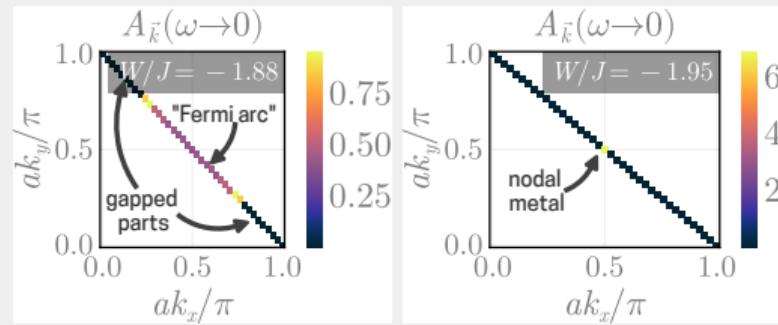


MAIN TAKEAWAYS

Our approach **simplifies** study of lattice models via appropriate **impurity models**.

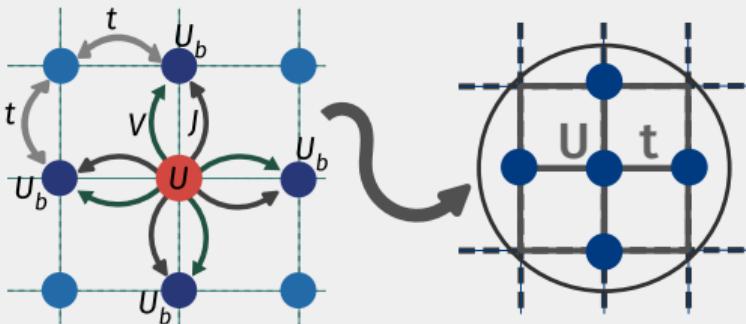


Our impurity model realises a **pseudogap-ping transition** in a correlated model.

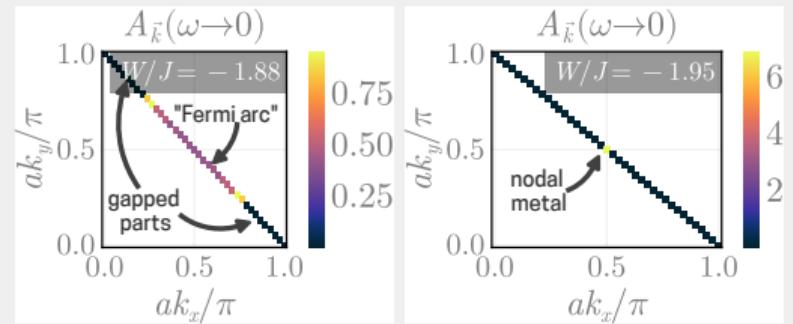


MAIN TAKEAWAYS

Our approach **simplifies** study of lattice models via appropriate **impurity models**.



Our impurity model realises a **pseudogap-ping transition** in a correlated model.



Generalisations and Extensions

- Tune impurity filling - simulate **doping!**
- Multiple impurities - symmetry-broken or **spin liquid** phases

