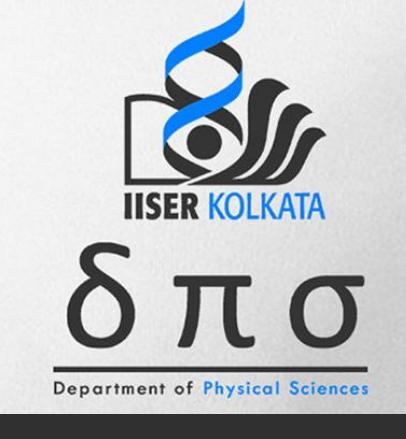


# Unitary RG Approach to Quantum Impurity Problems



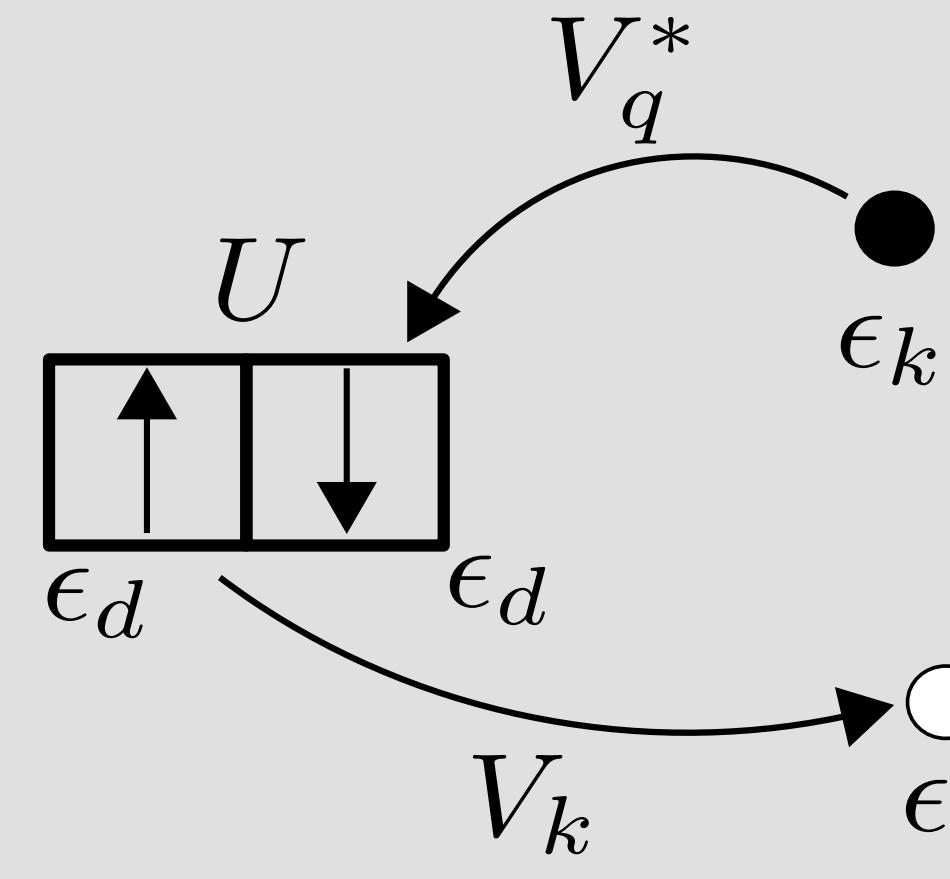
Phys. Rev. B 105, 085119 Anirban Mukherjee<sup>[1]</sup>, Abhirup Mukherjee<sup>[1]</sup>, N.S. Vidhyadhiraja<sup>[2]</sup>, A. Taraphder<sup>[3]</sup>, Siddhartha Lal<sup>[1]</sup>

[1] Department of Physical Sciences, IISER Kolkata

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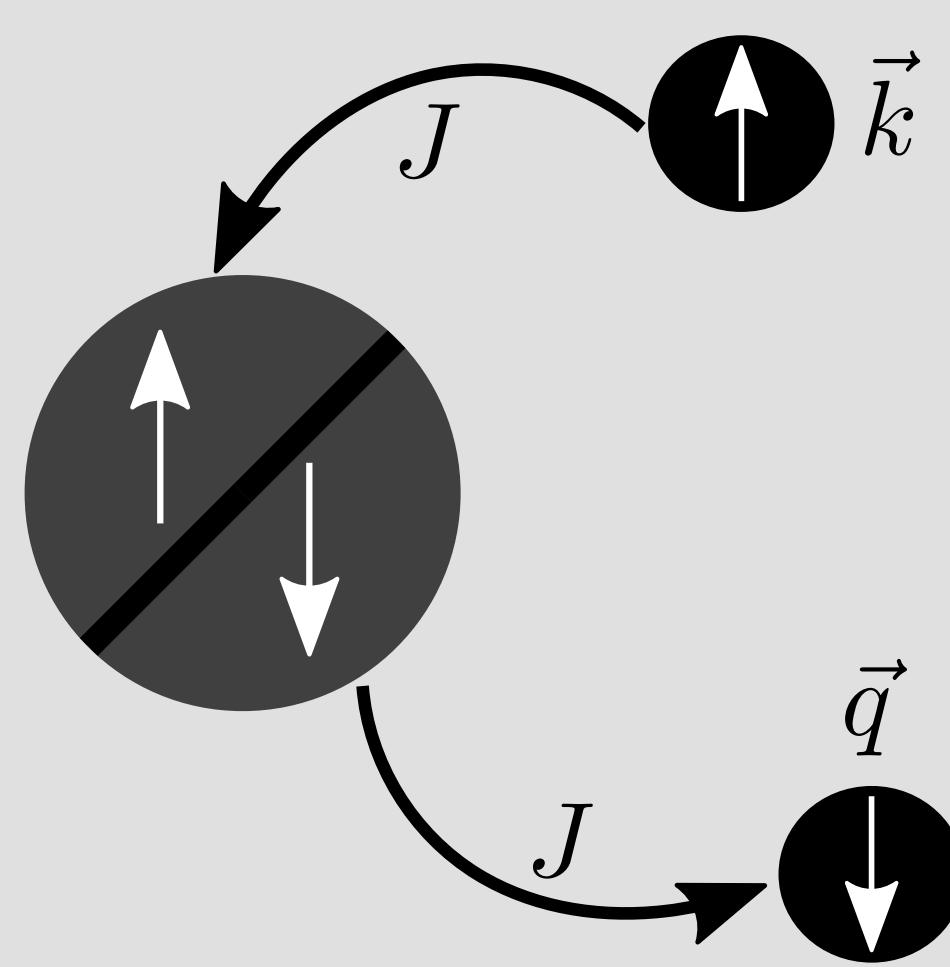
[3] Department of Physics, IIT Kharagpur

## The Anderson impurity model (SIAM)



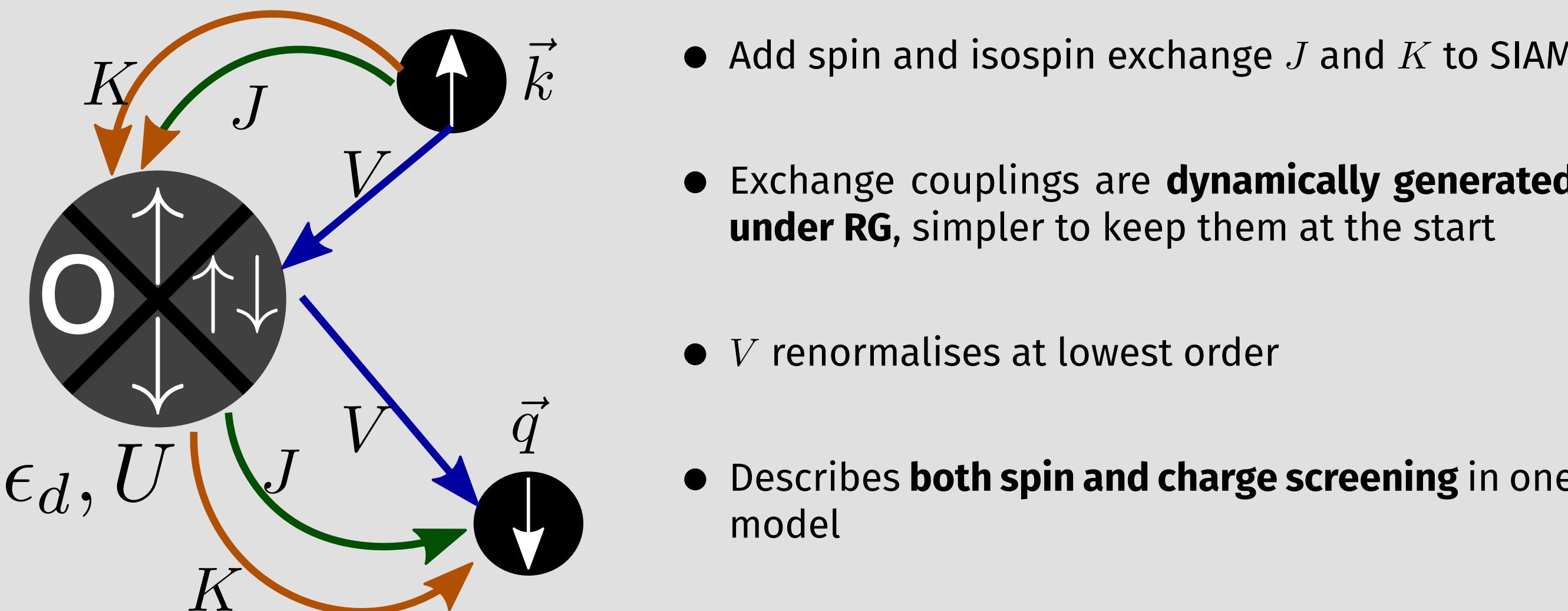
- Local impurity interacting with bath:  $H_{\text{bath}} = \sum_{k\sigma} \epsilon_k \hat{n}_{k\sigma}$
  - Hubbard repulsion  $U$  on impurity and 1-particle hybridisation  $V$  with bath
- $$H = H_{\text{bath}} + \epsilon_d \hat{n}_d + U \hat{n}_{d\uparrow} \hat{n}_{d\downarrow} + V \sum_{k\sigma} (c_{k\sigma}^\dagger c_{d\sigma} + \text{h.c.})$$
- Microscopic origin of local moments in metals**

## The (spin) Kondo model



- Impurity projected to spin-half Hilbert space
  - Spin-exchange coupling** with conduction bath spin
- $$H = H_{\text{bath}} + J \vec{S}_a \cdot \vec{s}$$
- Ground state is a **macroscopic singlet** formed by the impurity and the conduction bath
  - Charge variant involves **isospin exchange**

## Generalised Kondo-SIAM model

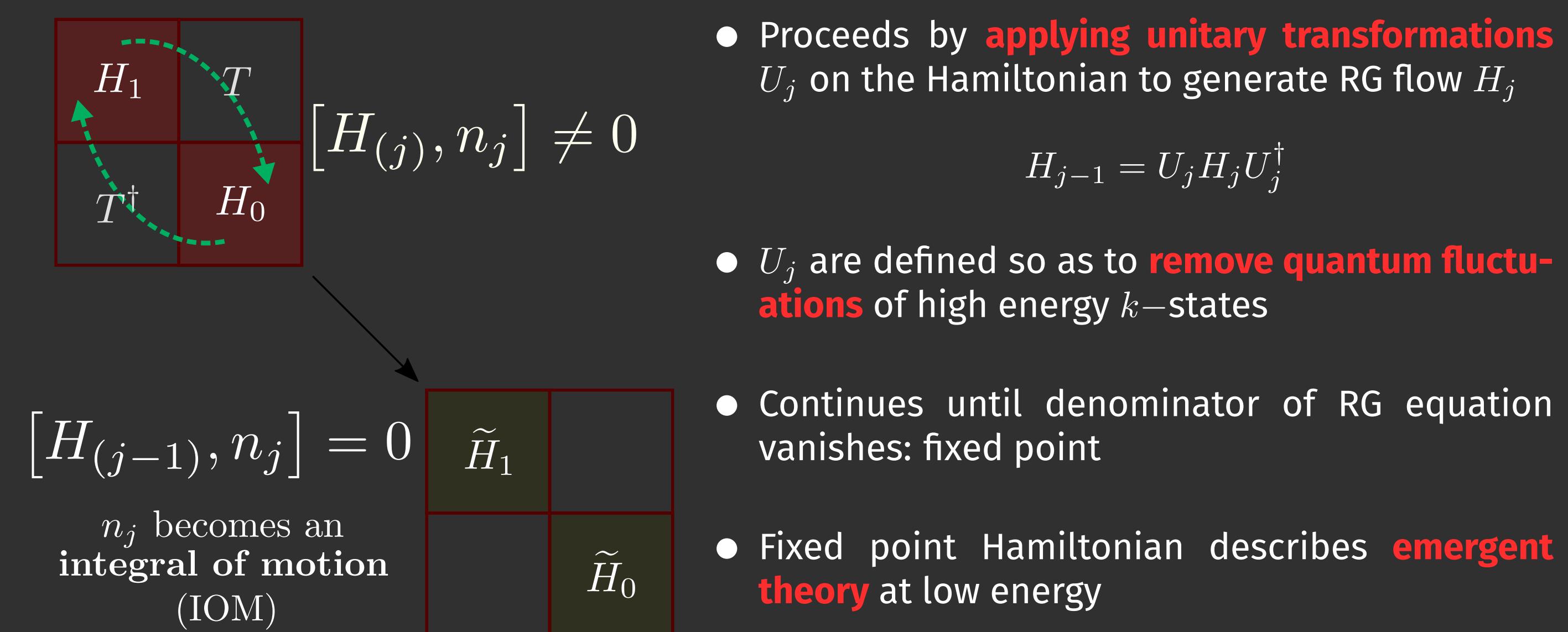


- Add spin and isospin exchange  $J$  and  $K$  to SIAM
- Exchange couplings are **dynamically generated under RG**, simpler to keep them at the start
- $V$  renormalises at lowest order
- Describes **both spin and charge screening** in one model

## Outstanding Questions

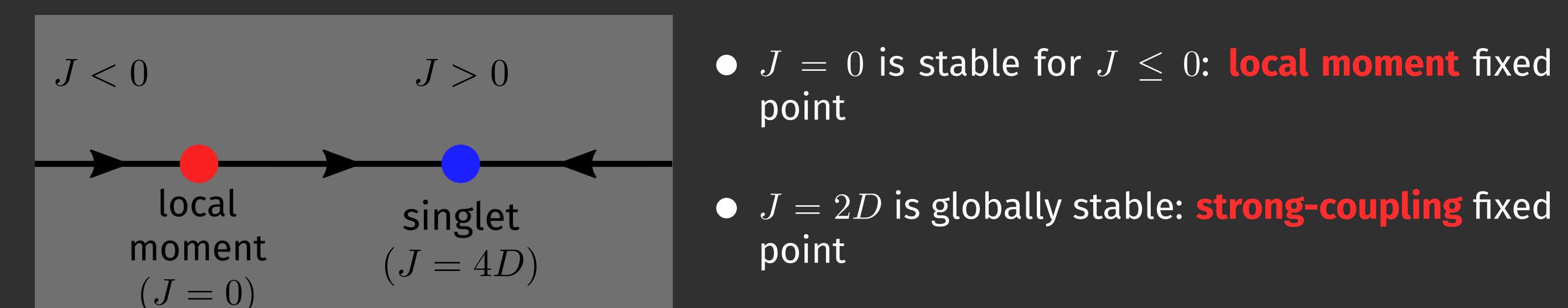
- What's the **effective Hamiltonian** for the conduction electrons that screen the impurity?
- What is the **nature of the metal** responsible for this screening?
- Quantitative insight into **many-particle entanglement** at and near the fixed point
- Does the interplay of  $V$ ,  $J$  and  $K$  change the phase diagram in the generalised SIAM?
- Is there any **topological quantity** that changes in the process of screening?
- Can the inclusion of  $J$  lead to a local **metal-insulator transition** on the impurity?

## The Unitary Renormalisation Group (URG) Method

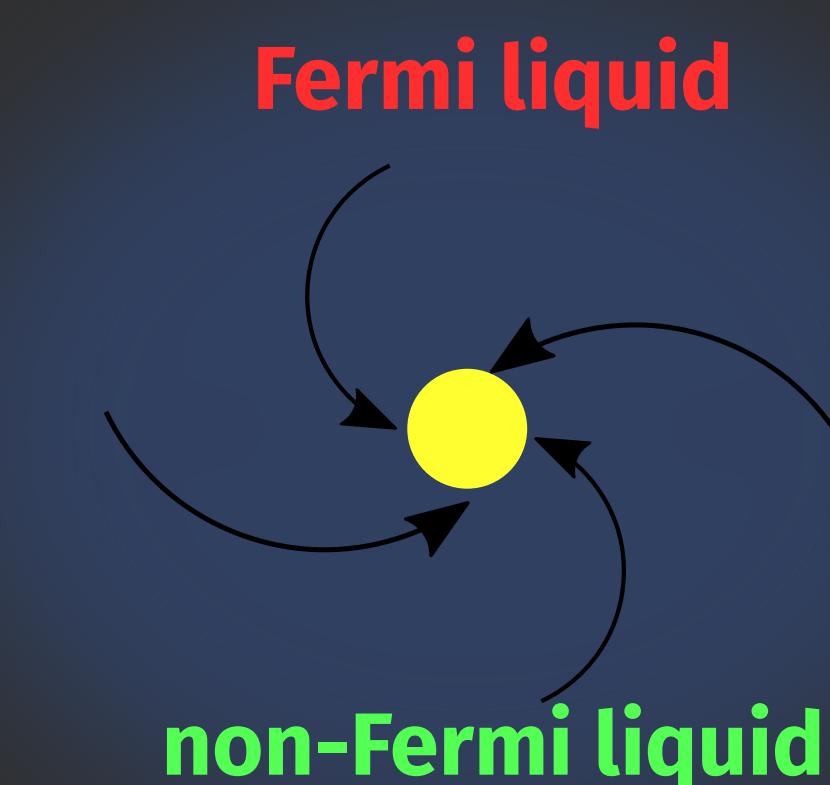


- Proceeds by **applying unitary transformations**  $U_j$  on the Hamiltonian to generate RG flow  $H_j$
$$H_{j-1} = U_j H_j U_j^\dagger$$
- $U_j$  are defined so as to **remove quantum fluctuations** of high energy  $k$ -states
- Continues until denominator of RG equation vanishes: **fixed point**
- Fixed point Hamiltonian describes **emergent theory** at low energy

## URG Flows of the Kondo Model: Phase Diagram

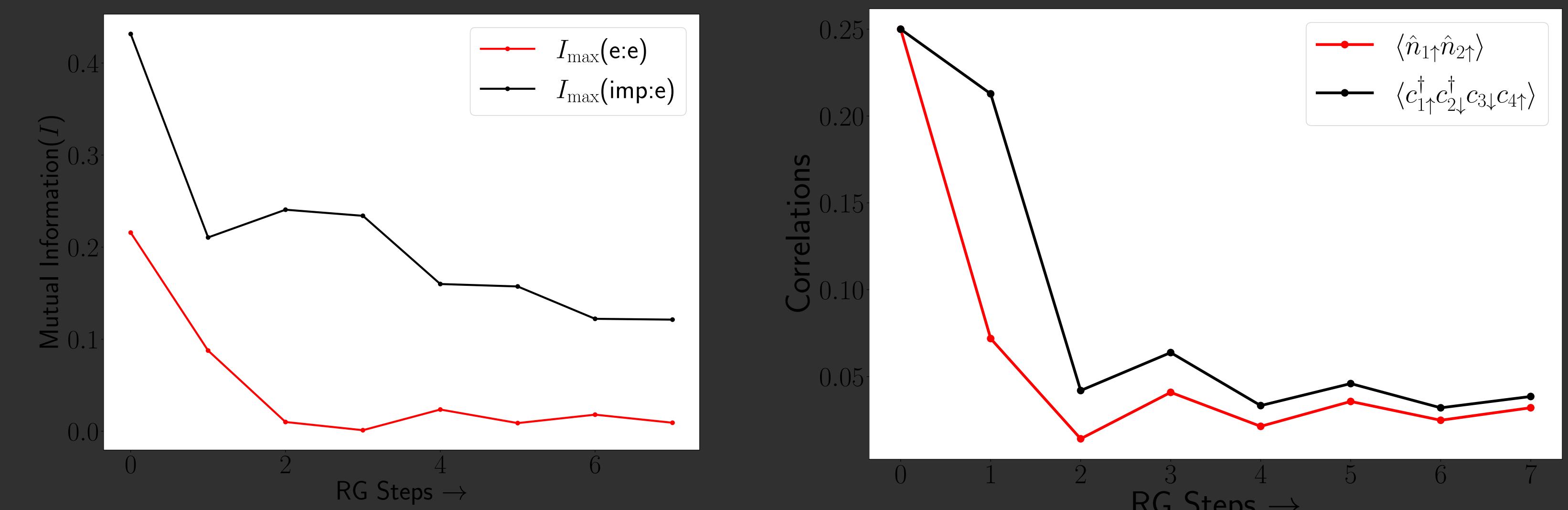


## Effective Hamiltonian for Kondo Cloud



- Treat kinetic energy as perturbation above singlet ground state
- Integrate out impurity dynamics** via Schrieffer-Wolff transformation
- Resultant effective Hamiltonian has diagonal Fermi liquid piece:  $\sum \epsilon_k \hat{n}_{k\sigma} + \sum f_{kk'} \hat{n}_{k\sigma} \hat{n}_{k'\sigma'}$
- More importantly, it has **off-diagonal non-Fermi** liquid terms:  $\sum_{k_1, k_2, k_3, k_4} \mathcal{F} c_{k_1\uparrow}^\dagger c_{k_2\downarrow}^\dagger c_{k_3\downarrow} c_{k_4\uparrow}$

## RG Evolution of Many-Particle Entanglement in the Kondo cloud



Mutual Information:  $I(1 : 2) = S(1) + S(2) - S(1, 2)$   
Information obtained about 1, on measuring 2

- Mut. Info. and correlations grow** towards strong-coupling IR fixed point
- Demonstrates the screening of impurity and formation of the singlet
- Consistent with the **presence of non-FL terms** in Kondo cloud Hamiltonian