Slave-rotor techniques in many-body electrons systems

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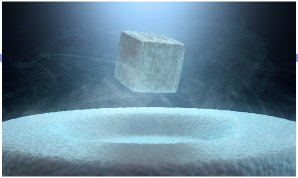
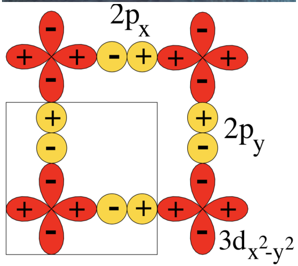
Strongly correlated many-body systems



Rich physics:

- Metal-insulator transitions
- Ferromagnetism
- Superconductivity (SC)
- etc ...

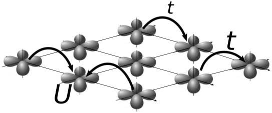


Model of high temperature SC

What do we mean by strong correlations?

$$\hat{H} = -t \sum_{<ij>,\sigma} \hat{c}^{\dagger}_{i\sigma} \hat{c}_{j\sigma} + \frac{U}{2} \sum_{i} (\underbrace{\hat{n}_{i\uparrow} + \hat{n}_{i\downarrow}}_{=\hat{N}_i} - 1)^2$$

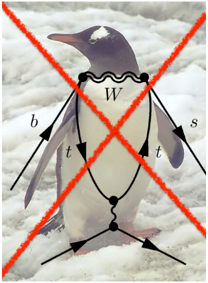
$$\text{if } U \neq 0 \Rightarrow \langle \hat{n}_{\uparrow} \hat{n}_{\downarrow} \rangle \neq \langle \hat{n}_{\uparrow} \rangle \langle \hat{n}_{\downarrow} \rangle$$



Hubbard model visualized

However: challenging to perform calculations

- Breakdown of mean-field theory
  $\langle \hat{n}_\uparrow \hat{n}_\downarrow \rangle \neq \langle \hat{n}_\uparrow \rangle \langle \hat{n}_\downarrow \rangle$
- Slow convergence of perturbative expansions
- Exact diagonalization: exponentially expensive
- Quantum Monte Carlo: Fermionic sign problem



Penguin diagrams won't work either.

Lightweight techniques needed - Slave Rotor Approach[1]

Basic idea: Use different energy scales of spin&charge fluctuations.
Decouple degrees of freedom by enlarging Hilbert space:

$$|\phi\rangle \rightarrow |\tilde{\phi}\rangle \otimes |n\rangle \ , \ \hat{c}^{\dagger}_{\sigma} \rightarrow \tilde{\hat{c}}^{\dagger}_{\sigma} e^{i\theta}$$

so that e.g. $\hat{c}^{\dagger}_{\uparrow} |0\rangle \rightarrow \tilde{\hat{c}}^{\dagger}_{\uparrow} |\tilde{0}\rangle \otimes e^{i\theta} |-1\rangle = |\tilde{\uparrow}\rangle \otimes |0\rangle$

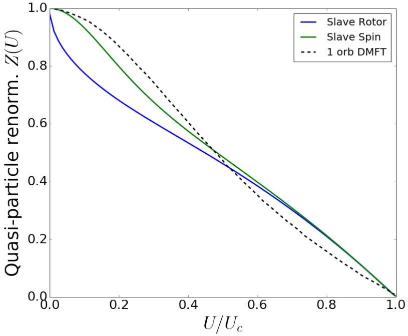
$\tilde{\hat{c}}^{\dagger}_{\sigma}$ represents spin - “pseudo-fermion”
$e^{i\theta}$ represents charge - “slave-rotor”

Slave rotor not slaves rowing

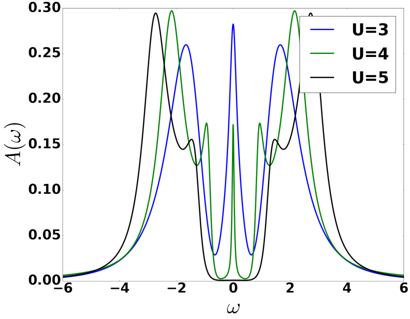
However: Spin& charge are not independent $\rightarrow$ ensure physicality by constricting charge state (the slave) to correspond (“obey”) to pseudo-spin state (the master).

[1] S. Florens and A. Georges, Phys. Rev. B 66 165111 (2002)

Benchmark: 1-orbital Hubbard model



Quasiparticle renormalization approaching MIT

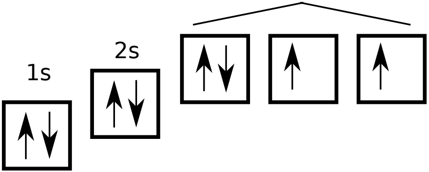


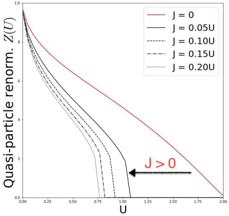
Spectral function for different interactions

- Reproduce metal-insulator transition (MIT)
- Qualitatively capture spectral properties

Application to more interesting multiorbital systems

•) Often, Hund's coupling J important (e.g. Iron based superconductors (SC))



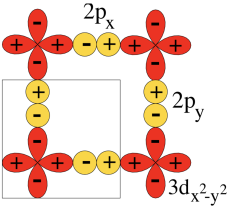


$Z(U)$ for different Hund's couplings J.

→ Slave rotor decoupling of total charge $\hat{N}$ and spin $\hat{\vec{S}}_i^2$.

•) Other application - interacting orbitals of different shells (e.g. "d" and "p" in Cuprate SC):

→ Apply same trick to decouple fluctuations of total electron number from individual d/p-orbital fluctuations: Able to capture high-energy physics!



Copper&Oxygen orbitals in Cuprates

Thanks for your attention!

d-p model: comparison of different methods.

Single particle Green's function for different values of $d-p$ interaction strength U_{dp}.