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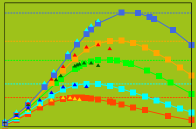

Nonequilibrium electron dynamics near Mott transition

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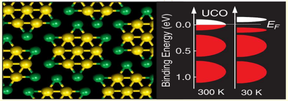
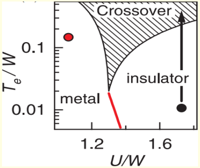
September 27, 2016

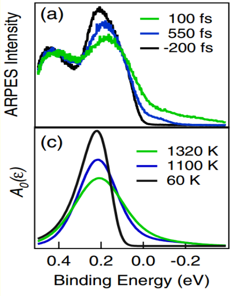
Photo induced Mott transition in $1T - TaS_2$



- Mott insulator at T=30 K

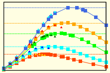
- Preparation of an excited state in crossover region
  $\hookrightarrow$ Induced **insulator-to-metal** transition





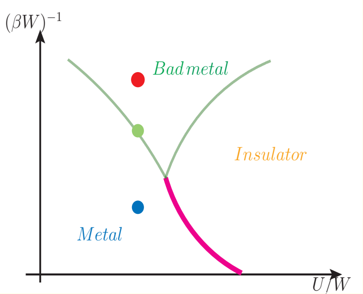
- Creation of **hot carriers**
- **Collapse** of the gap < 100 fs
- **Fast thermalization** < 100 fs
- Relaxation of the excited state > 500 fs
- **Electronic** relxation timescale
  < **electron-lattice** relxation timescale

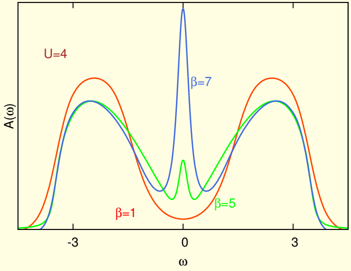
- L. Perfetti, *et al.*, Phys. Rev. Lett. **97**, 067402 (2006).

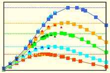


Mott transition in the half-filled Hubbard model

$$H = -J \sum_{\langle ij \rangle, \sigma} (c^\dagger_{i\sigma} c_{j\sigma} + h.c.) + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$







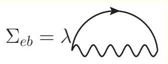
Relaxation to the Fermi liquid?

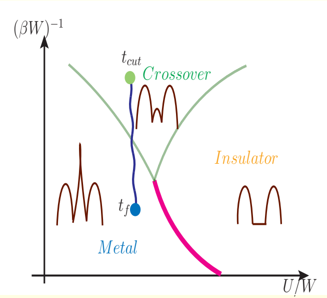
$$H = -J \sum_{\langle ij\rangle,\sigma} (c^{\dagger}_{i\sigma} c_{j\sigma} + h.c.) + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$

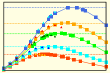
- Preparing the system in the **crossover region**:
  - **Excitation** (quench)
    Phys. Rev. Lett. **117**, 096403(2016).
  - +
  - **Fast thermalization**
    Phys. Rev. B **84**, 035122(2011).

- Studying the **relaxation dynamics** of the excited state

  +electrons coupled to the environment

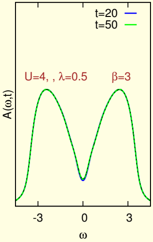


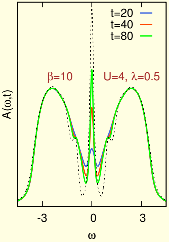




Slow-relaxing electronic characteristic timescale

Solved by DMFT:





✓ **Hubbard Bands** :: **Fast thermalization**

→ inverse One-body energy-scales $[\frac{1}{4}]$

✗ **Quasiparticle peak** :: **Slow retrieval** (for $\beta > 5$)

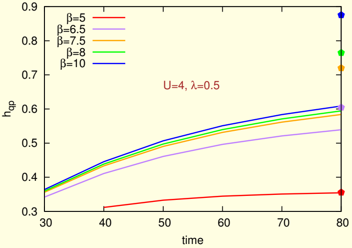
→ timescale

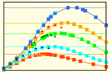
$>>$ inverse **One-body** energy-scales $[\frac{1}{4}]$

$>>$ inverse **quasiparticle** bandwidth $[\frac{1}{0.8}]$

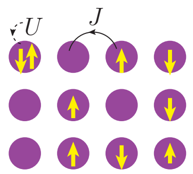
⌛ **Bottleneck of dynamics** (large β):

temperature-independent evolution of h_{qp}



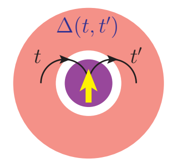


Dynamical mean field theory

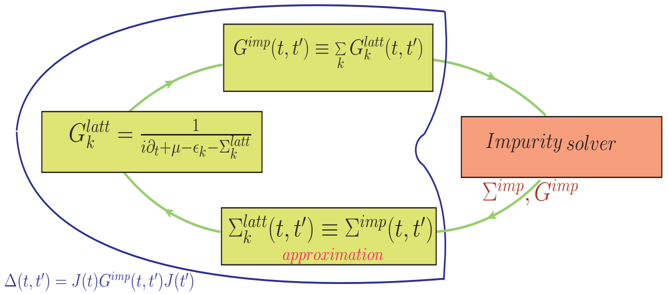


lattice problem → impurity-bath problem

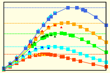
❓ Solving the impurity problem



DMFT self-consistency on Bethe lattice



Review on NEDMFT: Rev. Mod. Phys. 86, 779 (2014).



Impurity solver: U(1) slave-rotor

$$\underbrace{c_\sigma^\dagger}_{electron} = \underbrace{e^{i\theta}}_{X:rotor}\ \underbrace{f_\sigma^\dagger}_{spinon} \quad \Leftrightarrow \quad G_e = G_X . G_f$$

Atomic model:

$$\underbrace{\{|0\rangle, |\uparrow\rangle, |\downarrow\rangle, |\uparrow\downarrow\rangle\}}_{\text{electron}} \equiv \underbrace{\{|l=-1\rangle, |l=0\rangle, |l=0\rangle, |l=1\rangle\}}_{\textbf{Charge conservation: } l = n_f - 1} \otimes \underbrace{\{|0\rangle, |\uparrow\rangle, |\downarrow\rangle, |\uparrow\downarrow\rangle\}}_{\text{Spinon}}$$

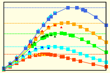
On the impurity site:

- Solving Dyson equations for
  - G_X with $\Sigma_X = \Delta . G_f$
  - G_f with $\Sigma_f = \Delta . G_X$
- Imposing constraints
  - Charge conservation
  - $|X|^2 = 1$

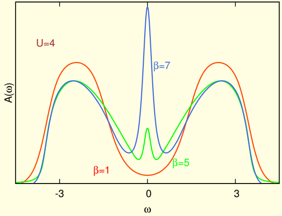
Why slave-rotor impurity solver:

- ✓ Accessibility of long time-evolution *(Similar to NCA)*
- ✓ Accurate phase diagram near Mott transition *(not the case in NCA)*

- **Equilibrium study:** *S. Florens and A. Georges, Phys. Rev. B. **66** 165111 (2002).*
- **Nonequilibrium study:** *Sh. S and M. Eckstein, Phys. Rev. Lett. **117**, 096403 (2016).*

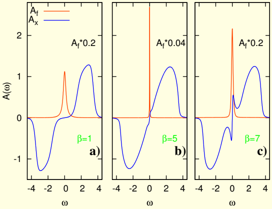


Equilibrium Physics: Slave-rotor Language

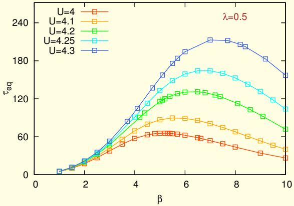


By decreasing the temperature:

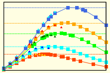
- Electron: height of the quasiparticle peak enhanced.
- Rotor: density at zero frequency formed.
- Spinon: nonmonotonous behavior as a function of β



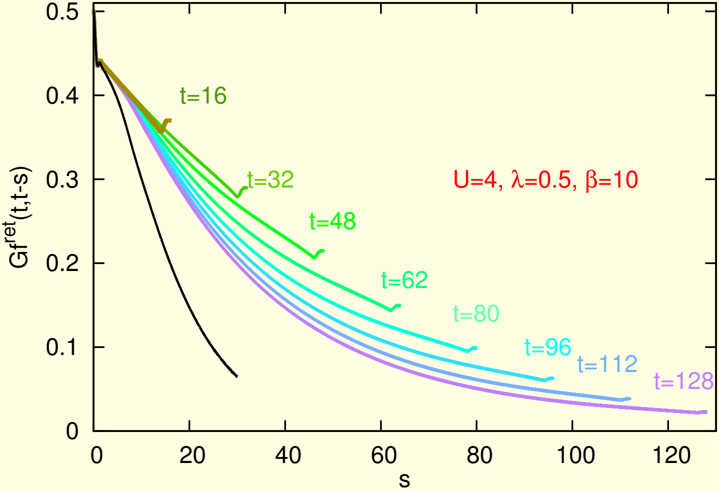
Maximum in the spinon inverse bandwidth



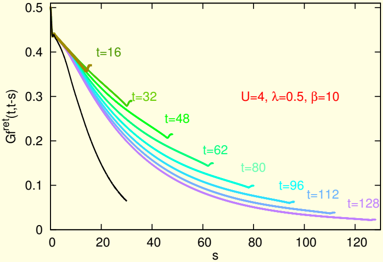
Footprint of this nonmonotonous response out of equilibrium ?



Spinon's response: presence of a "⋂" turn!



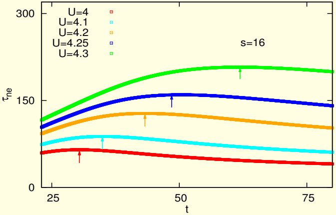
Spinon's response: presence of a "$\bigcap$" turn!



Time-evolution of $G_f^{\rm ret}$:

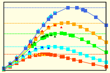
1. Evolving against equilibrium value initially
2. "$\bigcap$" turn: Reaching $\tau_{\rm max}$ at $t_{\rm max}$
3. Start evolving towards equilibrium value

$$\tau_{\rm ne}^{-1} = -\partial_s G_f^{\rm ret} / G_f^{\rm ret}$$

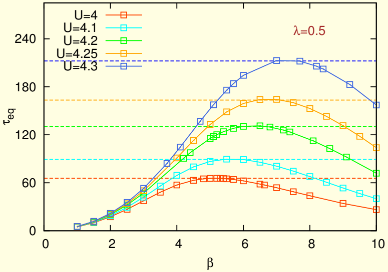


Nontrivial timescale:

- "$\bigcap$" turn: **Bottleneck of dynamics** at $t_{\rm max}$
- Quasiparticle **retrieval** only **after** $t = t_{\rm max}$



Spinon “$\bigcap$” turn: equilibrium and nonequilibrium

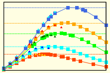


Spinon nontrivial response:

Agreement between $\tau_{eq}^{\max}$ and $\tau_{neq}^{\max}$

Spinon lifetime $(t_{\max}) \propto \tau_{\mathrm{eq}}^{\max}$

Spinon lifetime reflected in **electronic bottleneck** of dynamics

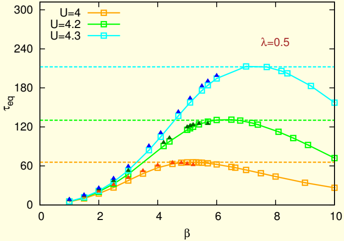


Reflection of spinon lifetime in other observables?

Assume : $\Im G_f(\omega) \approx \delta(\omega)/\pi$

$$\tau_{\rm ne}^{-1} = -\Sigma_f''(\omega=0) \approx -\pi J^2 \int \mathrm{d}\omega \frac{A(\omega)A(\omega)}{\cosh^2(\beta\omega/2)}$$

✓ Emergence of a **correlation** timescale



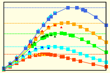
Nontrivial spinon response in multi-orbital physics:

"Frozen" spin-spin correlation function

Ph. Werner, et al., Phys. Rev. Lett. ***101****,166405 (2008).*

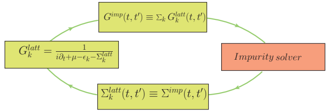
Non-Fermi-liquid behavior of optical conductivity in perovskite ruthenates ($\propto 1/\sqrt{\omega}$)

Y. S.Lee, et al., Phys. Rev. B ***66****, 041104 (2002).*

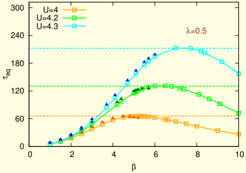


Conclusion and Summary

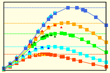
- Study the Hubbard model near Mott transition
- Investigate the system under a quick ramp
- slave-rotor impurity solver + DMFT



- Slow retrieval of the quasiparticle density
- Presence of a "⋂" turn in the spinon retarded Green's function
- Presence of a nonmonotonous spinon behavior in equilibri1um
- Agreement between equilibrium and nonequilibrium spinon response



Emergence of a **correlation** timescale



Thanks for your attention.