FRG for the Bilayer Square Lattice Hubbard Model

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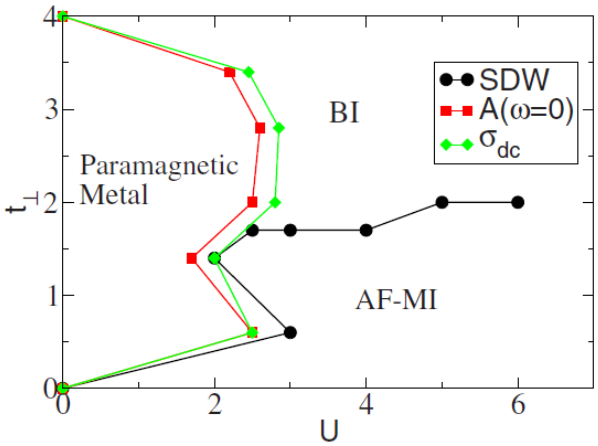
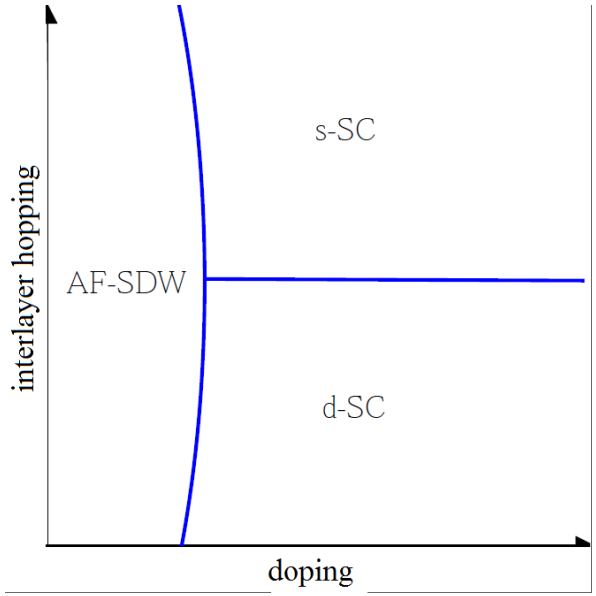
Why look at two dimensonal fermionic Hubbard system?

- single-layer: high-T_c superconductivity
- bilayer: multiple Fermi surfaces: electron and hole pockets
- Mott insulator $\leftrightarrow$ band insulator

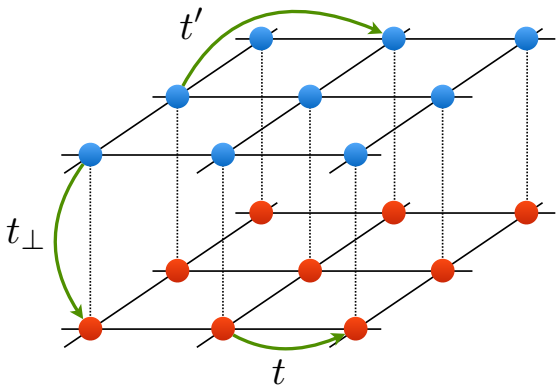


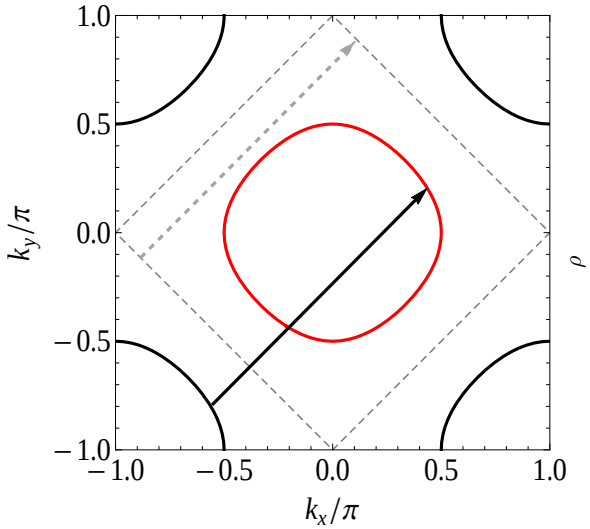
K. Bouadim, G. G. Batrouni, F. Hébert, and R. T. Scalettar, Phys. Rev. B **77**, 144527 (2008)

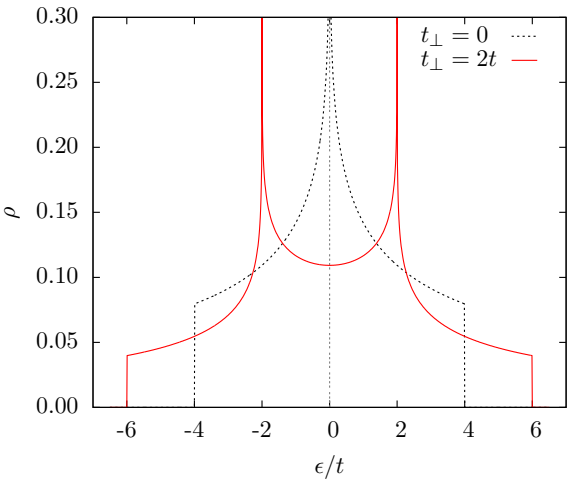


Zhai, Wang, & Lee, PRB **80**, 064517 (2009).

Bilayer tight binding model



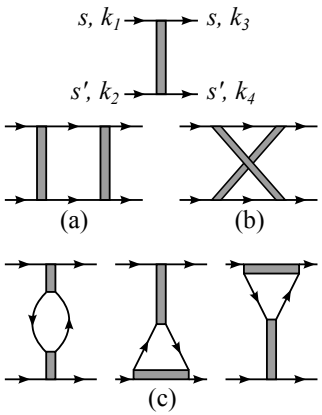




$$
\begin{aligned}
H_0 &= -t \sum_{\langle ij \rangle \sigma \lambda} (c^\dagger_{i\lambda\sigma} c_{j\lambda\sigma} + \text{h.c.}) - t' \sum_{\langle\langle ij \rangle\rangle \sigma \lambda} (c^\dagger_{i\lambda\sigma} c_{j\lambda\sigma} + \text{h.c.}) \\
&\quad - t_\perp \sum_{i\sigma} \left(c^\dagger_{i1\sigma} c_{i2\sigma} + \text{h.c.} \right) - \mu \sum_{i\sigma\lambda} n_{i\lambda\sigma} \\
\epsilon^{\pm}_{\text{BL}}(\vec{k}) &= \pm t_\perp + \epsilon_{\text{SL}}(\vec{k})
\end{aligned}
$$

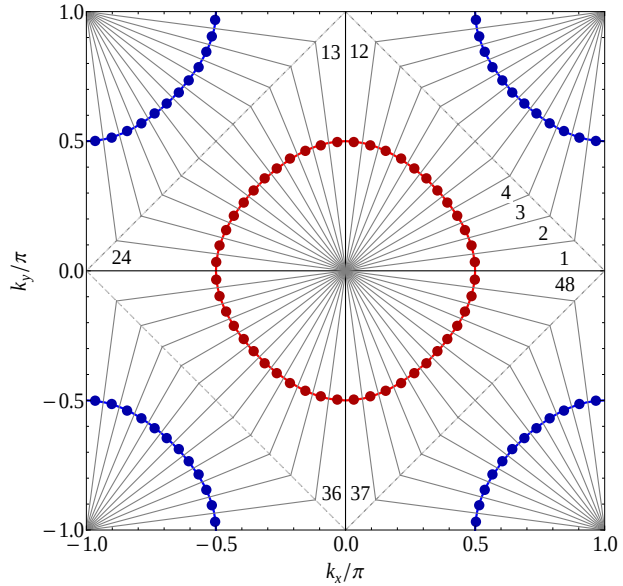
Interactions, the N-patch RG & patching scheme

$$H_{\text{int}} = U \sum_{i\lambda} n_{i\lambda\uparrow} n_{i\lambda\downarrow} + V_{\perp} \sum_{i\sigma\sigma'} n_{i1\sigma} n_{i2\sigma'}$$



- Two-particle interaction vertex: $V_\Lambda(k_1, k_2, k_3)$
- Momentum arguments include wavevector $\vec{k}_i$ and layer λ_i indices

cf. e.g. Honerkamp, Salmhofer (2001)

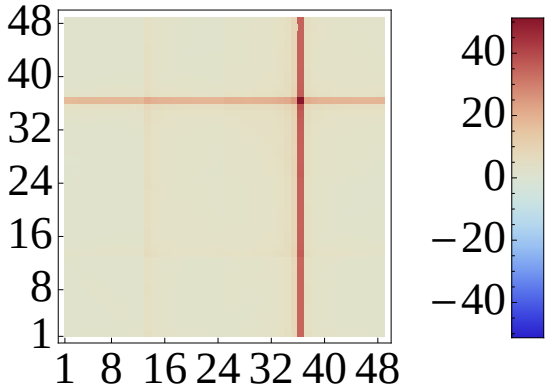


- Wavevector dependence is discretized by patching of 1st BZ
- Interaction constant within one patch
- Representative momenta lie at the Fermilines

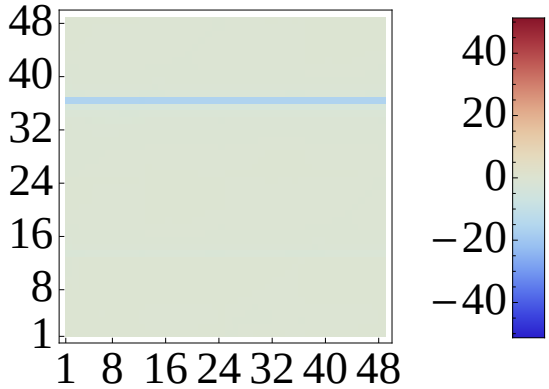
Emerging instabilities: AF-SDW

V_{Λ_c} showing antiferromagnetic spin-density wave for $t_\perp = 2t$ and $U = 3t$. $\vec{k}_3$ fixed at patch #1.

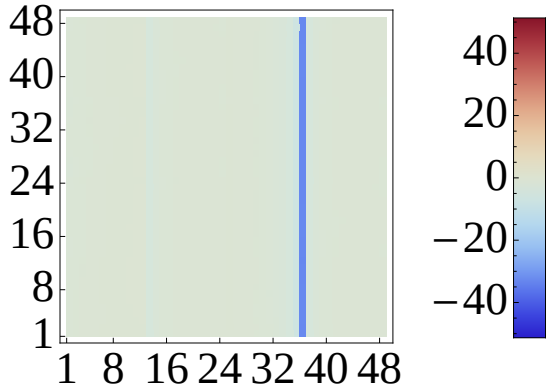
same layer



interlayer



interlayer

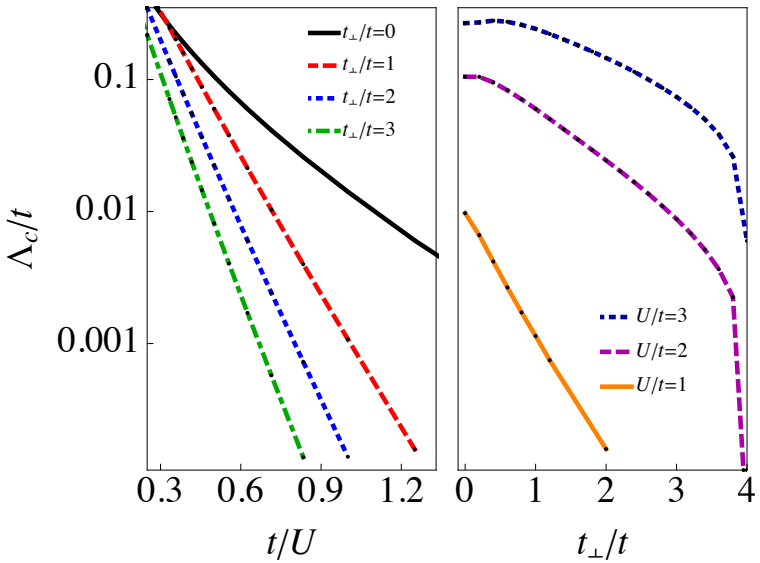


$$H_{\text{eff}} = -J \sum_{\lambda,i,j} e^{i\vec{Q}\cdot(\vec{R}_i - \vec{R}_j)} (\vec{S}_{i\lambda} \cdot \vec{S}_{j\lambda} - \vec{S}_{i\lambda} \cdot \vec{S}_{j\lambda'})$$

$$\vec{S}_{i\lambda} = \sum_{s,s'} c^\dagger_{i,\lambda,s} \vec{\sigma}_{s,s'} c_{i,\lambda,s'}$$

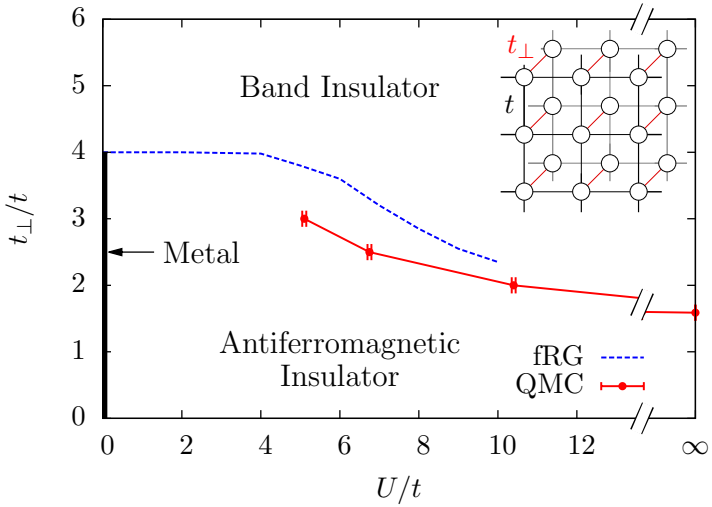
Results at half filling

Critical scale as function of U



- bilayer critical scale shows $\exp(-t/U)$ behavior
- singlelayer $\Lambda_C \sim \exp(-\sqrt{t/U})$ as expected from MFT & QMC

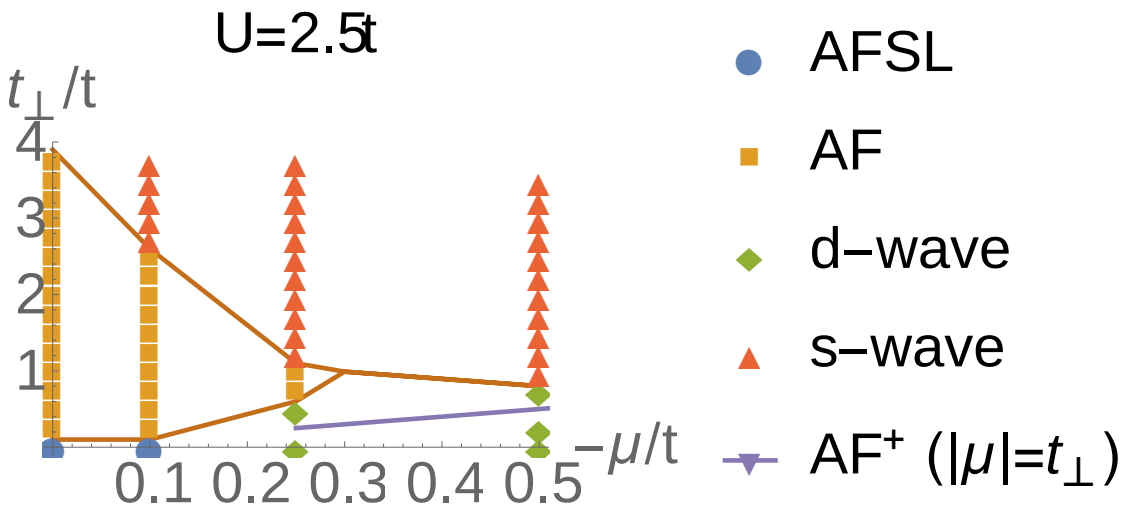
Mott insulator to band insulator transition: combined fRG-DQMC-result



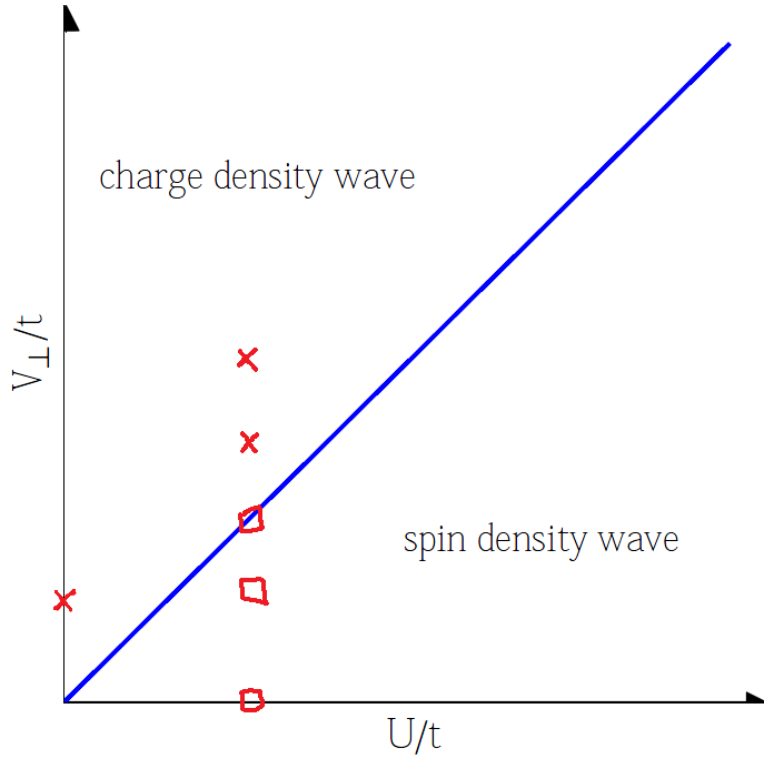
- no paramagnetic phase away from $U = 0$ (at T=0)

Tentative phase diagrams

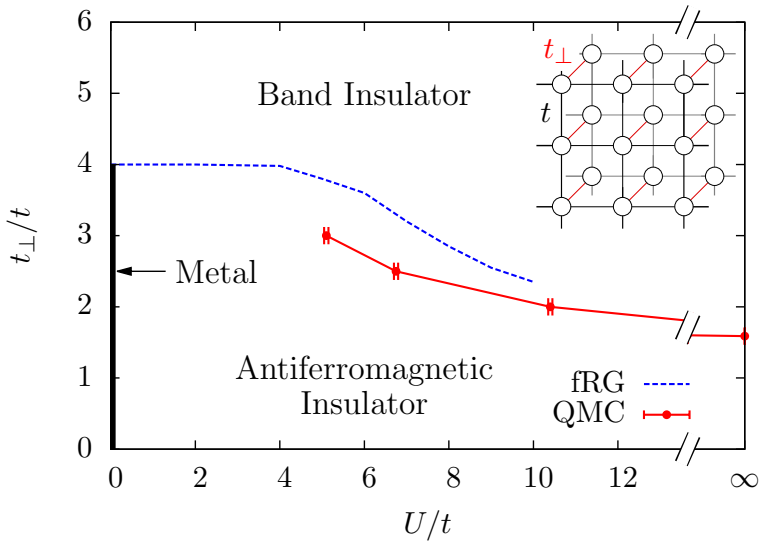
interlayer hopping vs. doping



interlayer- vs. onsite-interaction



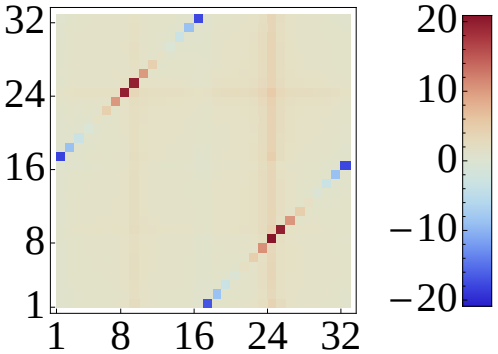
Conclusions



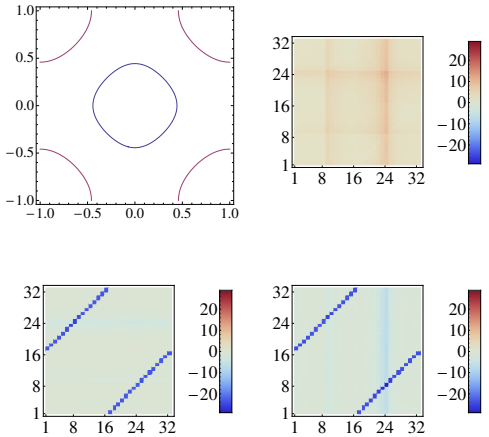
- N-Patch RG useful, unbiased
- rich phase diagram:
  - Mott insulator $\rightarrow$ band insulator
  - cuprate phenomenology $\rightarrow$ iron pnictide phenomenology
- fRG & QMC data fit reasonably well together
- at $T = 0$: no paramagnetic phase away from $U = 0$

Emerging instabilities: superconductors & CDW

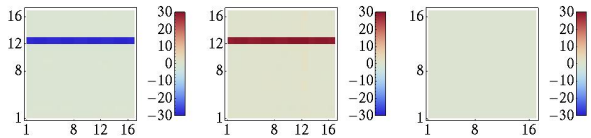
d-wave instability



s-wave instability



charge-density wave



$$H_{\text{eff}}^{dSC} = V_{dSC} \sum_{\vec{k},\vec{k}'} d(\vec{k}) d(\vec{k}') c^{\dagger}_{\vec{k}',\uparrow} c^{\dagger}_{-\vec{k}',\downarrow} c_{-\vec{k},\downarrow} c_{\vec{k},\uparrow}$$