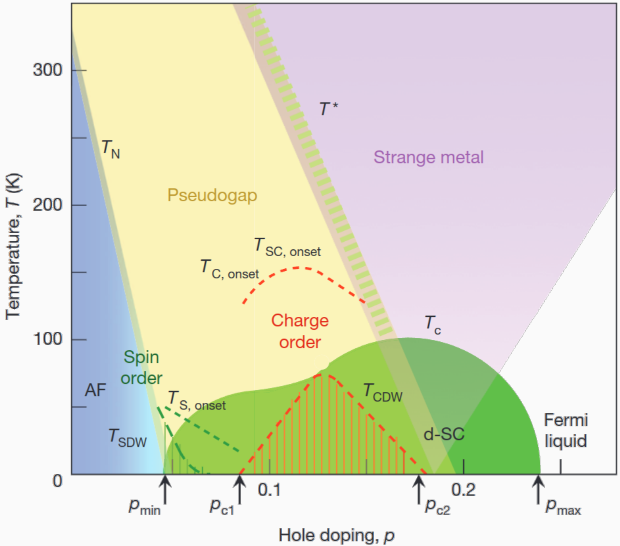
Fractionalized Fermi Liquids: Mean-Field Theories, Instabilities, and Variational Wavefunctions

Henry Shackleton

June 18, 2024

Cuprate phase diagram as an inspiration for correlated physics



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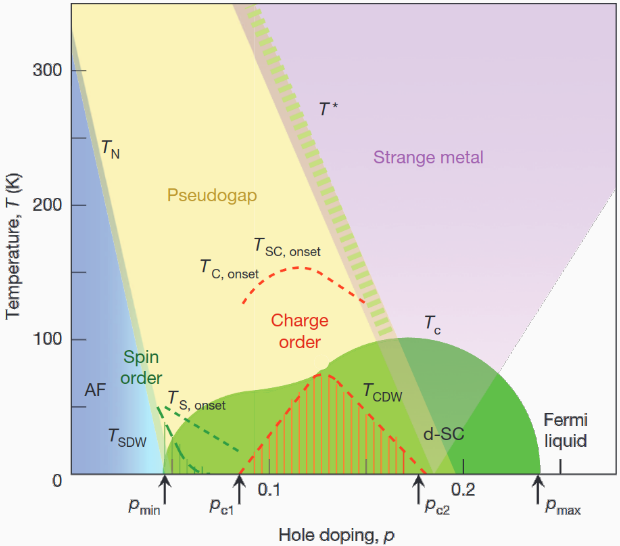

- "Strange metal" phase - T linear resistivity from a theory of a quantum critical metal

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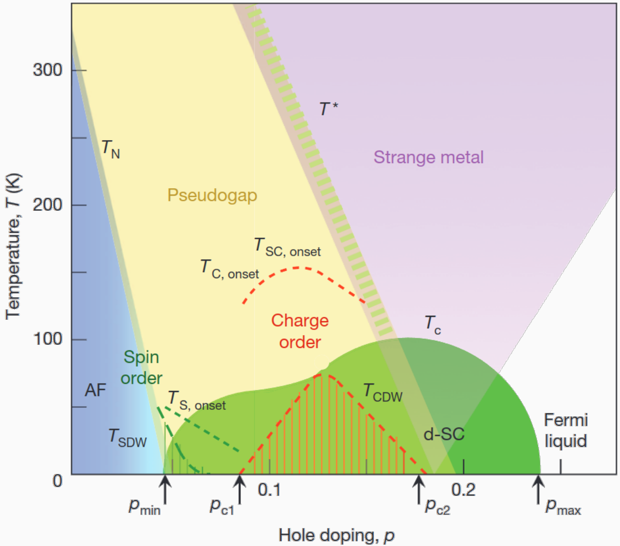


- “Strange metal” phase - T linear resistivity from a theory of a quantum critical metal
- Pseudogap metal and proximate ordered phases from a theory of fractionalized Fermi liquids

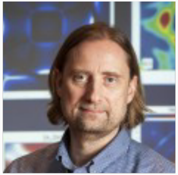
(Partial) acknowledgements

Subir Sachdev

Yahui Zhang

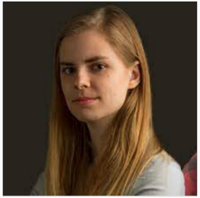
Maria Tikhanovskaya

Jonas von Milczewski



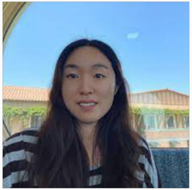
Dirk Morr

Darshan Joshi



Maine Christos

Alexander Nikolaenko



Zhu-Xi Luo

Eric Mascot

Parton construction for fractionalized insulators: quantum spin liquids

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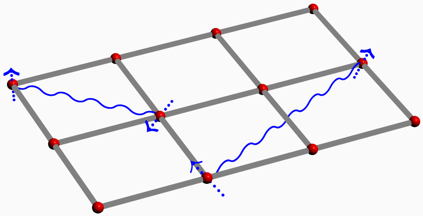

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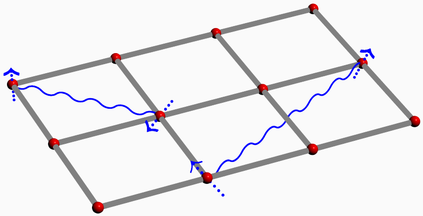

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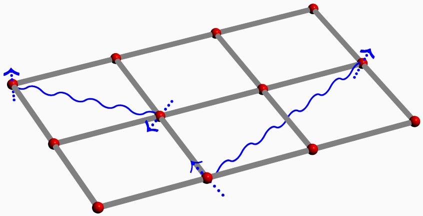

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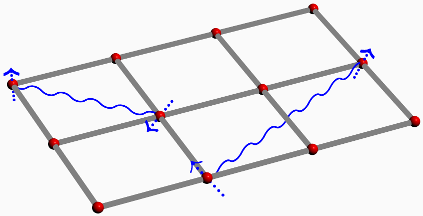
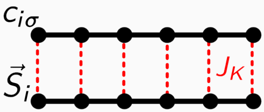


- Bosonic/fermionic theories, classification with projective symmetry groups
- Instabilities to ordered phases (spinon condensation, confining instabilities)
- Numerical evaluation of correlated wavefunctions, $\mathcal{P}_G \left|\psi_0\right\rangle$ - important for quantitative predictions

Fractionalized Fermi liquids in Kondo lattices[1]

$$H = \sum_p \epsilon_p c^\dagger_{p\sigma} c_{p\sigma} + \sum_{ij} J_{ij} \vec{S}_i \cdot \vec{S}_j + J_K \sum_i \vec{S}_i \cdot \vec{s}_i$$



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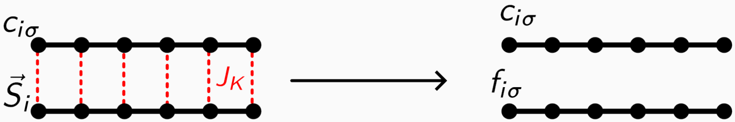

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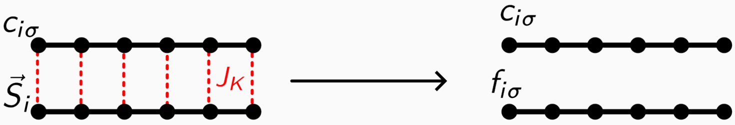

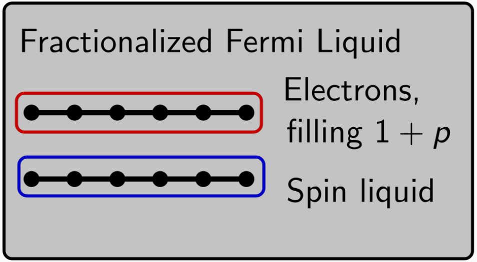

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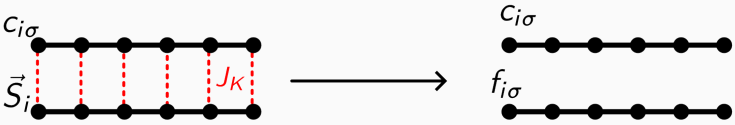

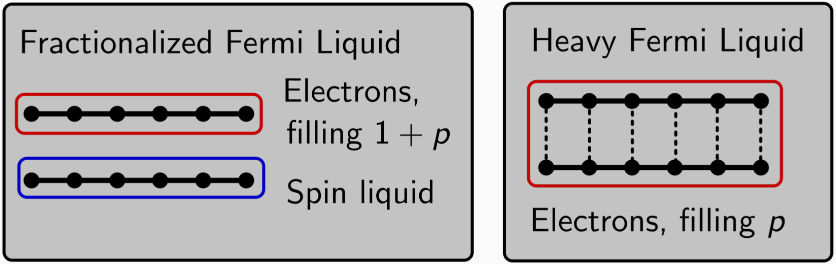

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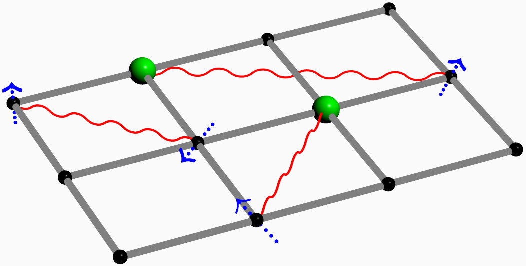

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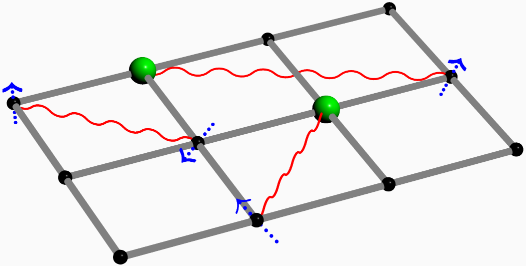

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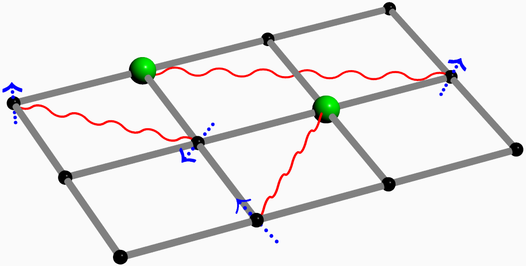

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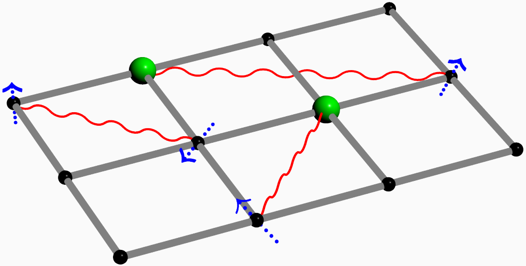

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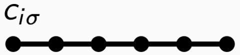
Mean-field theory from paramagnon fractionalization[3]



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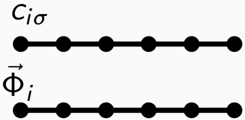

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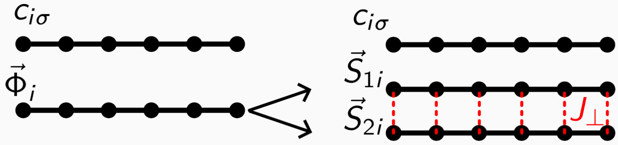

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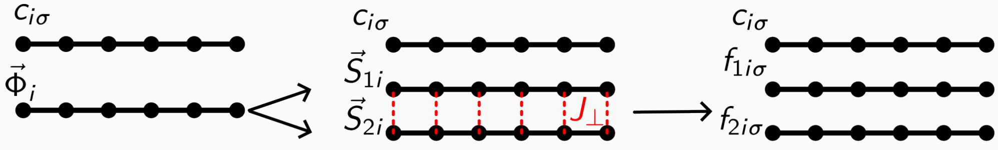

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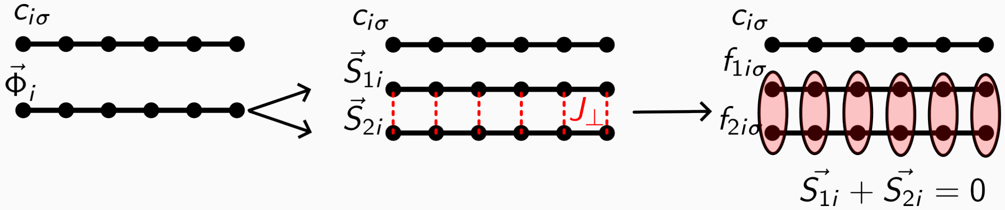

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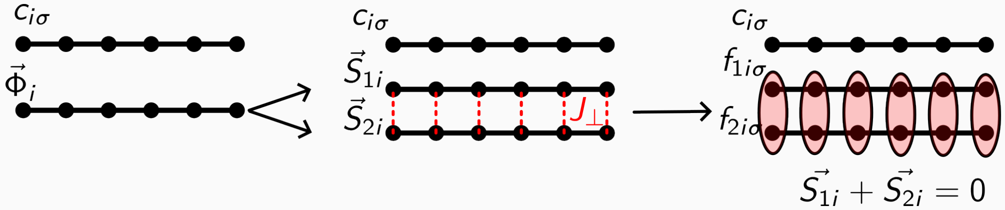

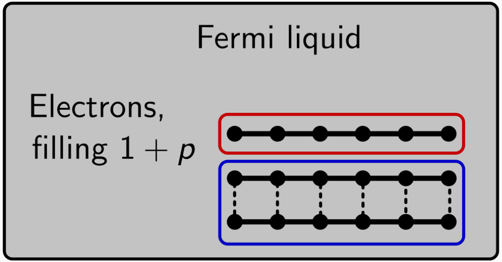

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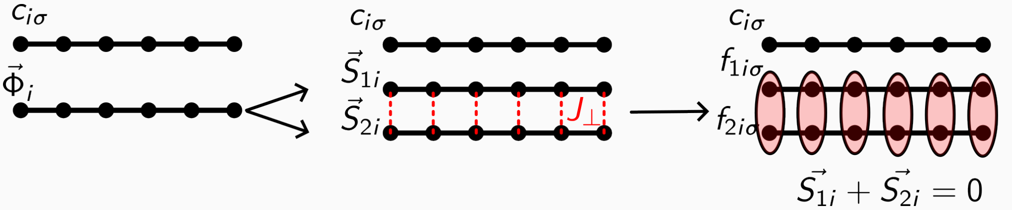

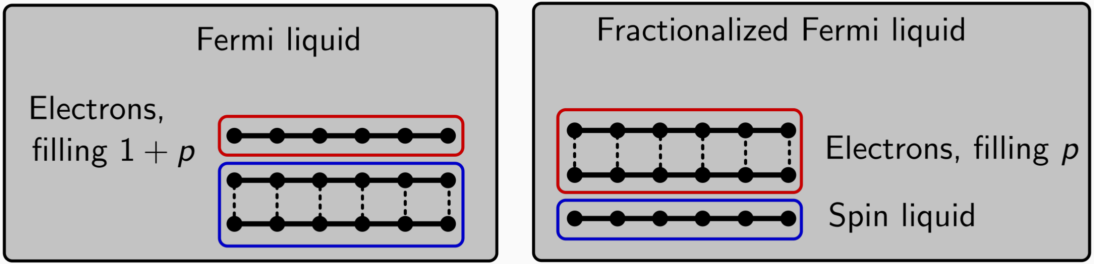

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Mean-field analysis on square lattice yields pseudogap-like features

Mean-field picture: electron-like quasiparticles + decoupled spin liquid [4]

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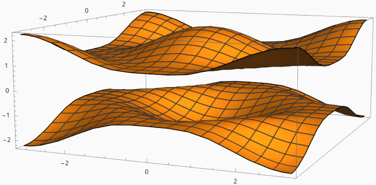
Half filling: Mott insulator with charge gap



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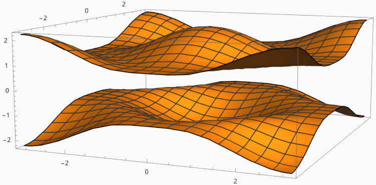
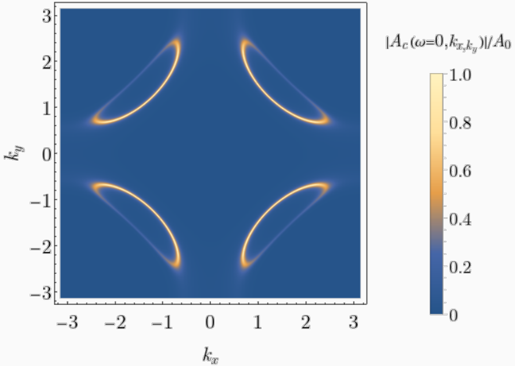


Hole doping similar to YRZ ansatz for Green's function[5]



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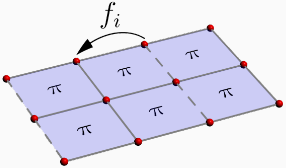
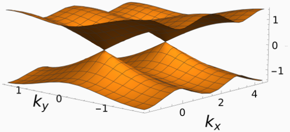
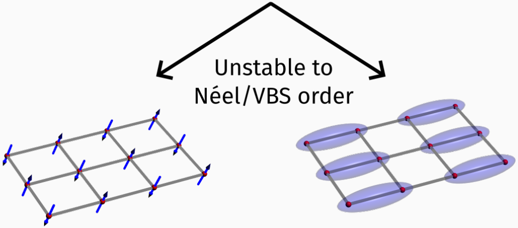
- Fermionic theory of a π-flux spin liquid leads to Néel/VBS order [6]





$N_f = 2$ QCD$_3$, emergent SO(5) symmetry



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"Pseudogap metal"
π-flux theory of spinons,
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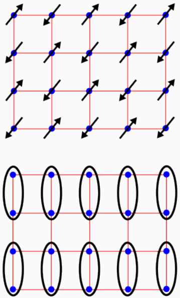

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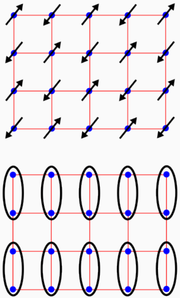
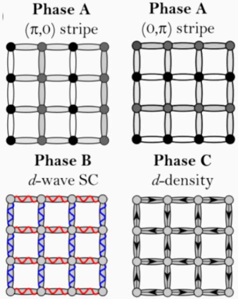


M. Christos, Z.-X. Luo, **H. Shackleton**, Y.-H. Zhang, M. S. Scheurer, and S. Sachdev, PNAS 120, e2302701120 (2023)



Polaronic correlations central for capturing doped Mott insulators

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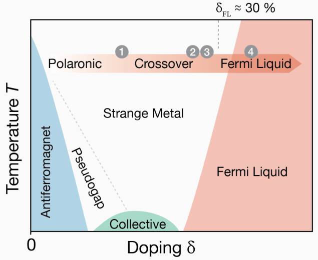

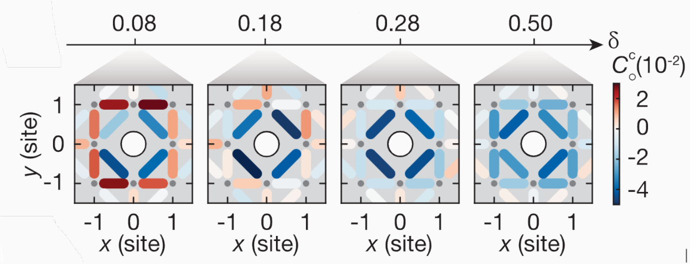

Koepsell et al., Science, 2021

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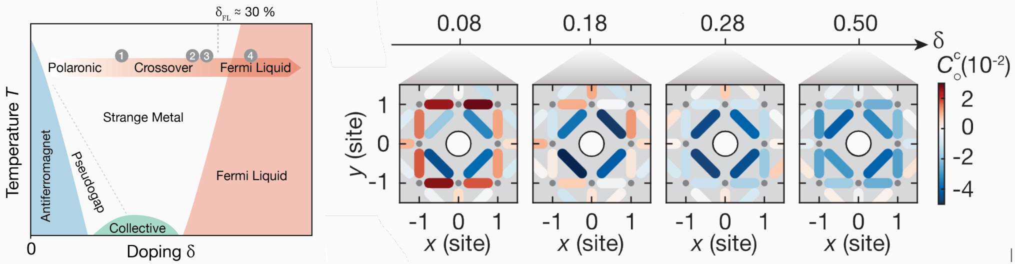
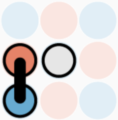


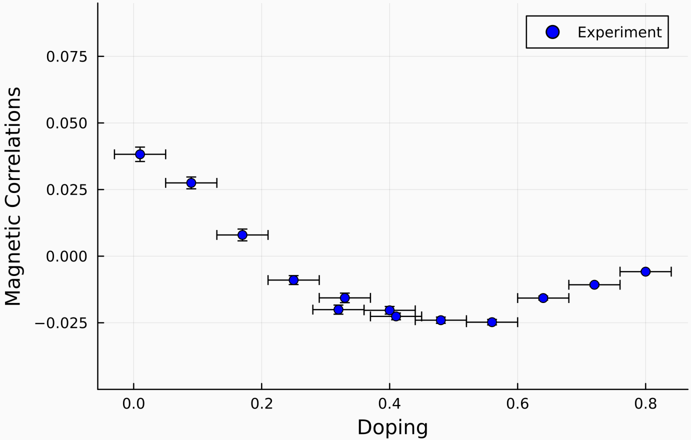
Do these wavefunctions support polaronic correlations?

Koepsell et al., Science, 2021

Nearest neighbor magnetic correlations ($U/t = 7.4$)

Polaronic correlations probed by multipoint correlator $\langle h_i S^z_j S^z_k \rangle$





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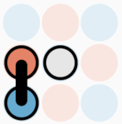

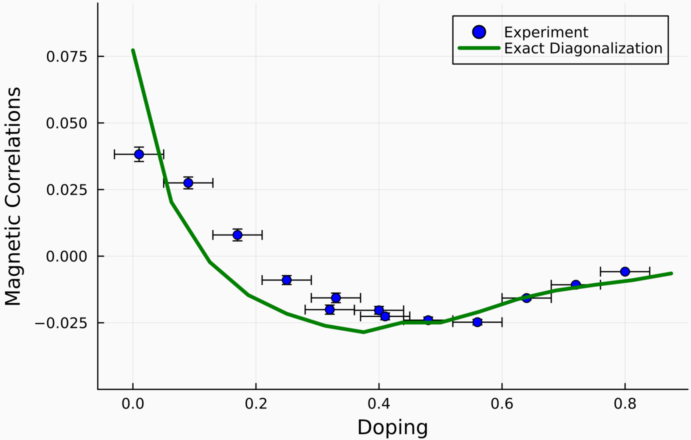

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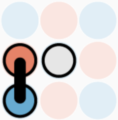

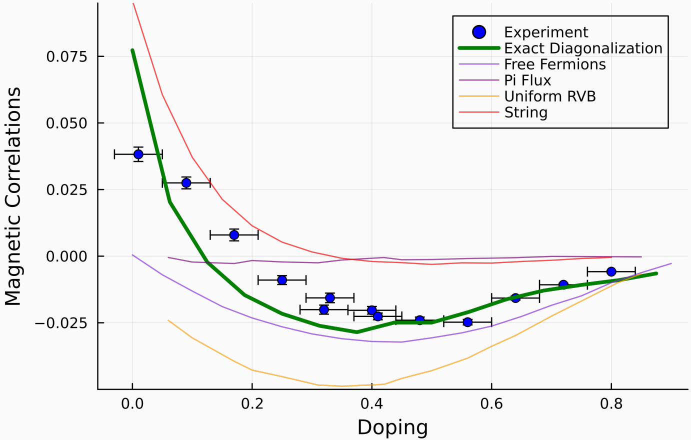

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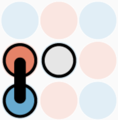
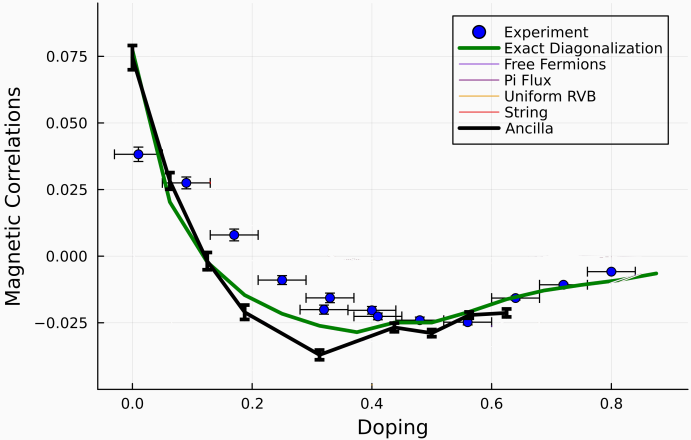
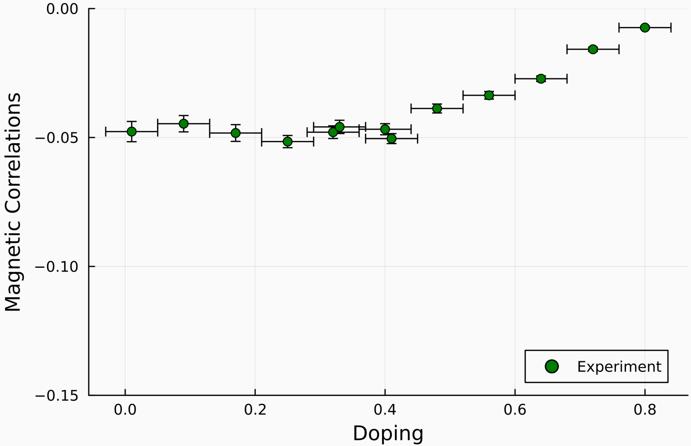




Next nearest neighbor magnetic correlations ($U/t = 7.4$)



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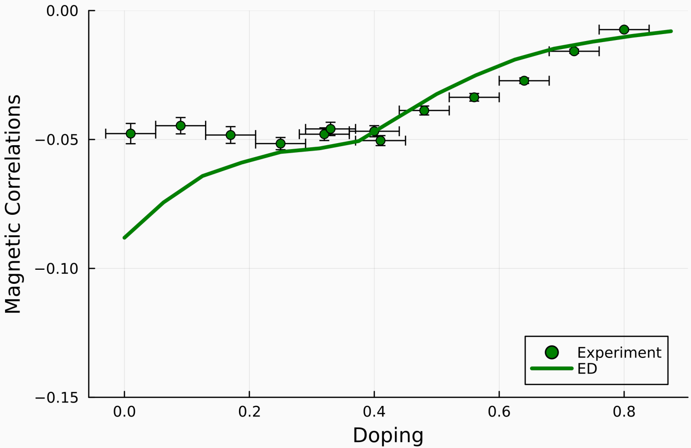

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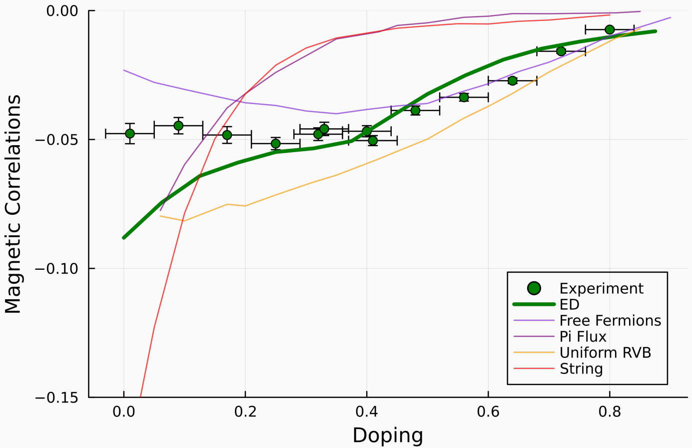

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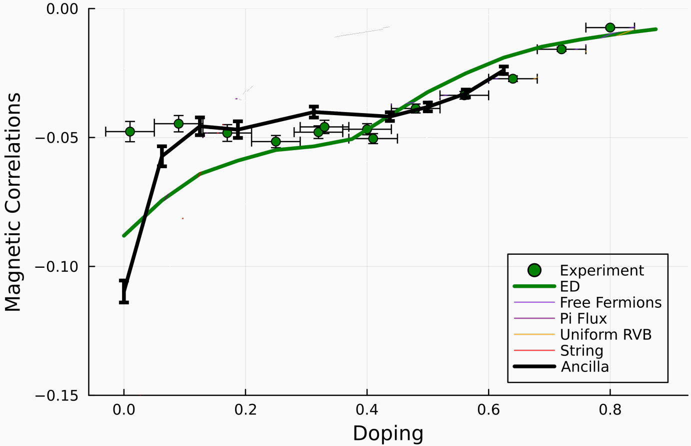
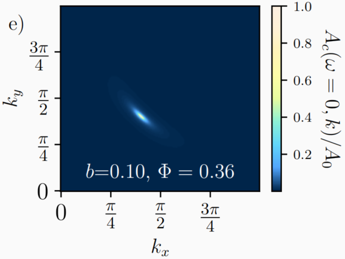


Related work and future directions

Nodal anisotropic quasiparticles in superconducting state [7]



[7] Christos and Sachdev, *npj Quantum Materials*, 2024
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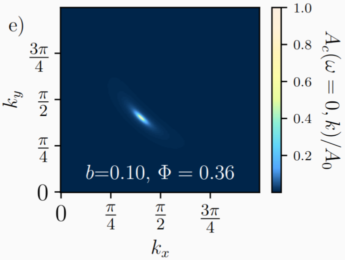
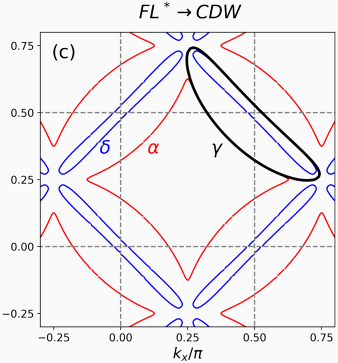


FS reconstruction in CDW[8]



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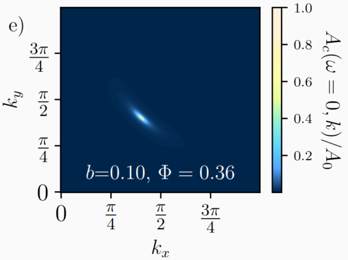

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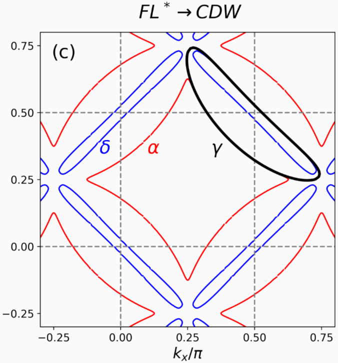
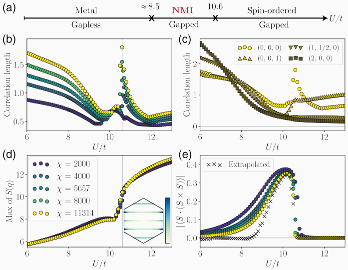


Variational wavefunctions for spin liquids emerging at metal/insulator transitions[9]



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Half-filling: wavefunctions behave favorably energetically

- Actual ground state: AF insulator for $U/t > 0$
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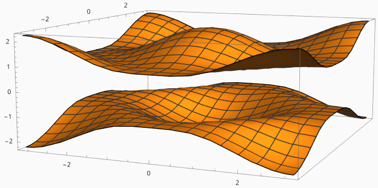
- Simple ansatz gives mean-field charge gap 2Φ, which we fix to be U



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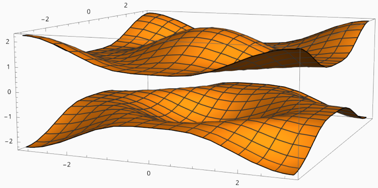

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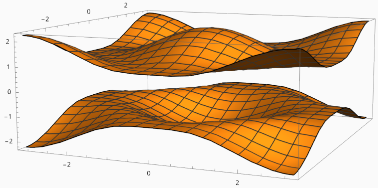

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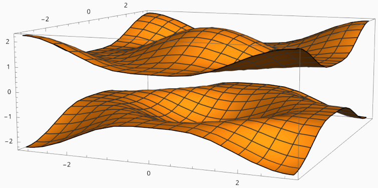

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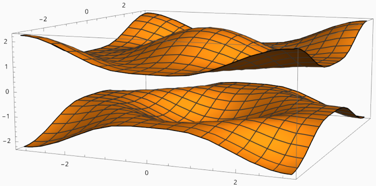

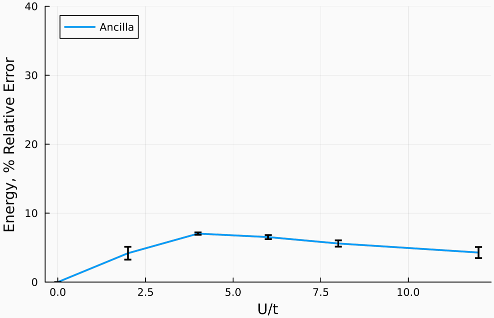

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