00BeccaKITP 00Sandvik18 00Becca20 00Imada20 00Gu20 00Wang17 00Song2

Deconfined quantum criticality and a gapless $\mathbb{Z}_2$ spin liquid in the square lattice antiferromagnet

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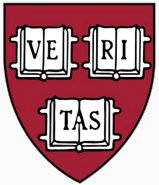


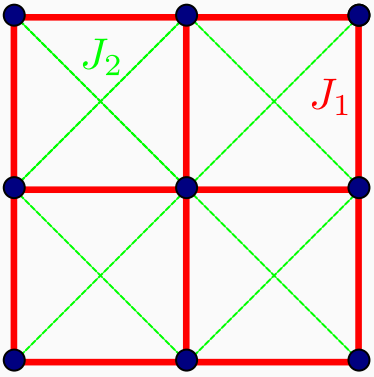
Alex Thomson

Subir Sachdev

Phys. Rev. B 104, 045110 (2021)
arXiv:2203.01962 (2022)

Numerical evidence for Néel/SL/VBS transition in J_1/J_2 model

$$H = J_1 \sum_{\langle i,j \rangle} \mathbf{S}_i \cdot \mathbf{S}_j + J_2 \sum_{\langle\langle i,j \rangle\rangle} \mathbf{S}_i \cdot \mathbf{S}_j$$



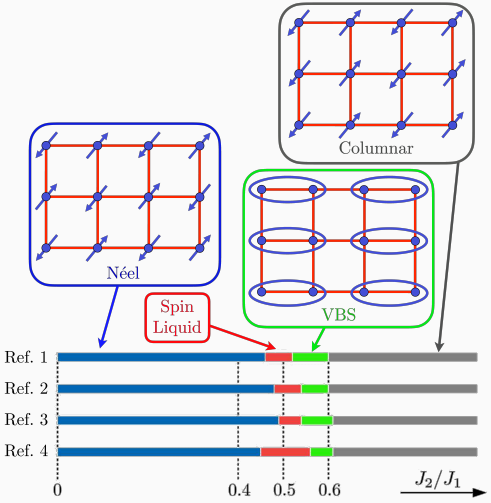
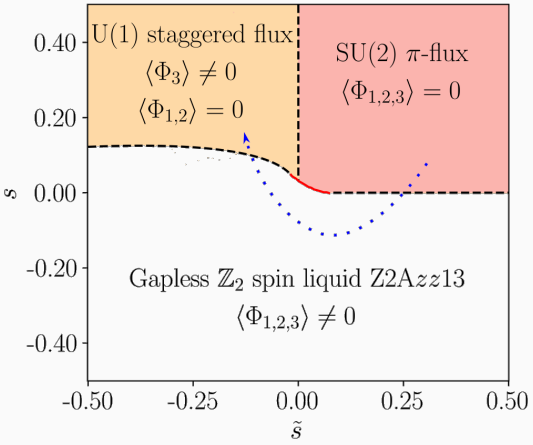


Figure adapted from Becca 2020

L. Wang and Sandvik 2018; Ferrari and Becca 2020; Nomura and Imada 2020; Liu et al. 2020.

Deconfined critical theory for Néel/$\mathbb{Z}_2$ and $\mathbb{Z}_2$/VBS transitions

- Transition described by Higgs condensation breaking $\mathrm{SU}(2) \to \mathbb{Z}_2$ or $\mathrm{U}(1) \to \mathbb{Z}_2$
- Both $\mathrm{SU}(2)$ (C. Wang et al. 2017) and $\mathrm{U}(1)$ (Song et al. 2019) spin liquids unstable to Néel or VBS order on square lattice



Large N_f critical theory of $\mathrm{U}(1)$ Higgs transition

$$\mathcal{L} = \mathcal{L}_{N=4\ \mathrm{QED}_3} + \mathcal{L}_{\mathrm{Yukawa}} + \overbrace{\Phi\overline{\psi}\mu^y \left(\gamma^x D_x - \gamma^y D_y\right)\psi}^{\text{Velocity anisotropy}}$$

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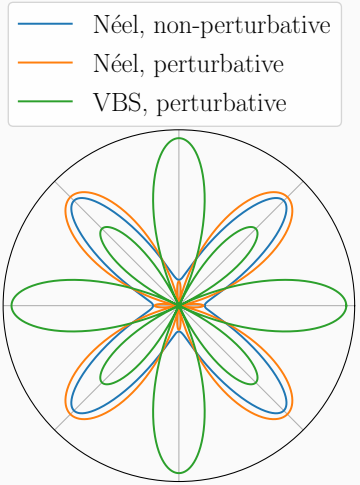
Fixed point to $\mathcal{O}\left(N_f^{-1}\right)$:

- $\Phi_c \approx 0.46$
- $z \approx 1 + 0.23 N_f^{-1}$
- $\eta_{\text{Néel}} = 0.065 N_f^{-1}$
- $\eta_{\text{VBS}} = -0.01 N_f^{-1}$



Large N_f critical theory of $\mathrm{SU}(2)$ Higgs transition

$$\mathcal{L} = \mathcal{L}_{N=2\ \mathsf{QCD}_3} + s\left(\Phi_1^a \Phi_1^a + \Phi_2^a \Phi_2^a\right) + \Phi_1^a\, \overline{\psi}\gamma^x \mu^z \sigma^a \psi + \Phi_2^a\, \overline{\psi}\gamma^y \mu^x \sigma^a \psi$$

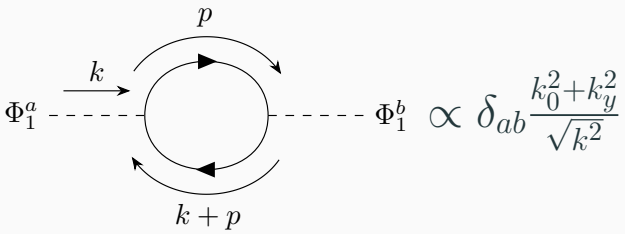
Large N_f critical theory of $\mathrm{SU}(2)$ Higgs transition

$$\mathcal{L} = \mathcal{L}_{N=2\ \mathrm{QCD}_3} + s\left(\Phi_1^a \Phi_1^a + \Phi_2^a \Phi_2^a\right) + \Phi_1^a\, \overline{\psi}\gamma^x \mu^z \sigma^a \psi + \Phi_2^a\, \overline{\psi}\gamma^y \mu^x \sigma^a \psi$$

$\overline{\psi}\not{\partial}\psi + \Phi_1^a\, \overline{\psi}\gamma^x \mu^z \sigma^a \psi$ invariant under subsystem "symmetry":

$$\psi \to e^{i f_a(x) \mu^z \sigma^a} \psi$$

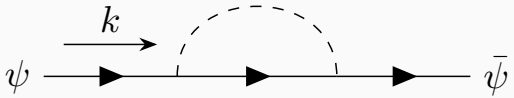
$$\Phi_1^a \to U_{ab}^{-1} \Phi_1^b + \partial_x f_a(x)$$



$$\propto \delta_{ab} \frac{k_0^2 + k_y^2}{\sqrt{k^2}}$$

Subsystem symmetries control universal behavior of critical theory

Must keep subleading "dangerously irrelevant" terms, $K\left(\Phi_1^a \partial^2 \Phi_1^a + \Phi_2^a \partial^2 \Phi_2^a\right)$, in order to regulate our theory.



$$\Sigma(k) \approx -\frac{3}{\pi^2 N_f} \not{k} \ln^2(K|k|)$$

$$G_{\text{Néel}}(r) \sim \frac{1}{r^\alpha} \exp\left[-\frac{12}{\pi^2 N_f} \ln^2(r)\right]$$

$$G_{\text{VBS}}(r) \sim \frac{1}{r^\beta} \exp\left[-\frac{6}{\pi^2 N_f} \ln^2(r)\right]$$

Conclusions and future directions

- Deconfined critical theories between spin liquids and Néel/VBS order captured by Higgs transitions to proximate unstable SLs
- Critical theories exhibit Lorentz symmetry breaking, violation of standard scale invariance, Néel/VBS asymmetry

Open questions:

- Numerical signatures?
- Other models with emergent subsystem symmetries at criticality?