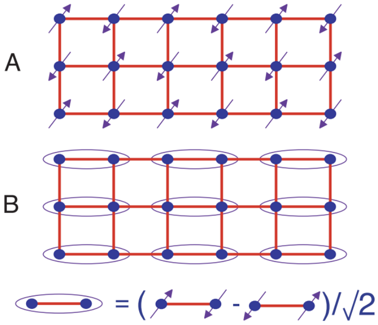
Signatures of deconfined quantum criticality in a spin-1 model on the square lattice

Vikas Vijigiri

Collaborators:
Dr. Nisheeta Desai (PDF, TIFR)
Prof. Sumiran Pujari (IIT Bombay)

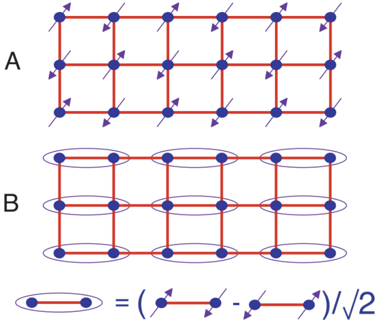
Department of Physics, IIT Bombay

Outline



Néel (A): Antiferromagnetic state, breaks rotational symmetry, SU(N).
Sensitive to quantum fluctuations.
Low energy excitations: Spin-waves.

Valence bond solid (VBS) (B): A non-magnetic state, and breaks lattice symmetry (e.g. translational for spin-1/2).
Product of quantum fluctuations.
Localized triplets ("confined spinons").



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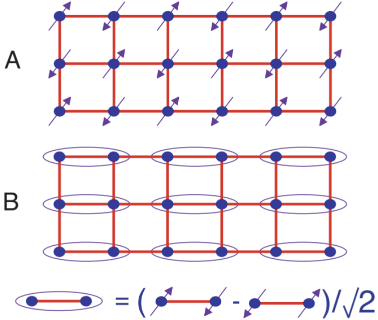
Introduction to DQC



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$$\mathcal{H} = J \sum_{\langle i,j \rangle} \vec{S}_i \cdot \vec{S}_j + \cdots$$

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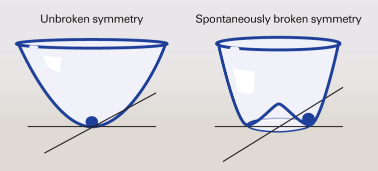
Deconfined quantum criticality is a...

'Critical region of interest' associated with Néel-Valence bond solid (VBS) quantum phase transition in magnetic systems. Can see 'deconfined' nature of spinons.

Why DQC is interesting?

$$\text{Para} \overset{\color{red}{\text{CPT}}}{\Longleftrightarrow} \begin{matrix}\color{blue}{\text{Néel, VBS}} \\ \text{FM}\end{matrix}$$



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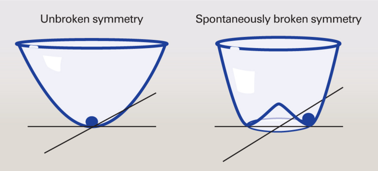

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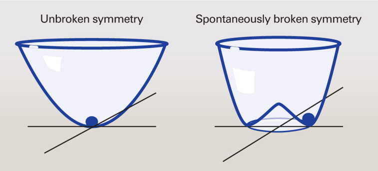

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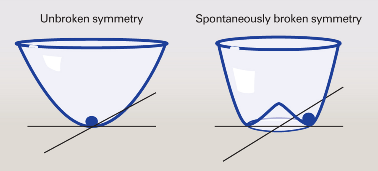

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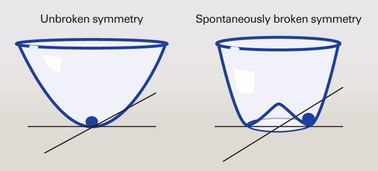

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1$^{\text{st}}$ order? (LGW)
co-existence of two orders? (LGW)
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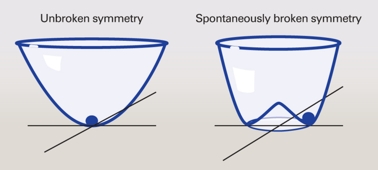

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Ground state to break the continuous symmetry of the Hamiltonian.

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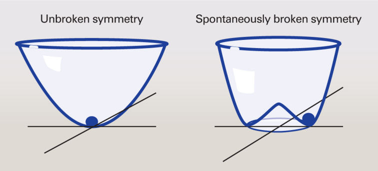

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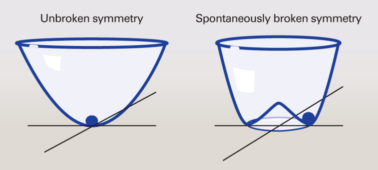

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Ground state to break the continuous symmetry of the Hamiltonian.

1. Order parameter description of phases.

2. An emergent gauge field and "deconfined" degrees of freedom associated with fractionalization of the order parameters. (Beyond LGW paradigm)

Lots of studies on spin-1/2's

Prior to 2015...

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Our approach lies in the idea that the above problem can be recasted into spin-1 with SU(3) symmetry and see the effect of criticality under reduced symmetry conditions, SU(2).

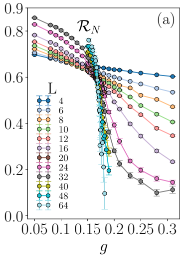
Hamiltonian:

$$\mathbf{SU(3)} : \mathcal{H} = J_{Bi} \sum_{\langle i,j \rangle} (\vec{S}_i \cdot \vec{S}_j)^2 - Q_n \sum_{ijkl} (\vec{S}_i \cdot \vec{S}_j)^2 (\vec{S}_k \cdot \vec{S}_l)^2 \quad (1)$$

$$\mathbf{SU(2)} : \mathcal{H}_p = \mathcal{H} + J_H \sum_{\langle i,j \rangle} \vec{S}_i \cdot \vec{S}_j \quad (2)$$

1. It can be shown that the terms in $\mathcal{H}$ are SU(3) symmetric.
2. It is of the following reasons, interesting to see the effect of a lower symmetric perturbation, SU(2), upon the deconfined critical point (DCP). There can be three questions now:
    1. Does the phases survive?
    2. If so, what is the universality class without perturbation?
    3. And the effect under reduced symmetry (SU(2)) perturbation?

Scaling of order parameter ratios, in the absence of perturbation



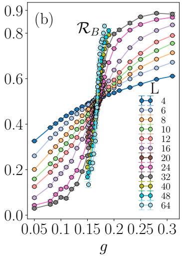
Neel parameters:

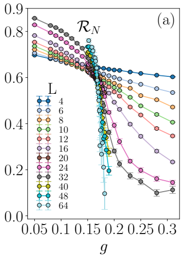
$$R_N^x = 1 - m(\pi + 2 * \pi/L, \pi)/m(\pi,\pi)$$
$$R_N^y = 1 - m(\pi, \pi + 2 * \pi/L)/m(\pi,\pi)$$

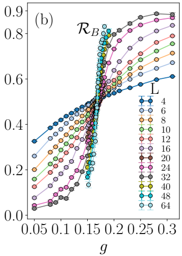
and $m \sim \langle S_i^z S_j^z \rangle$

VBS order parameter:

$$R_B^x = 1 - \frac{\tilde{C}^x(\pi, 2\pi/L)}{\tilde{C}(\pi, 0)},$$
$$R_B^y = 1 - \frac{\tilde{C}^y(2\pi/L, \pi)}{\tilde{C}(0, \pi)}$$
$$C^\alpha \sim \langle S_{\vec{r}} \cdot S_{\vec{r}+\hat{\alpha}} S_{\vec{r}'} \cdot S_{\vec{r}'+\hat{\alpha}} \rangle$$







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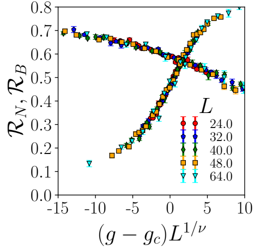

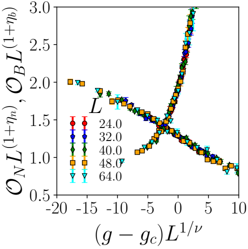

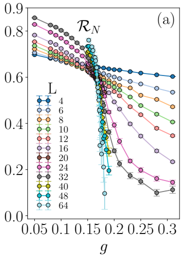

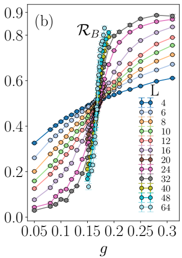

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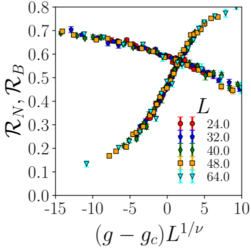
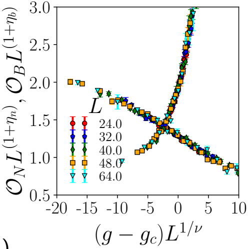
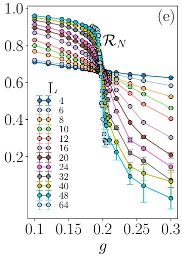


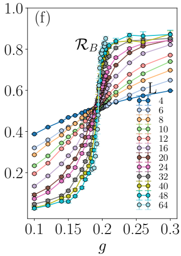
$J_H = 0.0$
$\nu_N = 0.49(5), 0.53(3)$
$\nu_V = 0.63(1), 0.63(1)$
$\eta_N = 0.44(5)$
$\eta_V = 0.49(2)$ $g_c = 0.168(1)$



In the presence of perturbation, $J_H = 0.05$



Look at the value of η_N, there is a consistent decrease in the values compared to the case of $J_H = 0.0$



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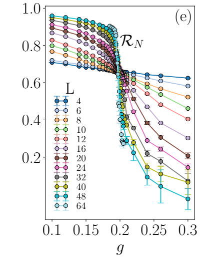
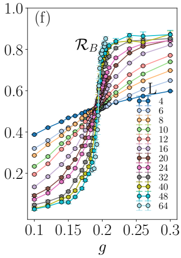
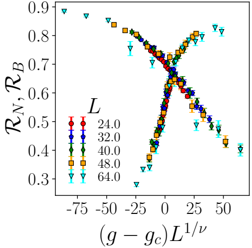
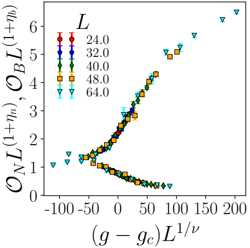




Look at the value of η_N, there is a consistent decrease in the values compared to the case of $J_H = 0.0$





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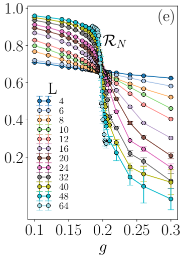

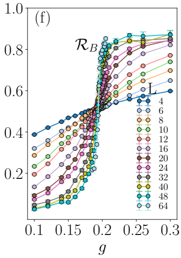

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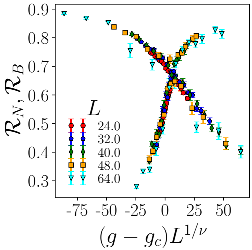
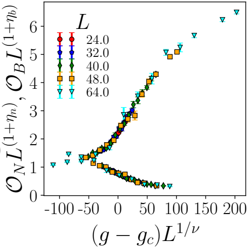


$J_H = 0.05$

$\nu_N = 0.40(3), 0.46(3)$

$\nu_V = 0.39(1), 0.38(1)$

$\eta_N = 0.20(9), \eta_B = 0.29(6)$



The exponent table

J_H	Parameter	ν_N	ν_V	η_N	η_V	g_{cN}	g_{cV}
0.0	$\mathscr{R}$	0.49(5)	0.63(1)	0	0	0.168(1)	0.167(1)
0.0	$\mathscr{O}$	0.53(3)	0.63(1)	0.44(5)	0.49(2)	0.167	0.167
0.05	$\mathscr{R}$	0.40(3)	0.46(3)	0	0	0.196(1)	0.195(1)
0.05	$\mathscr{O}$	0.39(3)	0.38(3)	0.20(9)	0.29(6)	0.195	0.195
0.1	$\mathscr{R}$	0.31(1)	0.40(1)	0	0	0.225(1)	0.223(1)
0.1	$\mathscr{O}$	0.33(2)	0.41(2)	0.13(2)	0.28(7)	0.224	0.224
0.15	$\mathscr{R}$	0.32(4)	0.44(2)	0	0	0.254(1)	0.252(1)
0.15	$\mathscr{O}$	??	??	??	??	0.253	0.253

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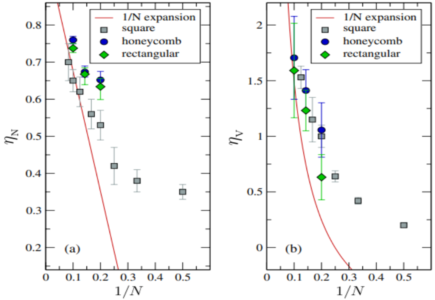

Block, Melko, *et al*, PRL 111, 137202 (2013)

Conclusion

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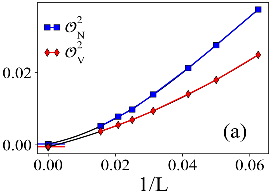
Conclusion

1. We have studied and seen a Neel-VBS transition in a spin-1 (SU(3) symmetric) Hamiltonian with Heisenberg (SU(2) symmetric) term as perturbation.
2. Our results match with the literature for $J_H = 0.0$ with critical exponents of SU(3) type.
3. However, as we turn on perturbation ($J_H = 0.05$) we see a shift in the universality class of SU(2) type.
4. Our results show some indications of deconfined criticality within the range $J_H \sim 0 - 0.1$.

Order parameter extrapolation



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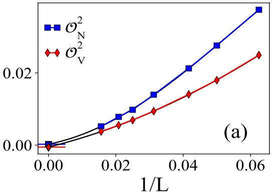
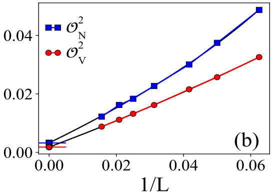
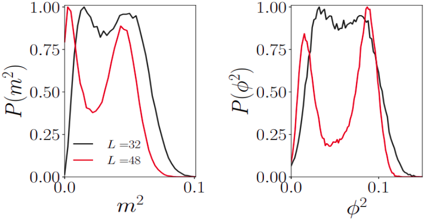


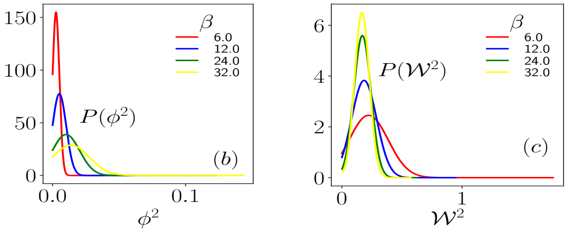


A finite value of order parameter starts appearing as we increase beyond $J_H = 0.1$.
A signature of first order phase transition (weak).

Histograms



Julia Wildeboer *et al*, PRB, 101, 045111 (2020)



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Spin-1 particles can behave like spin-1/2 particles! (Like two independent spins, in constrained environments).

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Thank you ALL