

Jamming in a spin liquid

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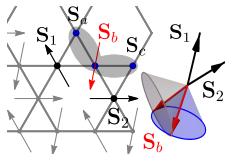
MPI-PKS

Roderich Moessner

MPI-PKS

Mike Zhitomirsky

Grenoble



Phys. Rev. Lett. 119, 247201 (2017)

Ingredients/Protagonists

Frustration & classical spin liquids

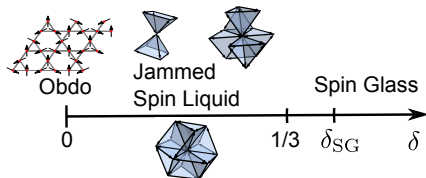
- ▶ recent additions Rehn et al., Benton et al.

Disorder in magnetism

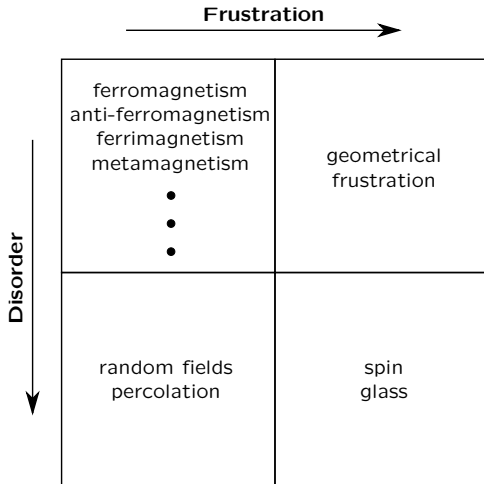
- ▶ distraction, probe, source of new physics
- ▶ with frustration: disorder-free glassiness?

Bond-disordered kagome

- ▶ marginal constraint
 - ▶ no order by disorder
 - ▶ discrete degeneracy
- ▶ unusual excitation spectrum
- ▶ termination by spin glass



Disorder and frustration



Ramirez, 1994

Bond disorder in frustrated magnets

Ancient subject

- ▶ spin glass physics:
Sherrington-Kirkpatrick model

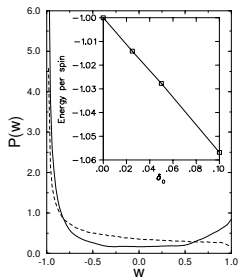
Highly frustrated magnets: pyrochlore

- ▶ lifts huge ground-state degeneracy

Bellier-Castella et al., Can. J. Phys. 2001

- ▶ leads to conventional spin freezing

Saunders + Chalker, PRL 2007



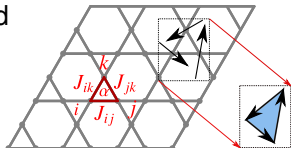
How general?

- ▶ Consider classical kagome magnet

Bond-disordered kagome magnet

Exchange strength J_{ij} random for each bond

$$\mathcal{H} = \sum_{\langle ij \rangle} J_{ij} \mathbf{S}_i \mathbf{S}_j$$



can be rewritten using $\gamma_{i\alpha} = \sqrt{J_{ij}J_{ik}/J_{jk}}$ as 'perfect square'

$$\mathcal{H} = \sum_{\alpha} \left(\sum_{i \in \alpha} \gamma_{i\alpha} \mathbf{S}_i \right)^2 = \sum_{\alpha} \mathbf{L}_{\alpha}^2$$

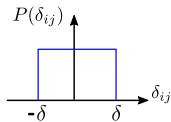
Ground-state constraint: $\mathbf{L}_{\alpha} = \sum_{i \in \alpha} \gamma_{i\alpha} \mathbf{S}_i = \mathbf{0}$ for each triangle α

- ▶ degrees of freedom per unit cell: $F = 3(n - 1)$
- ▶ constraints for unit cell: $K = 2n$
 - ▶ marginal constraint for Heisenberg, $n = 3$: $D = F - K = 0$

Ground state construction and entropy

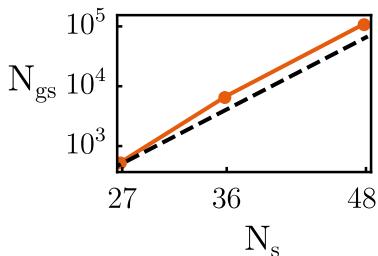
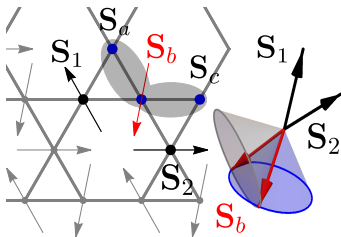
Box distribution for $J_{ij} = 1 + \delta_{ij}$

- ▶ boundedness useful



Ground-state construction by transfer matrix

- ▶ two choices at each step
- ▶ entropy $S \sim (\ln 2)/3$ per spin



Ground state & correlations

Constraint satisfaction ($E = 0$) until

$$\delta = 1/3$$

▶ $E \sim (\delta - \delta_c)^5$

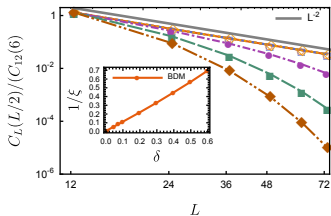
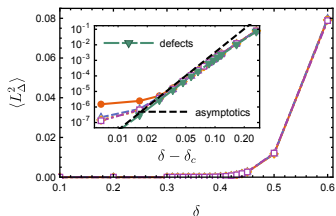
Bond-disordered model (BDM)

▶ “screened” with $\xi \sim 1/\delta$

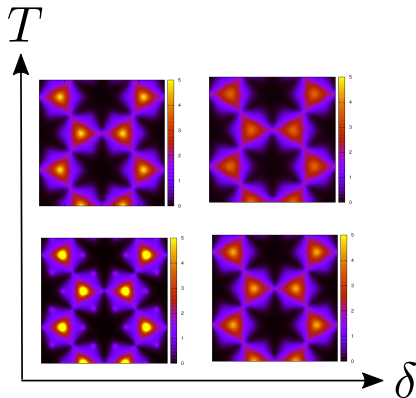
Restricted maximal Coulomb model

▶ $\gamma_{i\alpha} = \gamma_i \gamma_\alpha$
(5 d.o.f. per unit cell)

▶ algebraic “Coulomb”
correlations



- ▶ Peaks in structure factor disappear
- ▶ coplanar states higher in energy



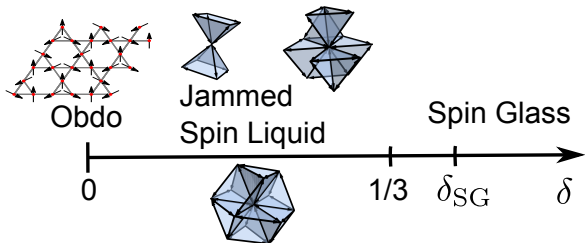
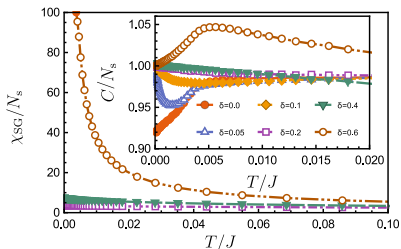
New non-coplanar ground states

cf. Roychowdhury et al., arxiv:1705.00015

Phase diagram with disorder strength δ

Terminated by order-by-disorder
($\delta = 0$) and spin glass ($\delta \geq \delta_{SG}$)

- ▶ $\delta_{SG} > 1/3$
- ▶ new liquid regime?



Jammed spin liquid

Jamming: critical constraint density

- ▶ e.g. transition in granular materials
 - ▶ exponential degeneracy

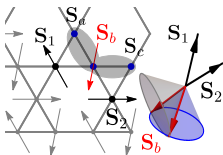
Marginally constrained, fully SAT Hamiltonian

- ▶ continuous SAT Parisi et al. 2017
- ▶ cf. Maxwellian lattices Kane+Lubensky



Open questions

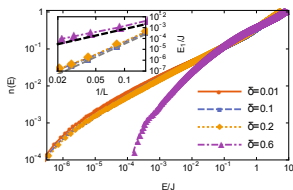
- ▶ exact ground-state entropy
- ▶ theory of soft excitations
- ▶ nature of (jamming?) transition
- ▶ existence of intermediate phase
- ▶ ...
- ▶ materials/realisations?
- ▶ dynamics (in prep.)



Local minima, soft excitations and continuity

Spectrum of fluctuations (Hessian)

- ▶ gapped
 - ▶ minima rather than saddles
 - ▶ unlike conventional SLs
- ▶ anomalously soft



Ground states vary continuously with δ

- ▶ limit $\delta \rightarrow 0$ appears non-singular

New set of states

- ▶ beyond spin origami

