Paired chiral spin-liquid in triangular lattice spin-1 model

Samuel Bieri

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SB, M. Serbyn, T. Senthil, P. A. Lee [arXiv:1208.3231].

$Ba_3NiSb_2O_9$

PRL 107, 197204 (2011) PHYSICAL REVIEW LETTERS week ending 4 NOVEMBER 2011

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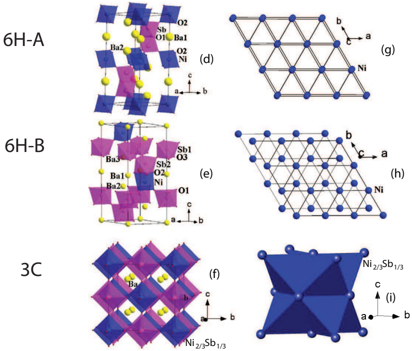

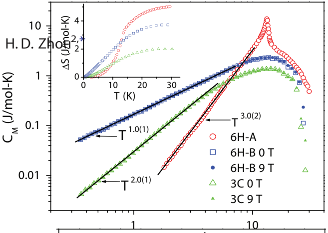

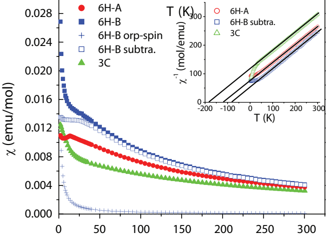

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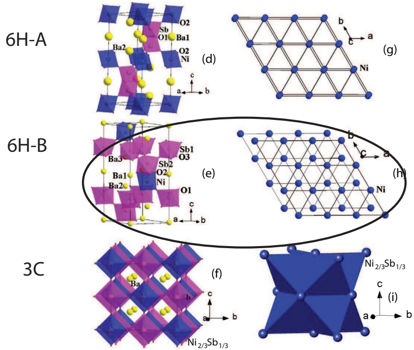

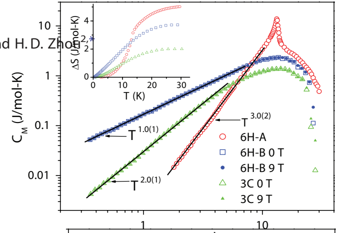

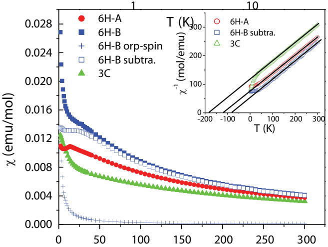

Goal of this work

- Construct Fermi surface QSL states for spin S=1
- Find microscopic Hamiltonians for these states

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Related theoretical works on $Ba_3NiSb_2O_9$:

- [C. Xu *et al.*, PRL 108, 087204 (2012)]:
  Four flavors of fermionic spinons, quadratic band touching, no microscopic Hamiltonian
- [G. Chen *et al.*, PRL 109, 016402 (2012)]:
  Strong inter-layer coupling, QCP

Construction of fermionic spin=1 liquids

Representation of spin operator via fermionic spinons:

$$\boldsymbol{S} = -i\boldsymbol{f}^{\dagger} \wedge \boldsymbol{f} = -i(\varepsilon^{abc} f_b^{\dagger} f_c) \ , \qquad a = x, y, z.$$

Physical subspace of spin states:

$$n = \sum_{a=1}^{3} f_a^{\dagger} f_a \equiv 1 \ (\text{or} \equiv 2; \text{hole rep.})$$

Local U(1) symmetry: $f_a \mapsto e^{i\phi} f_a$

[Liu *et al.*, PRB 82, 144422 (2010)]

QSL phenomenology

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- U(1) Fermi surface state:

$$H_{\mathrm{MF}} = -t \sum_{\langle i,j \rangle} f_{ia}^{\dagger} f_{ja} - \mu_a n_a \qquad (1)$$

$\rightarrow$ Strong gauge fluctuations; $C_M \propto T^{2/3}$, $\chi_0 \sim \mathrm{cst}$

[See Metlitski tutorial tomorrow]

- Higgs/pairing phases:

$$H_{MF} = \sum_{\langle i,j \rangle} \{-t\, f_{ia}^{\dagger} f_{ja} + \Delta_{ij}^{ab} f_{ai} f_{bj} + h.c.\} - \mu_a n_a \,. \qquad (2)$$

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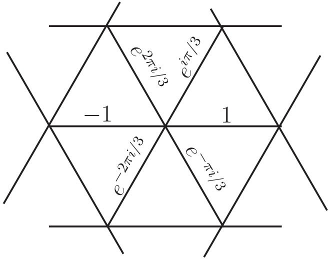

Fully gapped!

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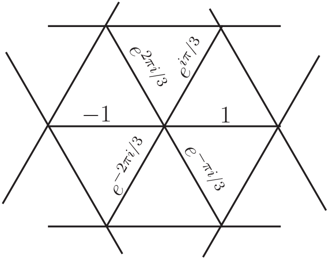

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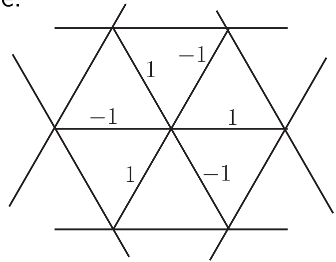
f-wave:



Nodal SC, Dirac fermions;
$C_M \propto T^2$, $\chi_0 \propto T$

[Liu *et al.*, PRB 81, 224417 (2010)]

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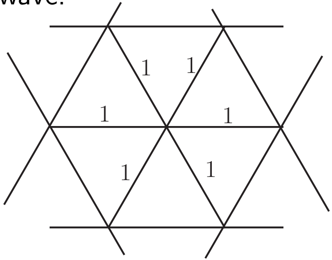

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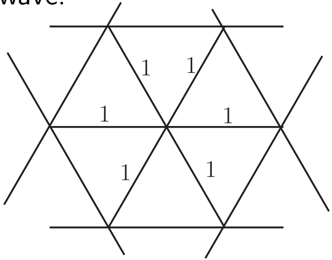

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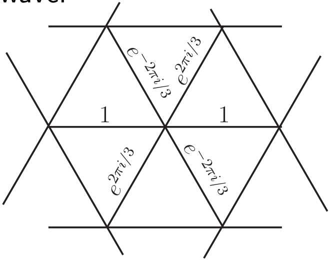

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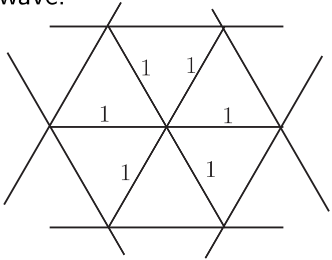

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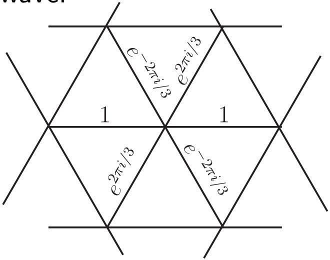

Higgs phases with spinon Fermi surface! $C_M \propto T$, $\chi_0 \sim$ cst

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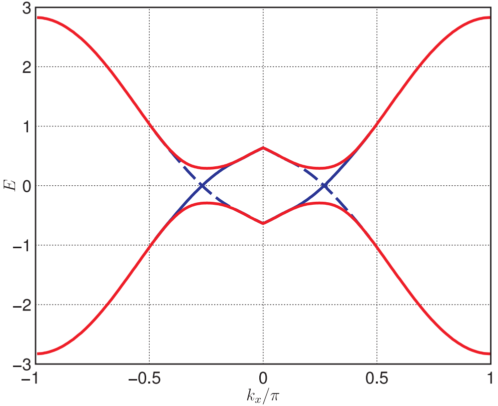
- Bulk Fermi surface of deconfined spinons, $C_M \propto T$
- Finite spin susceptibility as $T \to 0$
- Pair of chiral edge modes; thermal and spin Hall effect: $\kappa_{xy} > 0$, $\sigma_{xy}^{\text{spin}} > 0$



“Realistic" spin-1 model exhibiting such QSL phases?

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Construction of RVB spin-liquid wave functions:

Microscopic spin-1 wf obtained by Gutzwiller-projection,

$$|\psi\rangle = P(n_j = 1)|\psi_0\rangle \,,$$

where $|\psi_0\rangle$ is the gs of H_{MF}, Eqs. (1) or (2).

Competing three-sublattice ordered states:

a) Gutzwiller-projected ordered state:

$$H_{MF} = -t \sum_{\langle i,j \rangle} f^\dagger_{ia} f_{ja} - h \sum_j d_j^{a*} d_j^b f^\dagger_{aj} f_{bj} - \mu_a n_a \tag{3}$$

with d_j^a, identical on each sublattice.

$$|f\text{-}AF\rangle = P(n_j = 1)|\psi_0\rangle$$

b) Huse-Elser-type wave function:

$$|\mathcal{J}\text{-}AF\rangle = e^{\sum_{\langle i,j \rangle}\{\gamma S_{zi} S_{zj} + \sigma (S_{zi} S_{zj})^2\}} \prod_j |S_j\rangle$$

$\rightarrow$ Variational Monte Carlo to evaluate $\langle (\cdot) \rangle$; $N = 12 \times 12$.

$$H_{KD} = \sum_{\langle i,j \rangle} \{ \boldsymbol{S}_i \cdot \boldsymbol{S}_j + K(\boldsymbol{S}_i \cdot \boldsymbol{S}_j)^2 \} + D \sum_j S_{zj}^2$$

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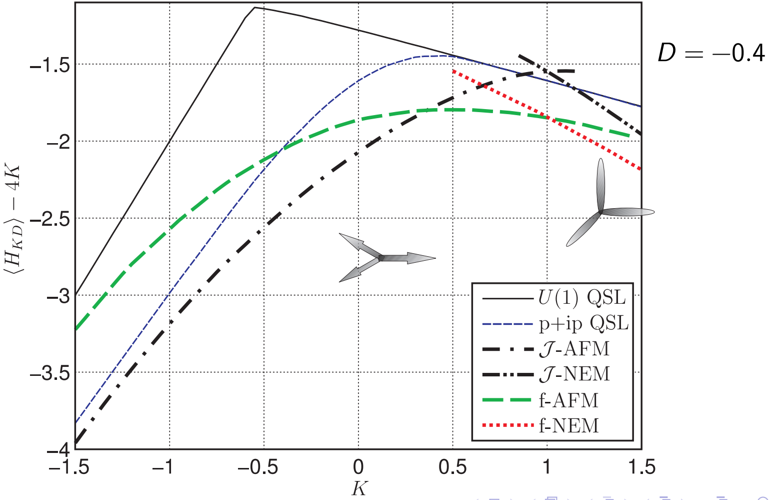

$$H_\alpha = \cos\alpha \sum_{\langle i,j\rangle} P_{ij} + \sin\alpha \sum_{\langle i,j,k\rangle} \{P_{ij}P_{jk} + h.c.\}$$

Heisenberg exchange operator: $P_{ij} = \boldsymbol{S}_i \cdot \boldsymbol{S}_j + (\boldsymbol{S}_i \cdot \boldsymbol{S}_j)^2 - 1.$

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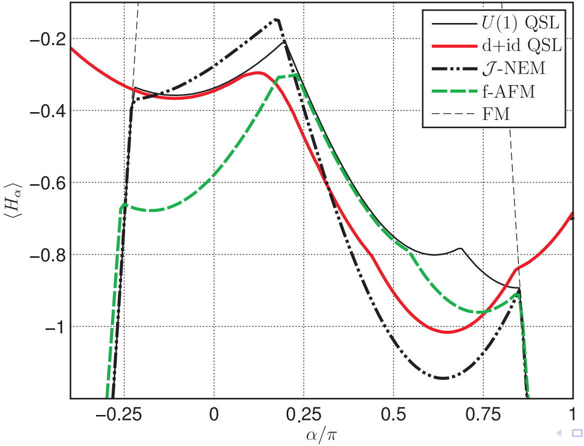

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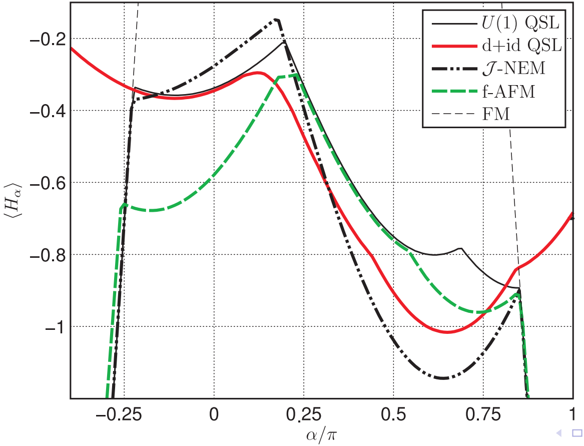

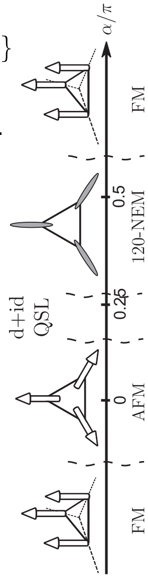

Remark: related $Ba_3CuSb_2O_9$ compound

PRL **106,** 147204 (2011) PHYSICAL REVIEW LETTERS week ending 8 APRIL 2011

Spin Liquid State in the $S = 1/2$ Triangular Lattice $Ba_3CuSb_2O_9$

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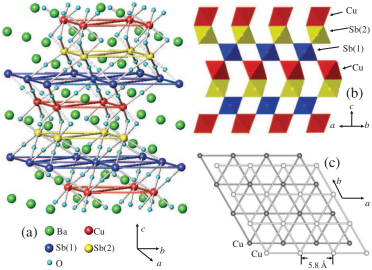

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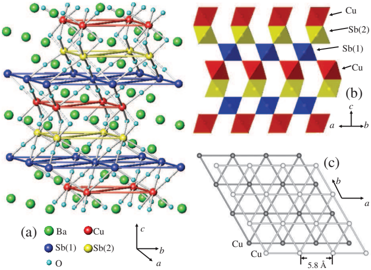

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Spin-Orbital Short-Range Order on a Honeycomb-Based Lattice

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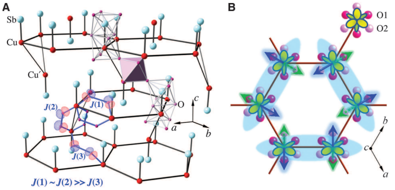

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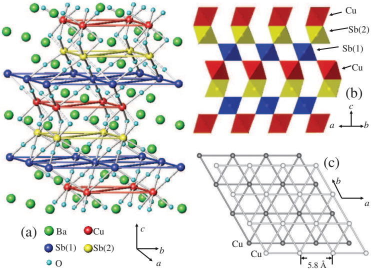

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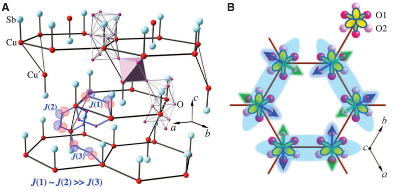

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Do we have the correct structure for the Ni compound ?

Conclusions:

- QSLs do not seem to arise in BL-BQ model with D term.
- Line $K = J$: strongly correlated, but still *3*-sublattice ordered ground state.
- Large (positive) ring-exchange term favors an exotic paired chiral QSL with a spinon FS.
- More experiments (and theory) needed to understand the B-phase of $Ba_3NiSb_2O_9$.