

PS-B-5

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**New phases induced by four-spin interaction
in stacked triangular-lattice
antiferromagnets in magnetic field**

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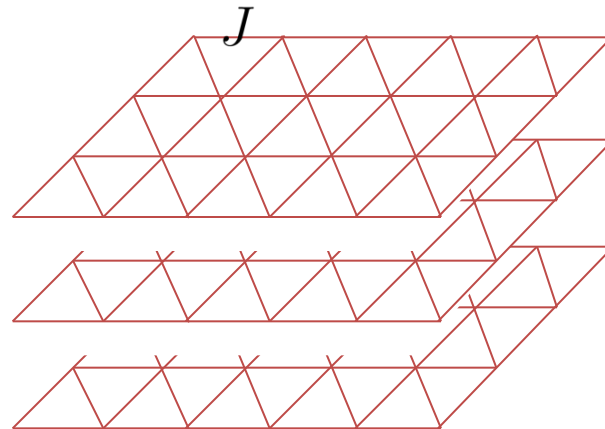
Masahiro Sato (Aoyama-gakuin University)

Introduction

- **Classical Heisenberg antiferromagnet on triangular lattice (CHAFT)** under magnetic field is one of the representative models in frustrated magnets.
- We consider **3D stacked** CHAFT by numerical methods for easier detection of ordered phases.

Stacked CHAFT

Nearest neighbor AF exchange in a layer



J_{\perp}

Ferromagnetic interlayer exchange

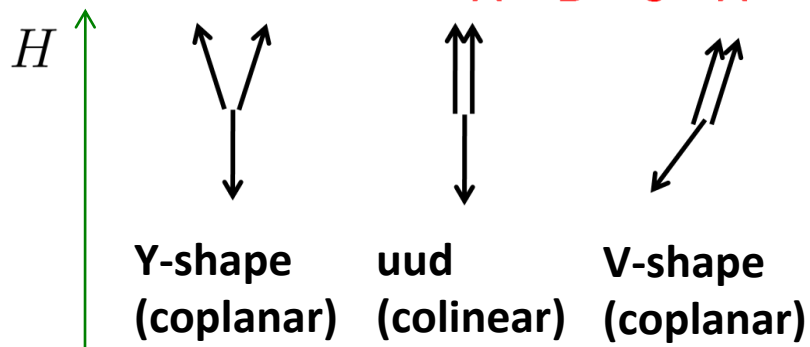
20 layers

$$J_{\perp} = -0.5J$$

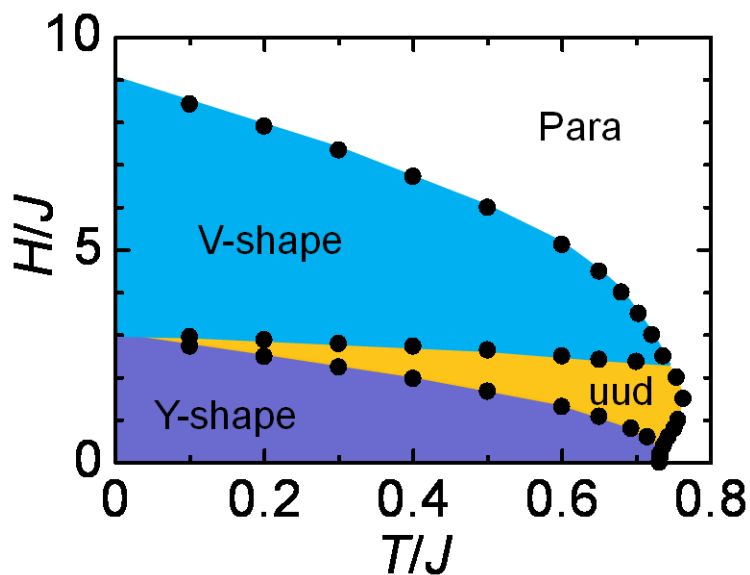
} fixed

Order by disorder

■ 3 sublattice



- ✓ Macroscopic degeneracy in ground state
- ✓ Order is selected by **thermal fluctuation** (Order by disorder)



Monolayer

H. Kawamura and S. Miyashita,
J. Phys. Soc. Jpn. **54**, 4530 (1985).
L.Saebra et al.,
arXiv:1109.2211 (2011).

Plausible perturbations

Phases stabilized due to “order by disorder”

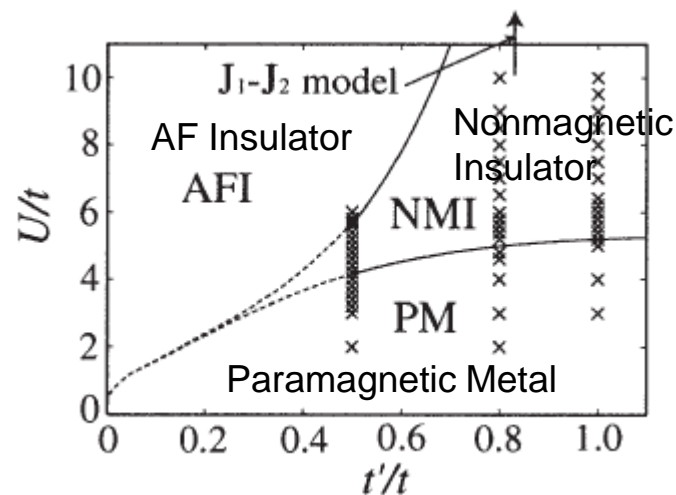
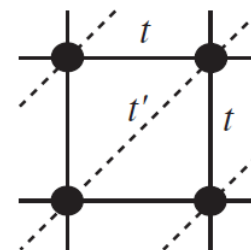


expected to be weak against a small variation of the system (perturbation)

We focus on 4-spin couplings in this study

The origin of 4-spin interactions

- higher order **electron hopping** in Mott insulators
- **spin-phonon couplings**



H. Morita, S. Watanabe and M. Imada,
J. Phys. Soc. Jpn. **71**, 2109 (2002).

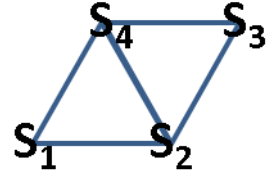
New Phases are induced by 4-spin interaction

– Ring exchange

M. Takahashi, J. Phys. C **10**, 1289 (1977).

$$\mathcal{H}_{\text{ring}} = J_4 \sum_p h_p$$

p represents a plaquette consisted from 4 sites (1,2,3,4)



$$h_p = \sum_{1 \leq i < j \leq 4} \mathbf{S}_i \cdot \mathbf{S}_j + (\mathbf{S}_1 \cdot \mathbf{S}_2)(\mathbf{S}_3 \cdot \mathbf{S}_4) + (\mathbf{S}_1 \cdot \mathbf{S}_4)(\mathbf{S}_2 \cdot \mathbf{S}_3) - (\mathbf{S}_1 \cdot \mathbf{S}_3)(\mathbf{S}_2 \cdot \mathbf{S}_4)$$

$S = 1$

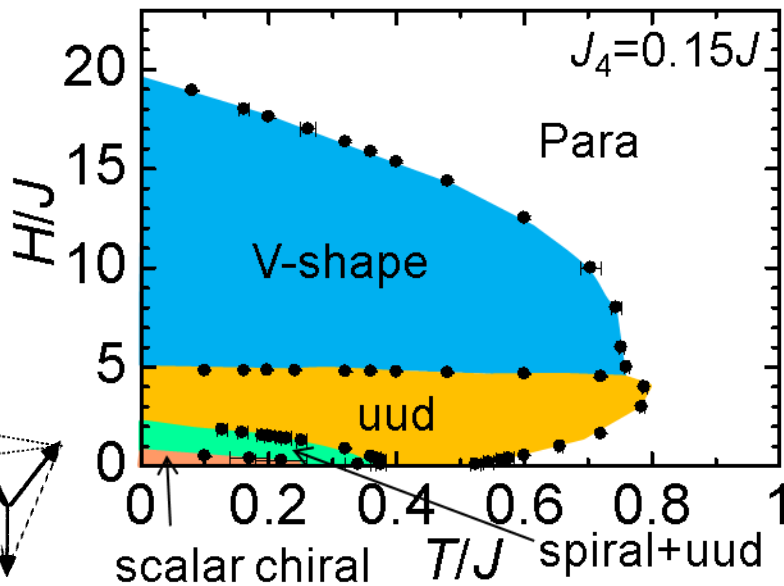
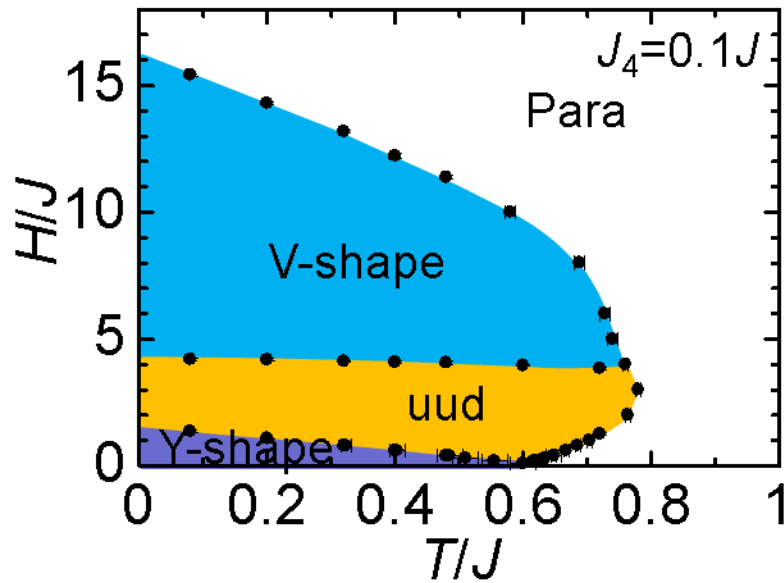
– Biquadratic interaction $\mathcal{H}_{\text{bq}} = -K \sum_{\langle i,j \rangle} (\mathbf{S}_i \cdot \mathbf{S}_j)^2$

- ✓ Somewhat large 4 spin interaction is needed to introduce a new phase in system without frustration.
E.g. Square lattice, ladder

$$J_4 \sim 0.23J$$

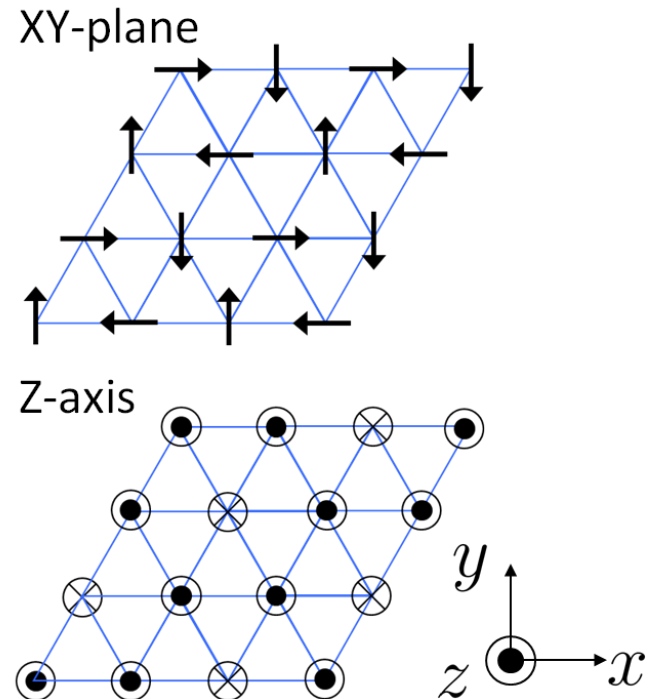
A. Lauchli et al.,
Phys. Rev. B **67**, 100409 (2003).
Phys. Rev. Lett. **95**, 137206 (2005).

Phase diagram with ring exchange



Classical Monte Carlo method

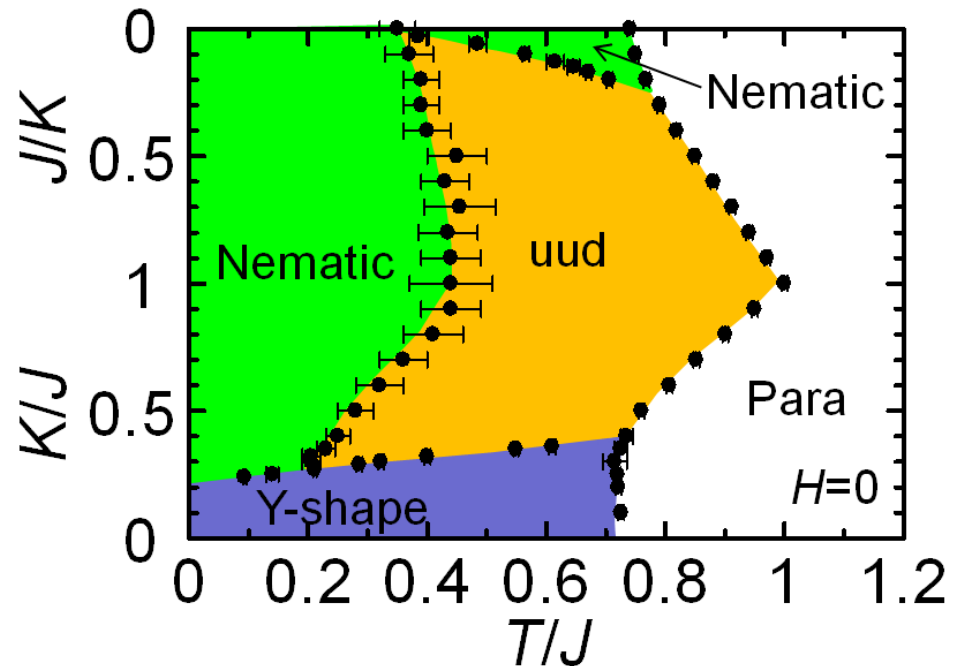
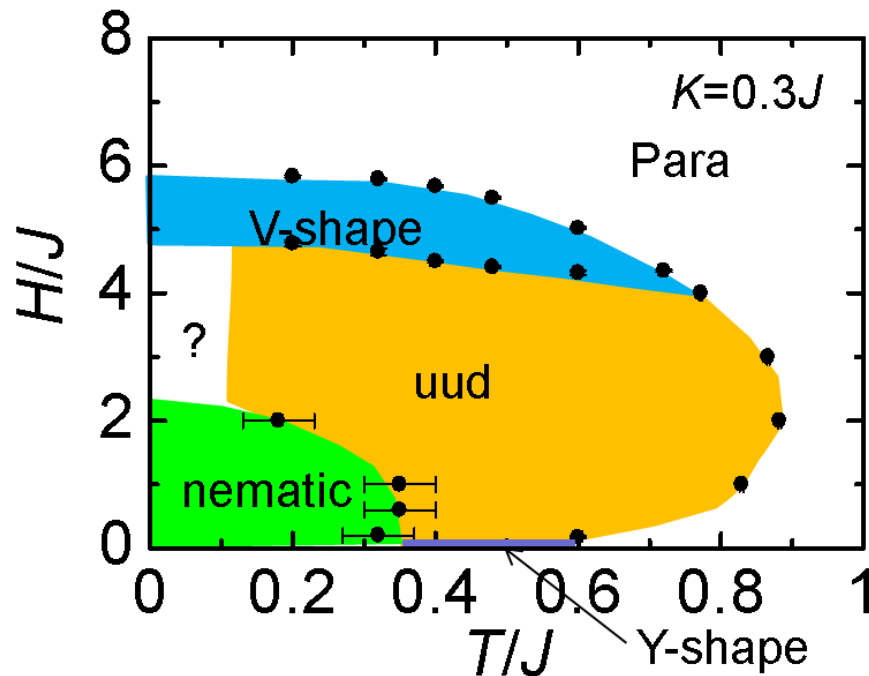
- Scalar chiral and XY spiral+uud phases appear above $J_4 \sim 0.13 J$.



Cf. 6-sublattice structure

T. Yasuda, D. Kinouchi and K. Kubo, J. Phy. Soc. Jpn. **75**, 104705 (2006).

Biquadratic Interaction



- At zero field, nematic and uud phases appear with strong biquadratic interaction.
- With external field, the $SO(3)$ symmetry is already broken and nematic phase is the same as paramagnetic phase.
- **Reentrant phenomenon** is observed at very large K .

Conclusion

- Y-shape, uud and V-shape structures appear in the stacked CHAFT under magnetic field due to the **thermal or quantum fluctuation** (order by disorder).
- We investigate how perturbations (4-spin interactions) affect these structures.
- When ring exchange interaction is increased, **uuud** (1/2 plateau), **scalar chiral** and **uud + XY spiral phases** emerge.
- When biquadratic term is small, the phase diagram does not change much. When it is large, **nematic phase** is induced.
- Smaller J_4 interaction induces new phases in the triangular lattice compared with the square lattice.