Spin Disorder in a Bulk Triangular Antiferromagnet

Satoru Nakatsuji,
Y. Nambu (M2), K. Onuma (M1), Y. Maeno

P-68 P-69

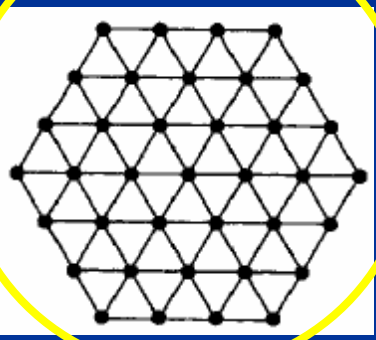
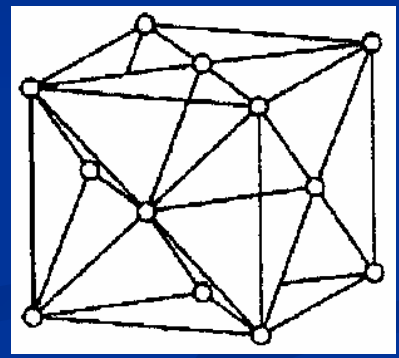
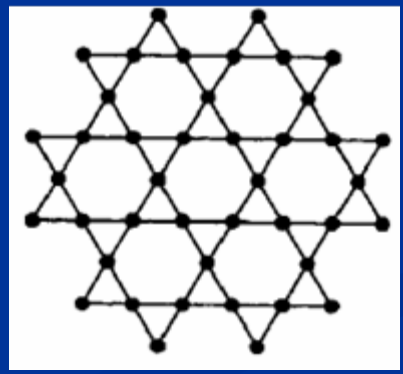
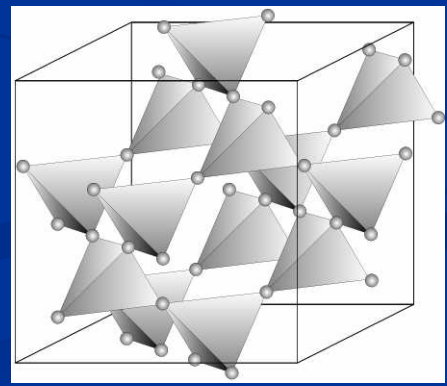
Department of Physics, Kyoto University

Content

- 2D Triangular AFM
  and Geometrically Frustration
- Novel Spin Disordered State
  on 2D Triangular Lattice in $NiGa_2S_4$
- Impurity Effects, Spin Size Effects
- Summary and Future Plans

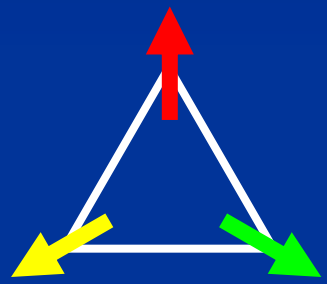
Search for Novel Quantum Phases in Geometrically Frustrated Lattices

Geometrical Frustration suppresses Magnetic Order.

	2D	3D
Most basic & studied	**Triangle**	**Face Centered Cubic**
Edge Sharing		
	Kagomé	**Pyrochlore**
Corner Sharing		

Triangular Lattice AFM

"the only geometrically frustrated 2D Bravais lattice"

- Ising (Wannier, Hushimi 1950) Disordered State with Residual Entropy.
- Classical  120° spin order, Chirality
- Quantum (Anderson 1973) Quantum Spin Liquid
- XY (Miyashita and Shiba 1984) Kosteritz-Thouless type transition, (Z_2) Vortex

Heisenberg (Kawamura and Miyashita 1984)

Novel Quantum Phases in 2D Triangular Lattice?

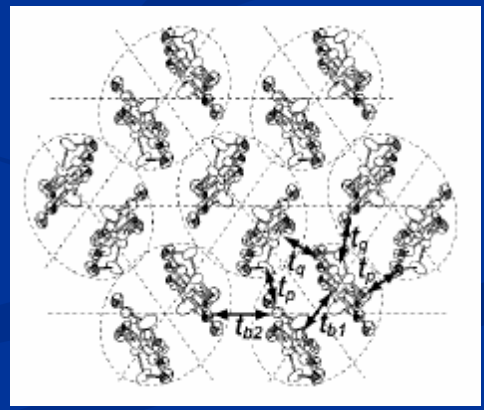
How about Experiments?

Triangular Lattice with Low spin ($S \leq 1$) Experiments

New Candidates from Japan!

- ^{3}He thin film absorbed on carbron: O-19 Fukuyama
  Gapless Spin Liquid, $S = 1/2$
  (K. Ishida et al. PRL **79**, 3451 (1997).
  R. Matsutomi et al. PRL 92, 025301 (2004).)

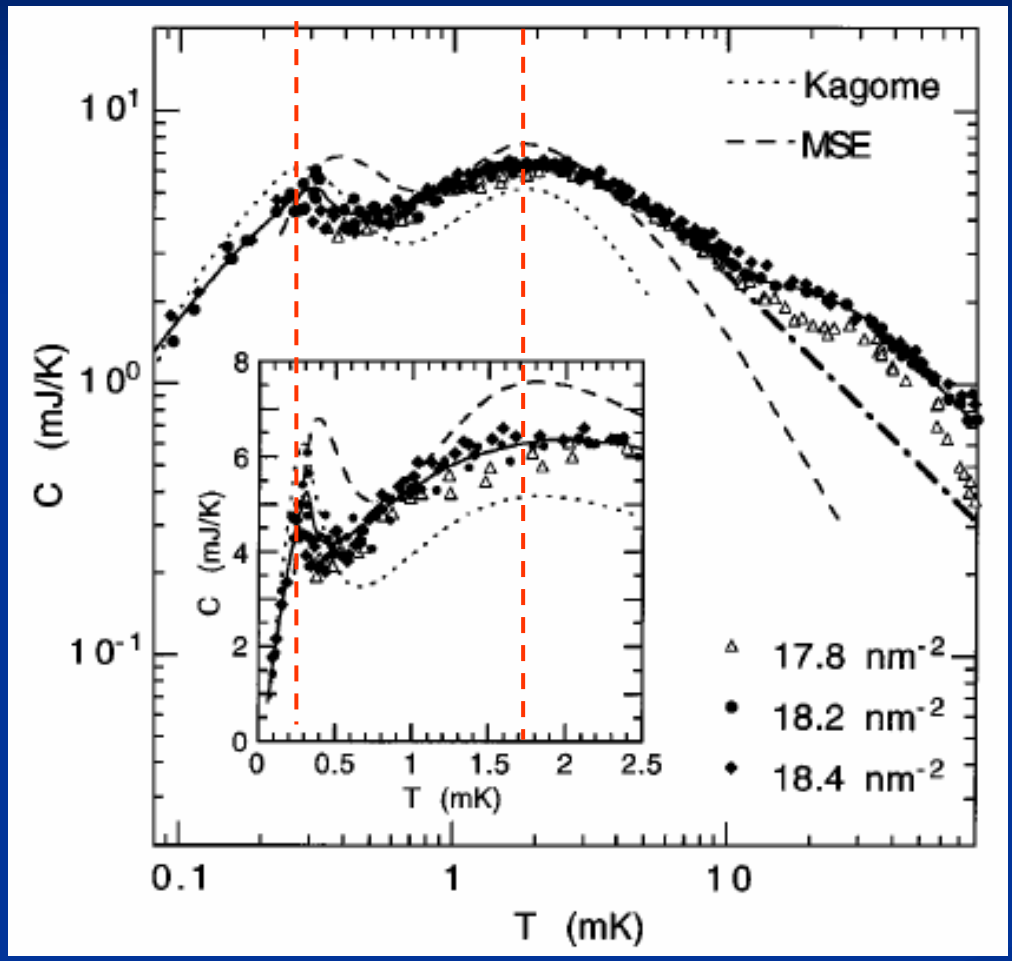
- κ-(BETS-TTF)$_2$Cu$_2$CN$_3$: O-24 Kanoda
  Distorted (Anisotropic) triangular lattice
  Gapless Spin Liquid, $S = 1/2$
  (Y. Shimizu et al. PRL **91**, 107001 (2003).)



To our knowledge,
no low spin ($S \leq 1$) bulk system with exact triangular lattice

Signature of Geometrical Frustration

2D Triangular AFM of Solid ^{3}He



K. Ishida et al. PRL **79**, 3451 (1997).

Double Peak in Specific Heat

Higher T peak

$T \sim \theta_W \sim O(J)$

Short range order

Lower T peak

$T \sim \theta_W/10$

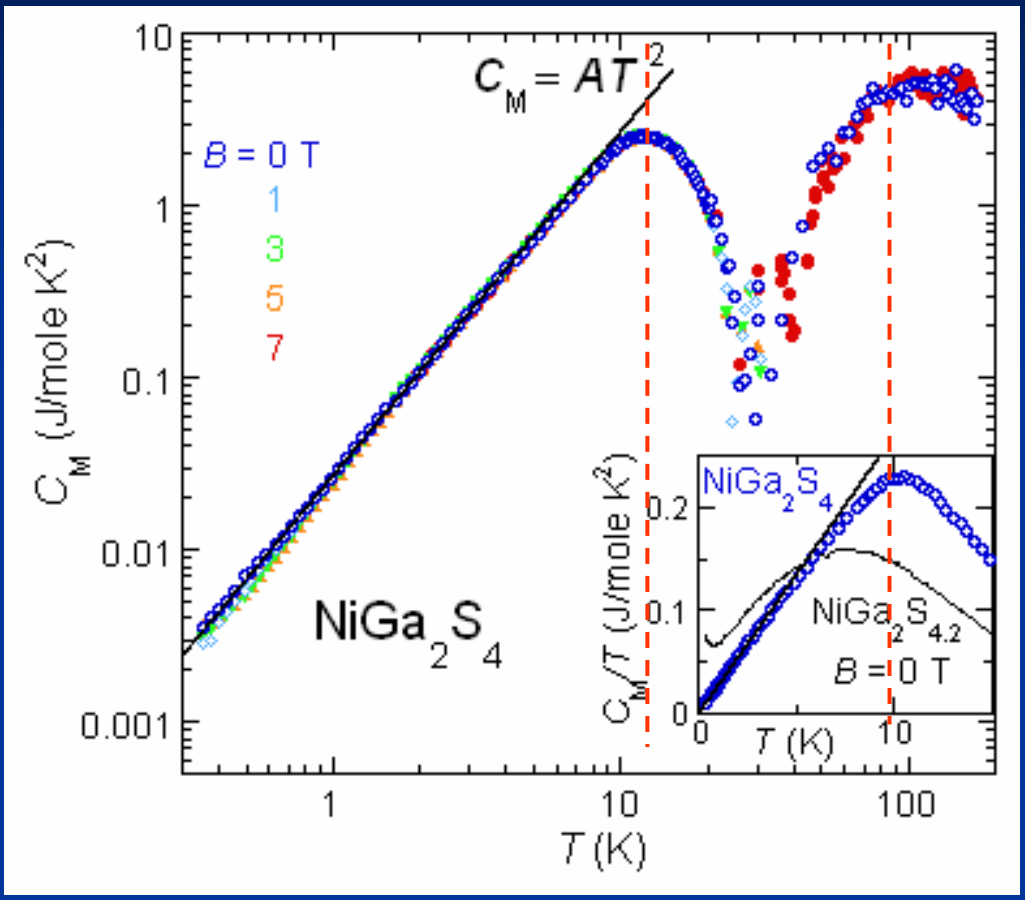
High Degeneracy at $T << J$

Formation of Novel Disordered State

Gapless Spin Liquid?

Double Peak in Specific Heat

in $NiGa_2S_4$



Higher T peak

$T \sim \theta_W \sim O(J)$

Short range order

Lower T peak

$T \sim \theta_W/10$

High Degeneracy

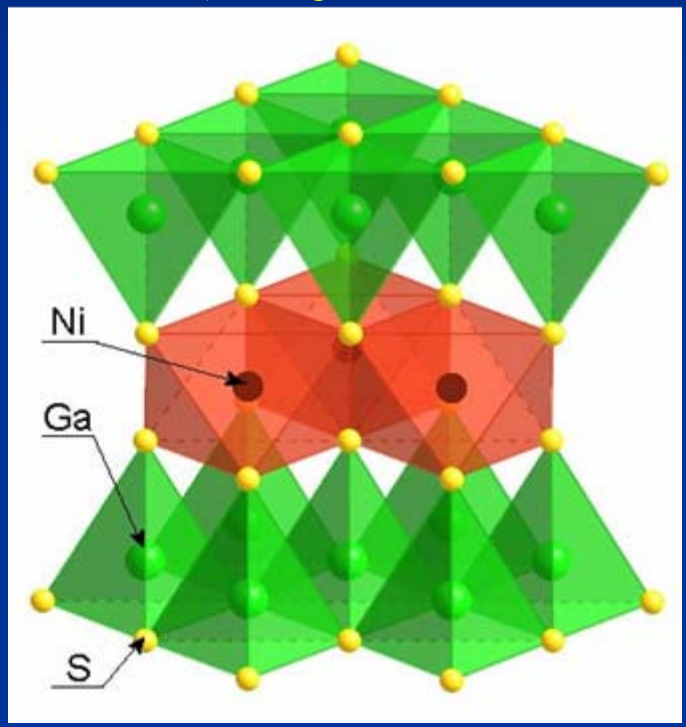
at $T << J$

Formation of

Novel Disordered State?

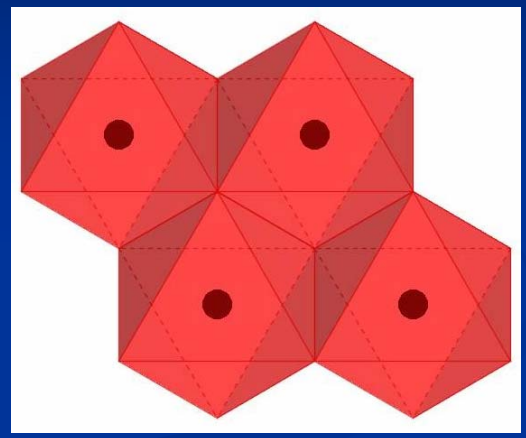
Bulk 2D Triangular AFM: $NiGa_2S_4$

$P\bar{3}m1$ symmetry above $T > 1.5$ K
No disorder (x-ray, neutron, ICP)



Ni distance $a = 3.67$ Å intra-layer
$c = 11.99$ Å inter-layer

Mott Insulator



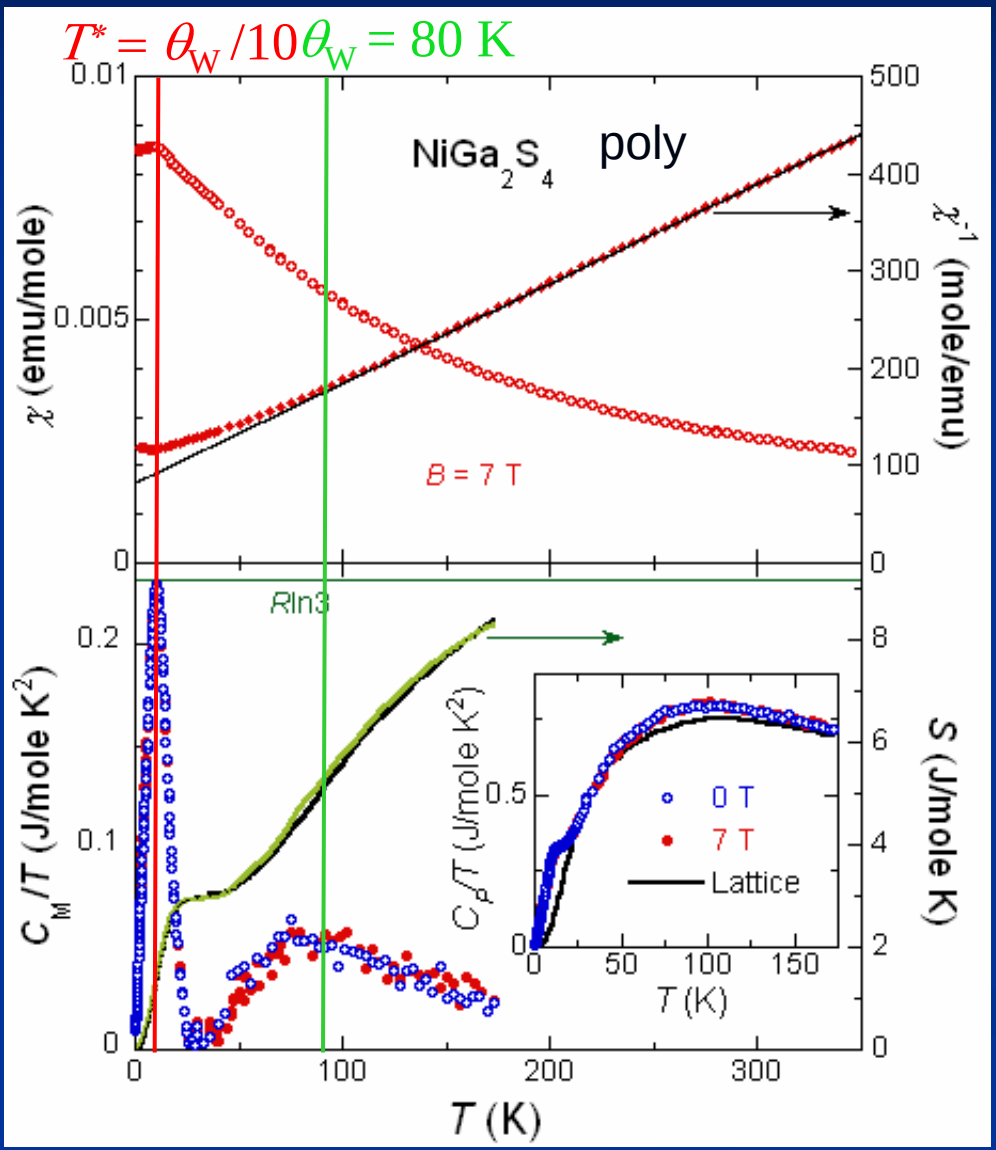
2D NiS_2 layer

c.f. 1. CoO_2 layer of $Na_xCoO_2yH_2O$
2. Mott transition in NiS

Ni^{2+}: $t_{2g}^6 e_g^2$
$S = 1$ Heisenberg spin

S. Nakatsuji, Y. Nambu, H. Tonomura, O. Sakai, S. Jonas, C. Broholm, H. Tsunetsugu, Y. Qiu and Y. Maeno, *Science* **309**, 1697 (2005).

No conventional AF order



- p_{eff} = 2.86 μ_B (S = 1, 2.84 μ_B)
  θ_W = -80 K (AF)
- No anomaly except
  a weak peak around 10 K
- No evidence of LRO in C_P

Spins remain disordered.

- Two crossover temperatures:

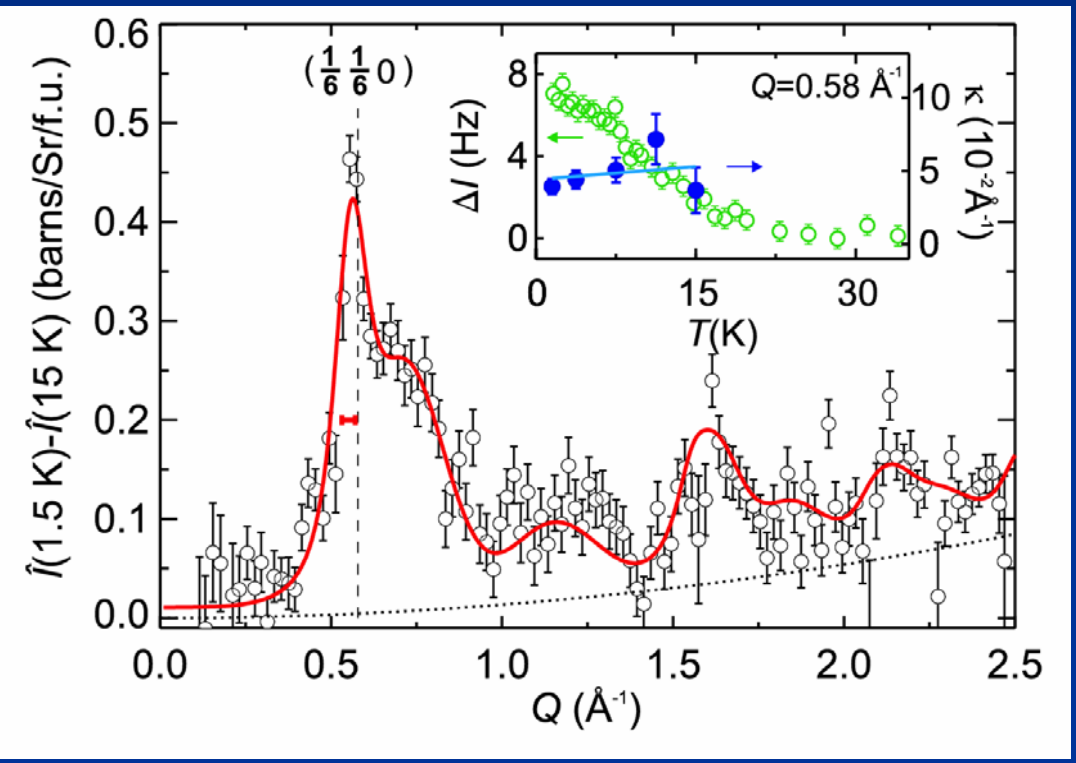
1. $T \sim \theta_W$: *short range order*

2. $T \sim \theta_W/10$: *novel phase formation?*

Nano-scale short-range order

Collin Broholm, Seth Jonas @ Johns Hopkins, USA

Magnetic neutron scattering at 1.5 K



No resolution limited peaks

Development of the **incommensurate correlation near (1/6, 1/6, 0)** below 20 K, corresponding to C_M/T peak.

Normally, 120° structure with (1/3,1/3,0) correlation.

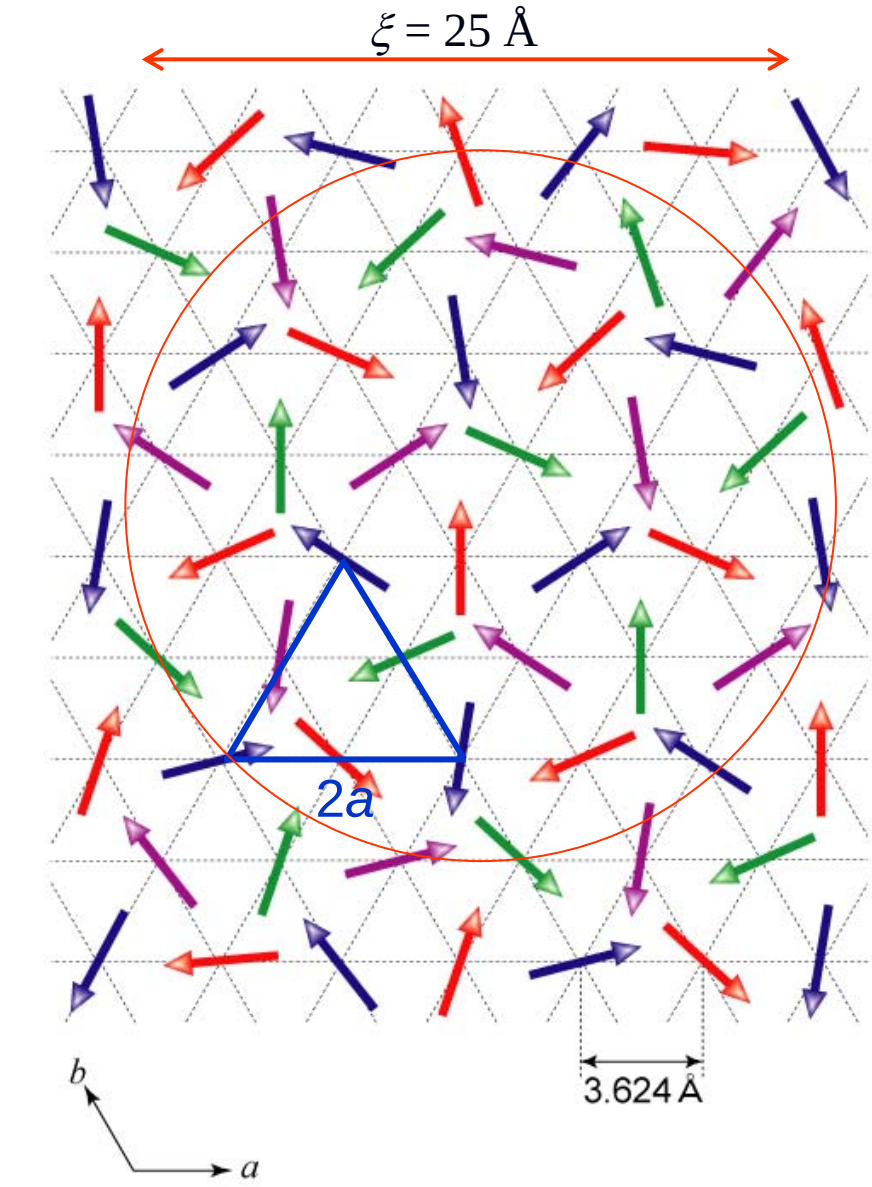
Nano scale correlation

short: $\xi = 1/\kappa \sim 2.5$ nm

slow: $\tau > 10^{-9}$ sec

Nearly no correlation between the planes: Highly 2D magnet

(1/6,1/6,0) correlation



Twice larger unit cell
in comparison with (1/3, 1/3, 0)

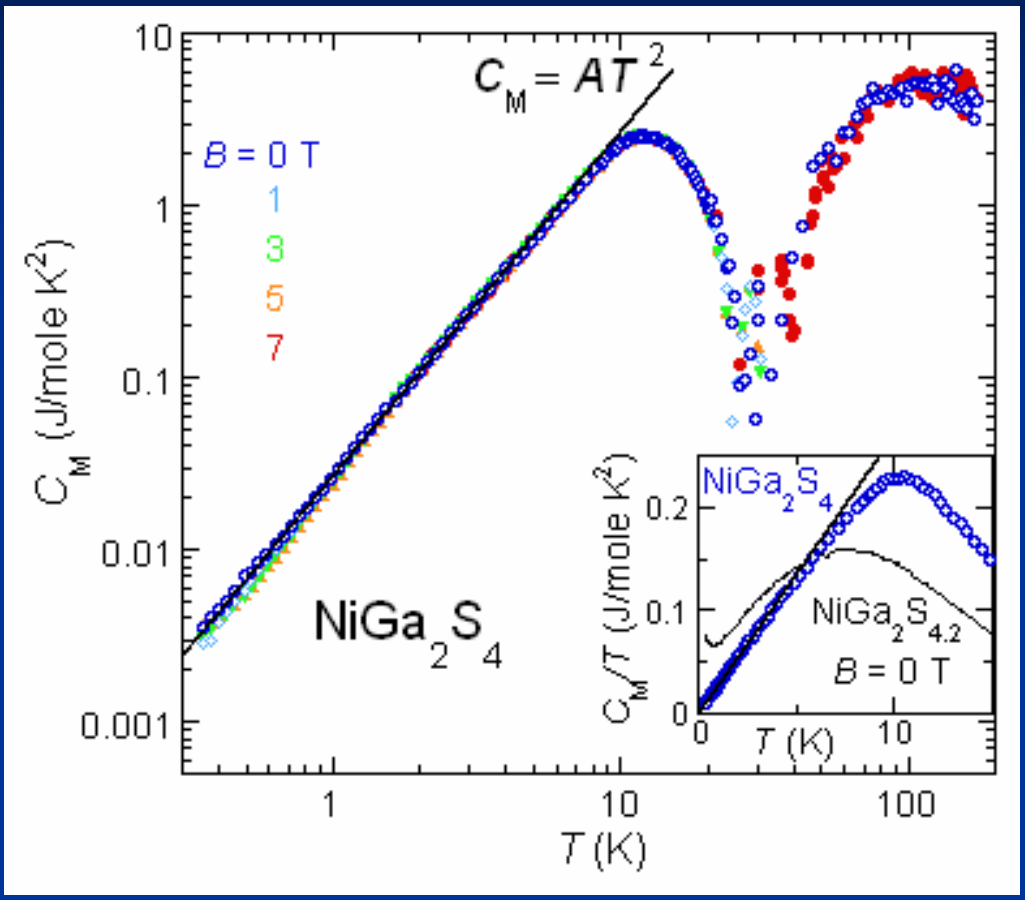
Possible origins

- Dominant 3rd nearest neighbor interactions

→ 4 sublattices of 120° order with 2*a* periodicity

- Multiple spin exchange due to proximity to Metal-Insulator transition

Coherence without magnetic order



- **Power Law Behavior**

$C_M \propto T^{\alpha}$ $\alpha = 2.001(5)$
at 0.35 K < T < 4 K

$C_M/T \rightarrow$ 0.0(1) mJ/mole K²

Similar to 2D AFM LRO

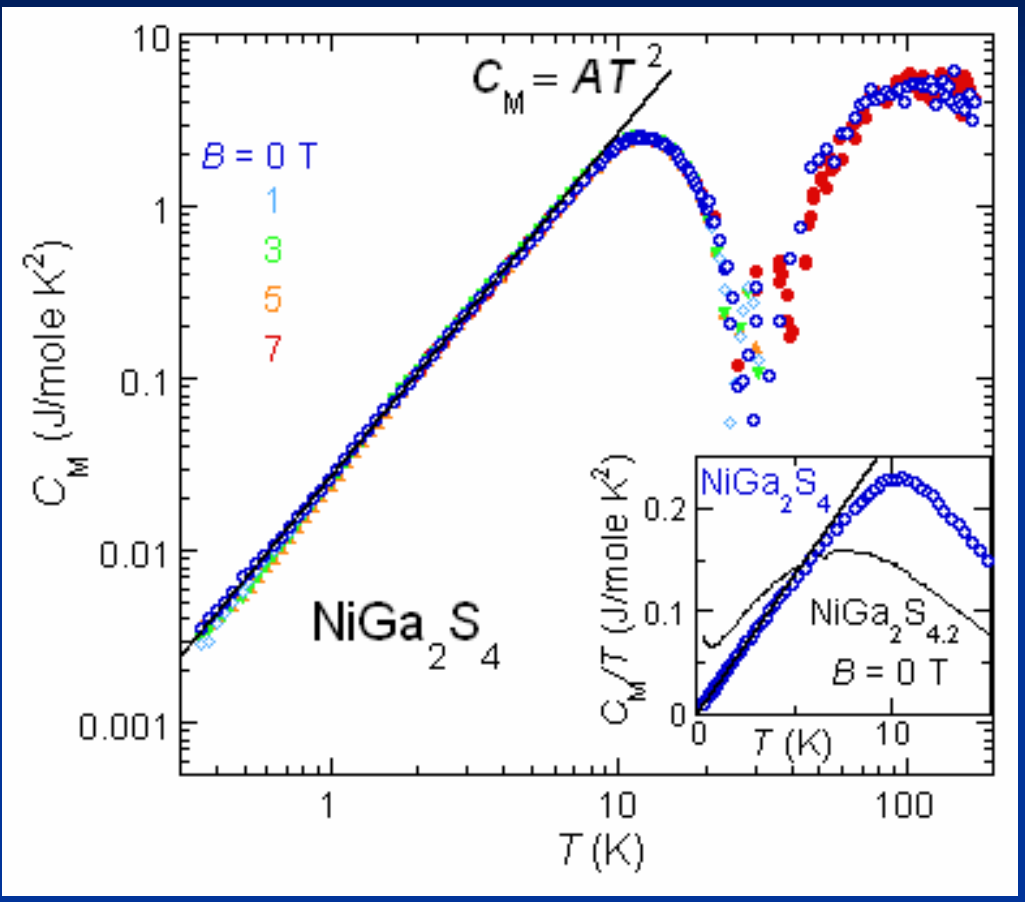
Novel Gapless Linearly Dispersive Mode in 2D

Coherence Length > 100 nm

- **Fragile against Impurities**

5% extra Sulfur doping → Residual C_M/T (0 K)

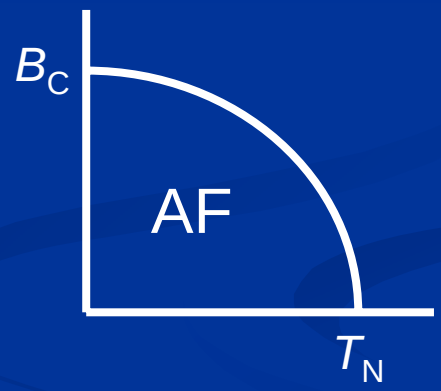
Moment-Free Excitations



- **Insensitive to Field**

No response even to

$B_c = k_B T_{peak}/\mu_B S \sim 7$ T



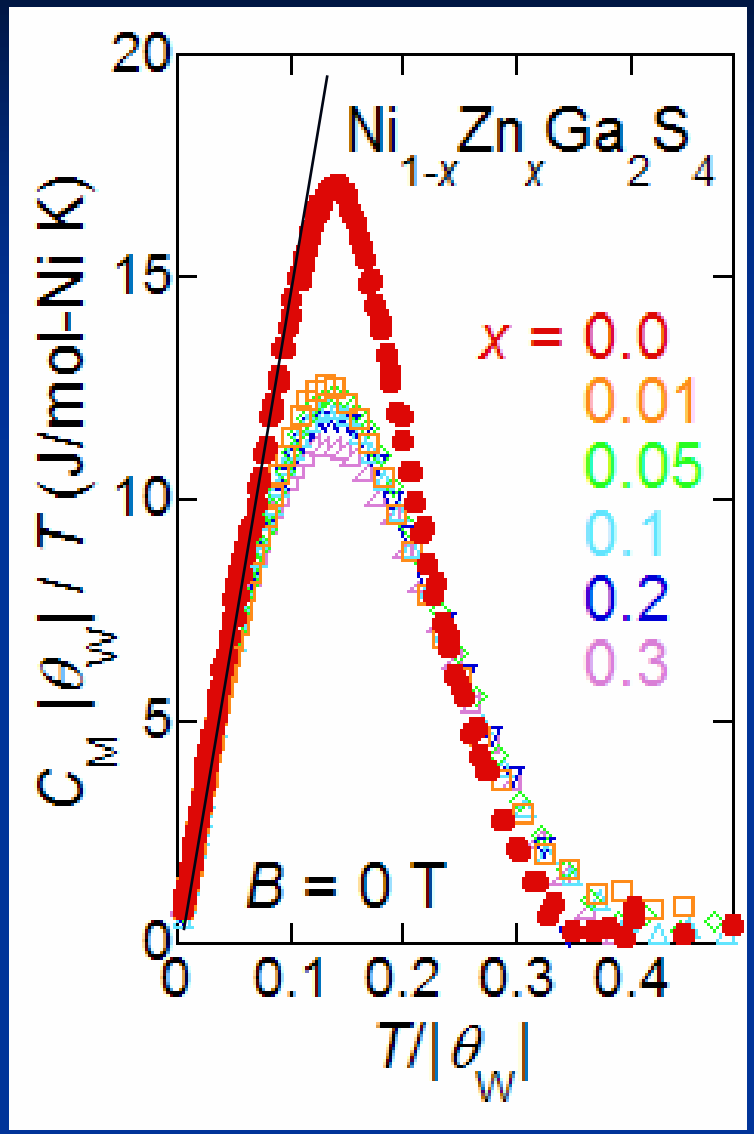
Spin excitation is
Not AF short range order

But, Moment Free
(Spinless) Clusters

Impurity Effects

➡ P-68 南部雄亮

Nonmagnetic Impurity (Zn: $S = 0$) Effect



Robust $C_M \sim T^2$ behavior

Scaling with θ_W

$$\rightarrow \quad C_M \propto \frac{T^2}{|\theta_W|^2}$$

Nambu-Goldstone mode in 2D AFM

↳ Symmetry Breaking

Y. Nambu, S. Nakatsuji, Y. Maeno, cond-mat/0511739

Summary

$NiGa_2S_4$: the first 2D triangular lattice with $S = 1$

- No AF order despite strong AF coupling
- Long-Range Coherence due to Symmetry Breaking
- Possibility of Novel Type of Magnetic Order or Spin Liquid State