Magnetic Frustration at Triple-Axis

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- Magnetism, Neutron Scattering, Geometrical Frustration

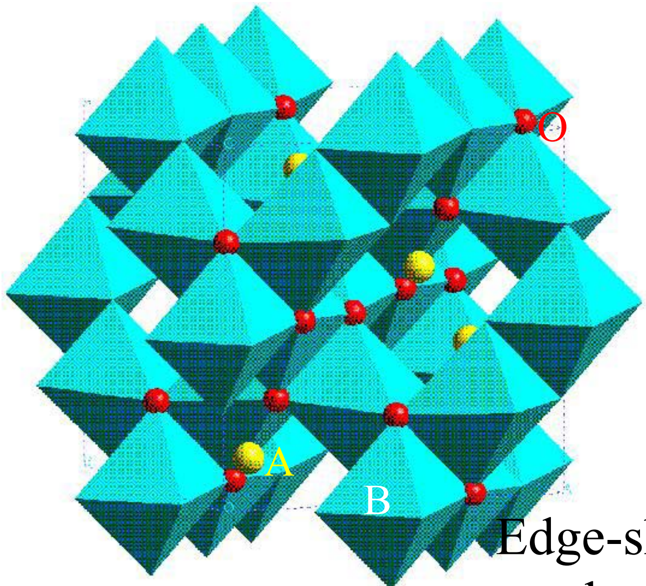
- $ZnCr_2O_4$: The Most Frustrated Magnet

  How are the fluctuating spins in the Spin Liquid phase correlated with each other?
  How does nature respond to the ground state degeneracy?

- Summary

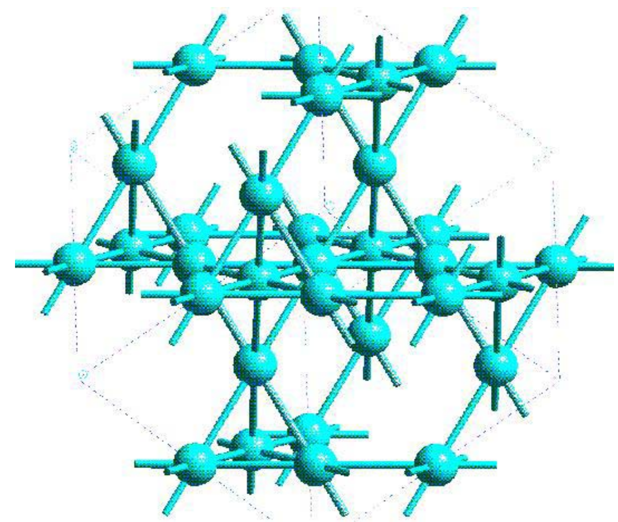
$ZnCr_2O_4$

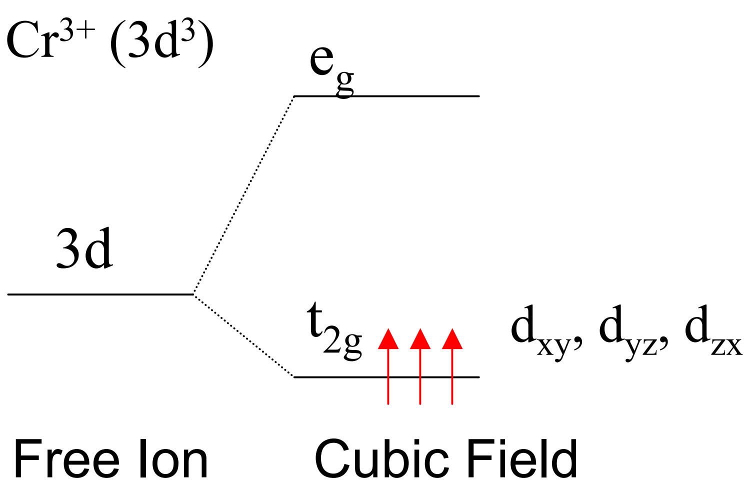
Space group Fd3m



Edge-sharing octahedra

Lattice of B sites
: Corner-sharing tetrahedra





$$H = -J \sum_{nn} \mathbf{S_i} \cdot \mathbf{S_j}$$

Magnetic Neutron Scattering

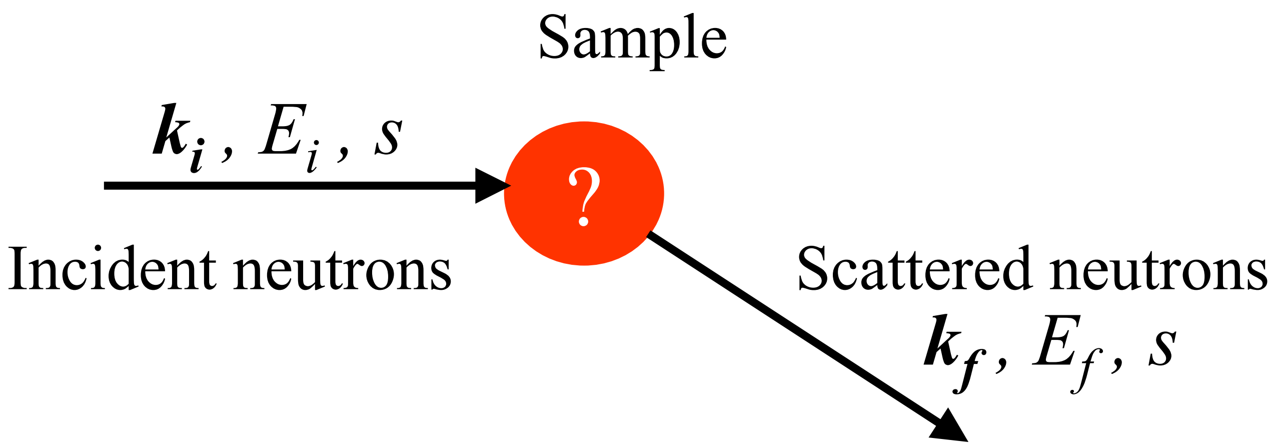
Neutron:

- Wavelength comparable with interatomic spacings
- Penetrating → bulk properties are measured
- has spin $s = \frac{1}{2}$ so interacts with atomic moments

Scattering by atomic
magnetic moments: $I = (0.54)^2 S(S+1)$

Magnetic scattering intensities can be comparable to nuclear scattering !!

Neutron Scattering



measures scattering cross section as a function of Q and ω

$$\frac{d^2\sigma}{d\Omega d\omega}(\mathbf{Q},\omega)$$

Magnetic Neutron Scattering Cross Section

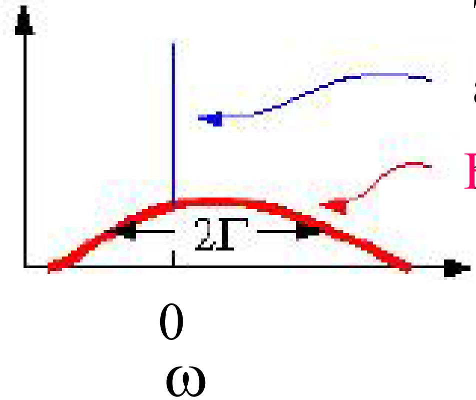
Spin-Spin Correlation Function

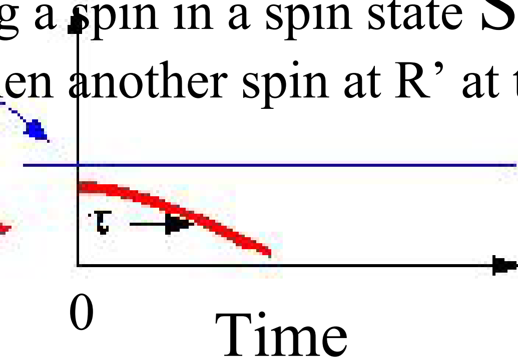
$$\frac{d^2\sigma}{d\Omega d\omega} \quad \xleftrightarrow{\text{Fourier Transform}} \quad < S_R(t)\, S_{R'}(0) >$$

The probability of finding a spin in a spin state S_R at position R at time t when another spin at R’ at time t=0 is in a spin state $S_{R'}$

Ordered moment

Fluctuating moment

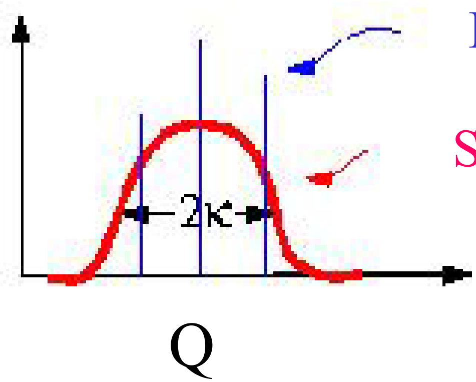


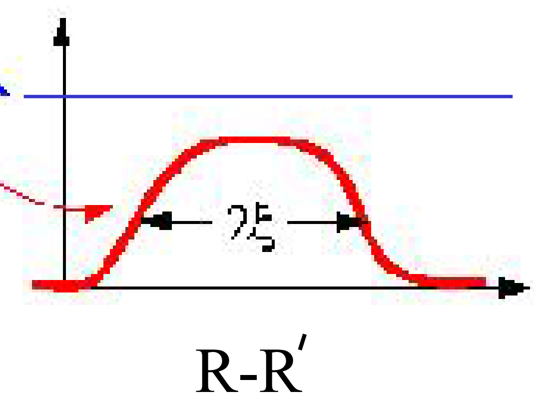


$\Gamma \sim \hbar/\tau$

Long range order

Short range order





$\kappa \sim 1/\xi$

Γ : relaxation time

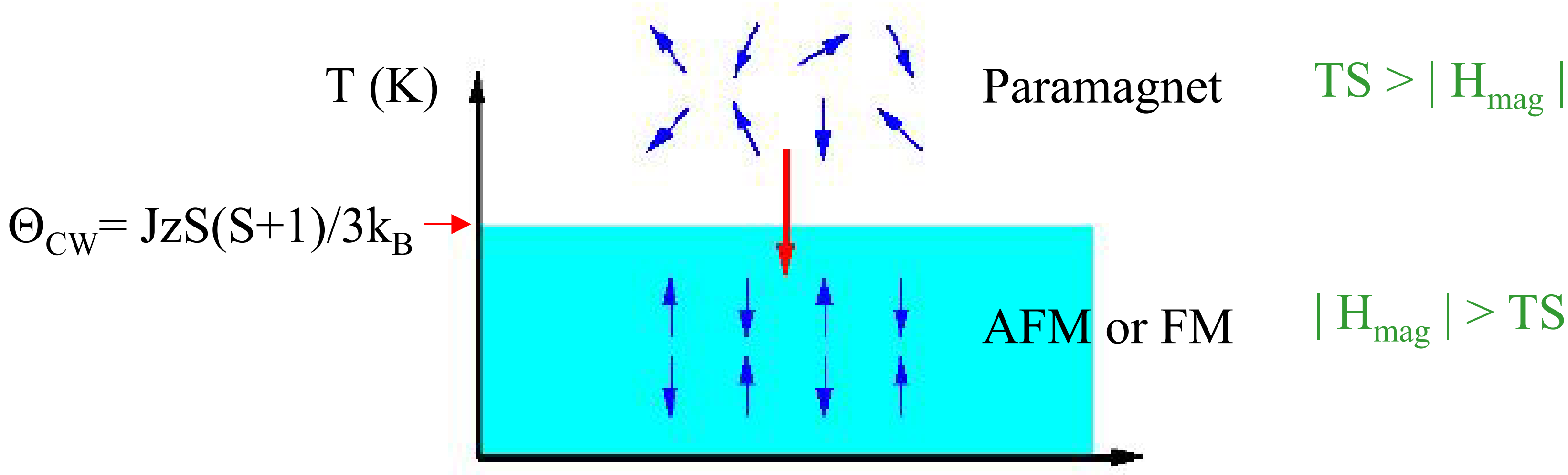
κ : intrinsic linewidth

τ : lifetime

ξ : correlation length

Phase Diagram for an Ordinary Magnet

$$F = H_{mag} - TS = - \Sigma J S_i S_j - TS$$



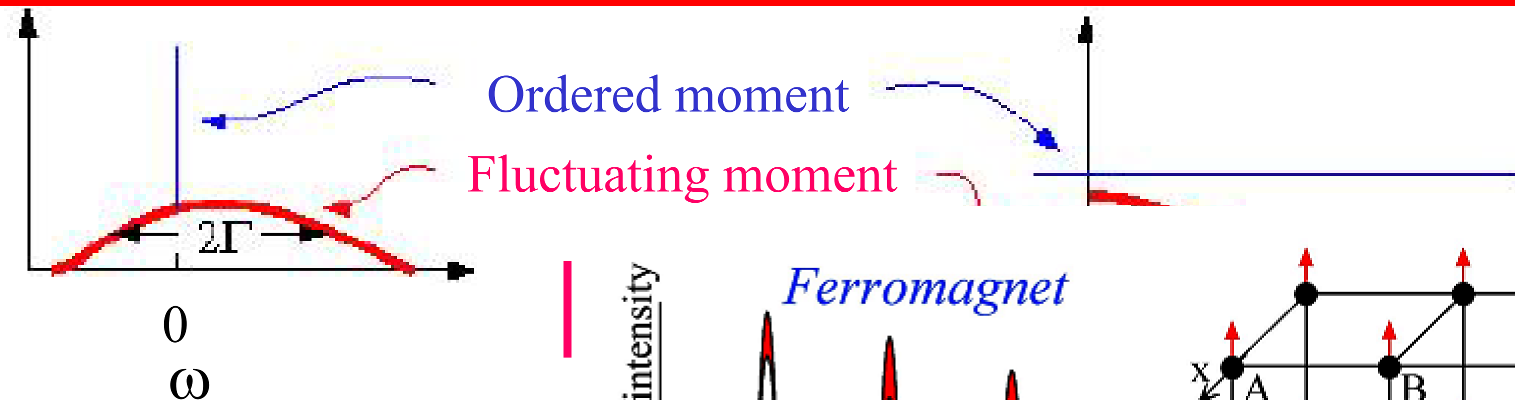
Ground State : Long range (anti)ferromagnetically ordered state.

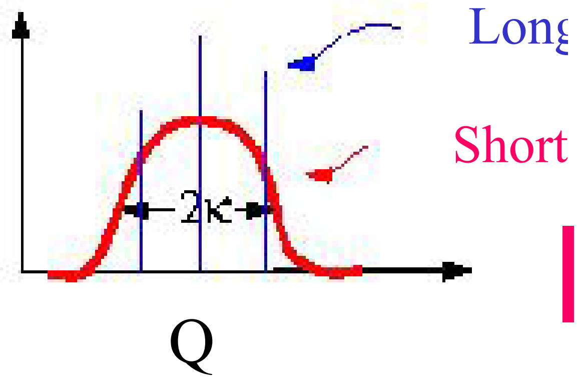
Low Energy Excitations : linear spin waves around the ordered state.

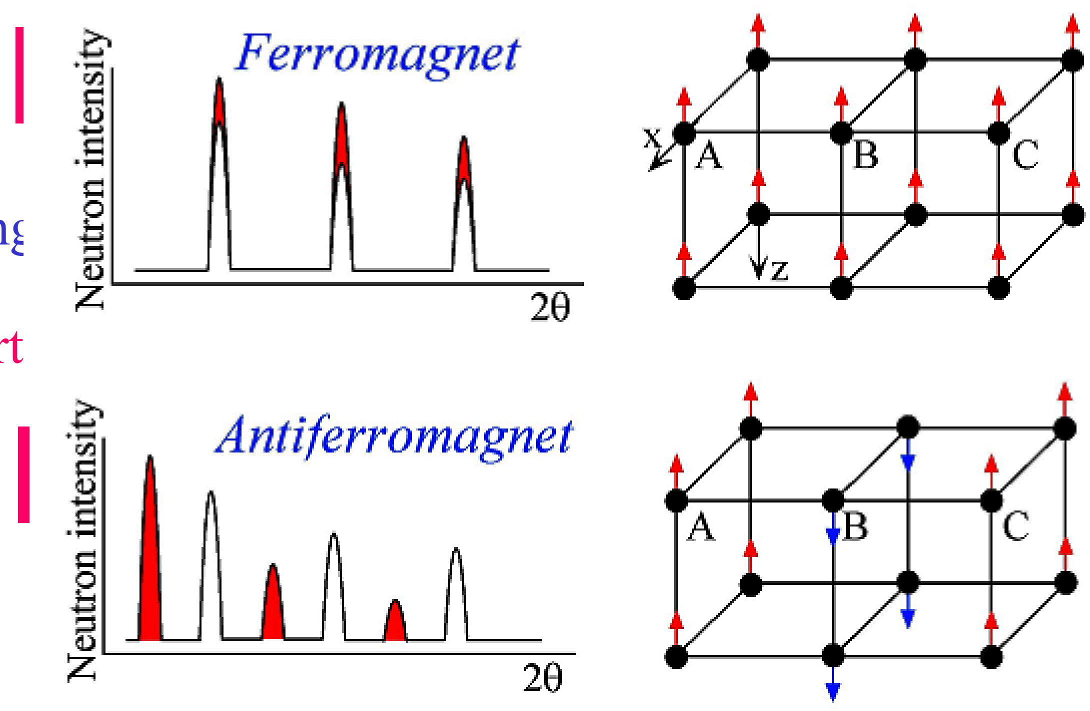
Neel phase:
What kind of magnetic scattering signal in Q and ω space would you expect?

(1) Any Elastic signal?

(2) Any Inelastic signal?   If any, what kind of shape in the ω- and Q-space?







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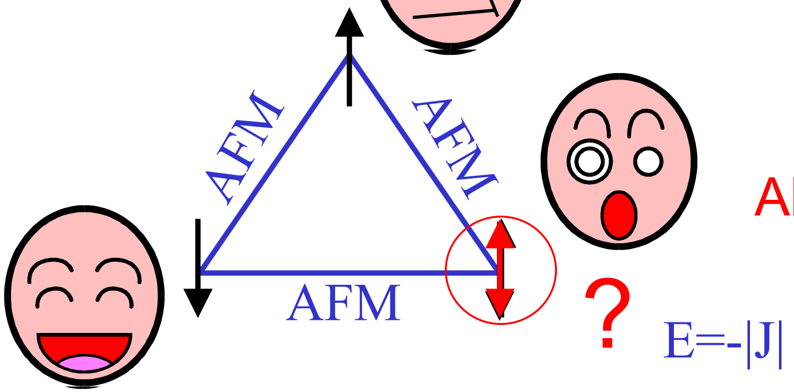
Geometrical Frustration

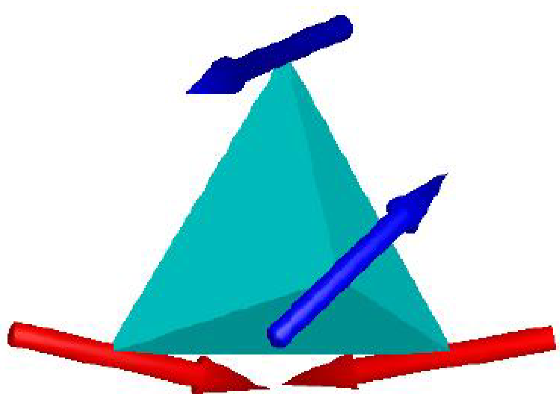
A simplest [illegible]le: a Triangle of three antiferromagnetic Ising spins



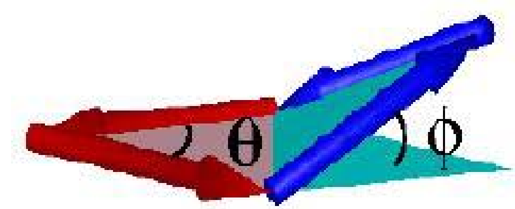
$$H = -J \sum \mathbf{S_i} \cdot \mathbf{S_j}$$

All exchange interactions can not be satisfied.

A tetrahedron with four isotropic spins



$\sum \mathbf{S_i} = 0$

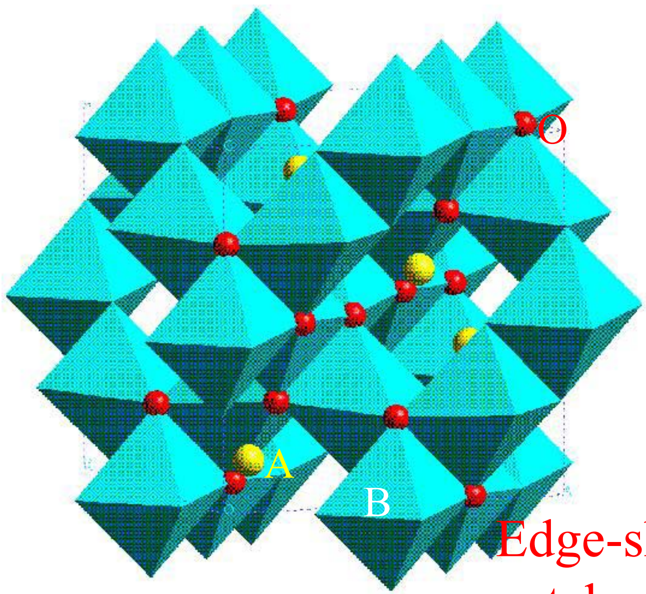


Zero energy modes
in the ground state manifold

Geometrical frustration leads to a large degeneracy in the ground state

Why $ZnCr_2O_4$?

Space group Fd3m



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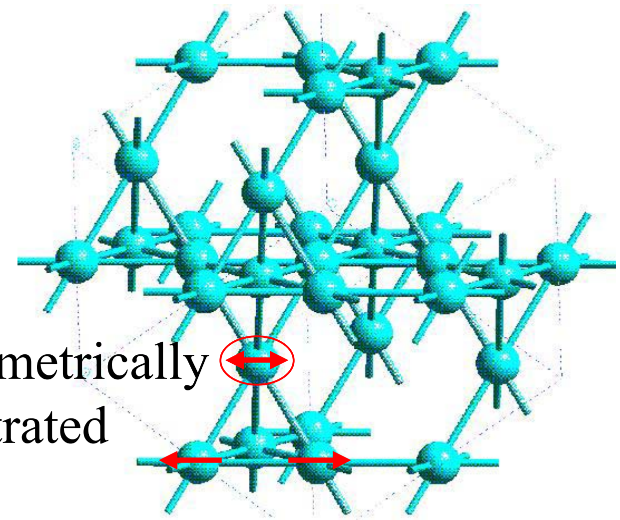
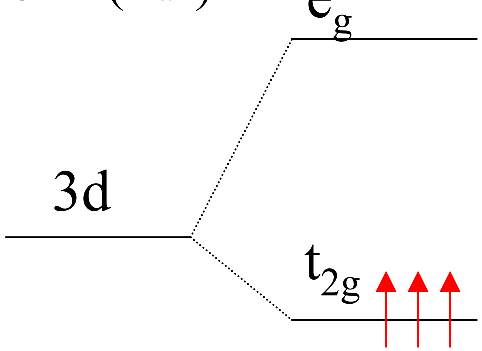


Geometrically frustrated

Cr^{3+} $(3d^3)$



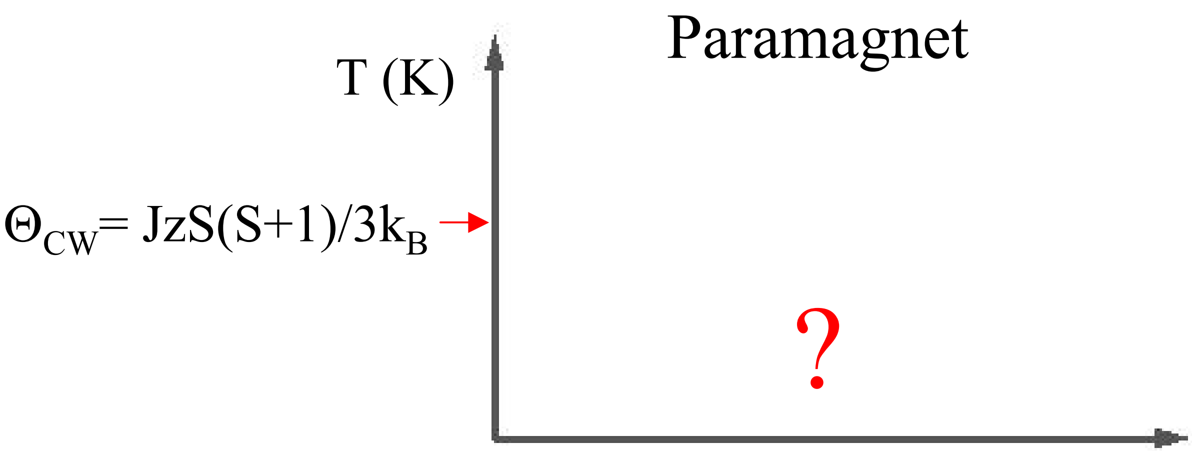
Interaction between nearest neighbor Cr^{3+} ions through direct overlap of t_{2g} orbitals is dominant.

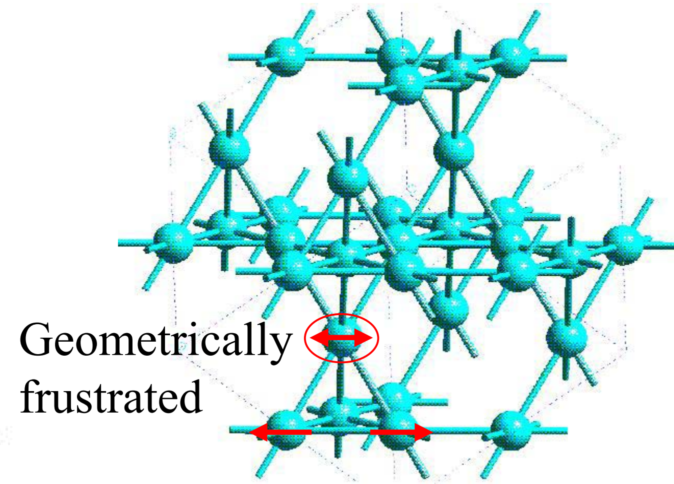
Best candidate for a system with

$$H = -J \sum_{nn} \mathbf{S_i} \cdot \mathbf{S_j}$$

Phase Diagram for Geometrical Frustration

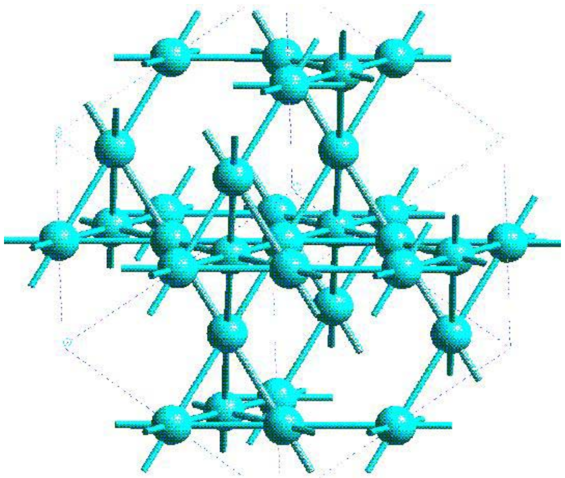
$$F = H_{mag} - TS = - \Sigma J S_i S_j - TS$$





What is the nature of the low temperature phase ?

Theory of spins with AFM interactions on corner-sharing tetrahedra



$$H = -J \sum \mathbf{S_i} \cdot \mathbf{S_j}$$

SPIN TYPE	SPIN Value	LOW T PHASE	METHOD	REFERENCE
Isotropic	S=1/2	**Spin Liquid**	Exact Diag.	Canals and Lacroix PRL ’98
Isotropic	S=∞	**Spin Liquid**	MC sim.	Reimers PRB ’92 Moessner, Chalker PRL ’98

Issues

- **Nature of the Spin Liquid State**

  How are the fluctuating spins in the SL phase correlated with each other?

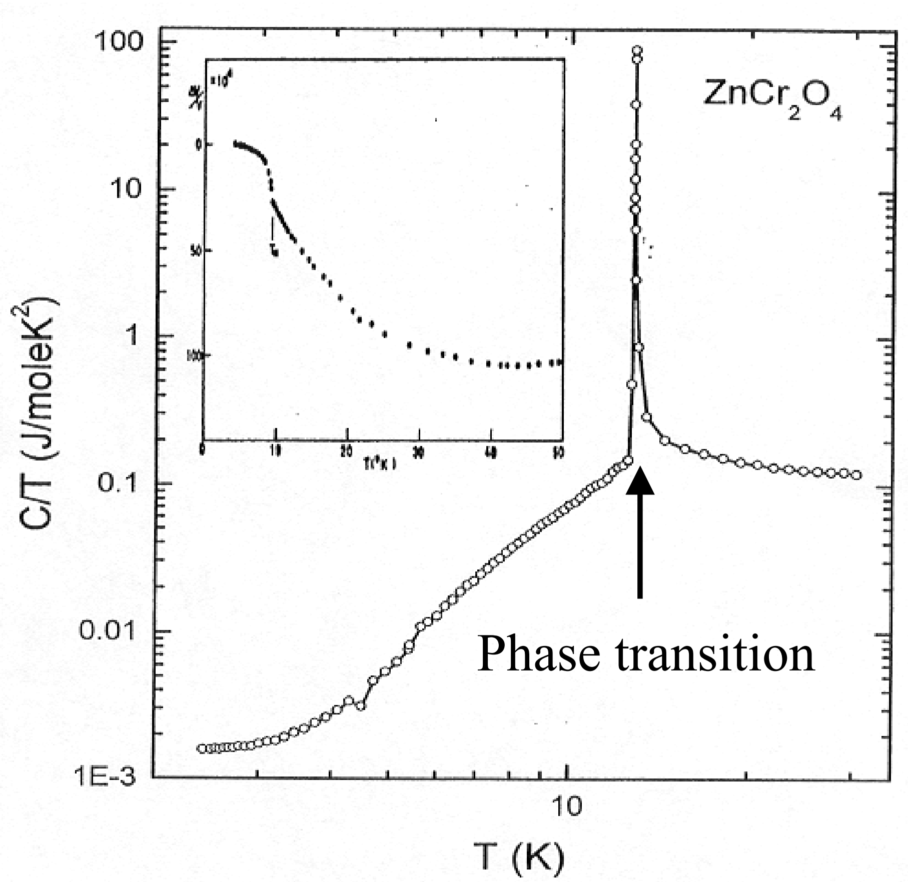
- **Novel Phase Transition?**

  How does nature respond to the ground state degeneracy?

You will be able to answer the questions after the demonstration session at SPINS!

A Phase Transition in $ZnCr_2O_4$

A.P. Ramirez, unpublished



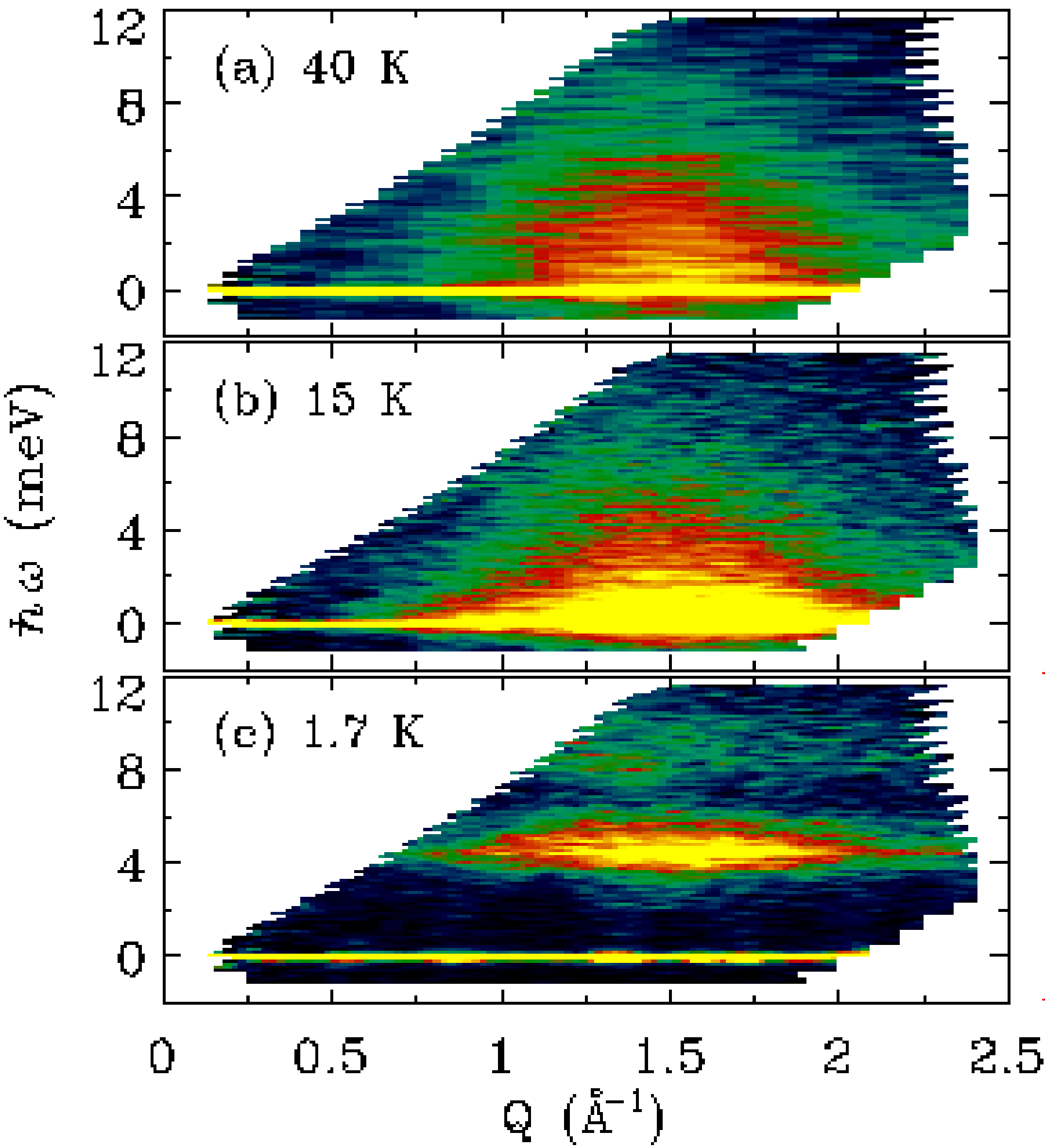
Θ_{CW} = -390 K

T_N = 12.5 K

What is the nature of the phase transition?

Neutron Scattering from $ZnCr_2O_4$

SHL et al., PRL 84, 3718 (2000)

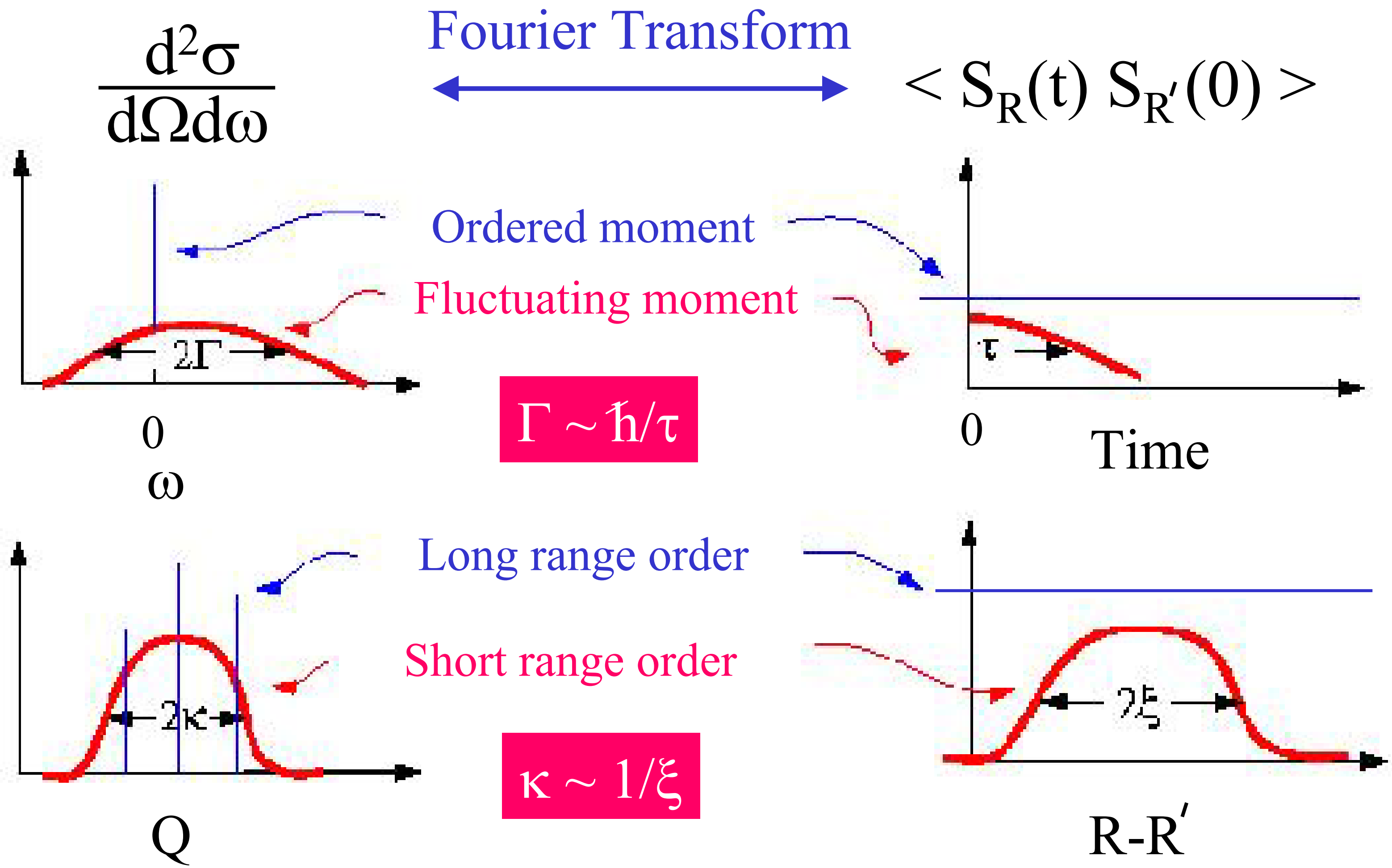


Paramagnetic fluctuations in frustrated AFM

Local spin resonance in magneto-elastic LRO phase

Keep in mind !!!

Neutron scattering is the most powerful technique to study magnetism!!



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SPINS : Cold Neutron Triple-Axis Spectrometer