Neutron scattering studies on frustrated spin systems

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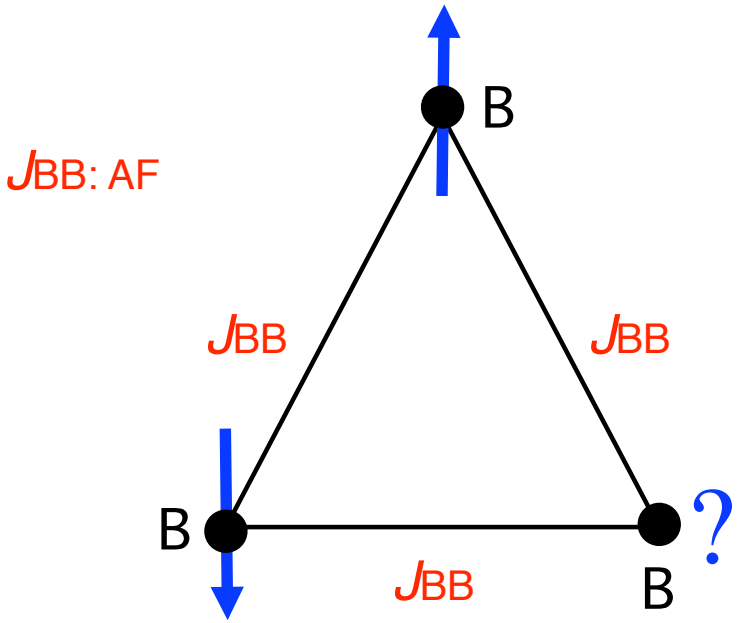
Topics:

- Novel excited state in geometrically frustrated magnet
- High-magnetic-field measurement on triangular lattice magnet

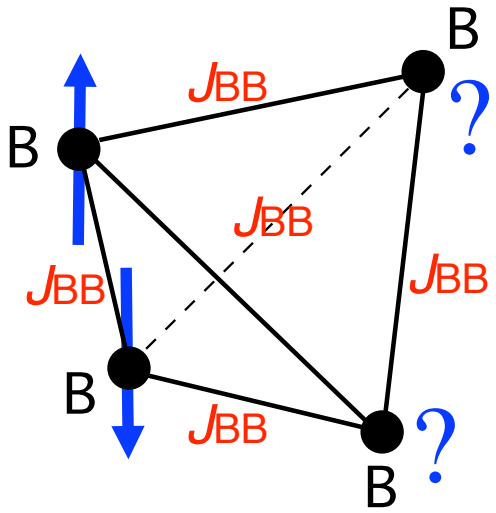
Introduction I

What is geometric frustration?

On regular triangle



On regular tetrahedron



No classic spin arrangement

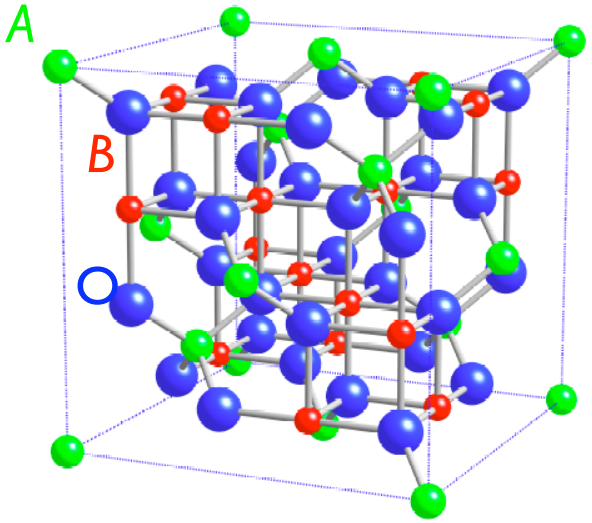
Spin frustration ≡ Many degenerated spin arrangements, generated by such cancellation of exchange interactions

G. H. Wannier, Phys. Rev. **79**, 357 (1950). P. W. Anderson, Phys. Rev. **102**, 1008 (1956).

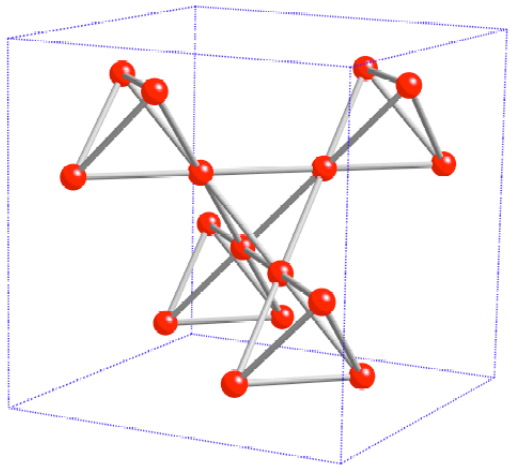
Introduction I

Real materials

spinel AB_2O_4

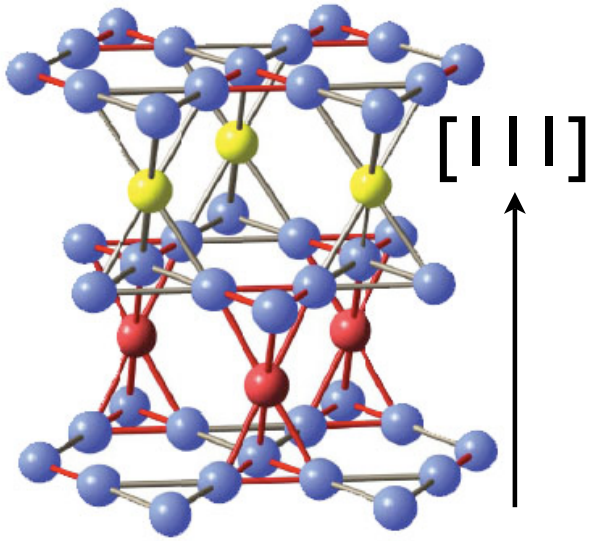


C15-Laves phase AB_2



pyrochlore lattice (Corner sharing tetrahedra)

Today's topics, ACr_2O_4, LiV_2O_4, YMn_2 *etc.*



... -kagome-triangle-kagome-triangle- ...

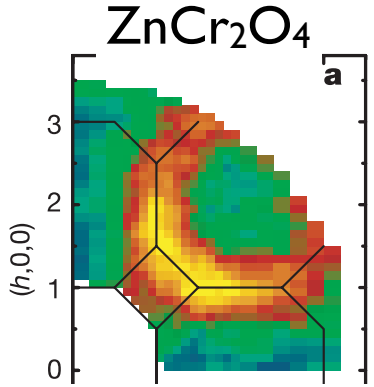
Ideal geometrically frustrated lattice, including pyrochlore $A_2B_2O_7$ also.

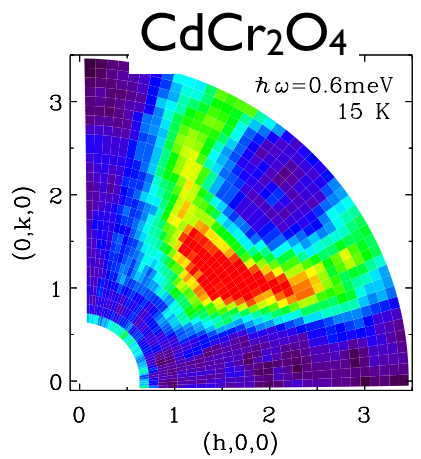
Long-range magnetic order can take place with lattice distortion.

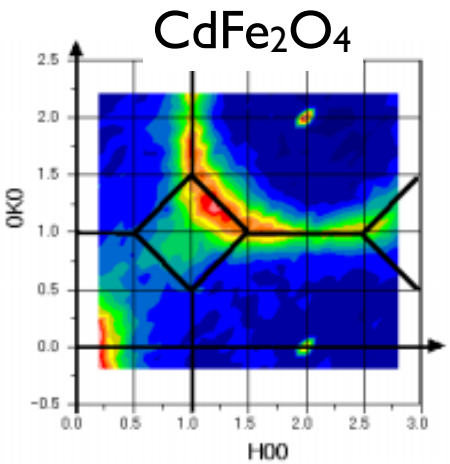
Y. Horibe *et al*. PRL **96**, 086406 (2006).

Introduction I

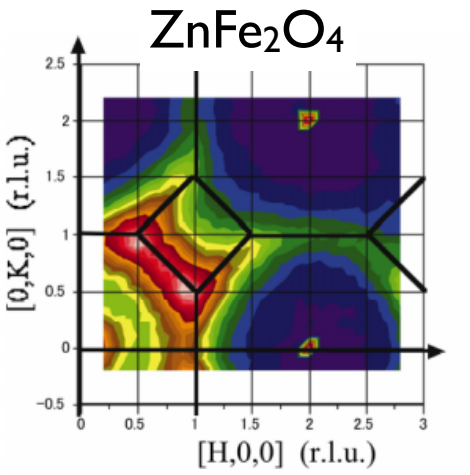
Paramagnetic scattering of *d*-el. systems



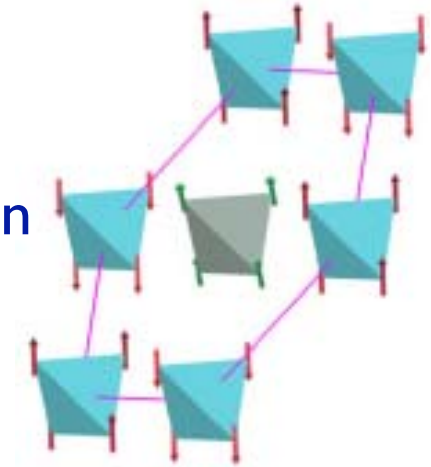




Small hexagon



Large hexagon



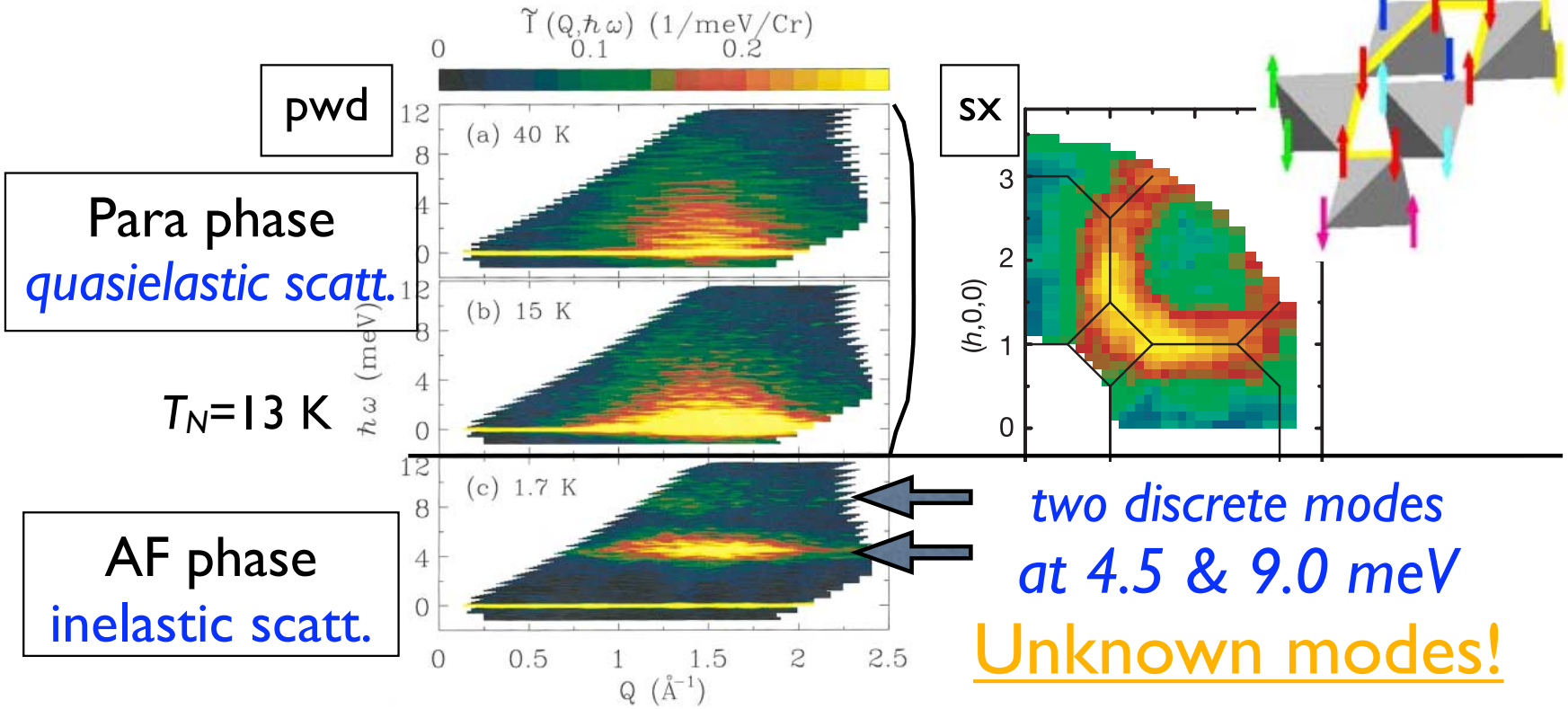
S.-H. Lee *et al.*, *Nature* **418**, 856 (2002). J.-H. Chung *et al.*, *PRL* **95**, 247204 (2005).
K. Kamazawa *et al.*, *PRB* **70**, 024418 (2004). K. Kamazawa, Ph.D thesis (2004).

Introduction 2

(a) Expanded geometric frustration?

$ZnCr_2O_4$

- in magnetically ordered phase

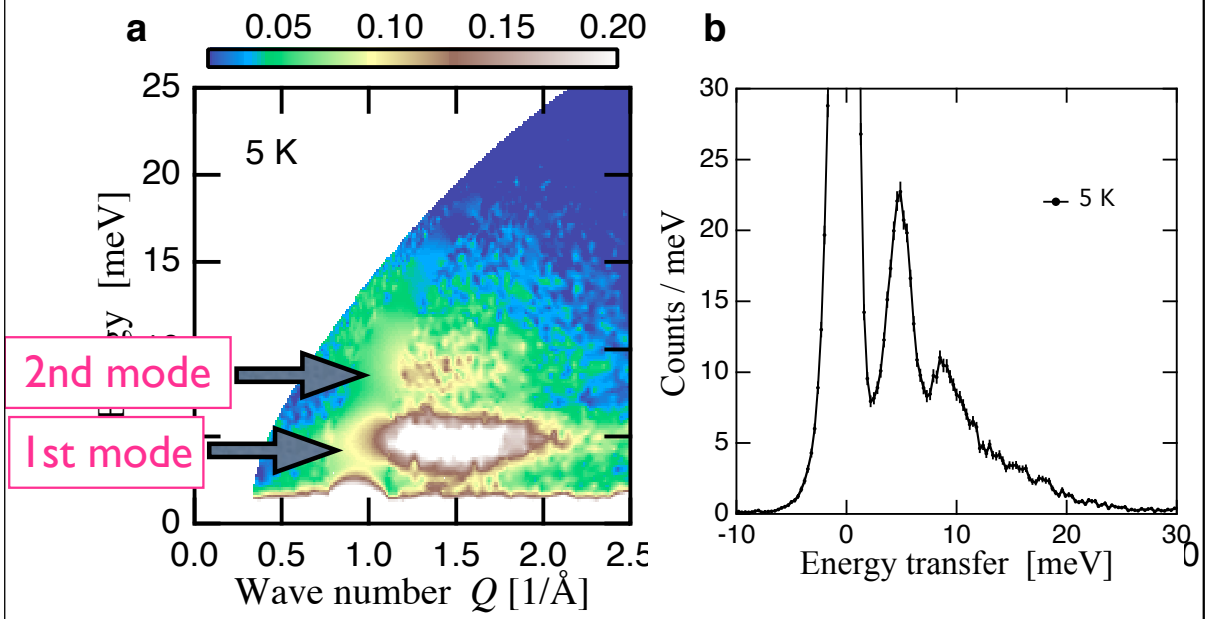


S.-H. Lee *et al.*, *PRL* **84**, 3718 (2000).

Results on $MgCr_2O_4$

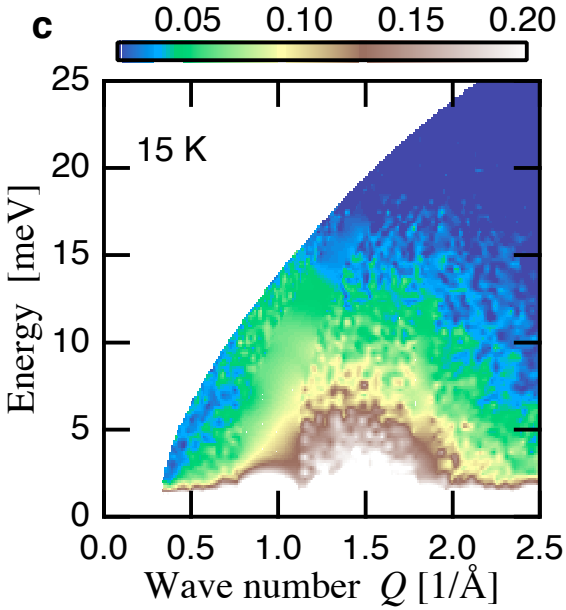
PWD inelastic scatt. data

ordered phase



discrete modes.

para phase



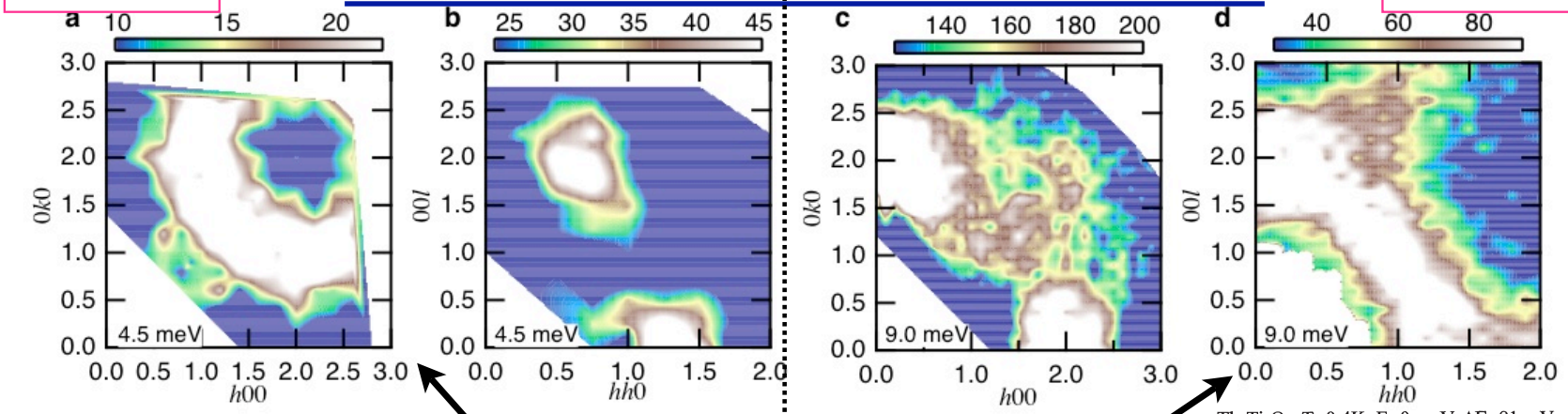
quasielastic scatt.

Results on $MgCr_2O_4$

SX inelastic scatt. data

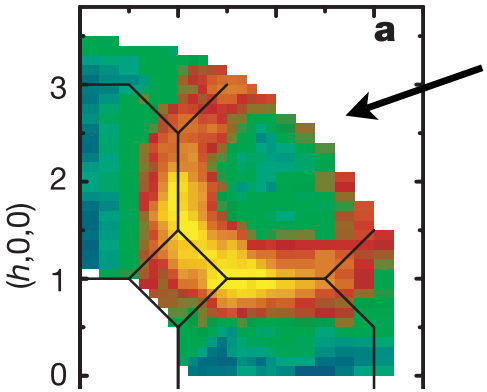
1st mode

2nd mode

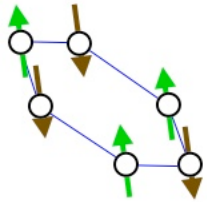


same

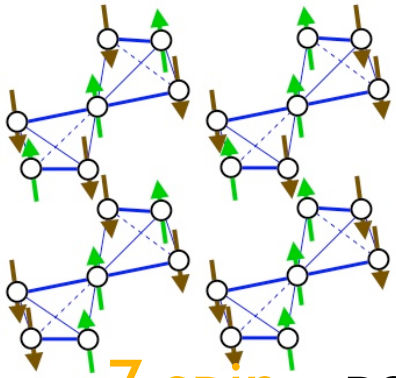
similar



paramagnetic data on $Zn/MgCr_2O_4$

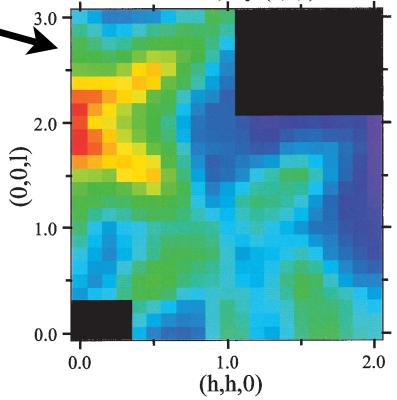


6 spin cluster



7 spin cluster

$Tb_2Ti_2O_7$, T=0.4K, E=0 meV, ΔE=81μeV observation, Q=(h,h,l)

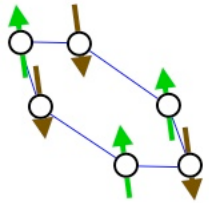


paramagnetic data on $Tb_2Ti_2O_7$

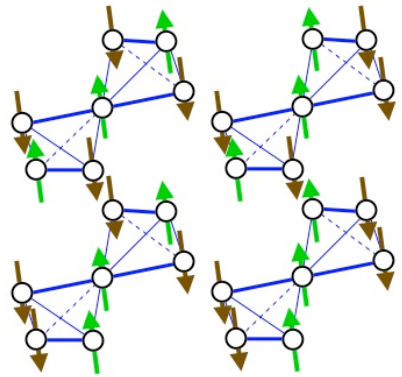
S.-H. Lee *et al.*, *Nature* **418**, 856 (2002).

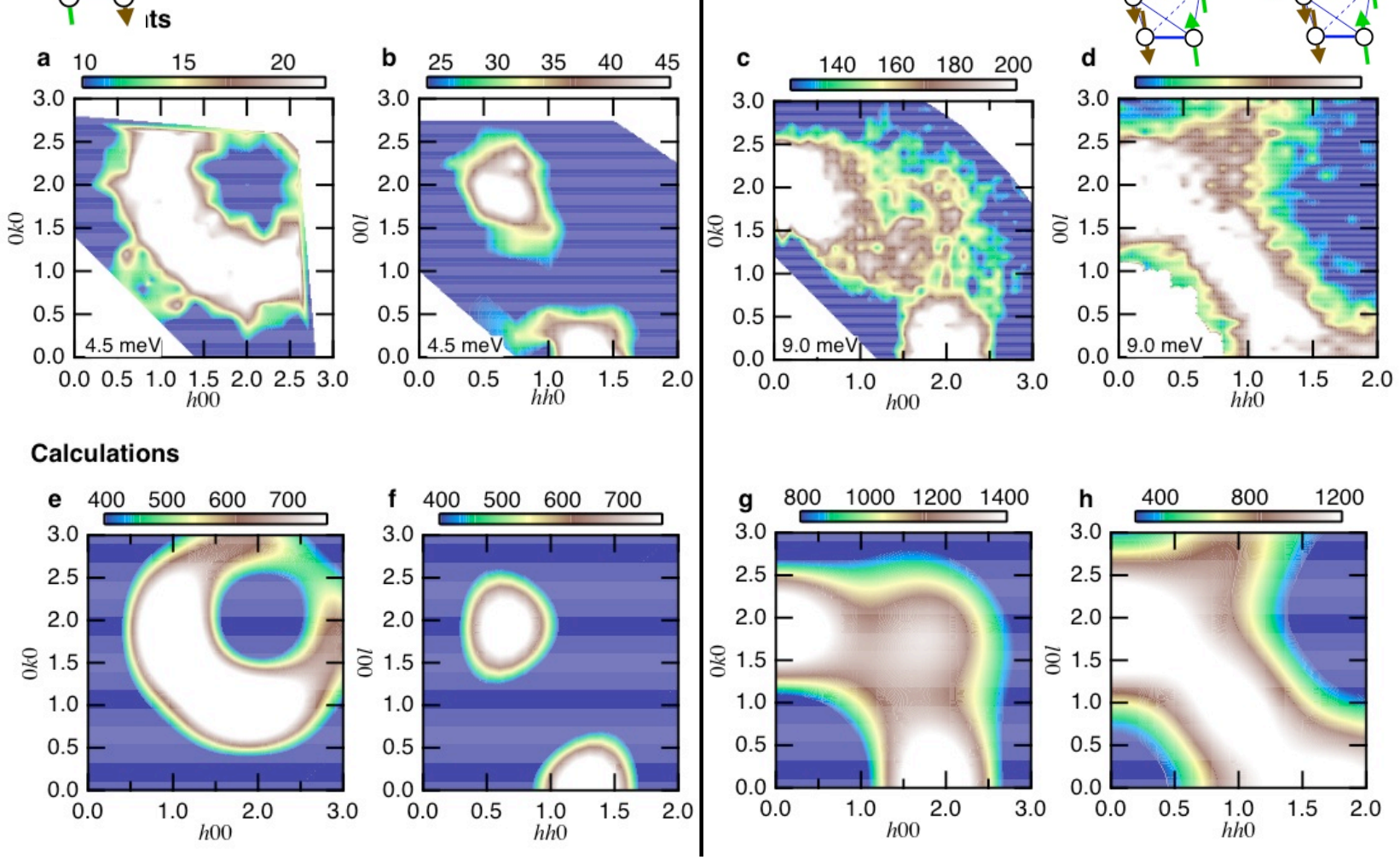
Y. Yasui *et al.*, *JPSJ* **71**, 599 (2002).

Results on $MgCr_2O_4$



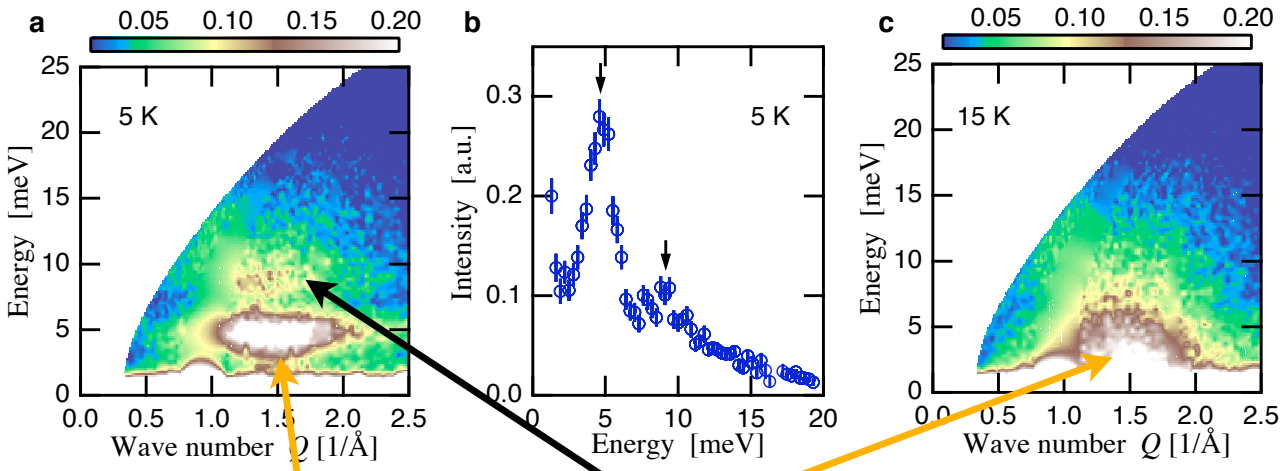
SX inelastic scatt. data

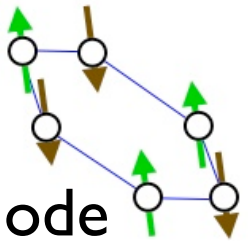




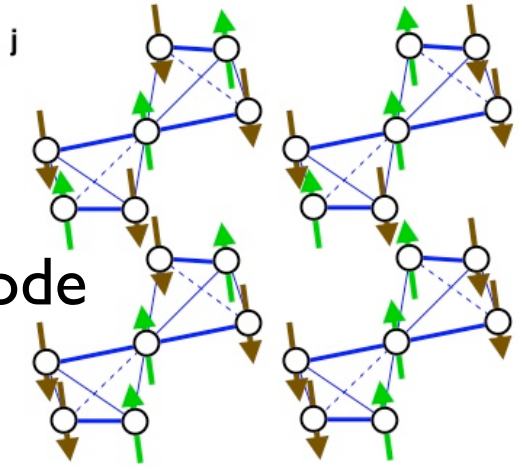
Results on $MgCr_2O_4$

Summary of results





para & 1st mode



2nd mode

Universarity of spin molecule and the origin?

High-magnetic-field measurement on triangular lattice magnet

principal investigator

Dr. K. Ohoyama

collaborators:

T. Yoshii,
Y. H. Matsuda
H. Nojiri

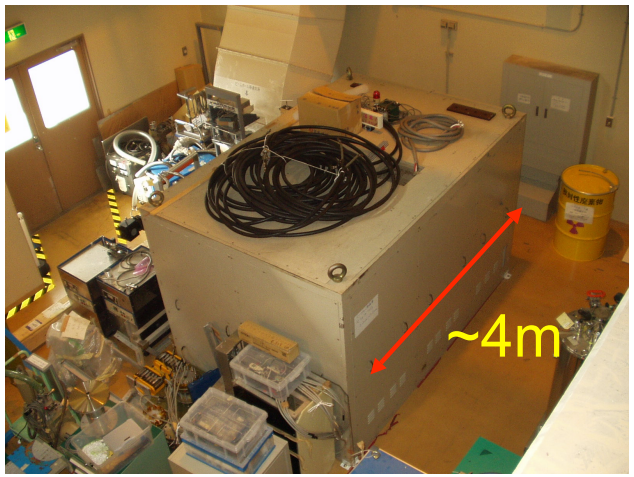
The Present situation of Magnetic Field for ND

The Present Situation of Neutron Diffraction

SC magnet: H<17.5T(Germany, HMI)
H<13T(Japan, JAEA)
Pulsed Magnet: H<25T (in KEK)
(Motokawa et al, Mitsuda et al.)

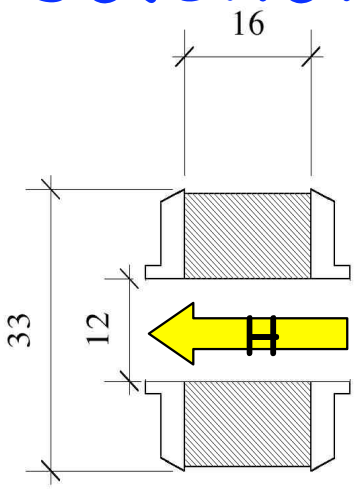
ND experiments over 10T are still difficult and limited for the present.

Easier and more Diffusive techniques are ambitioned.



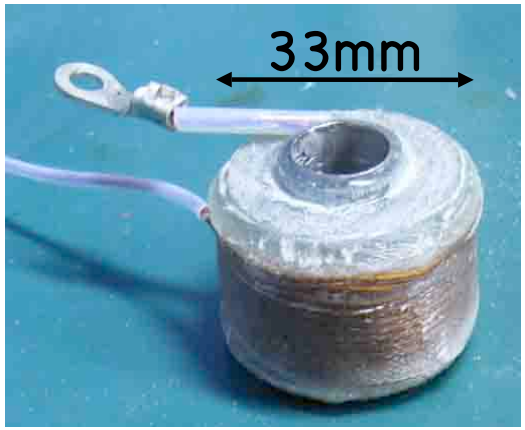
The Condenser Bank used in KEK
(It's too large!)

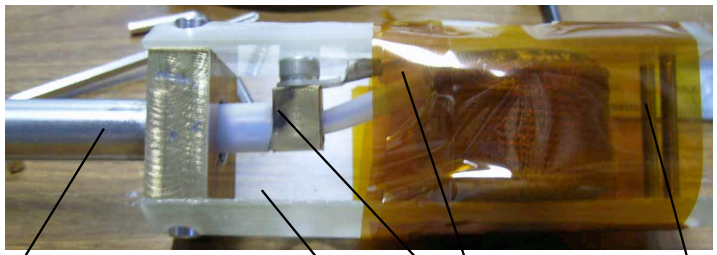
Solenoid Coil Magnet

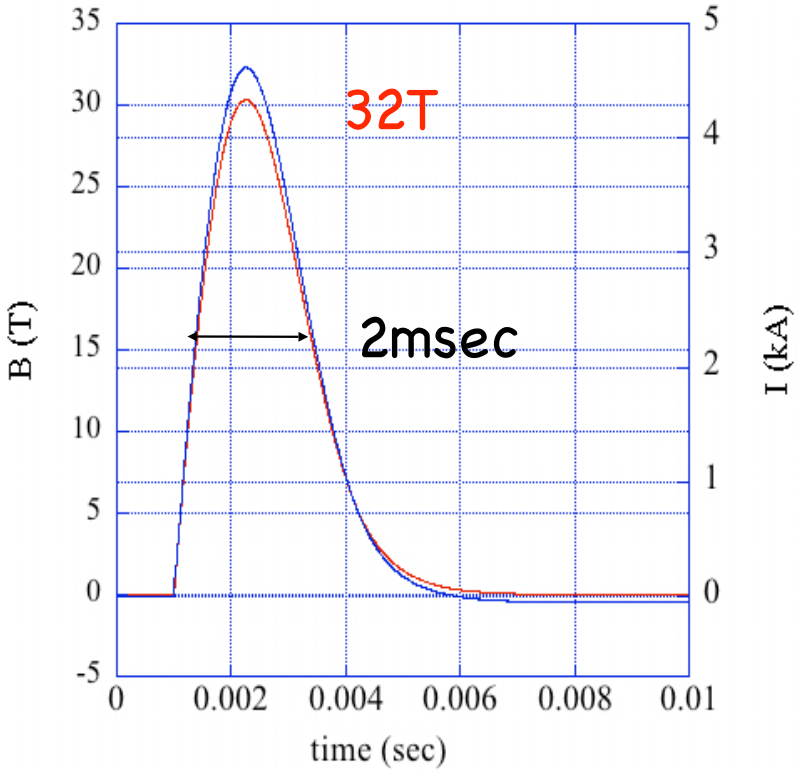


Coil Parameter
ID=12 mm, OD~33mm, length=16 mm filling factor 65 %
Wire 1 mm diameter Cu-Ag round wire
Resistance 82 % of Cu at R.T. R_{77K}/R_{RT}=0.27
~14 turn/layer, 10 layer
L=0.226 mH, R_{77K}=73 mOhm

An example wave form with our Capacitor bank of C=5.6 mF, L=8 microF, R=40 mOhm and charging voltage of 1.5 kV
30 T at 4.6 kA







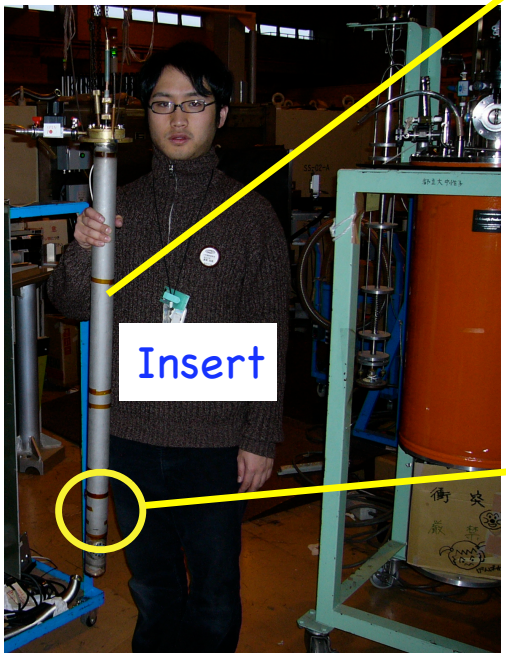
Coil Cooling System

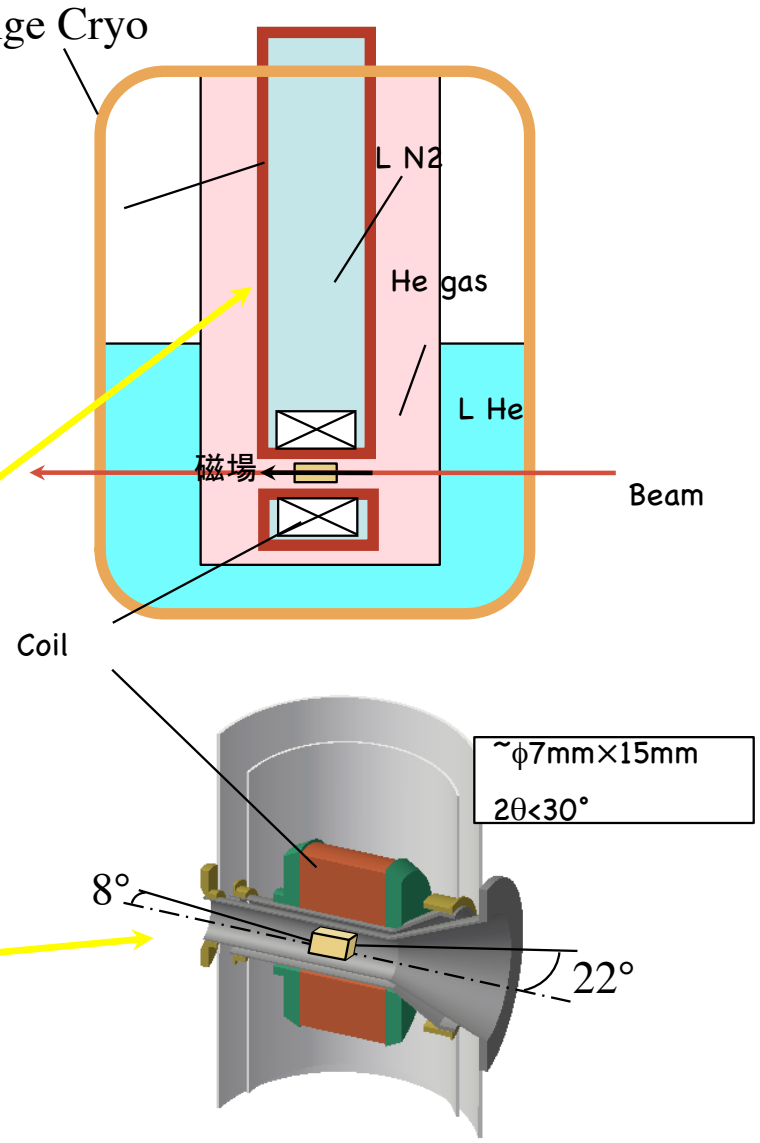
Interval is dependent on the cooling power.

Higher Cooling Power
Coil : Liquid N_2
Sample : Liquid He

Shortening of pulse interval
(~3-5min.)

2msec/5min
~0.001%

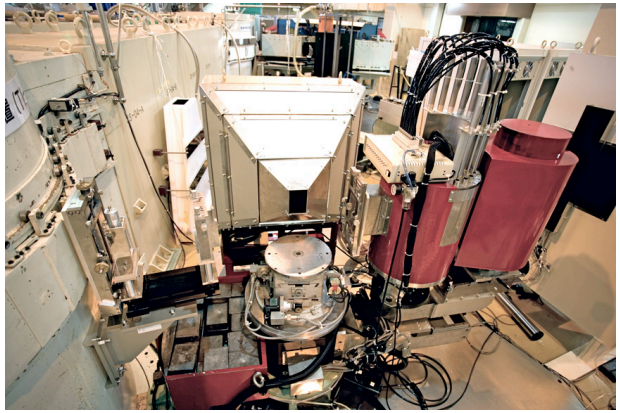


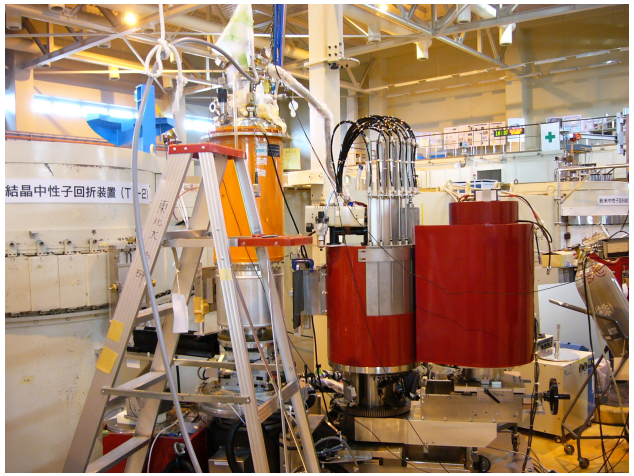


Instruments

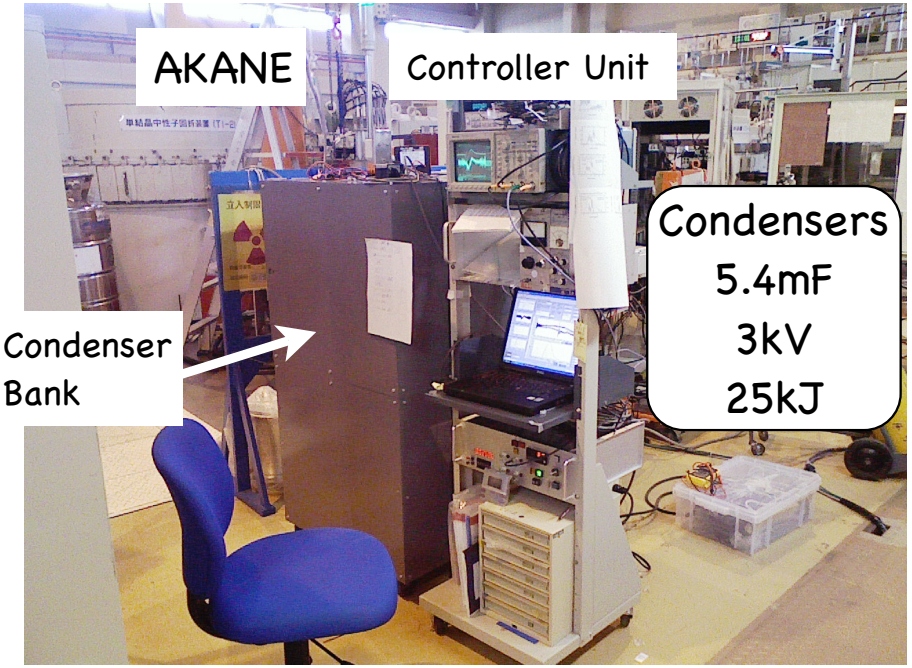
Tohoku Univ. Neutron Spectrometer AKANE

@ JRR-3M, JAEA(Tokai, Japan)





Compact Experiments!

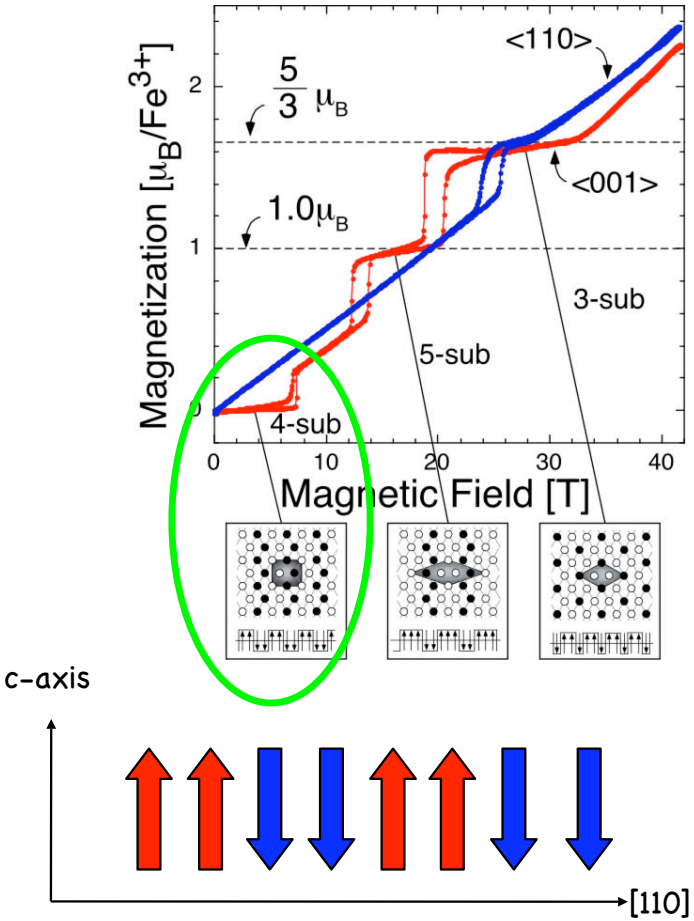


H_{max}~40T

This system can be installed at any spectrometers in Japan and oversea Facilities.

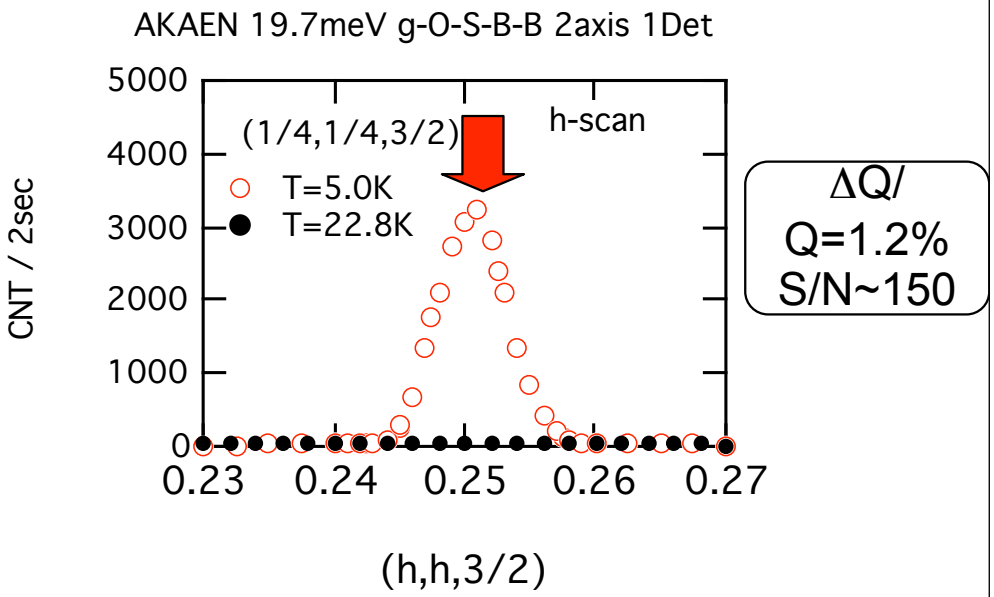
Results: $CuFeO_2$: ND on AKANE (H=0T)

Single Crystal (Mitsuda)
ϕ3.5mm×5mm



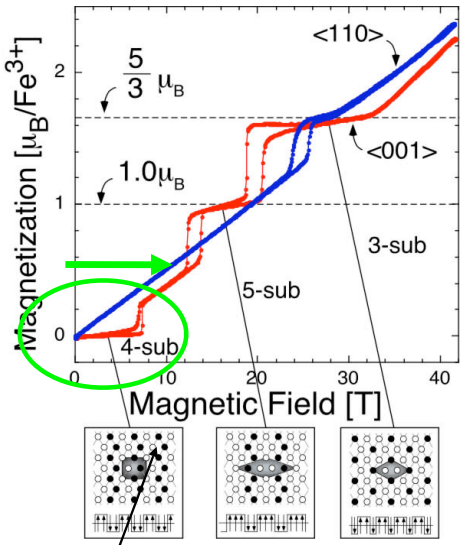
4-Sub. Peak at (1/4,1/4,3/2)

H=0T

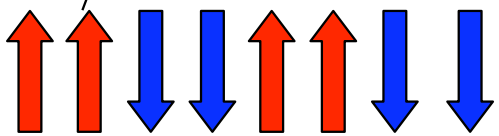


We measured the time dependence of the peak top intensity under magnetic field.

Disappearance of 4-Sub. Peak under H=10T

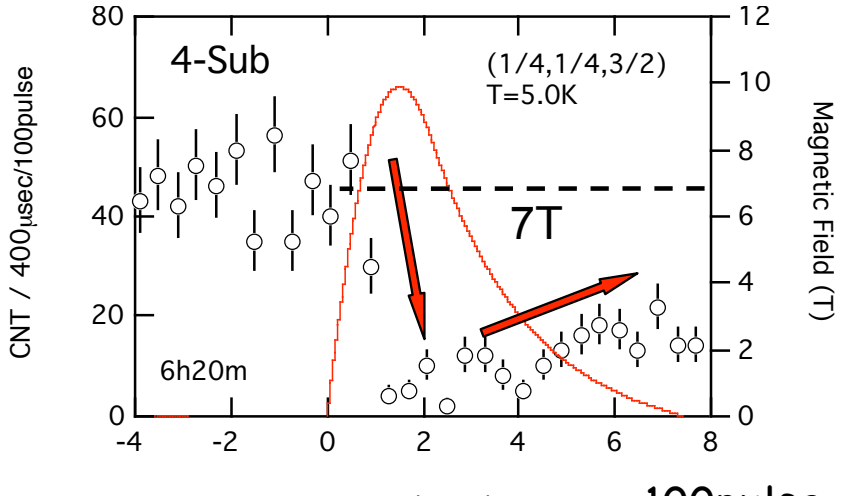


(1/4,1/4,3/2)



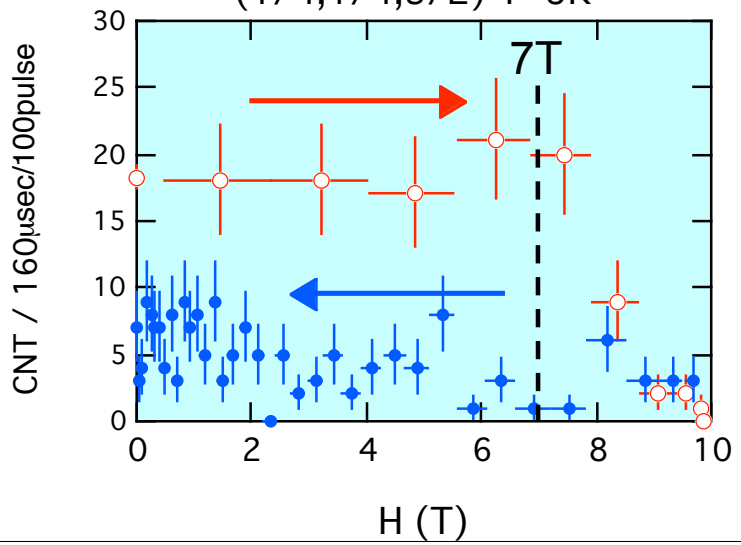
4-Sub. Peak disappears for H>7T.

Peak Top Intensity of 4-Sub. Peak
At (1/4,1/4,3/2)



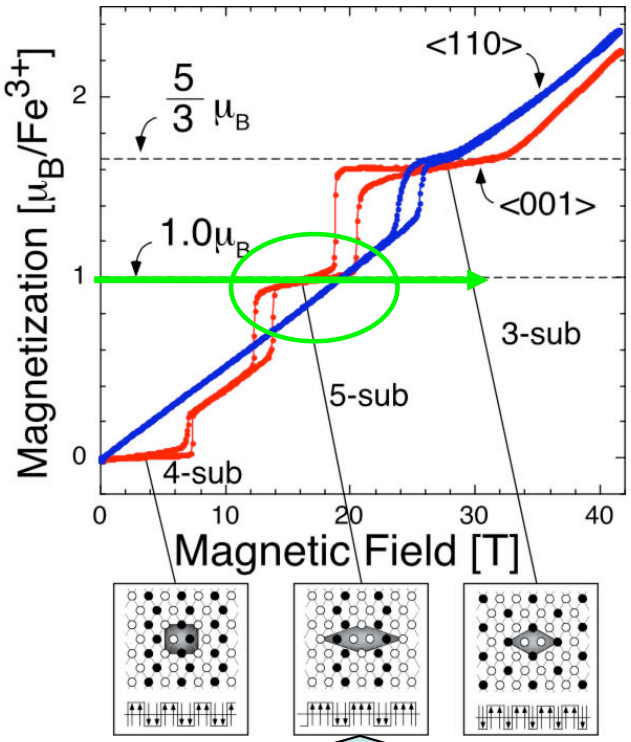
100pulse, 6.5hr

(1/4,1/4,3/2) T=5K



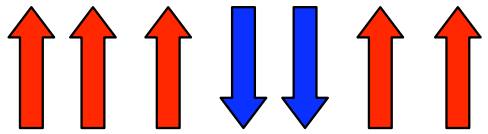
31.5T Experiments: World Record for ND!

5-Sub. Peak

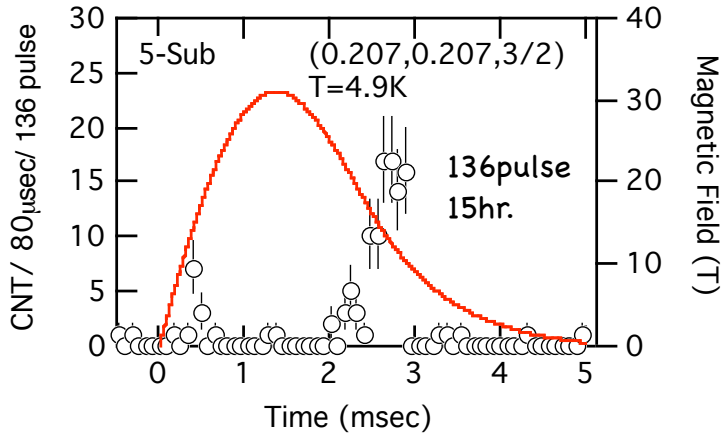


5-Sub.

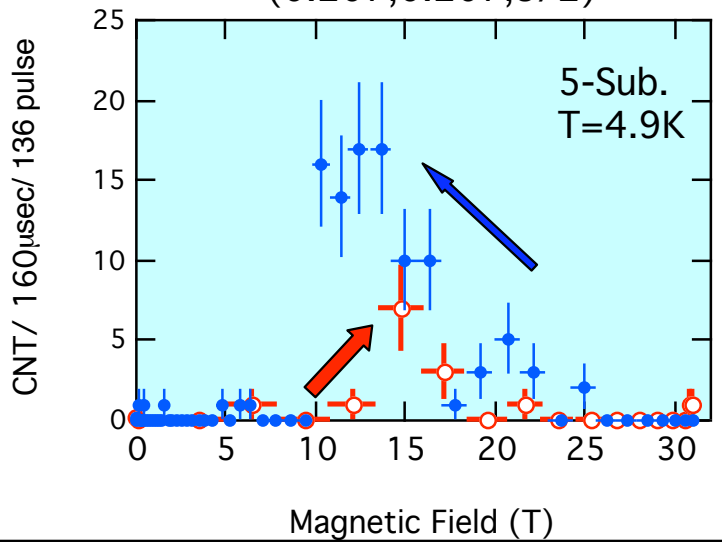
(0.207,0.207,3/2)



AKAEN 19.7meV g-O-S-B-B 2axis 1Det



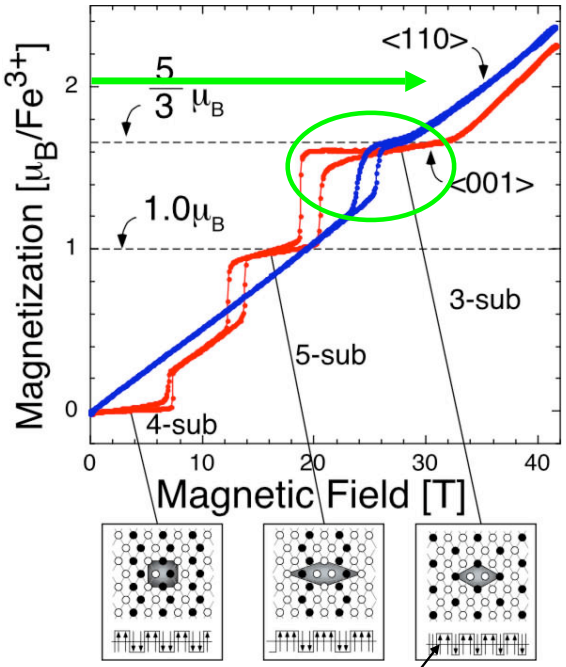
(0.207,0.207,3/2)

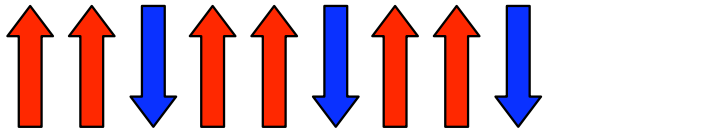


31.5T is the highest magnetic field in the World for ND. ⇨ 40T

3-Sub. Peak under 29T

22T<H<32T

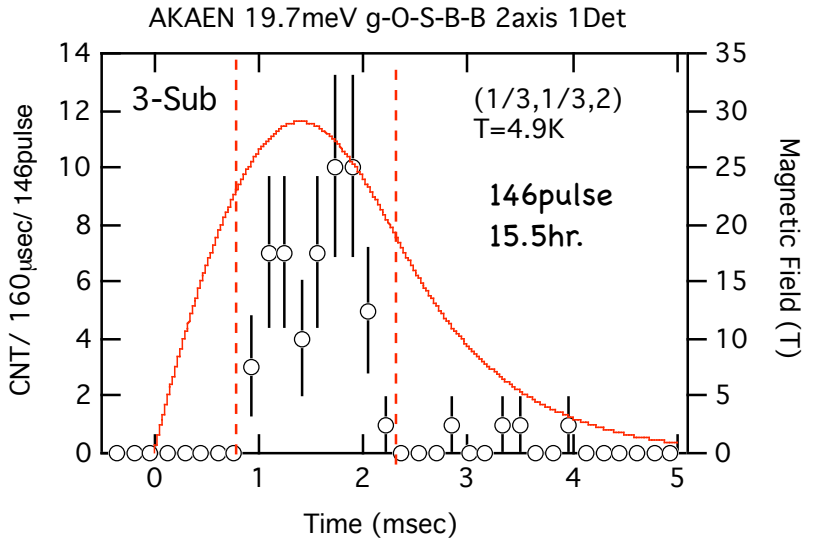


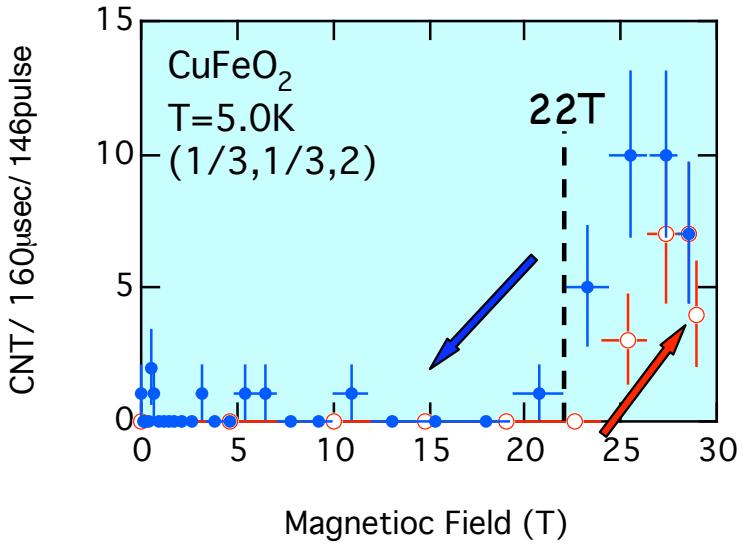


(1/3,1/3,2)

3-Sub. Structure

Neutron Counts at (1/3,1/3,2)





3-Sub. Structure is induced above 20T.

Summary

Novel excited state in geometrically frustrated magnet

- ***Nature of frustration*** is quite robust

  as molecular spin excitations were observed in the ordered phase.

  Study for the universality of dynamic geometric frustration and the origin of spin molecules is important.

High-magnetic-field measurement on triangular lattice magnet

- ***Compact system of magnetic field generation*** for neutron scattering experiment was developed.

  We succeeded in observing change of magnetic reflections in $CuFeO_2$ under 31.5T, the highest magnetic field for ND experiments.