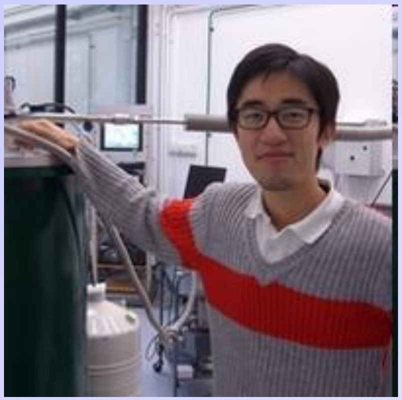
Kagome quantum spin liquids: some recent experimental developments

M. Jeong, F. Bert, E. Kermarrec, J. Quilliam, P. Mendels
Laboratoire de Physique des Solides,
Université Paris-Sud, Orsay, France

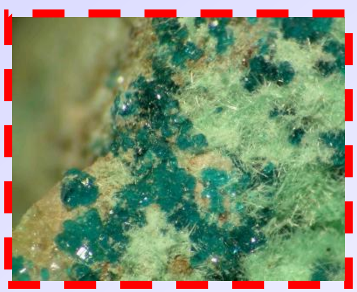


cnrs
UNIVERSITÉ PARIS SUD
IUF
TRIANGLE DE LA PHYSIQUE
AGENCE NATIONALE DE LA RECHERCHE ANR
EUROPEAN SCIENCE FOUNDATION

Cu^{2+} S=1/2
Materials are all existing minerals !

Herbertsmithite

Volborthite



Haydeeite

Kapellasite

Vesignieite

Kagome Physics vs time (exp[al]) :

- SrCrGaO (SCGO) Cr^{3+} (S=3/2) 90'
  - kagome bilayers
  - spin-glass freezing but large density of low energy excitations
  - Spin textures (A.Sen et al. Phys. Rev. Lett. **106**, 127203)

- Jarosites (classical spins) 90'
  - Neel transitions
  - importance of DM interactions

- Volborthite 2001
  - First S=1/2 kagome compound (1st nn interactions)
  - ordering, fluctuations(μSR), distorted lattice, field induced transitions

- Expansion of the quantum kagome universe 2005
  - Discovery of Herbertsmithite (2005)
  - No freezing (2007): a spin liquid state
  - Many cuprates : Kapellasite, Vesigneite, Haydeite
  - Also Hyperkagome ($Na_3Ir_4O_8$)

M.I.T., 2005

J|A|C|S COMMUNICATIONS

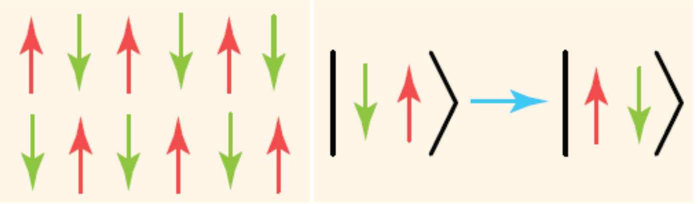
Published on Web 09/09/2005

A Structurally Perfect $S = {}^{1}/_{2}$ Kagomé Antiferromagnet

Matthew P. Shores, Emily A. Nytko, Bart M. Bartlett, and Daniel G. Nocera*

Department of Chemistry, 6-335, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139-4307

An End to the Drought of Quantum Spin Liquids



Patrick A. Lee

After decades of searching, several promising examples of a new quantum state of matter have now emerged.

Sciences, perspectives sept 2008

Outline

- Zn and Mg Herbertsmithite $Cu_3(Zn,Mg)(OH)_6Cl_2$
    - a gapless quantum spin liquid (summary)
    - field induced solidification of the QSL

Quantum criticality
Dzyaloshinky-Moriya interactions

- Vesignieite $Cu_3Ba(VO_5H)_2$
    - local susceptibility (NMR)
    - ~~heterogeneous~~ frozen ground state (µSR+NMR)

-Kapellasite, Haydeite $Cu_3(Zn,Mg)(OH)_6Cl_2$
    - competing exchange interactions
    - A new QSL, cuboc-2 type

J1-J2 model on kagome lattice
Novel spin liquid?

Zn and Mg Herbertsmithite $Cu_3(Zn,Mg)(OH)_6Cl_2$

- discussion about defects
- Mg-Herbertsmithite
- a gapless quantum spin liquid (summary)
- field induced solidification of the QSL

Collaborations

Samples

Ross H Colman, David Boldrin, Andrew S Wills, *UCL, UK*
P. Strobel, Institut Neel, *Grenoble, France*
J. C. Trombe, F. Duc, *CEMES, Toulouse, France*
M. de Vries, A. Harrison, *Edinburgh, UK*

ESR

A. Zorko, Inst J. Stefan, Slovenia

Magnetization

P. Bonville, CEA Saclay (France)

μSR

PSI (A. Amato, C. Baines); ISIS (A. Hillier, J. Lord)

M.I.T., 2005

J|A|C|S COMMUNICATIONS

Published on Web 09/09/2005

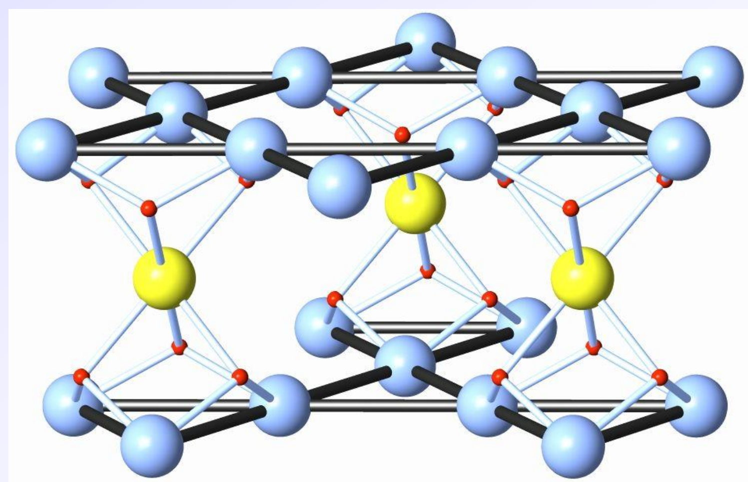
A Structurally Perfect $S = {}^{1}/_{2}$ Kagomé Antiferromagnet

Matthew P. Shores, Emily A. Nytko, Bart M. Bartlett, and Daniel G. Nocera*

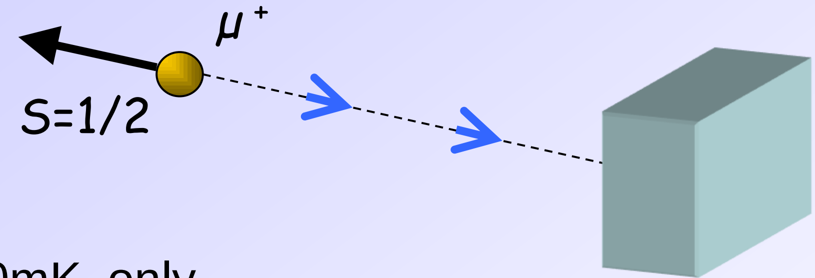
Department of Chemistry, 6-335, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139-4307

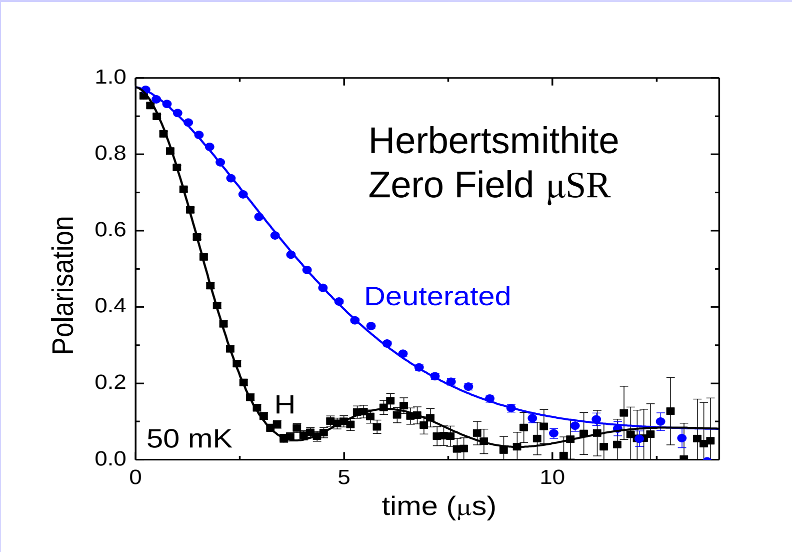
Herbertsmithite:
$ZnCu_3(OH)_6Cl_2$

Cu^{2+}, S=1/2



Muon spin relaxation (μSR)





P. Mendels et al, PRL 98, 077204 (2007)

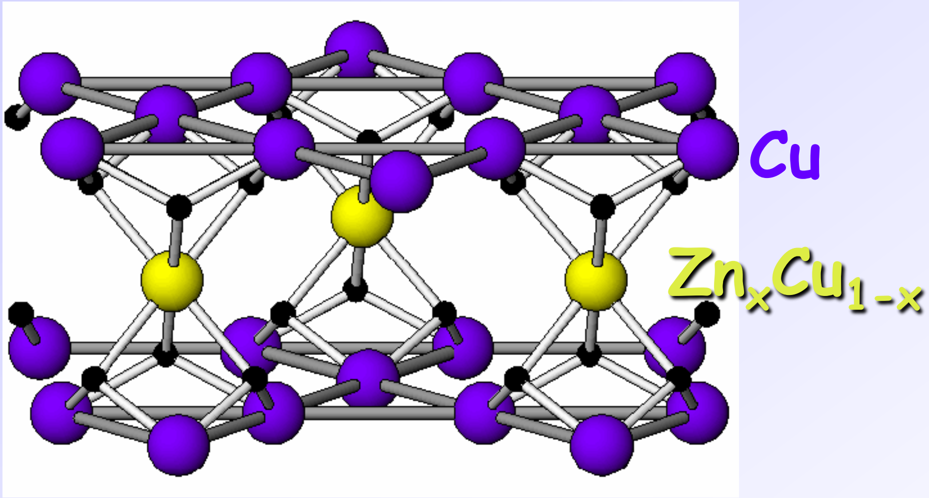
At 50mK, only small "static" nuclear fields.

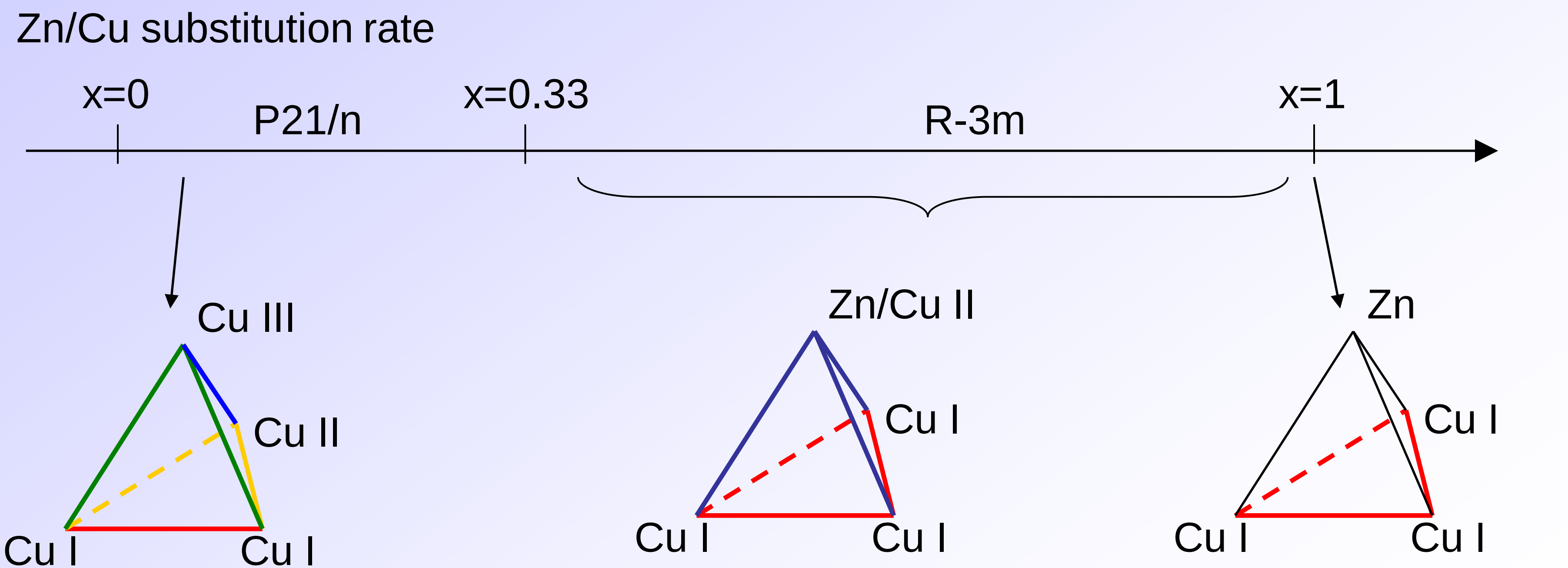
upper limit of a frozen moment for Cu^{2+}, if any : $6 \times 10^{-4}\ \mu_B$

Also: ac-χ, Neutron Scattering Helton et al, PRL 98 107204 (2007)

No order or frozen disorder down to 20 mK ($\sim 10^{-4}$ J) despite J=180 K !

$Zn_xCu_{4-x}(OH)_6Cl_2$ atacamite family



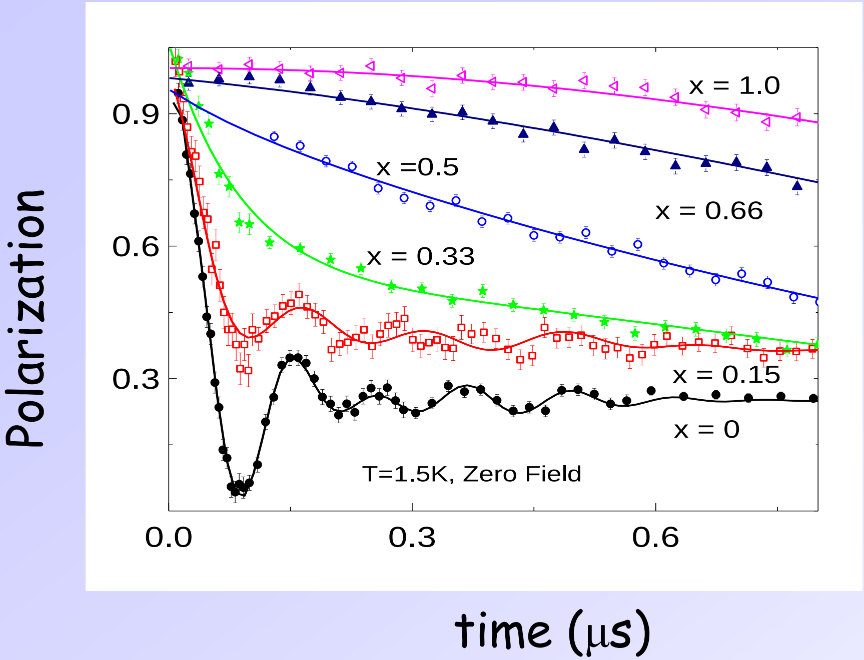


Clinoatacamite
$Cu_2(OH)_3Cl$

Zn-paratacamite
$Zn_xCu_{4-x}(OH)_6Cl_2$

Herbertsmithite
Braithwaite et al, 2004

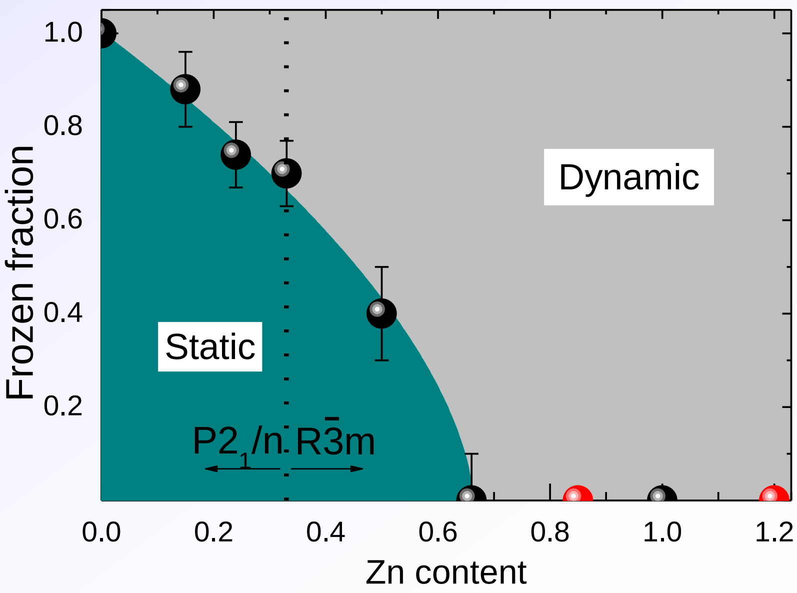
μSR : Zn atacamtites $Zn_xCu_{4-x}(OH)_6Cl_2$



-x=0 : fully ordered below ~18K
X.G. Zheng et al, PRL 95, 057201 (2005)

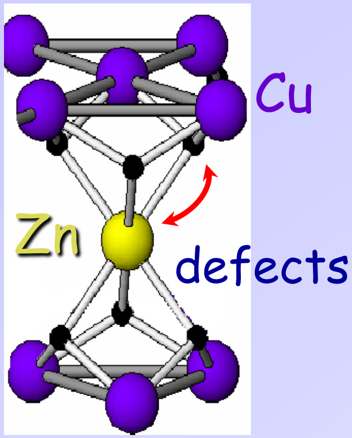
When x increases from 0 to 1 :
- -Oscillations are smeared out
- -A paramagnetic (x=1 type) component emerges at the expense of the frozen one

Large domain of stability 0.66<x<1.2 of a dynamical ground state



P. Mendels et al, PRL 98, 077204 (2007)

Magnetic defects : Zn/Cu intersite mixing

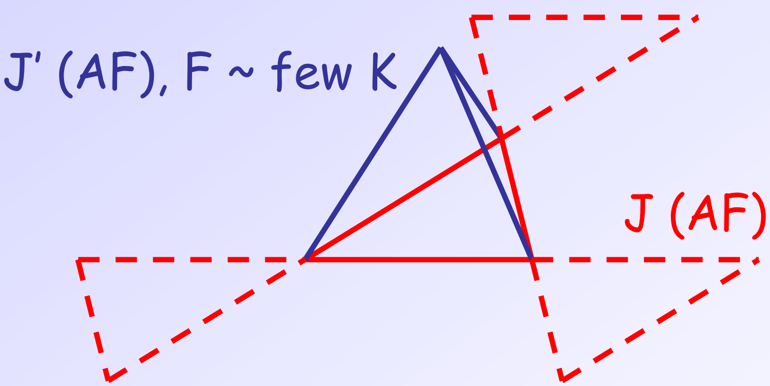


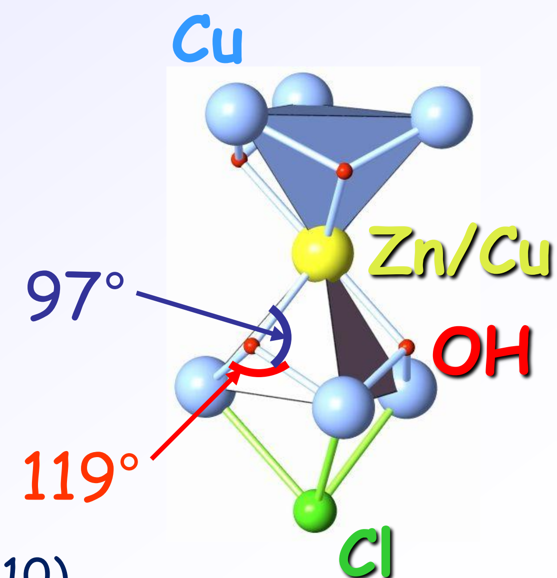
Cu on the Zn site
Nearly free ½ spins (~ 15-25 %)

Freedman et al, JACS, 132 (2010)

Zn in the kagome plane
-> magnetic vacancy (~ 1 - 7%)

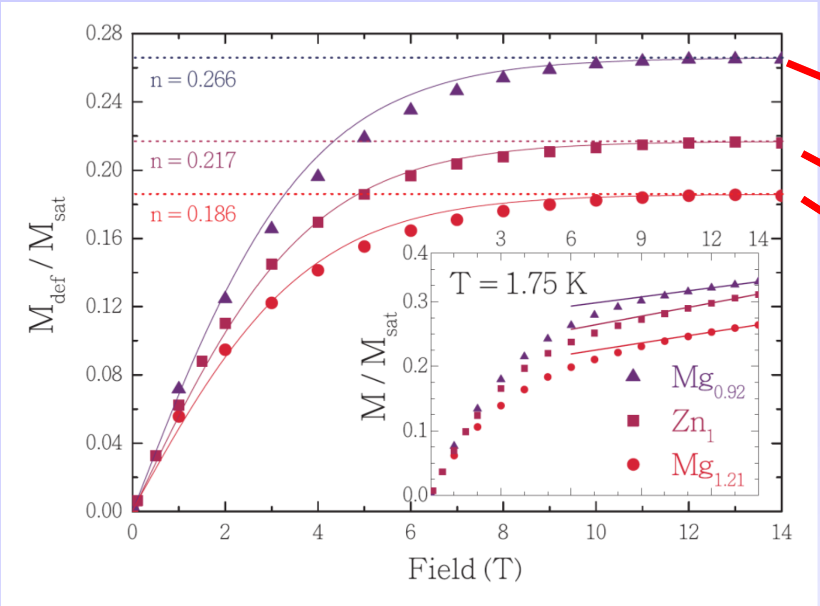
?

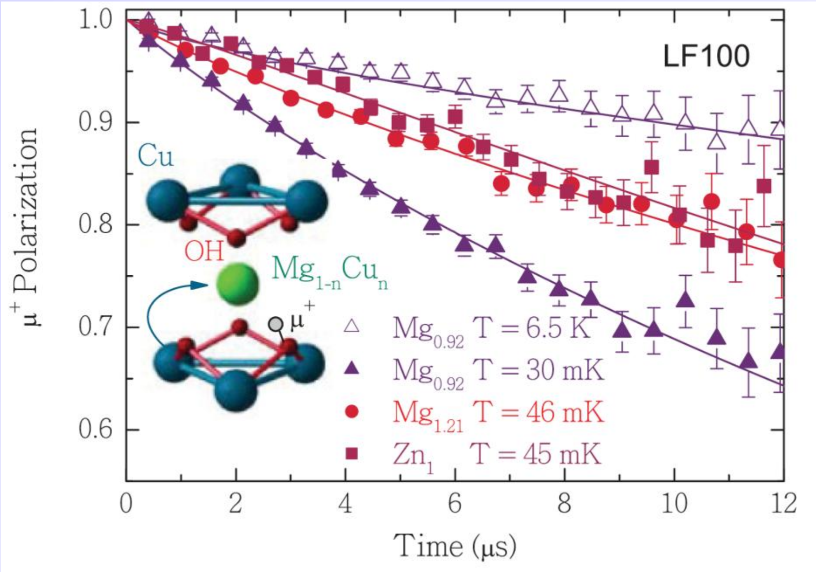


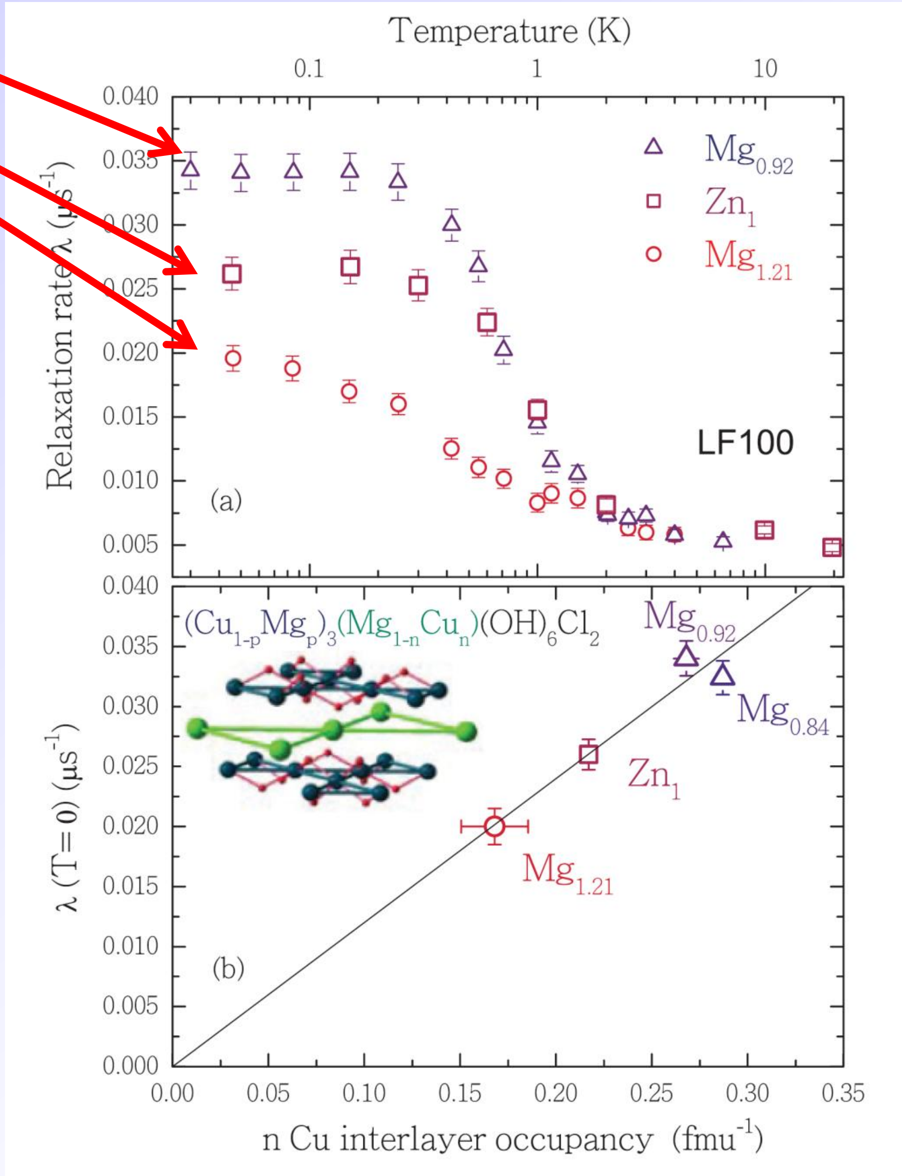


For a review and discussion, see
P. Mendels and F. Bert, J. Phys. Soc. Jpn 79 011001 (2010)
J. Phys. Conf. Series (2011)

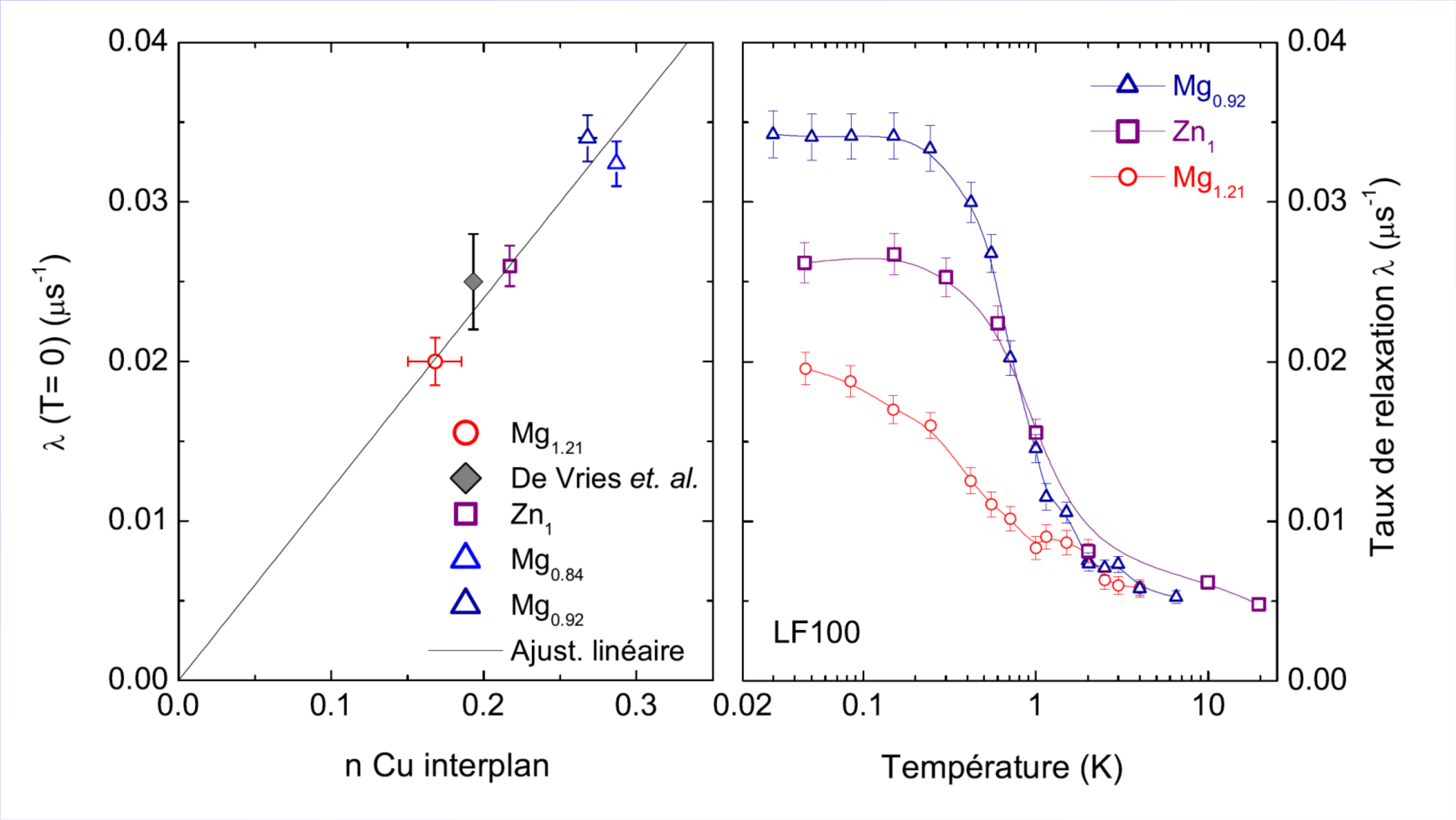
Mg- Herbertsmithite: control of *inter-site* defects







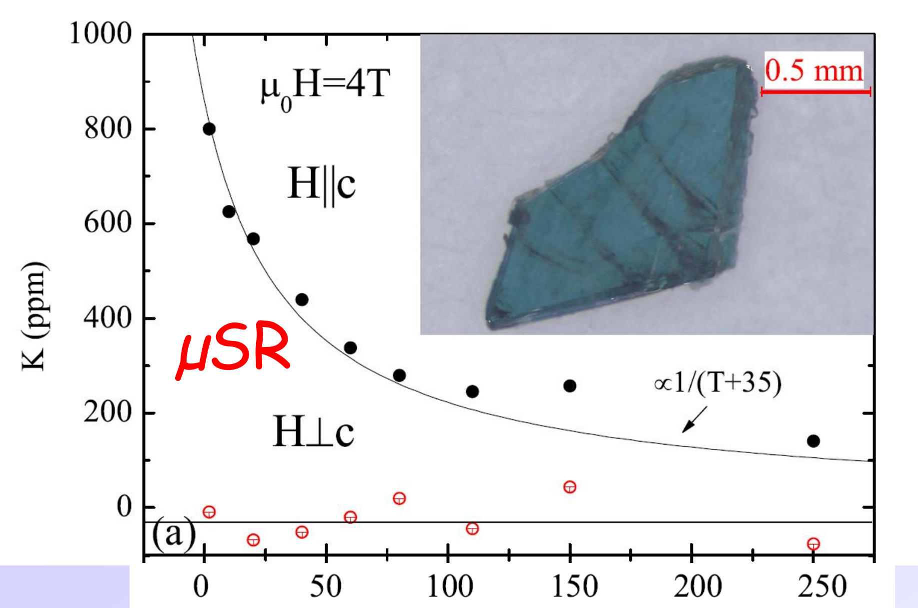
E. Kermarrec, Phys. Rev. B (R) (2011)



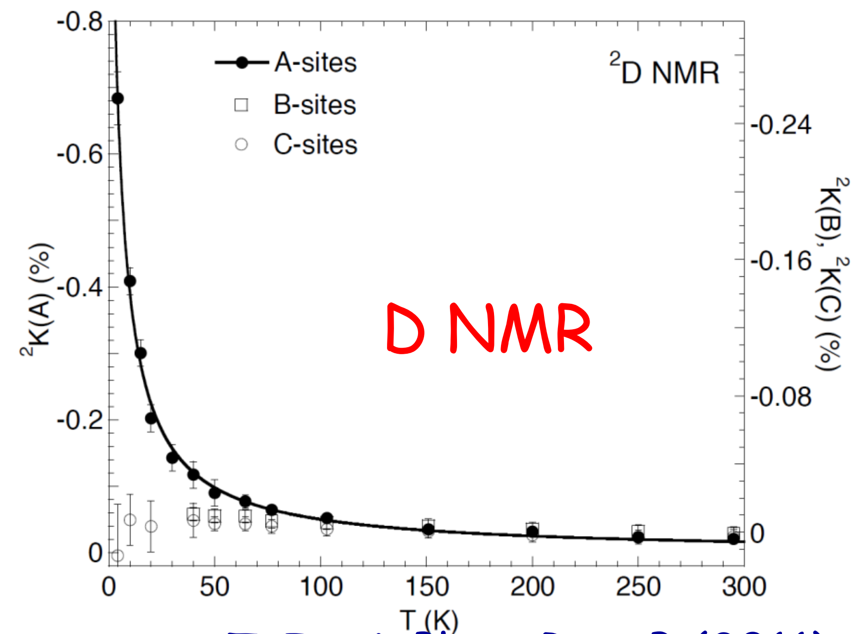
- Indirect coupling between inter-site defects (through Kagme planes?)
- Dynamics of inter-site defects governed by the kagome planes physics?

E. Kermarrec, Phys. Rev. B (R) (2011)

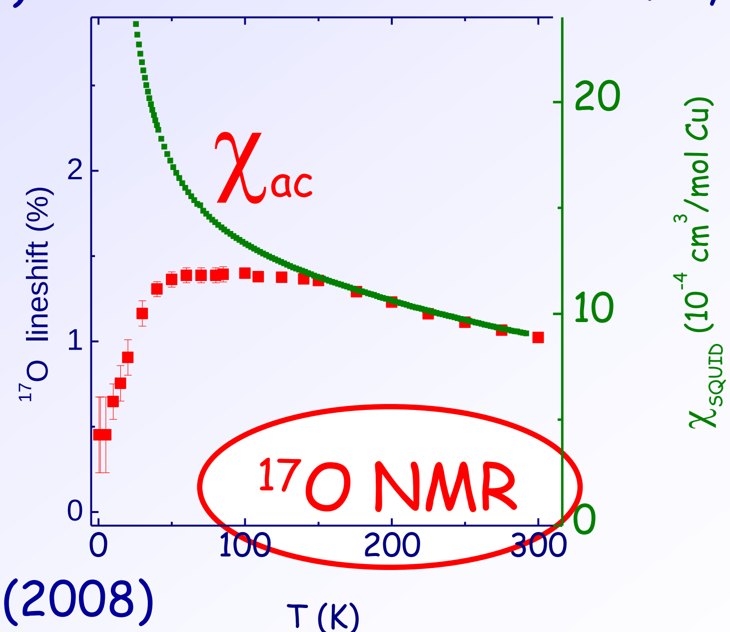
Susceptibility: χmuons, D NMR vs 17O NMR (*intrinsic*, defects)

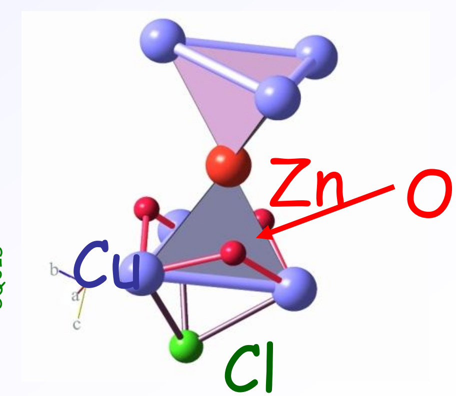


O. Ofer et al., ArXiv (2010)



T. Imai, Phys. Rev. B (2011)



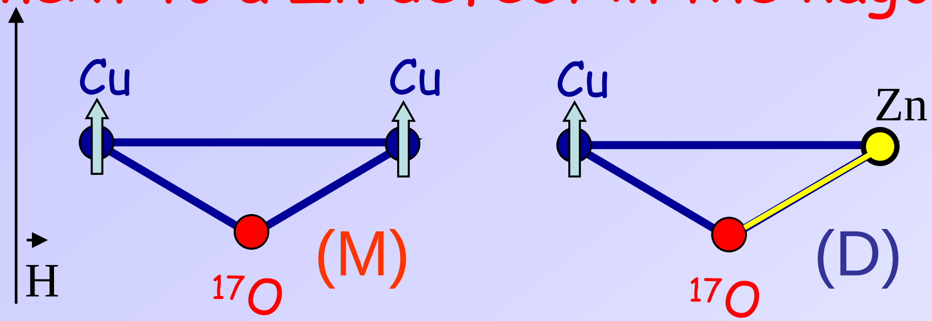


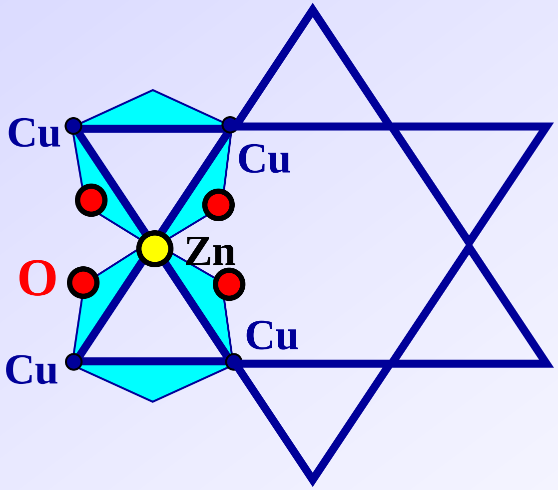
A. Olariu et al., Phys. Rev. Lett (2008)

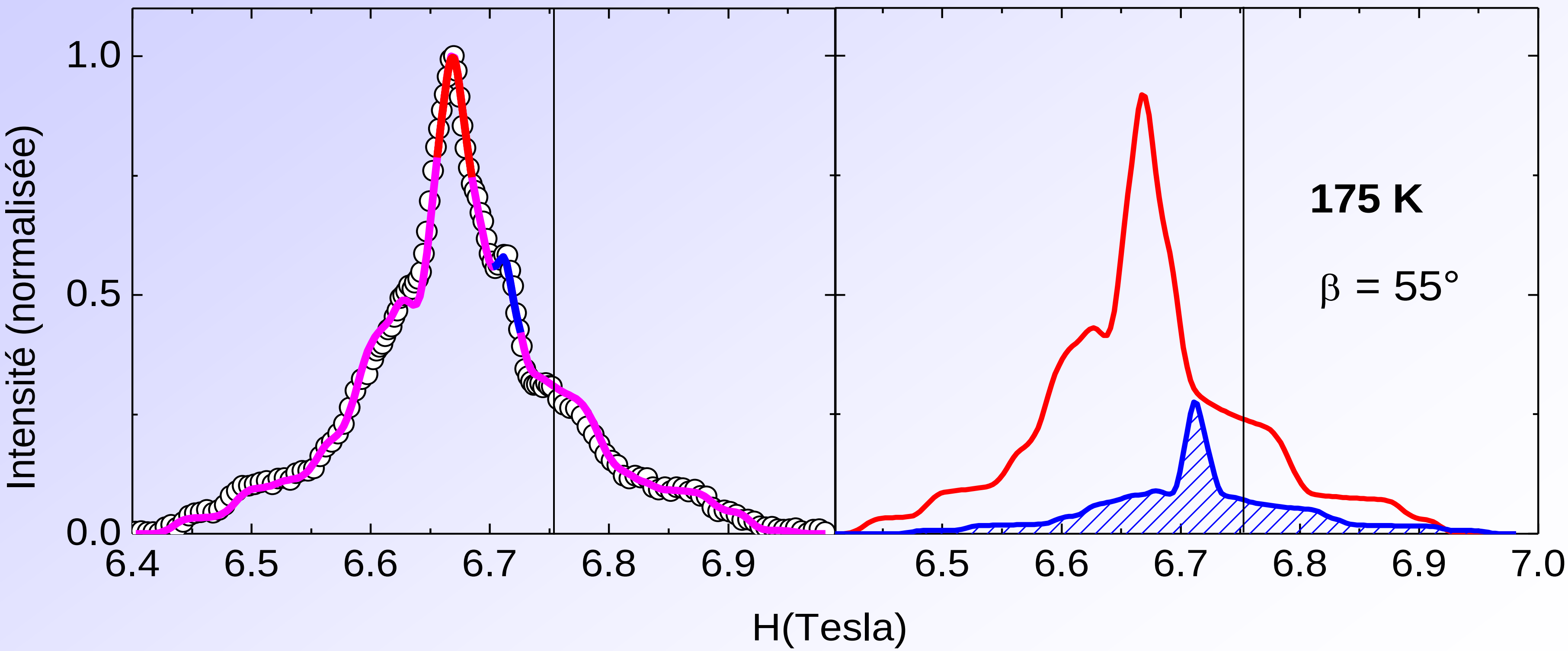
Local

Two O sites

O next to a Zn defect in the kagome plane







~ 20% intensity -> ~ 5% Zn/Cu defects in kagome planes

ICP, diffraction, ^{17}O NMR (*intrinsic*, defects)

n = inter- plane Cu^{2+}defect ↔ M(H); diffraction (Mg case)
p = intra-plane dilution (%) ↔ ^{17}O,;diffraction (Mg case)
x= total Mg (Zn) content per f.u.↔ ICP

$$(Cu_{1-p}M_p)_3(M_{1-n}Cu_n)(OH)_6Cl_2 = Cu_{4-x}M_x(OH)_6Cl_2$$

Composé	ICP	Diffraction[a]			M(H)	RMN ^{17}O
$x = 3p - n + 1$	x	x	n	p	n	p
Mg 0.55	-	0.55	0.45	0	0.5(1)	-
Mg 0.84	0.84(1)	0.83[b]	0.287(4)	0 .041(1)	-	-
Zn 0.85	0.85(3)	-	-	-	0.297(4)	-
Mg 0.92	0.92(1)	0.91[b]	0.266(3)	0.063(1)	0.266(4)	-
Mg 0.93	-	-	-	-	0.282(4)	0.07(2)
Zn 1	1.00(7)	1.0(1)	0.27(6)	0.09(2)	0.217(5)	-
Mg 1.21	1.25(3)	1.21(4)	0.15(1)	0.12(1)	0.186(4)	-
Mg 1.2	-	1.2	?	?	0.182(4)	0.12(2)

With Mg- Herbertsmithite, we check the overall consistency of the three methods to determine the amount of substitution on each site.

Conclusion about "defects"

- Intersite defects: Cu^{2+} on Zn sites

  fair agreement between all methods: neutrons, M, specific heat,...

- Intraplane defects: Zn^{2+} on Cu sites: spin vacancies

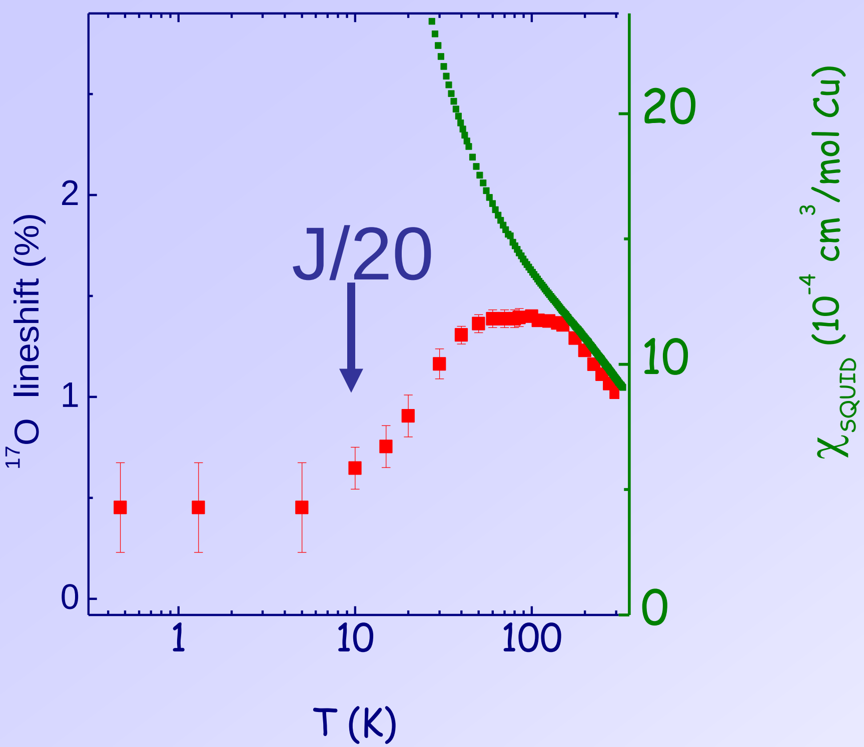
Pro: 17 O NMR
ICP constrain ⊕ number of intersite defects

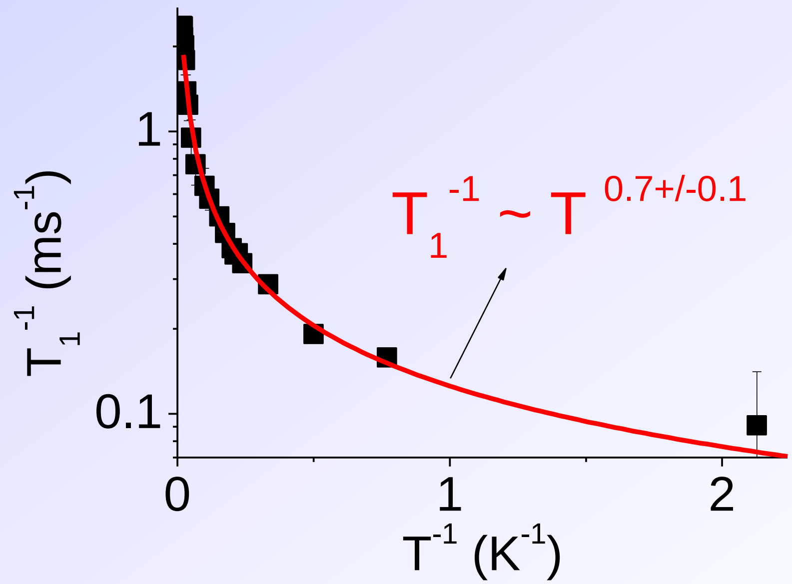
Contra: anomalous diffraction ⊕ no better refinement
skepticism about ICP (if not, hard to reconcile the two measurements)

Question: Can intersite defects induce a response in the planes? If not then NMR linewidth not interpreted in the contra scenario

Issue: Different samples? « MIT » crystals vs « Orsay » powders

Gapless spin liquid





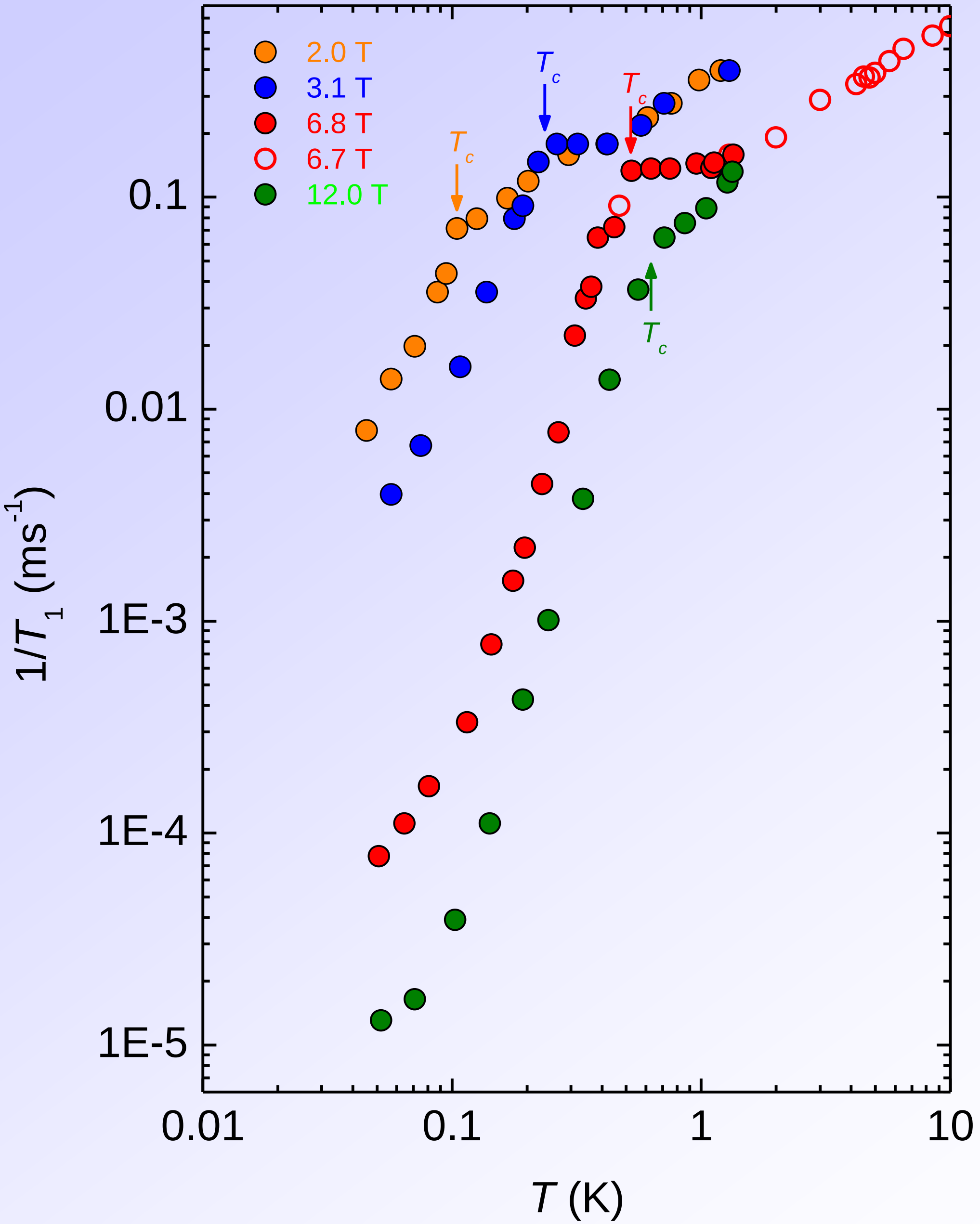
Olariu et al, PRL 100, 087202 (2008)

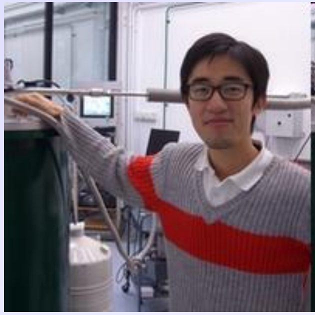
See also Imai et al, PRL 100, 077208 (2008)

Inelastic Neutron scattering: Helton et al, PRL 98 107204 (2007)

$\chi'' \sim \omega^{-0.7}$

Very Low T Spin Dynamics: freezing under a field

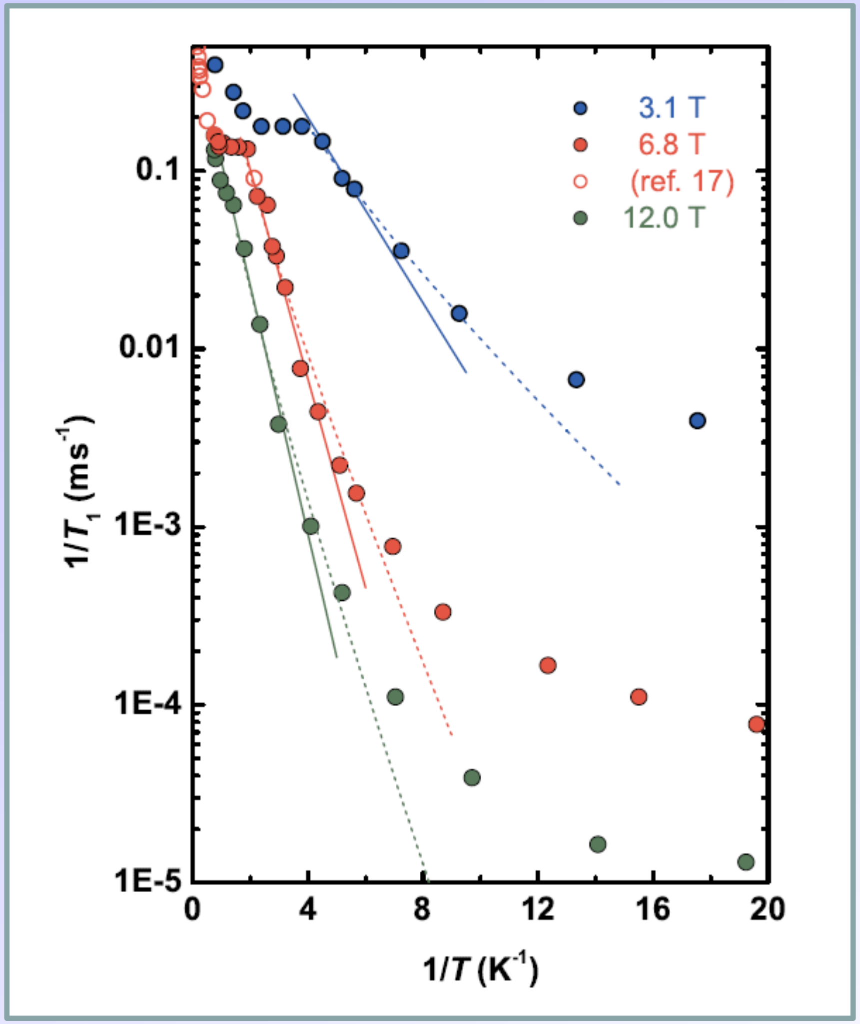


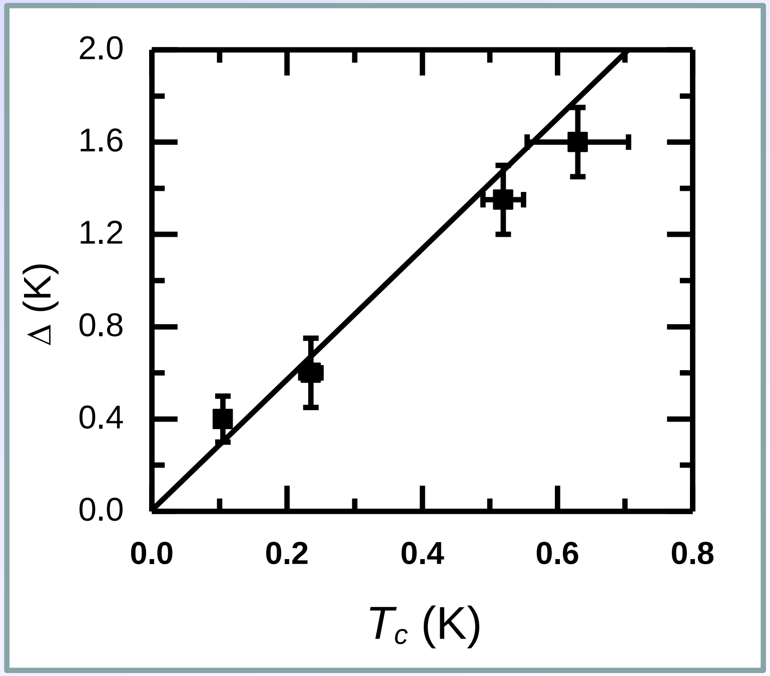


M. Jeong et al,
Phys. Rev. Lett **107** (2011)

T_c increases with H

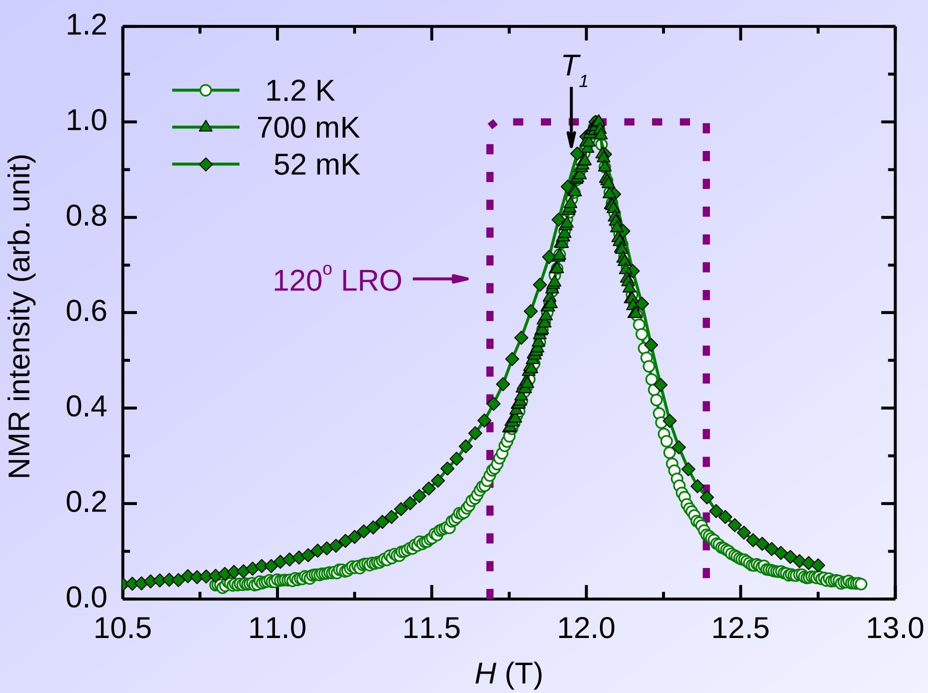
Field induced spin-gap

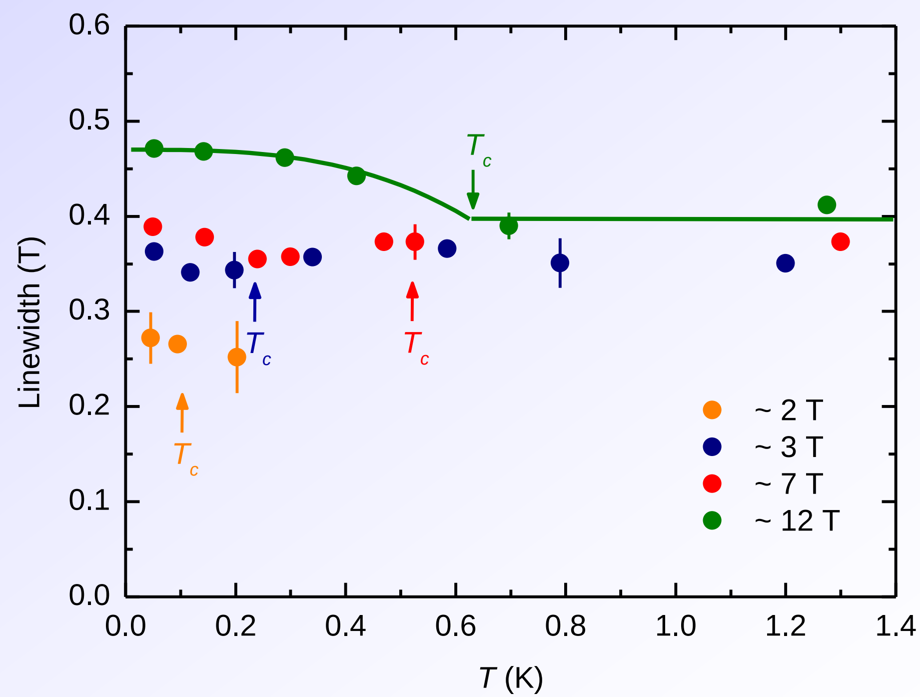




$\Delta \sim 2.3\ k_B T_c$

Very Small frozen moment





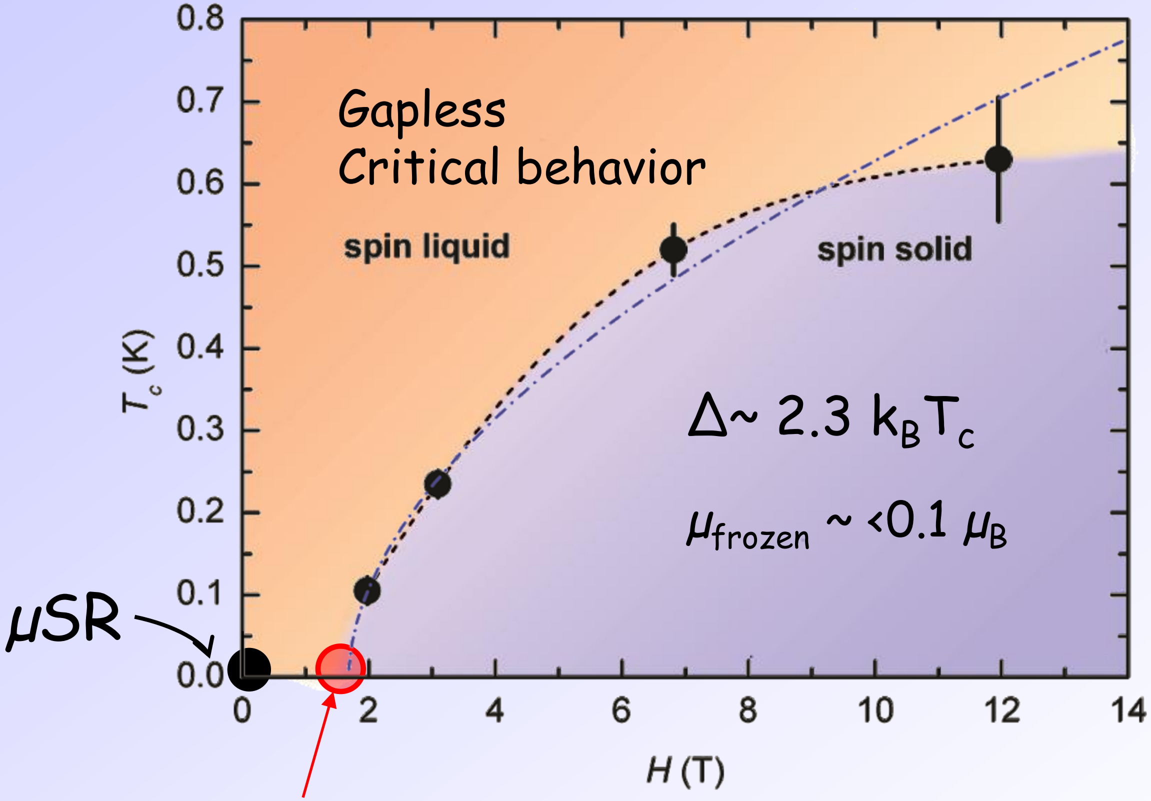
Hyperfine constant: 3.5 T/μ_B

No ordered structure

μ_{frozen} ~ 0.1 μ_B @ 12 T

μ_{frozen} smaller for H ↘

A Quantum Critical Point ?



$T_c \sim (H-H_c)^{0.65}$

$H_c = 1.55(25)$ T

$\mu_B Hc \sim J/180$

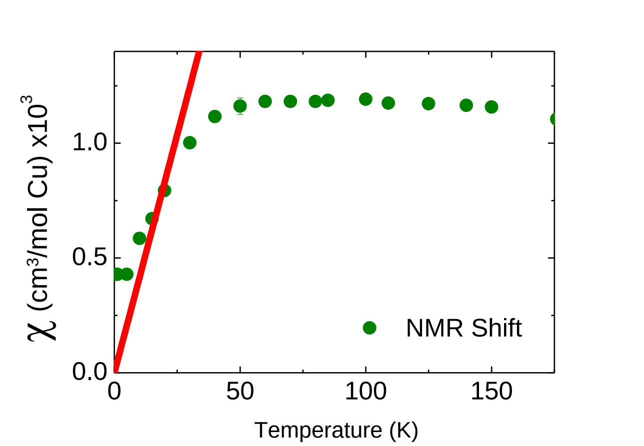
Comparison to theories

- Algebraic critical spin liquid - U(1)

  Ran et al, PRL **98**, 117205 (2007)
  Hermele et al, PRB **77**, 224413 (2008)

$$\chi(T) = \frac{3.2\mu_B^2}{J^2}(k_B T)$$

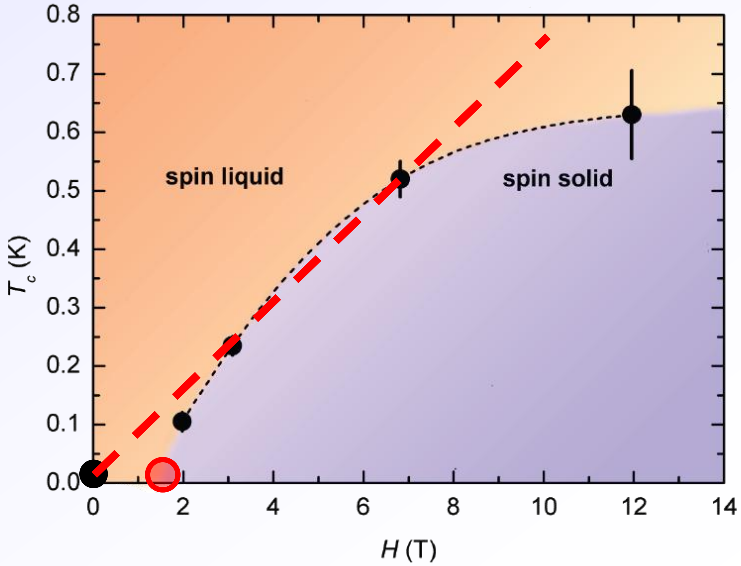
$$\frac{1}{T_1} \propto T^{\eta}$$



-Gapless
-Critical behavior

-Instability (H≠ 0) M ~ H^{α} but Tc ~ H
Ran et al, PRL **102** 117205 (2009)

-Unstable to anisotropy
DM interaction -> L.R.O.
Hermele et al, PRB **77**, 224413 (2008)



Comparison to theories

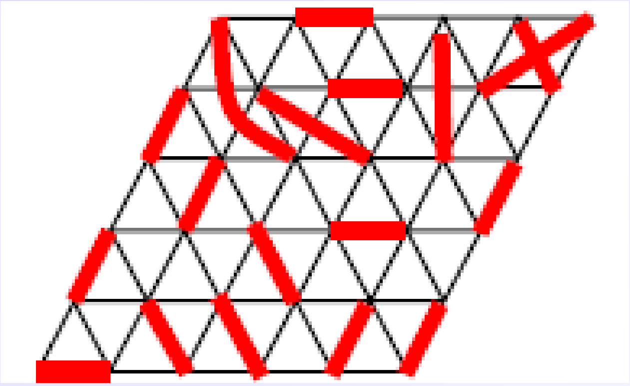
- Z_2 spin liquid

  Yan et al, Science (2011)

  Gapped magnetic excitations (S=1/2)

  Gapped non-magnetic excitations

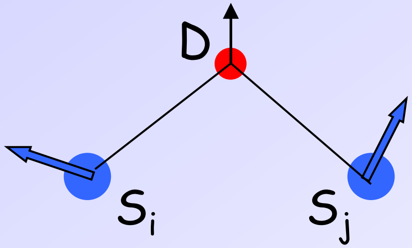
  $C_v \sim e^{-\Delta/T}$; $\chi \sim e^{-\Delta'/T}$



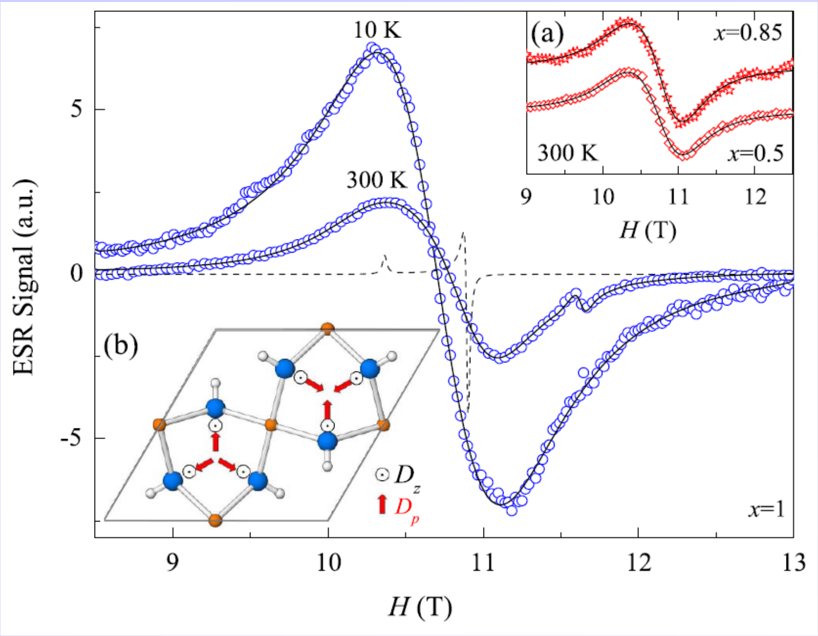
Short range RVB

Need to restore
ground state susceptibility
and some criticality…

Dzyaloshinskii-Moriya interactions



$H_{DM}=D.(S_i \wedge S_j)$

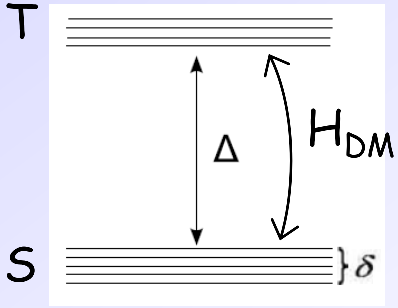


Broad room T ESR line <- magnetic anisotropy from DM

$|D_z|=0.08J$, $|D_p|\sim 0.01J$

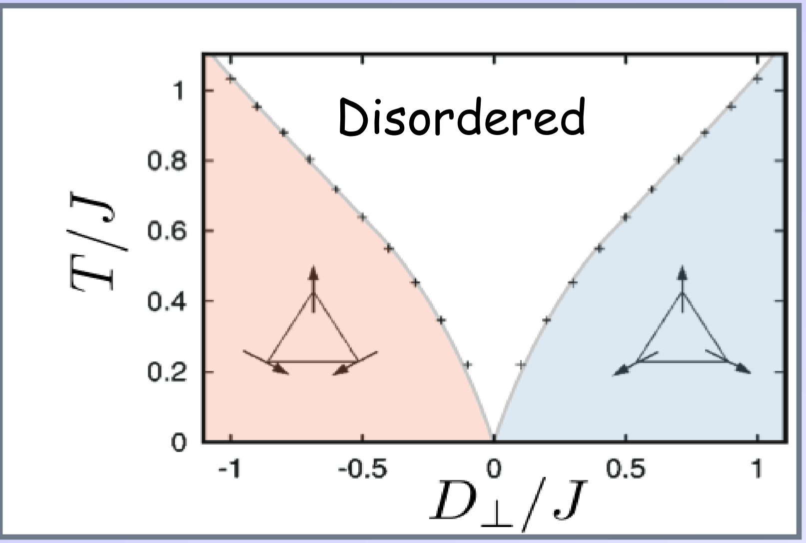
A. Zorko et al, PRL **101**, 026405 (2008)
S. El Shawish et al, PRB **81**, 224421 (2010)

- DM interaction mixes singlet and triplet which restores a susceptibility at T=0



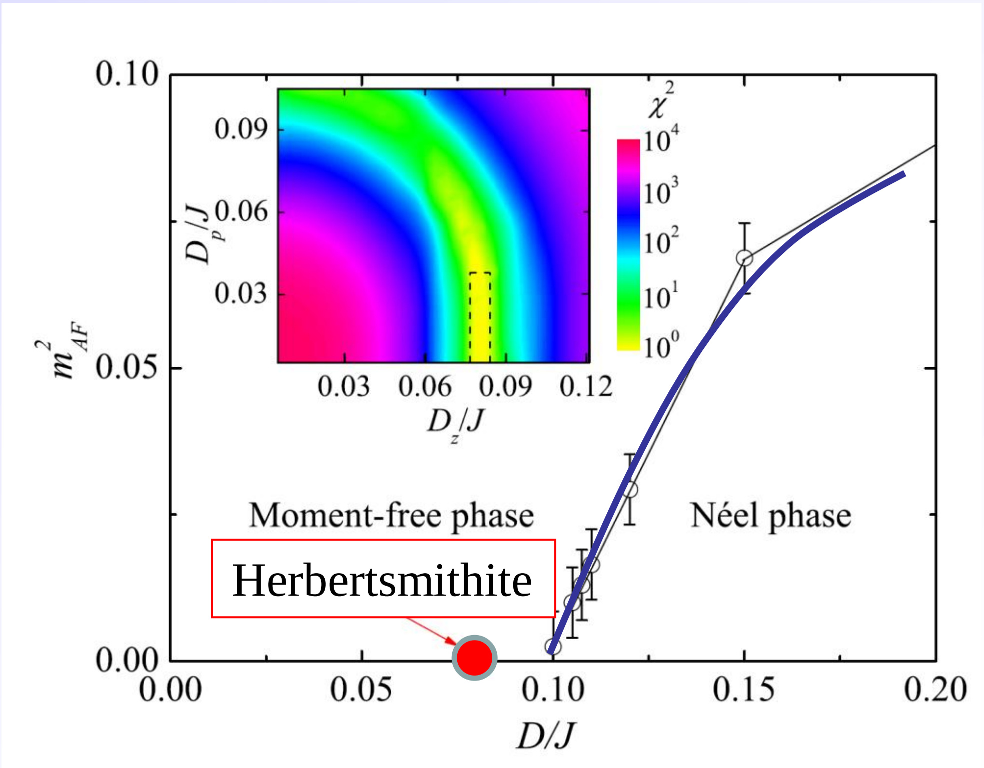
Miyahara et al. PRB **75**, 184407 (2007)
Tovar et al, PRB **79**, 024405 (2009)

Dzyaloshinskii-Moriya interactions: quantum criticality



For classical spins, DM stabilizes ordered phases (cf jarosites)

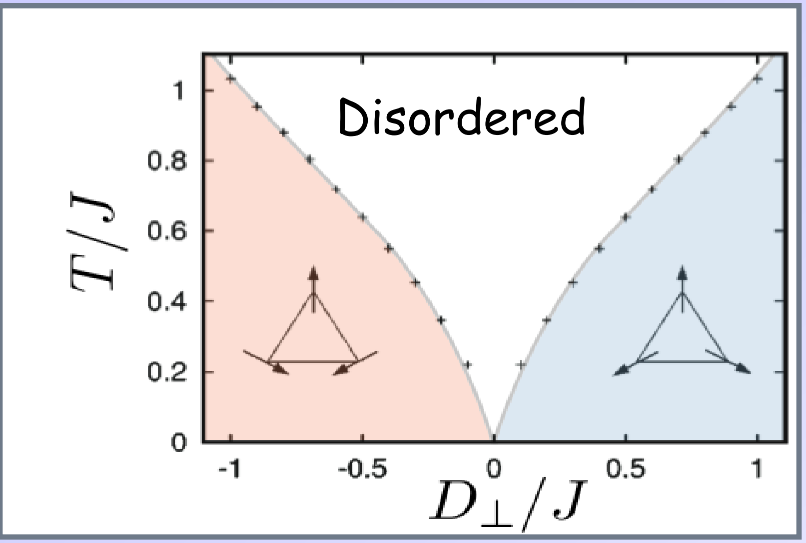
M. Elhajal et al, PRB **66**, 014422 (2002)



In the quantum case, a moment free phase survives up to D/J~0.1

O. Cepas et al, PRB **78**, 140405 (R) (2008)
Y. Huh et al, PRB **81**, 144432 (2010)
L. Messio et al, PRB **81** , 064428 (2010)

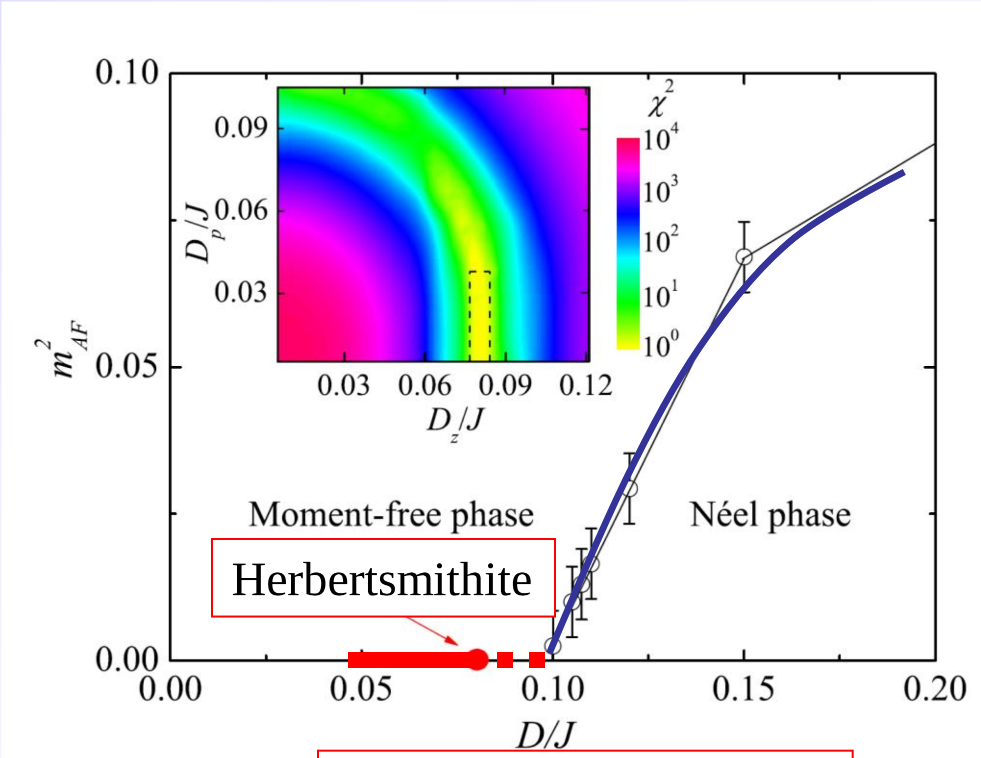
Dzyaloshinskii-Moriya interactions: quantum criticality



For classical spins, DM stabilizes ordered phases (cf jarosites)

M. Elhajal et al, PRB **66**, 014422 (2002)

In the quantum case, a moment free phase survives up to D/J~0.1



ESR: A. Zorko et al., PRL 101 (2008)

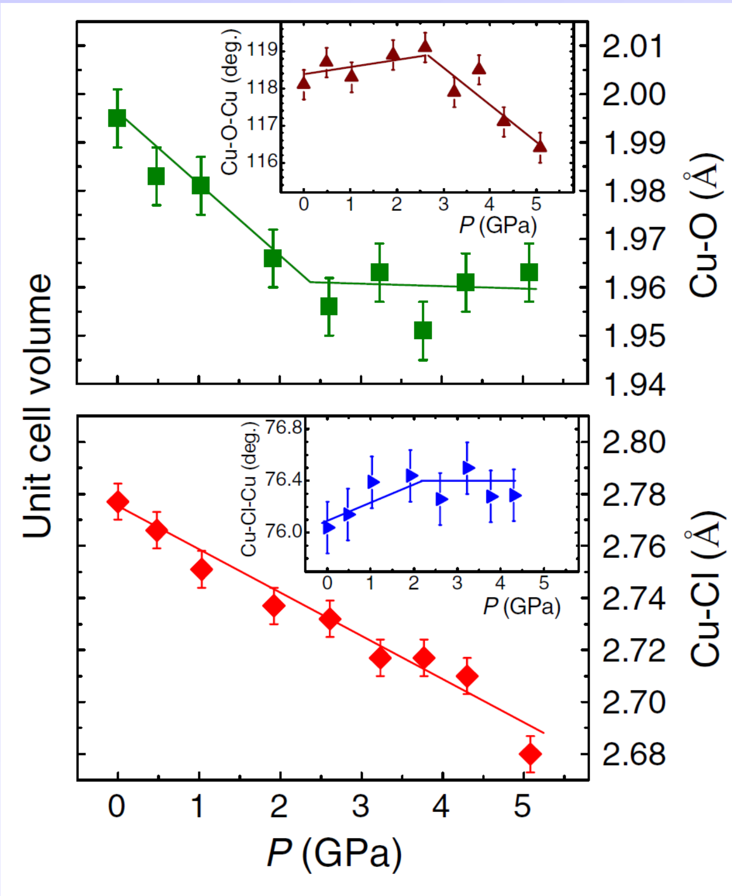
O. Cepas et al, PRB **78**, 140405 (R) (2008)
Y. Huh et al, PRB **81**, 144432 (2010)
L. Messio et al, PRB **81**, 064428 (2010)

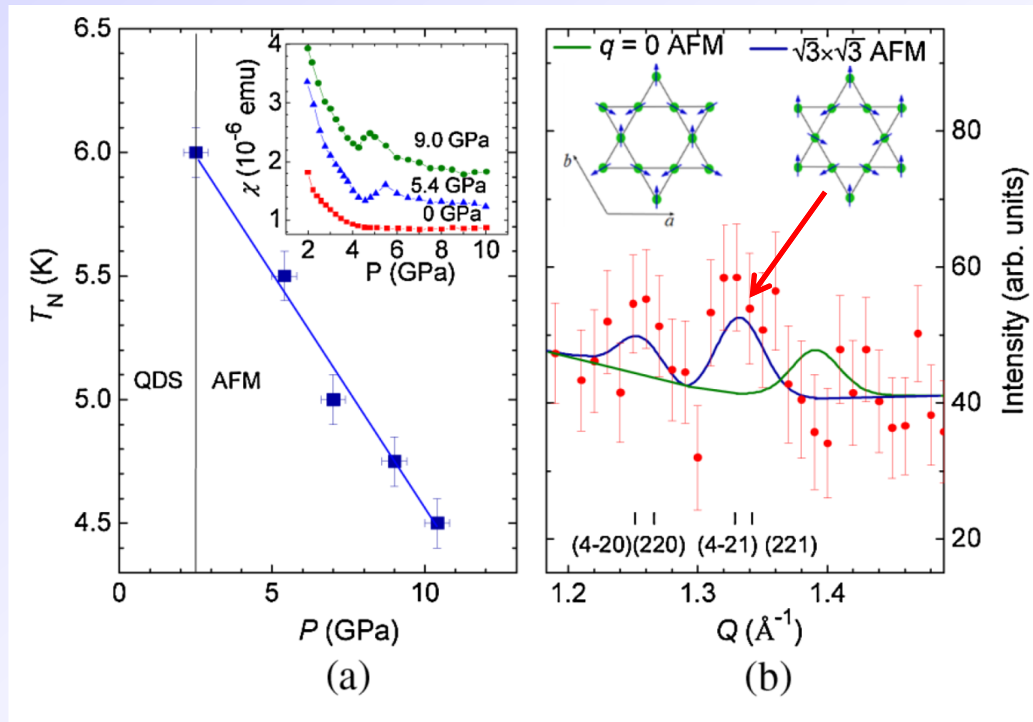
S. El Shawish et al, PRB 81, 224421 (2010)

$H_c \sim D_c - D_{herb}$

Pressure effects: order restored

- *μSR: no effect up to 2 Gpa (Orsay, unpublihed)*
- Neutrons: D.P. Kozlenko et al., PRL **108**, 187207 (2012)





Crystal symmetry R$\underline{3}$m; Changes in DM: No

Local disymmetry of the exchanges paths ~clinoatacamite?

Outline

- Zn and Mg Herbertsmithite $Cu_3(Zn,Mg)(OH)_6Cl_2$
    - a gapless quantum spin liquid (summary)
    - field induced solidification of the QSL

- Vesignieite $Cu_3Ba(VO_5H)_2$
    - local susceptibility (NMR)
    - heterogeneous frozen ground state (μSR+NMR)

Quantum criticality
Dzyaloshinky-Moriya interactions

-Kapellasite $Cu_3Zn(OH)_6Cl_2$
    - competing exchange interactions

Collaborations

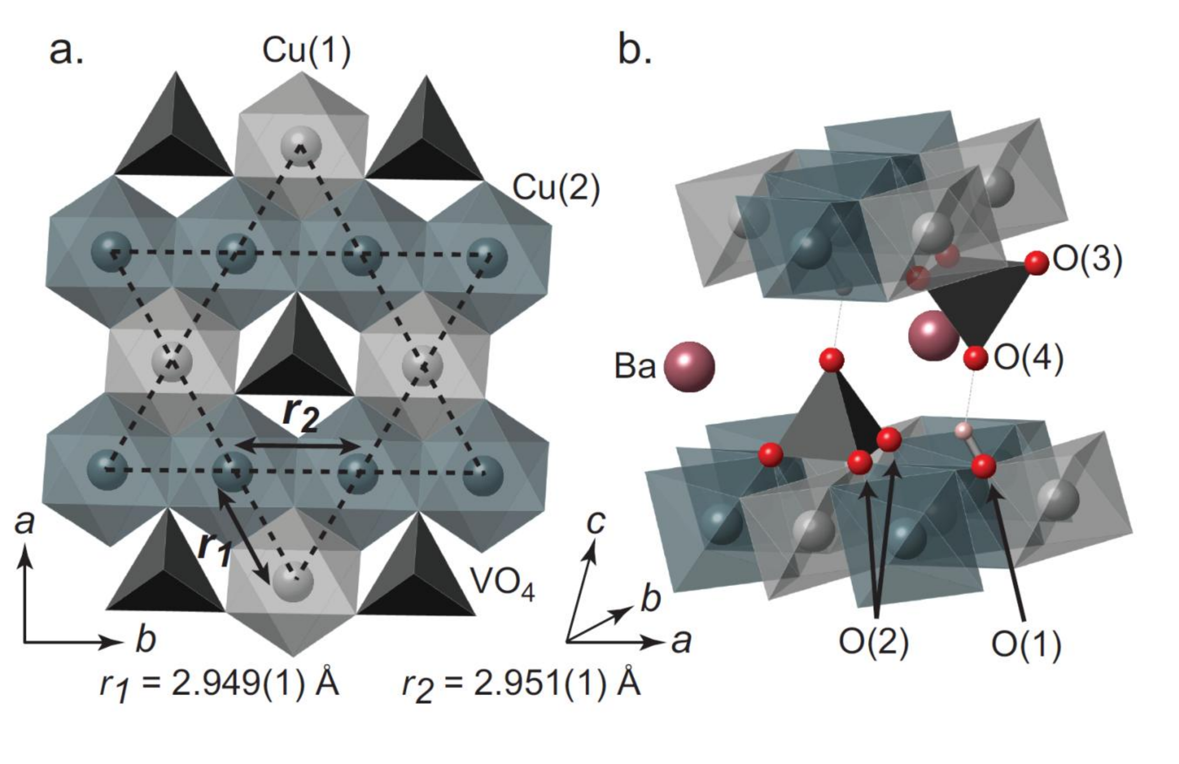
Samples:
Ross H Colman, David Boldrin, Andrew S Wills, UCL, UK

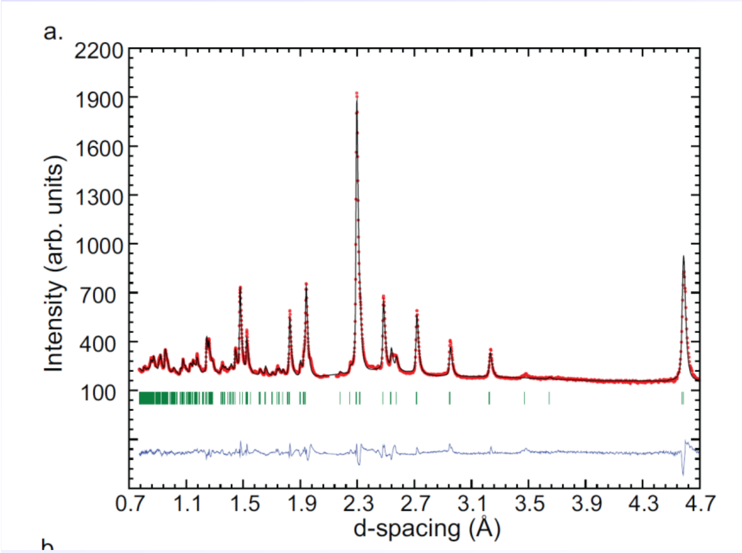
μSR:
- C. Baines, A. Amato, PSI, Switzerland
- *J. Lord, A.D. Hillier, ISIS, UK*

Vesignieite

$Cu_3Ba(VO_5H)_2$

Y. Okamoto et al, JPSJ **78**, 33701 (2009)



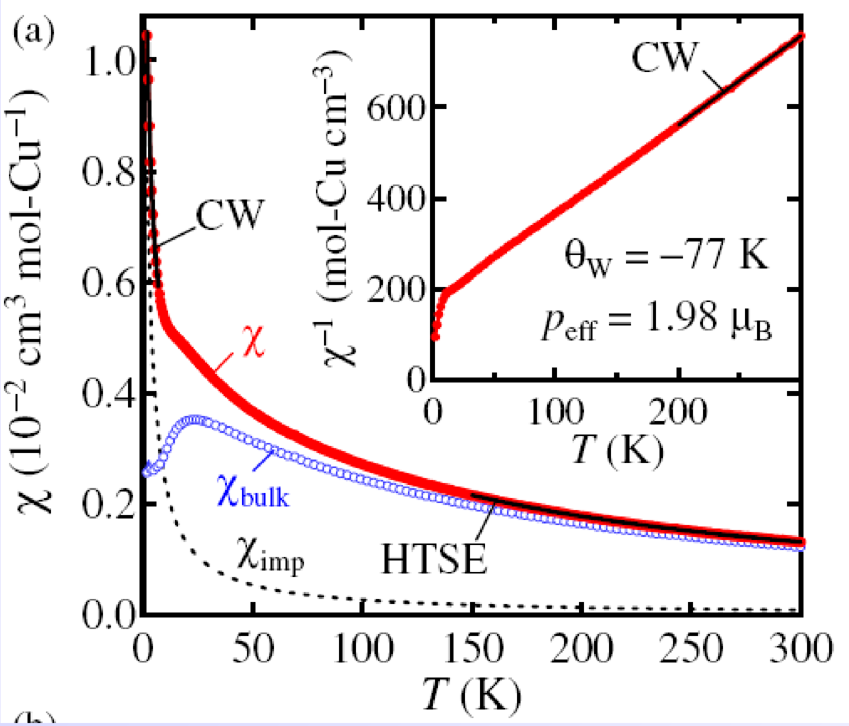


a **weakly** distorted kagome lattice 0.1 %
(Volborthite : 3%)

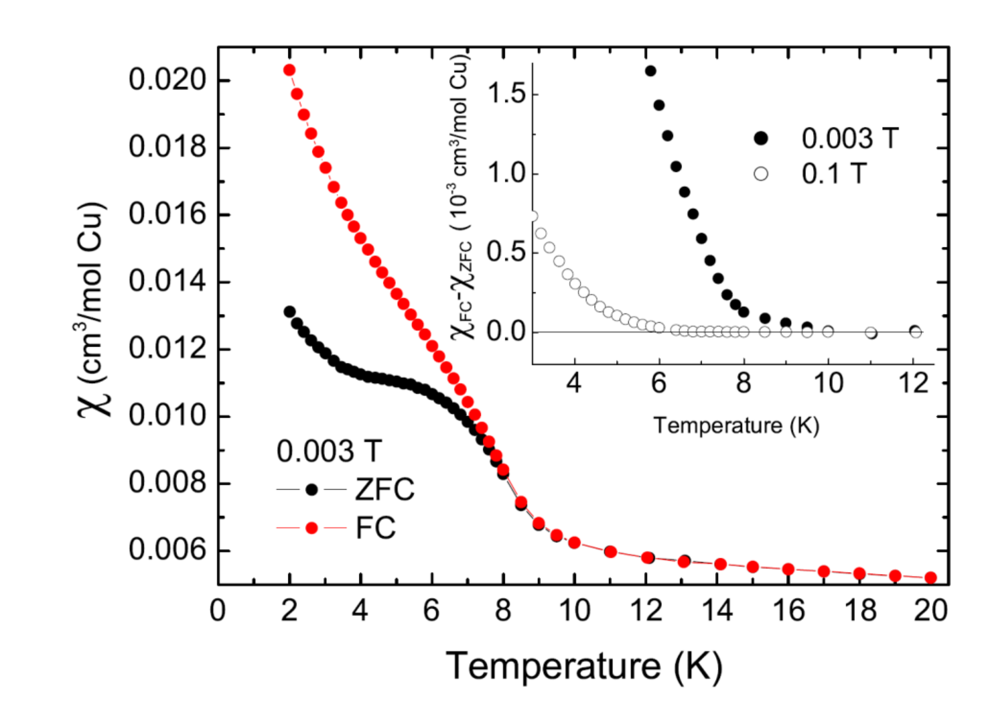
R.C. Colman et al., Phys Rev B, Rapid Com 2011

Coll. UCL London

Vesignieite susceptibility



Y. Okamoto et al (2009)



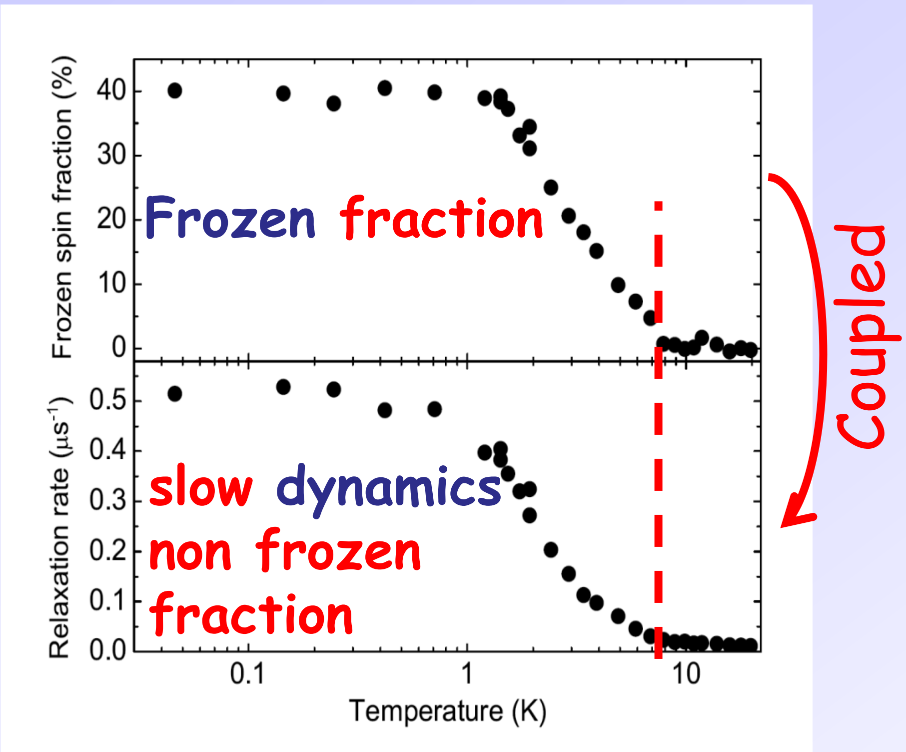
R.C. Colman et al (2011)

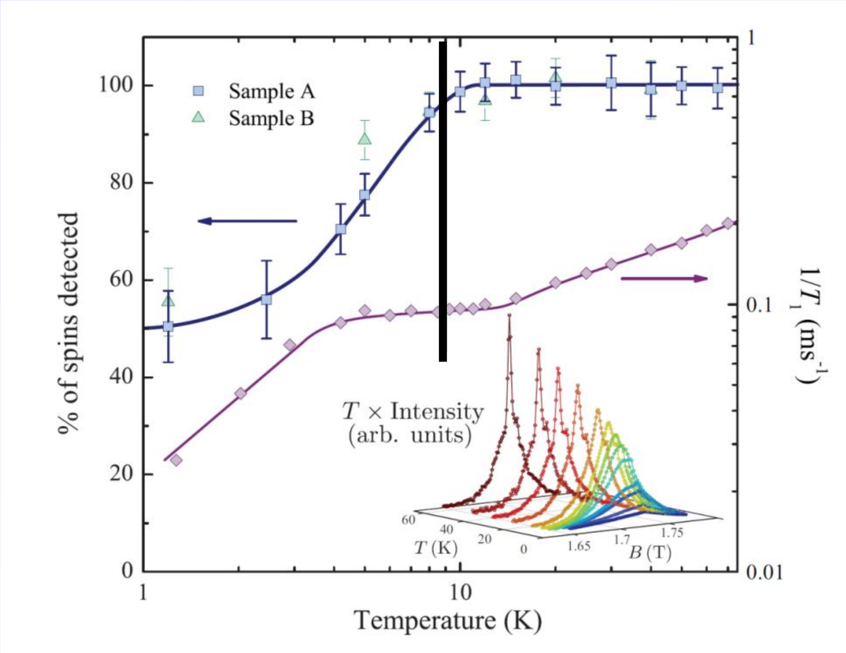
- J ~ 54 K
- Curie tail =~7% S=1/2
- Kink + FC/ZFC at T~9K~J/6

Ground state: two components

μSR

NMR





- No macroscopic phase separation.
- Spin dynamics of all Cu^{2+} suppressed down to spin freezing for 40%.

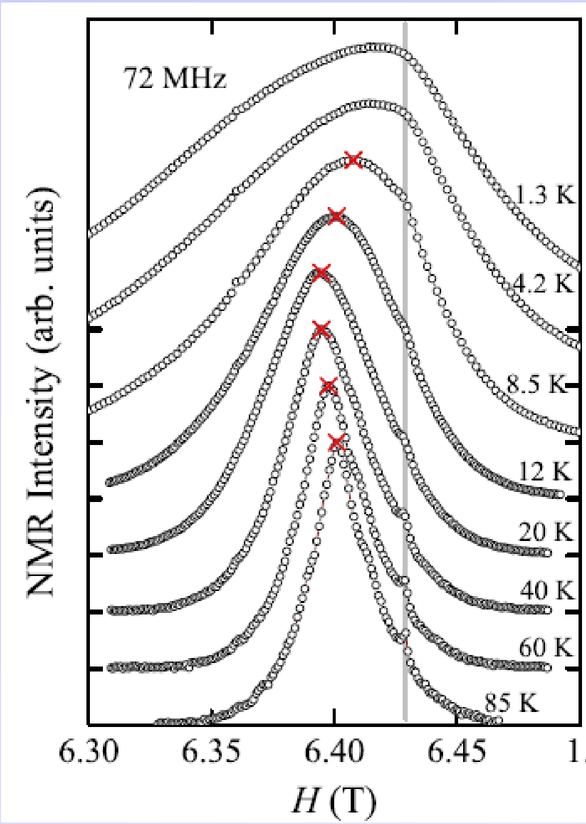
R.C. Colman et al (2011)

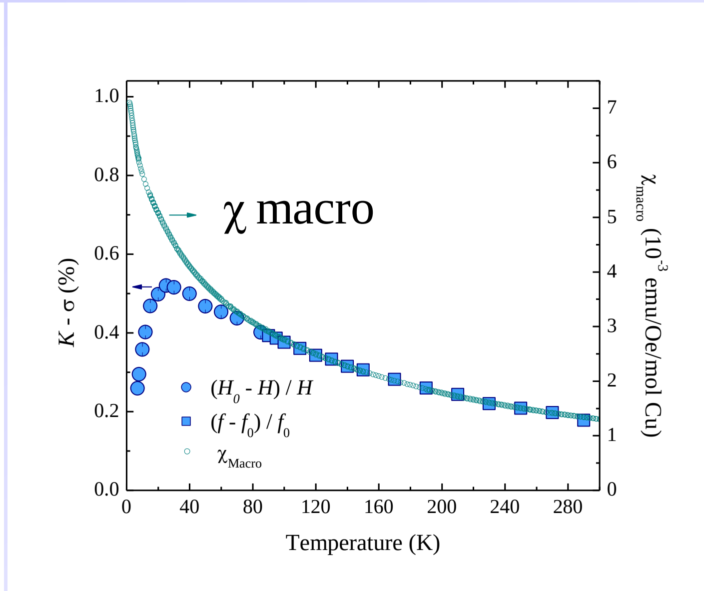
J. Quilliam et al. (2011)

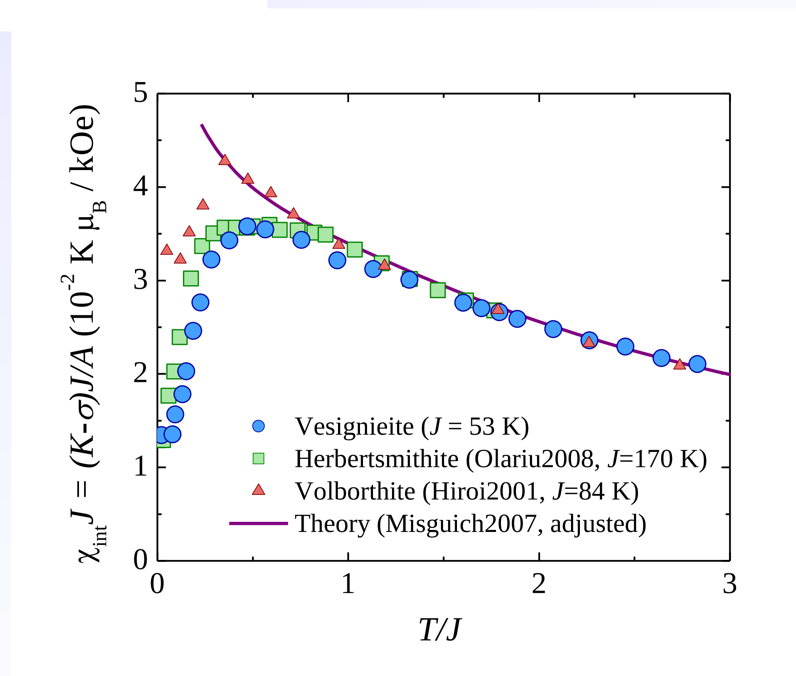
Vesignieite

V NMR (T>9K)

V @ Cu hexagon





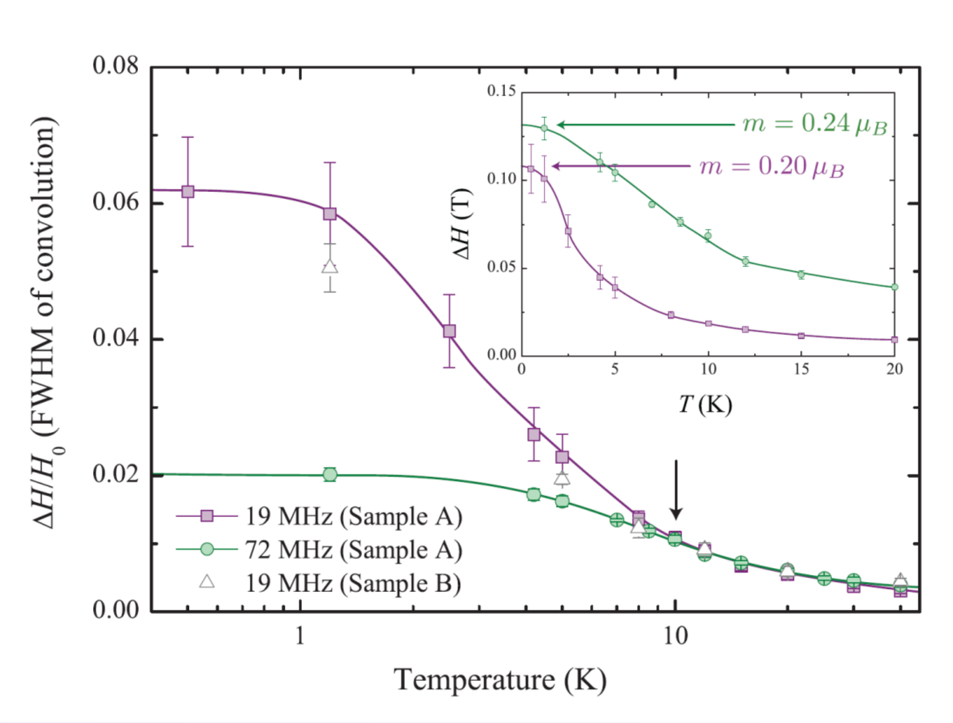


Shift ≡ Herbertsmithite

J. Quilliam et al, PRB (R) 2011

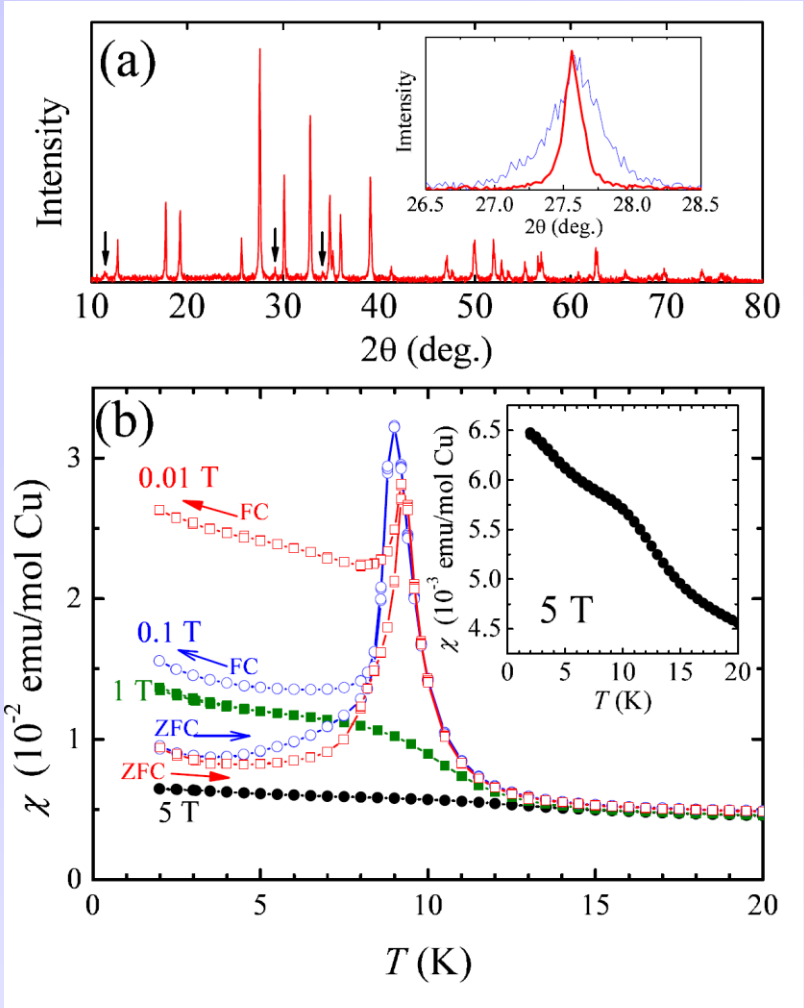
Vesignieite

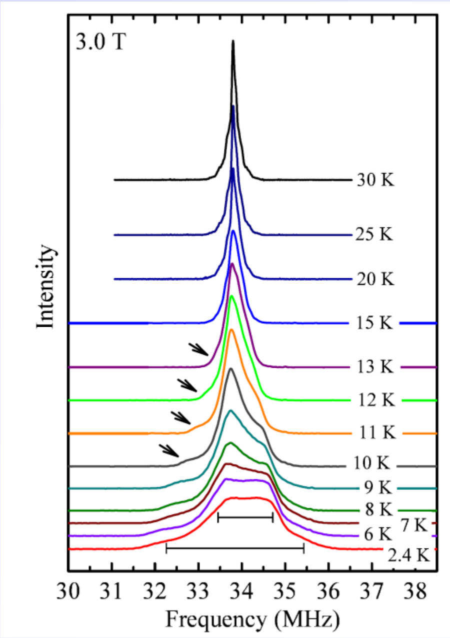
^{51}V NMR (T<9K)



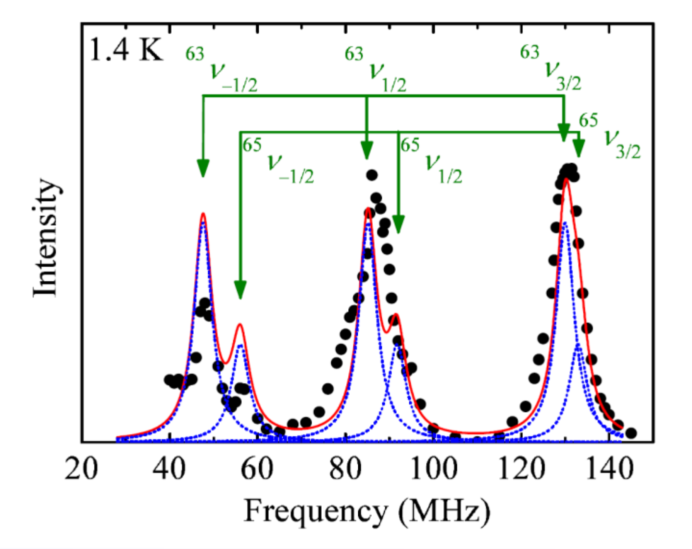
Static component below 9 K ~ 0.2 μ_B

Vesignieite: more recent NMR results





V NMR



Cu ZFNMR

Yoshida et al., JSPJ (2012)

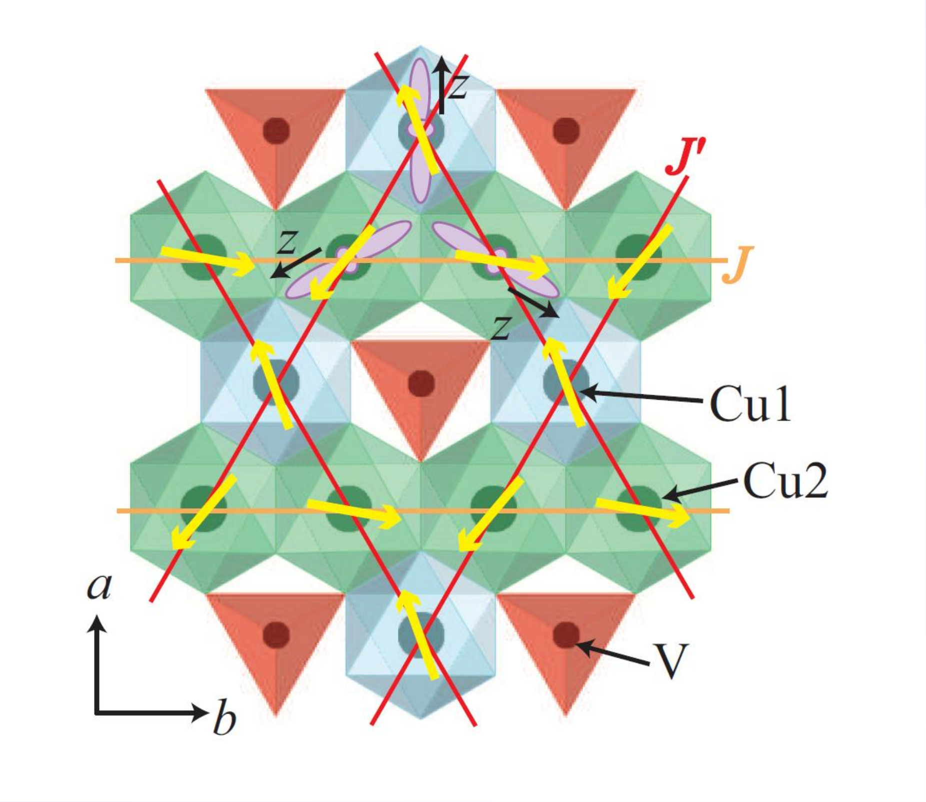
Q = 0 structure

- Quilliam et al.

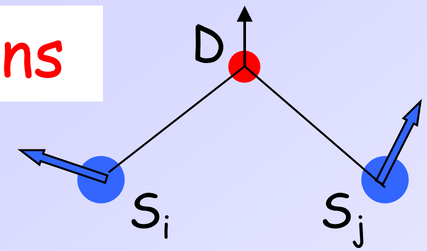
Disordered freezing at 9 K
Moment from V NMR 0.2 μ_B

- Yoshida et al.

Q=0 order (120°)
$\mu_{//}$ from Cu NMR 0.6 μ_B
$\mu_{\perp}$ from V NMR 0.1 μ_B

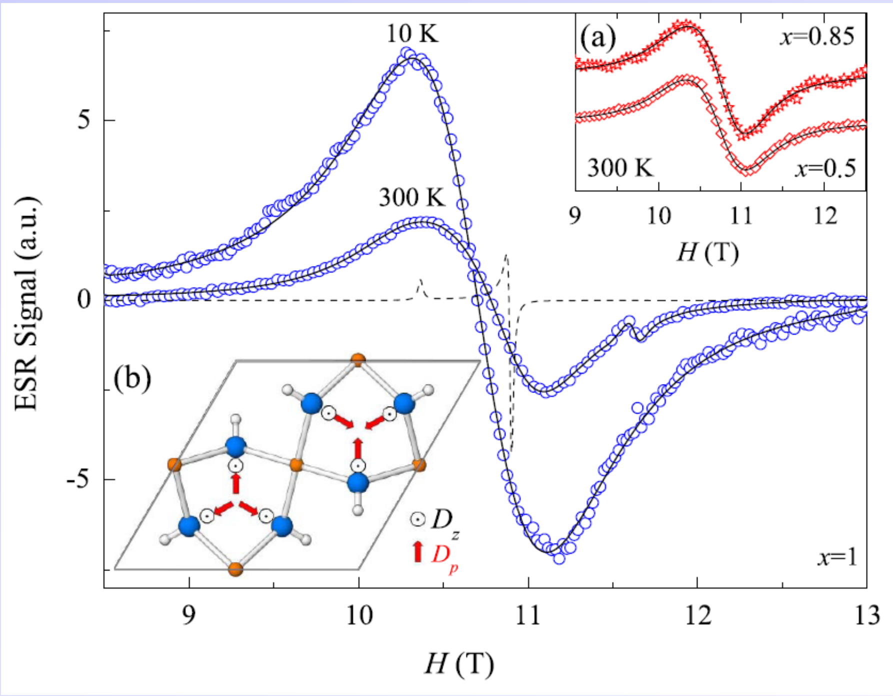


Dzyaloshinskii-Moriya interactions

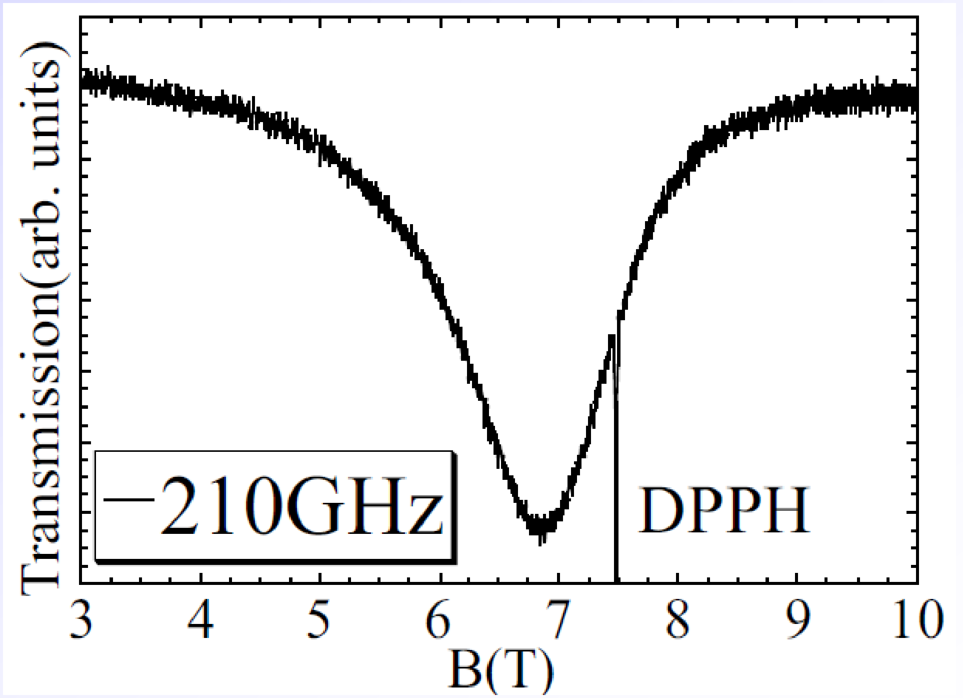


$H_{DM} = D.(S_i \wedge S_j)$

Herbertsmithite



Vesignieite



$|D_z|=0.08J$, $|D_p|\sim 0.01J$

$J_{vesi} \sim J_{herb}/3$; $\Delta H_{vesi} \sim \Delta H_{volb}$

ESR: $\Delta H \sim D^2/J$

$D/J_{vesi} \sim$ 1.7 $D/J_{herb} \sim$ 0.14 Dc/J

A. Zorko et al, PRL **101**, 026405 (2008)

W. Zhang, H. Ohta et al., JSPJ (2010)

Summary (II)

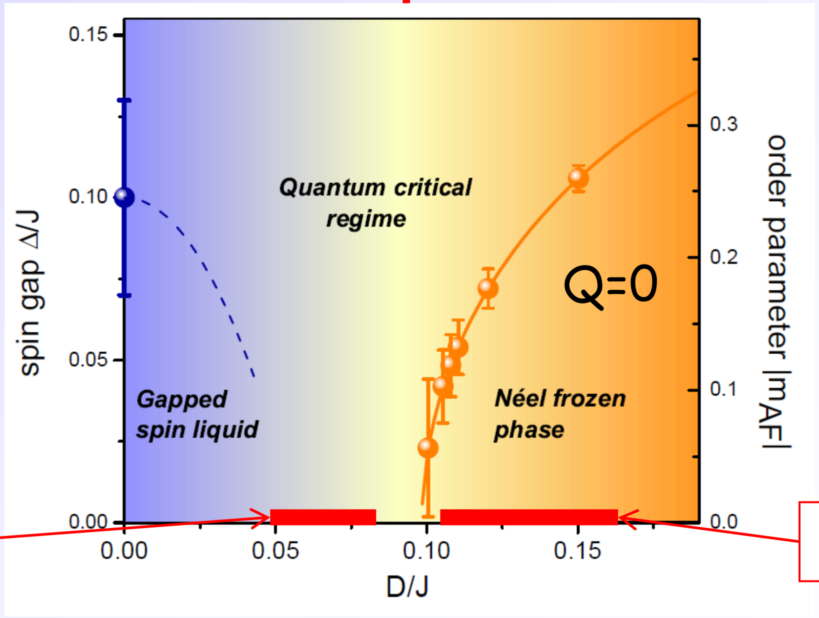
Herbertsmithite

- Perfect kagome
- No freezing at H=0
- $0.44 < D/J < 0.08 < D_c$
- Field induced freezing

QCP

Vesignieite

- Close to perfect kagome
- Q=0 ordered state @ J/6
- $D_c < 0.1 < D/J < 0.17$
- Moment 0.6 μ_B close to max



Herbertsmithite

Vesignieite

Outline

- Zn and Mg Herbertsmithite $Cu_3(Zn,Mg)(OH)_6Cl_2$
  - a gapless quantum spin liquid (summary)
  - field induced solidification of the QSL

- Vesignieite $Cu_3Ba(VO_5H)_2$
  - local susceptibility (NMR)
  - heterogeneous frozen ground state (μSR+NMR)

Quantum criticality
Dzyaloshinky-Moriya interactions

-Kapellasite $Cu_3Zn(OH)_6Cl_2$
  - competing exchange interactions

Collaborations

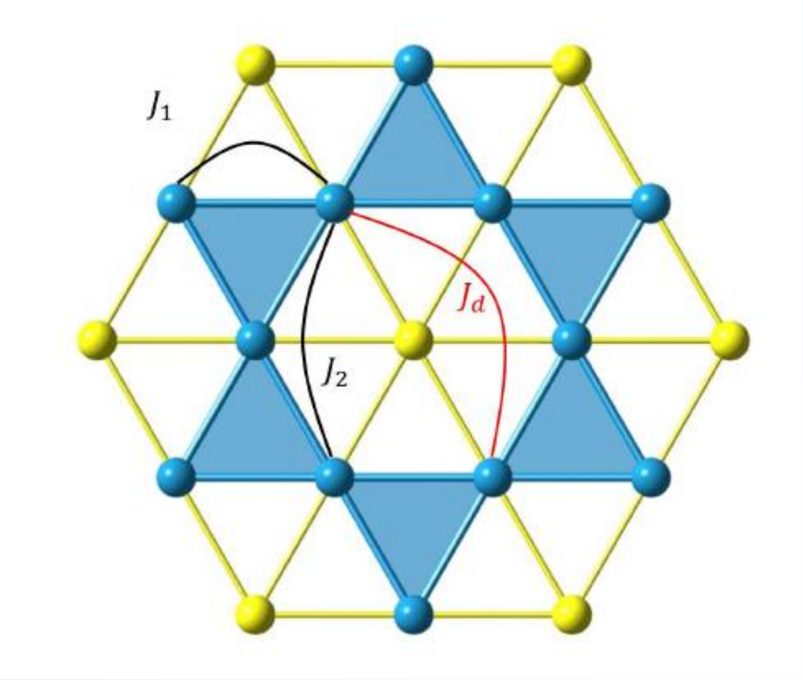
Samples: Ross H Colman, David Boldrin, Andrew S Wills, UCL, UK
Neutrons: B. Fak, CENG, Grenoble, France
Magnetization: P. Bonville, CEA Saclay
Theory: L. Messio, C. Lhuillier, B. Bernu, Paris, France

Quantum Kagome Antiferromagnets $ZnCu_3(OH)_6Cl_2$

PRL **101,** 106403 (2008) PHYSICAL REVIEW LETTERS week ending 5 SEPTEMBER 2008

Modified Kagome Physics in the Natural Spin-1/2 Kagome Lattice Systems: Kapellasite $Cu_3Zn(OH)_6Cl_2$ and Haydeeite $Cu_3Mg(OH)_6Cl_2$

O. Janson,[1] J. Richter,[2] and H. Rosner[1,*]
[1]*Max-Planck-Institut für Chemische Physik fester Stoffe, D-01187 Dresden, Germany*
[2]*Institut für Theoretische Physik, Universität Magdeburg, D-39016 Magdeburg, Germany*
(Received 26 May 2008; published 3 September 2008)

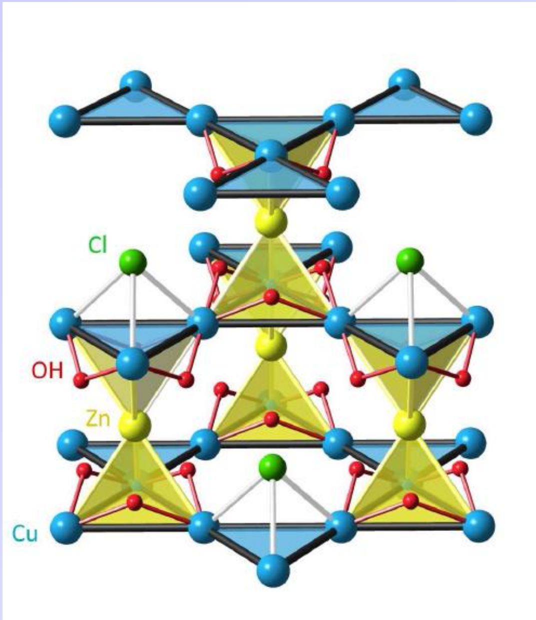


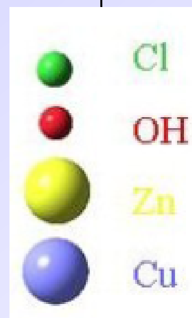
Kapellasite : a polymorph of Herbertsmithite

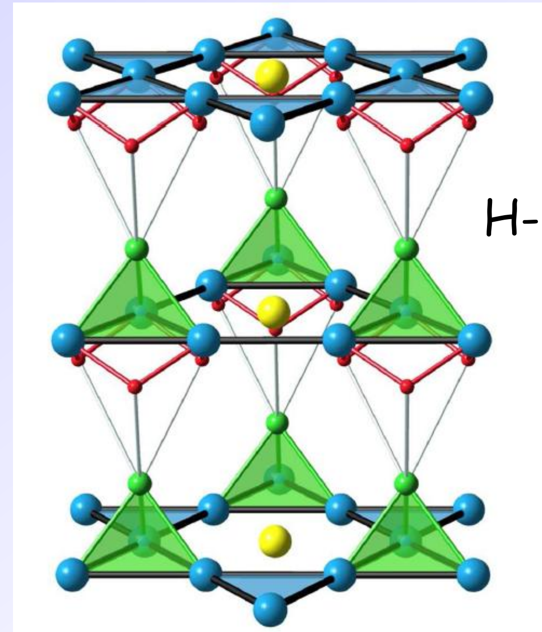
Herbertsmithite

Kapellasite

$Cu_3Zn(OH)_6Cl_2$



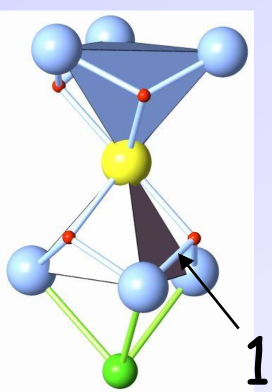




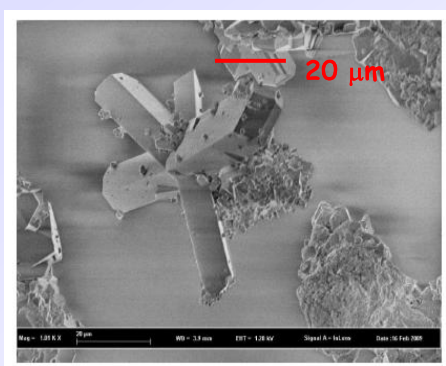
Weak H-Cl bonds

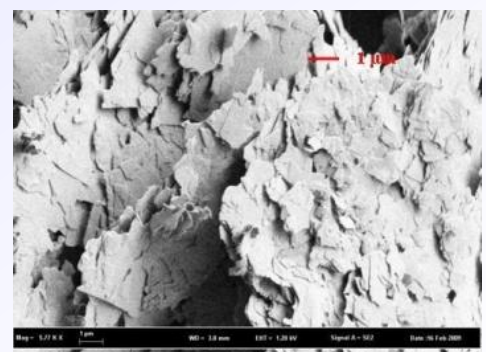
$R\bar{3}m$

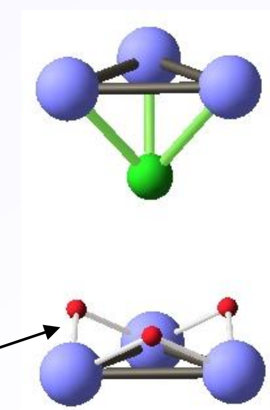
$P\bar{3}m1$



119°



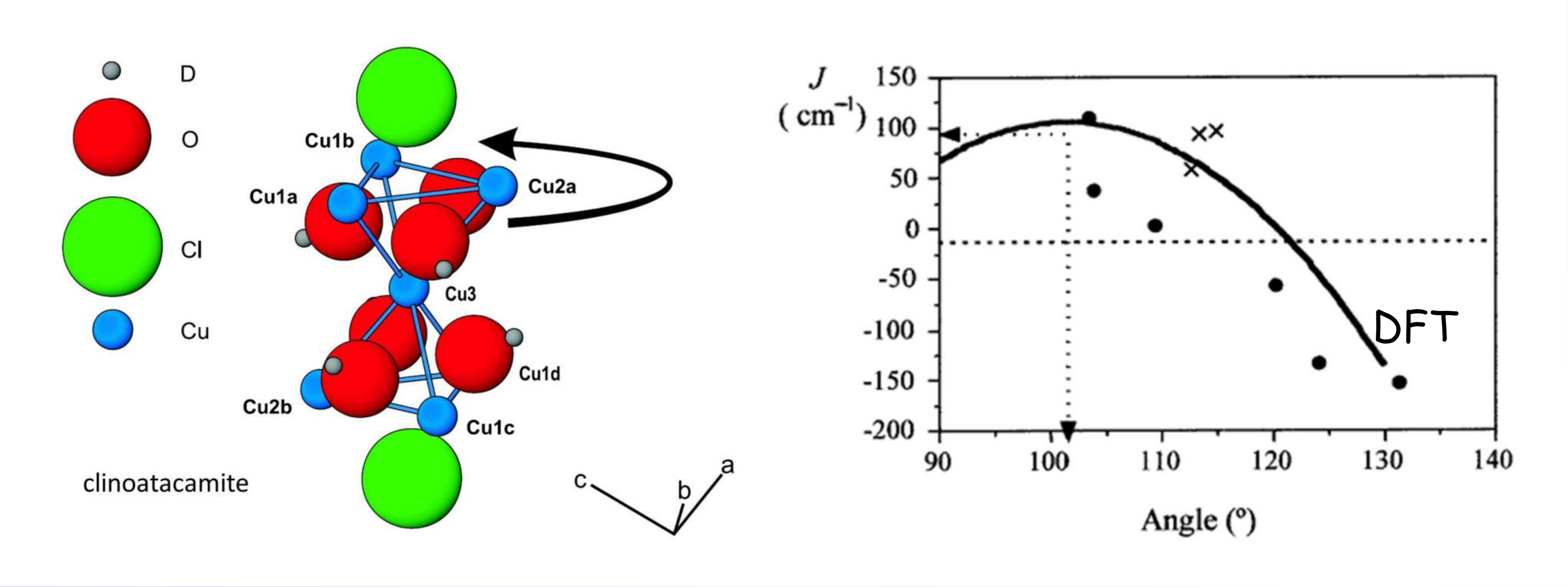




105°

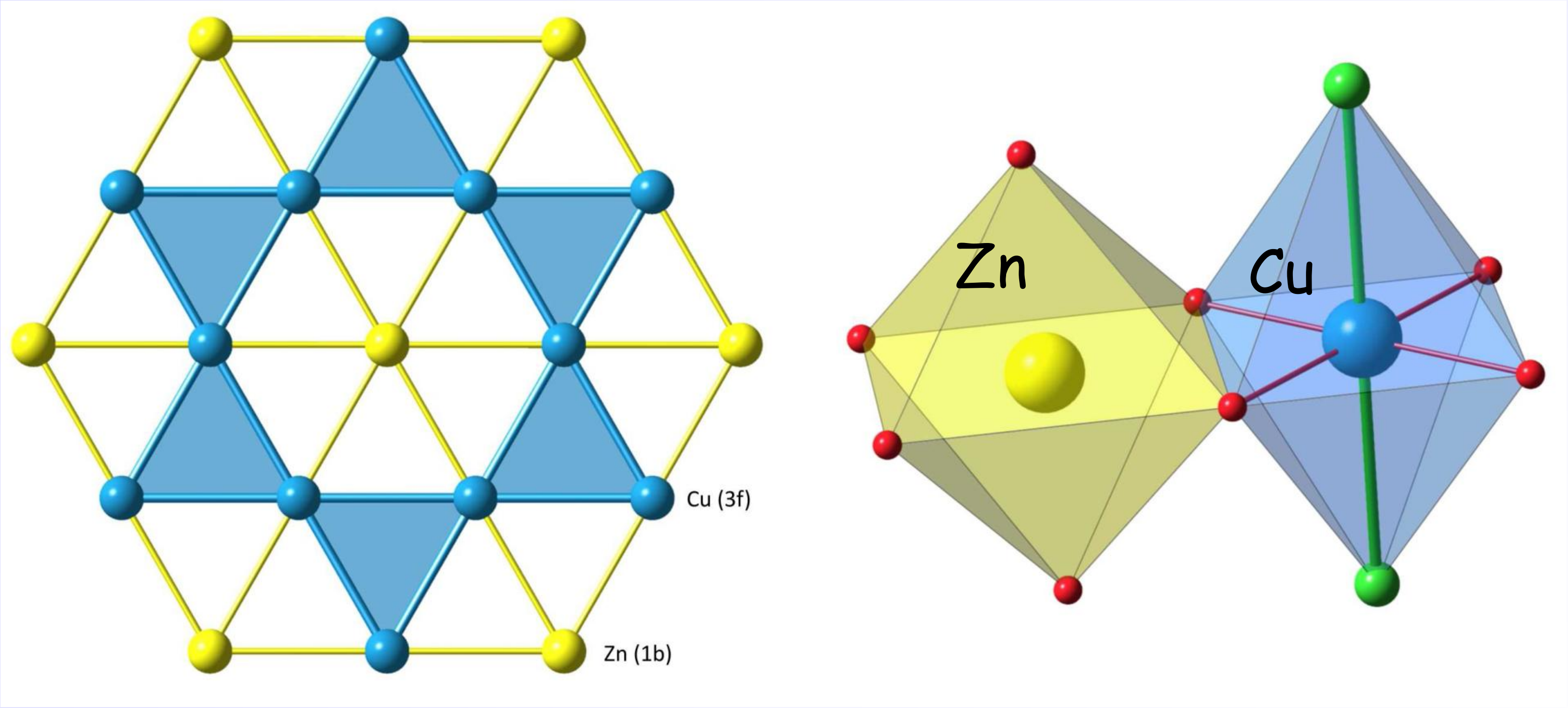
R.H Colman et al. *Chem. Mater.* ***22***, 5774 (2010)

Smallness of interactions Cu-O-Cu angle



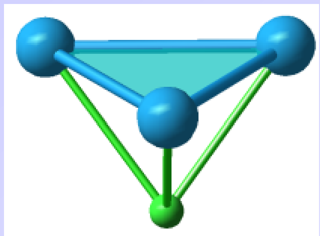
Janson et al. *Phys. Rev. Lett.* (2008)
Gutierrez L. et al., *Eur. J. Inorg. Chem.* 2094 (2002)

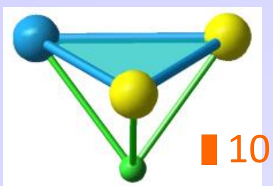
Two different crystallographic sites in the triangular plane



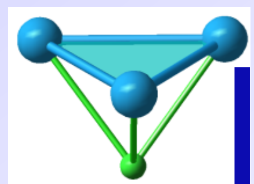
^{35}Cl NMR (oriented powders) → Diluted kagome plane

One Cl site expected in NMR

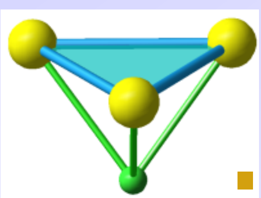




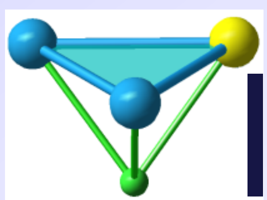
10 %



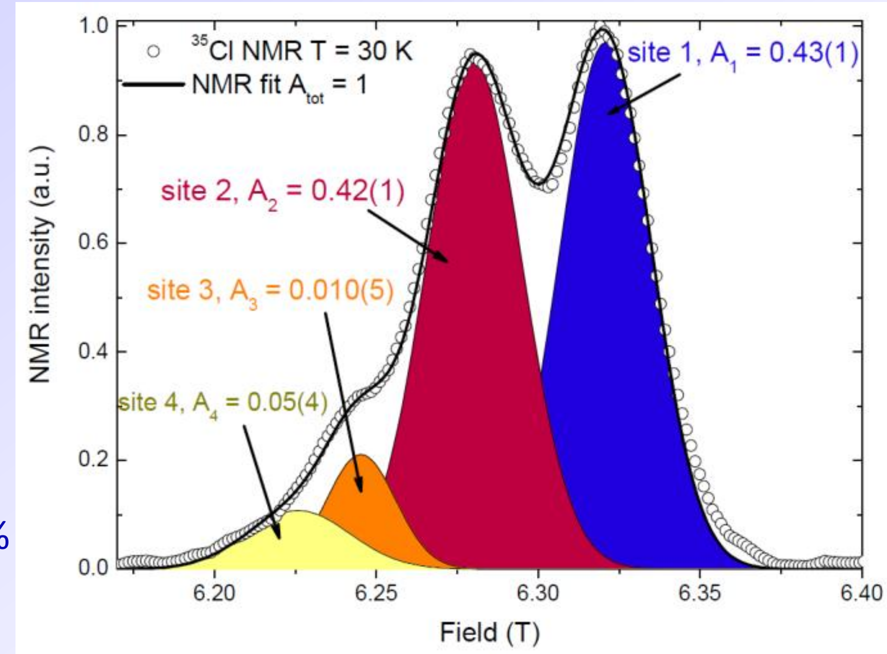
43 %



5 %



42 %



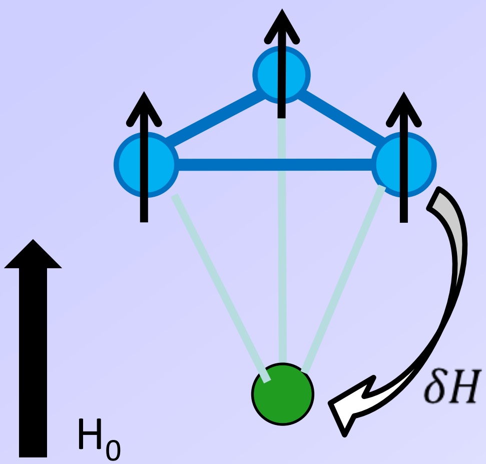
ICP
Neutrons
NMR

$(Cu_{0.73}Zn_{0.27})_3(Zn_{0.88}Cu_{0.12})(OH)_6Cl_2$

Kagome site occupancy $p = 0.73 > p_c \approx 0.652...$

R.H Colman, A. Sinclair, A.S Wills, Chem. Mater. ***22****, 5774 (2010)*

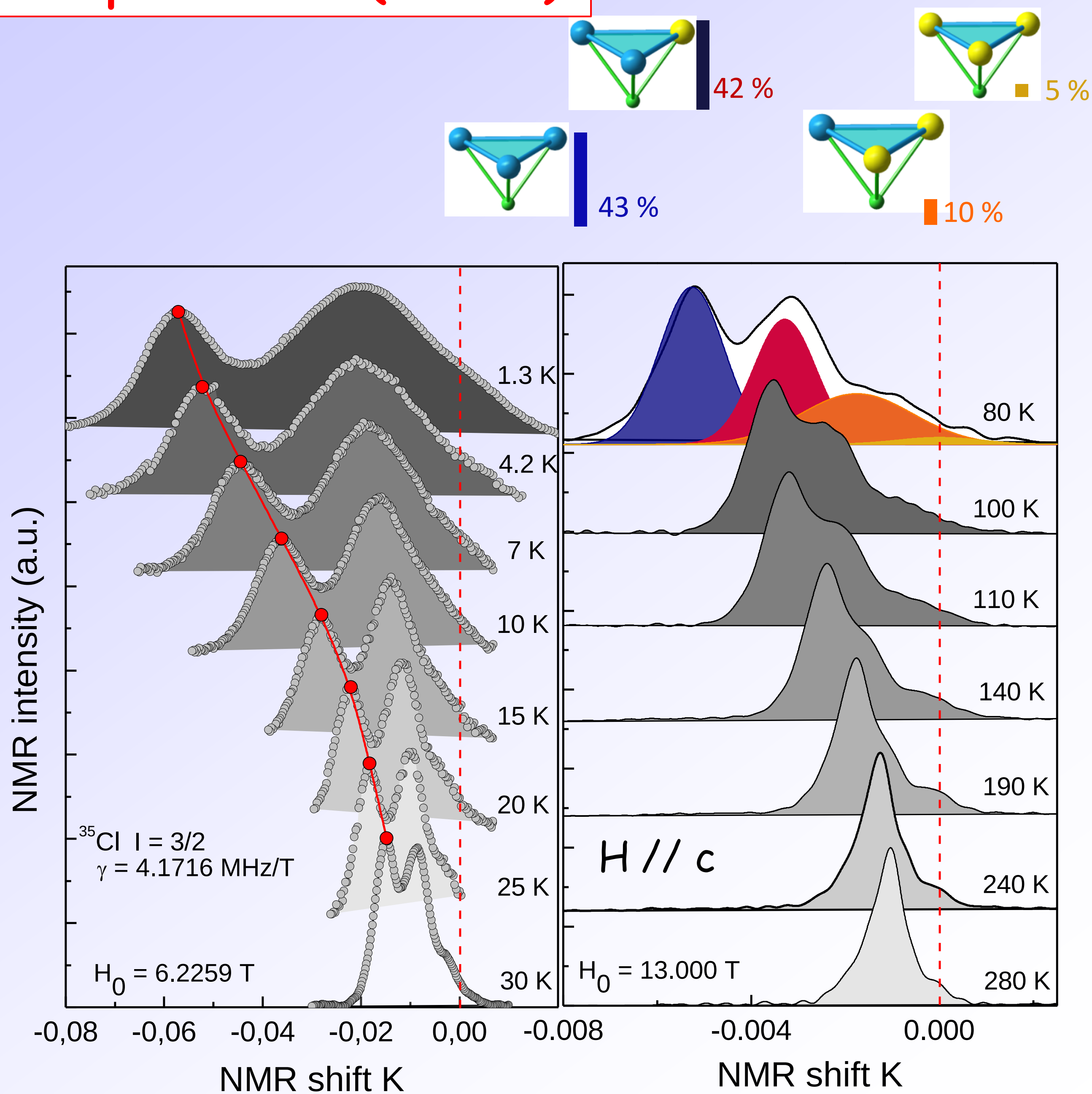
^{35}Cl NMR: oriented powders (>85%)



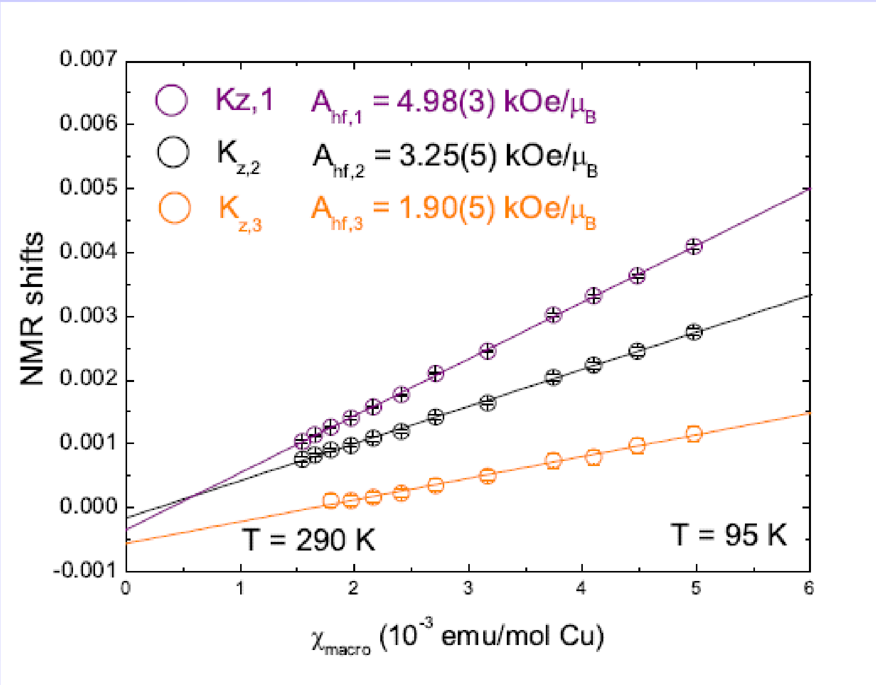
$$H_{res} = H_0 + \delta H$$

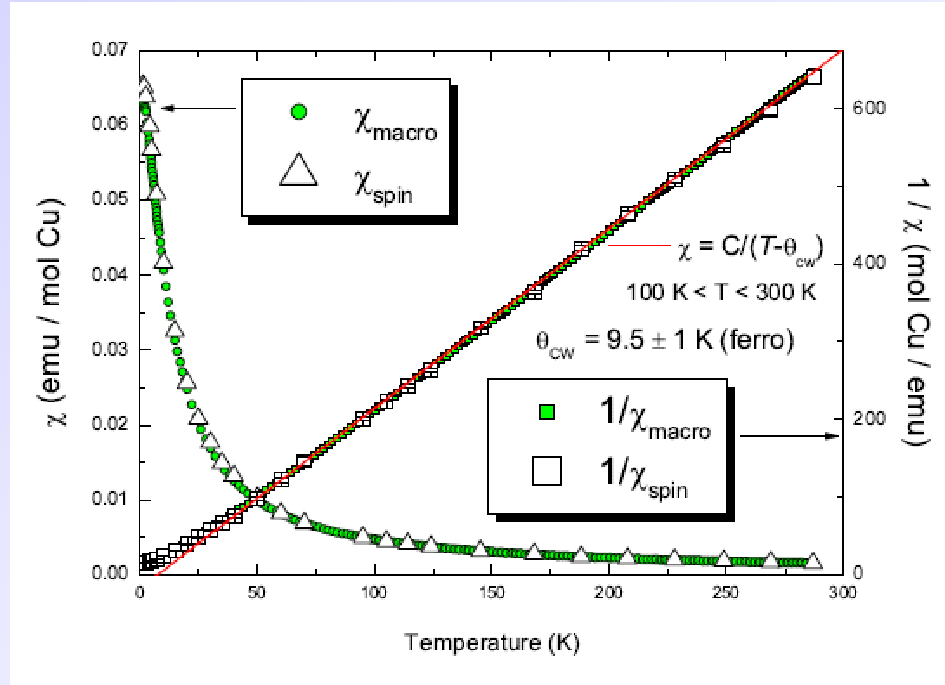
$$\delta H = K H_0$$

$$K(T) = \frac{A_{hf}}{N_A \mu_B} \chi_{spin}(T)$$

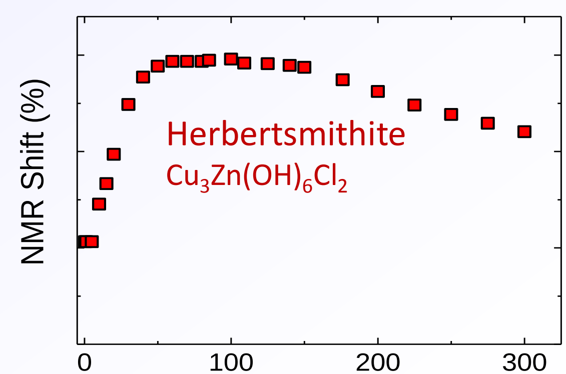


^{35}Cl NMR: local susceptibility



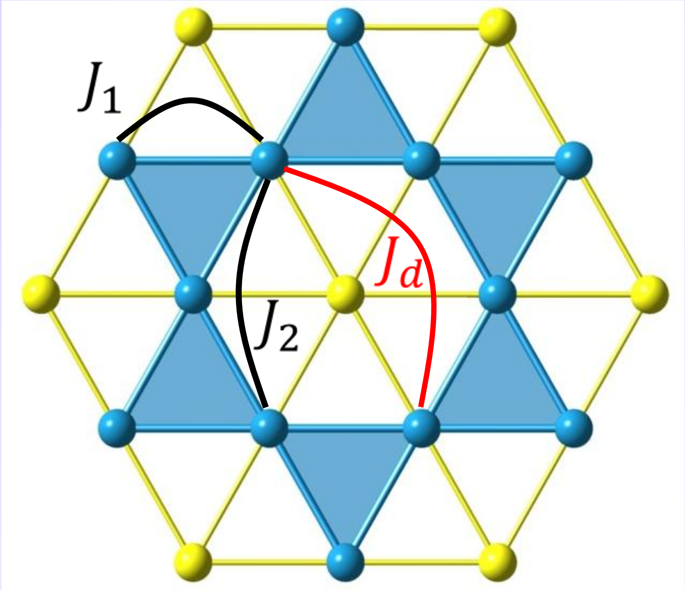


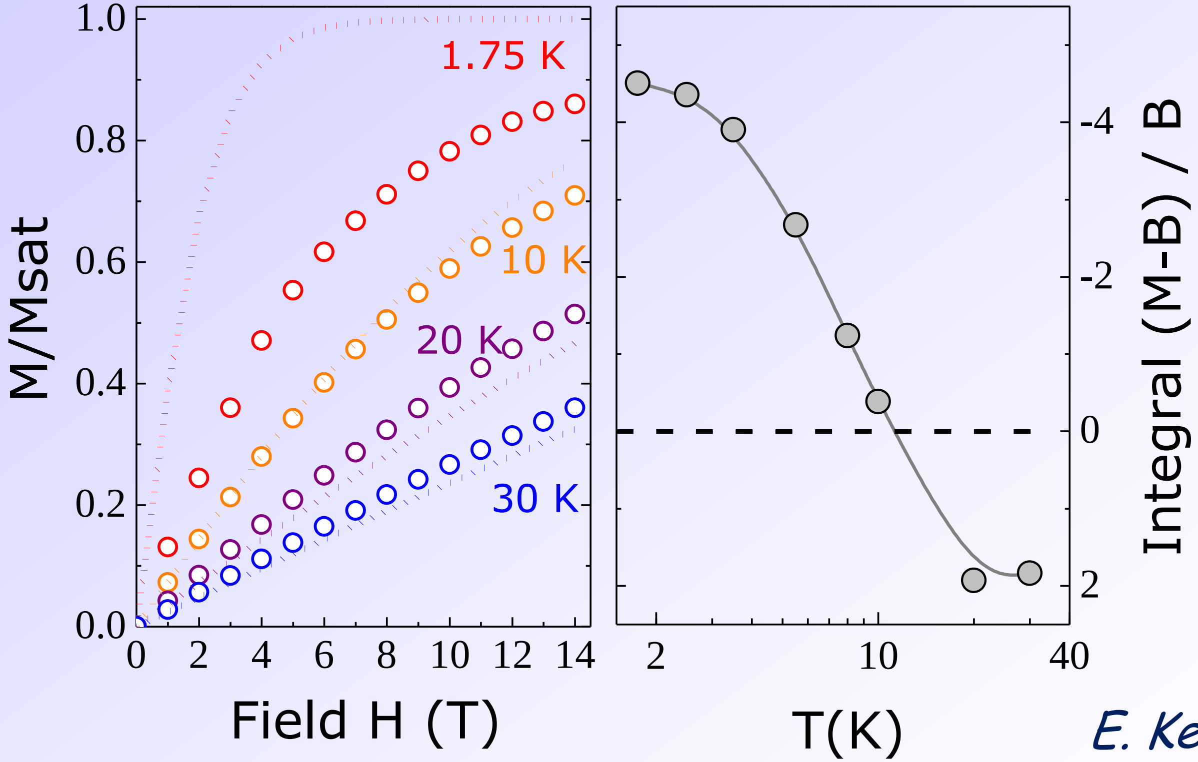
B. Fak, E. Kermarrec et al., Phys. Rev. Lett. ***109****, 037208 (2012)*



A. Olariu, et al, PRL, **100**, 087202 (2008)

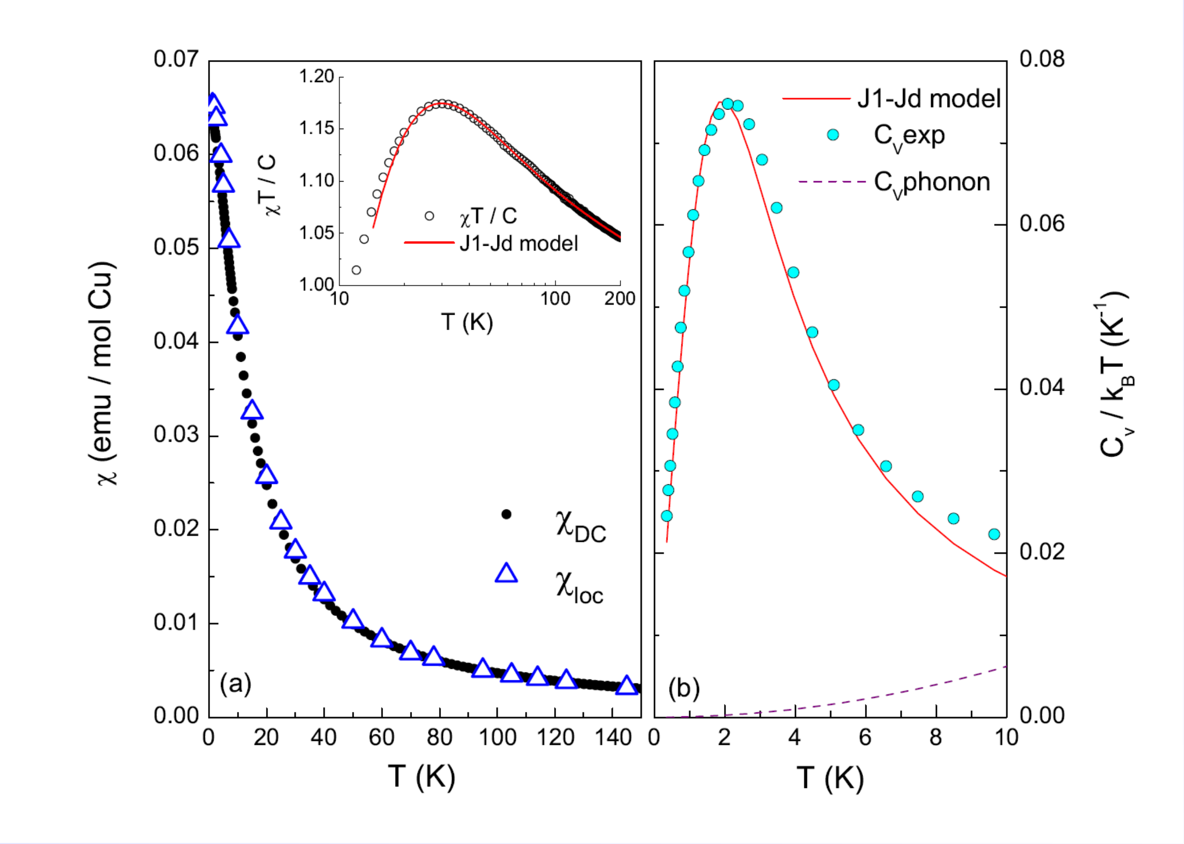
Magnetization measurements





E. Kermarrec et al., in preparation

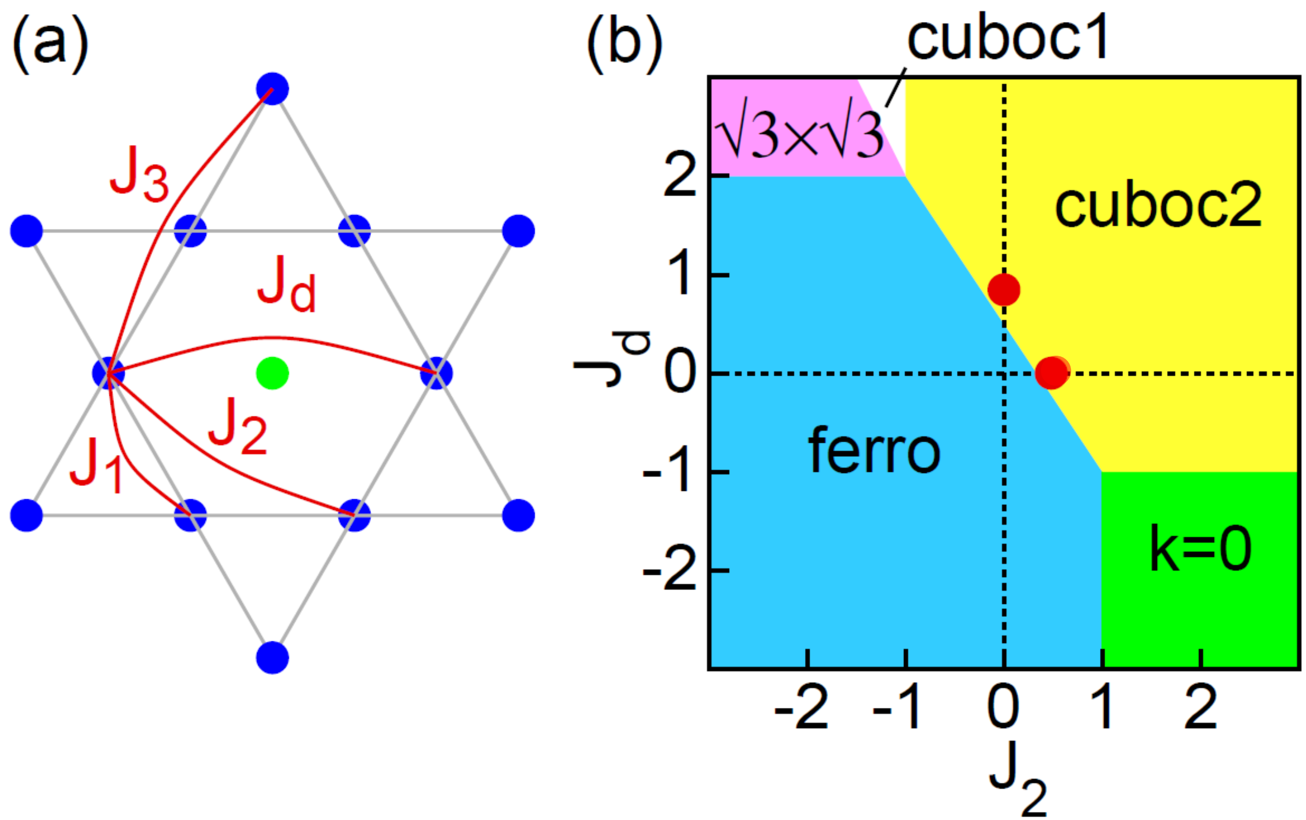
High-Temperature series expansion analysis



J_1 ferro -15 K ~ further neighbor J_d 13 K

B. Bernu, et. al, arXiv 1210.2549

Interactions scheme

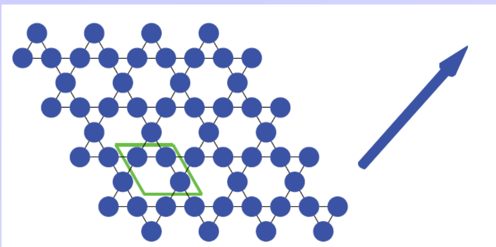


L. Messio, et. al, PRB ***83****, 184401 (2011)*

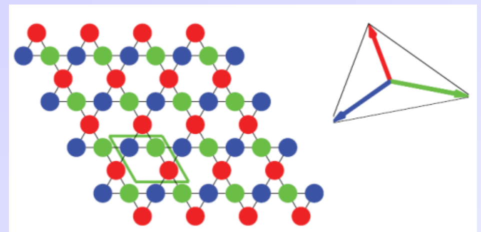
Classical ordered states on the Kagome lattice

L. Messio, C. Lhuillier, G. Misguich, LPTMC Paris, CEA

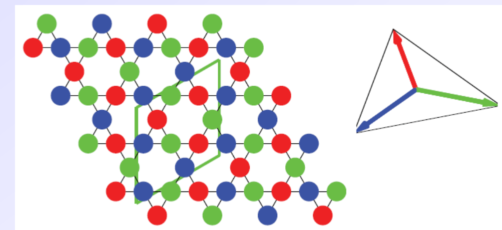
8 Classical long-range ordered **states** allowed by symmetries



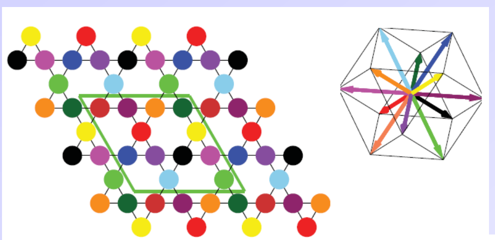
(a) Ferromagnetic (F) state.



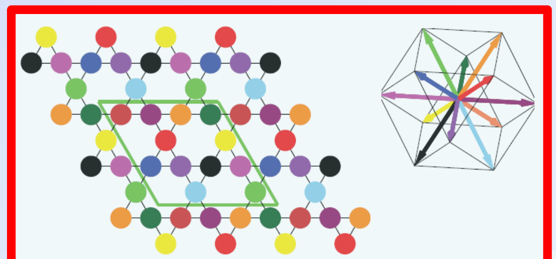
(b) $\mathbf{q} = \mathbf{0}$ state.



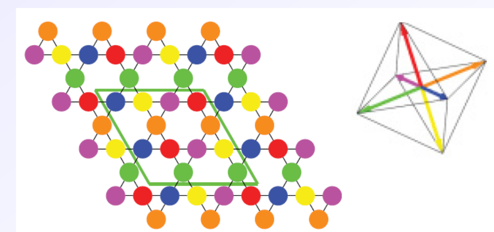
(c) $\sqrt{3} \times \sqrt{3}$ state.



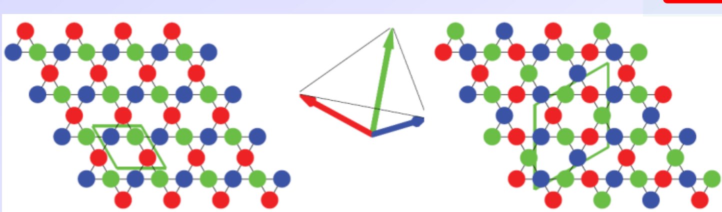
(e) Cuboc1 state.



(f) Cuboc2 state.



(d) Octahedral state.



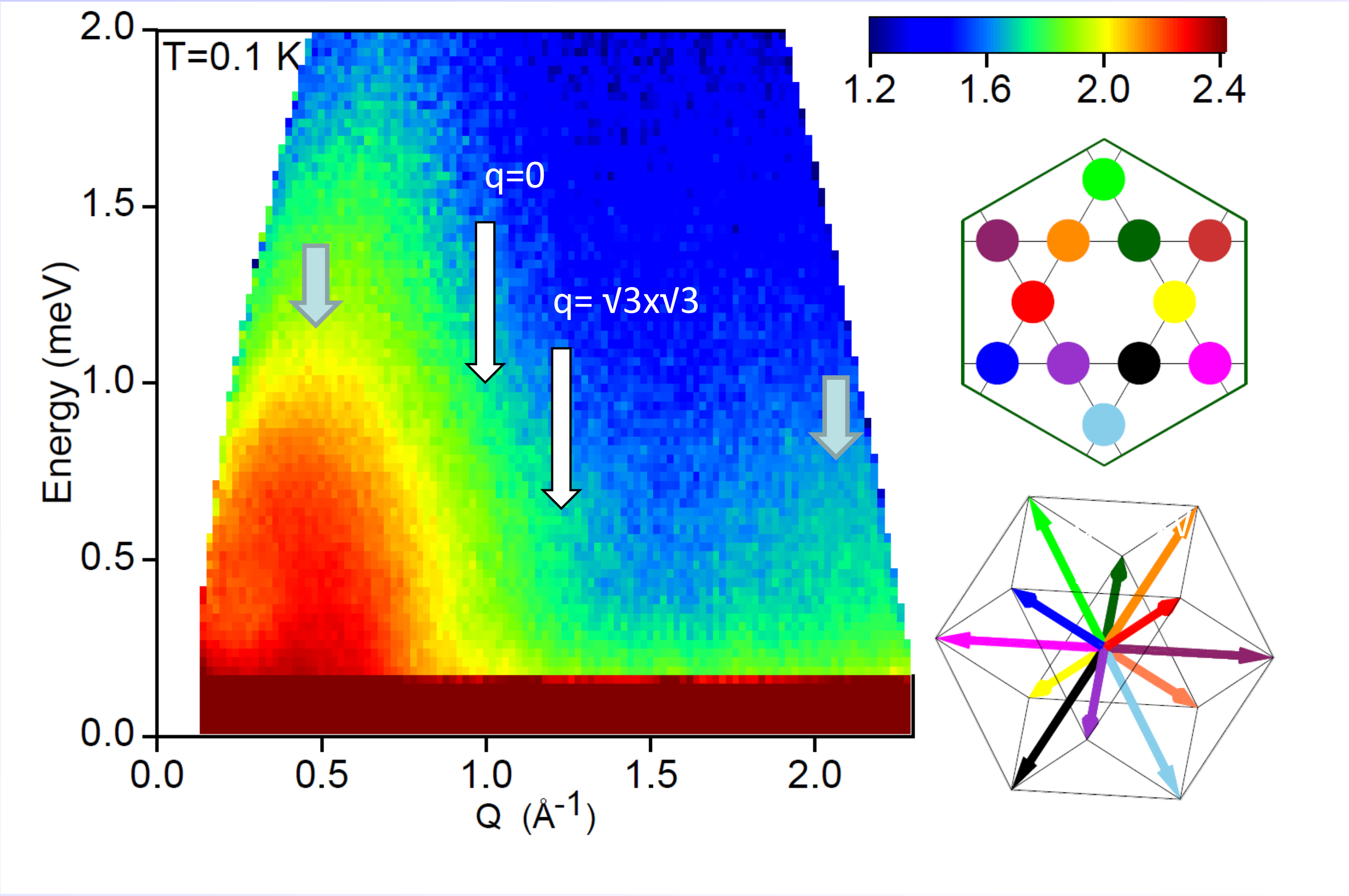
(g) $\mathbf{q} = \mathbf{0}$ (left) and $\sqrt{3} \times \sqrt{3}$ (right) umbrella states.

Non coplanar state

- 12 sublattice spins order : « cuboc2 »
- Neutrons experiment shows correlations reminiscent of this peculiar state

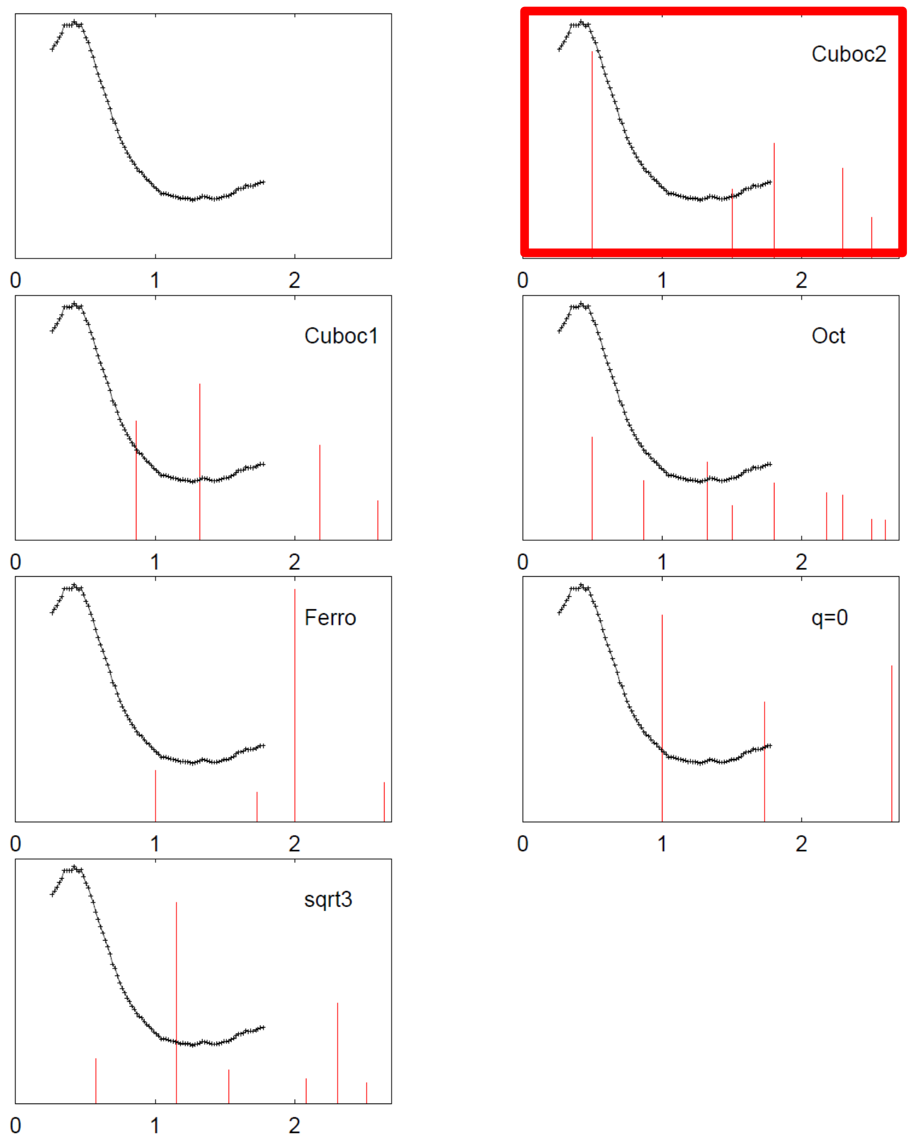
*L. Messio, et. al, PRB **83**, 184401 (2011)*

Neutron scattering (B. Fak, ILL)

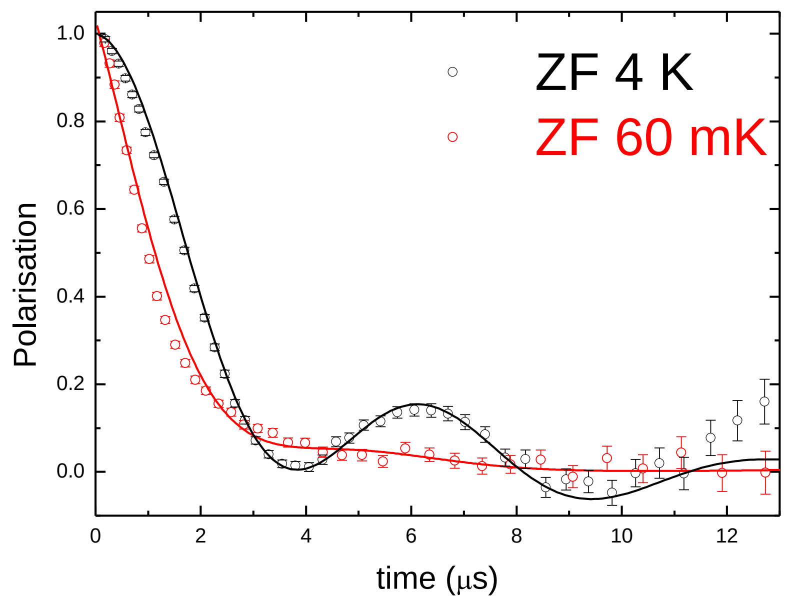


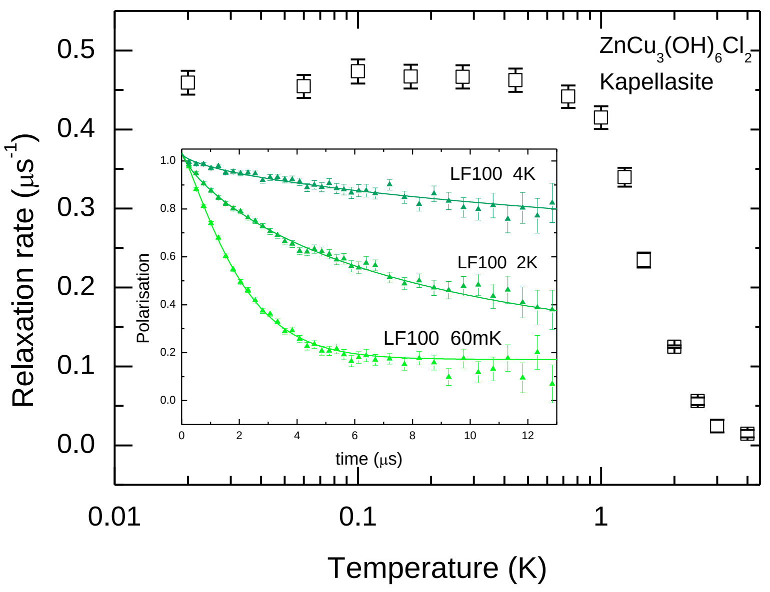
Cuboc-2 correlations survive up to 100 K (also specific heat)

B. Fak, E. Kermarrec et al., Phys. Rev. Lett. ***109****, 037208 (2012)*


Cuboc2
Cuboc1
Oct
Ferro
q=0
sqrt3
0
1
2

μSR: dynamical study

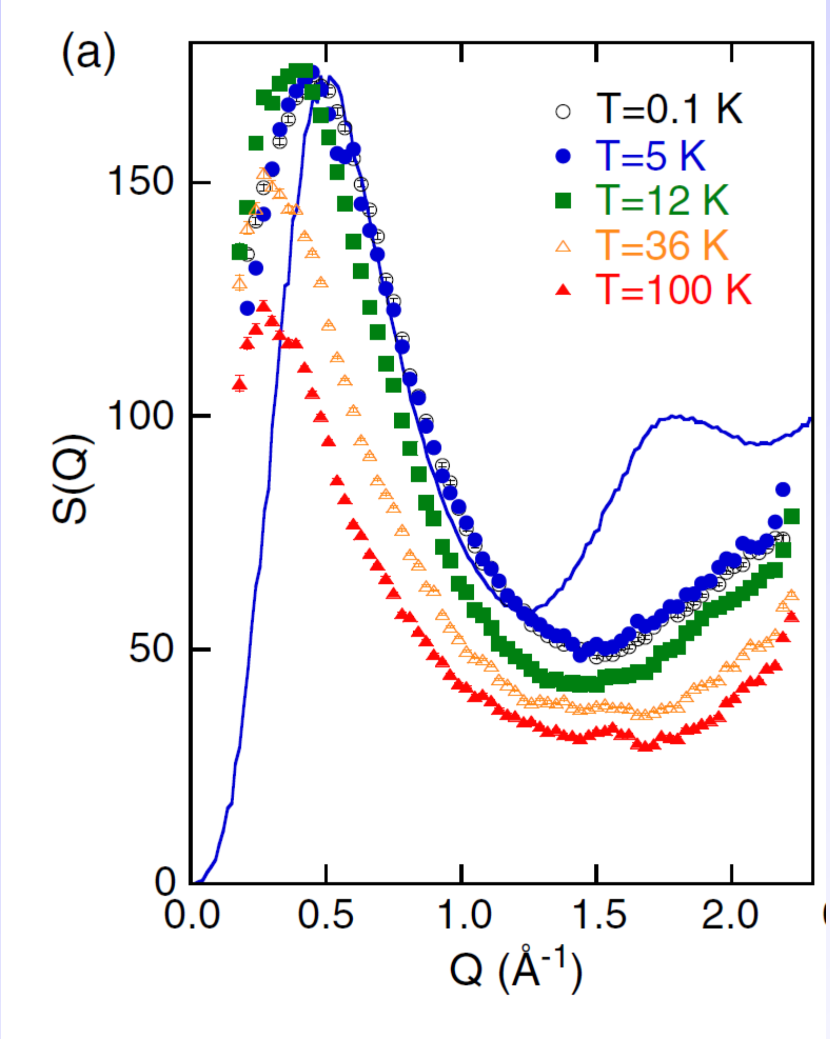


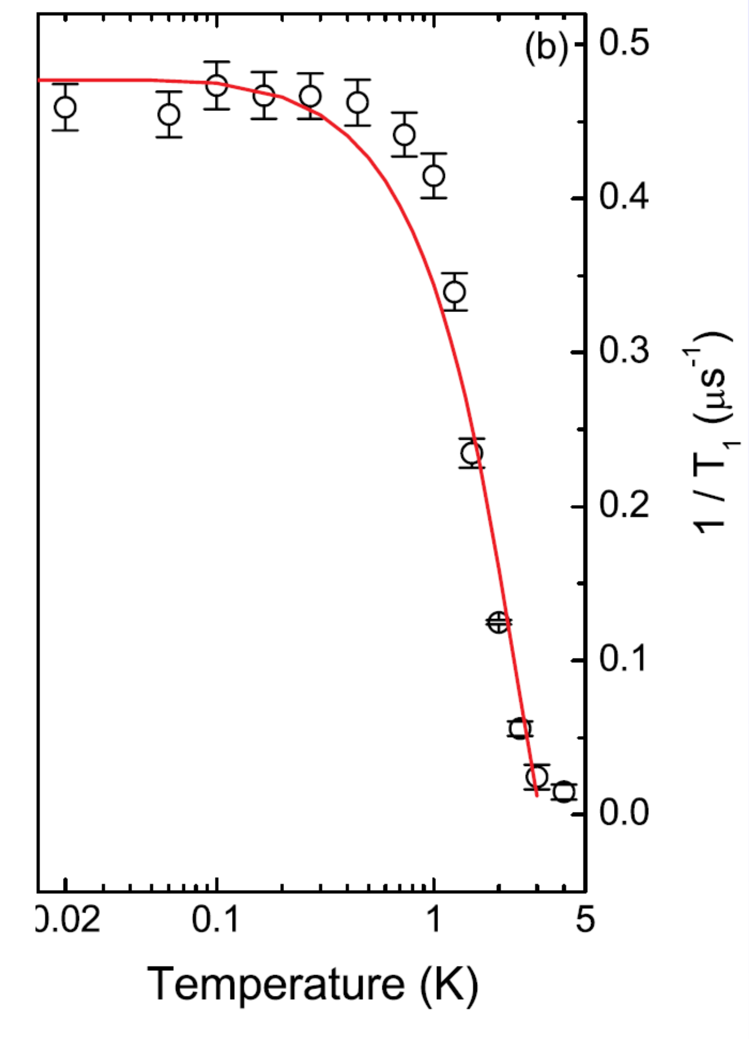


-no freezing

-Persistent slow fluctuations

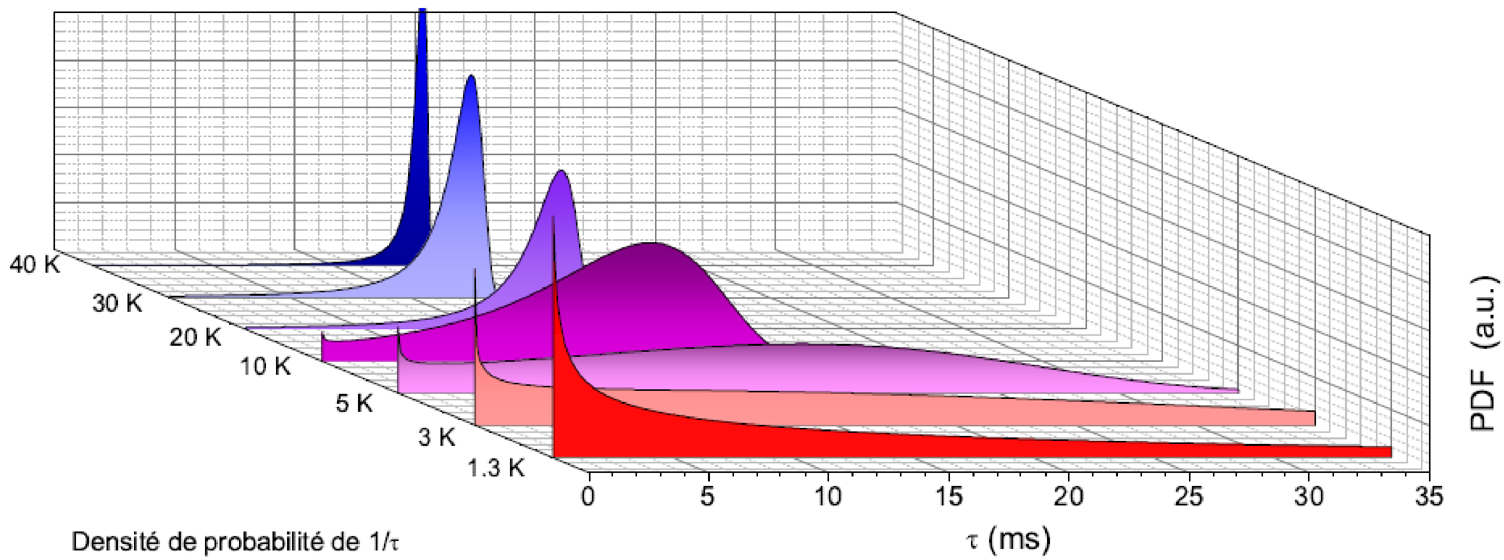
Schwinger boson MFT: captures S(Q), low energy scale

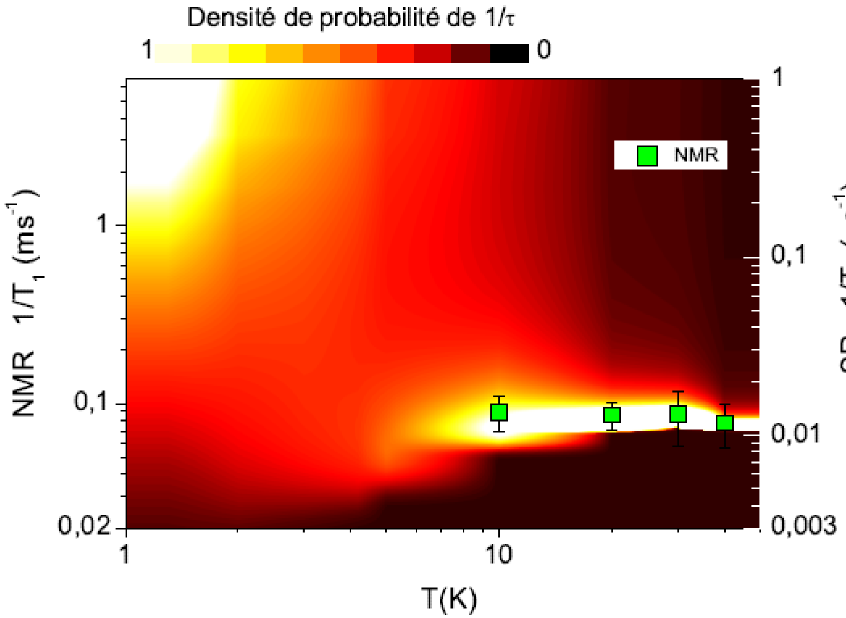


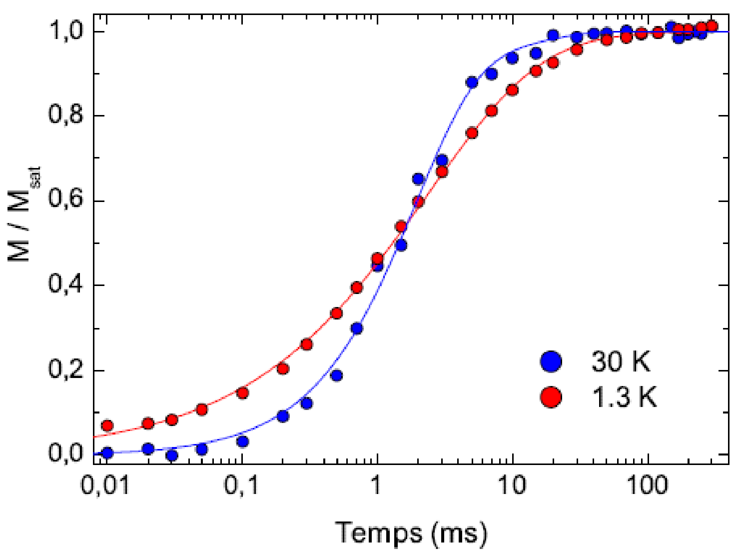


but SBMFT: predicts order at T=0, spin wave-like excitations

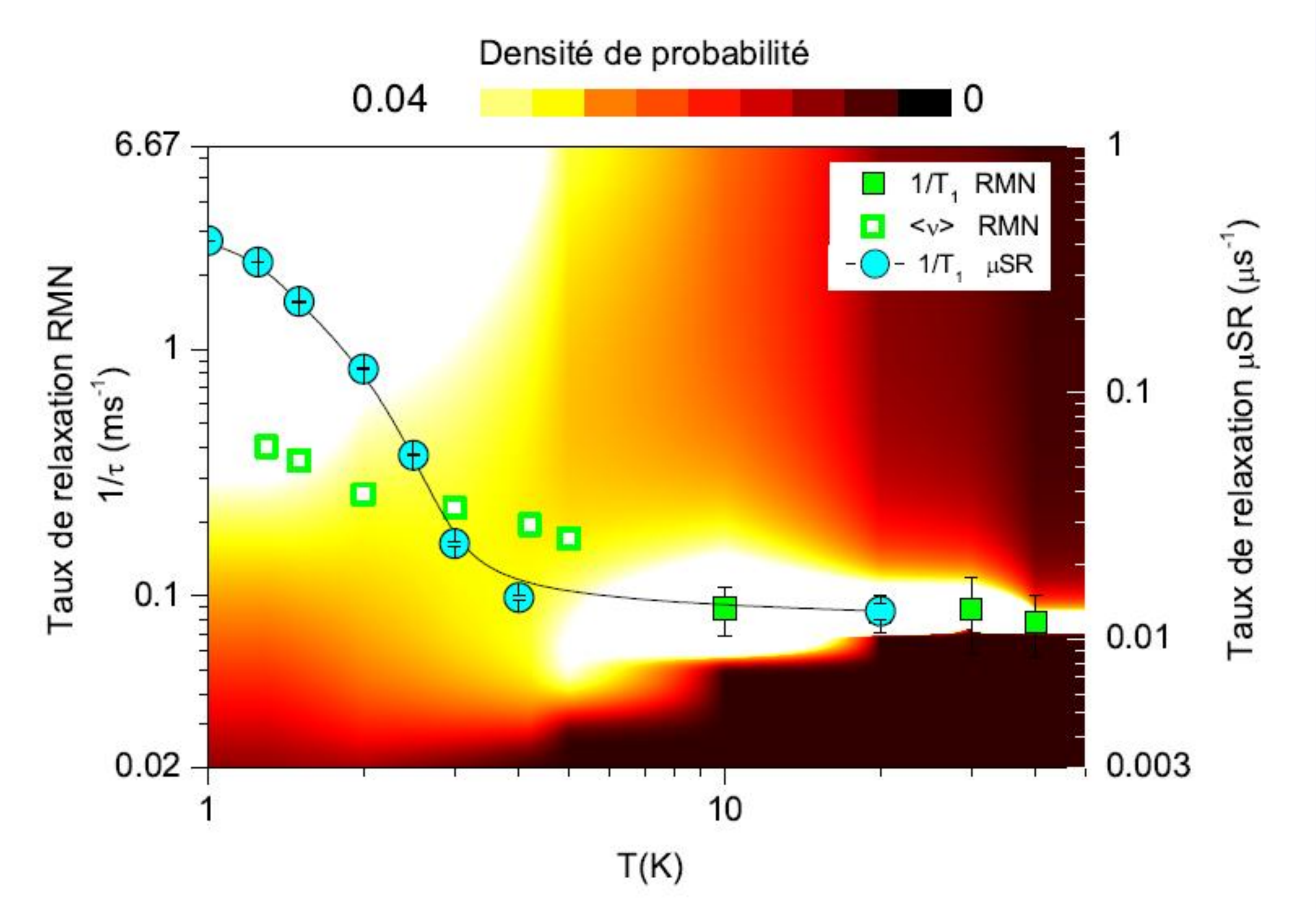
NMR: dynamical study







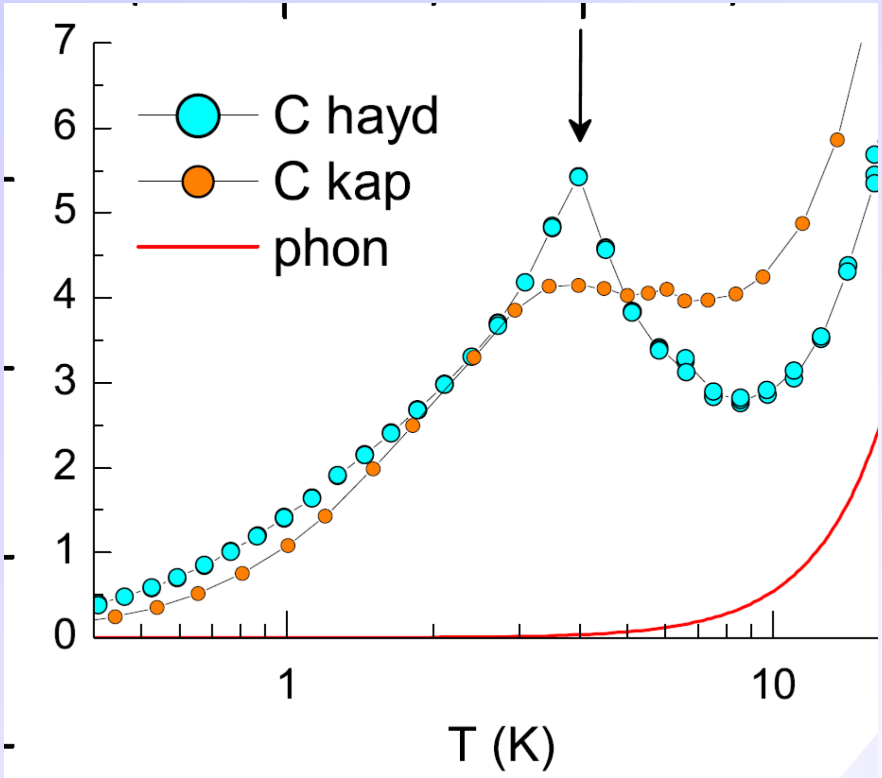
NMR: dynamical study

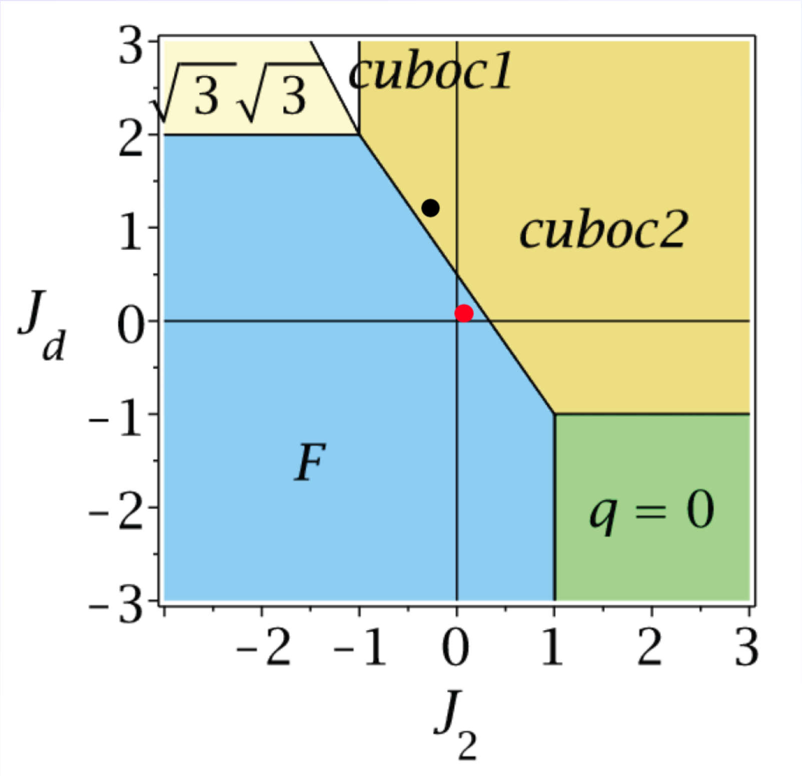


NMR: more local than μSR: more inhomogeneous?

Haydeite = Mg-Kapellasite

- 55% freezing @ T= 4K
- Peak in specific heat
- KT series J1= 12.4 K, Jd = -2.1K, J2= -1.2 K





B. Bernu, E. Kermarrec et al., unpublished

Summary III and open issues (kapellasite)

✓ Experimentally:

a new quantum spin liquid: quantum cuboc-2 phase

✓ Theoretically:

- Schwinger Boson MFT captures low energy physics
  $S(Q,E)$, $1/T_1)_{\mu SR}$
- SBMFT predicts spin waves around 0.5 mEV for T<3K
  (not observed)
- Fermionic chiral approach (C. Lhuillier, L. Messio, B. Bernu)
- Disorder?

Thank you!

Last but not least: some (personal) feeling

- ✓ Kagome lattice dilution: does not impact much the physcis
  (SCGO, Herbertsmithite,Vesignieite?)

- ✓ Non-equivalent interactions matters
  (Volborthite)

- ✓ Low symmetry lattices -> DM