Defects in Frustrated Systems

Art Ramirez (Bell Labs)

Geometrical Frustration – Materials Considerations

Frustration →

Disorder ↓

Antiferromagnetism Ferromagnetism Metamagnetism Ferrimagnetism	Geometrical Frustration
percolation, random fields	Spin glass

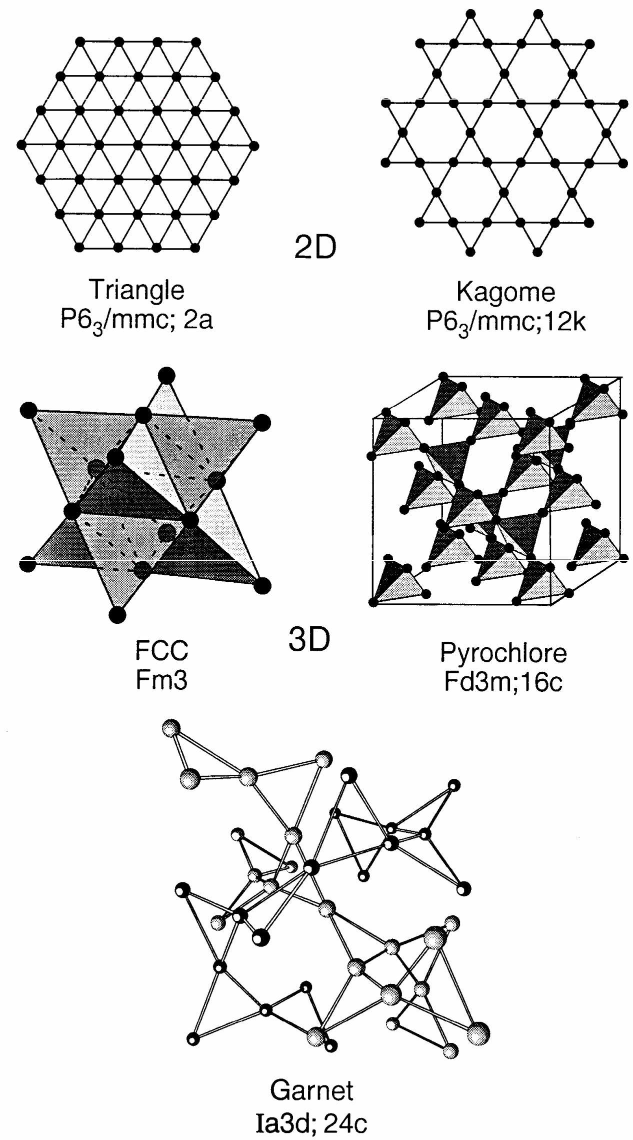

Fig. 19

But what about defects?

VOLUME 64, NUMBER 17 PHYSICAL REVIEW LETTERS 23 APRIL 1990

Strong Frustration and Dilution-Enhanced Order in a Quasi-2D Spin Glass

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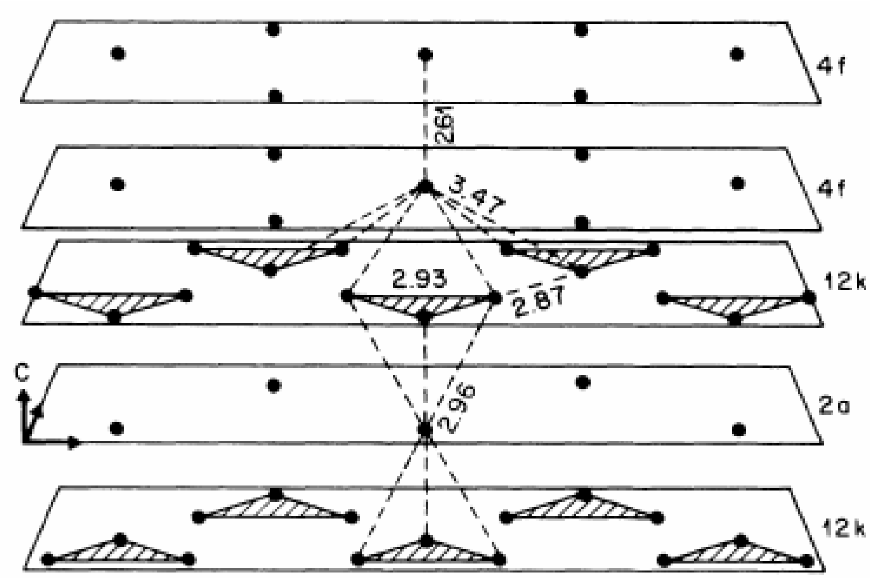
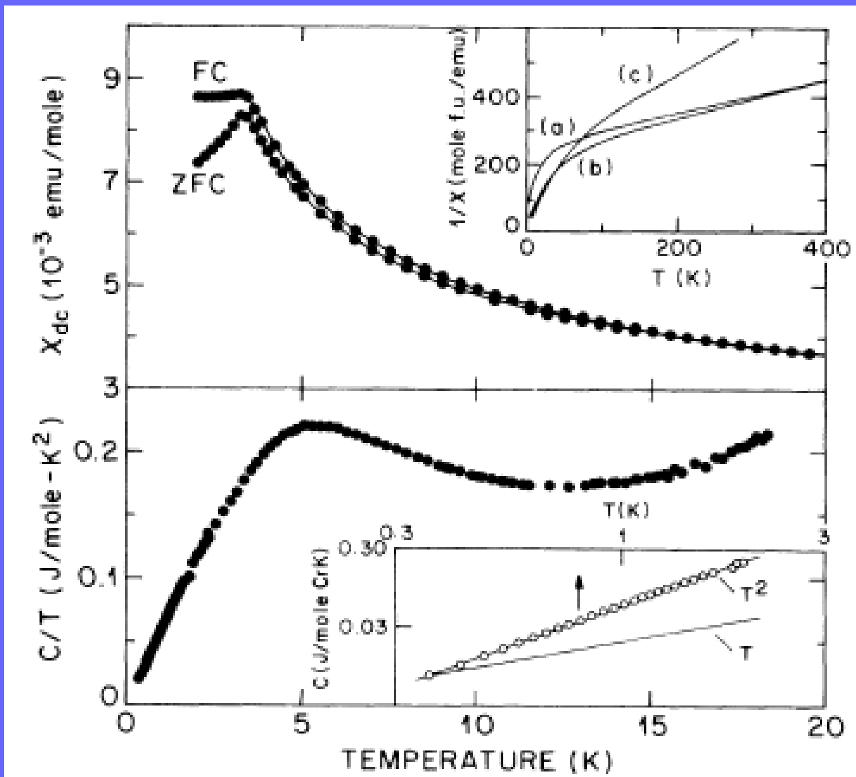
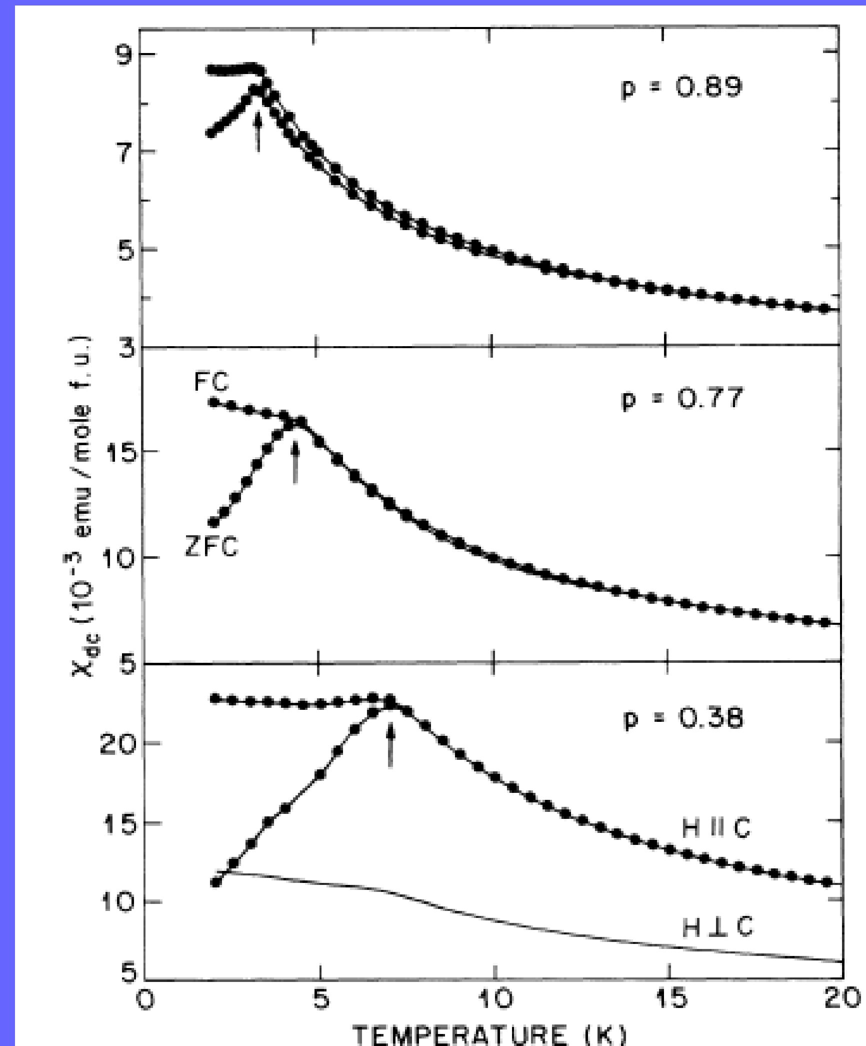
(Received 14 August 1989)



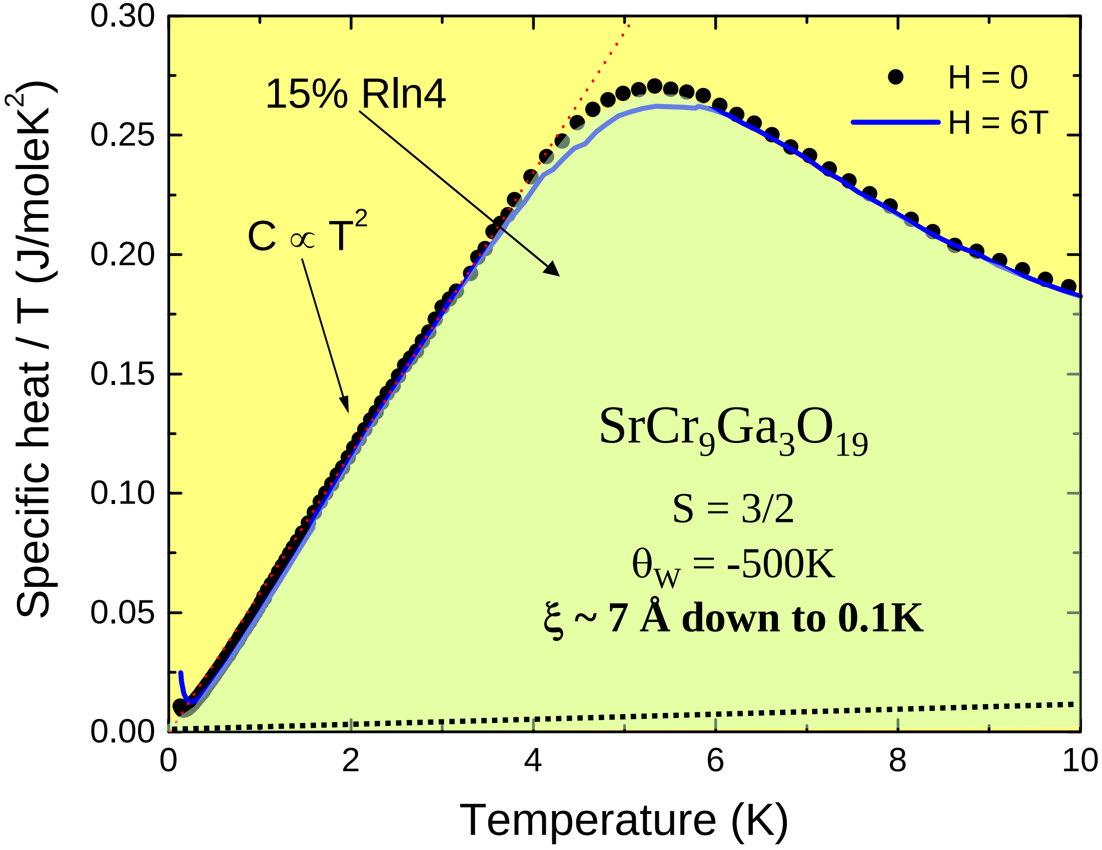
Correlated behavior in $SrCr_{9x}Ga_{1-x}O_{19}$



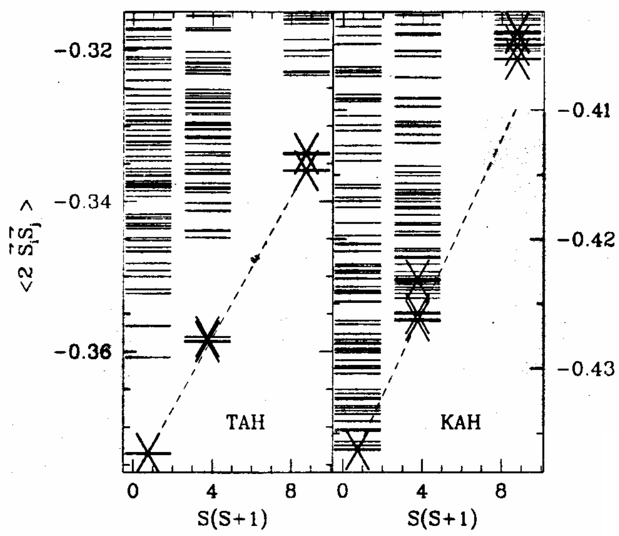


Alcatel·Lucent

What's the medium? - Spectral weight downshift in a 2D kagome magnet - $SrCr_9Ga_3O_{19}$



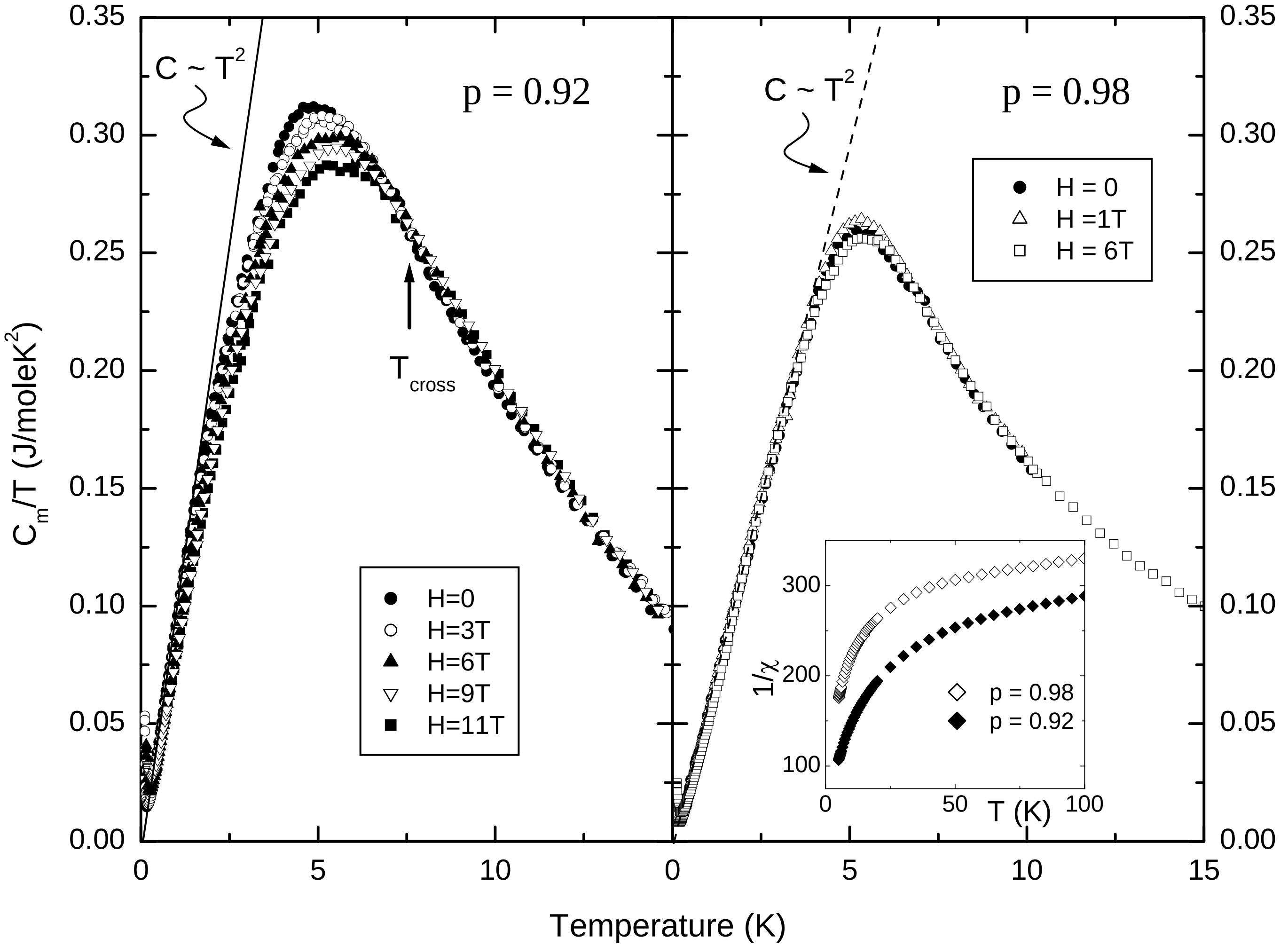
Exact diagonalization, N = 27



Lecheminant, Lhuillier et al. PRB, **56**, 2521 (1997)

APR et al., PRL, **64**, 2070 (1990)

What’s the medium?



APR et al, PRL, 2000

Interaction-Induced Spin Coplanarity in a Kagomé Magnet: $SrCr_{9p}Ga_{12-9p}O_{19}$

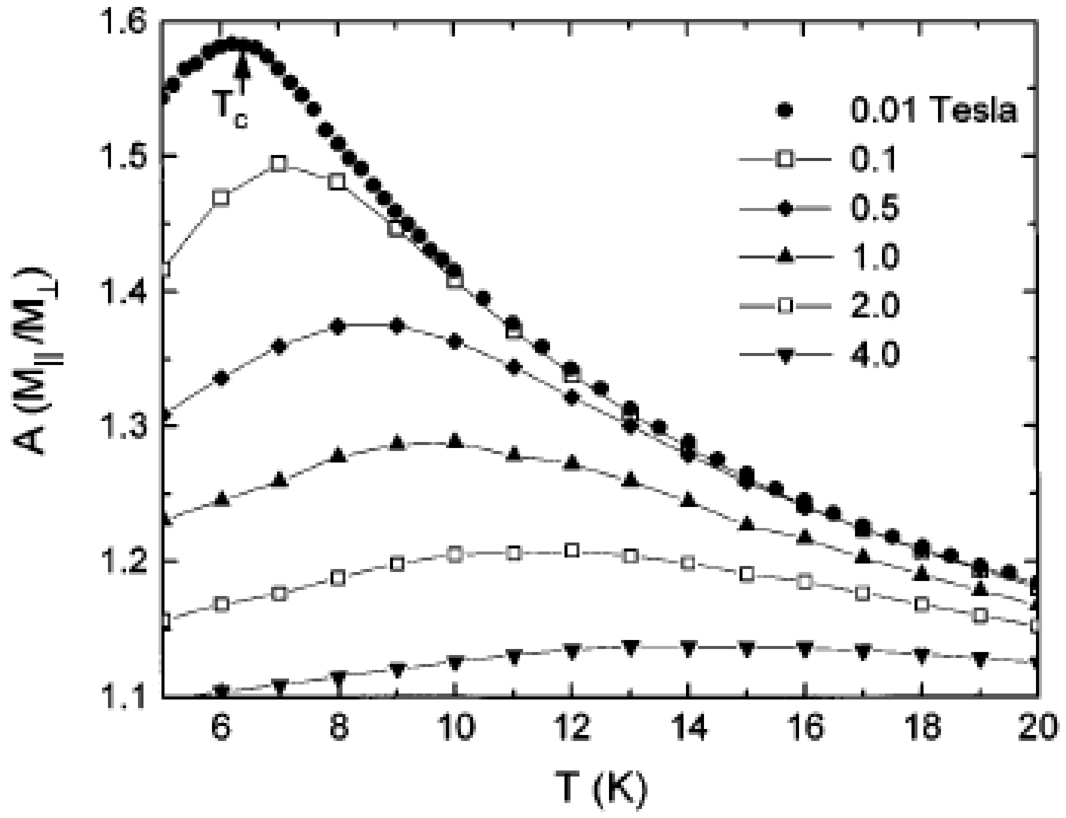


FIG. 2. The anisotropy of the magnetization as a function of temperature at various magnetic fields. Note that application of a strong field suppresses the peak in $A(T)$ and moves it to a higher temperature.

Schiffer et al., PRL 1996

Algebraic vortex liquid theory of a quantum antiferromagnet on the kagome lattice

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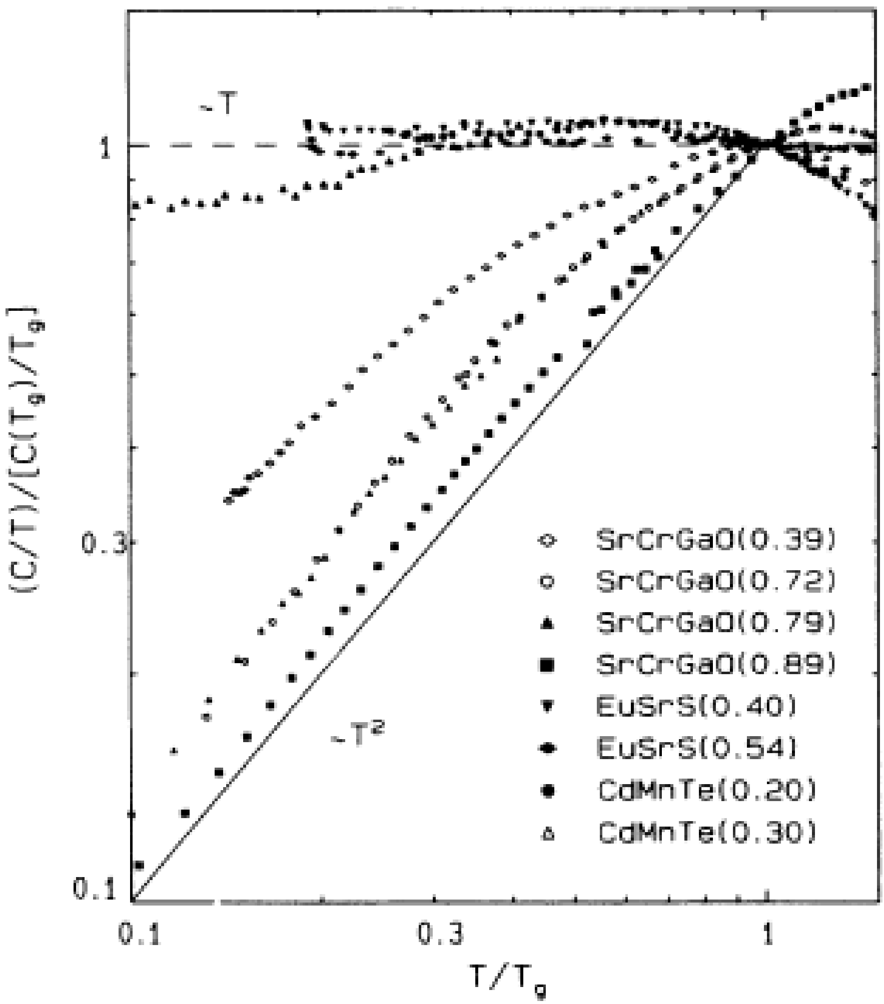
[2]*Department of Physics, California Institute of Technology, Pasadena, CA 91125, USA*
[3]*Department of Physics, University of California, Santa Barbara, CA 93106, USA*
(Dated: January 16, 2007)

Projected wavefunction study of Spin-1/2 Heisenberg model on the Kagome lattice

Ying Ran,[1] Michael Hermele,[1] Patrick A. Lee,[1] and Xiao-Gang Wen[1]
[1]*Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*
(Dated: November 13, 2006)

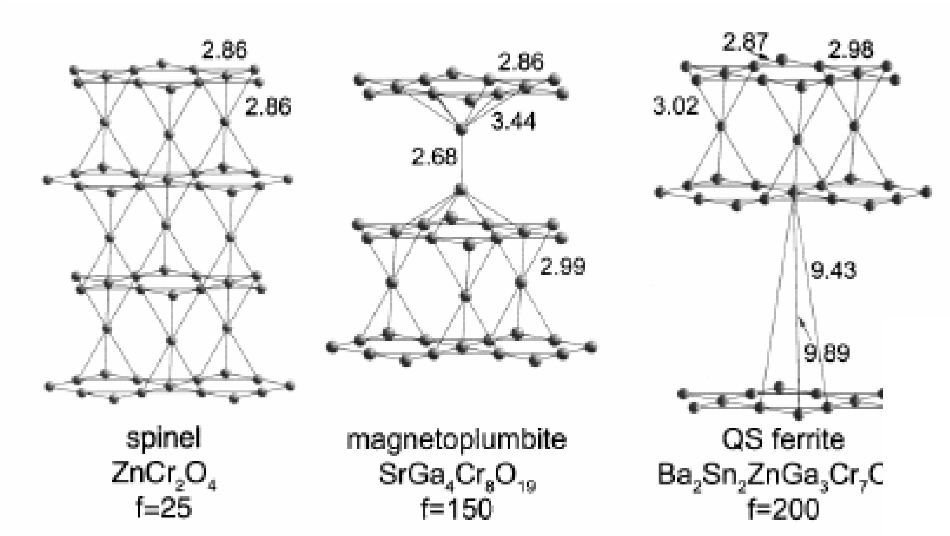
The specific heat T^2 behavior is robust to disorder

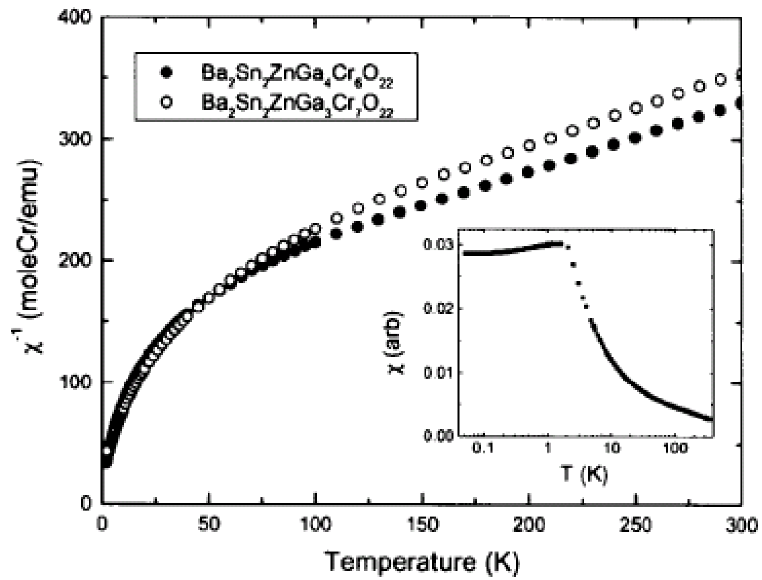


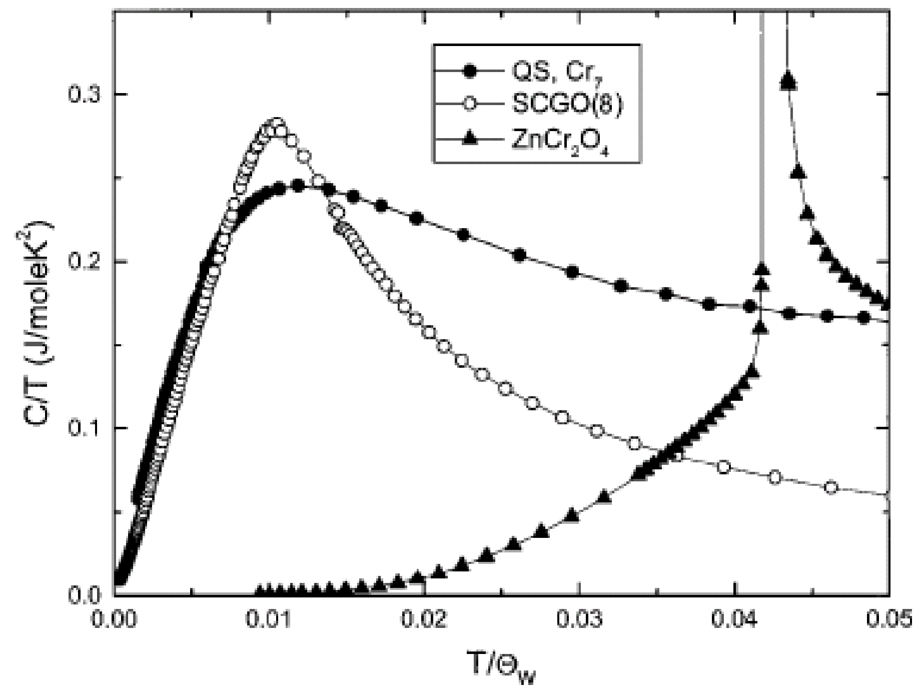
Ramirez et al, *PRB*, 1992

Behavior not confined to SCGO

The "Ruddelsden-Popper" series for spinels





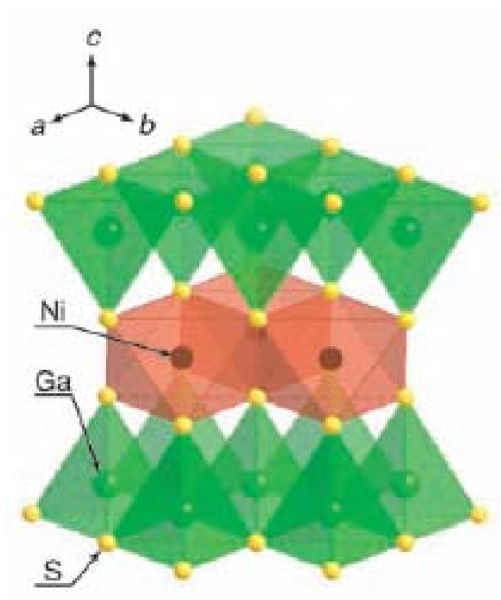


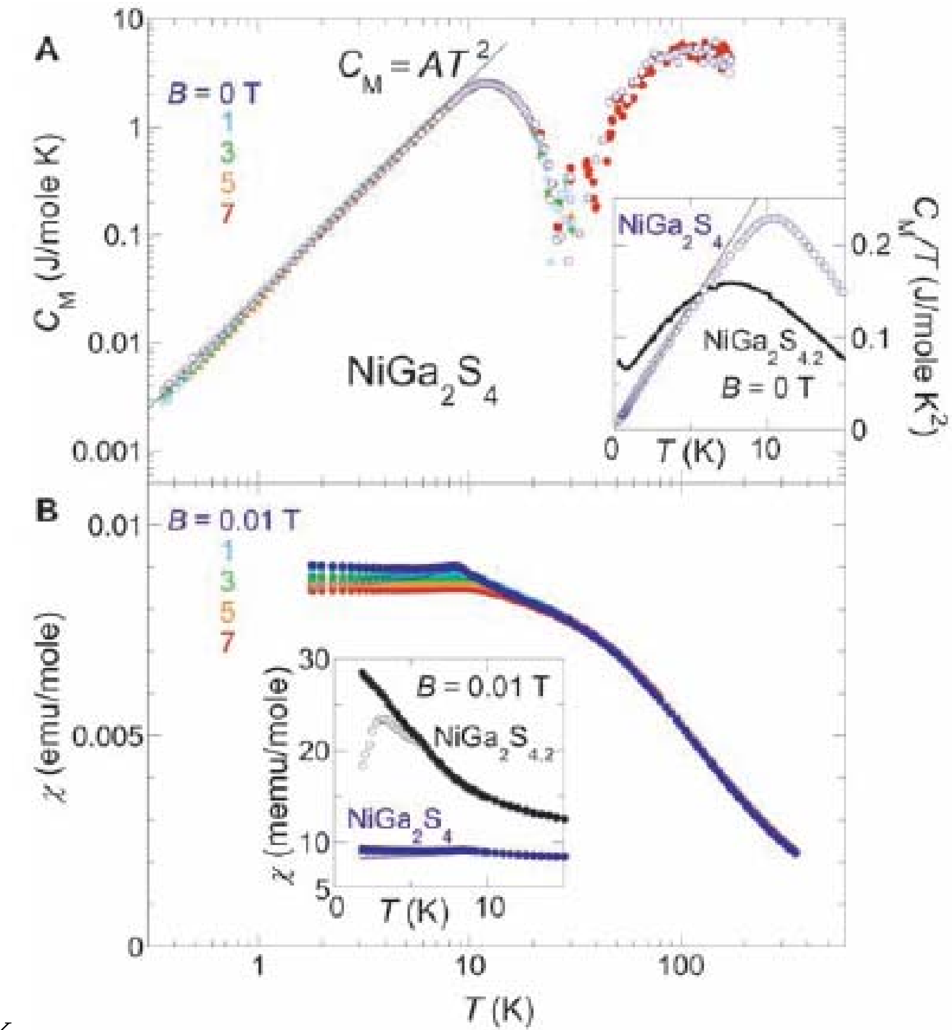
Hagemann et al, *PRL*, 2001

Spin Disorder on a Triangular Lattice

Satoru Nakatsuji,[1*] Yusuke Nambu,[1] Hiroshi Tonomura,[1]
Osamu Sakai,[1] Seth Jonas,[3] Collin Broholm,[3,4]
Hirokazu Tsunetsugu,[2] Yiming Qiu,[4,5] Yoshiteru Maeno[1,6]

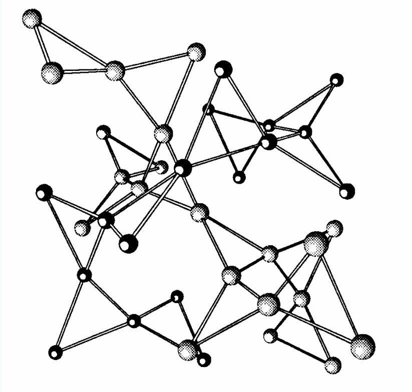
SCIENCE VOL 309 9 SEPTEMBER 2005



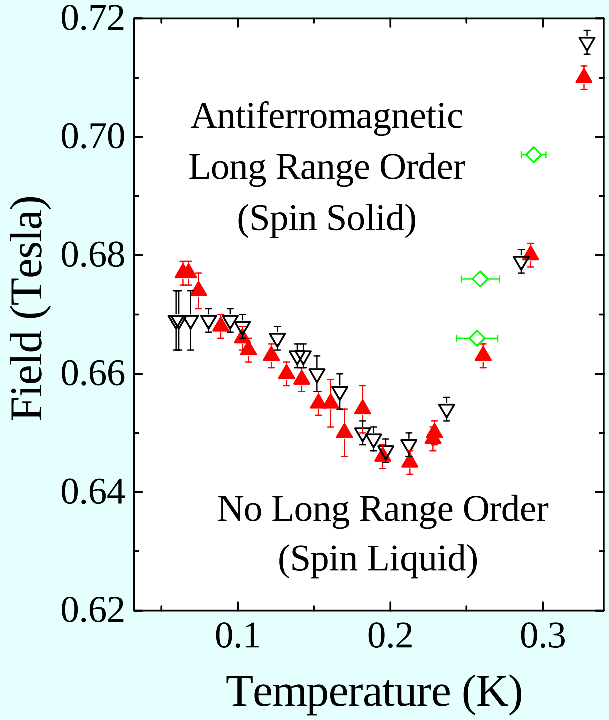


What about 3D? Frustration-generated phases in $Gd_3Ga_5O_{12}$

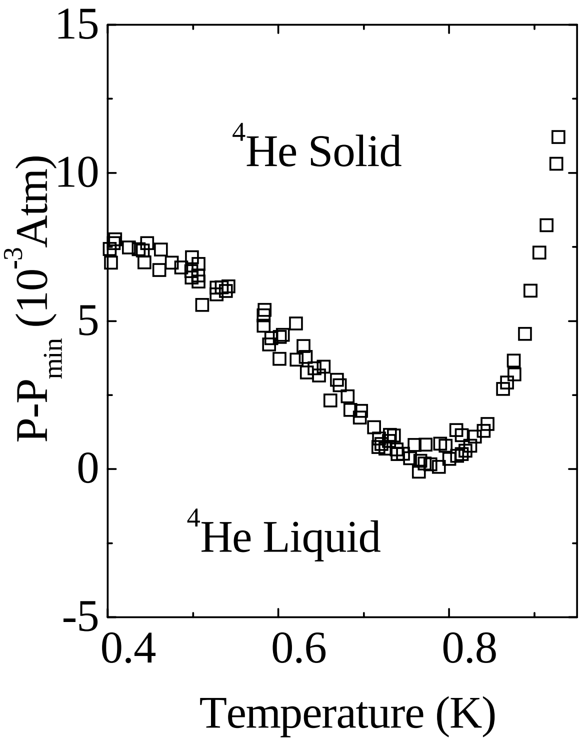
$Gd_3Ga_5O_{12}$



Garnet structure

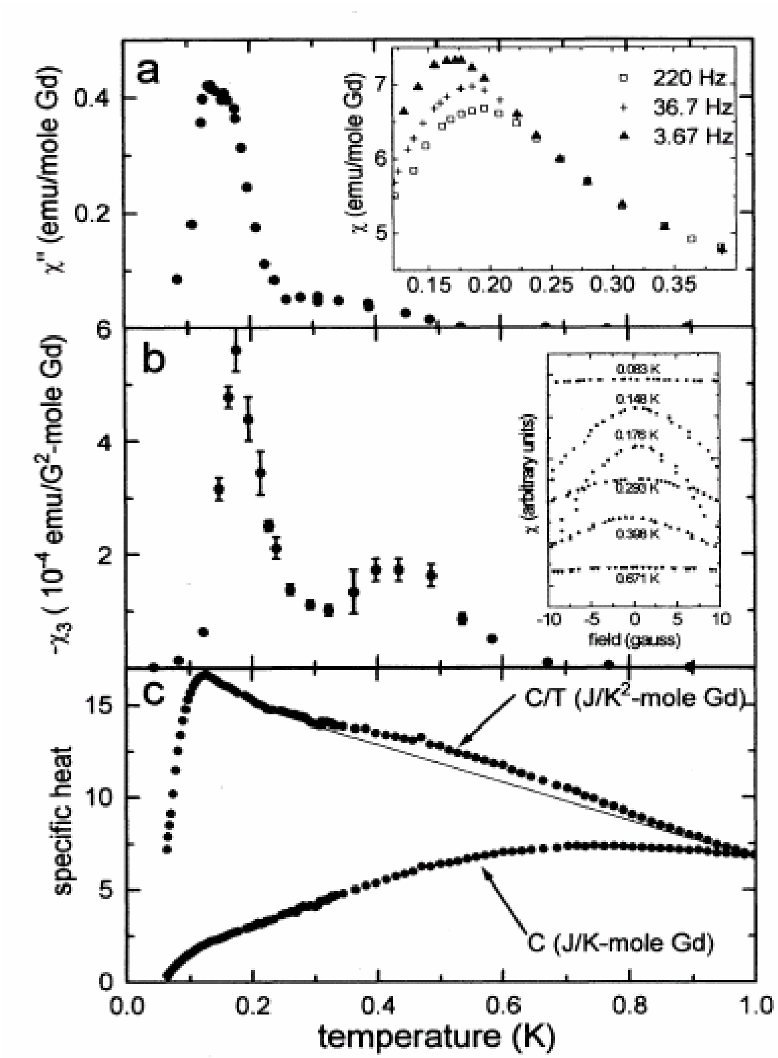


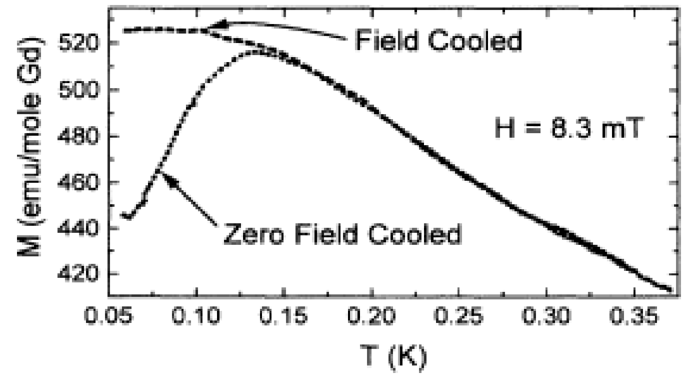
Helium-4

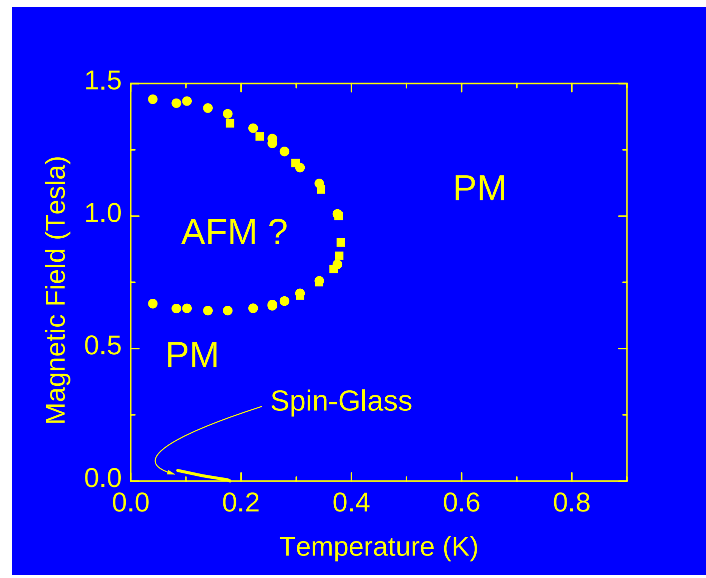


Schiffer et al, *PRL*, 1994,1999

Frustration Induced Spin Freezing in a Site-Ordered Magnet: Gadolinium Gallium Garnet





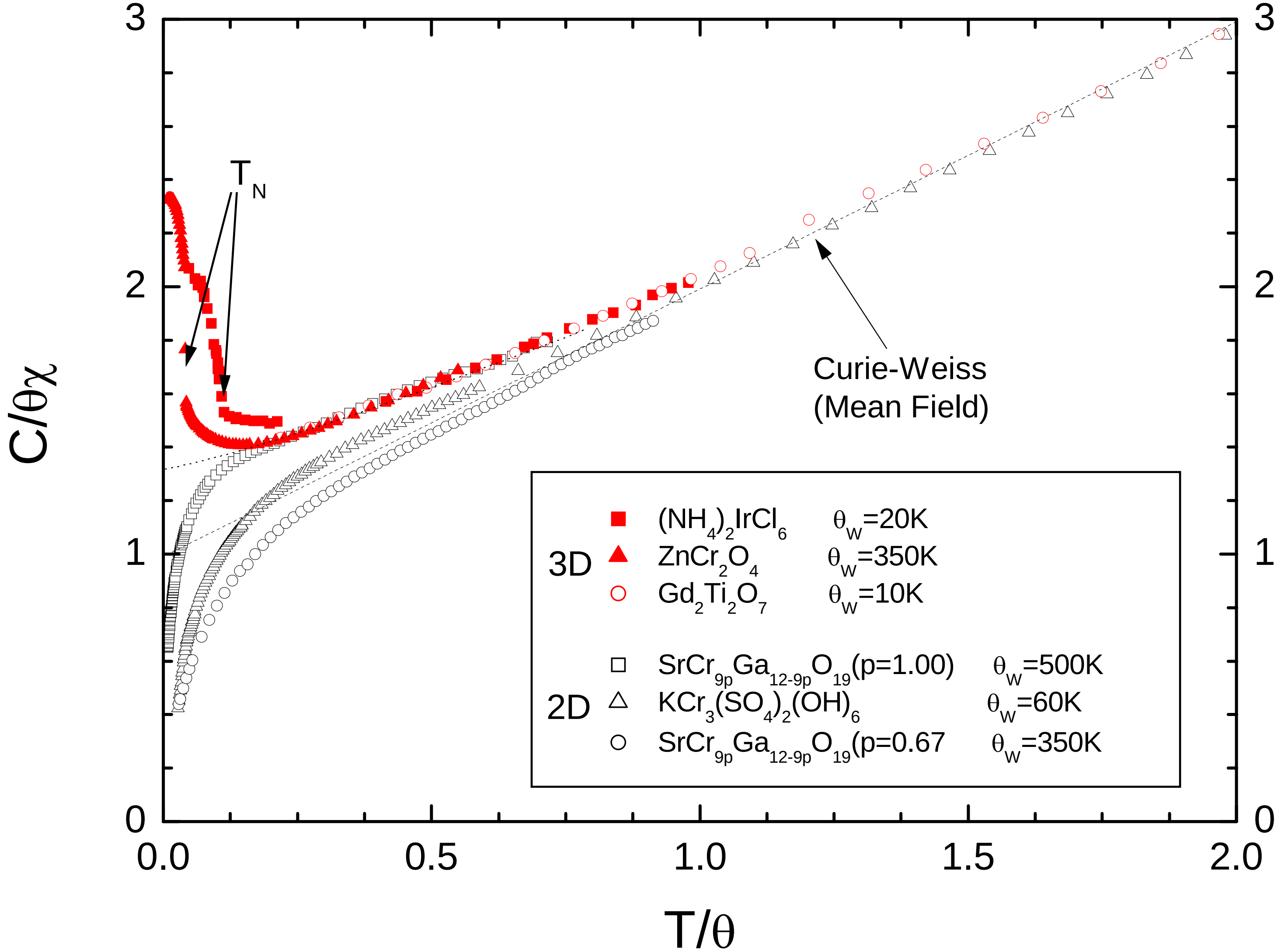


Schiffer et al, PRL 1995

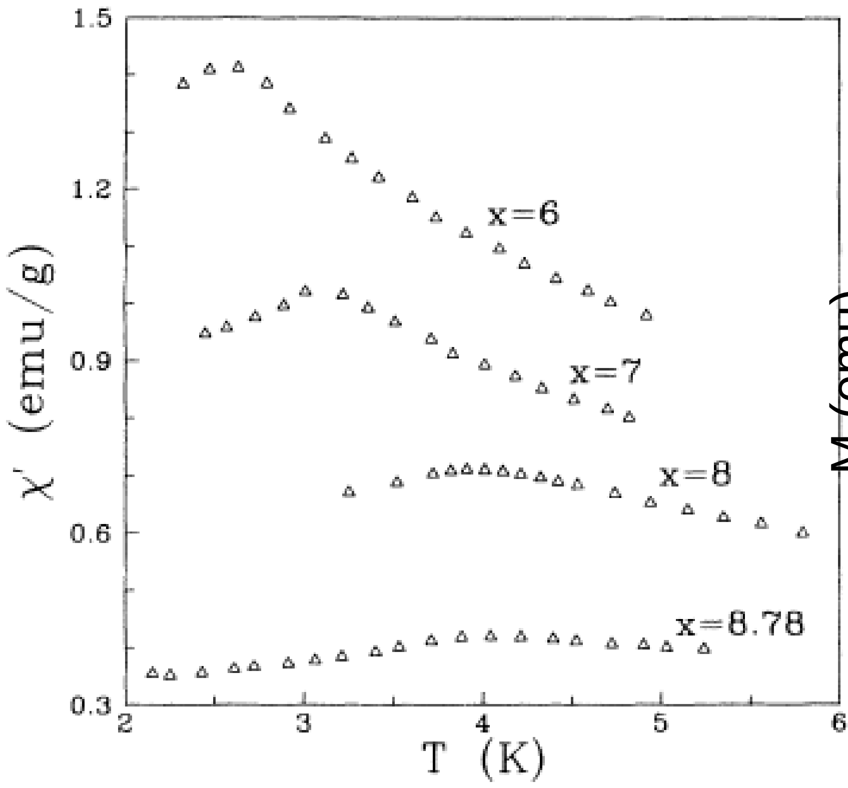
Table 1 Strongly Geometrically Frustrated Compounds

Compound	magnetic lattice	$-\theta_W$ (K)	T_c (K)	f	Order Type	Elect. Config.	Reference
2D MAGNETS							
VCl_2	triangular	437	36	12	AF	$3d^3$	(Hirakawa and al. 1983)
$NaTiO_2$	triangular	1000	<2	>500	—	$3d^1$	(Hirakawa, Kadowaki et al. 1985)
$LiCrO_2$	triangular	490	15	33	AF	$3d^3$	(Tauber, Moller et al. 1972)
$Gd_{0.8}La_{0.2}CuO_2$	triangular	12.5	0.7	16	SG	$4f^7$	(Ramirez, Jager-Waldau et al. 1991)
$SrCr_8Ga_4O_{19}$	kagome	515	3.5	150	SG	$3d^3$	(Ramirez, Espinosa et al. 1990)
$KCr_3(OH)_6(SO_4)_2$	kagome	70	1.8	39	AF	$3d^3$	(Townsend, Longworth et al. 1986)
3D MAGNETS							
$ZnCr_2O_4$	B-spinel	390	16	24	AF	$3d^3$	(Fiorani, Viticoli et al. 1983; Fiorani 1984; Fiorani, Viticoli et al. 1984; Fiorani, Dormann et al. 1985)
K_2IrCl_6	FCC	32.1	3.1	10	AF	$5d^5$	(Cooke, Lazenby et al. 1959)
FeF_3	pyrochlore	240	15	16	AF	$3d^5$	(DePape and Ferey 1986; Ferey, DePape et al. 1986)
$CsNiFeF_6$	pyrochlore	210	4.4	48	SG	$3d^8$,$3d^5$	(Alba, Hammann et al. 1982)
$MnIn_2Te_4$	zinc-blende	100	4	25	SG	$3d^5$	(Doll, Anghel et al. 1991)
$Gd_3Ga_5O_{12}$	garnet	2	0.1	20	SG	$4f^7$	(Hov, Bratsberg et al. 1980; Schiffer, Ramirez et al. 1994)
Sr_2NbFeO_6	perovskite	840	28	30	SG	$3d^4$	(Rodriguez and al. 1985)
$Gd_2Ti_2O_7$	pyrochlore	10	1.0	10	AF	$4f^7$	(Cashion, Cooke et al. 1968)

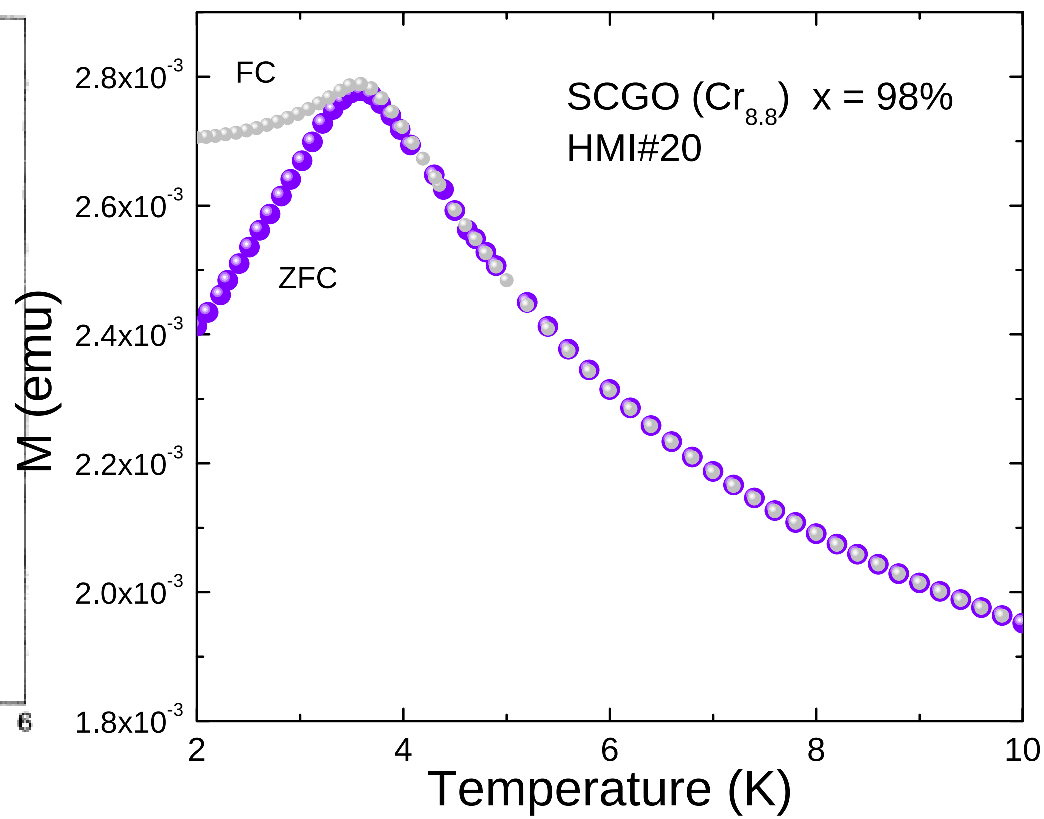
Two-population model is suggested the high-temperature behavior



Low-energy defect-magnetism in $SrCr_{9x}Ga_{12-9x}O_{19}$



Martinez et al PRB 1992



Ramirez et al, unpublished

Nonmagnetic impurity effects on the spin disordered state in $NiGa_2S_4$ ☆

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[b]Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba 277-8581, Japan

Available online 27 November 2006

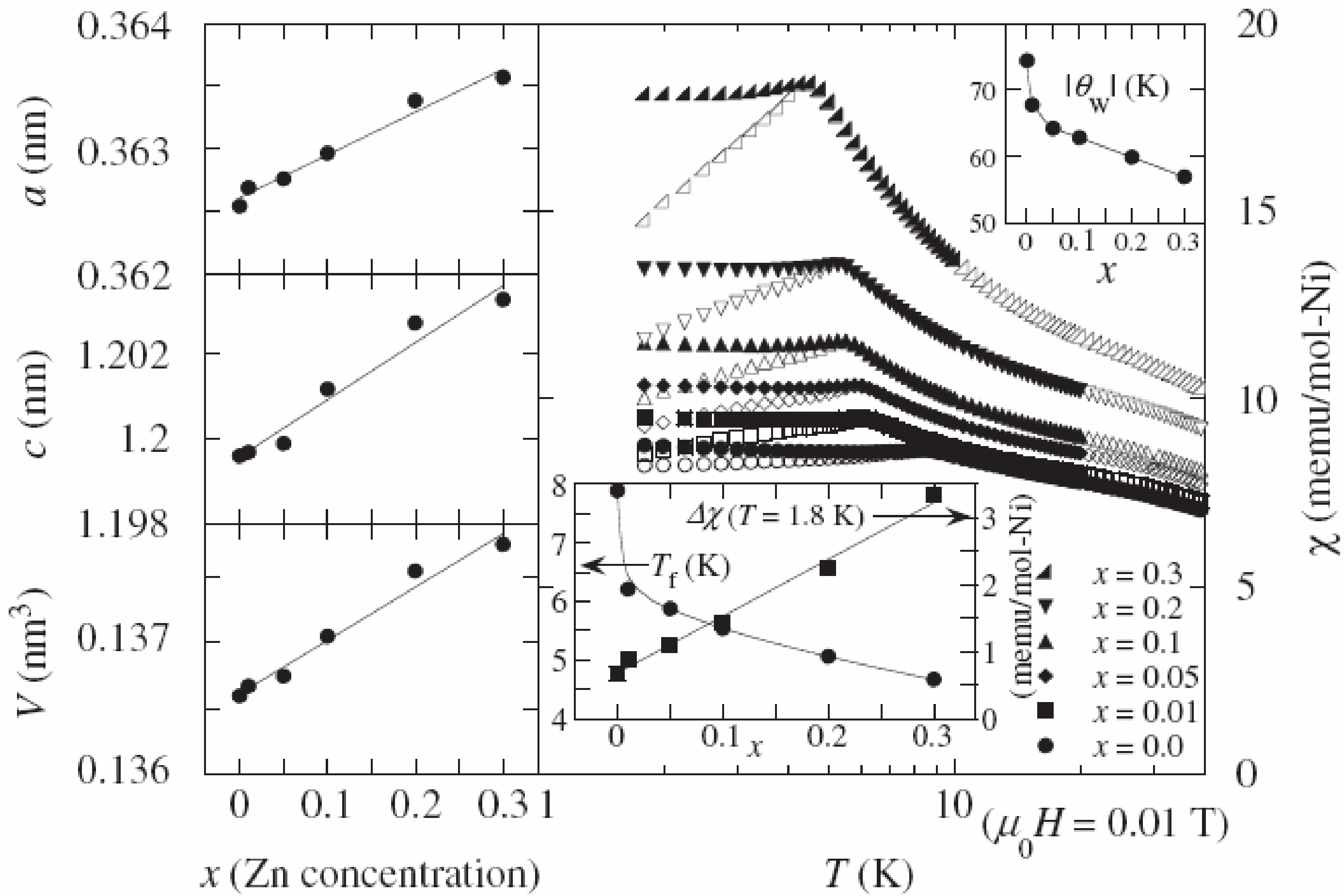
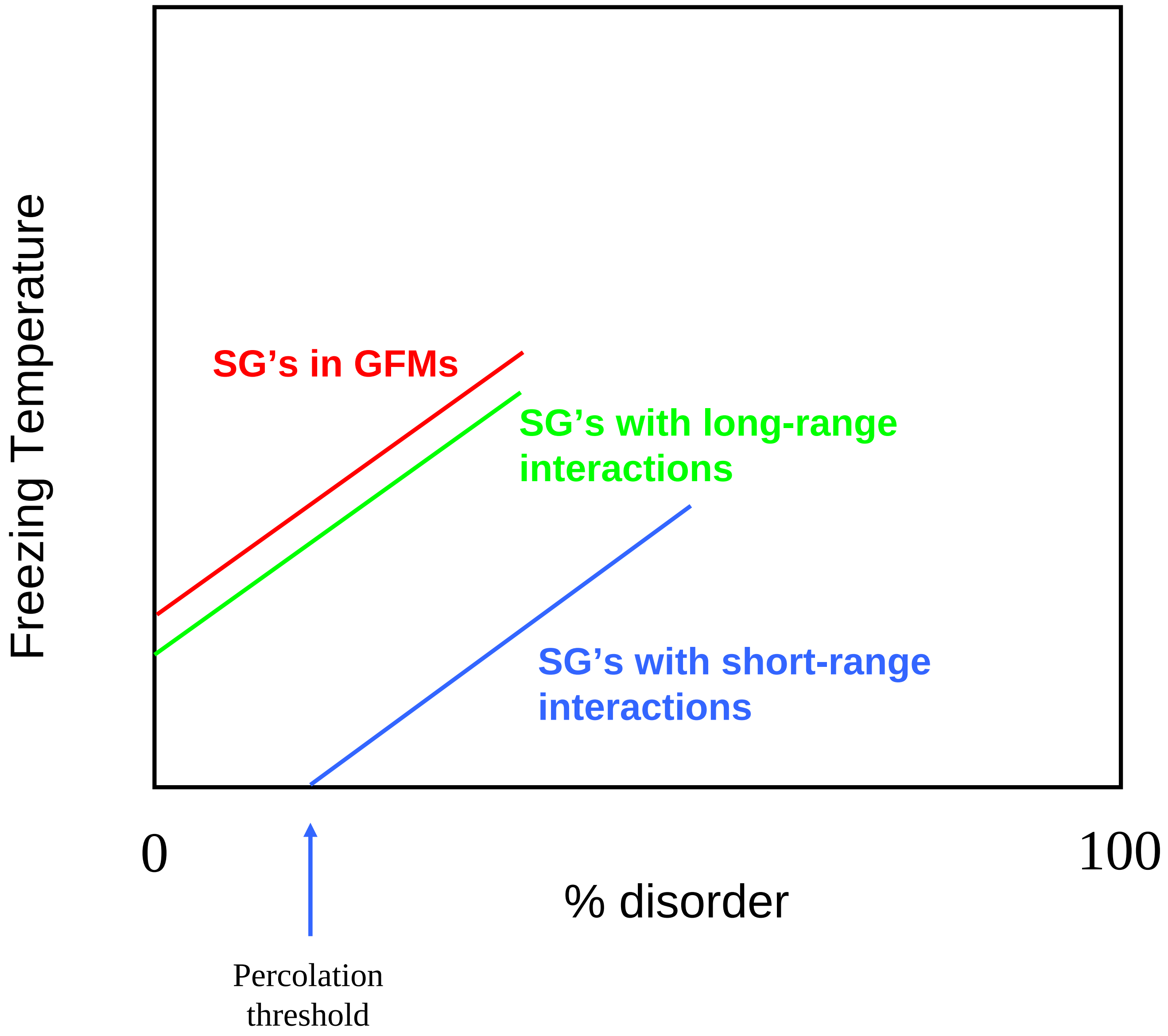


TABLE I. Critical concentrations p_c^b and p_c^s for bond and site percolation on various lattices with nearest neighbour or further neighbour interactions. z is the coordination number.

Lattice	(nth neighbour interactions)	z	p_c^b	p_c^s	zp_c^s	zp_c^b
Chain	(1)	2	1	1	2	2
Honeycomb	(1)	3	0.6527	0.70	2.10	1.96
Square	(1)	4	0.5000	0.59	2.36	2.00
Triangular	(1)	6	0.3473	0.5	3.00	2.08
Square	(1, 2)	8	—	0.41	3.28	—
Triangular	(1, 2)	12	—	0.295	3.54	—
Honeycomb	(1, 2, 3)	12	—	0.300	3.60	—
Square	(1, 2, 3)	12	—	0.292	3.50	—
Triangular	(1, 2, 3)	18	—	0.225	4.05	—
Diamond	(1)	4	0.388	0.43	1.72	1.55
s.c.	(1)	6	0.247	0.31	1.86	1.48
b.c.c.	(1)	8	0.178	0.243	1.94	1.42
f.c.c.	(1)	12	0.119	0.195	2.34	1.43
s.c.	(1, 2)	18	—	0.137	2.47	—
b.c.c.	(1, 2)	14	—	0.175	2.45	—
f.c.c.	(1, 2)	18	—	0.136	2.45	—
s.c.	(1, 2, 3)	26	—	0.097	2.52	—
b.c.c.	(1, 2, 3)	26	—	0.095	2.47	—
f.c.c.	(1, 2, 3)	42	—	0.061	2.56	—

Stinchcombe, 1983


Freezing Temperature
SG's in GFMs
SG's with long-range interactions
SG's with short-range interactions
0
100
% disorder
Percolation threshold

Solid State Communications Vol. 4, pp. 541-544 1966.

FERROMAGNETIC EXCHANGE COUPLING IN THE SPINEL LATTICE

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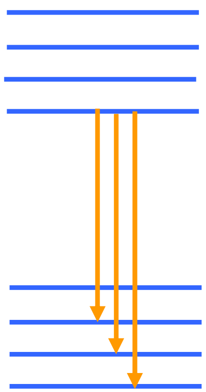
Pair spectrum



Exchange-split R lines

Exchange-split ground state

$H = J S_1 \cdot S_2$

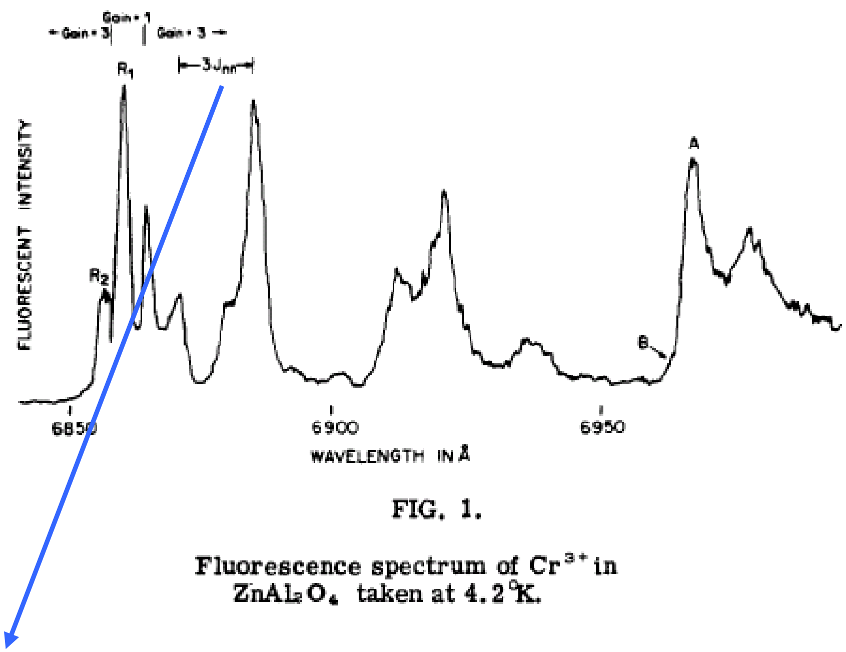


FIG. 1.

Fluorescence spectrum of Cr^{3+} in $ZnAl_2O_4$ taken at 4.2°K.

$J_{nn} \sim 14K \rightarrow \theta_W \sim 250K$ ferromagnetic!

Collaborators:

GFM:

G. Aeppli
C. Broholm
E. Bucher
R. Cava
P. Schiffer
C. Kloc
G. Espinosa
A. S. Cooper
S. W. Cheong
D. Huse
D. Bishop
P. Gammel
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S. Rosenkranz
G. Lawes