Iron Arsenides—The New Family of High T_C Magnetic Superconductors

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Outline

- Properties of Conventional Superconductors
- (Brief) History of Magnetic Superconductors
  - Magnetic Impurities
  - Long Range Magnetic Order: Coexistence and Competition
- Cuprate Superconductors—Highly Correlated Electron Systems
  - Undoped systems: Mott Insulators. Magnetic Order and Spin Waves
  - Doping dependence of properties
- Hole-doped systems
  - Magnetic Resonance and Incommensurate spin dynamics
  - Doping dependence
  - Universal spin dynamics
  - Effects of a Magnetic Field
- Electron-doped Systems
  - Commensurate Spin Dynamics
  - Field dependence of the magnetic order
  - Magnetic Resonance in the Spin Dynamics
  - Field dependence of the Resonance, and Condensation Energy
  - Nature of the ground state without Superconductivity
- Iron-based Superconductors
- Summary

Systems under Investigation with Neutron Scattering

Oxides

- CMR systems, Multiferroics (La-CaMnO_3, HoMnO_3)
- Iron-based Superconductors (La(O-F)FeAs)
- Magnetic Order and Fluctuations in Cuprates (e-doped)
- Cobaltates (Na_xCoO_2) *Just add water for Superconductivity*

Other Systems

- Magnetic Superconductors (e.g. RNi_2B_2C, $RuSr_2GdCu_2O_8$)
- Heavy Fermion Materials ($CeRhIn_5$, $PrOs_4Sb_{12}$, …)
- Non-Fermi Liquids ($UCu_{5-x}Pd_x$, $Sc_{1-x}U_xPd_3$)
- Vortex Lattice/Melting in Superconductors (Nb)
- Frustrated Magnets

  – http://www/ncnr.nist.gov/staff/jeff

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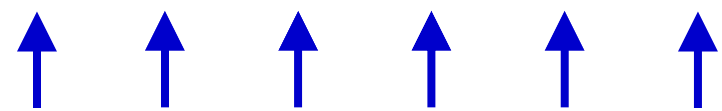
Magnetic Superconductor History

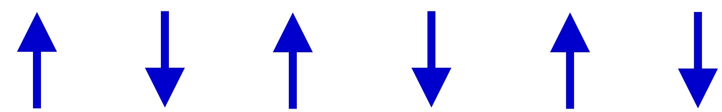
- Pure Superconductors
- Magnetic Impurities
- Concentrated Magnetic Systems (Exceptions to the Rule!)
  C-15 Cubic Laves phase (Ce-Ho)Ru_2 ('60's-'70's)
- Magnetic Sublattice—Long Range Order
  Chevrel Phase $DyMo_6S_8$ ('70's)
- Ferromagnets—Competition & Coexistence
  - Chevrel Phase $HoMo_6(S\text{-}Se)_8$, $ErRh_4B_4$ ('70's)
- High T_C cuprates—Cu spin order & fluctuations
  Cuprates $RBa_2Cu_3O_7$, R_2CuO_4 ('80's→…) ⇐
- Borocarbides
  - $HoNi_2B_2C$, $ErNi_2B_2C$ ('90's→…)
- New Ferromagnetic Superconductors
  - Ruthenates $RuSr_2GdCu_2O_8$, $RuSr_2(Eu\text{-}Ce)_2Cu_2O_{10}$; $ZrZn_2$, UGe_2 (2000 →…)
- Sodium cobaltates (Magnetic, thermoelectric, and Superconducting)
  - Na_xCoO_2 (+ H_20)
- Iron-based superconductors ⇐
  - $R(O_{1-x}F_x)FeAs$

Magnetic Structures

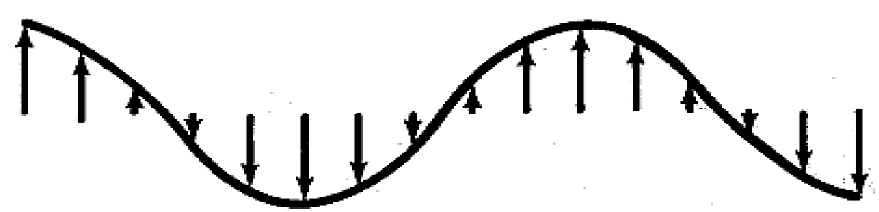
Ferromagnet



Antiferromagnet



Spin Density Wave



Ferromagnetic Superconductors

$(Ce\text{-}Ho)Ru_2$

$HoMo_6S_8$, $HoMo_6Se_8$, $ErRh_4B_4$

$ErNi_2B_2C$

$RuSr_2GdCu_2O_8$ & $RuSr_2Eu_{2-x}Ce_xCu_2O_{10}$

UGe_2, $ZrZn_2$, URhGe, C/S

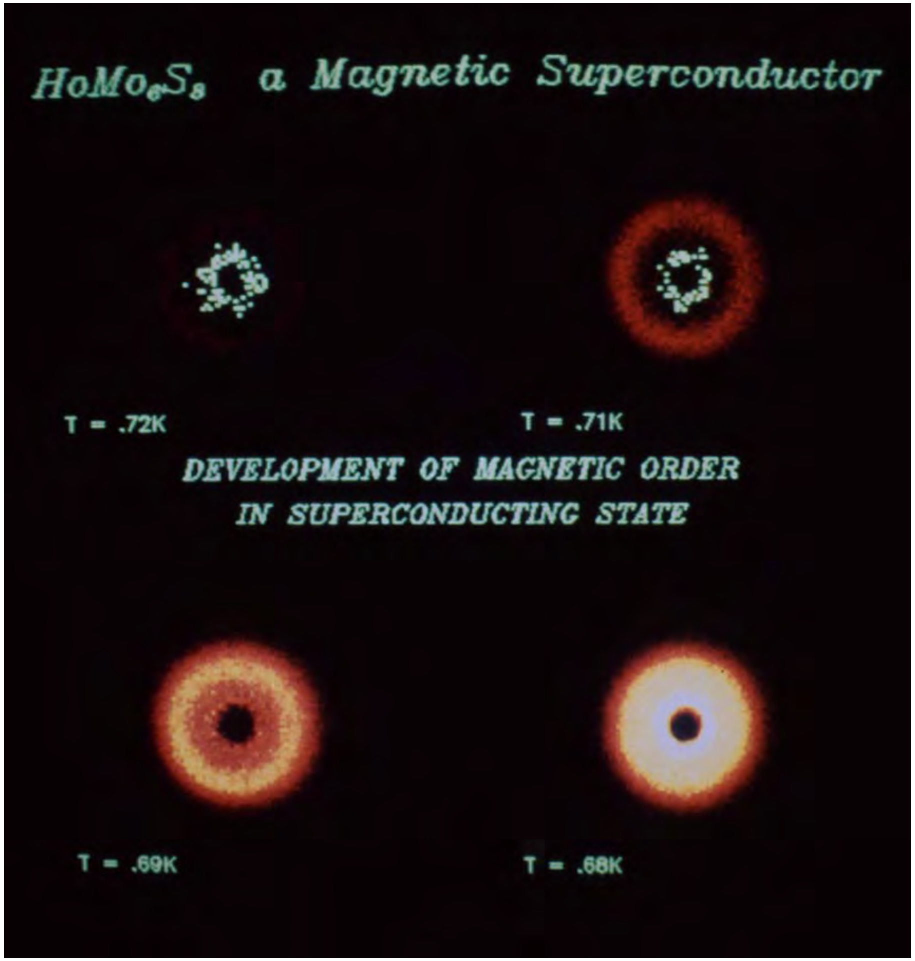
Chevrel Phase Superconductors

$HoMo_6S_8$, $HoMo_6Se_8$,

[$(HoS_8)Mo_6$ Magnetic Lattice Isolated]

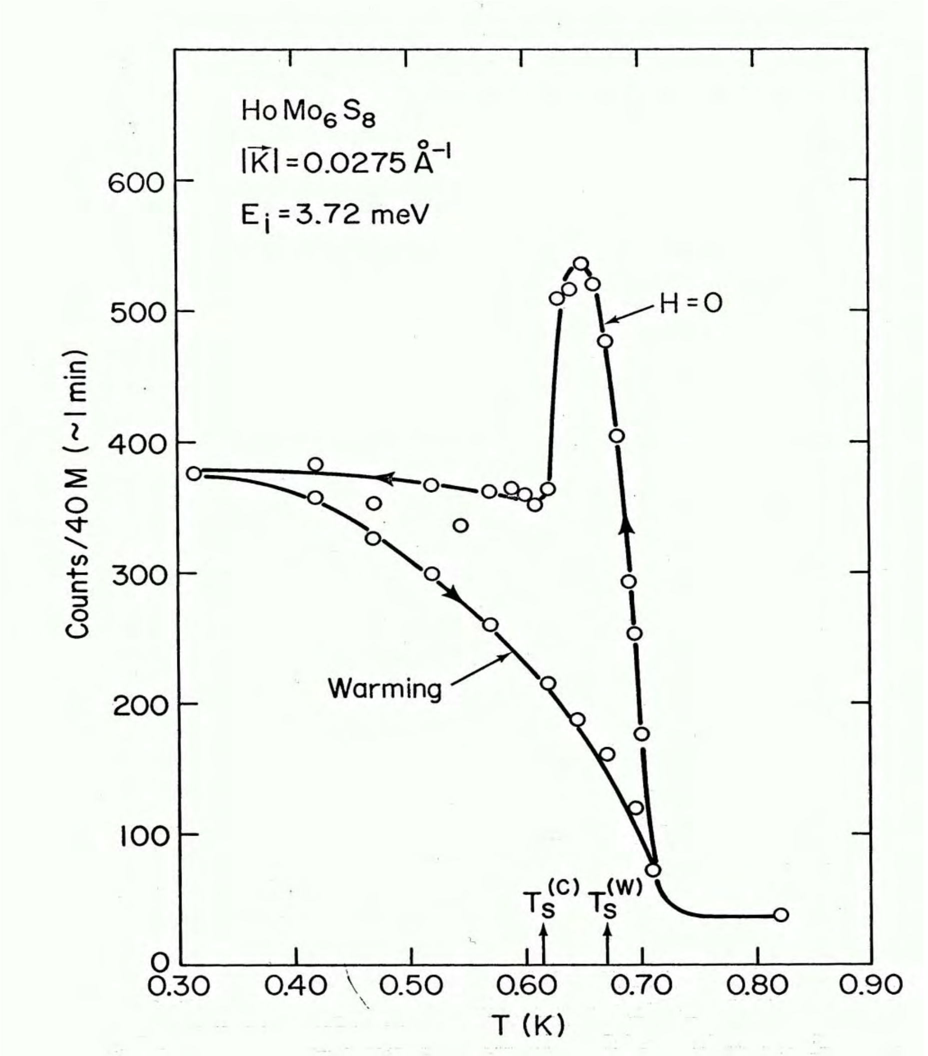
T_{super}	= 1.8 K	5.6 K
T_{ferro}	= 0.7 K	0.5 K
$T_{reentrant}$	= 0.7 K	< 0 K

$HoMo_6S_8$



Small Angle Neutron Scattering

$HoMo_6S_8$ Order Parameter

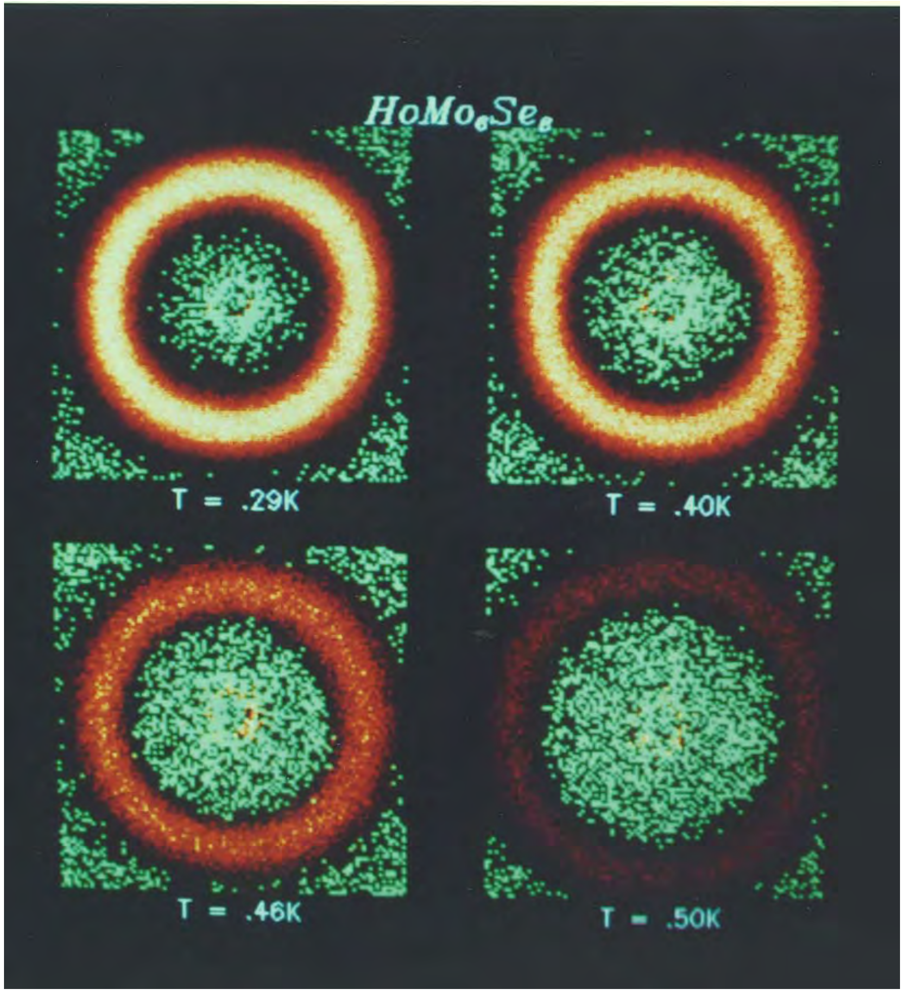


Sol. St. Comm. **26**, 493 (1978); Phys. Rev. Lett. **46**, 368 (1981);
J. de Physique Lettres **42**, L45 (1981); Phys. Rev. B**24**, 3817 (1981).

$HoMo_6Se_8$

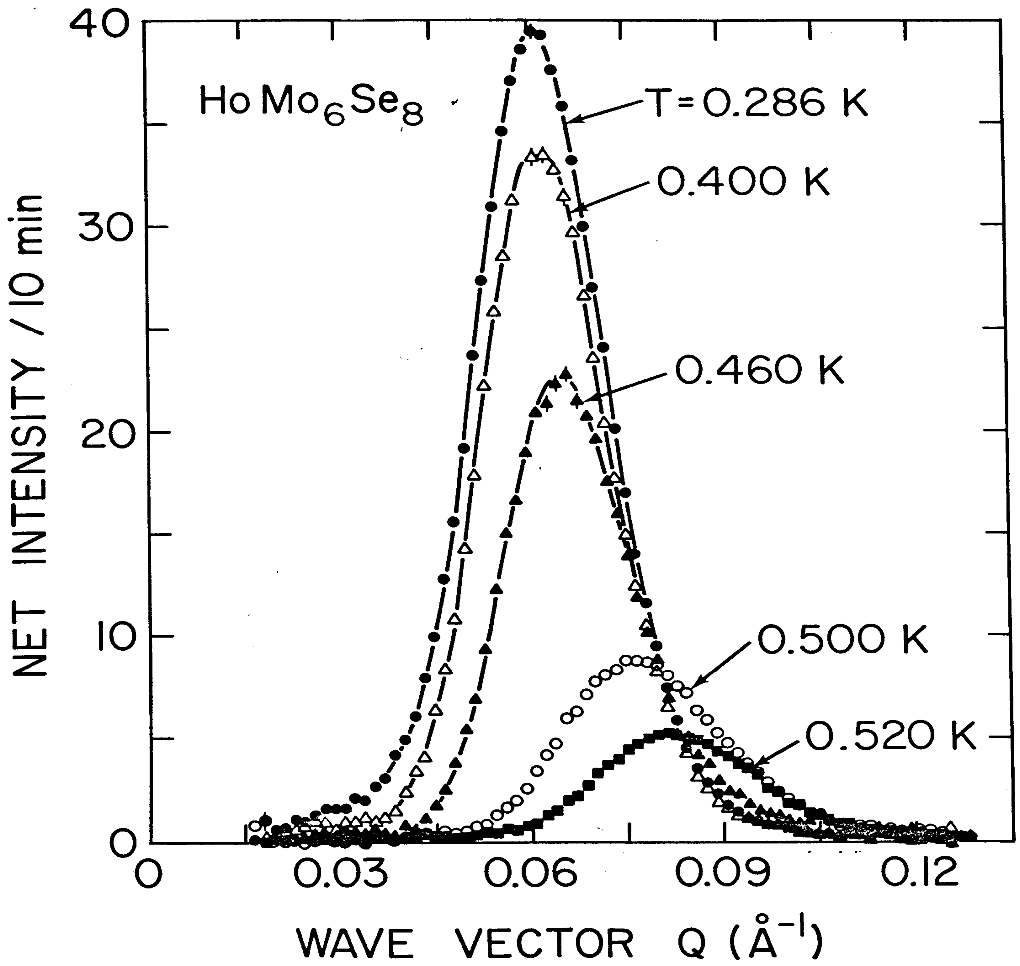
T_S=5.6 K

T_M=0.5K

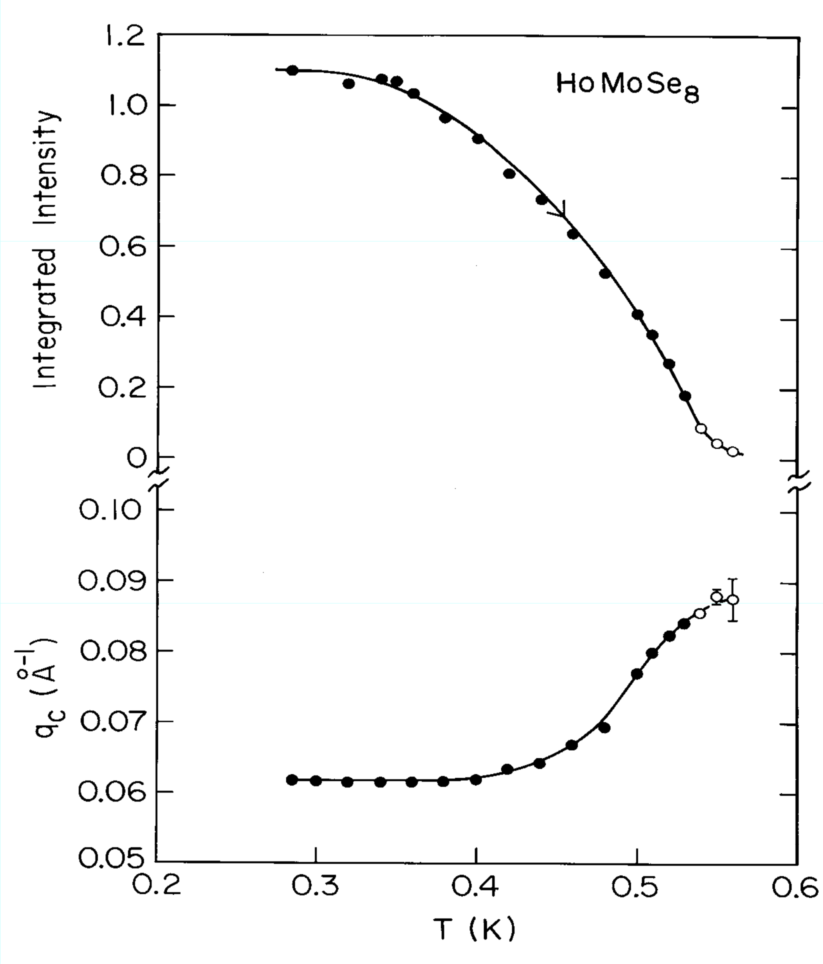


Small Angle Neutron Scattering

$HoMo_6Se_8$


HoMo6Se8
T=0.286 K
0.400 K
0.460 K
0.500 K
0.520 K
NET INTENSITY / 10 min
WAVE VECTOR Q (Å⁻¹)
0
10
20
30
40
0
0.03
0.06
0.09
0.12

$HoMo_6Se_8$



J. W. Lynn, J. A. Gotaas, R. W. Erwin, R. A. Ferrell, J. K. Bhattacharjee, R. N. Shelton and P. Klavins, Phys. Rev. Lett. **52**, 133 (1984)

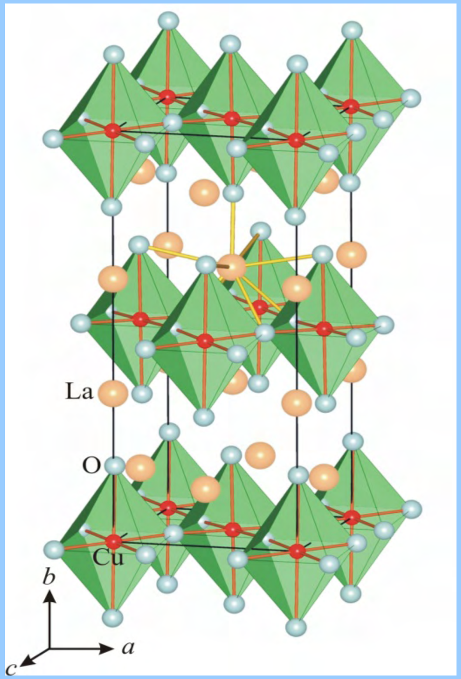
Ferromagnetic Superconductor

$RuSr_2GdCu_2O_8$

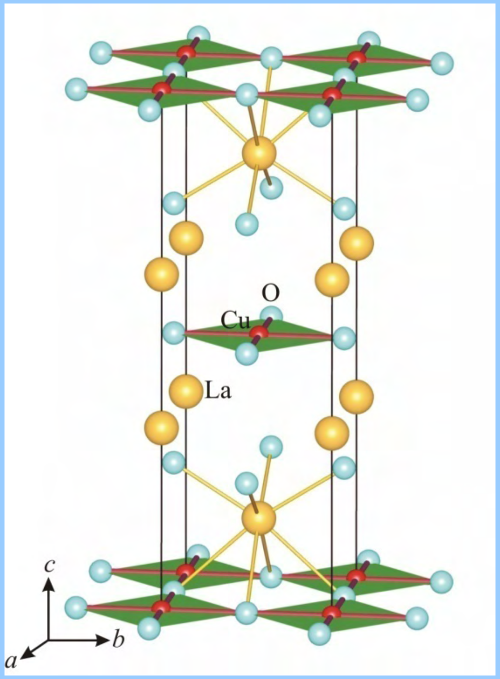
- T(Ru) = 135 K
- T(Superconductivity) = 35 K
- T(Gd) = 2.5 K
- J. W. Lynn, B. Keimer, C. Ulrich, C. Bernhard, and J. L. Tallon, Phys. Rev. B**61**, 14964 (2000)

Cuprate (High T_C) Superconductors

Structure of Cuprate Superconductors

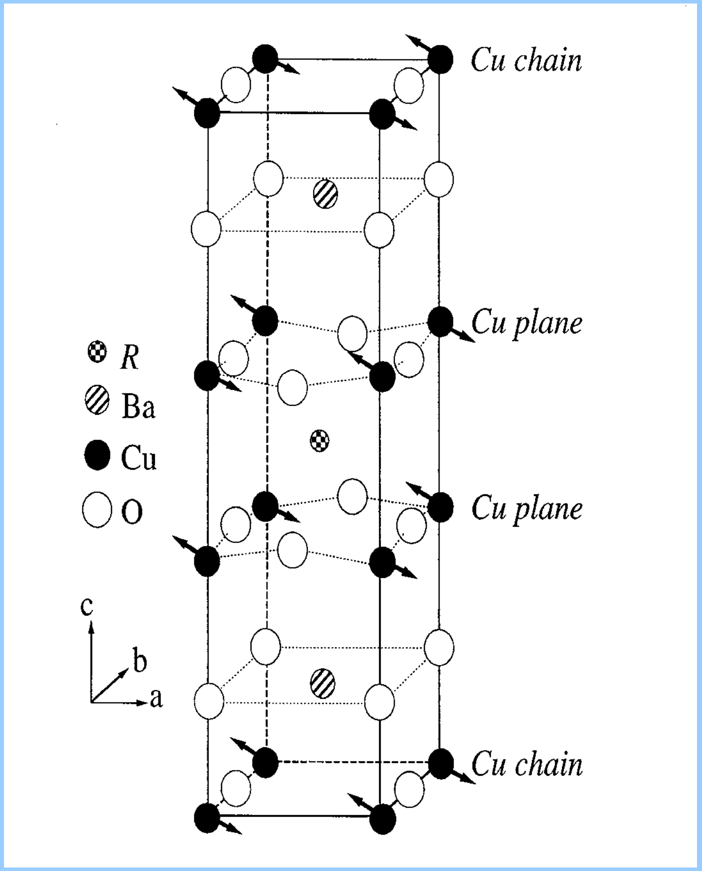


La_2CuO_4



Nd_2CuO_4

Single Layer



Double Layer

$YBa_2Cu_3O_7$

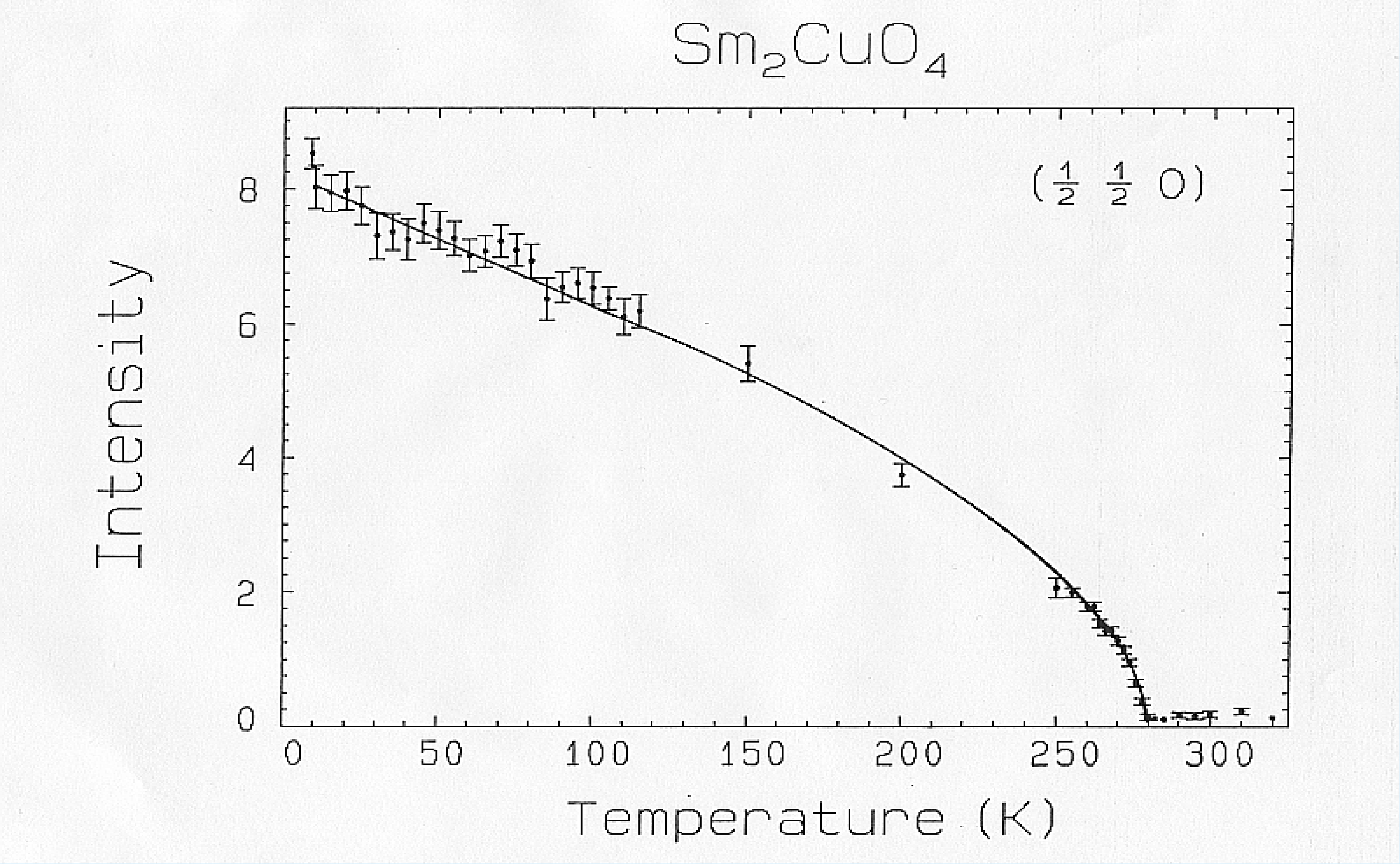
Cuprate Superconductors

Antiferromagnets

- Undoped Systems

  Qualitative Failure of Band Theory
  Highly Correlated Electron Systems
  Mott Insulators
  Quantum Spins (S=1/2)
  Low dimensional magnetism

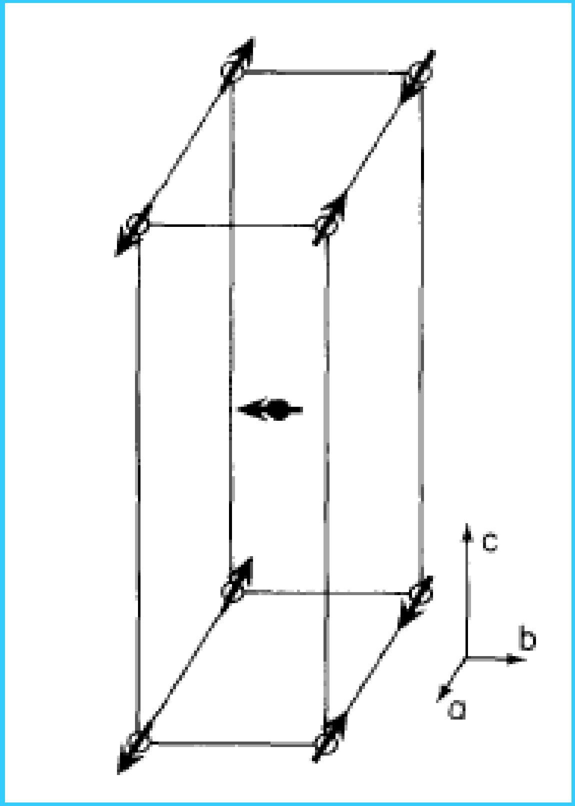
Cu Magnetic Order

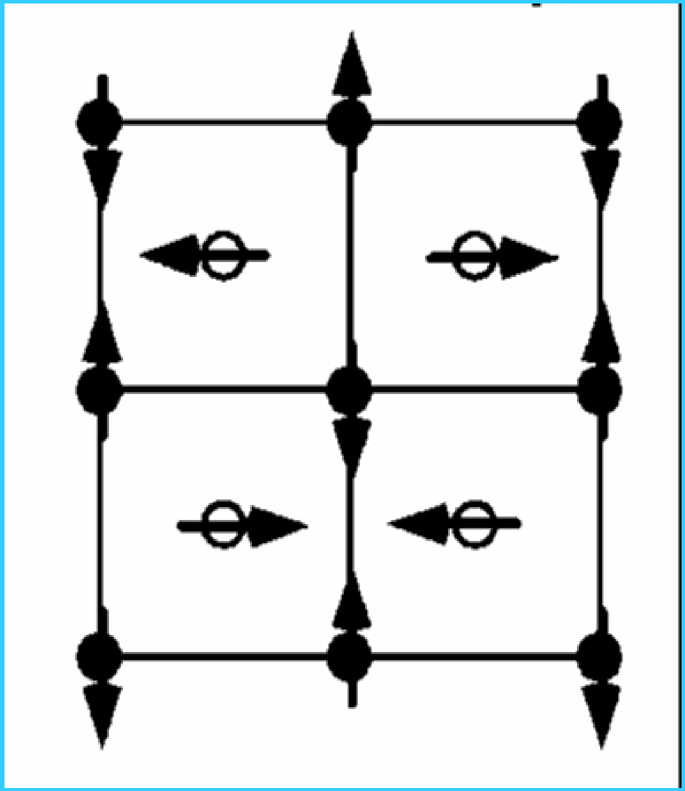


S. Skanthakumar, J. W. Lynn, J. L. Peng and Z. Y. Li, J. Appl. Phys. **69**, 4866 (1991)

Magnetic Configuration
Spin Direction
Ordered Moment
Ordering temperature

Spin Dynamics …





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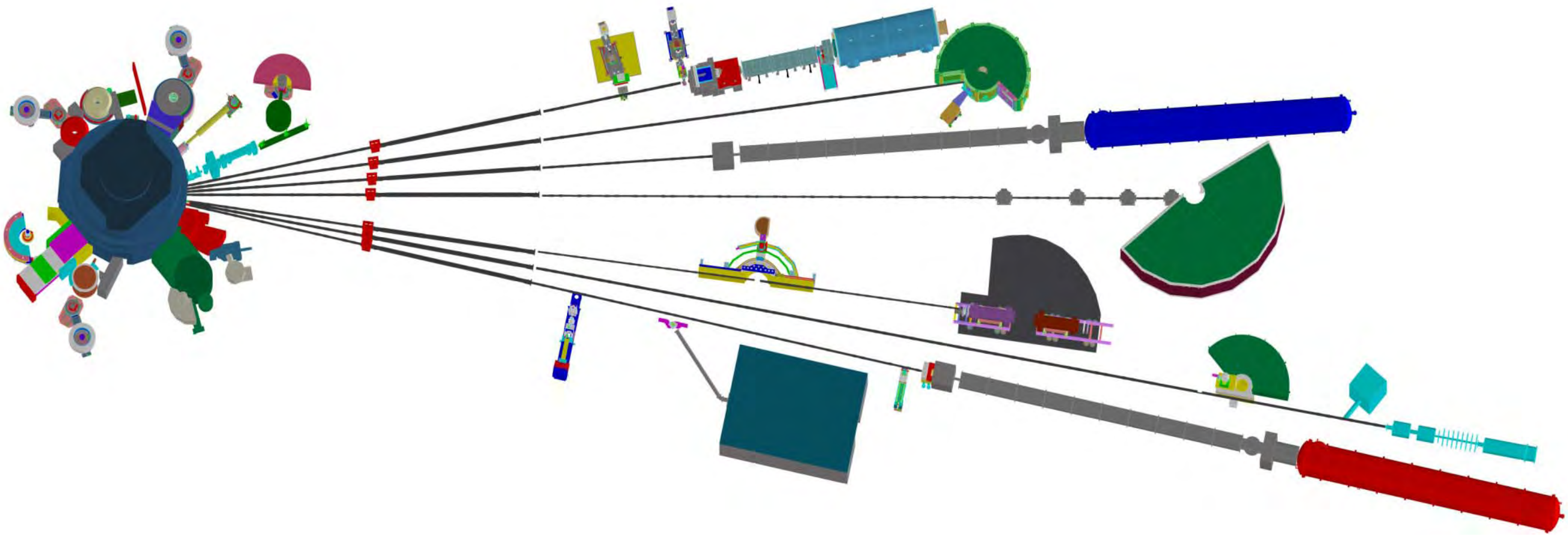
Facilities

Structure: Diffraction (2); SANS (3); Reflectometry (3)

Dynamics: TAS (5+1); TOF (1); Spin Echo (1)

Prompt-γ (2); Depth Profile (2); Topography (2); Activation Analysis; Fundamental Properties (3)--Interferometry



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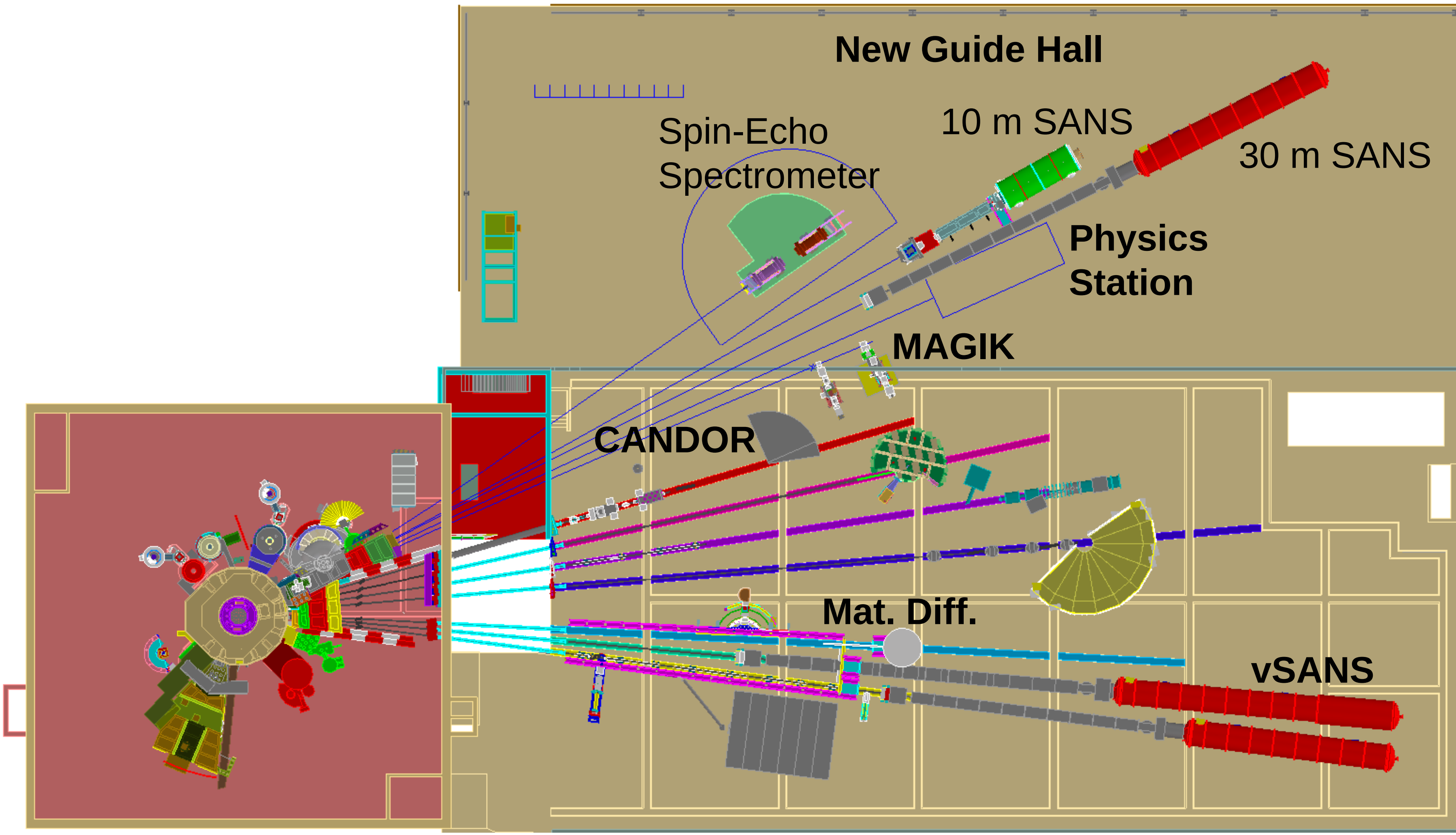
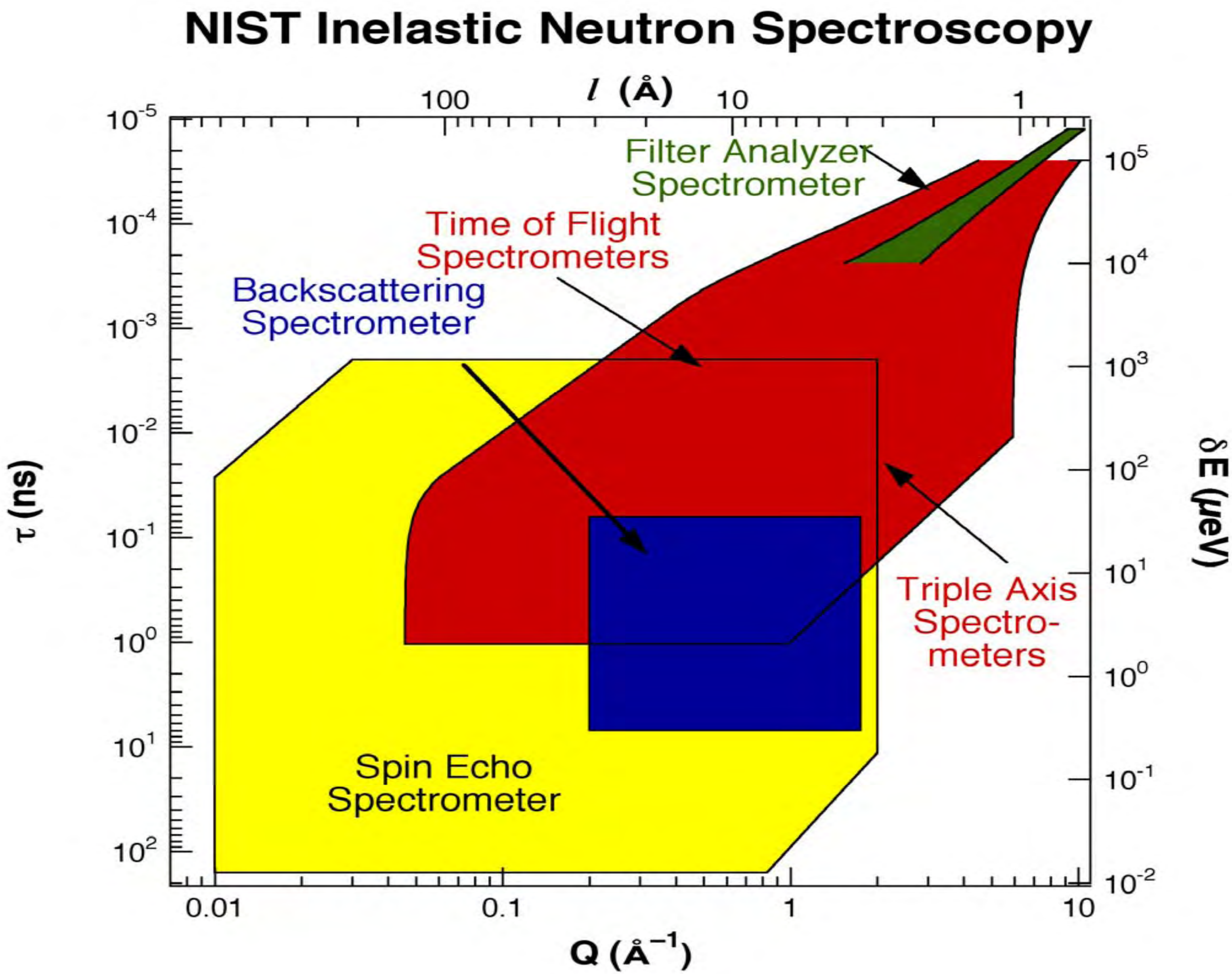
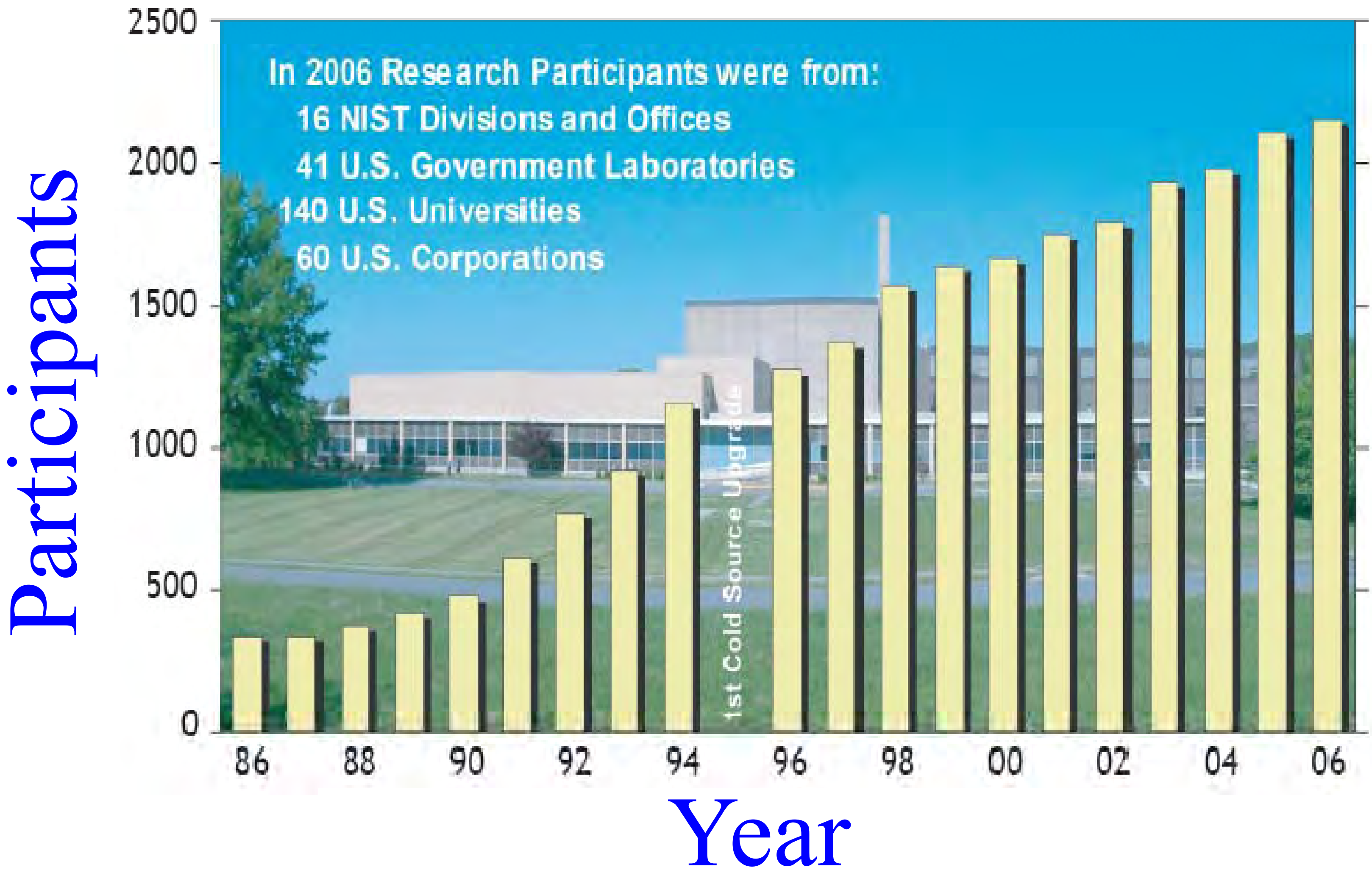
NCNR Expansion—2nd Guide Hall



http://www.ncnr.nist.gov

Dynamic Range

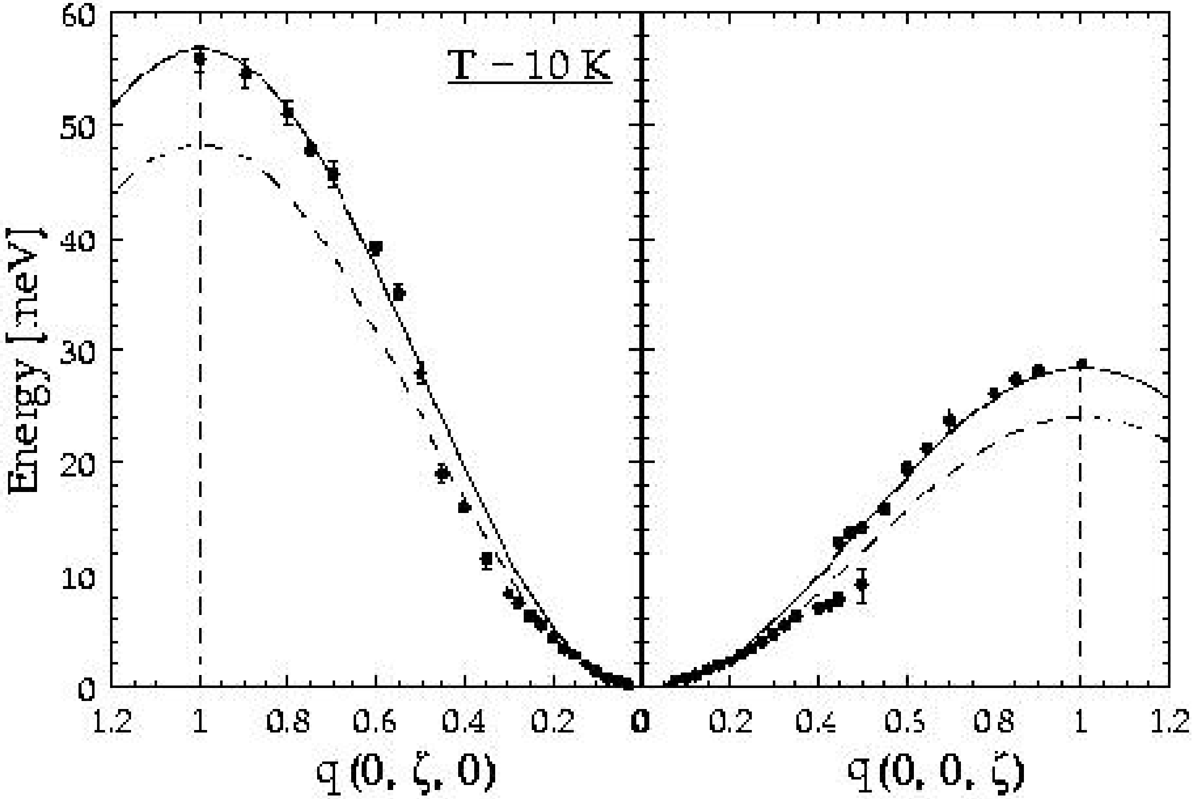




http://www.ncnr.nist.gov

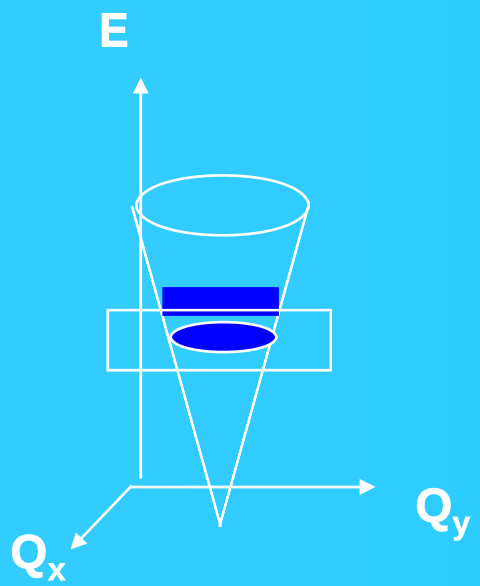
Spin-waves in a typical system with an ordering temperature of ~RT

$La_{0.85}Sr_{0.15}MnO_3$

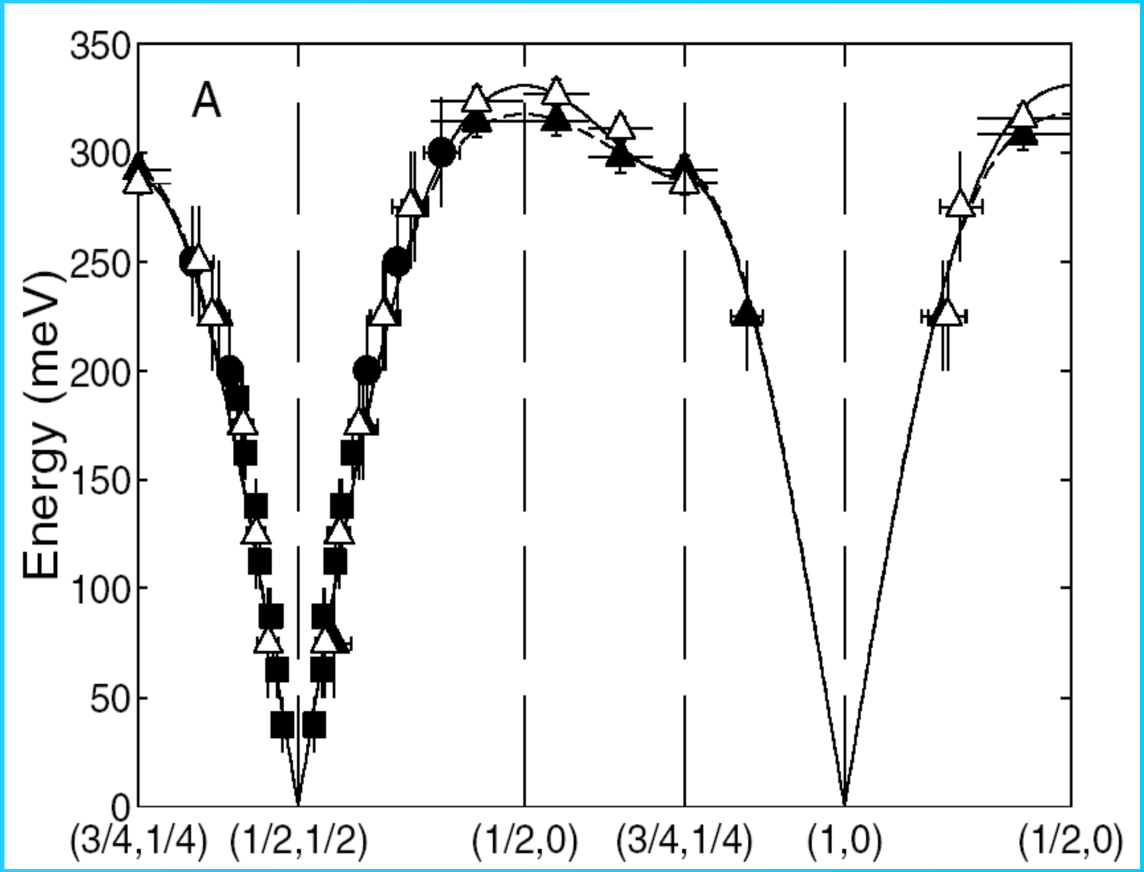


L. Vasiliu-Doloc, J. W. Lynn, A. H. Moudden, A. M. de Leon-Guevara, and A. Revcolevschi, Phys. Rev. B**58**, 14913 (1998).

Spin-waves in the parent compounds of single layer hole-doped high-T_c superconductors



$$H = \sum_{<ij>} J_{ij} \vec{S}_i \cdot \vec{S}_j$$



La_2CuO_4 : R. Coldea *et al.* PRL 86 (2001) 5377

High T_C Superconductors

- Undoped Systems
  - Qualitative Failure of Band Theory
  - Highly Correlated Electron Systems
  - Mott Insulators
  - Quantum Spins (S=1/2)
- Doped Systems
  - S=1/2, square lattice—2d Quantum Percolation
    - O. P. Vajk, et al. Science **295**, 1691 (2002);
    - P. K. Mang, et al. Phys. Rev. Lett. **93**, 027002 (2004)

Change electron count:

- metallic
- then superconducting
- then normal Fermi liquid behavior in overdoped regime

Cuprate (High T_C) Superconductors

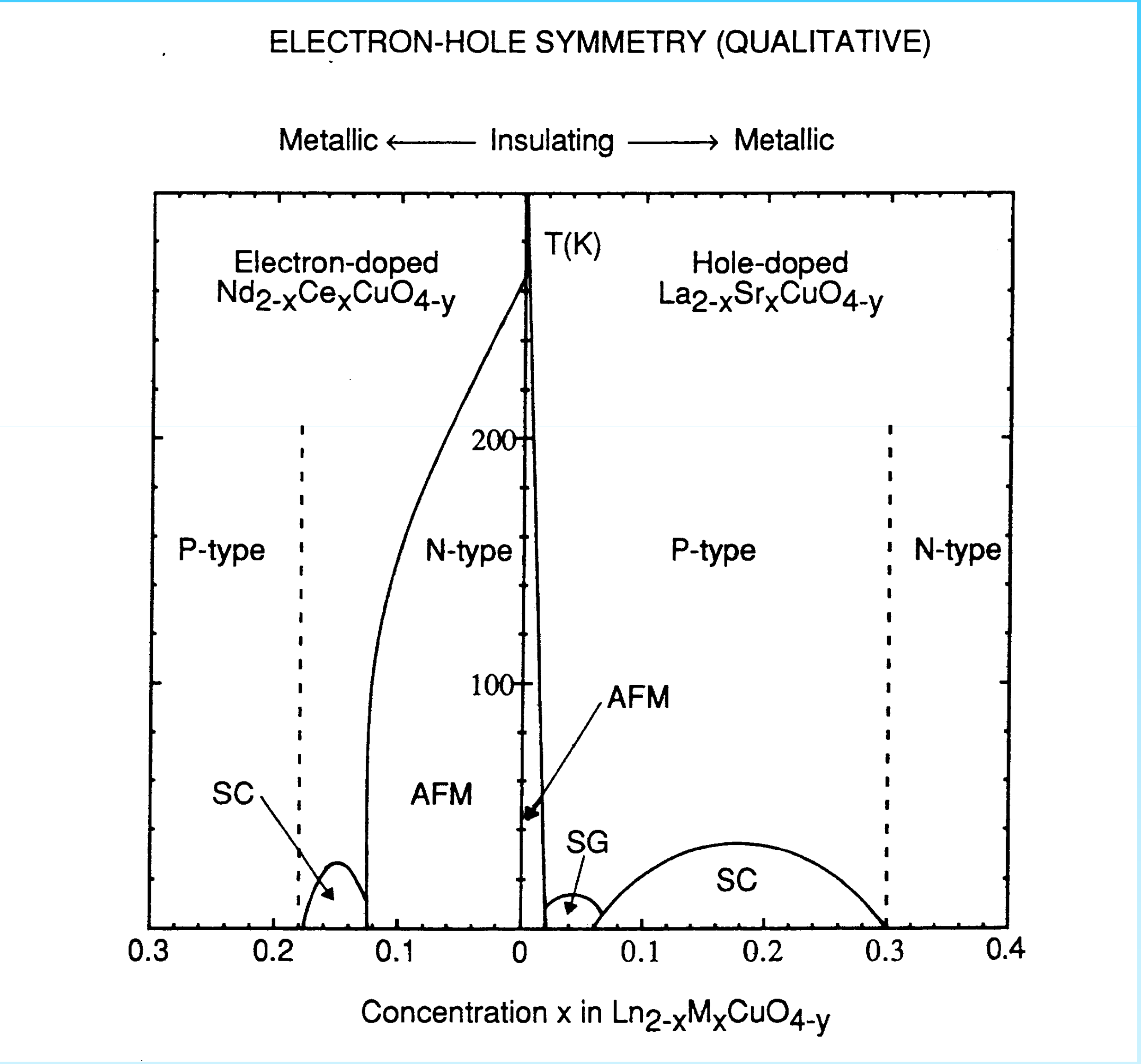
Hole-doping	**Electron-doping**
$R\mathrm{Ba_2Cu_3O_7}$	$R_2\mathrm{CuO_4}$
$Er\mathrm{Ba_2Cu_3O_7}$	$(Sm\text{-}Ce)_2\mathrm{CuO_4}$

	Hole-doping	Electron-doping
$T_{magnetic}$ =	525 K	280 K
T_{super} =	92 K	25 K
$T_{rare\ earth}$ =	0.5 K	6 K

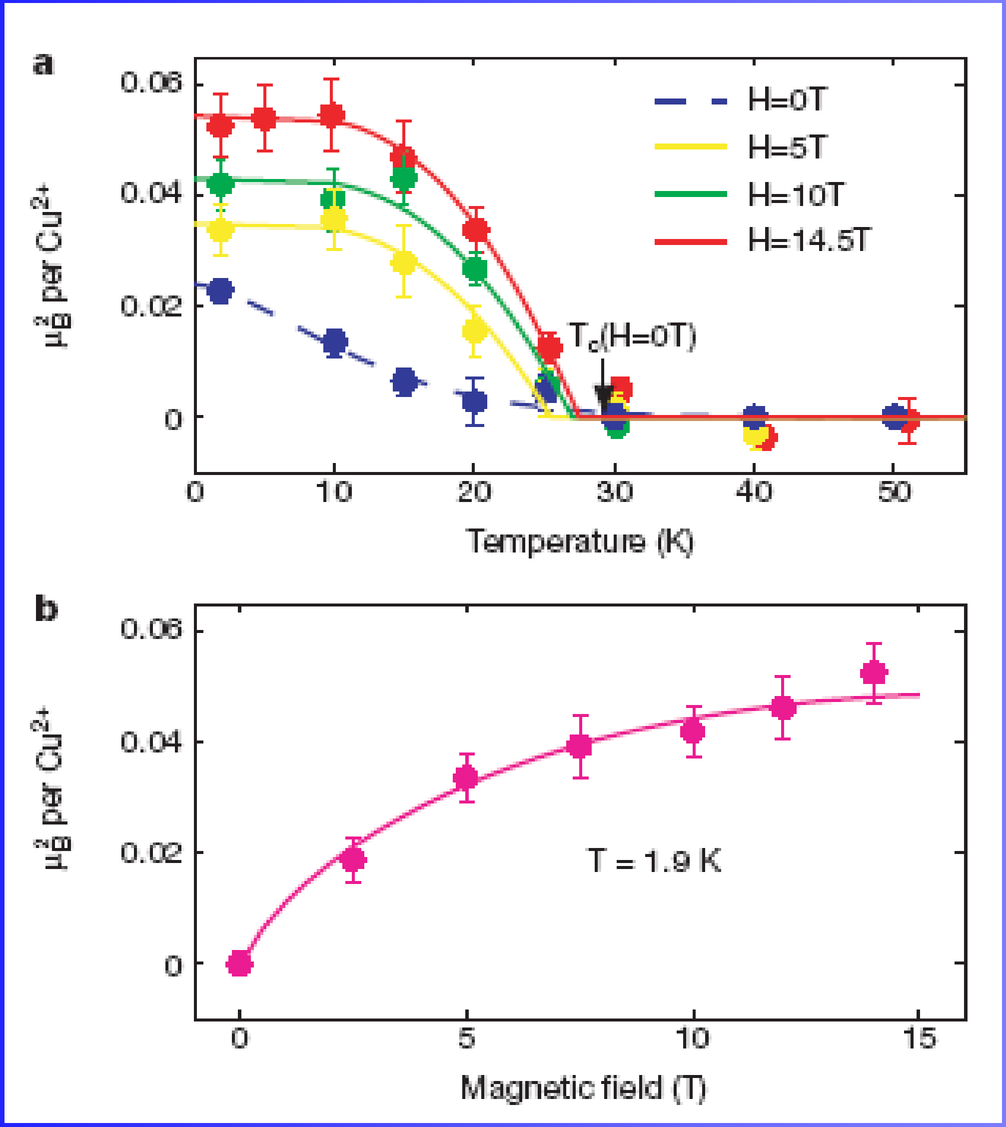
$\mathrm{YBa_2Cu_3O_7}$ YBCO

High Temperature Superconductivity,
ed. by J. W. Lynn (Springer-Verlag, 1990) .

Phase diagram



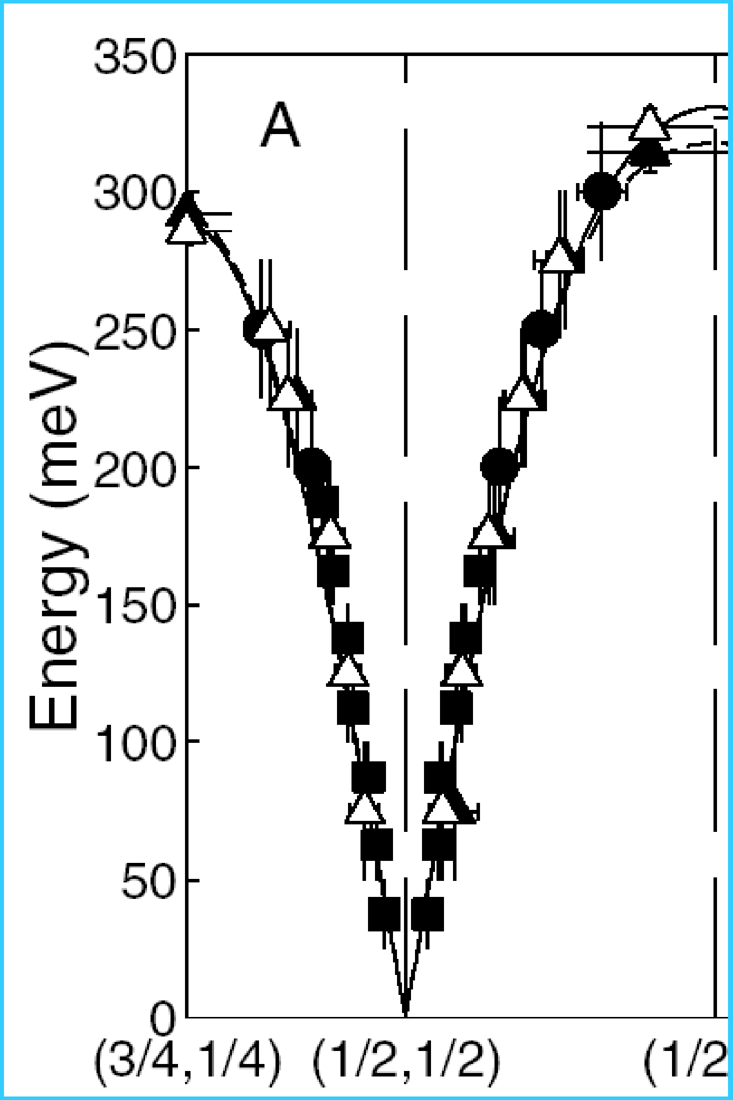
Coexistence of SDW and superconductivity in $(La\text{-}Sr)_2CuO_4$



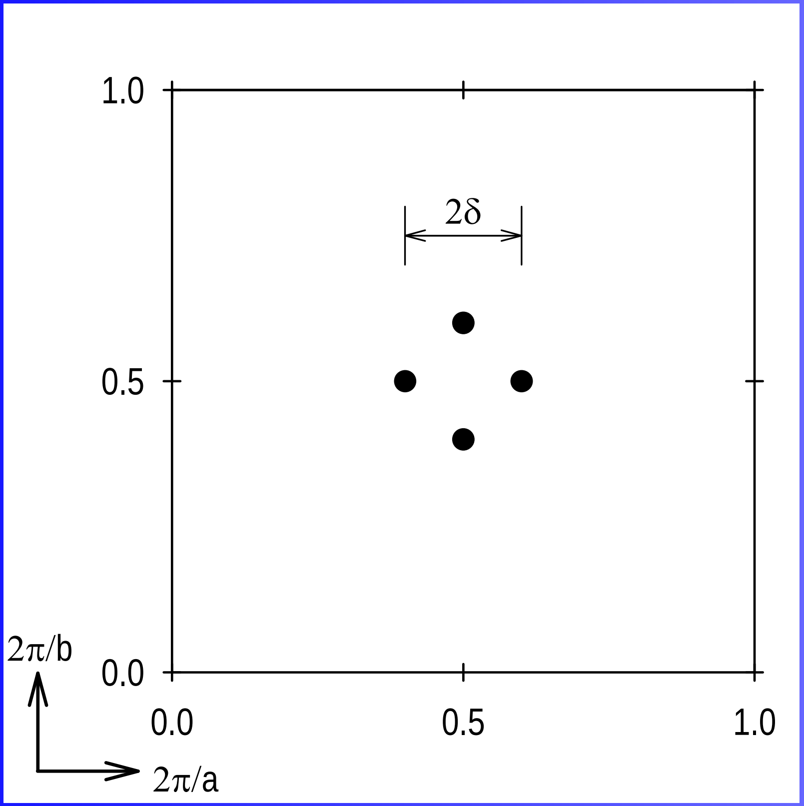
- **Magnetic field enhances the SDW at the expense of superconductivity.**
- **Effect starts to occur below T_c.**
- **Suggest SDW competes with superconductivity.**
- **B. Lake, *et al.*, *Nature* 415, 299 (2002).**

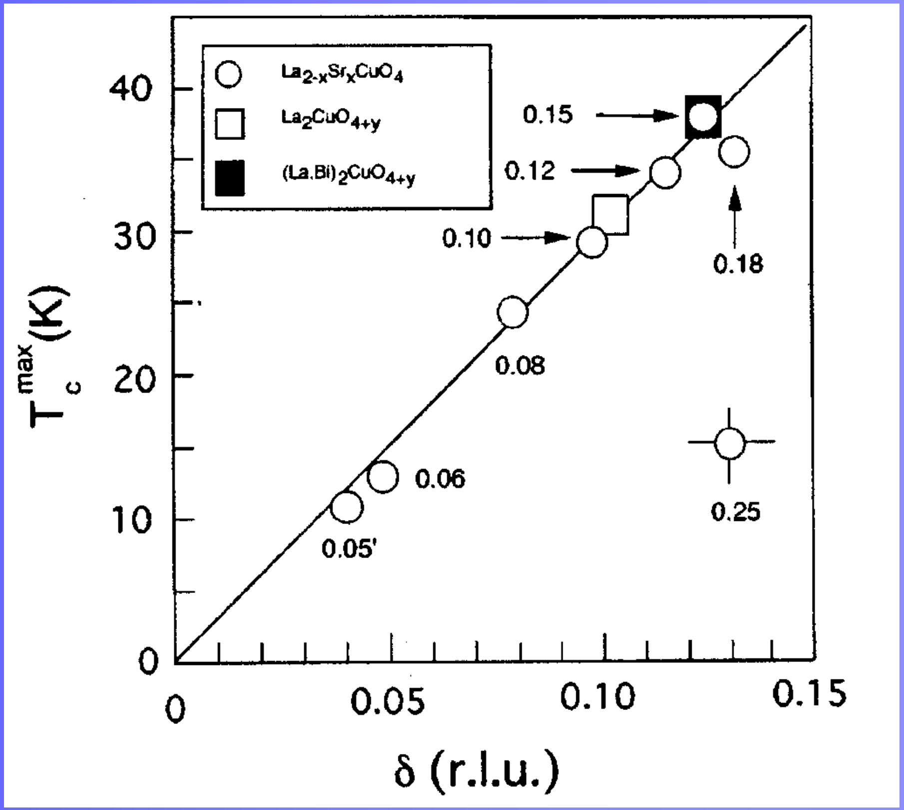
Spin Dynamics of Hole-doped Systems

- How do the spin dynamics change with:
- Doping?
- Temperature?
- Applied Magnetic Field?



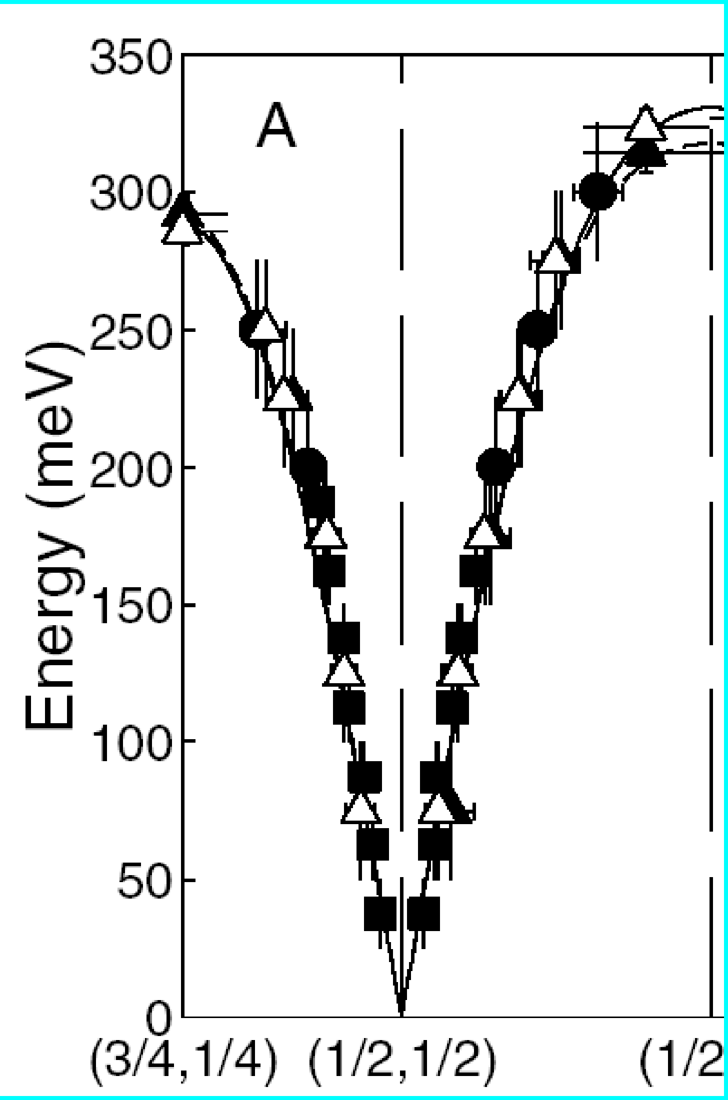
Spin fluctuations in single layer $La_{2-x}Sr_xCuO_4$

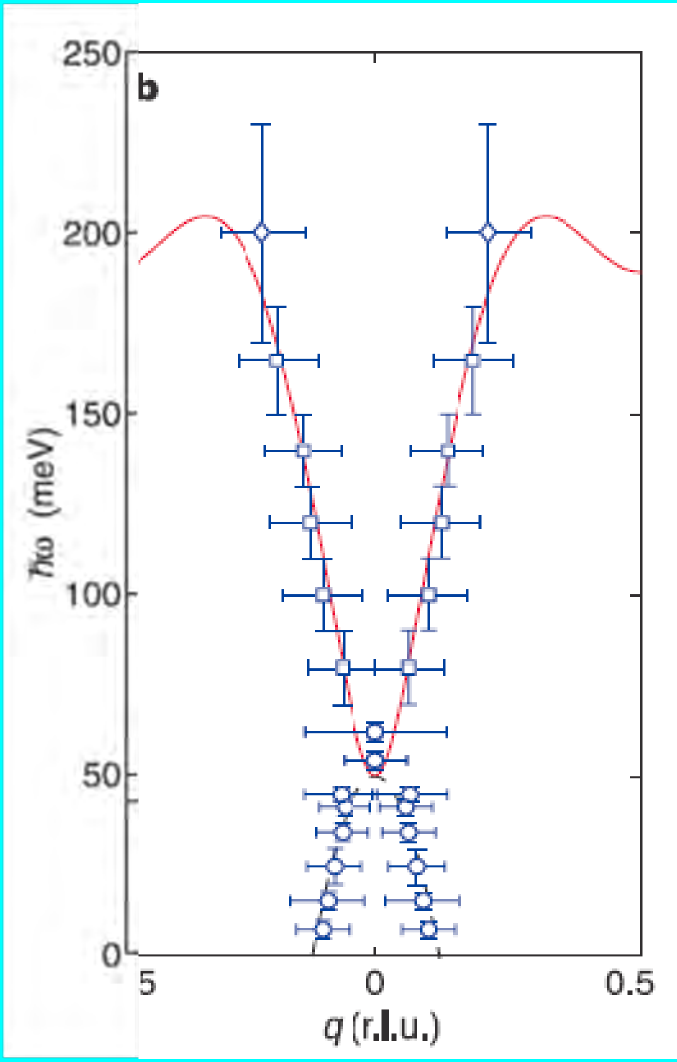




- **Low-energy spin fluctuations are incommensurate—split away from (1/2,1/2).**
- **δ is proportional to T_c.**

Energy dependence of Magnetic Excitations in LBCO

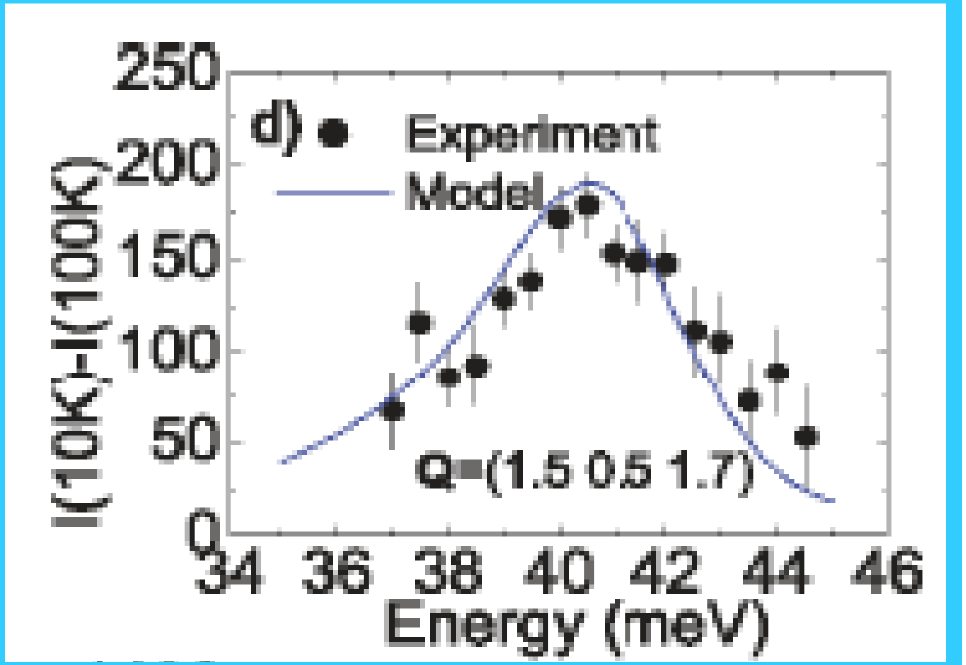


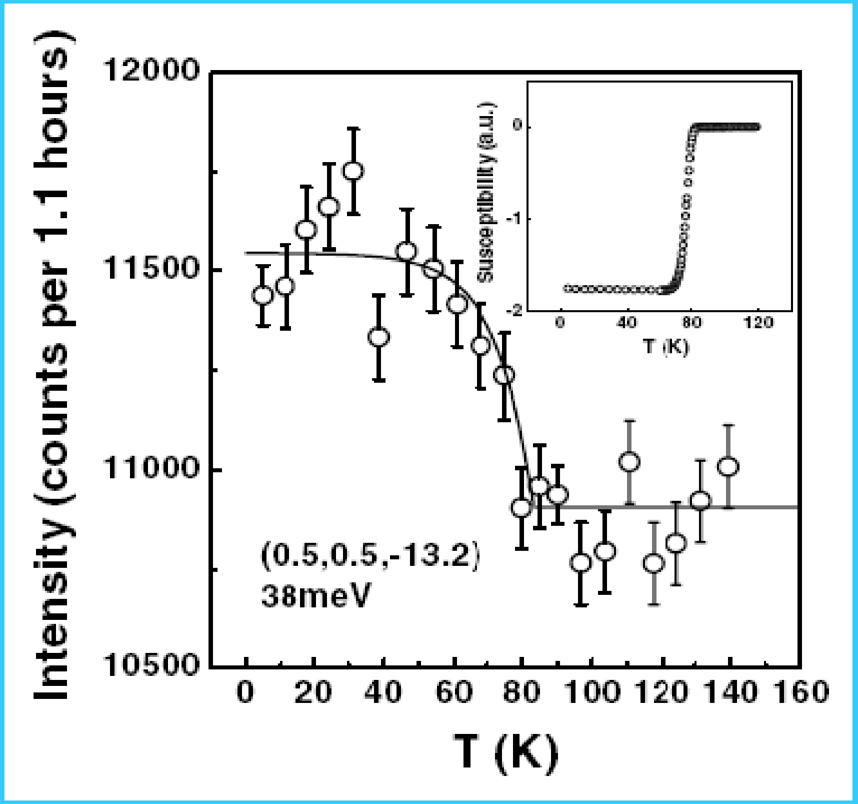


Tranquada, *et al.*

Nature 429, 534 (2004)

Magnetic Resonance

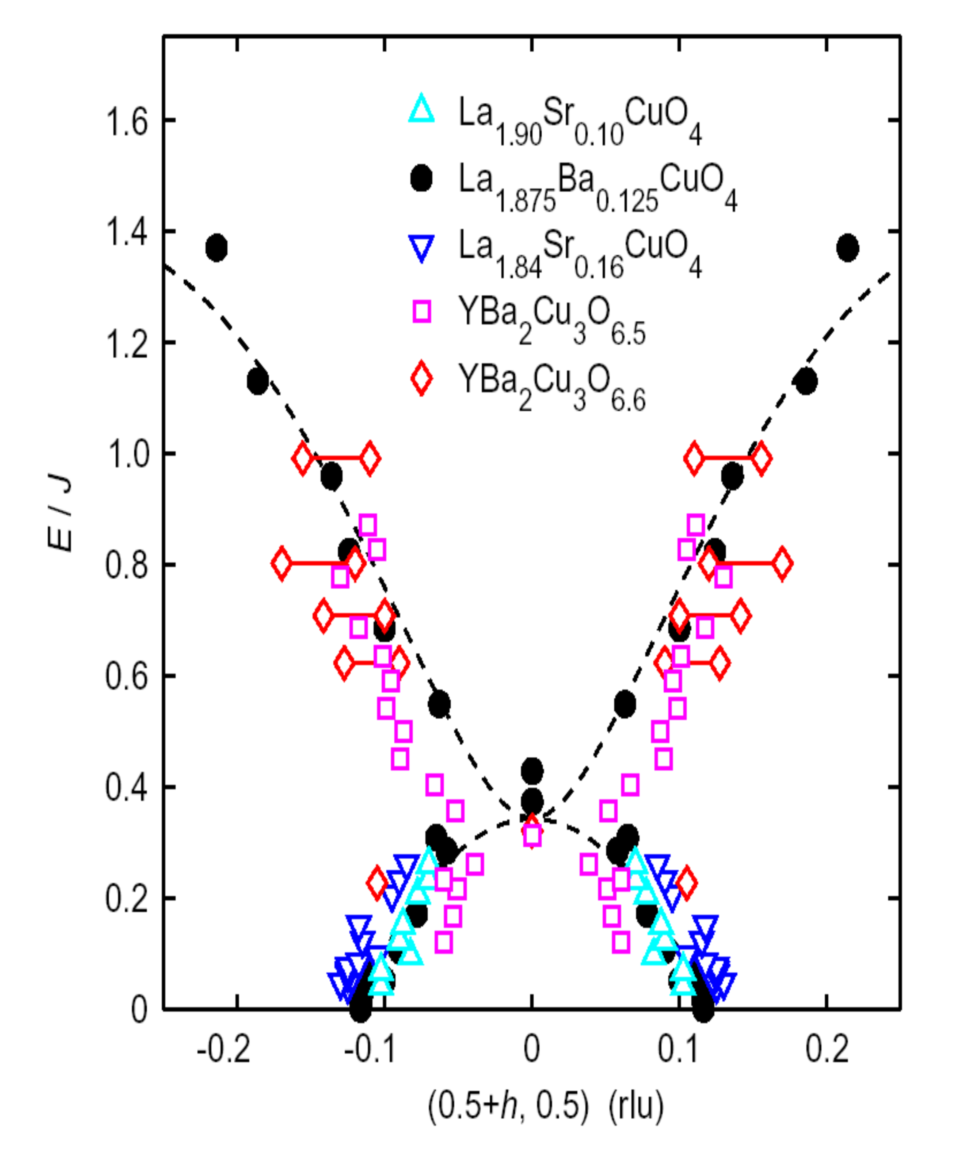




YBCO T_C=93K
D. Reznik, et al. PRL 93, 207003 (2004).

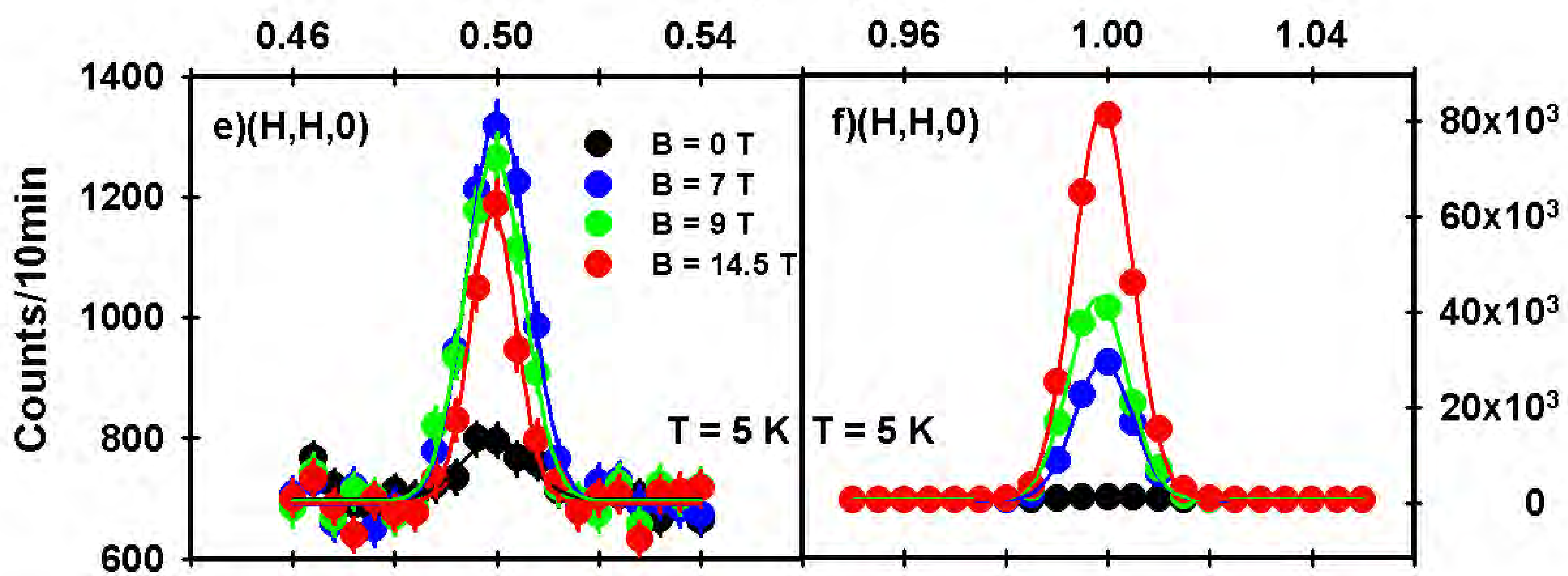
Bi2212 T_C=83K
H. He, et al. PRL 86, 1610 (2001).

Universality in hole-doped high-Tc cuprates



J. Tranquada, J. de Physique 131, 67 (2005).

$Nd_{1.85}Ce_{0.15}CuO_4$
Electron-doped cuprate superconductor



AF **Net Mag.**

T_C = 25 K

H. J. Kang, Pengcheng Dai, J. W. Lynn, M. Matsuura, J. R. Thompson, Shou-Cheng Zhang, D. N. Argyriou , Y. Onose & Y. Tokura, Nature **423**, 522 (2003).

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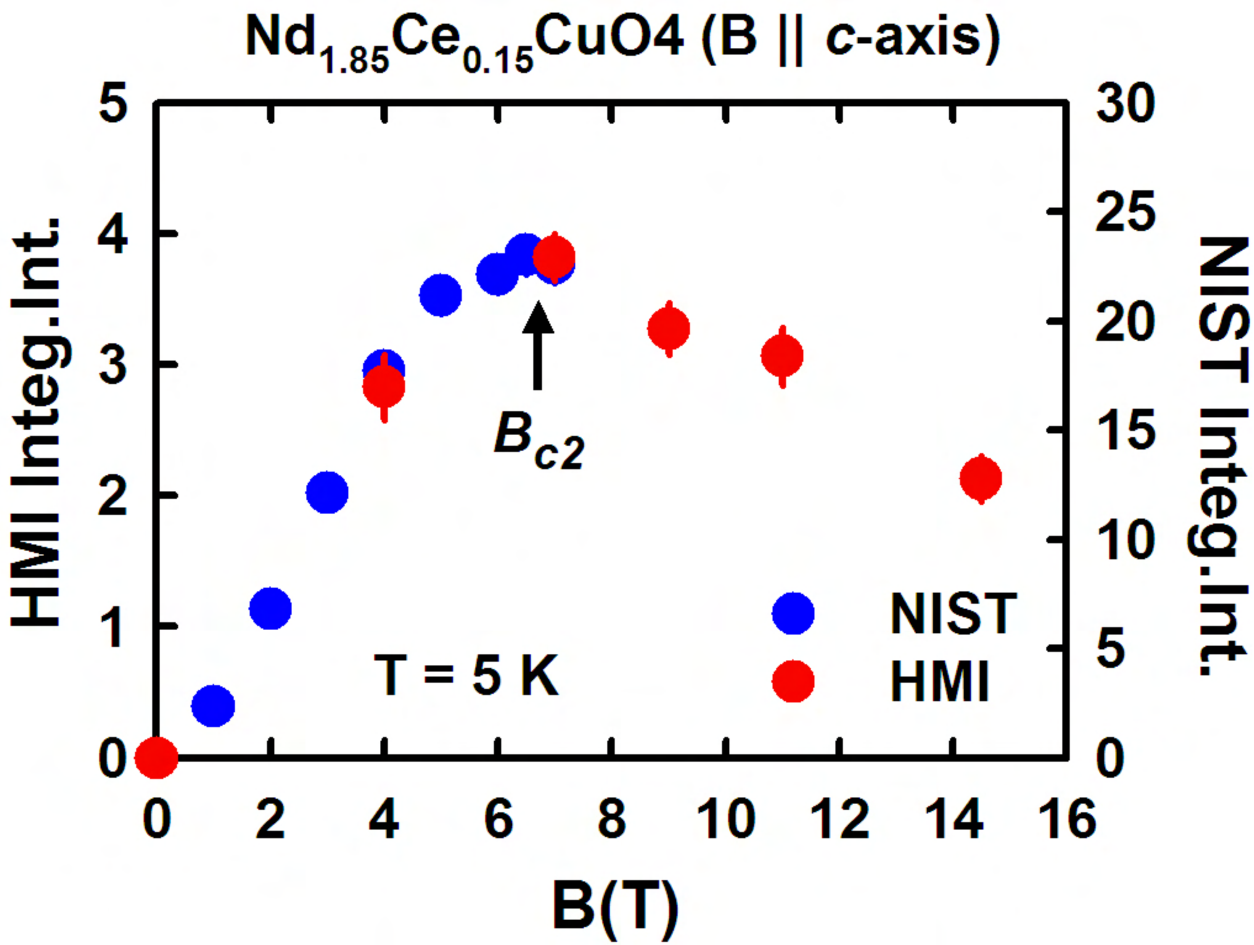
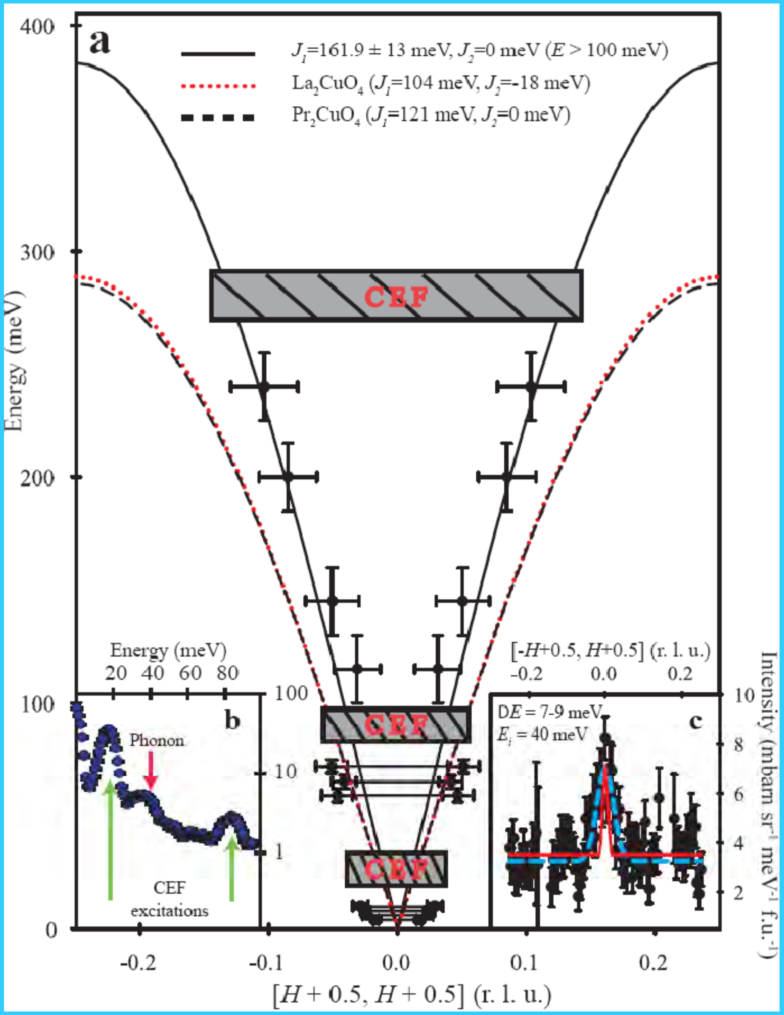
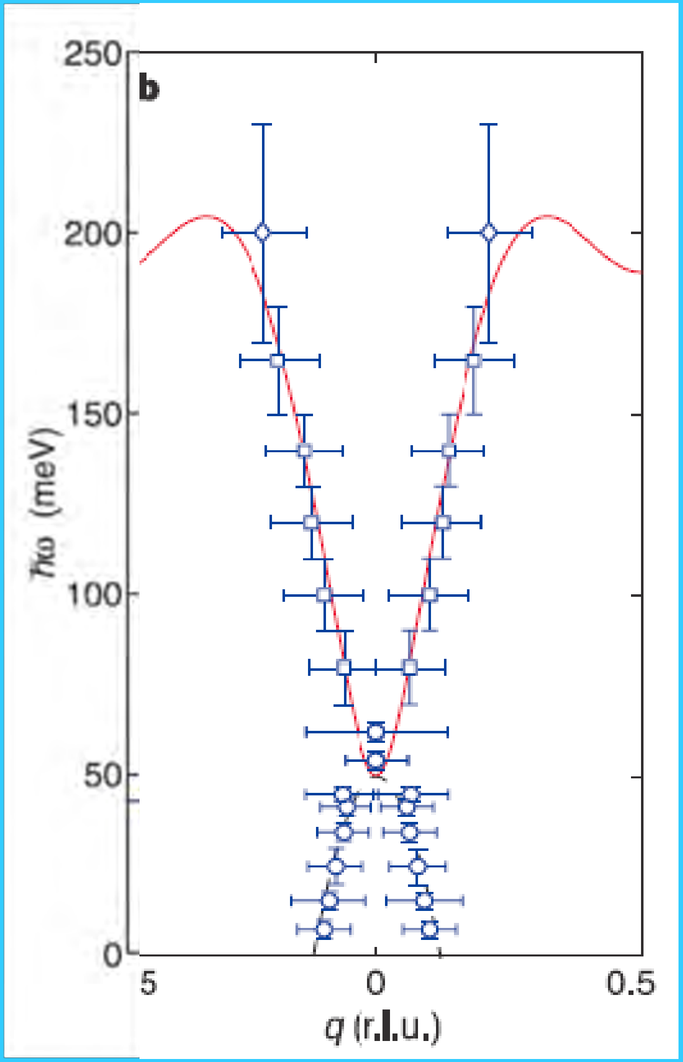
Induced moment first increases and then decreases



Spin Fluctuations in $Pr_{0.88}LaCe_{0.12}CuO_4$

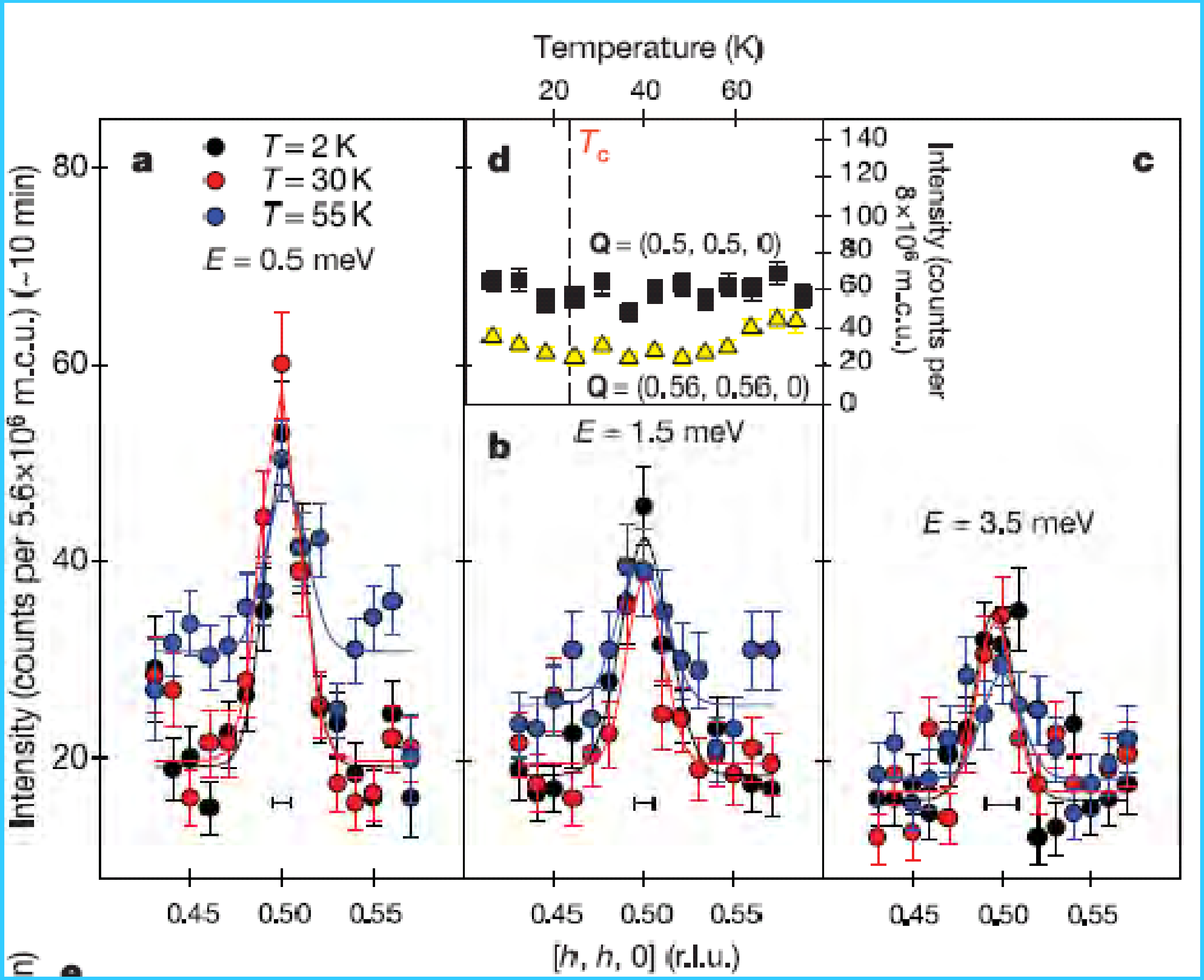


PLCCO

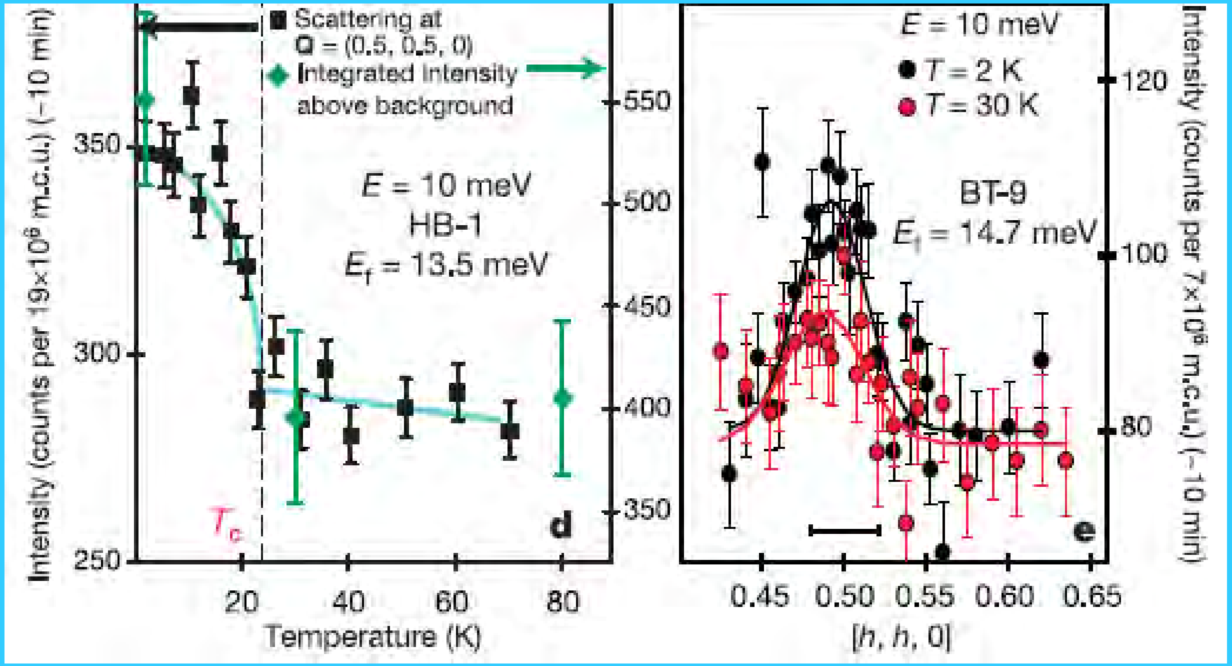


LBCO

Low-energy spin excitations in PLCCO (T_c =24 K) are Commensurate



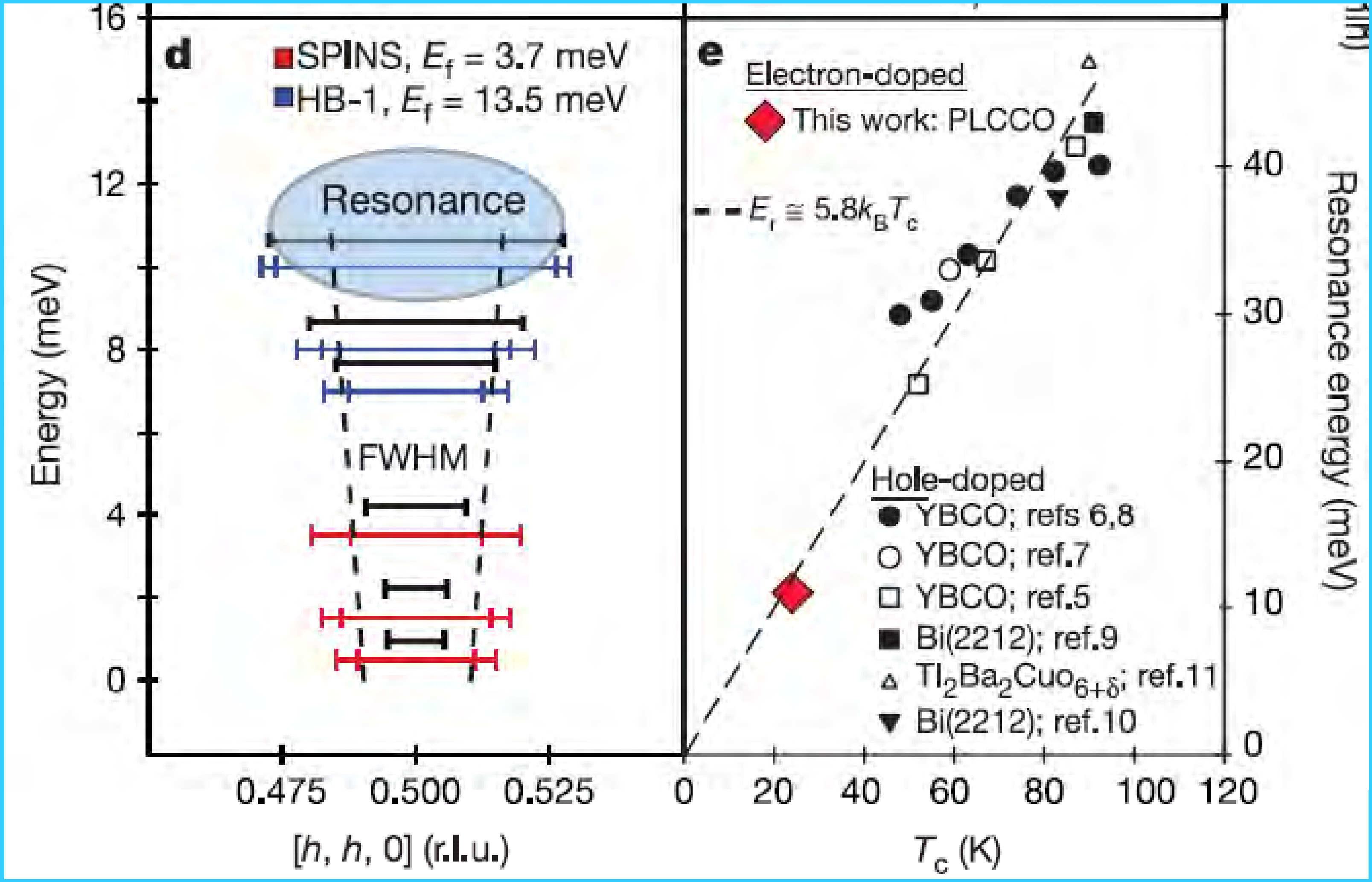
Low-energy magnetic scattering does not follow Bose population factor. There is no Spin Gap.



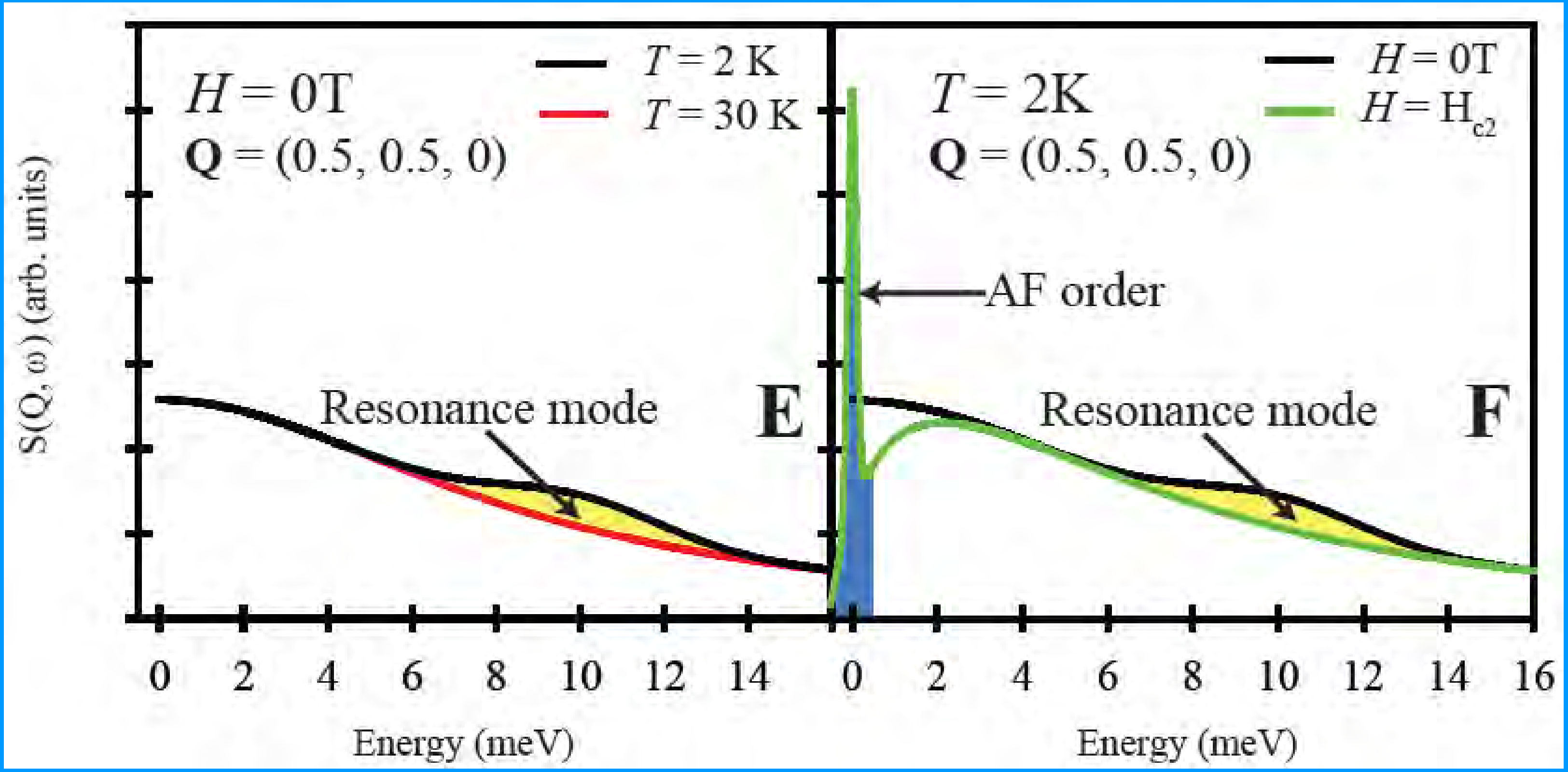
Temperature and energy dependence of the scattering around 10 meV for PLCCO (Tc = 24 K). Consistent with resonance in hole-doped materials.

S. D. Wilson, P. Dai, S. Li, S. Chi, H. Kang, & J. W. Lynn, Nature 442, 59 (2006).

Summary of neutron results



So the picture of spin excitations through superconducting-normal phase transition is:



There is a direct competition between superconducting phase without AF order and the AF phase without superconductivity.

Iron-based superconductors under Investigation with Neutron Scattering

- $LaO_{1-x}F_xFeAs$ (1:1:1:1)
- $CeO_{1-x}F_xFeAs$
- $NdO_{1-x}F_xFeAs$
- $PrO_{1-x}F_xFeAs$
- $BaFe_2As_2$ $SrFe_2As_2$ (1:2:2)
- $CaFe_2As_2$, Under Pressure
- Fe(Se-Te) (1:1)
  - http://www/ncnr.nist.gov/staff/jeff

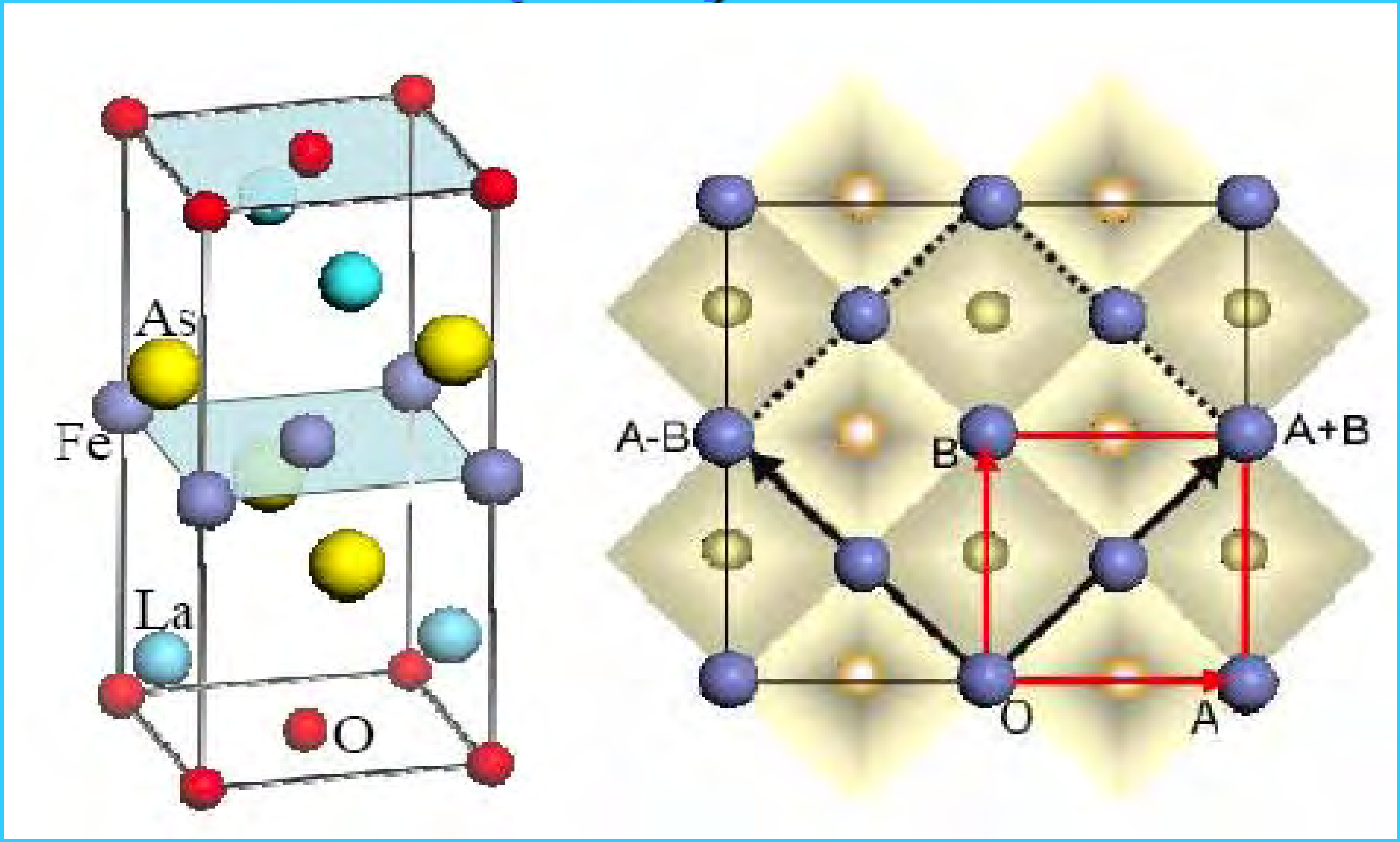
Collaborations

- U. Tennessee/ORNL (Pengcheng Dai, et al.)
- LANL (Wei Bao, et al.)
  - Beijing Institute of Physics
  - (Nan Ling Wang, et al.; X. H. Chen, et al.)
- Princeton University (Bob Cava, et al.)
- Iowa State University/Ames Lab (Alan Goldman, Paul Canfield, Rob McQueeney, et al.)
- NCNR (Qing Huang, William Ratcliff, Ying Chen, Sung Chang, Ben Ueland, Mark Green)
  - http://www/ncnr.nist.gov/staff/jeff

Properties of *RE*(O,F)Fe(As,P)

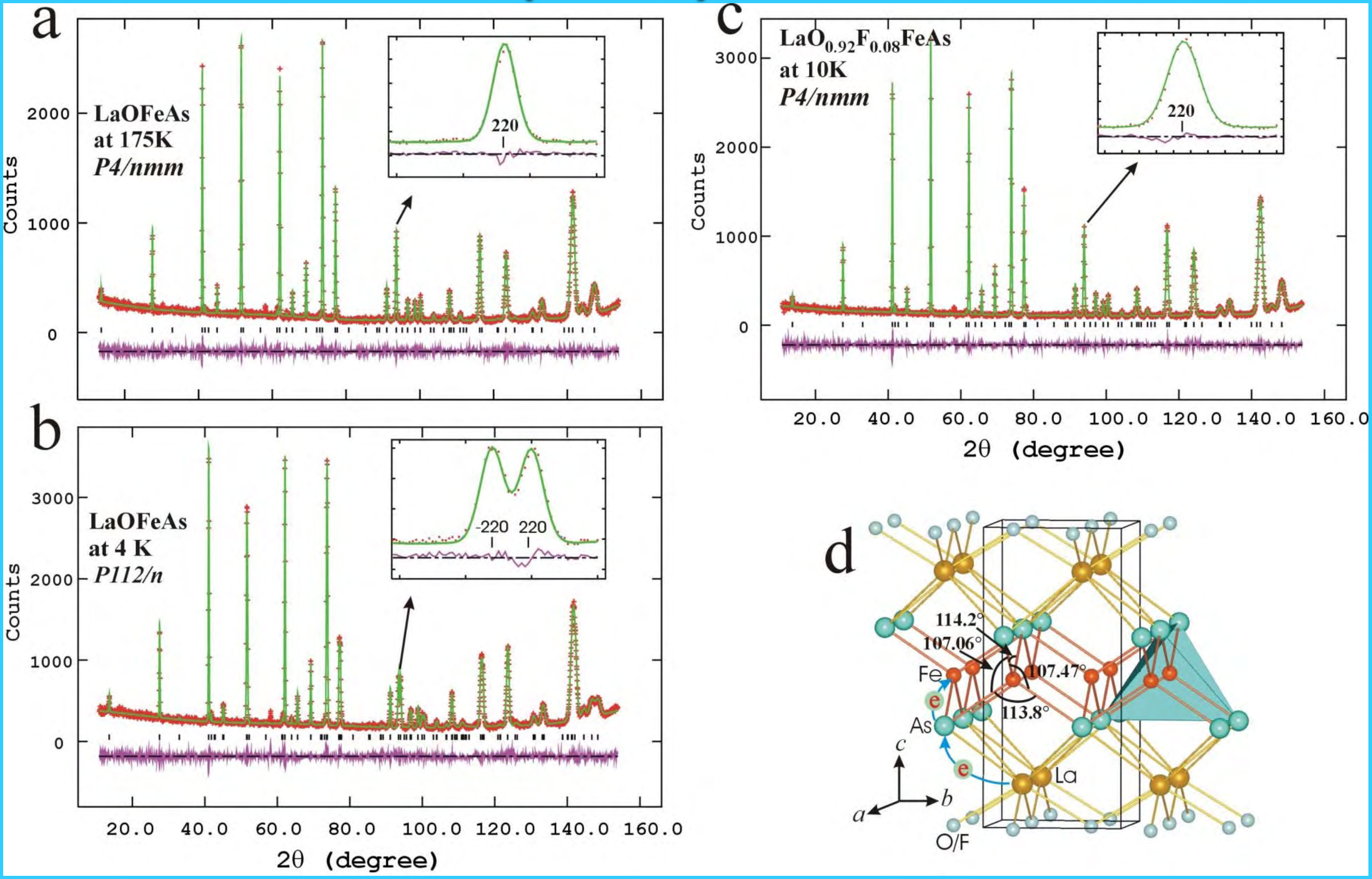
- Parent Materials
  - Metallic (poor metal)
  - Anisotropic (ranging from 5 – 30)
  - Have a structural distortion (T ~ 150 K)
  - Fe spins are antiferromagnetically ordered (T_N ~ 140 K)
- Superconductors
  - T_C as high as 55 K
  - Anisotropic
  - Very high upper critical fields 300 T

Crystal Structure of La(O,F)FeAs

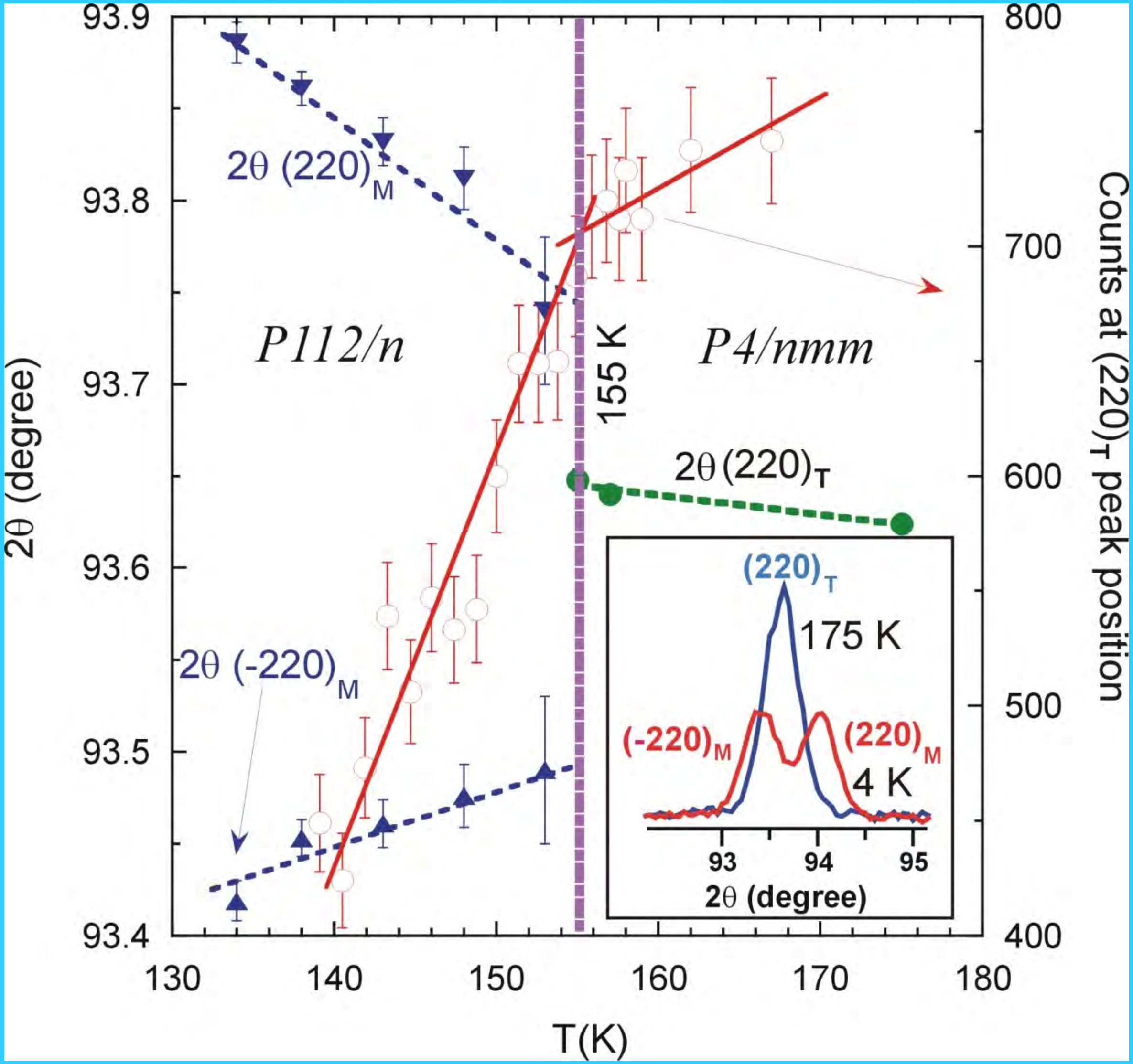


Magnetic Order Close to Superconductivity in the Iron-based Layered La($O_{1-x}F_x$)FeAs systems,
C. de la Cruz, Q. Huang, J. W. Lynn, J. Li, W. Ratcliff II, J. L. Zarestky, H. A. Mook, G. F. Chen, J. L. Luo, N. L. Wang, and P. Dai, P. Dai, *Nature* **453**, 899 (2008).

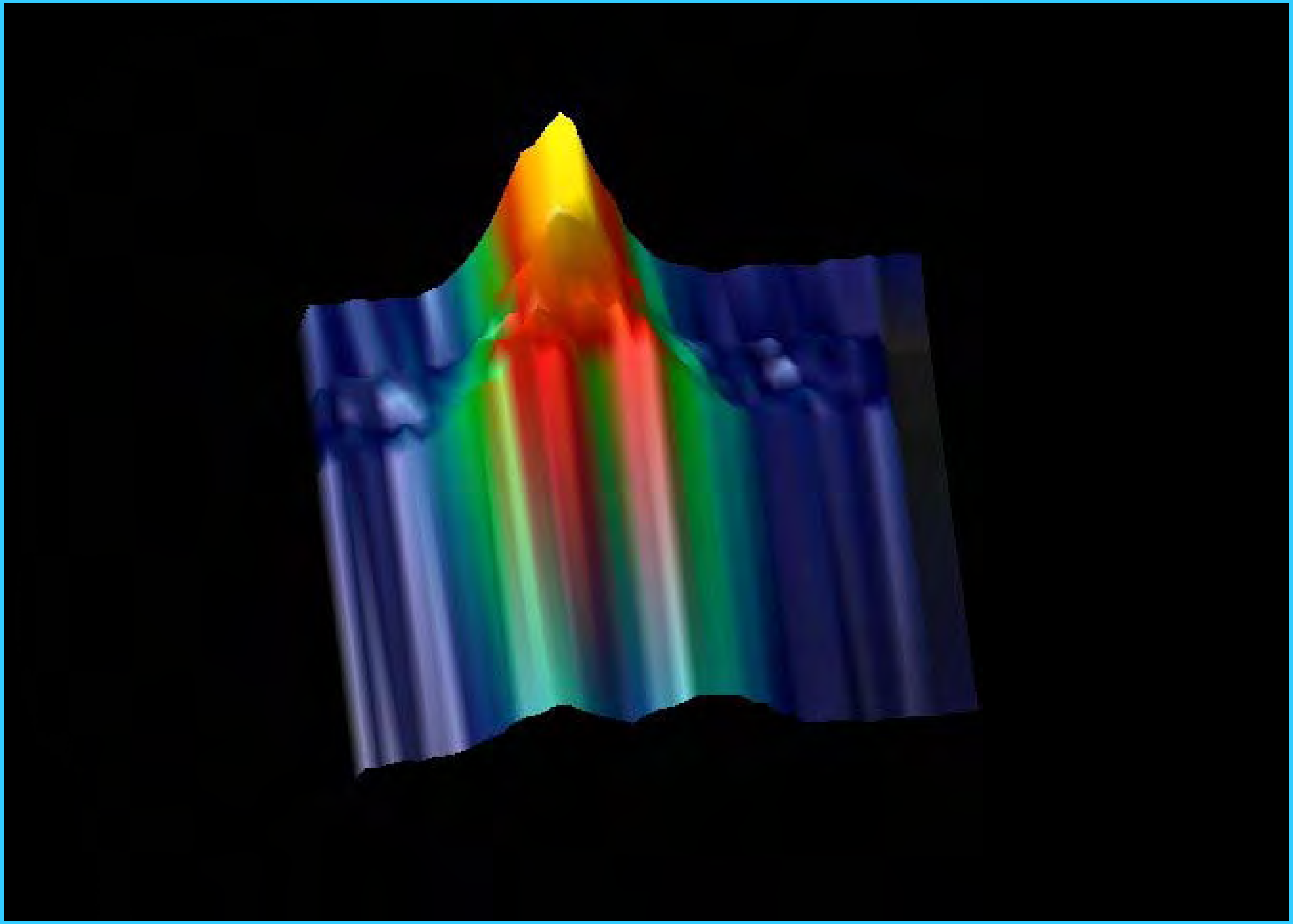
Crystal Structure of La(O,F)FeAs



Crystal Structure of La(O,F)FeAs

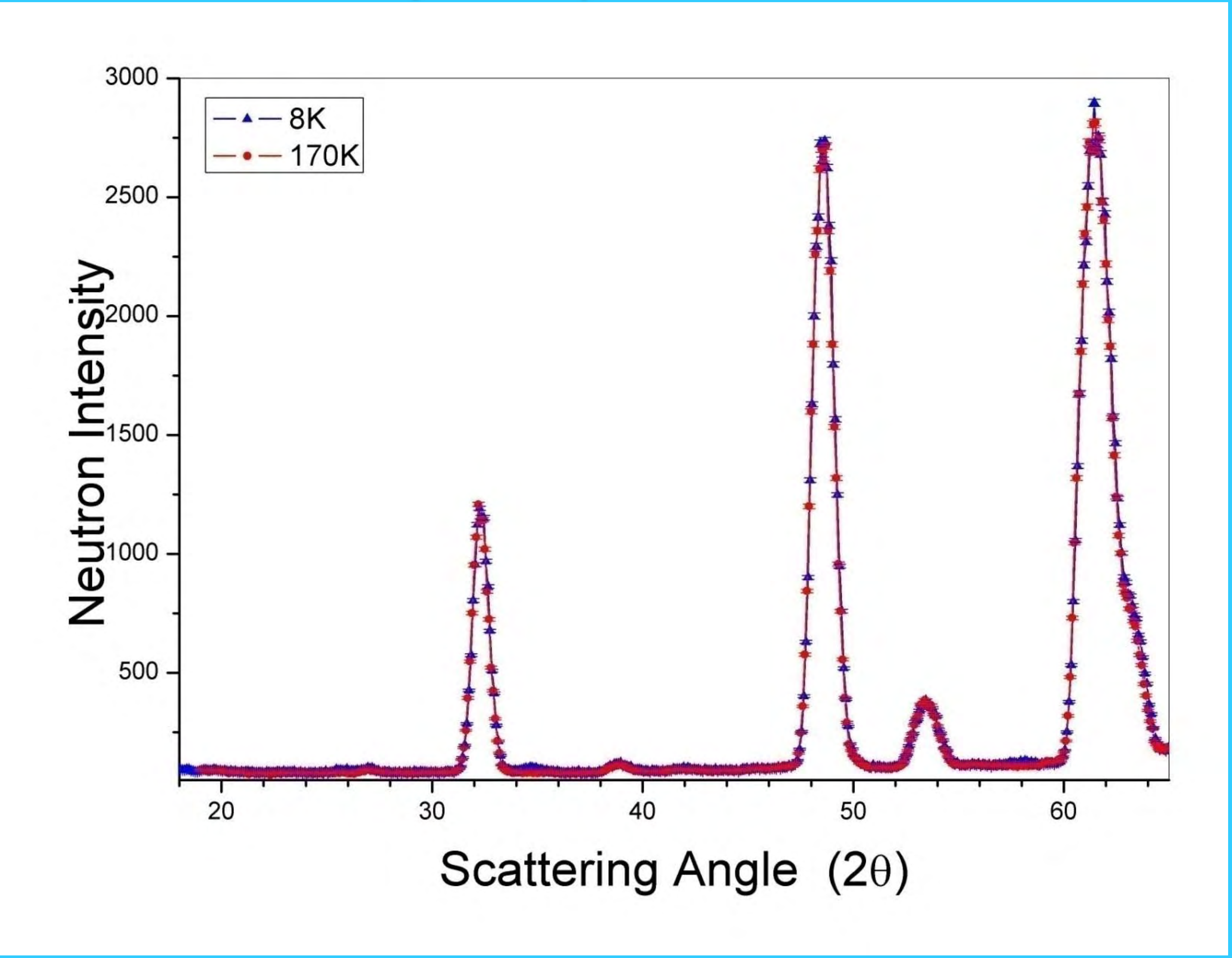


Crystal Structure of La(O,F)FeAs



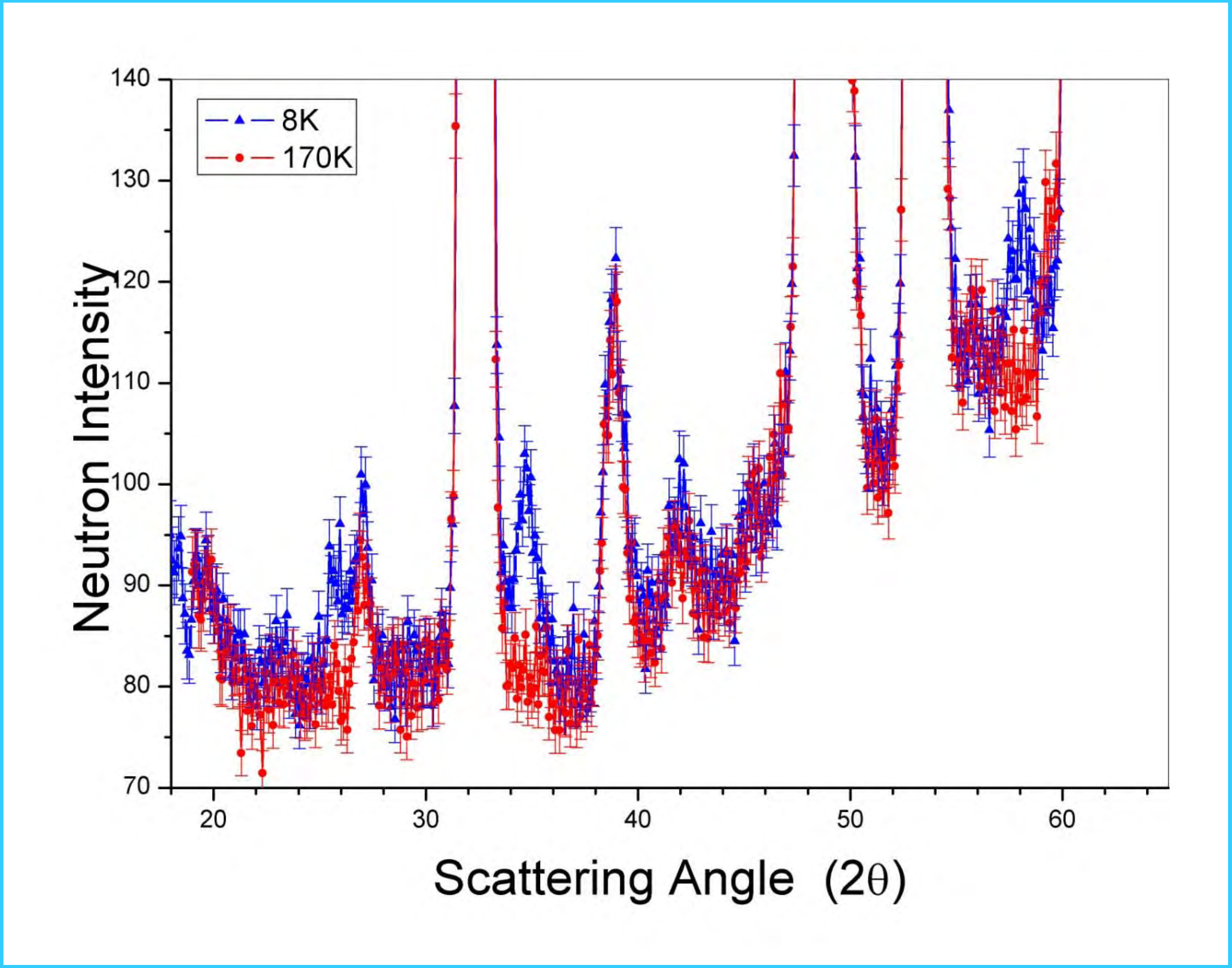
Magnetic Scattering from La(O,F)FeAs

PSD on BT-7

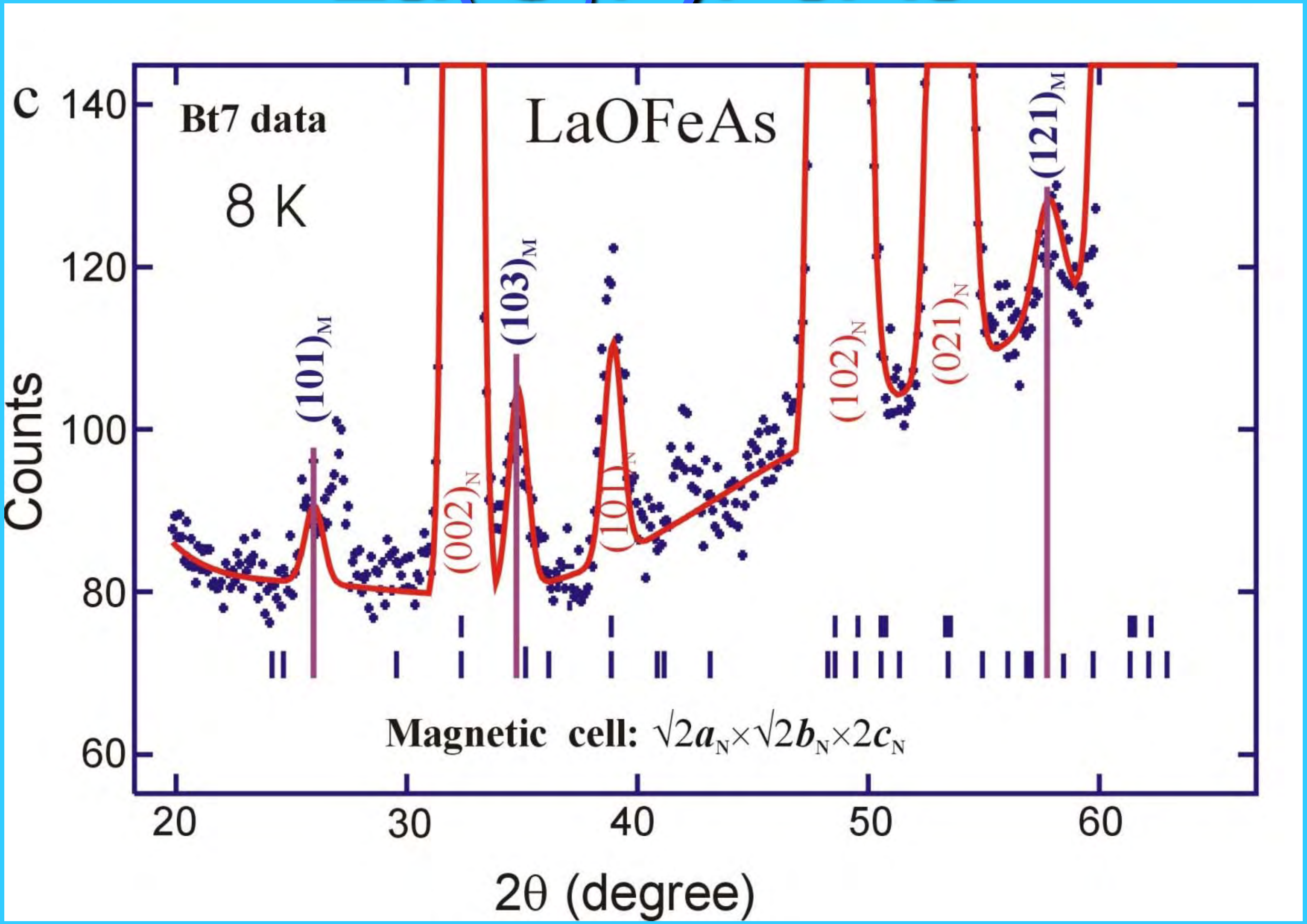


Magnetic Scattering from La(O,F)FeAs

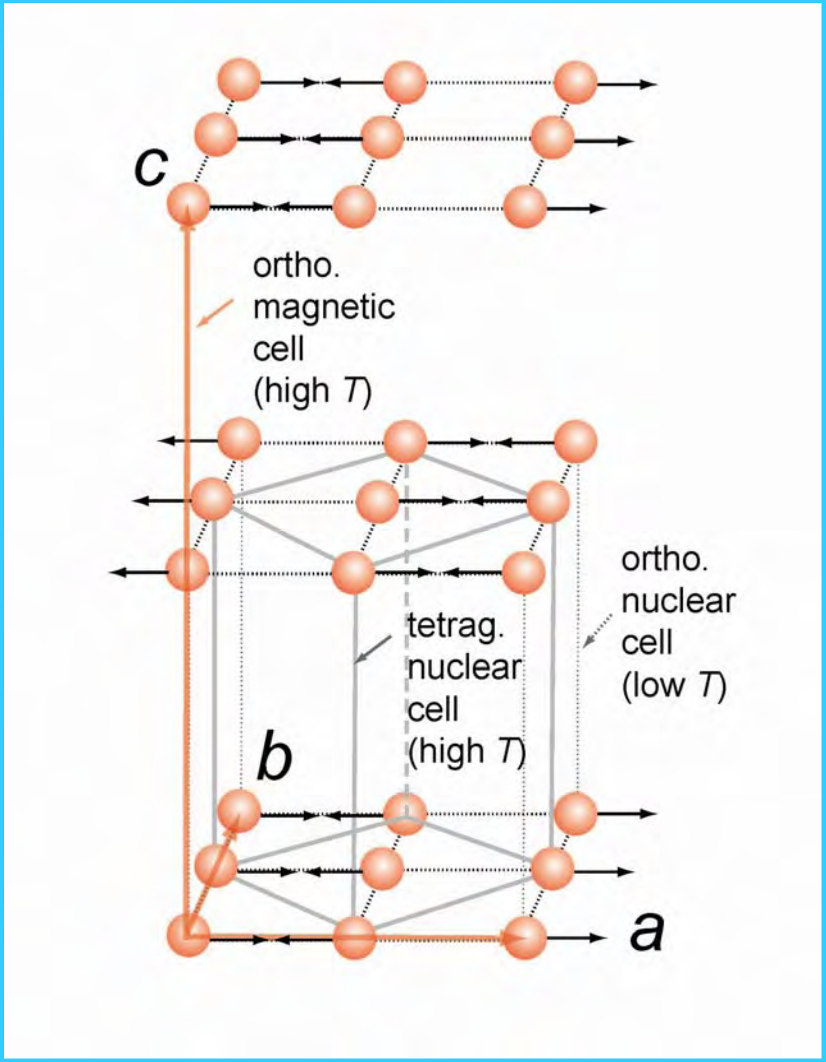
PSD on BT-7



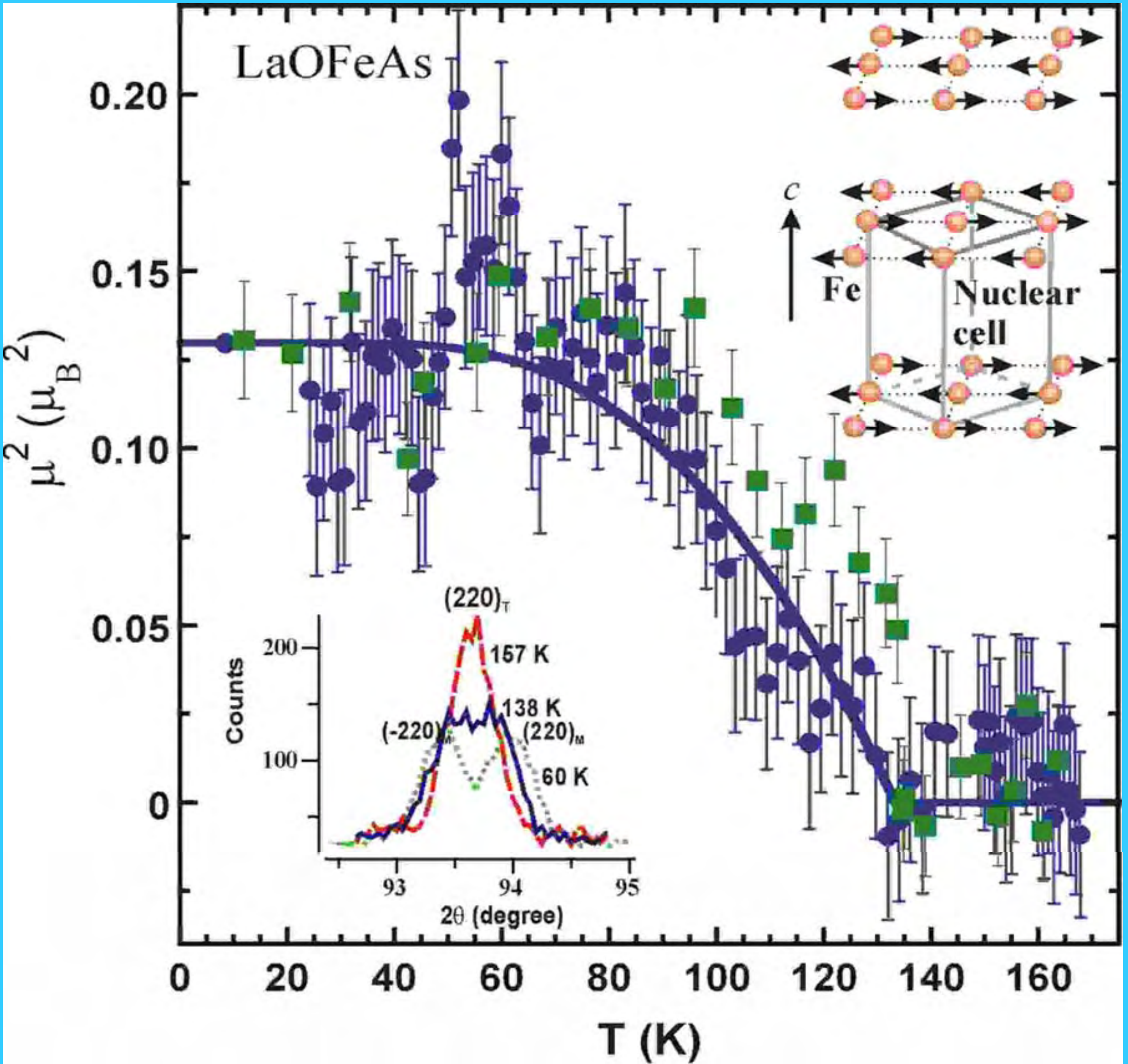
Magnetic Structure
La(O,F)FeAs



Magnetic Structure of La(O,F)FeAs



Magnetic Structure
La(O,F)FeAs



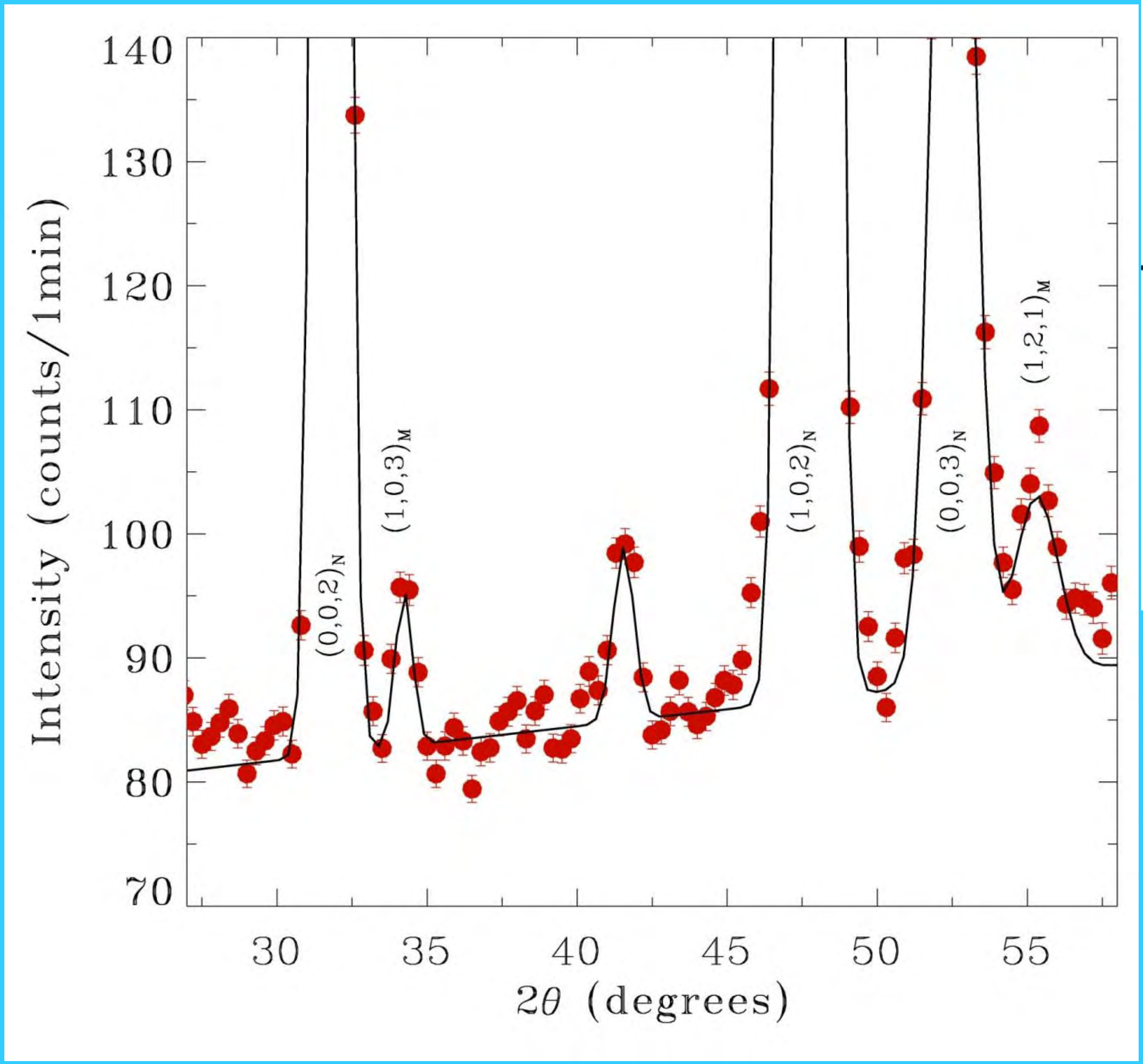
La(O,F)FeAs

- Magnetic Order Close to Superconductivity in the Iron-based Layered $La(O_{1-x}F_x)FeAs$ systems, C. de la Cruz, Q. Huang, J. W. Lynn, J. Li, W. Ratcliff II, J. L. Zarestky, H. A. Mook, G. F. Chen, J. L. Luo, N. L. Wang, and P. Dai, P. Dai, *Nature* **453**, 899 (2008).
- Intrinsic Properties of Stoichiometric LaOFeP, T. M. McQueen, M. Regulacio, A. J. Williams, Q. Huang, J. W. Lynn, Y. S. Hor, D.V. West, and R. J. Cava, Phys. Rev. B**78**, 024521 (2008).
- Neutron scattering study of the oxypnictide superconductor $LaO_{0.87}F_{0.13}FeAs$, Y. Qiu, M. Kofu, Wei Bao, S.-H. Lee, Q. Huang, T. Yildirim, J. R. D. Copley, J. W. Lynn, T. Wu, G. Wu, and X. H. Chen, *Phys. Rev*. B **78,** 052508 (2008).
- Doping Evolution of Antiferromagnetic Order and Structural Distortion in $LaFeAsO_{1-x}F_x$, Q. Huang, J. Zhao, J. W. Lynn, G. F. Chen, J. L. Lou, N. L. Wang, and P. Dai, Phys. Rev. B **78,** 054529 (2008).

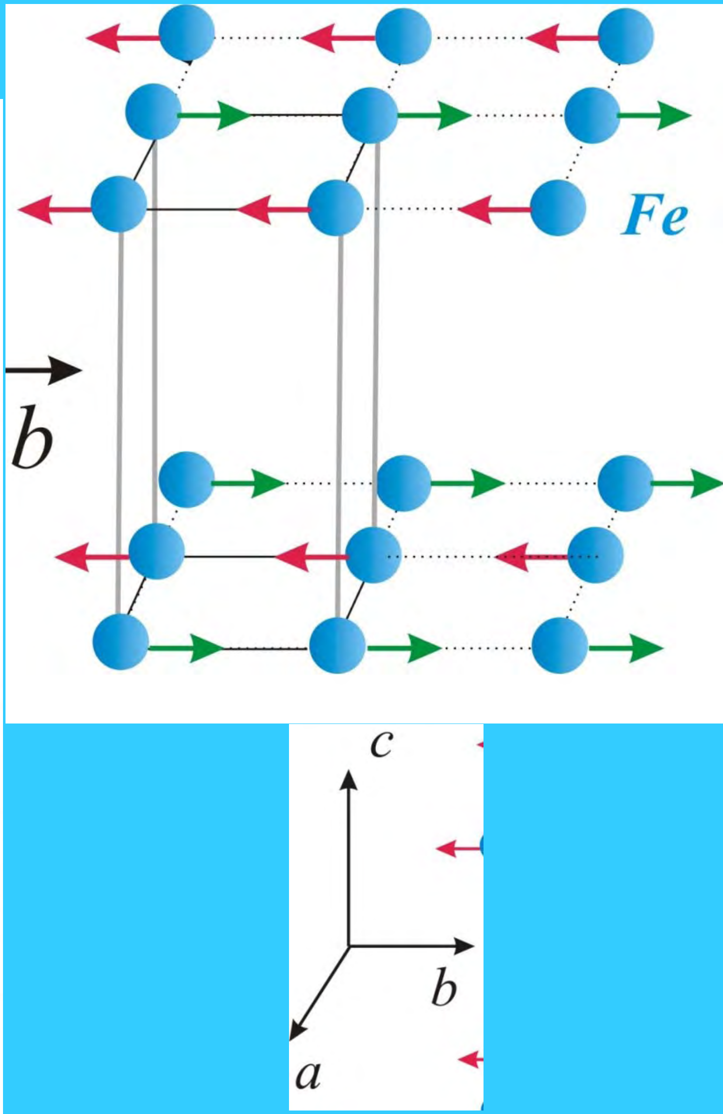
Properties of *Nd*(O,F)FeAs
T_C = 52 K

- Magnetic Order of the Iron Spins in NdOFeAs, Y. Chen, J. W. Lynn, G. F. Chen, G. Li, Z. C. Li, J. L. Luo, N. L. Wang, P. Dai, C. dela Cruz, and H. A. Mook, Phys. Rev. B**78,** 064515 (2008).
- Structure and Magnetic Order in the $NdFeAsO_{1-x}F_x$ Superconductor System, Y. Qiu, W. Bao, Q. Huang, T. Yildirim, J. M. Simmons, M. A. Green, J.W. Lynn, Y.C. Gasparovic, J. Li, T. Wu, G. Wu, and X.H. Chen, (submitted).

NdOFeAs

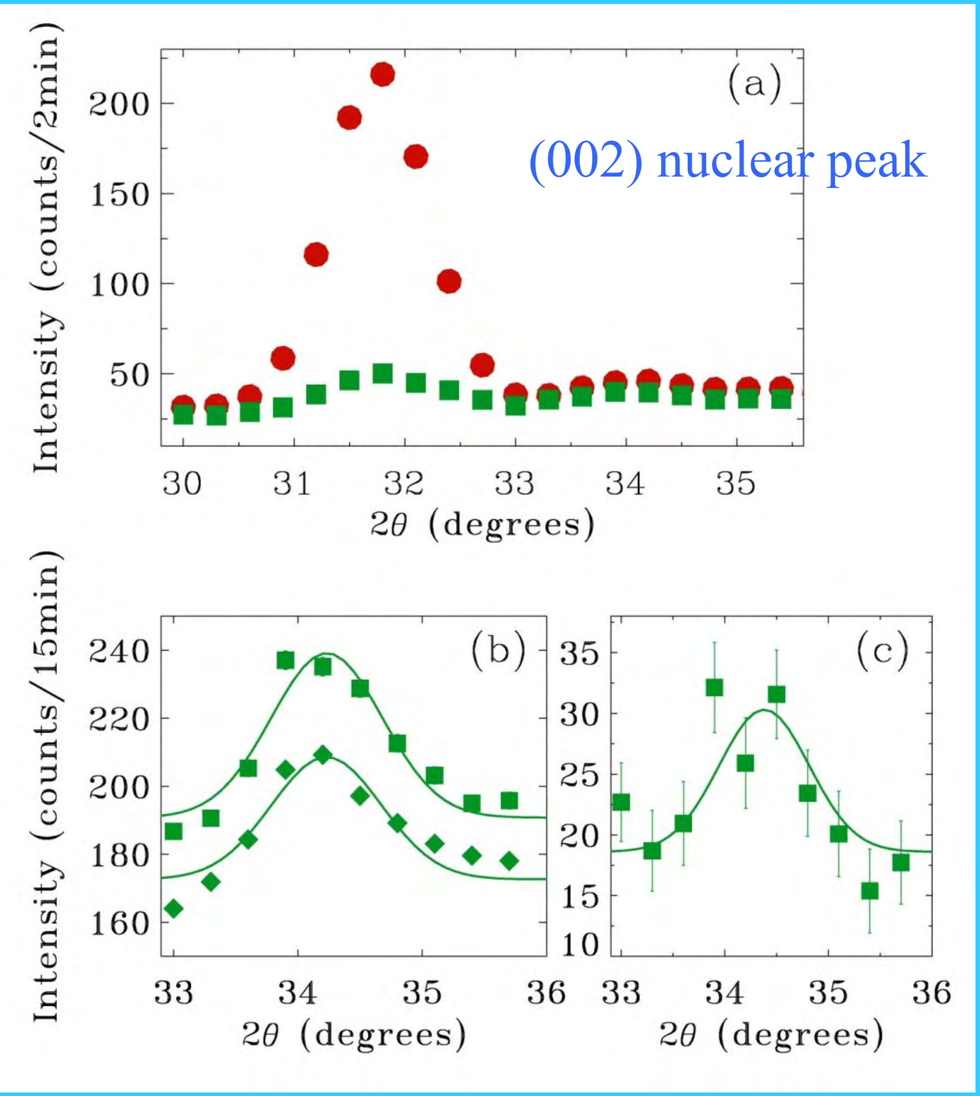


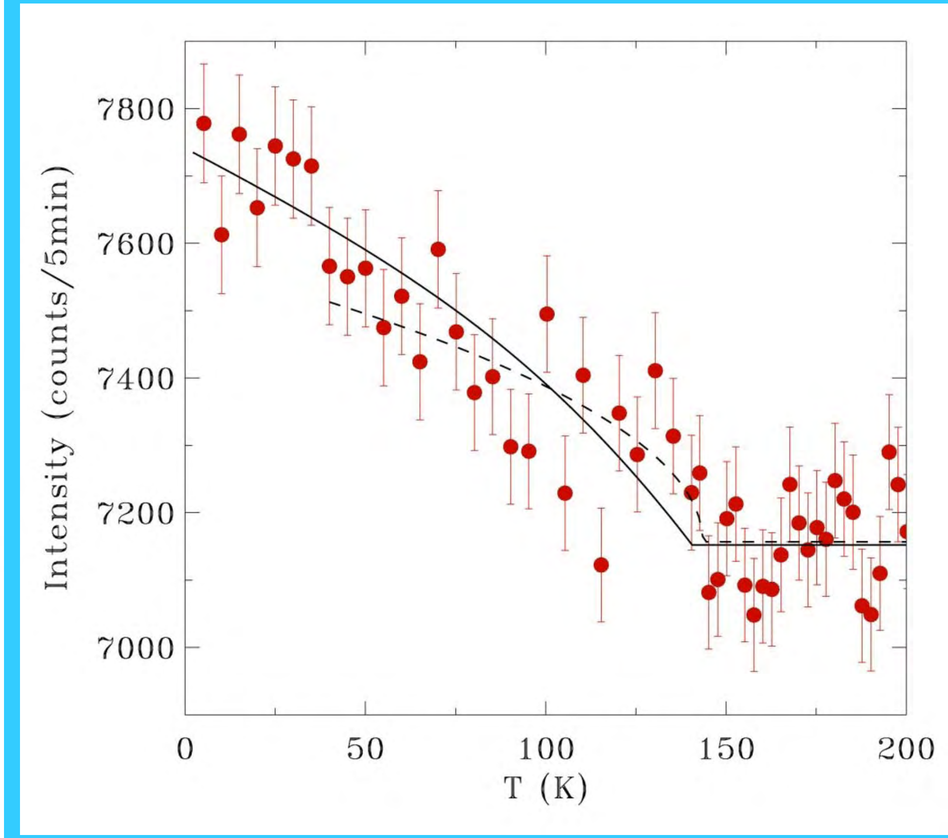
Intensity (counts/1min)
140
130
120
110
100
90
80
70
30
35
40
45
50
55
2θ (degrees)
(0,0,2)N
(1,0,3)M
(1,0,2)N
(0,0,3)N
(1,2,1)M



Fe
b
c
b
a

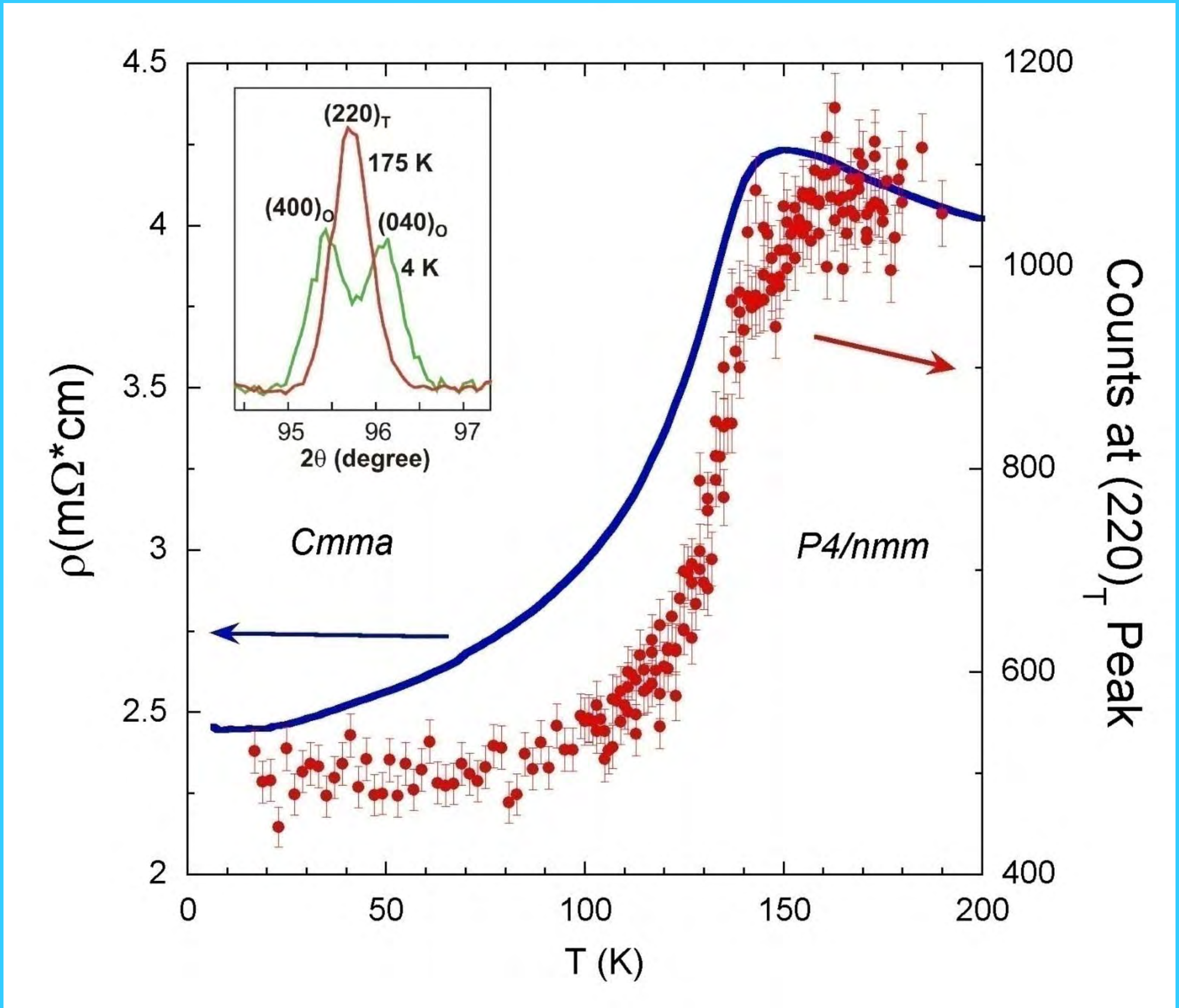
NdOFeAs



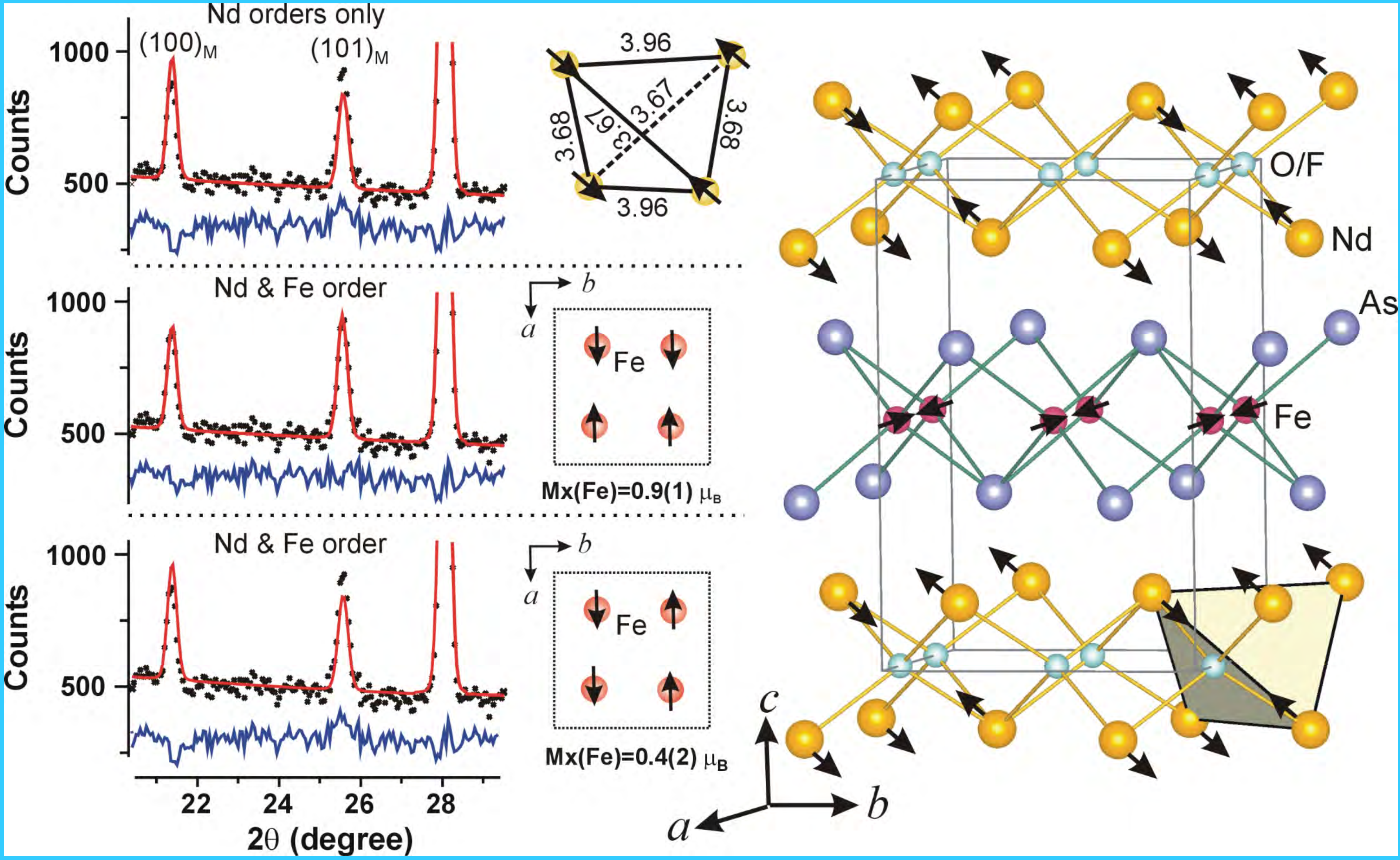


Polarized Beam (**P**||**Q** (squares) and **P**⊥**Q** (diamonds))

NdOFeAs Structure

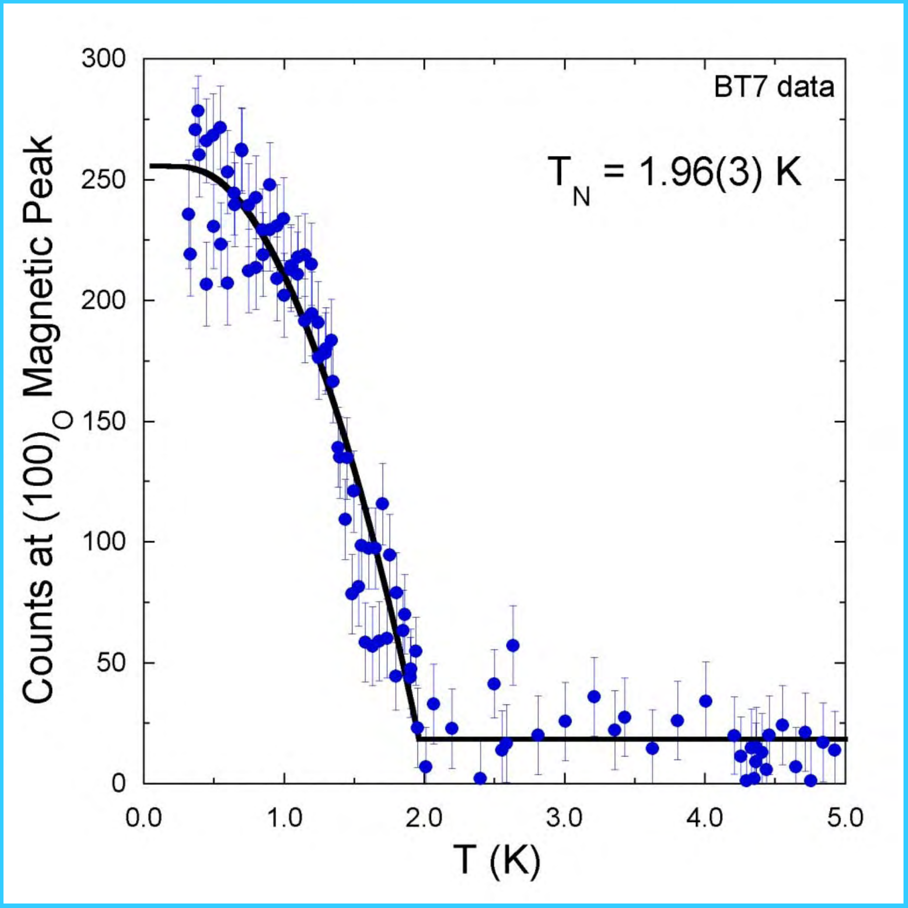


NdOFeAs



Nd orders only
(100)M
(101)M
Counts
1000
500
Nd & Fe order
Counts
1000
500
Nd & Fe order
Counts
1000
500
22
24
26
28
2θ (degree)
3.96
3.67
3.67
3.68
3.68
3.96
b
a
Fe
Mx(Fe)=0.9(1) μB
b
a
Fe
Mx(Fe)=0.4(2) μB
O/F
Nd
As
Fe
c
b
a

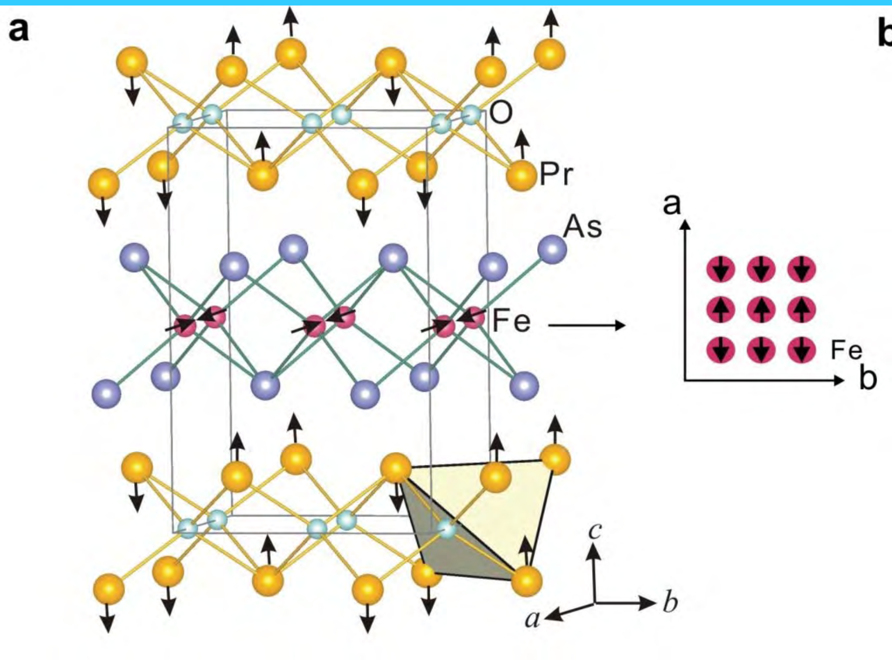
NdOFeAs Structure



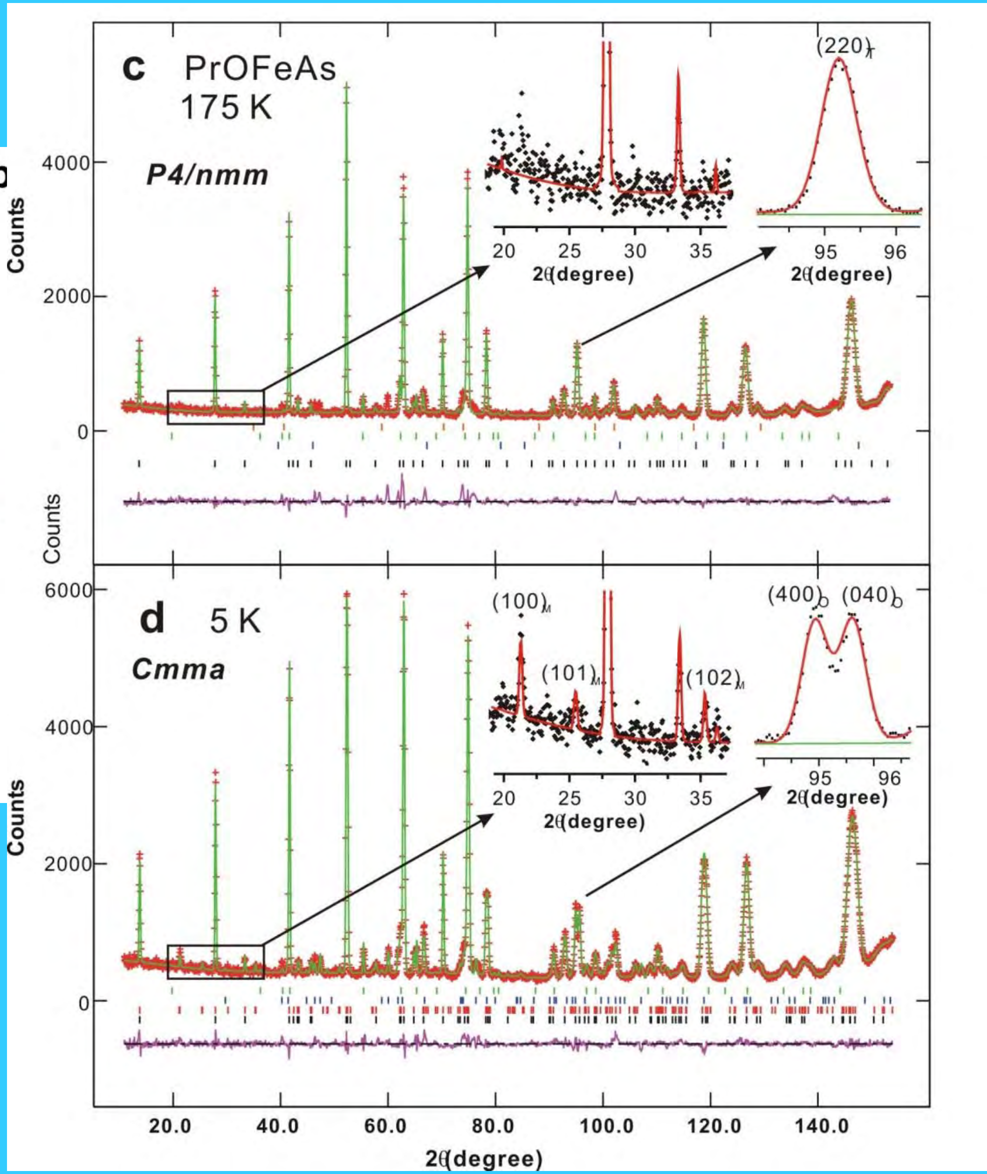
Properties of *Pr*(O,F)FeAs

- Lattice and Magnetic structures of PrFeAsO, $PrFeAsO_{0.85}F_{0.15}$ and $PrFeAsO_{0.85}$, Jun Zhao, Q. Huang, Clarina de la Cruz, J. W. Lynn, M. D. Lumsden, Z. A. Ren, Jie Yang, Xiaolin Shen, Xiaoli Dong, Zhongxian Zhao, and Pengcheng Dai, *Phys. Rev.* B (submitted)

PrOFeAs

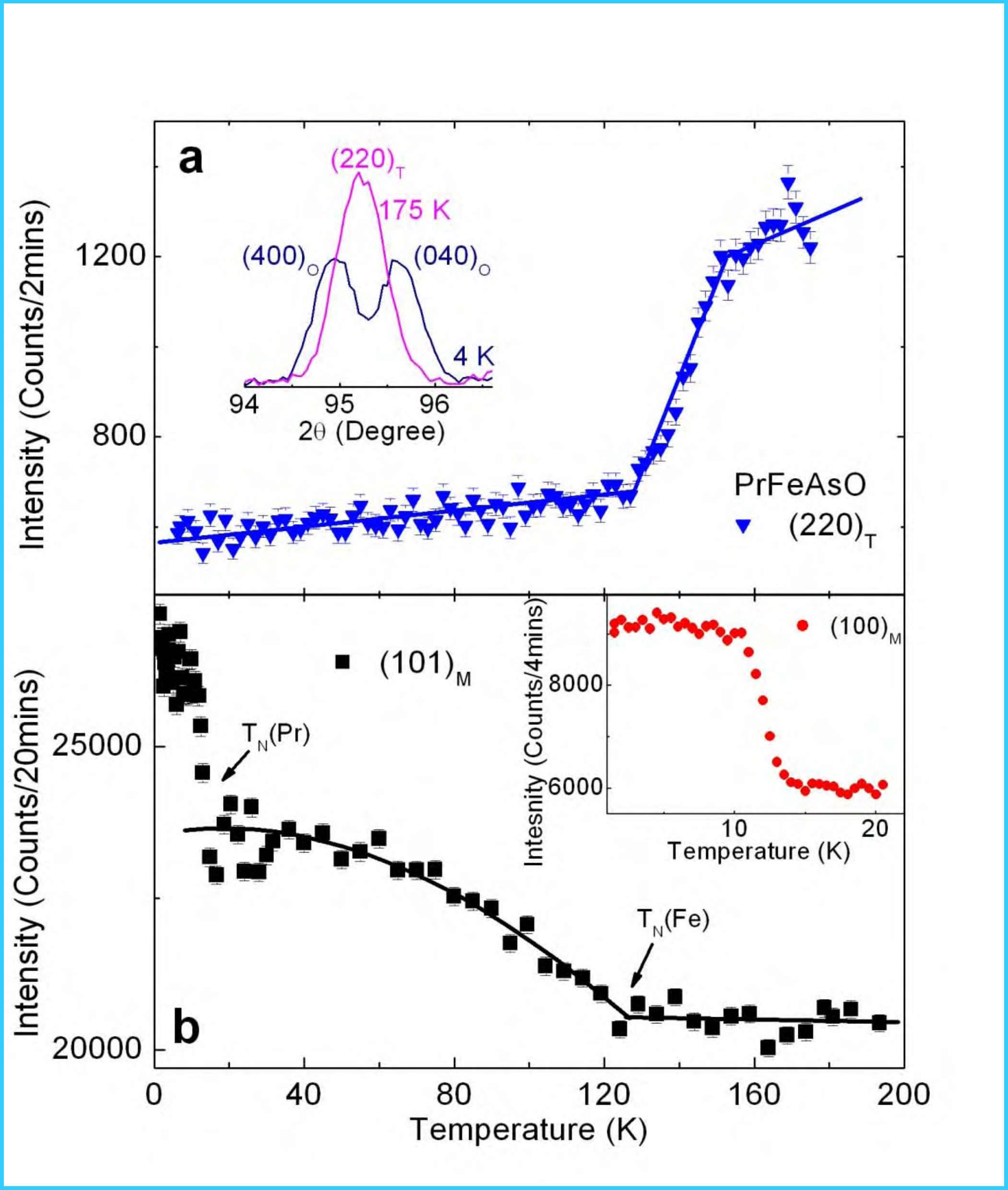


a
b
O
Pr
As
Fe
a
Fe
b
c
a
b



c
PrOFeAs
175 K
P4/nmm
(220)T
Counts
4000
2000
0
20
25
30
35
2θ(degree)
95
96
2θ(degree)
Counts
d
5 K
Cmma
(100)M
(101)M
(102)M
(400)O
(040)O
6000
4000
2000
0
Counts
20
25
30
35
2θ(degree)
95
96
2θ(degree)
20.0
40.0
60.0
80.0
100.0
120.0
140.0
2θ(degree)

PrOFeAs

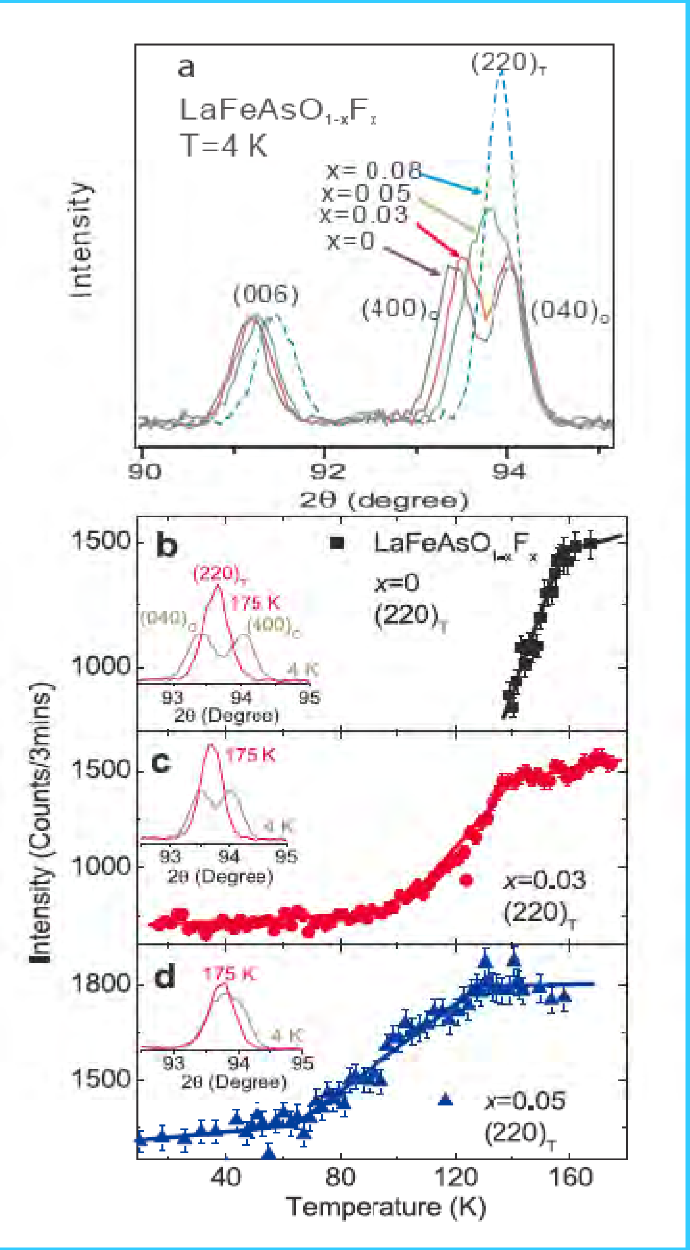


a
(220)T
175 K
(400)O
(040)O
4 K
94
95
96
2θ (Degree)
1200
800
Intensity (Counts/2mins)
PrFeAsO
(220)T
b
(101)M
TN(Pr)
TN(Fe)
25000
20000
Intensity (Counts/20mins)
(100)M
8000
6000
Intesnity (Counts/4mins)
10
20
Temperature (K)
0
40
80
120
160
200
Temperature (K)

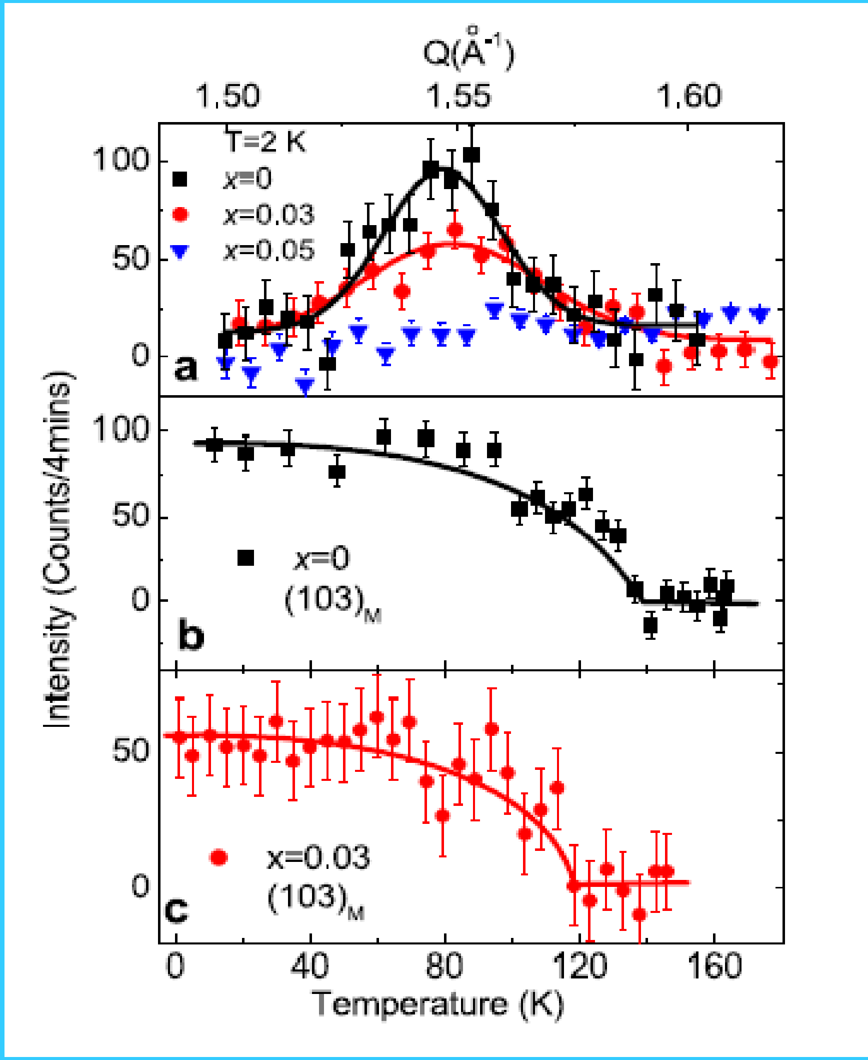
Doping Dependence of La(O,F)FeAs

- Doping Evolution of Antiferromagnetic Order and Structural Distortion in $LaFeAsO_{1-x}F_x$, Q. Huang, J. Zhao, J. W. Lynn, G. F. Chen, J. L. Lou, N. L. Wang, and P. Dai, Phys. Rev. B **78,** 054529 (2008).

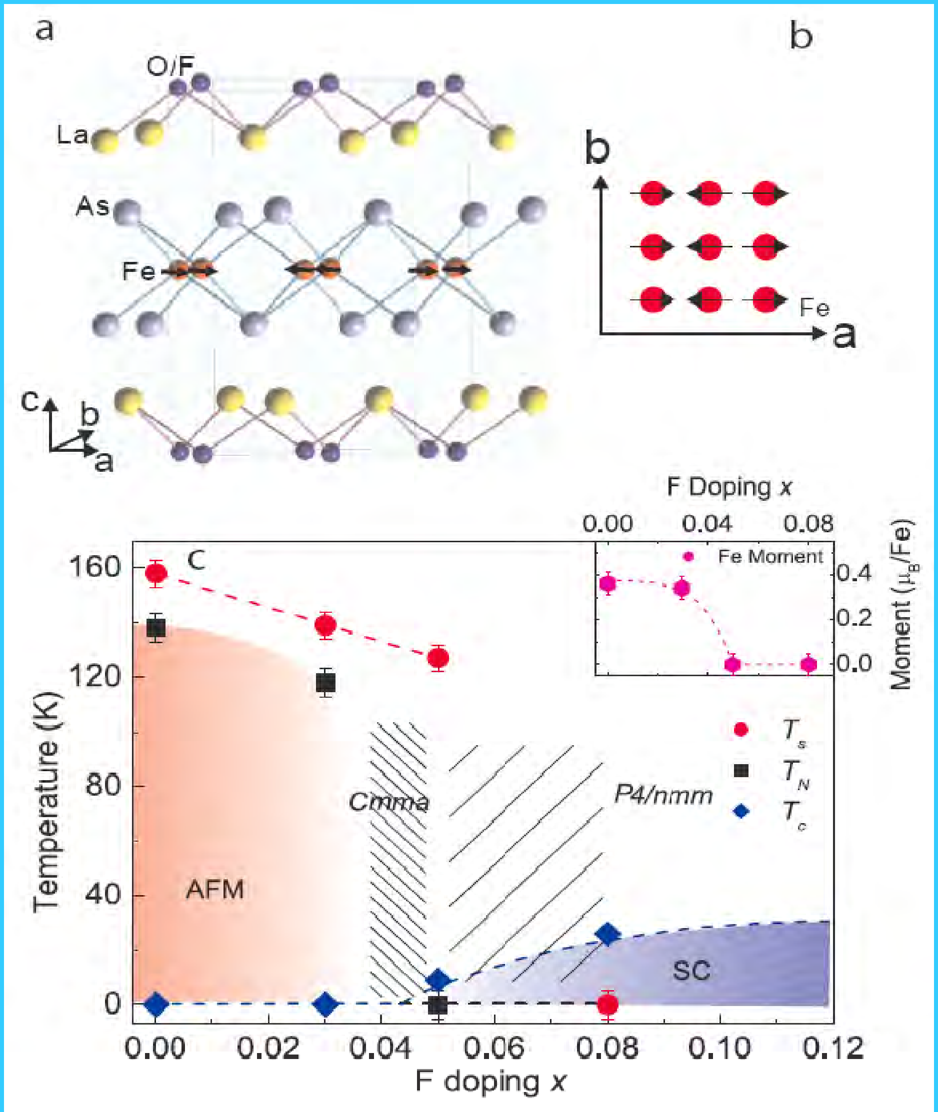
LaOFeAs Structural Phase Transition



LaOFeAs Magnetic Phase Transition



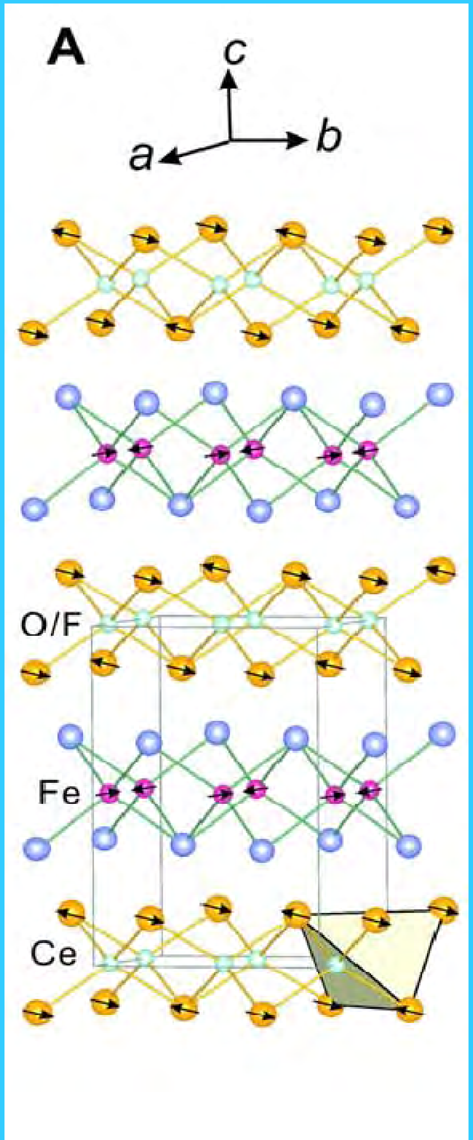
LaOFeAs Phase Diagram



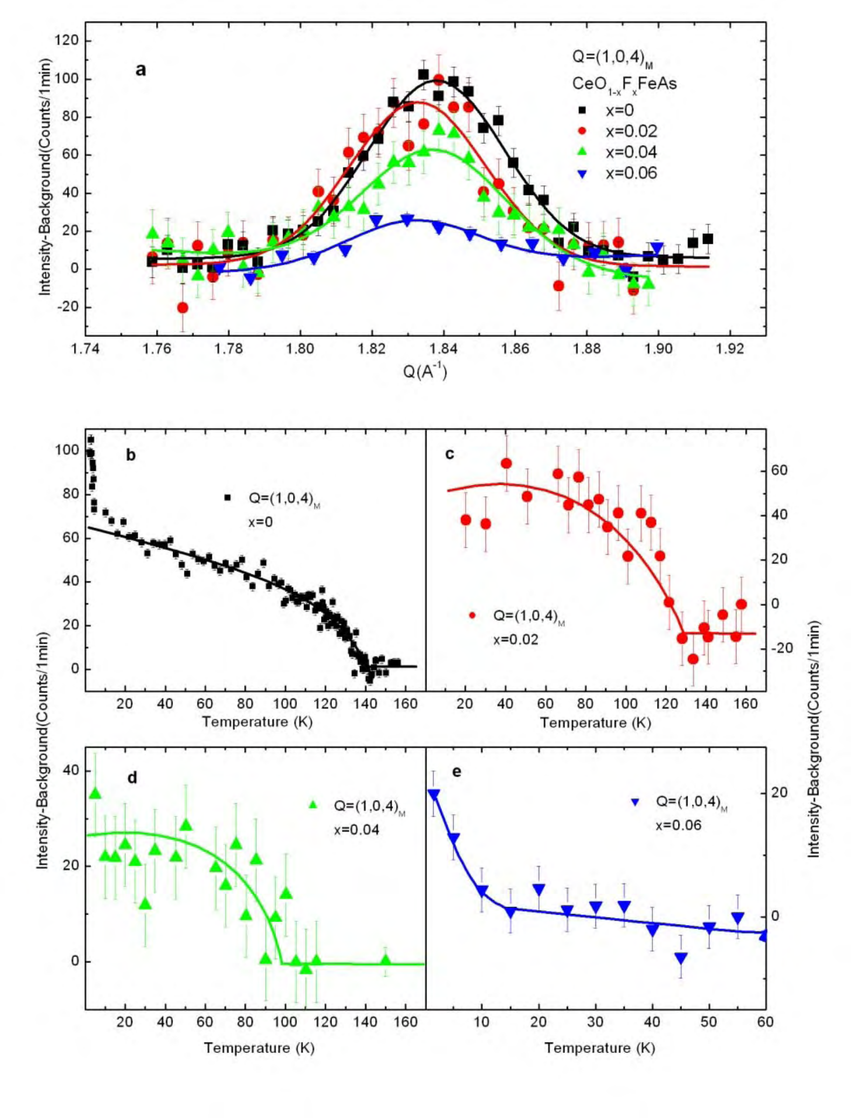
Doping Dependence of Ce(O,F)FeAs

- Structural and Magnetic Phase Diagram of $CeFeAsO_{1-x}F_x$ and its Relationship to High-Temperature Superconductivity, J. Zhao, Q. Huang, C. de al Cruz, S. Li, J. W. Lynn, Y. Chen, M. A. Green, G. F. Chen, G. Li, Z. C. Li, J. L. Luo, N. L. Wang, and P. Dai, Nature Materials (submitted).

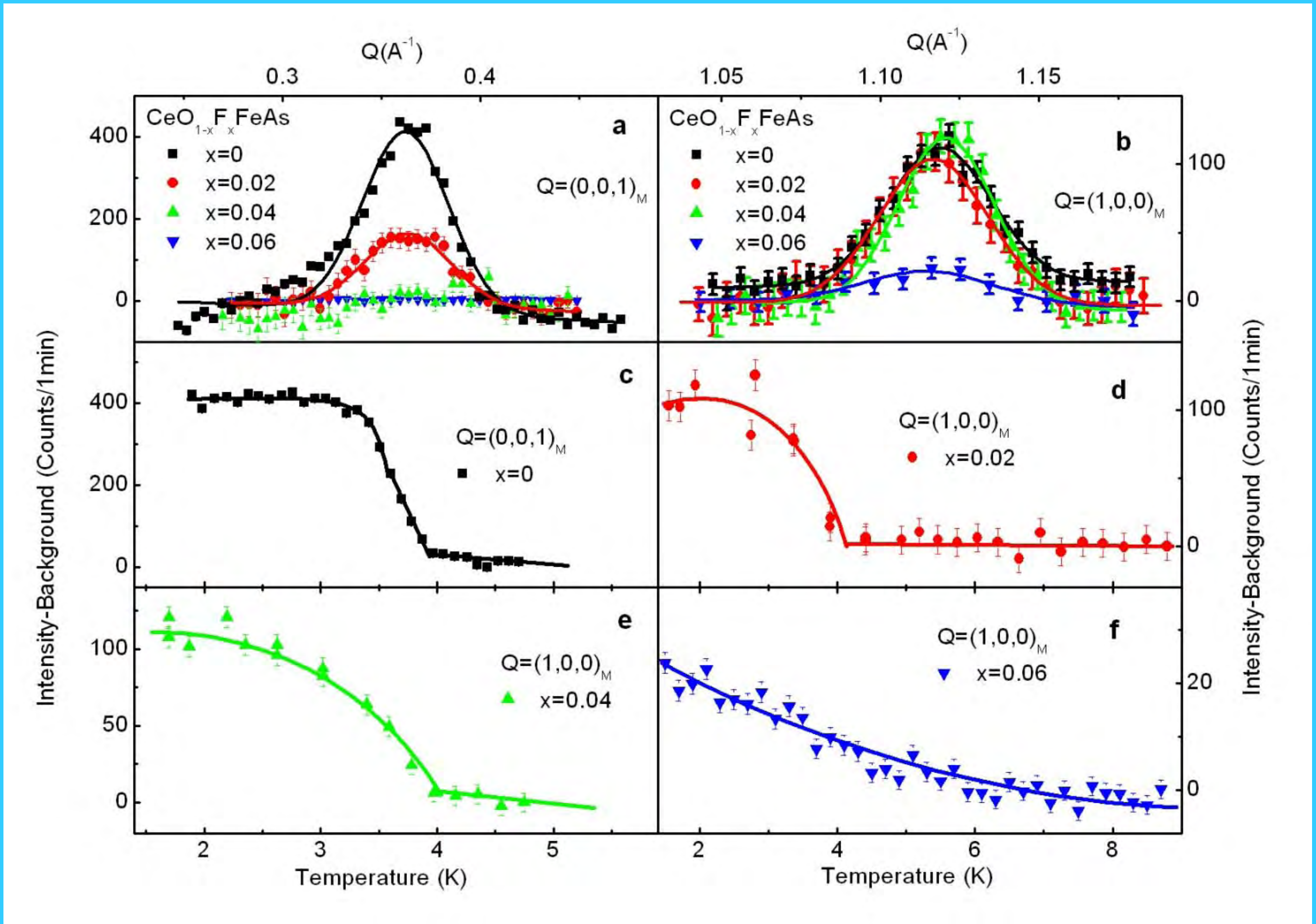
Magnetic Structure of Ce(O,F)FeAs



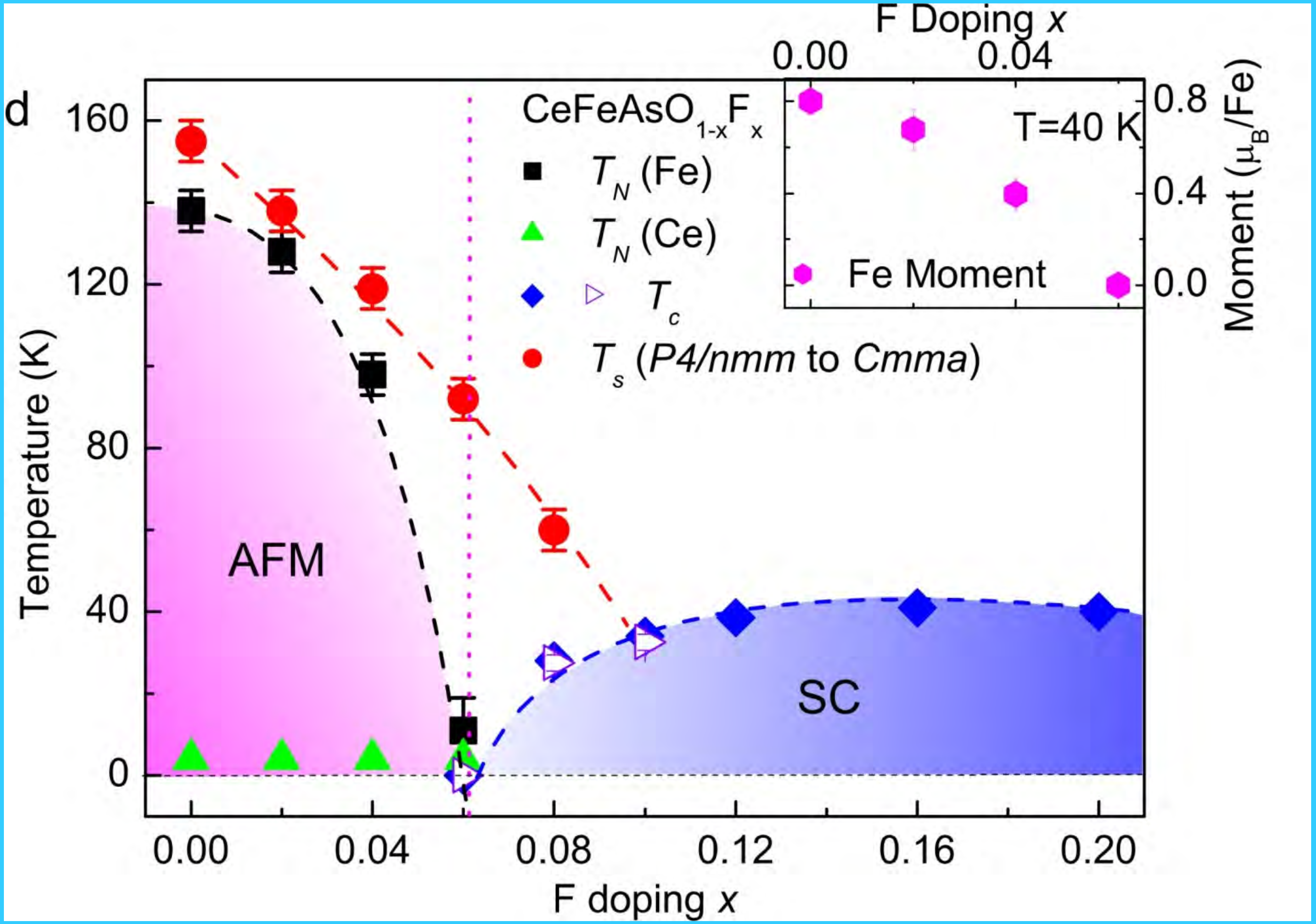
Fe Magnetic Structure of Ce(O,F)FeAs



Ce Magnetic Structure of Ce(O,F)FeAs

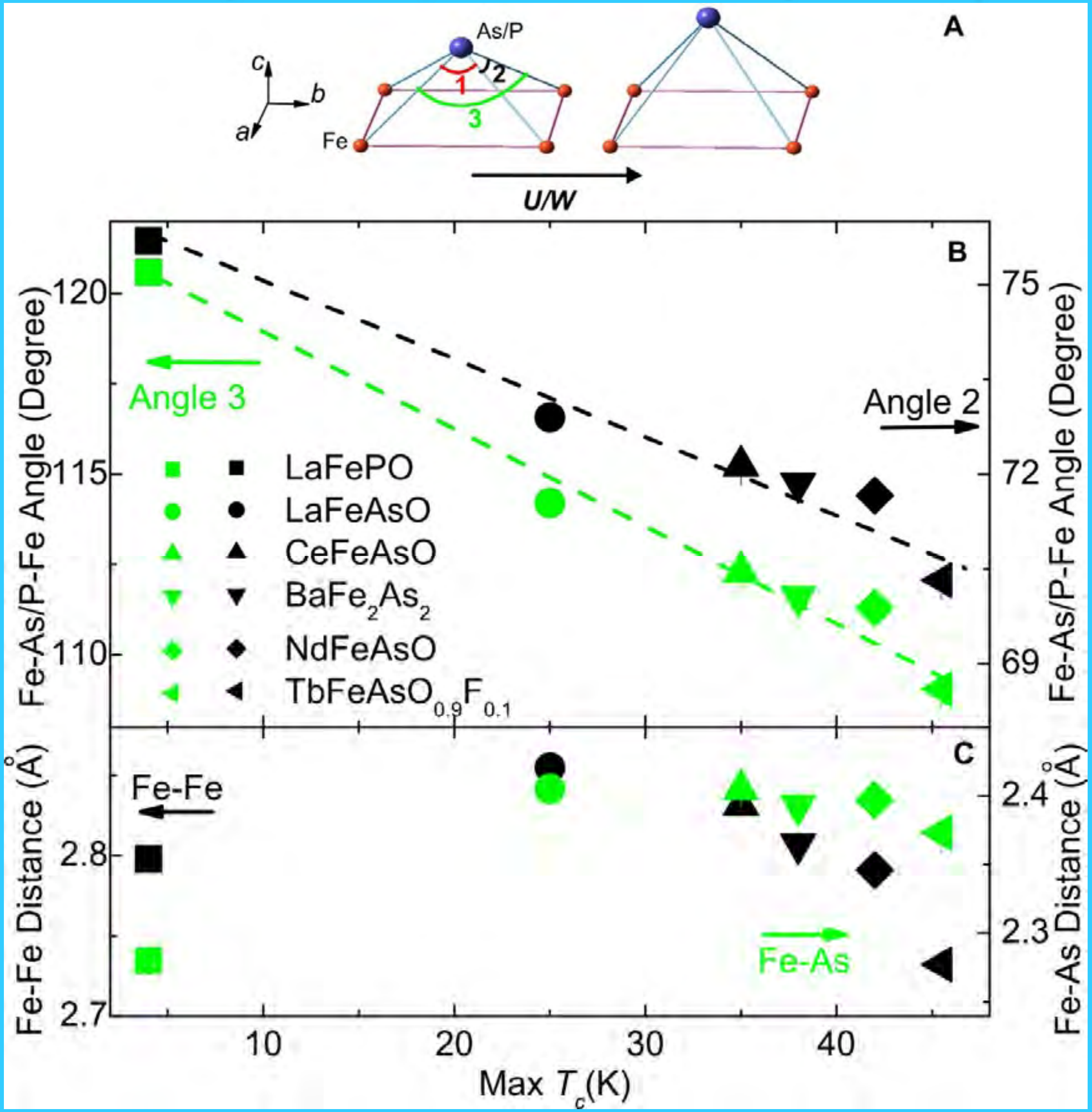


Phase Diagram of Ce(O,F)FeAs



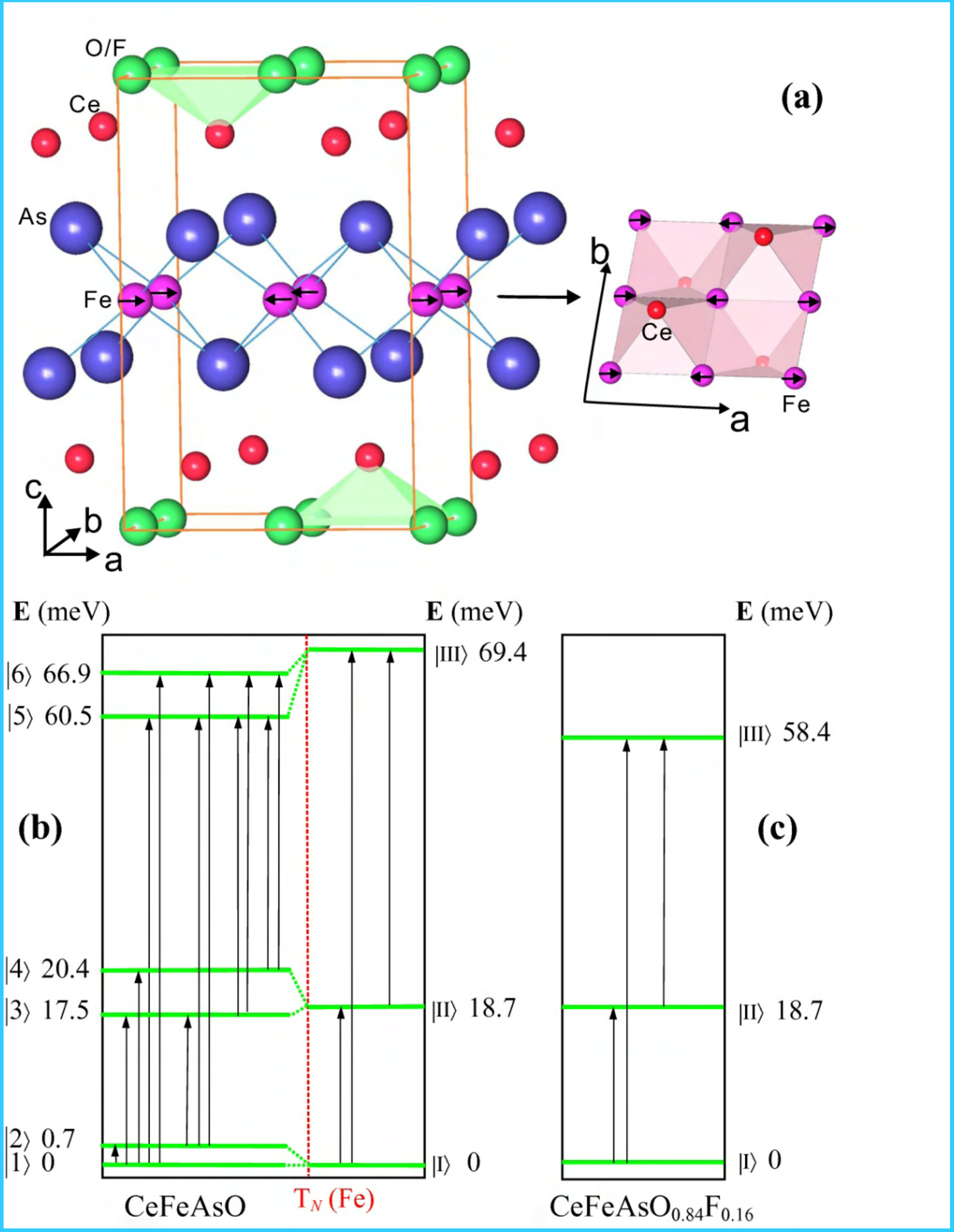
J. Zhao, Q. Huang, C. de la Cruz, S. Li, J. W. Lynn, Y. Chen, M. A. Green, G. F. Chen, G. Li, Z. Li, J. L. Luo, N. L. Wang, and P. Dai, Nature Materials (submitted).

General T_C dependence for optimally doped *RE*(O,F)FeAs



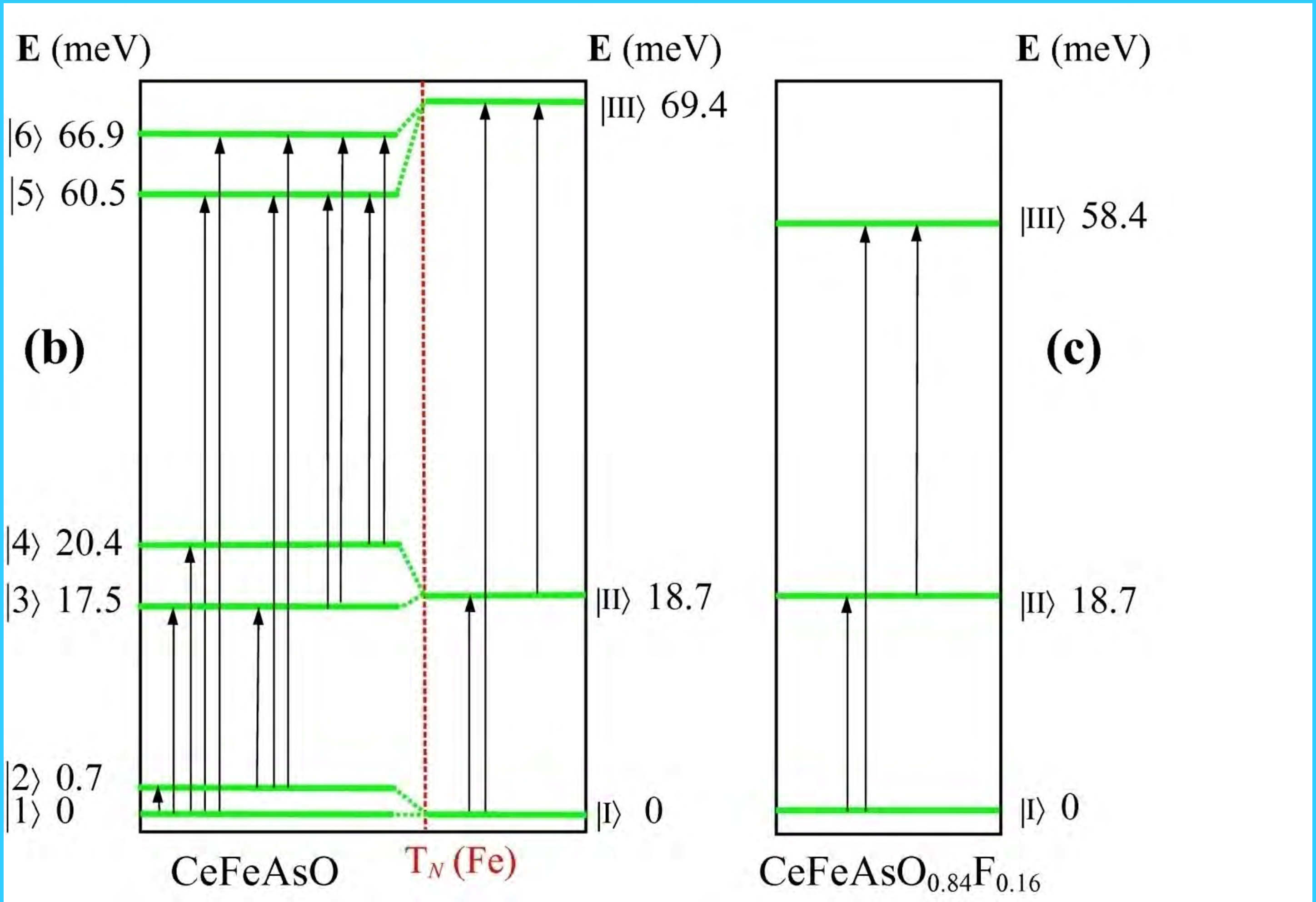
Ce Crystal Fields in $CeO_{1-x}Fe_xAs$

- The crystalline electric field as a probe for long range antiferromagnetic order and superconductivity in $CeFeAsO_{1-x}F_x$, S. Chi, D. T. Adroja, T. Guidi, R. Bewley, Shliang Li, Jun Zhao, J. W. Lynn, C. M. Brown, Y. Qiu, G. F. Chen, J. L. Lou, N. L. Wang, and Pengcheng Dai, (preprint).



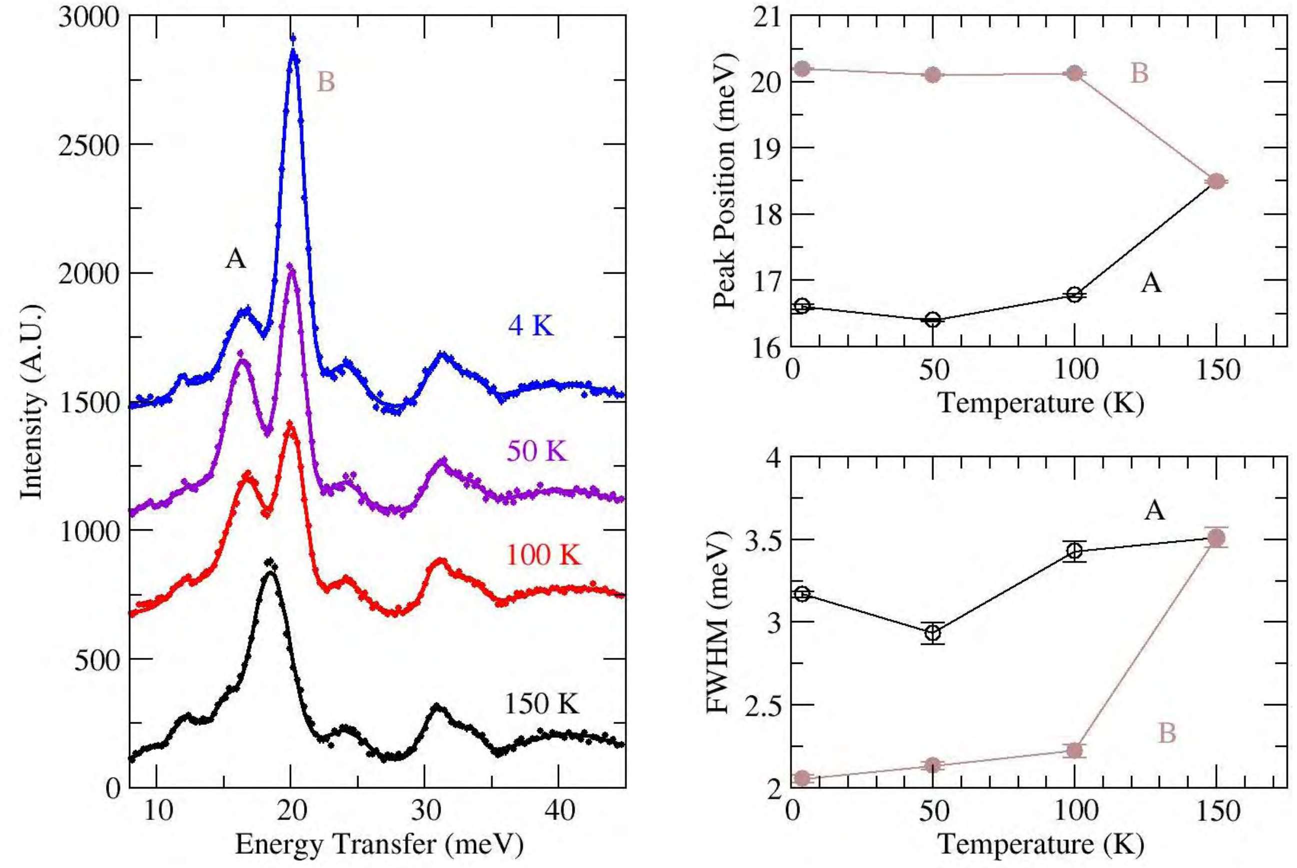
O/F
Ce
As
Fe
(a)
b
a
Ce
Fe
c
b
a
E (meV)
E (meV)
E (meV)
|6⟩ 66.9
|5⟩ 60.5
(b)
|4⟩ 20.4
|3⟩ 17.5
|2⟩ 0.7
|1⟩ 0
|III⟩ 69.4
|II⟩ 18.7
|I⟩ 0
|III⟩ 58.4
(c)
|II⟩ 18.7
|I⟩ 0
CeFeAsO
T_N (Fe)
CeFeAsO0.84F0.16

CeOFeAs

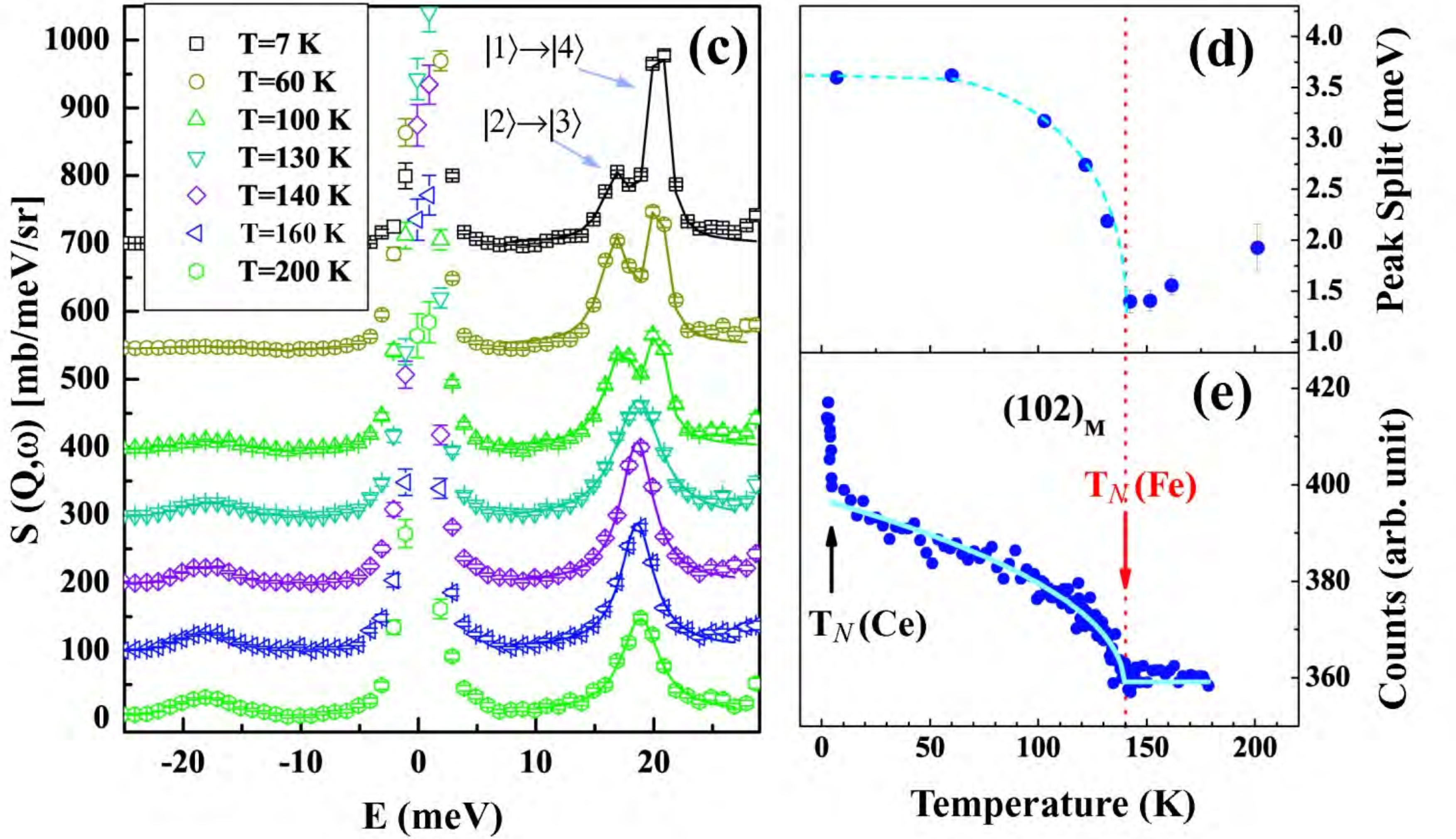


E (meV)
E (meV)
E (meV)
|6⟩ 66.9
|5⟩ 60.5
|4⟩ 20.4
|3⟩ 17.5
|2⟩ 0.7
|1⟩ 0
|III⟩ 69.4
|II⟩ 18.7
|I⟩ 0
(b)
CeFeAsO
T_N (Fe)
|III⟩ 58.4
|II⟩ 18.7
|I⟩ 0
(c)
$CeFeAsO_{0.84}F_{0.16}$

Crystal Field Levels in CeOFeAs

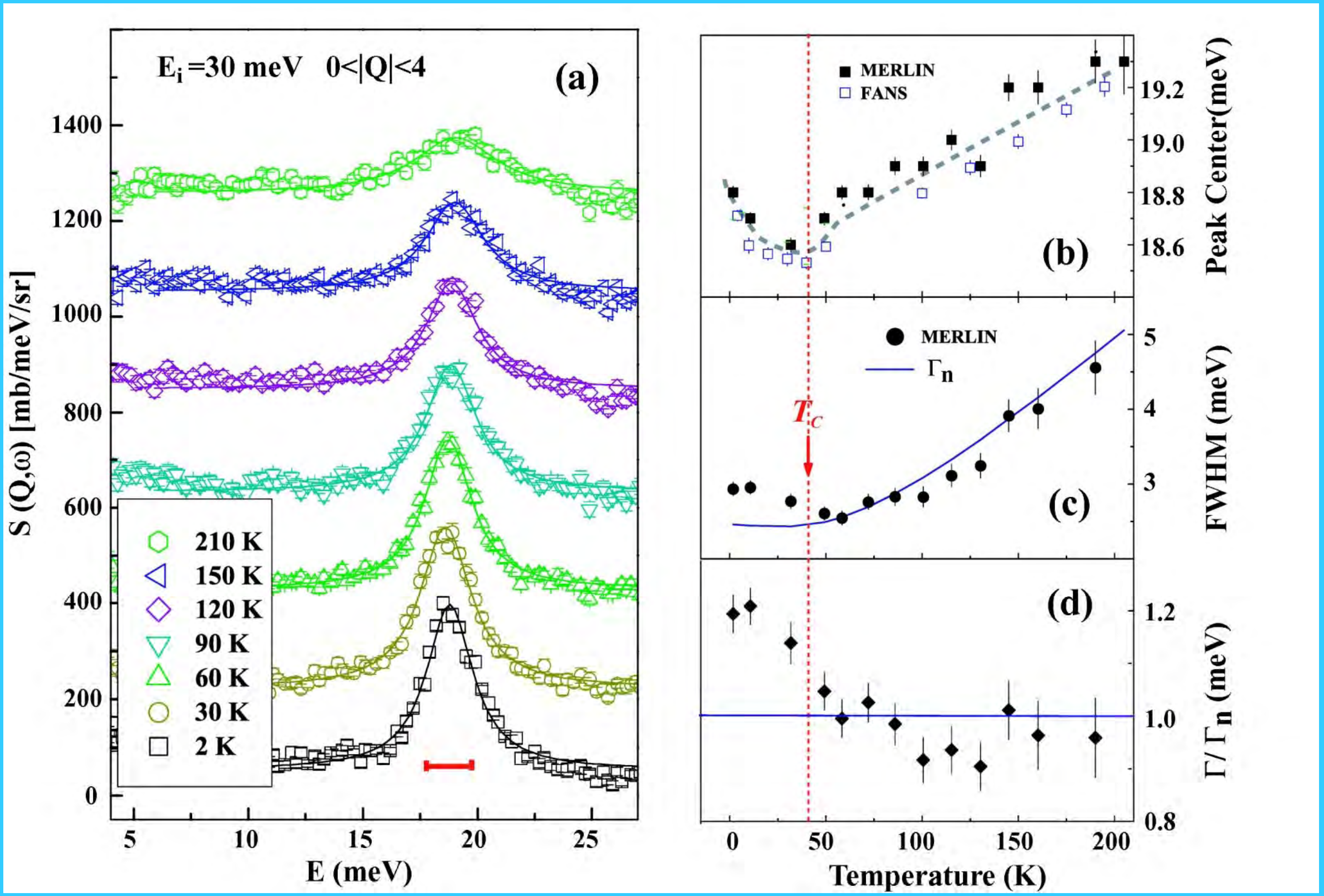


CeOFeAs

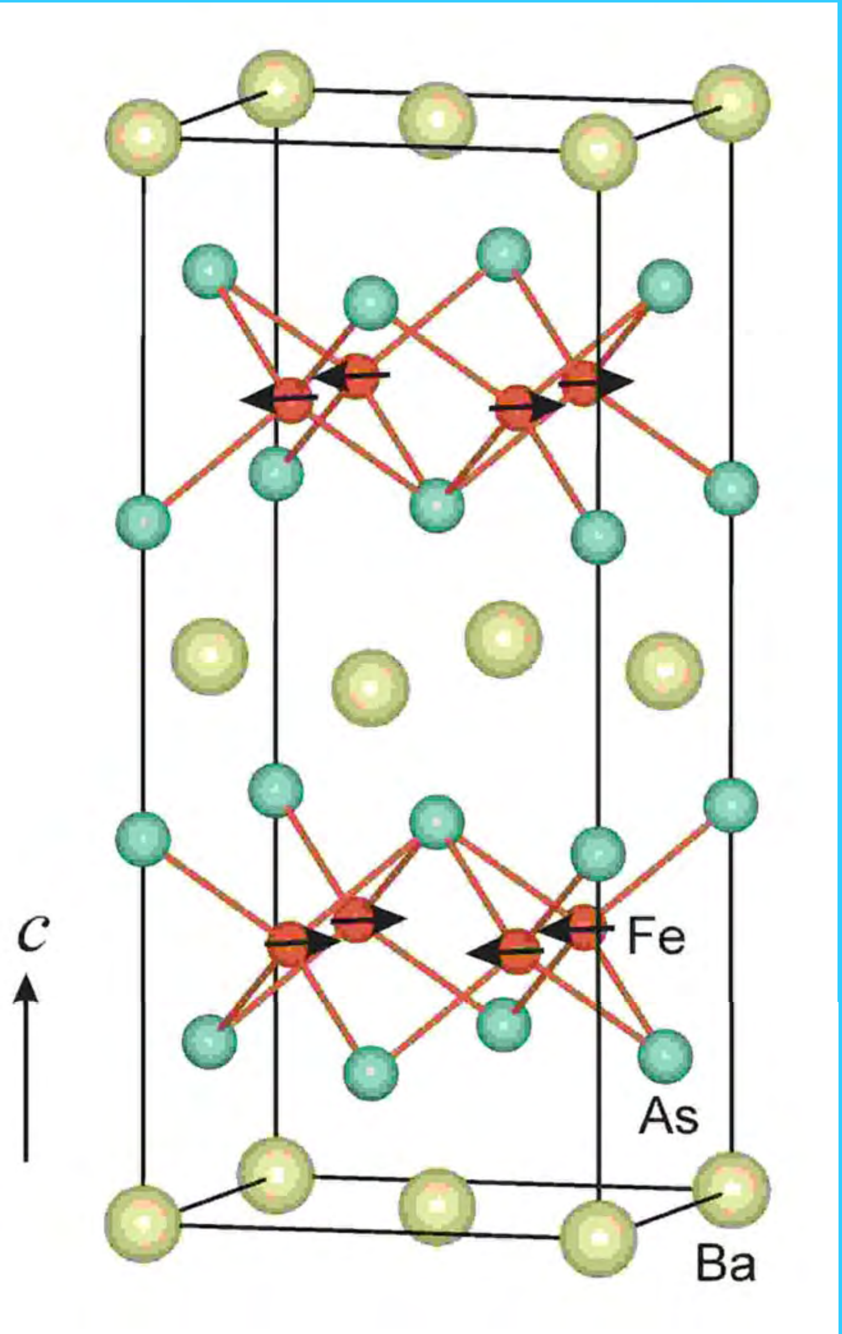


(c)
T=7 K
T=60 K
T=100 K
T=130 K
T=140 K
T=160 K
T=200 K
|1⟩→|4⟩
|2⟩→|3⟩
S (Q,ω) [mb/meV/sr]
E (meV)
(d)
Peak Split (meV)
(e)
(102)M
TN (Fe)
TN (Ce)
Counts (arb. unit)
Temperature (K)

Superconductor Linewidth vs. T

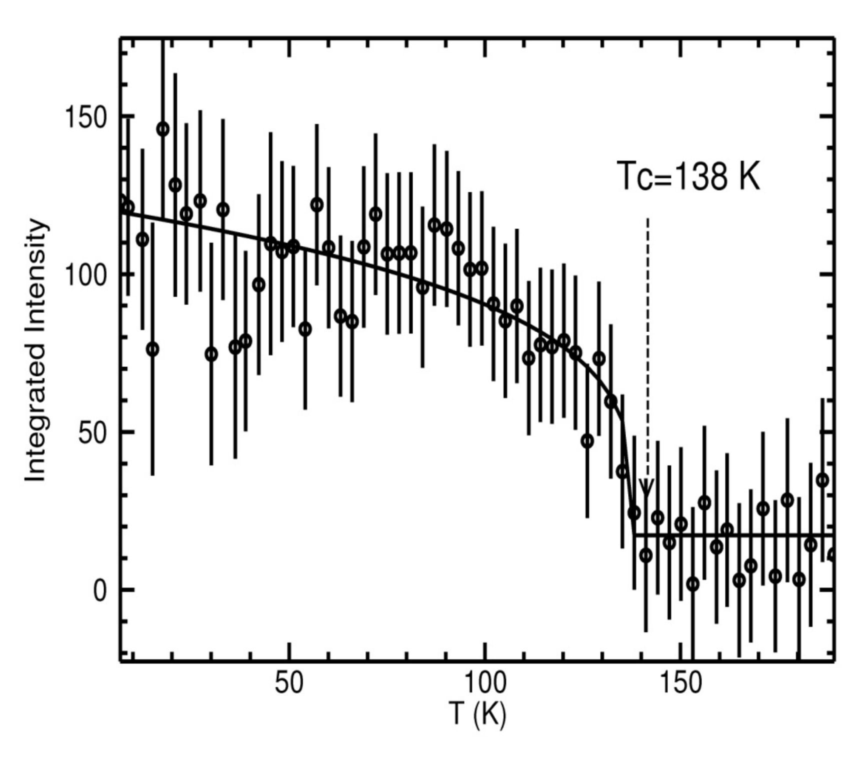


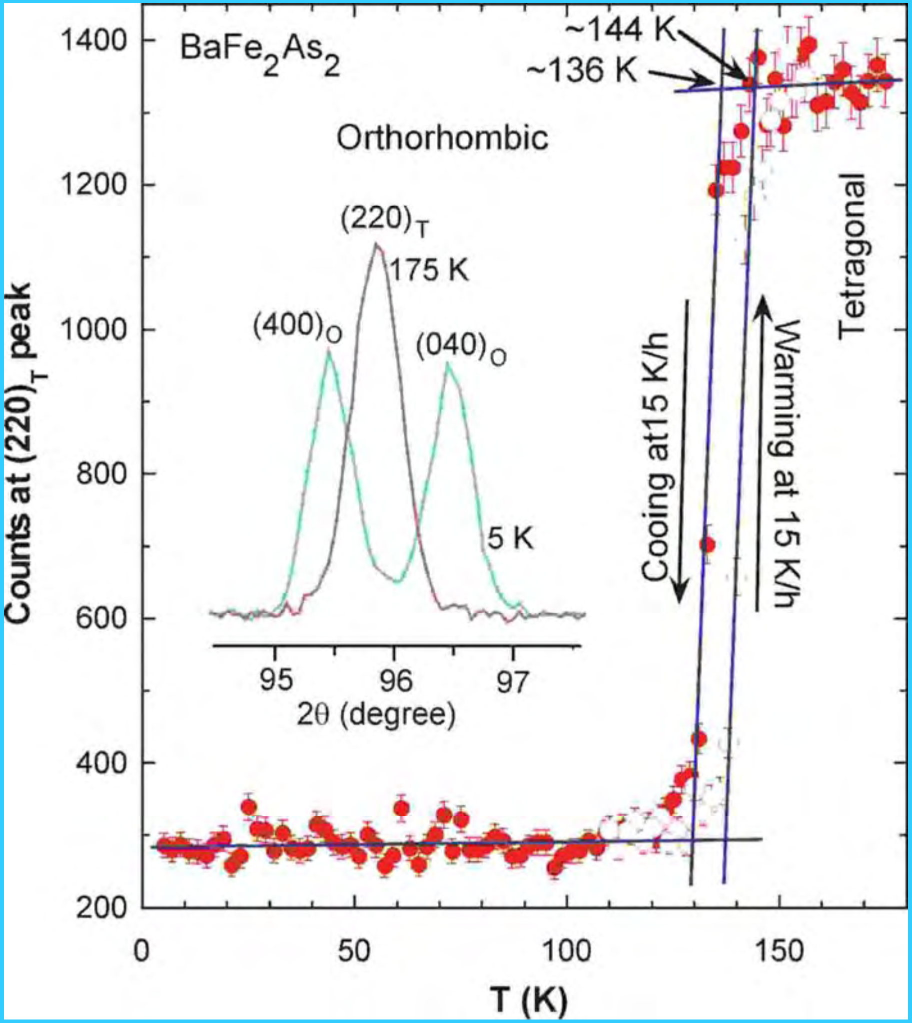
$(Ba, Ca, Sr)Fe_2As_2$ Systems



Magnetic and Crystal Structures of (Ba,Sr,Ca)Fe_2As_2

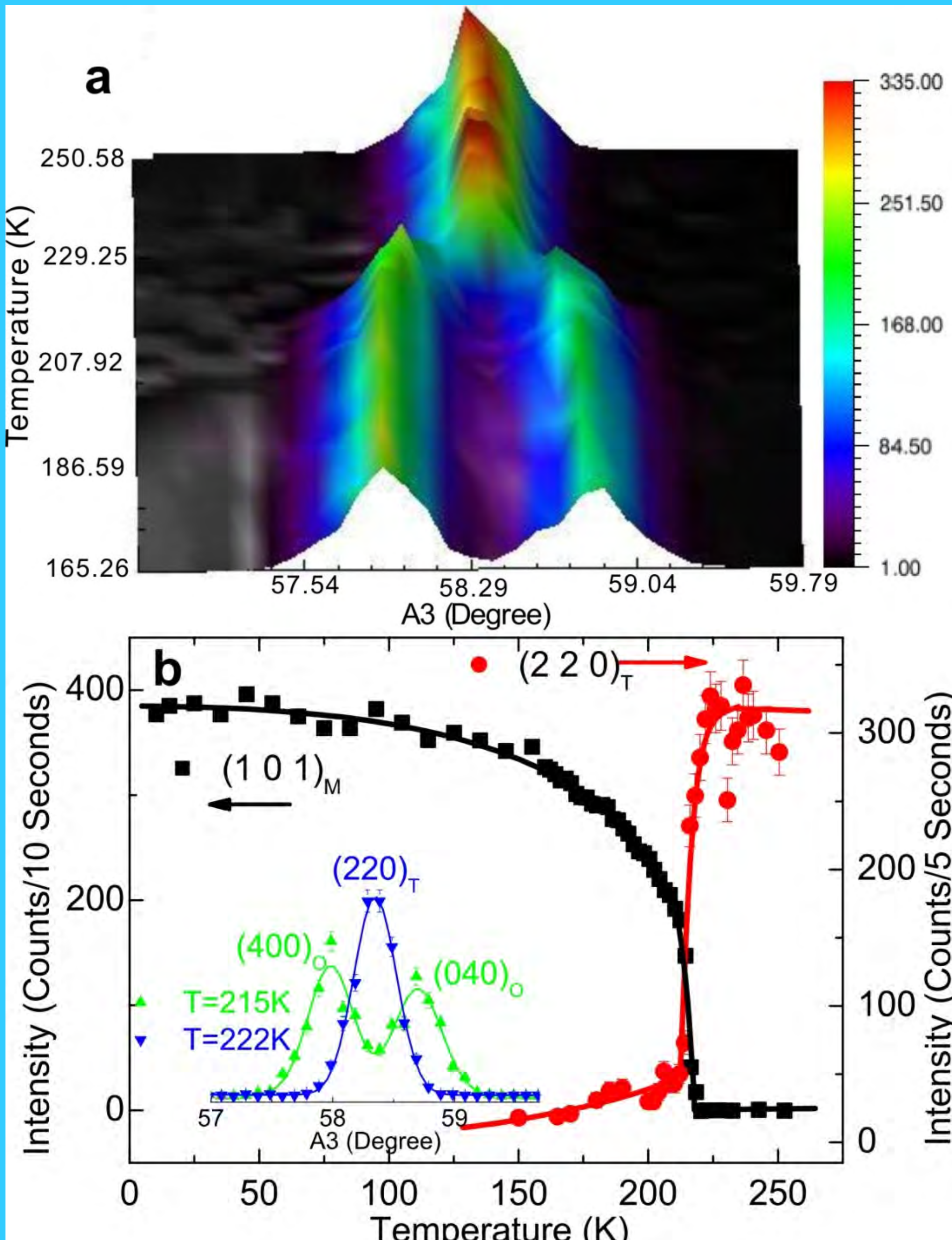
$BaFe_2As_2$

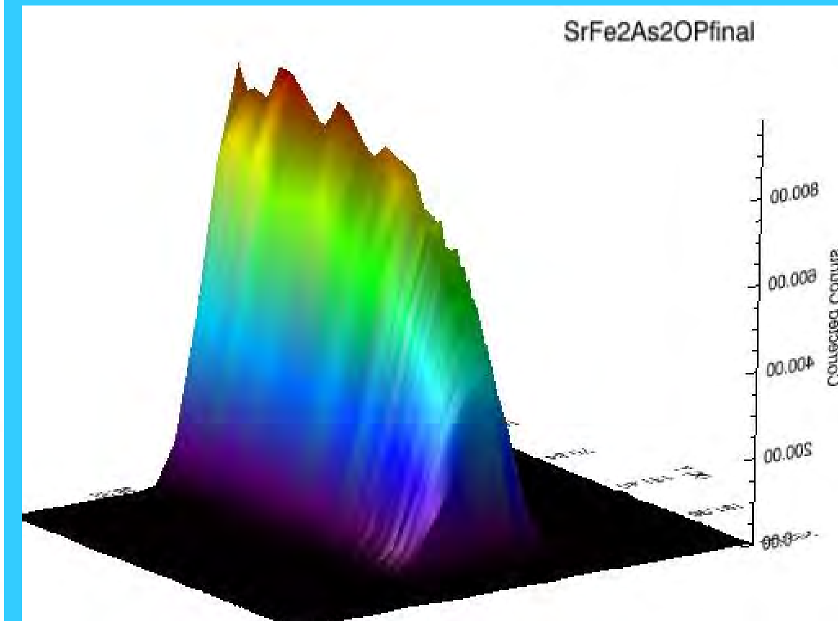




Q. Huang, Y. Qiu, W. Bao, J.W. Lynn, M. Green, T. Wu, G. Wu & X. H. Chen (submitted

Single Crystal $SrFe_2As_2$

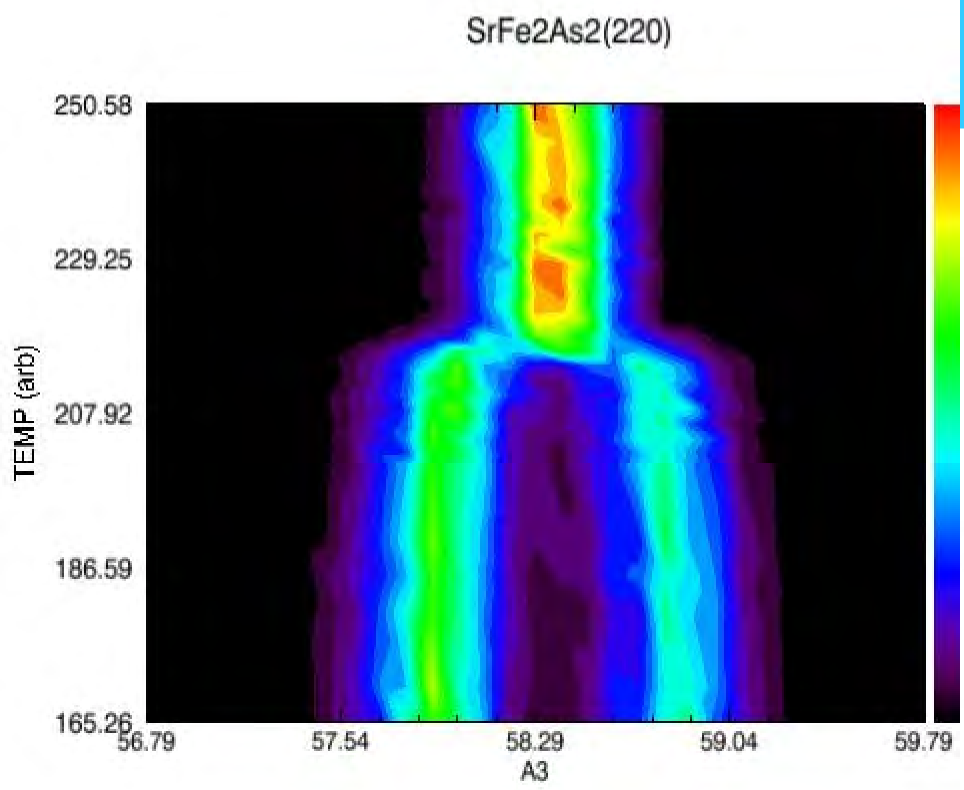


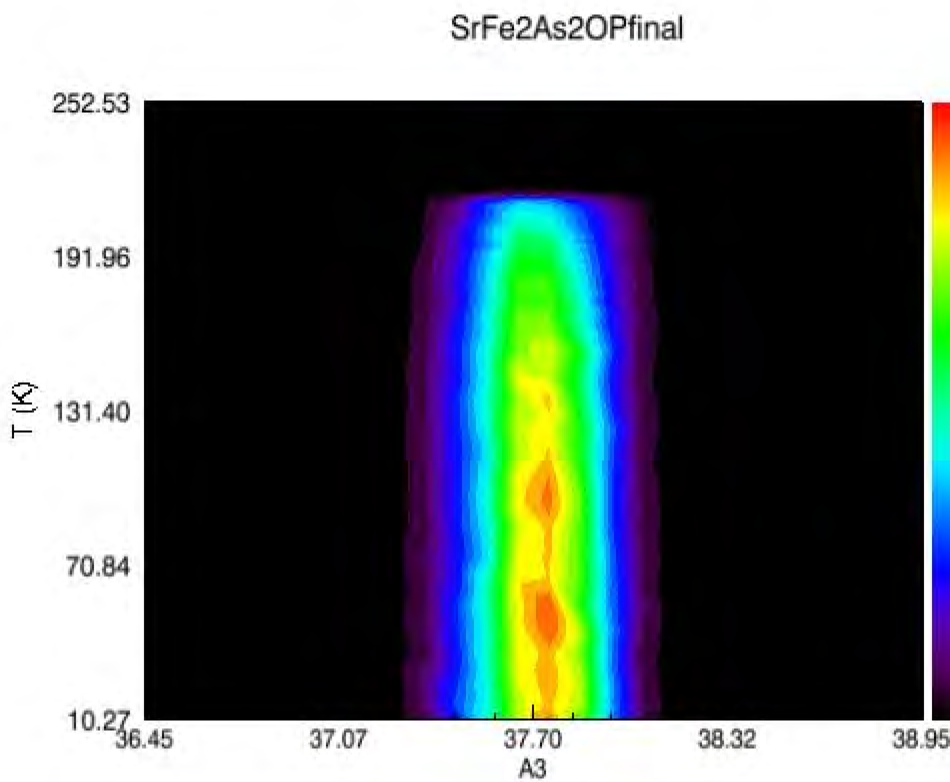


Spin and Lattice Structure of Single Crystal $SrFe_2As_2$, Jun Zhao, W. Ratcliff-II, J. W. Lynn, G. F. Chen, J. L. Luo, N. L. Wang, Jiangping Hu, and Pengcheng Dai, Phys. Rev. B (accepted).

$SrFe_2As_2$

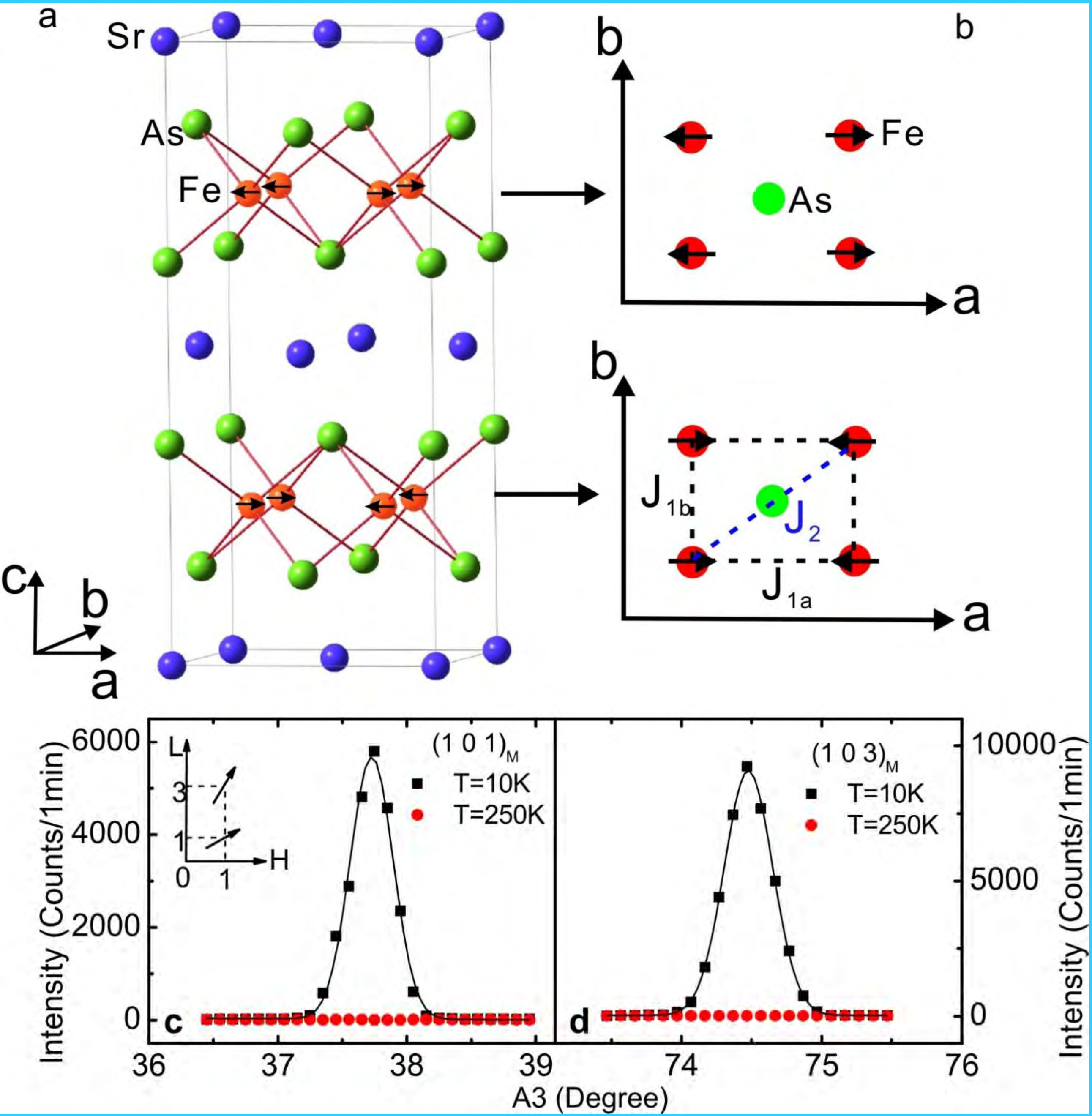
Magnetic





Structure

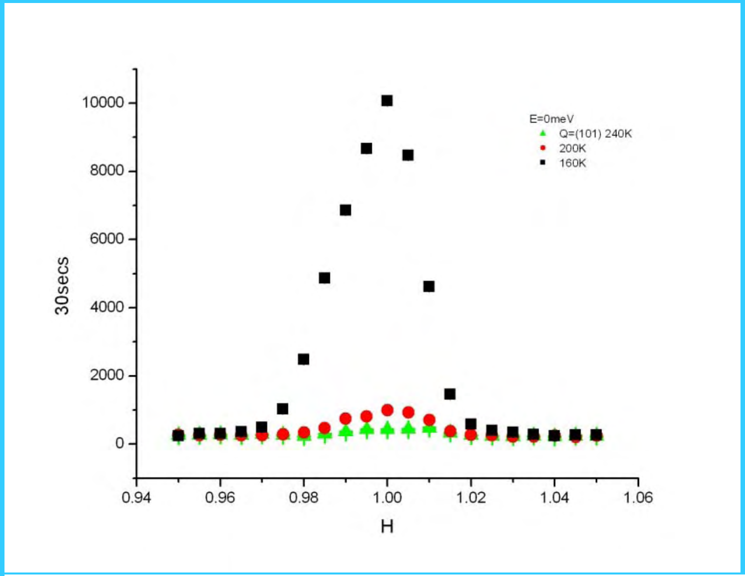
$SrFe_2As_2$

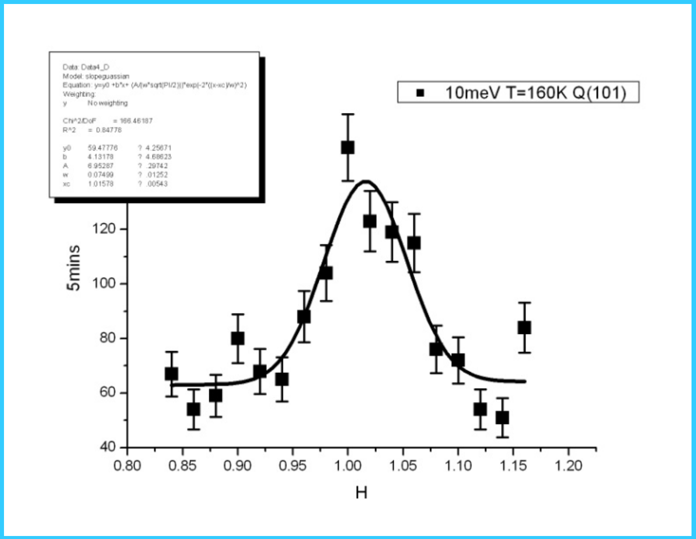


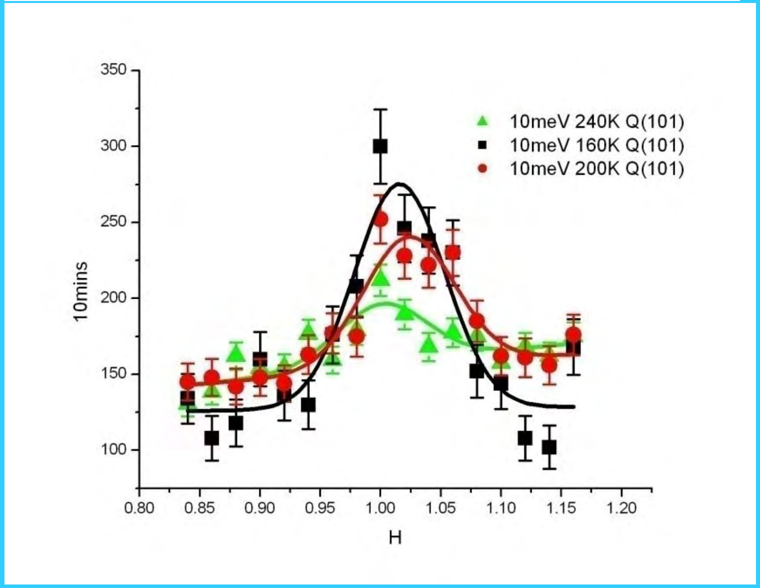
a
Sr
As
Fe
c
b
a
b
Fe
As
a
b
J1b
J2
J1a
a
(1 0 1)M
T=10K
T=250K
L
3
1
0
1
H
Intensity (Counts/1min)
6000
4000
2000
0
c
36
37
38
39
(1 0 3)M
T=10K
T=250K
d
74
75
76
10000
5000
0
Intensity (Counts/1min)
A3 (Degree)

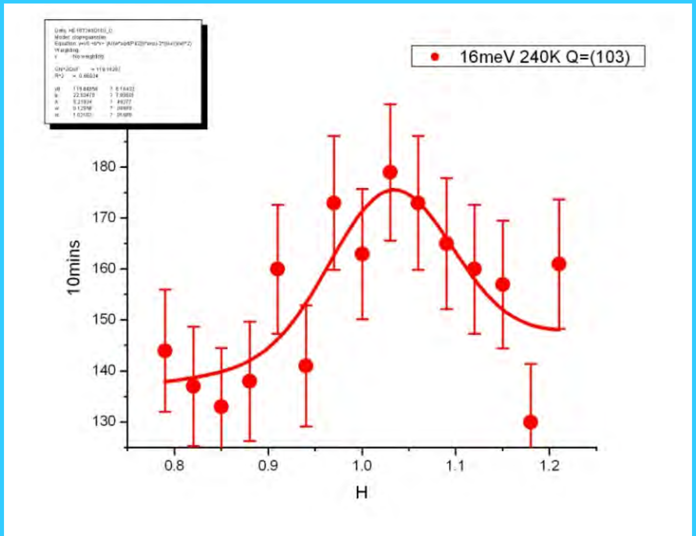
Inelastic Scattering
Spin Waves

Spin Waves In $SrFe_2As_2$

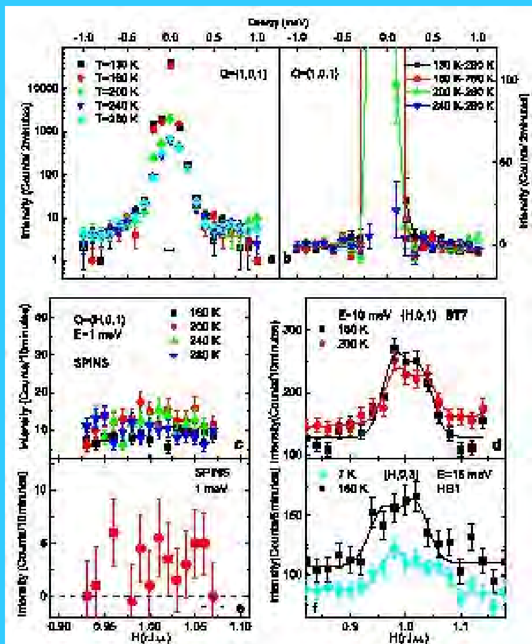


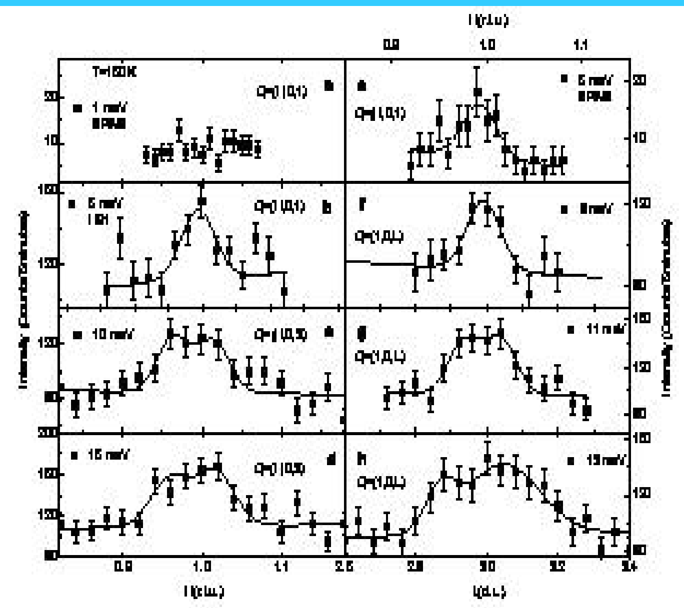


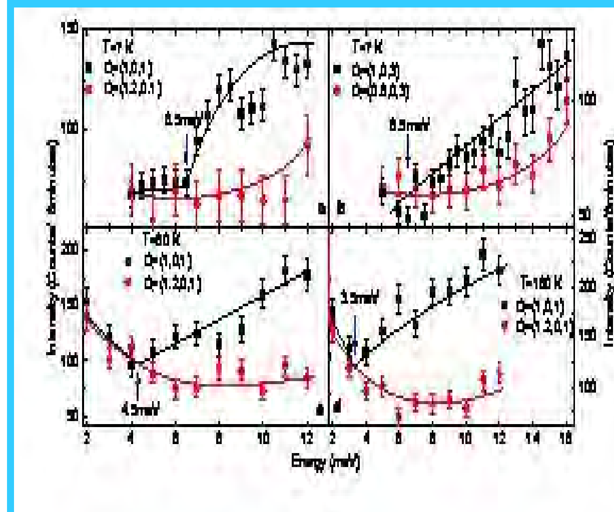




Spin Waves In $SrFe_2As_2$



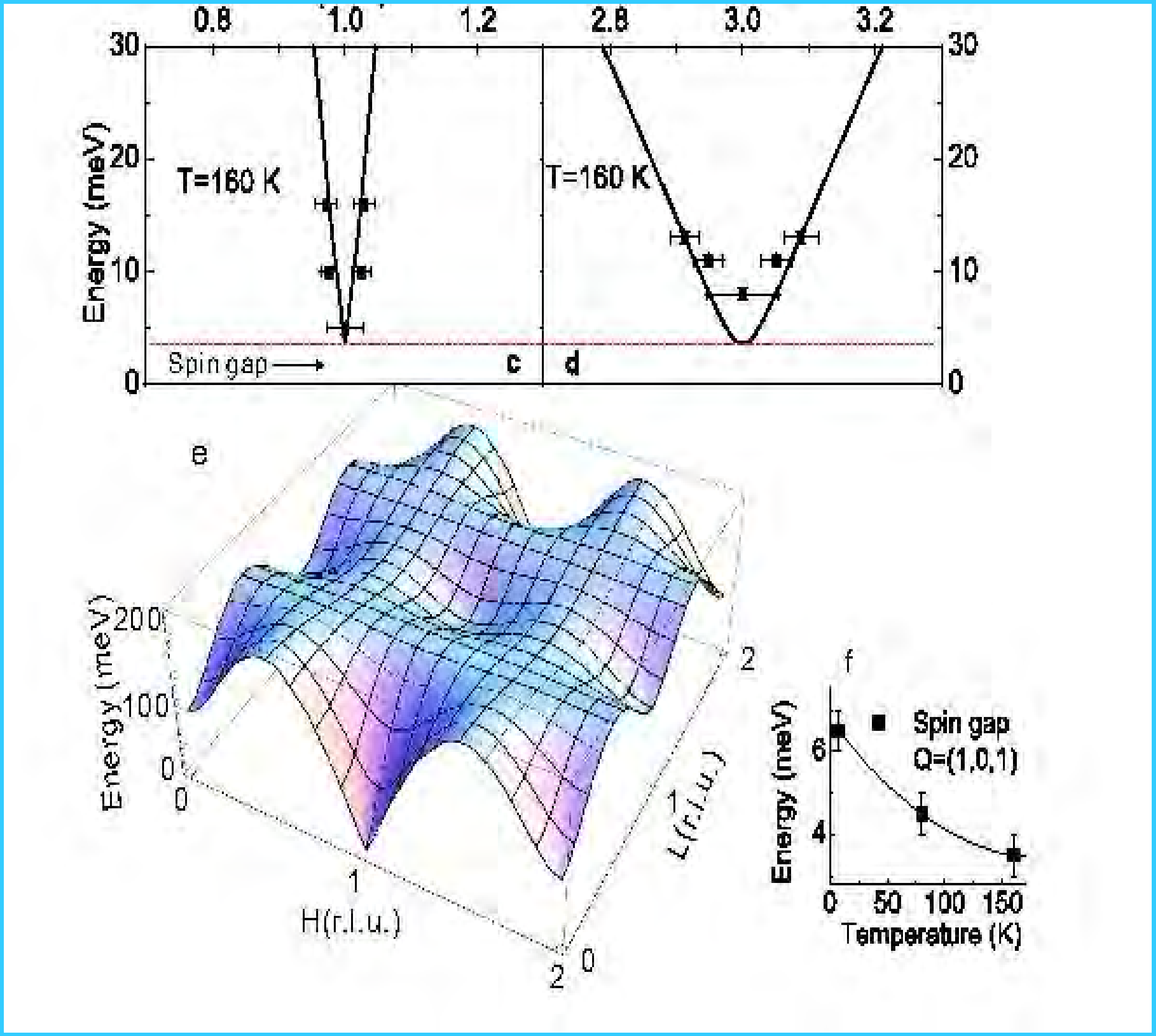




Low energy spin waves and magnetic interactions in $SrFe_2As_2$, Jun Zhao, Dao-Xin Yao, Shiliang Li, Tao Hong, Y. Chen, S. Chang, W. Ratcliff II, J. W. Lynn, H. A. Mook, G. F. Chen, J. L. Luo, N. L. Wang, E. W. Carlson, Jiangping Hu, and Pengcheng Dai, Phys. Rev. Lett. (submitted).

Gap

Spin Waves In $SrFe_2As_2$



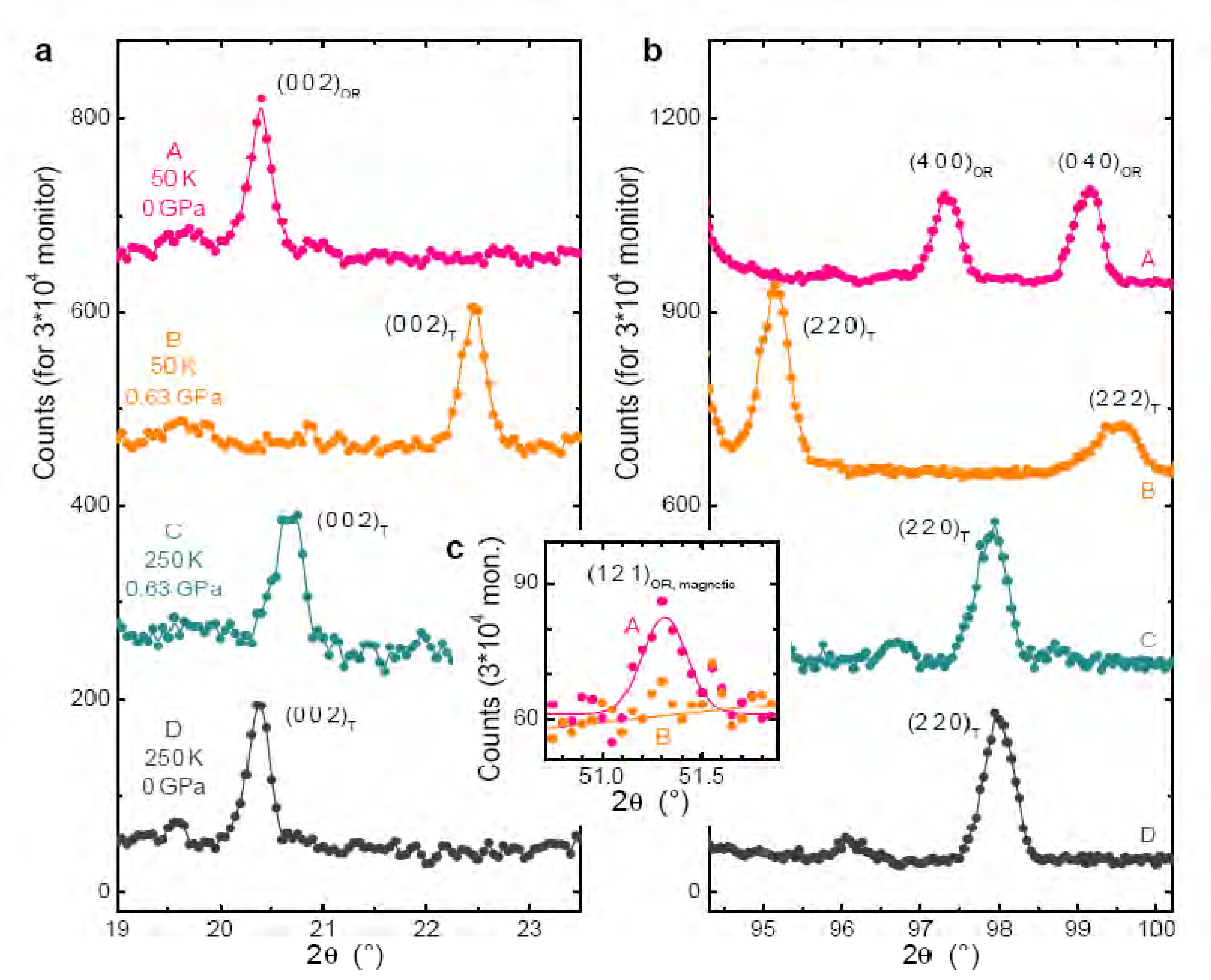
Low energy spin waves and magnetic interactions in $SrFe_2As_2$, Jun Zhao, Dao-Xin Yao, Shiliang Li, Tao Hong, Y. Chen, S. Chang, W. Ratcliff II, J. W. Lynn, H. A. Mook, G. F. Chen, J. L. Luo, N. L. Wang, E. W. Carlson, Jiangping Hu, and Pengcheng Dai, Phys. Rev. Lett. (submitted).

$CaFe_2As_2$ System

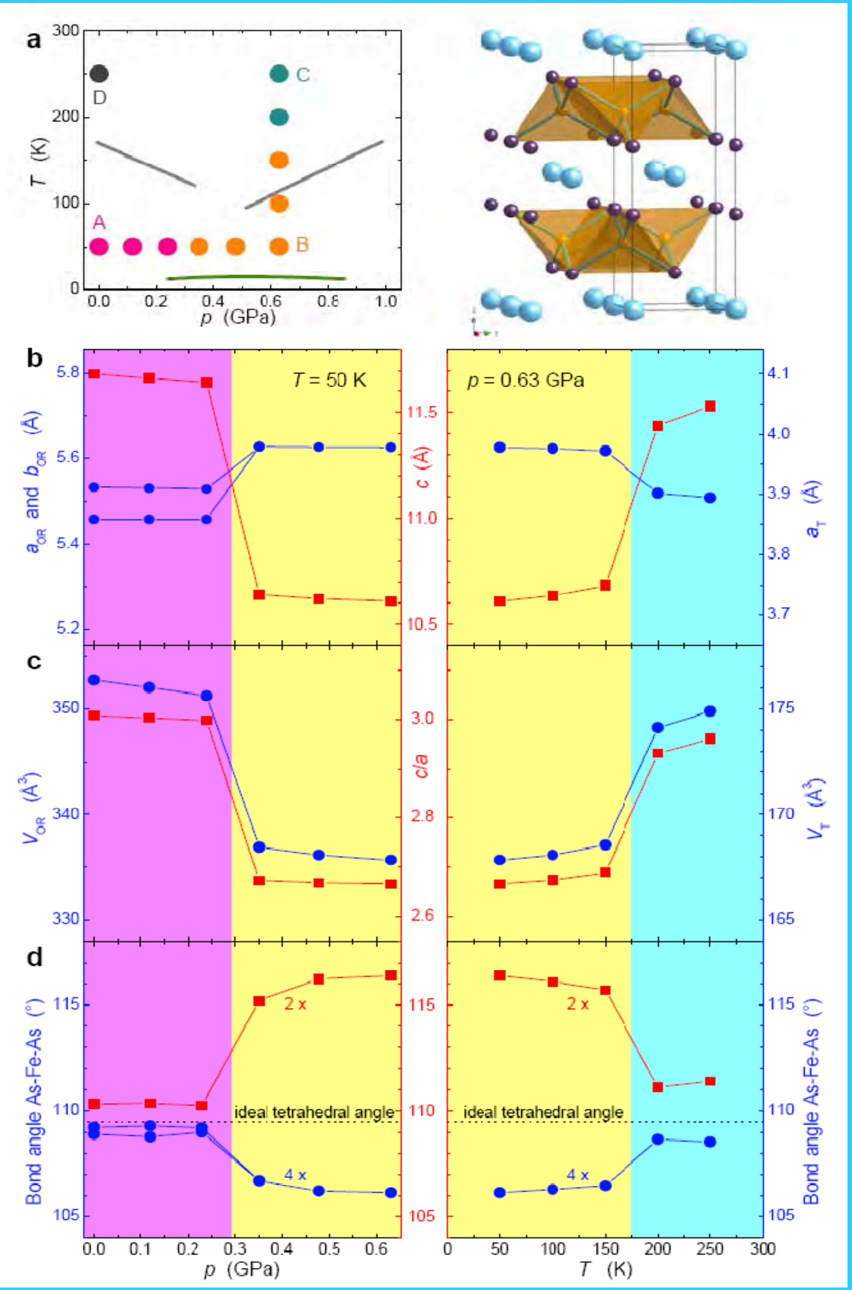
- Squeezing the Magnetism out of Superconducting $CaFe_2As_2$—a Volume and Moment "Collapsed" Superconducting Phase,

  A. Kreyssig, M. A. Green, Y. B. Lee, G. D. Samolyuk, P. Zajdel, J. W. Lynn, S. L. Bud'ko, M. S. Torikachvili, N. Ni, S. Nandi, J. Leão, S. J. Poulton, D. N. Argyriou, B. N. Harmon, P. C. Canfield, R. J. McQueeney, and A. I. Goldman, Nature (submitted).

$CaFe_2As_2$

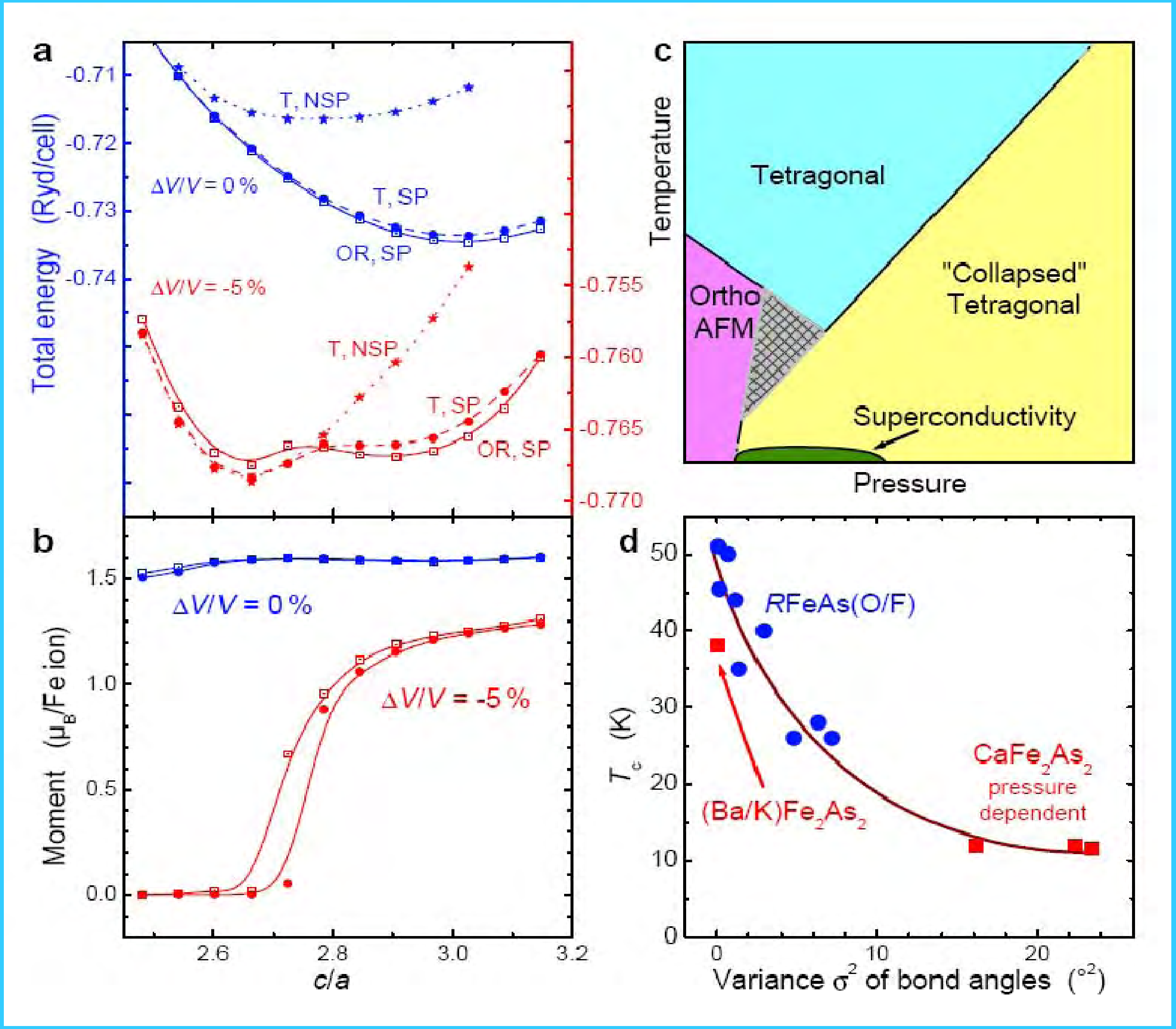

a
b
c
(0 0 2)OR
(0 0 2)T
(0 0 2)T
(0 0 2)T
A
50 K
0 GPa
B
50 K
0.63 GPa
C
250 K
0.63 GPa
D
250 K
0 GPa
Counts (for 3*10^4 monitor)
800
600
400
200
0
19
20
21
22
23
2θ (°)
(4 0 0)OR
(0 4 0)OR
(2 2 0)T
(2 2 2)T
(2 2 0)T
(2 2 0)T
1200
900
600
95
96
97
98
99
100
(1 2 1)OR, magnetic
Counts (3*10^4 mon.)
90
60
51.0
51.5

$CaFe_2As_2$



a
D
C
A
B
T (K)
p (GPa)
b
T = 50 K
p = 0.63 GPa
a_OR and b_OR (Å)
c (Å)
a_T (Å)
c
V_OR (Å³)
c/a
V_T (Å³)
d
Bond angle As-Fe-As (°)
2 x
4 x
ideal tetrahedral angle
p (GPa)
T (K)

$CaFe_2As_2$


a
Total energy (Ryd/cell)
-0.71
-0.72
-0.73
-0.74
T, NSP
ΔV/V = 0 %
T, SP
OR, SP
ΔV/V = -5 %
T, NSP
T, SP
OR, SP
-0.755
-0.760
-0.765
-0.770
b
Moment (μB/Fe ion)
1.5
1.0
0.5
0.0
ΔV/V = 0 %
ΔV/V = -5 %
2.6
2.8
3.0
3.2
c/a
c
Temperature
Tetragonal
Ortho
AFM
"Collapsed"
Tetragonal
Superconductivity
Pressure
d
Tc (K)
50
40
30
20
10
0
RFeAs(O/F)
CaFe2As2
pressure
dependent
(Ba/K)Fe2As2
0
10
20
Variance σ2 of bond angles (°2)

Overall Summary

- Magnetic Superconductors have a rich and interesting history, ranging from "***shouldn't have magnetic spins in the lattice***" to "***must have magnetic spins in* the lattice**"
- For Cuprate Superconductors, the Cu spin dynamics provide the needed high energy scale. The magnetic resonance is directly tied to the superconducting state for both hole and electron-doped cuprates.
- the iron-based superconductors exhibit a similar phase diagram to the cuprates. The 'parent' systems exhibit a ubiquitous structural transition, below which long range antiferromagnetic occurs. The magnetic energetics is ~200 meV, also similar to the cuprates. The possible role of spin fluctuations in the superconducting pairing is to be determined

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