Institute of Physics, CAS

Pressure-induced magnetic quantum critical point and unconventional superconductivity in CrAs and MnP

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Collaborators

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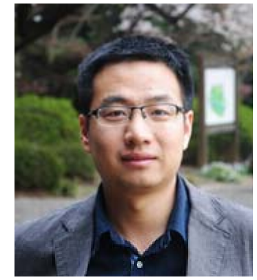

Y. Uwatoko, K. Matsubayashi

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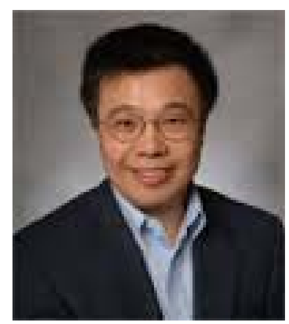
Q. Si
R. Yu



OUTLINE

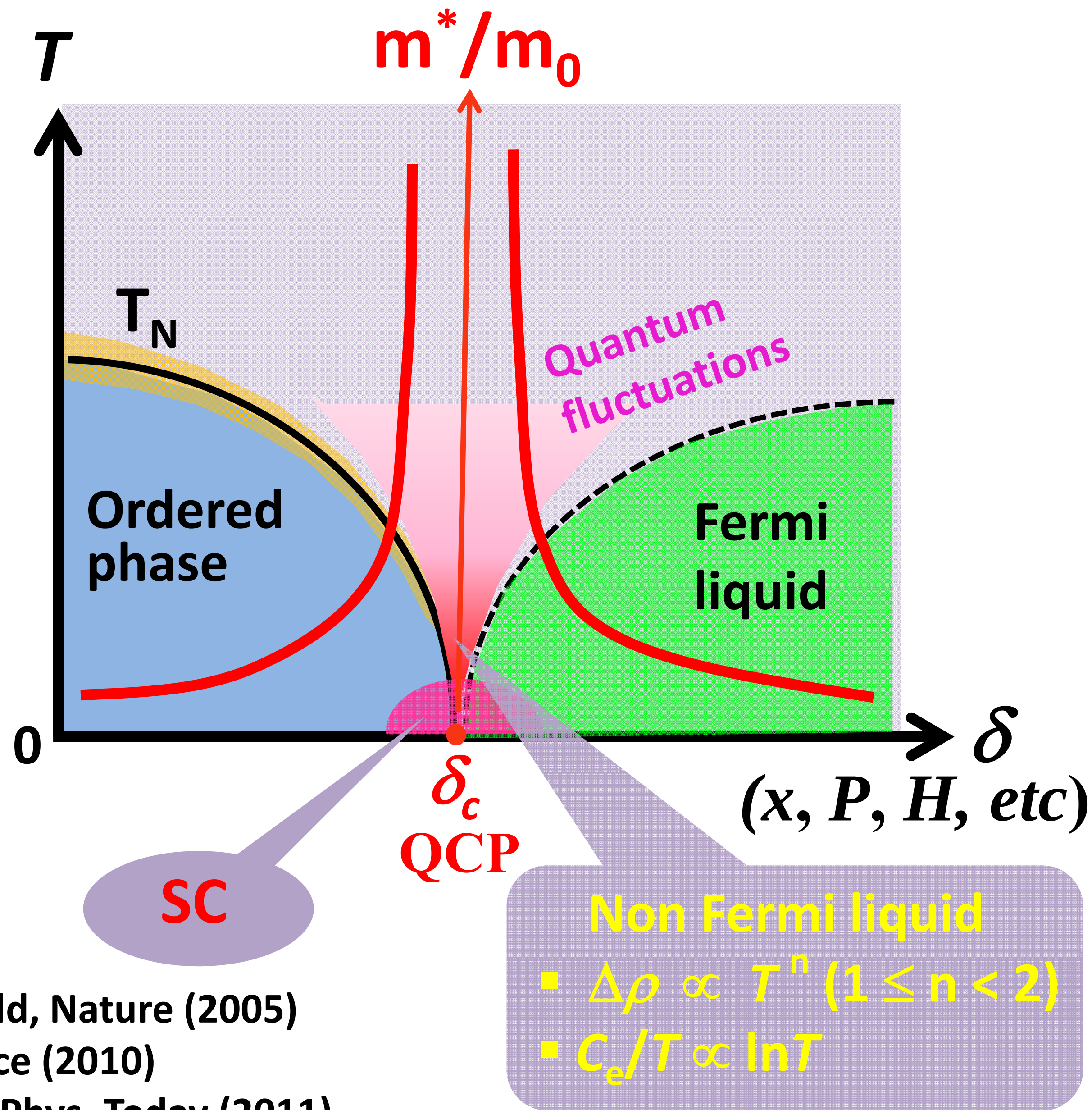
1 QCP and unconventional SC

2 P-induced SC in CrAs

3 P-induced SC in MnP

4 Conclusion and outlooks

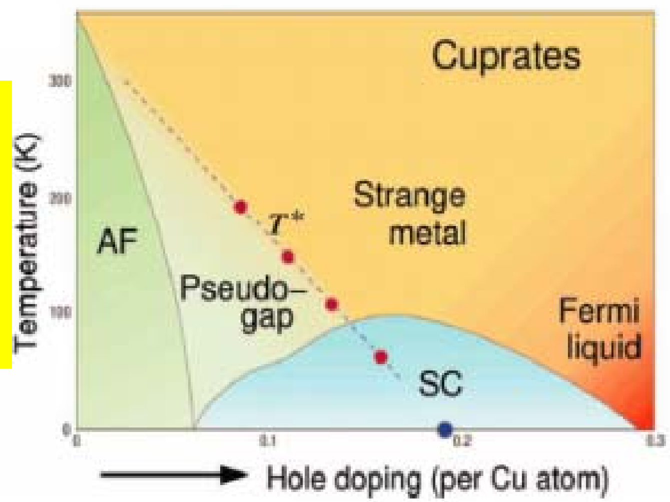
Quantum critical point (QCP)

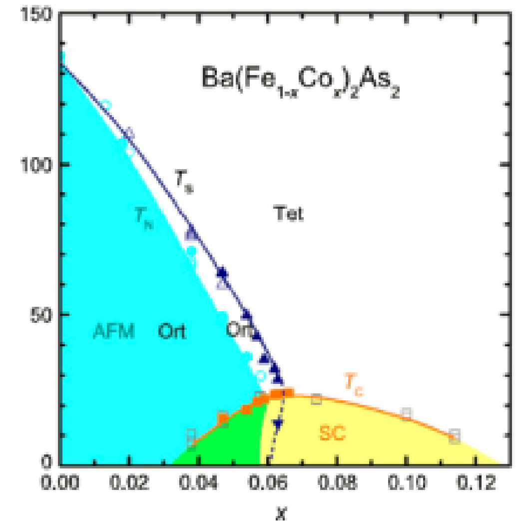


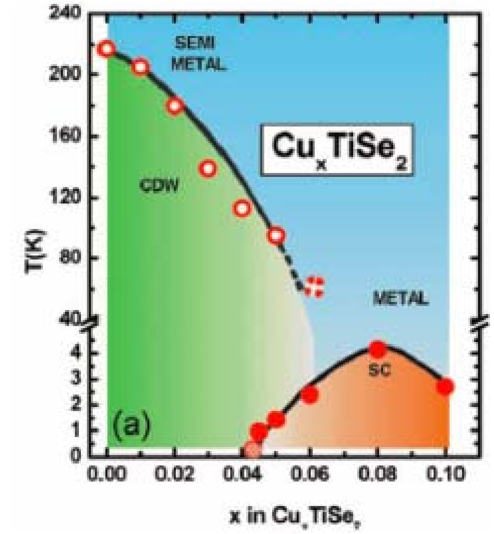
Coleman & Schofield, Nature (2005)
Si & Steglich, Science (2010)
Sachdev & Keimer, Phys. Today (2011)

QCP and unconventional SC

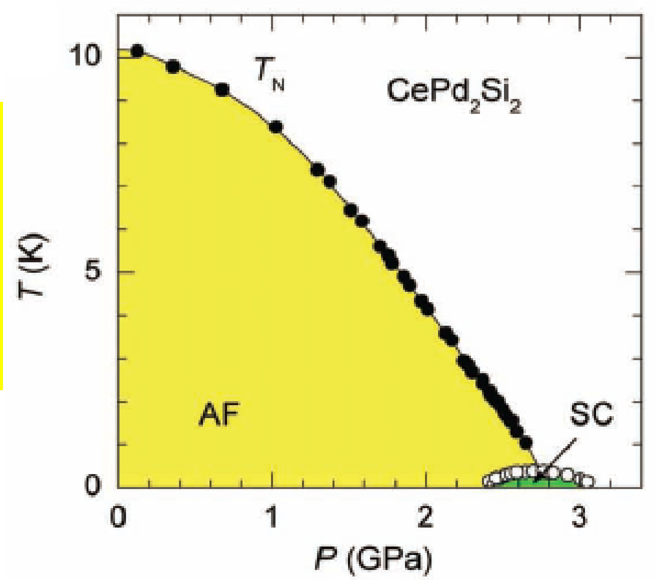
Chemical doping

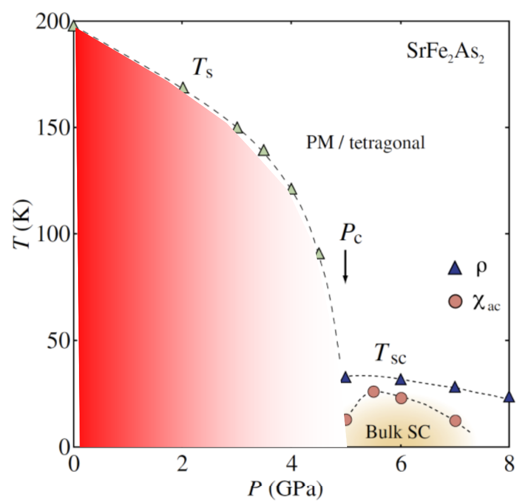


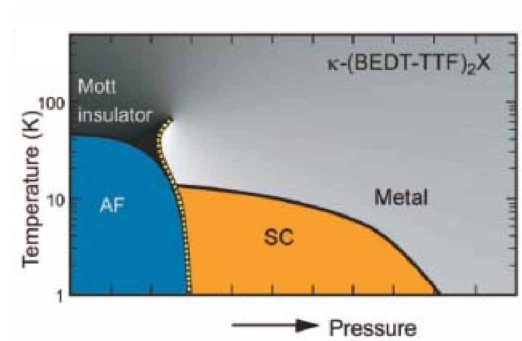




Pressure



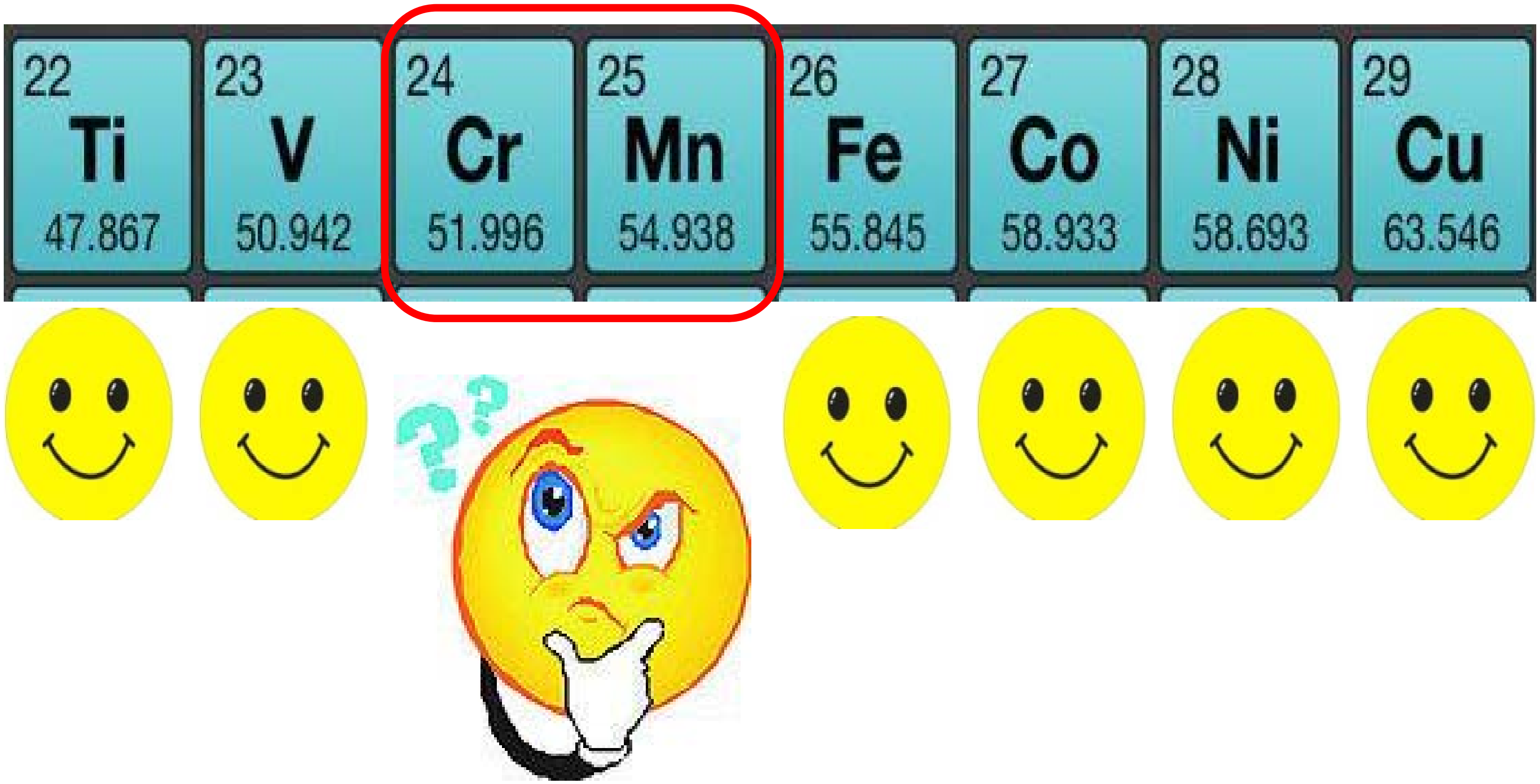




Advantages

- ✓ *clean*
- ✓ *fine and precise*

Cr- and Mn-based superconductor?



SC

OUTLINE

1 QCP and unconventional SC

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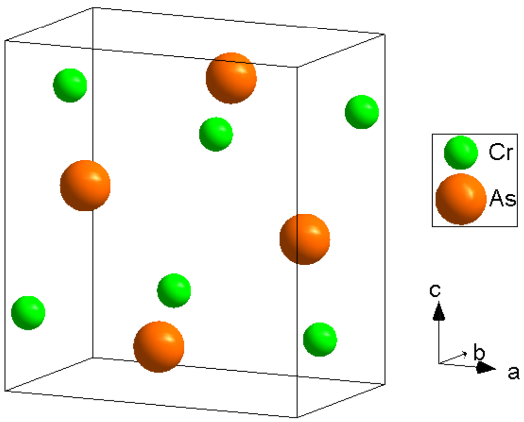
3 P-induced SC in MnP

4 Conclusion and outlooks

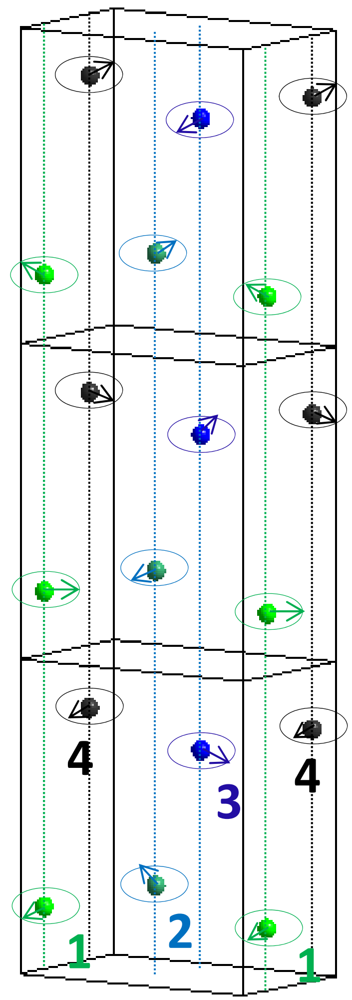
1^{st} order AF transition of CrAs

Orthorhombic MnP-type crystal structure

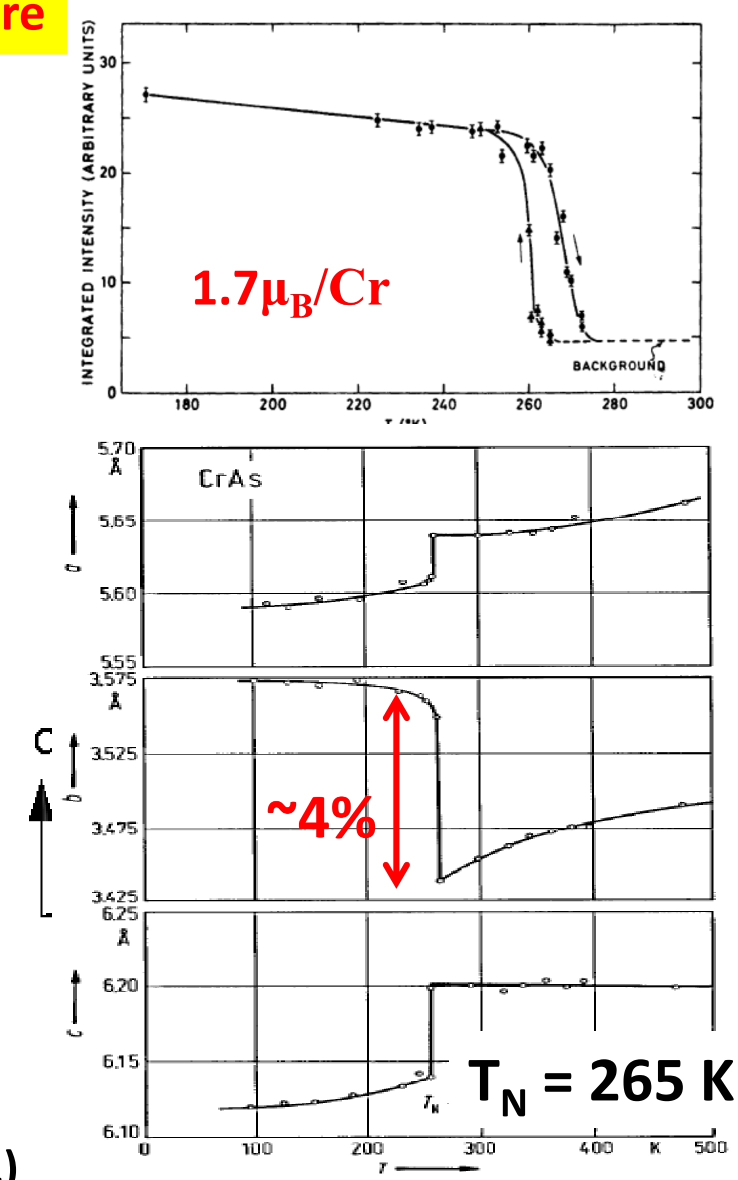


Pnma (62)
a = 5.6680 Å
b = 3.4670 Å
c = 6.2210 Å

Helimagnetic structure

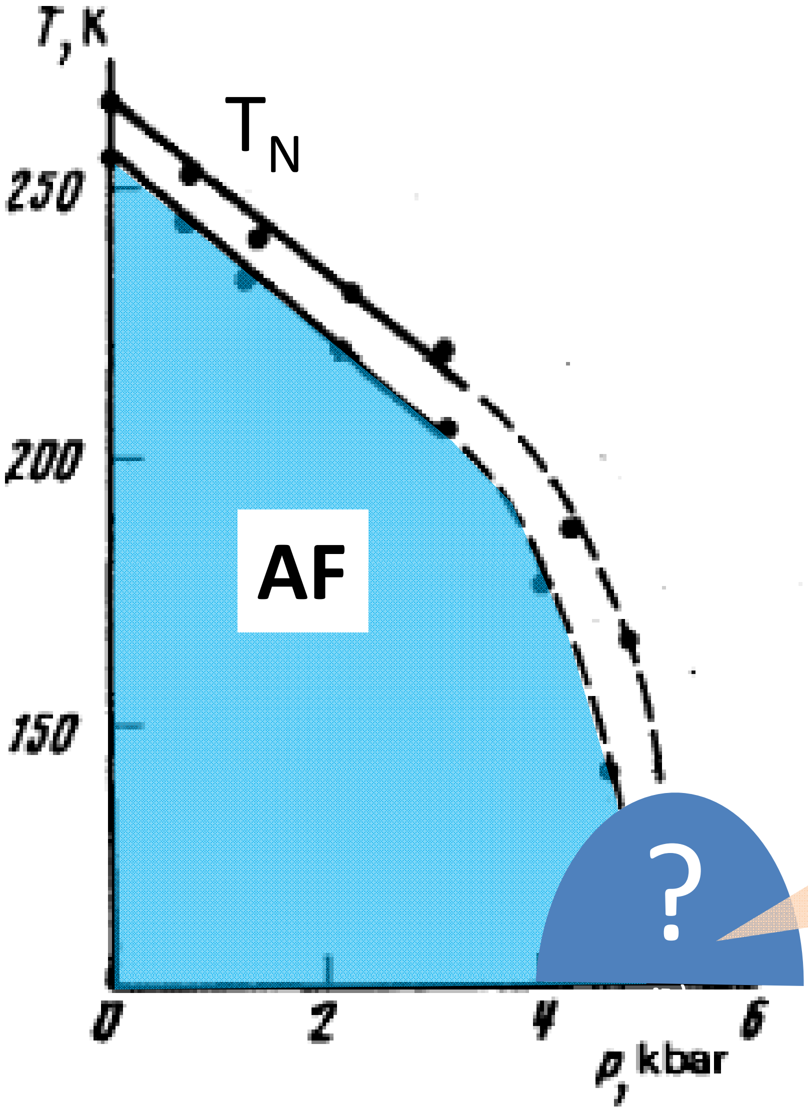


$Q = 0.353 \cdot 2\pi c^*$
$\alpha_{1,2} = \alpha_{3,4} = -120°$
$\alpha_{2,3} = \alpha_{4,1} = +183°$

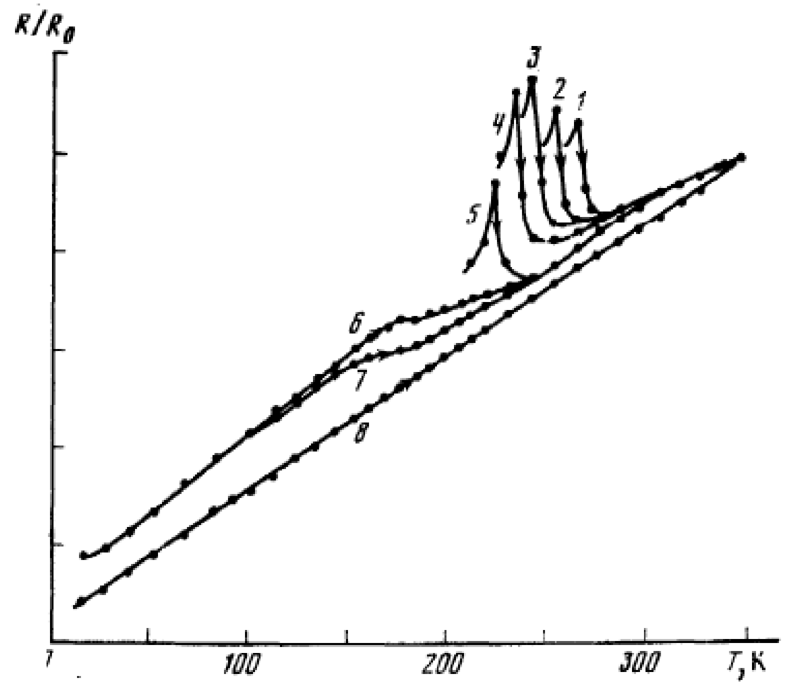


Acta. Chem. Scan. 25, 1703 (1971); JPSJ 30, 1319 (1971)

Earlier high pressure studies and motivation



Sov. Phys. JETP 51, 542 (1980)



G. 1. Plots of $R(T)/R_0$ at various pressures P, kbar: 1—-0.75; 3—1.4; 4—2.2; 5—3.2; 6—4.3; 7—4.9; 8—9.0.

What will happen at the magnetic critical point? Superconductivity??

High-quality CrAs single crystals are important

SCIENCE CHINA
Physics, Mechanics & Astronomy

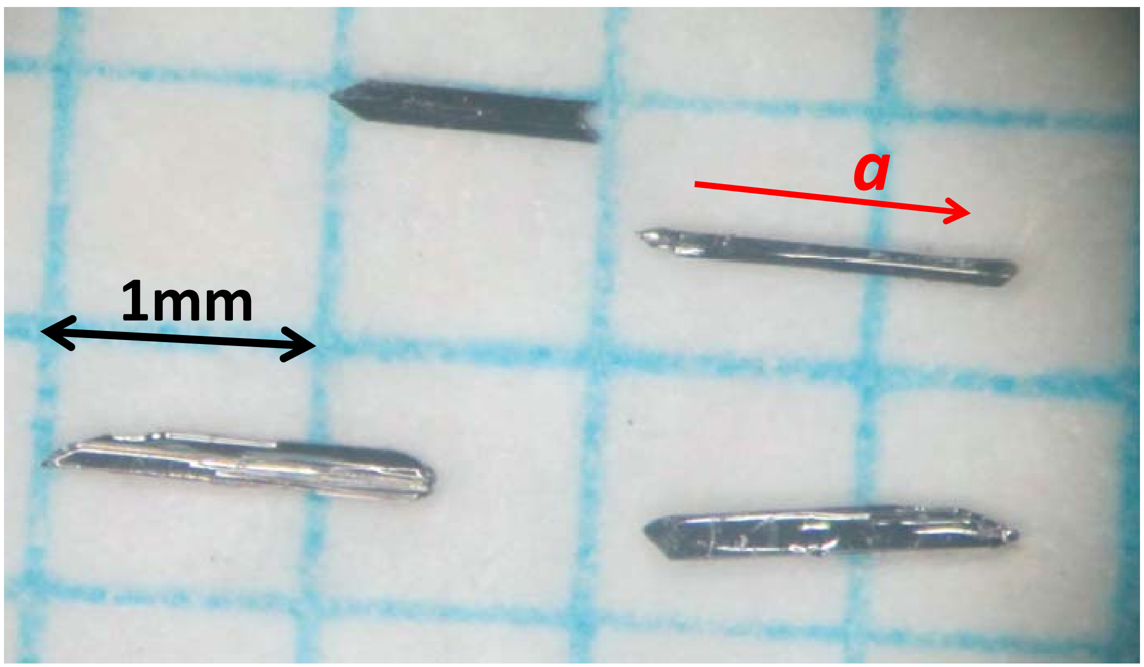
• Research Paper •
Recent Development of Iron Pnictide Superconductors

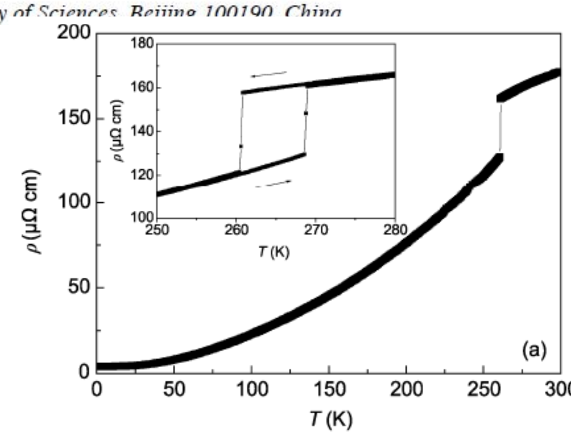
July 2010 Vol.53 No.7: 1207–1211
doi: 10.1007/s11433-010-4006-1

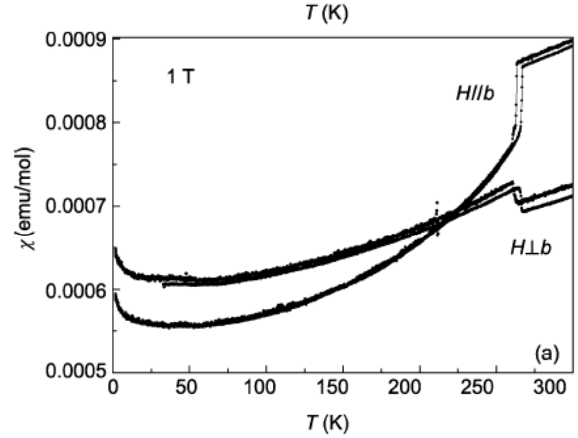
Low temperature properties of pnictide CrAs single crystal

WU Wei, ZHANG XiaoDong, YIN ZhiHua, ZHENG Ping, WANG NanLin & LUO JianLin*

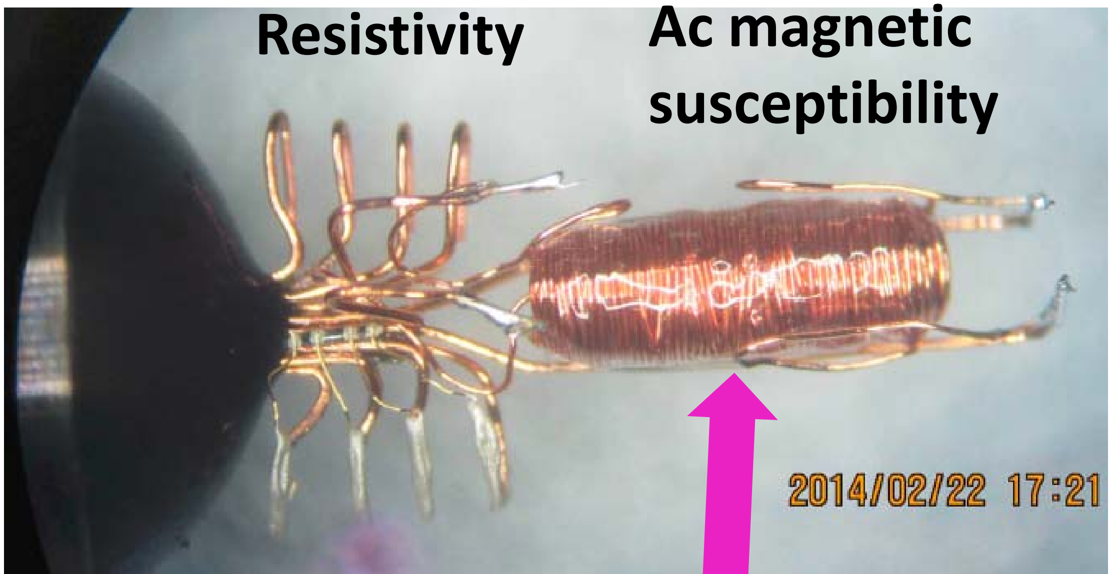
Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China





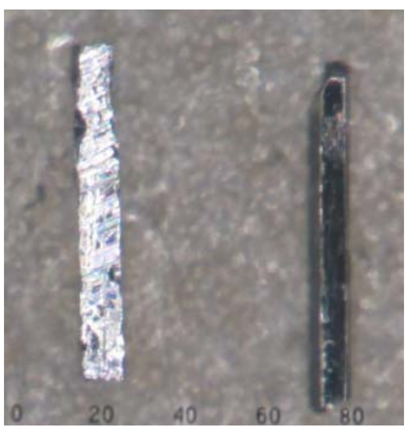


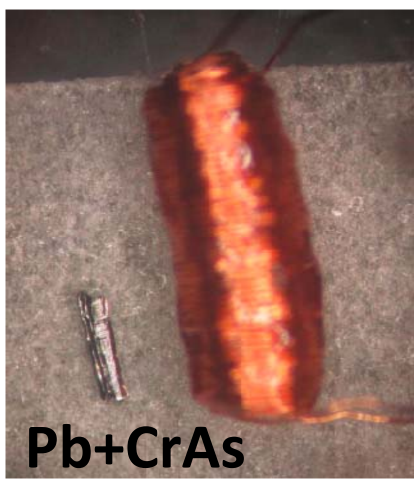
HP measurements on the CrAs crystals

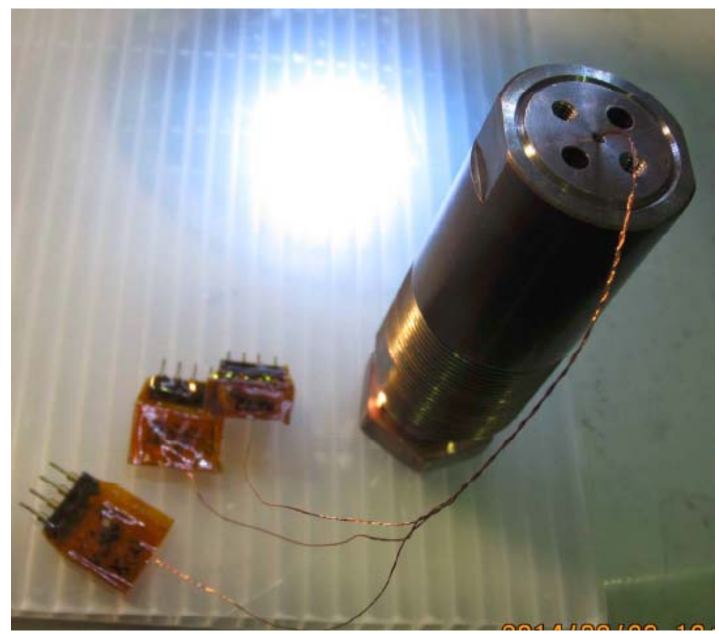


- ➢Piston-cylinder cell
- ➢Pressure manometer: Pb
  P(kbar) = (7.2-T_c)/0.0365
- ➢ Pressure medium: Glycerol

Pb CrAs

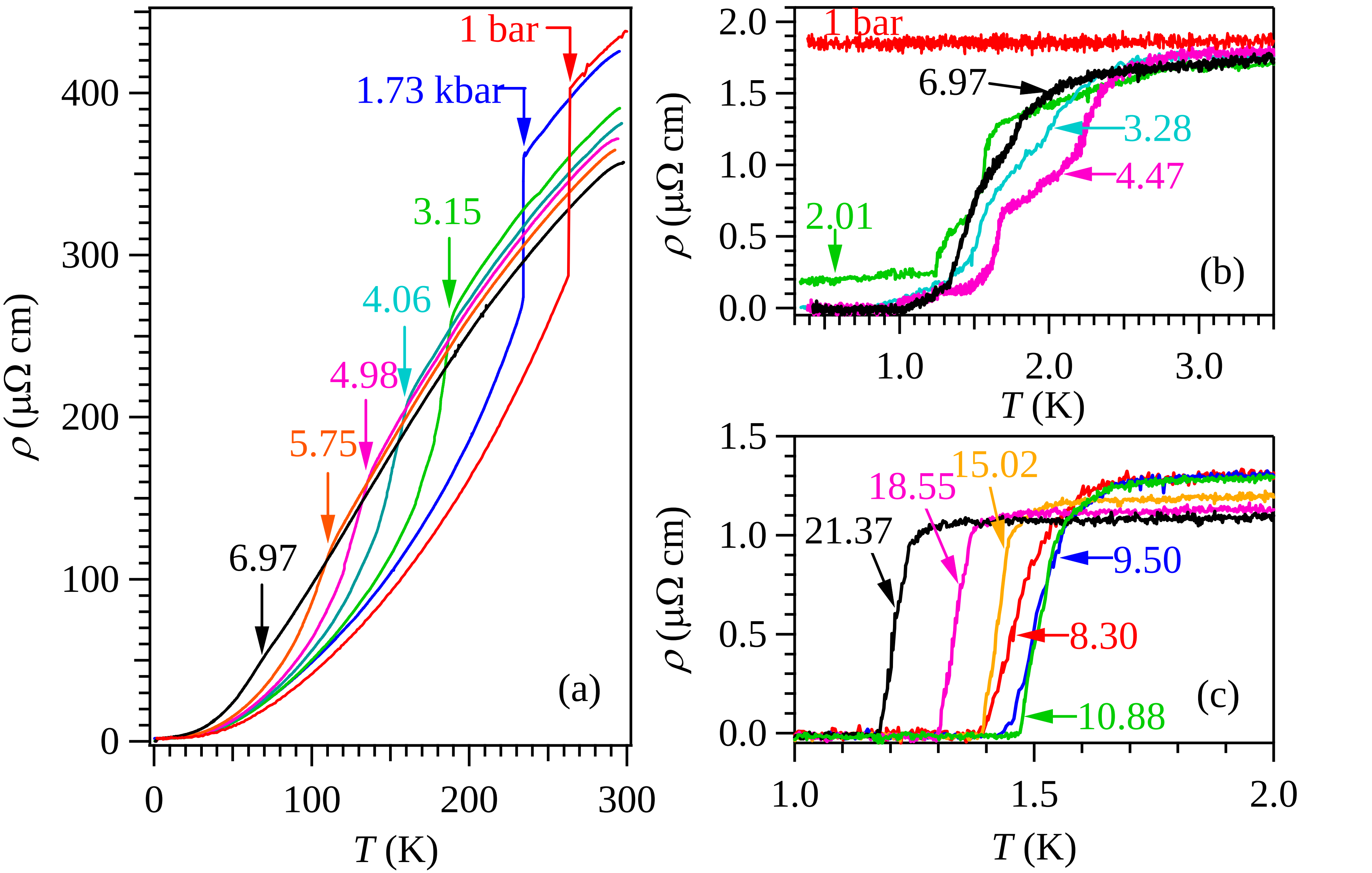




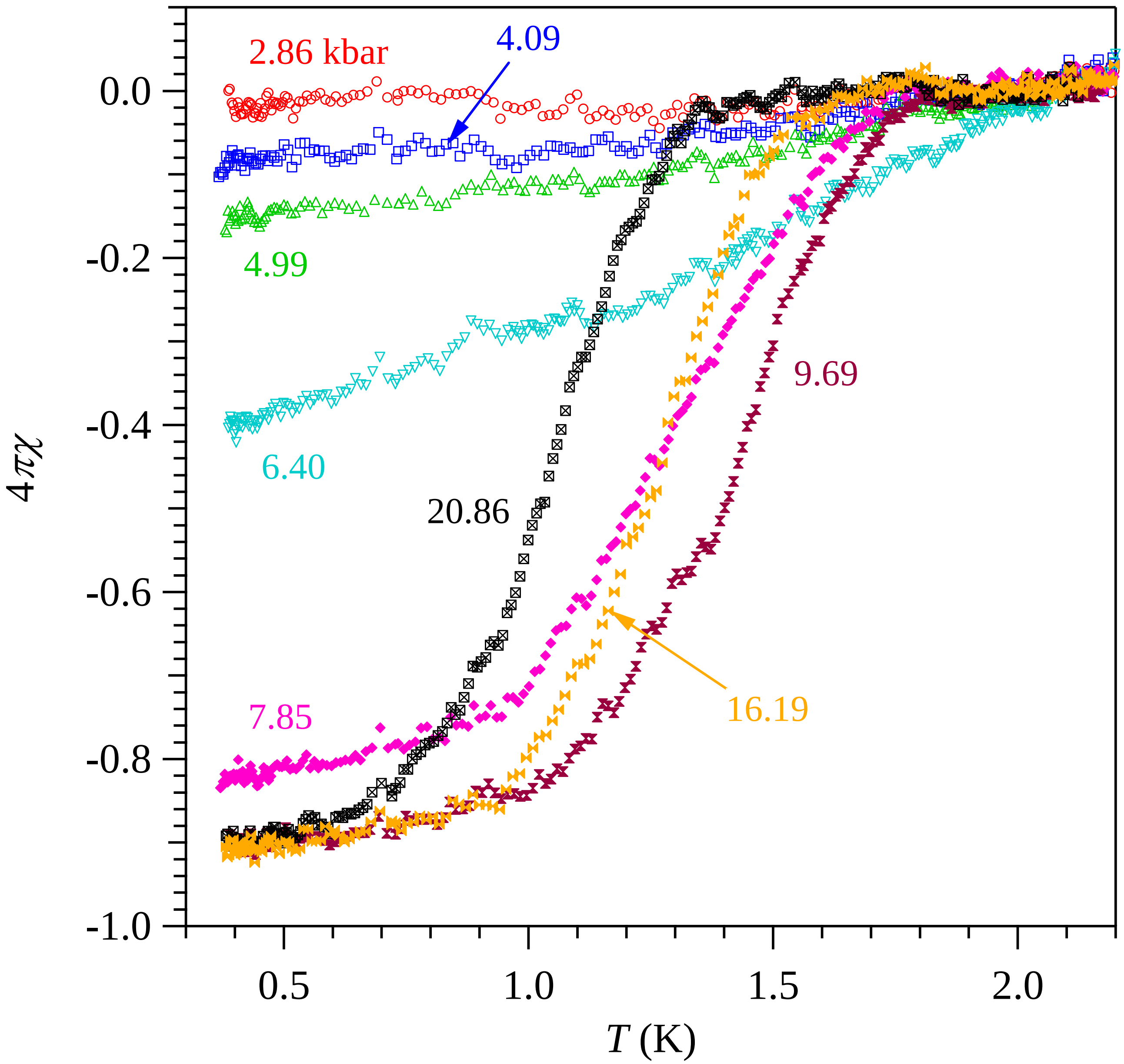


Discovery of P-induced SC in CrAs

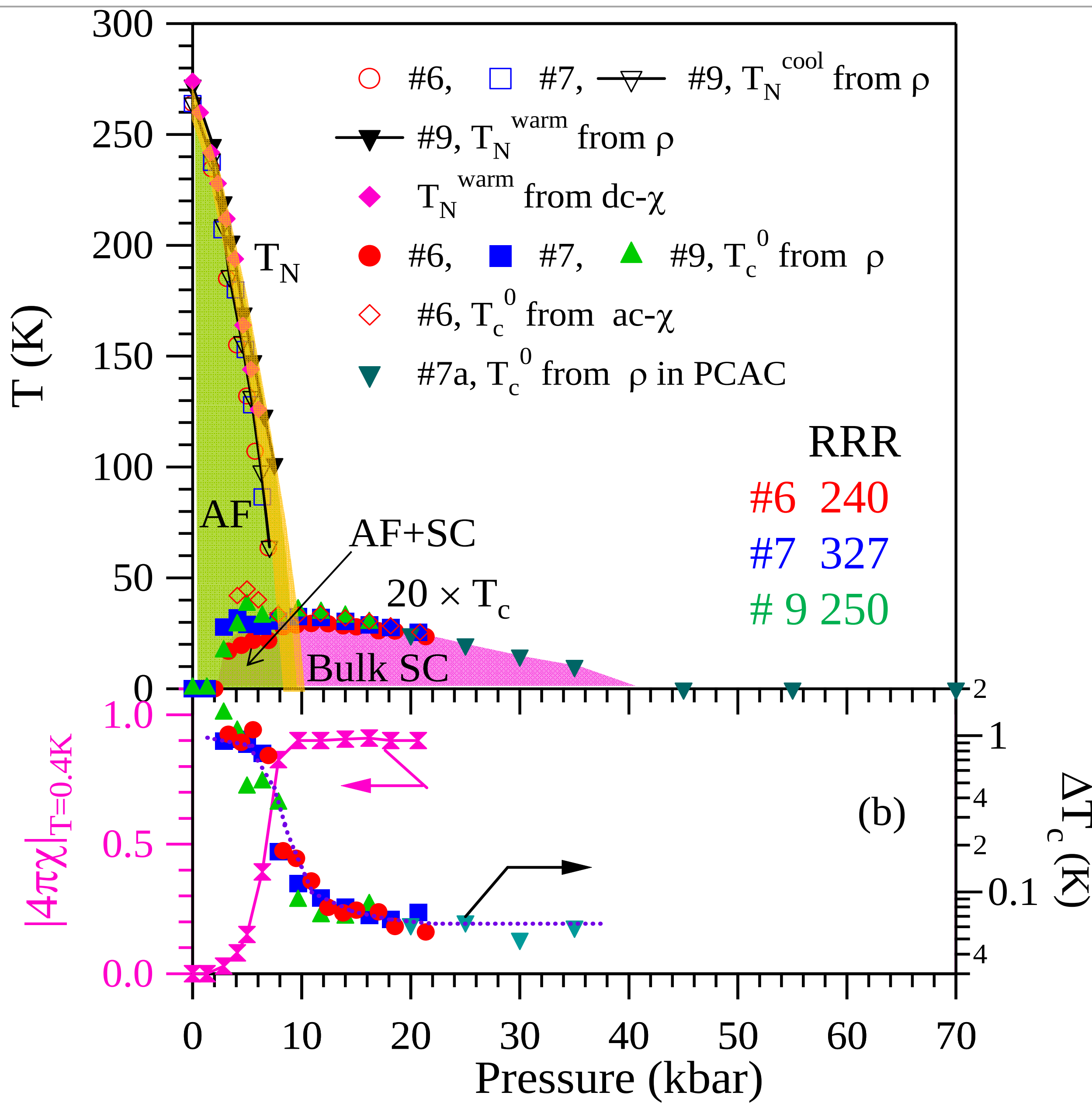
#6 RRR =240

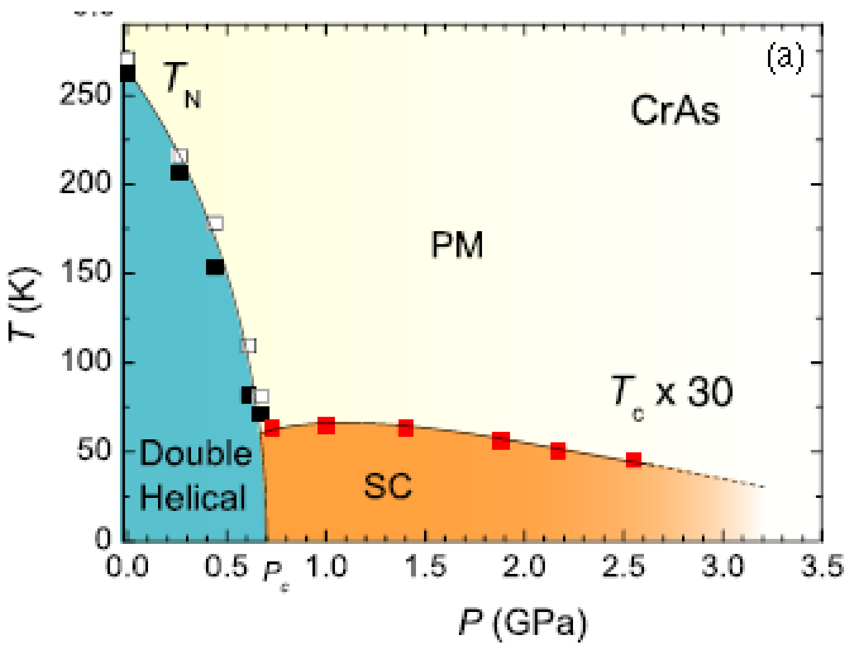


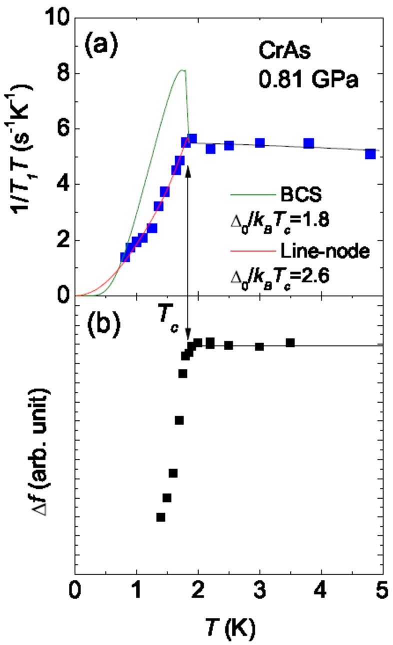
Bulk SC evidenced from ac susceptibility

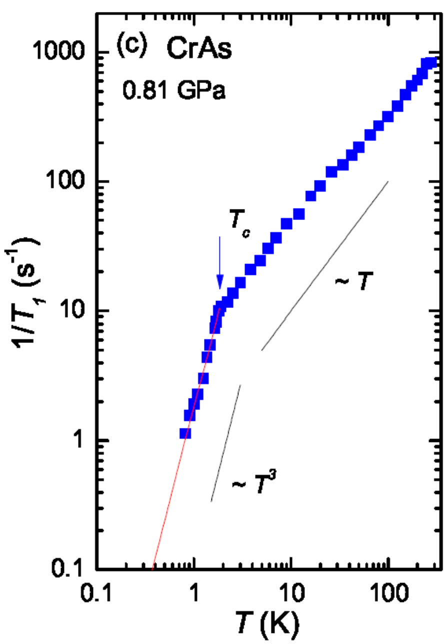


T-P phase diagram of CrAs

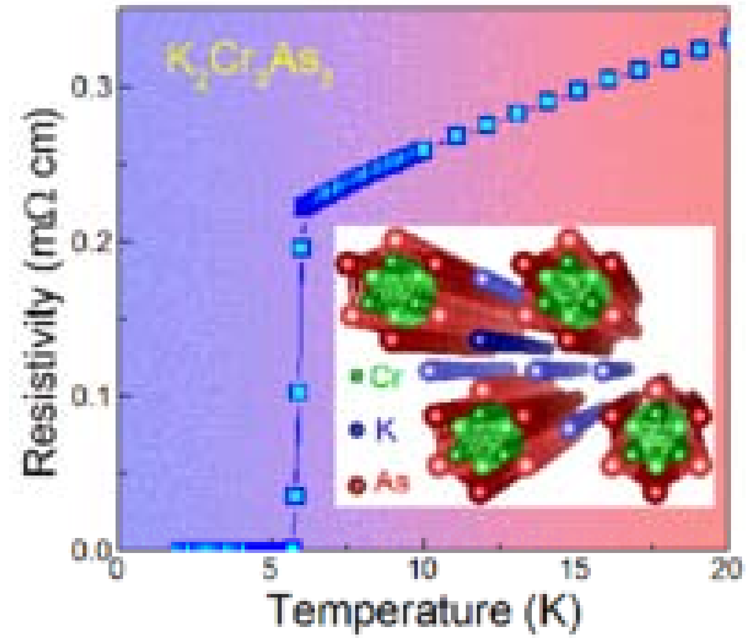








Kotegawa, JPSJ (2014) , PRL (2015)



$A_2Cr_3As_3$

(A=K, Rb, Cs)

(G. Cao, Zhejiang Univ.)

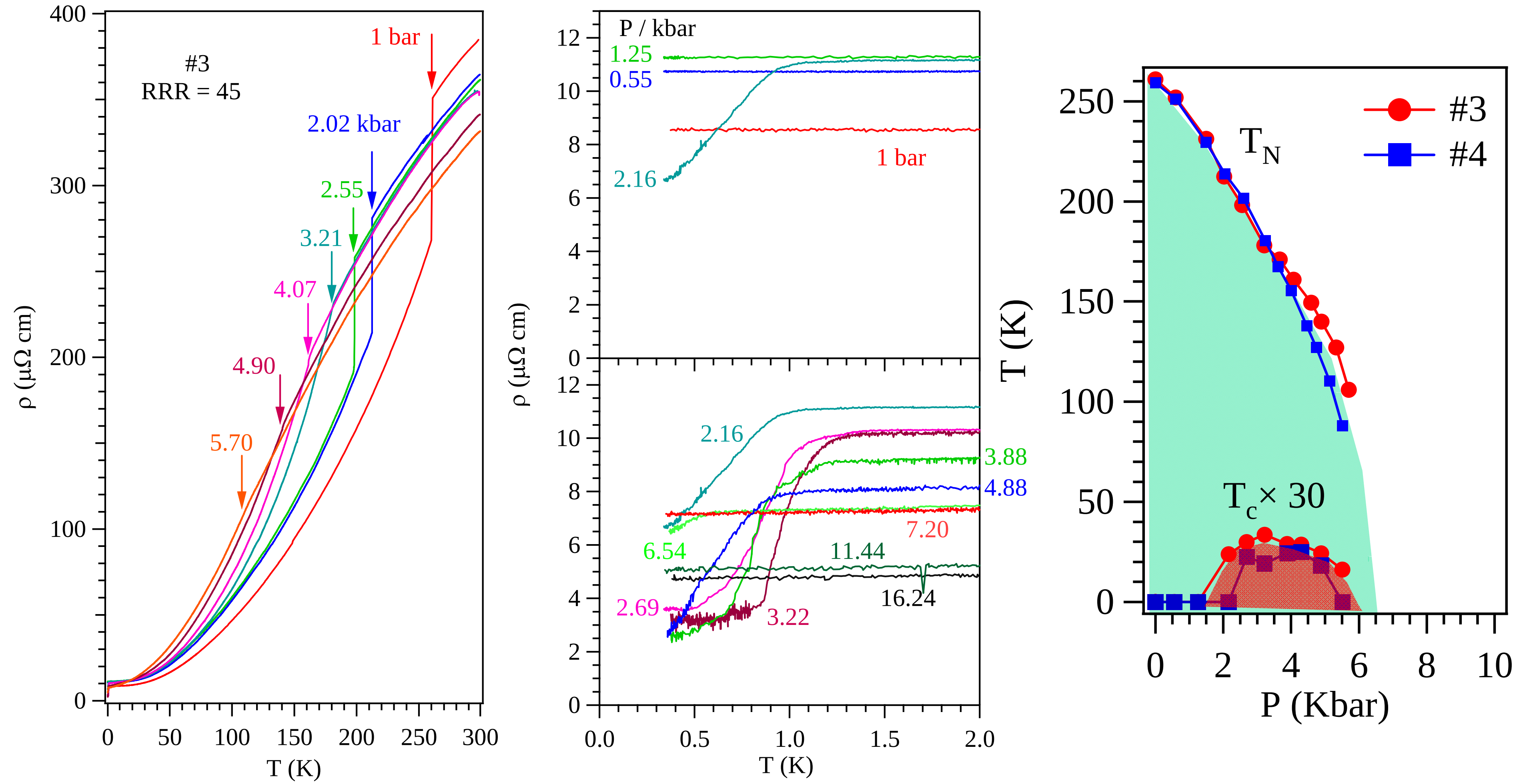
PRX (2015)

PRB (2015)

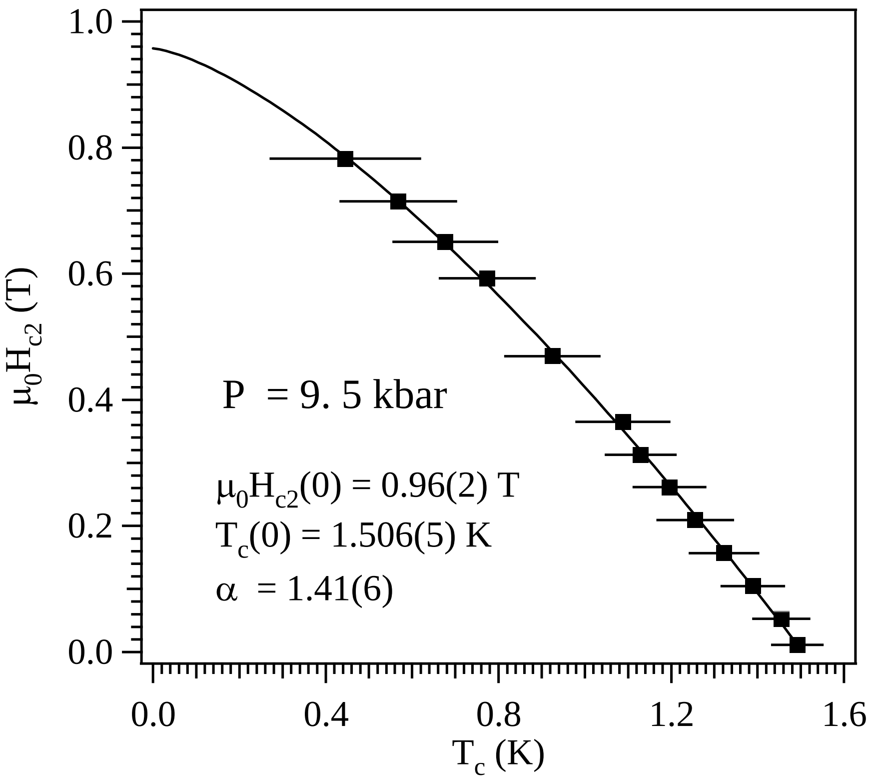
SCM(2015)

SC sensitive to disorder

#3 RRR = 45



Coherent length vs Mean free path



$\mu_0 H_{c2}(T) = \mu_0 H_{c2}(0)\,\{1-[T_c/T_c(0)]^{\alpha}\}$

$\mu_0 H_{c2}(0) = \Phi_0/2\pi\xi^2$

$\xi = 185$ Å

$R_H \approx 2.6\times10^{-10}\ \mathrm{m^3/C}$ at 5 K

$\rightarrow n = 2.4\times10^{28}\ \mathrm{m^{-3}}$

$$L_{mfp} = \frac{\hbar}{e^2\rho_0}(3\pi^2)^{\frac{1}{3}} n^{-\frac{2}{3}}$$

RRR ~250

$\rho_0 = 2\times10^{-8}\ \Omega$ m

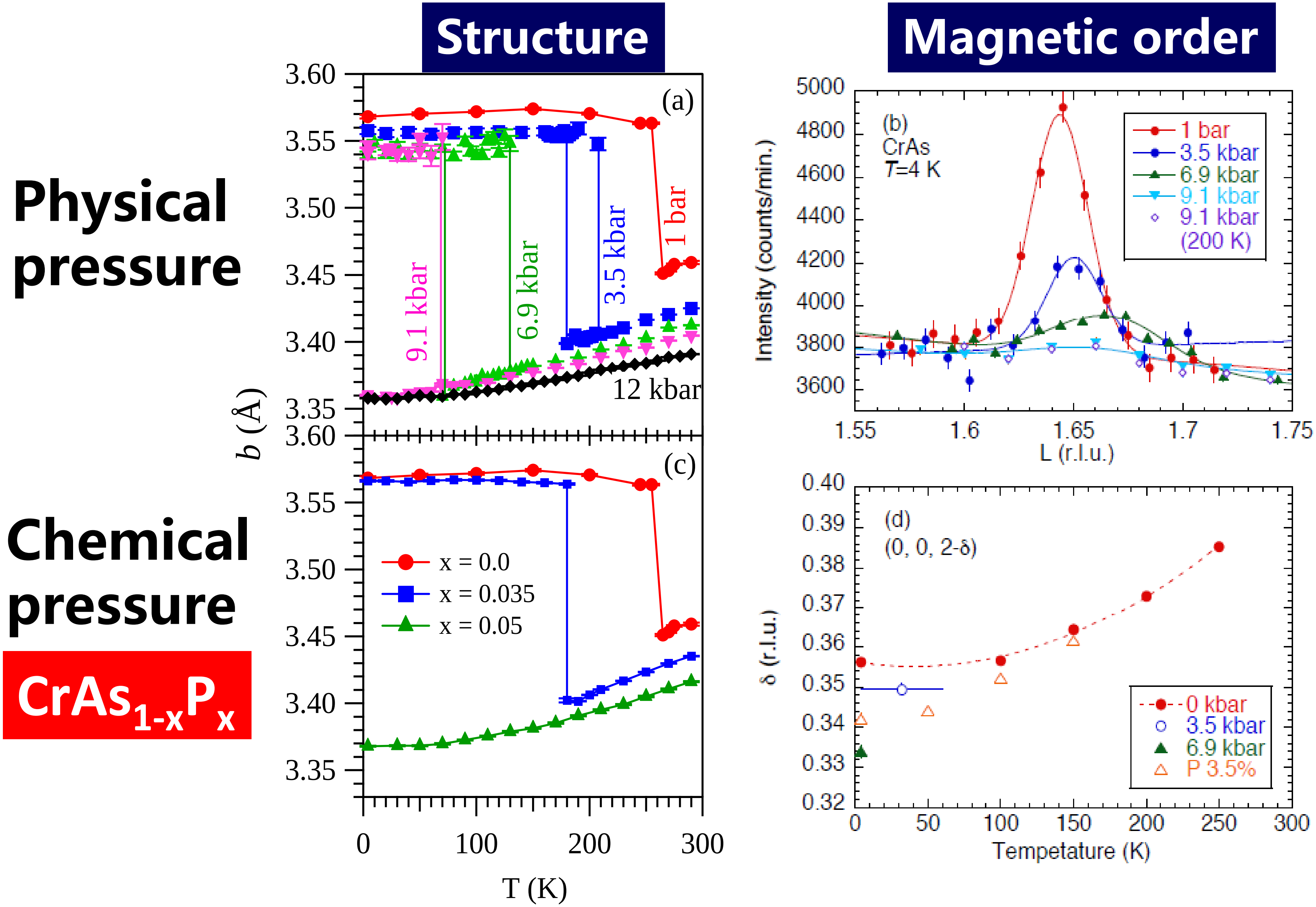
$L_{mfp} = 766$ Å

RRR ~50

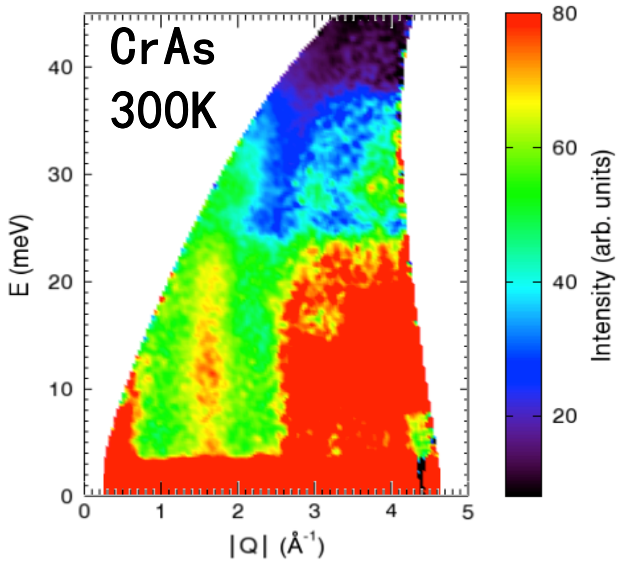
$\rho_0 = 10\times10^{-8}\ \Omega$ m

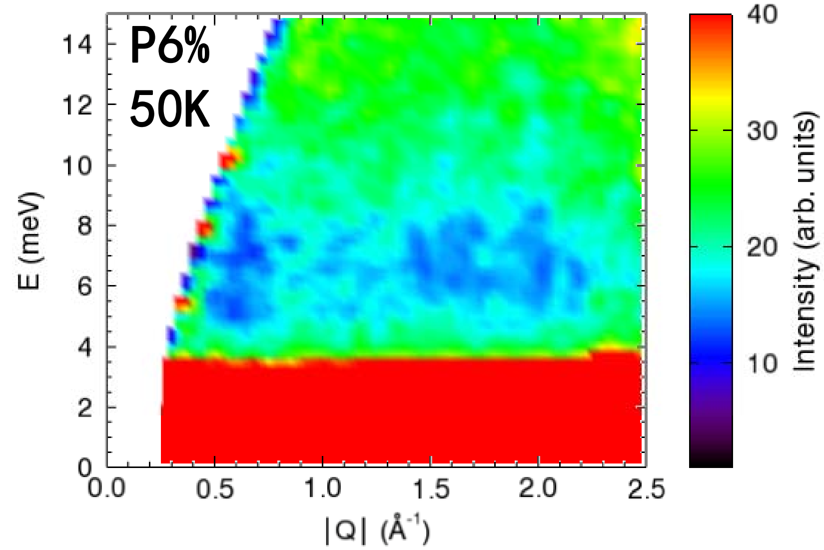
$L_{mfp} = 153$ Å

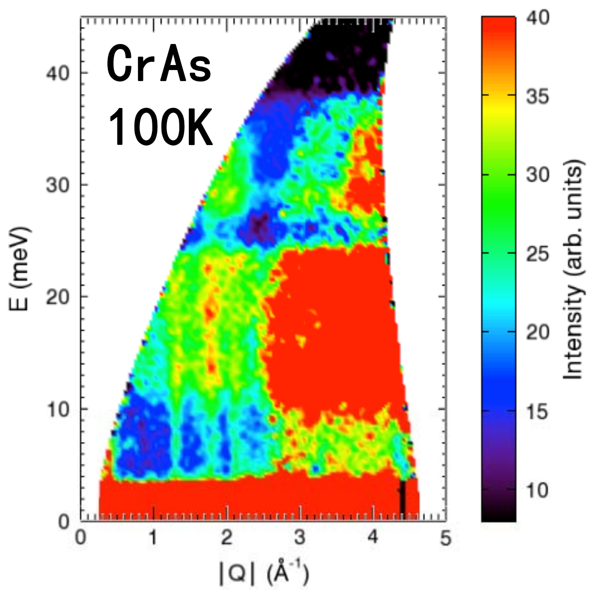
Neutron scattering : Phys. vs Chem. P

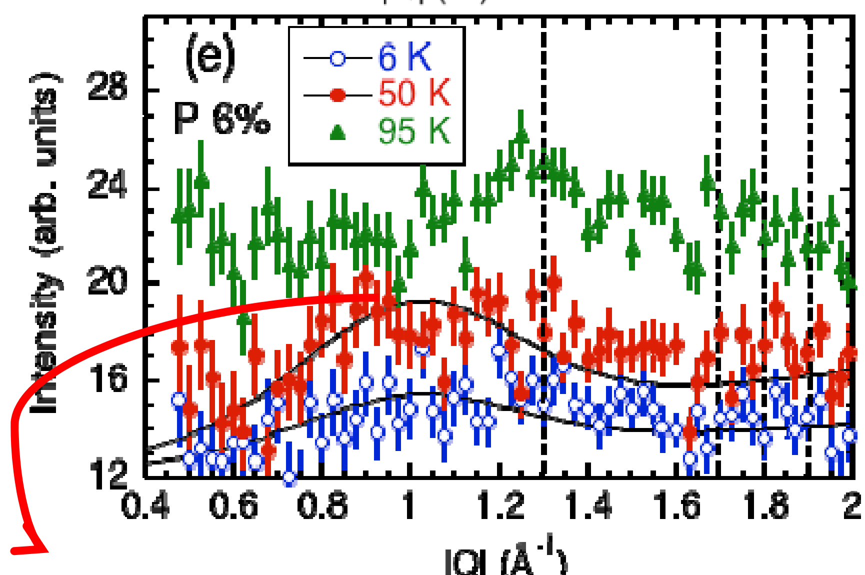


Inelastic neutron scattering



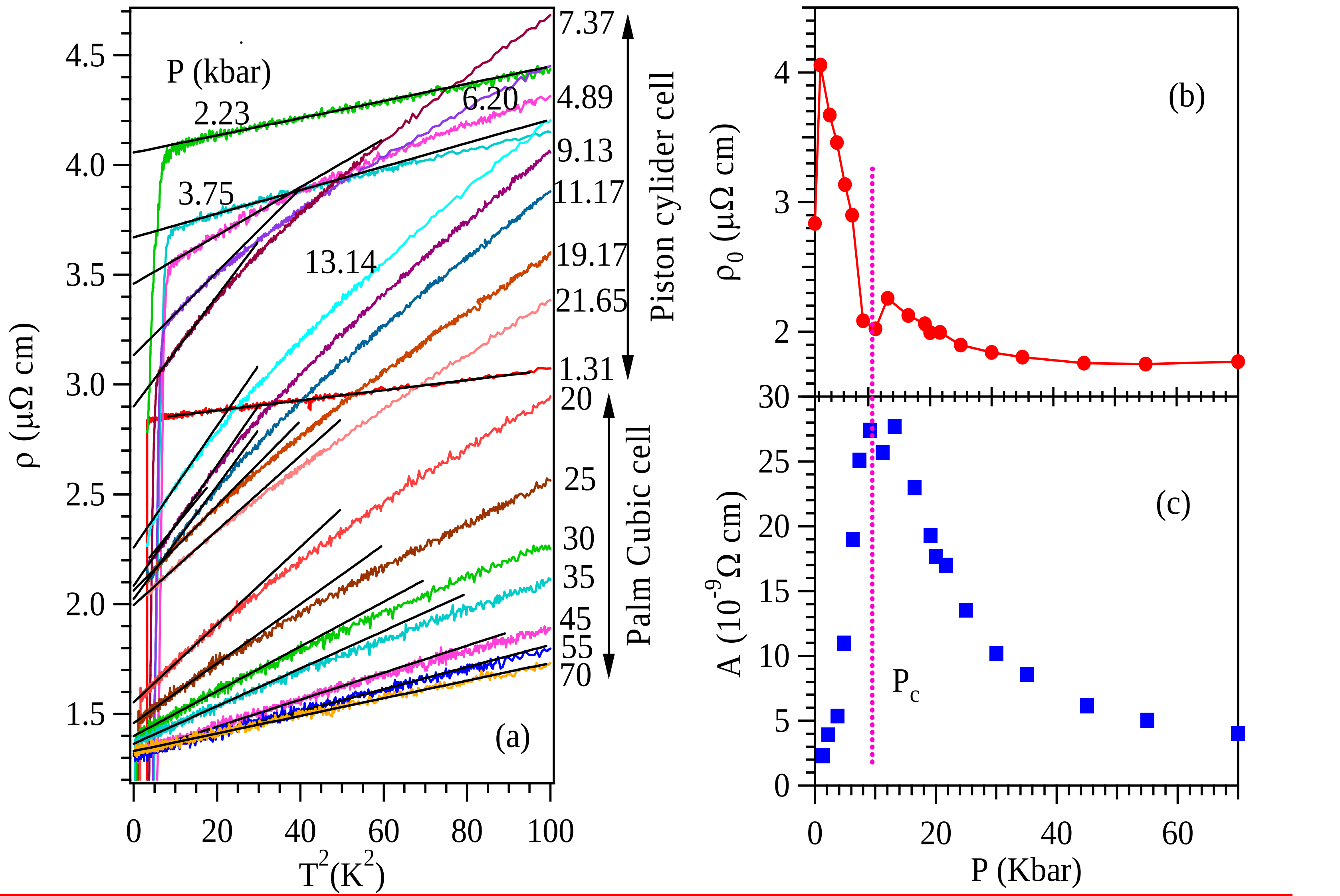






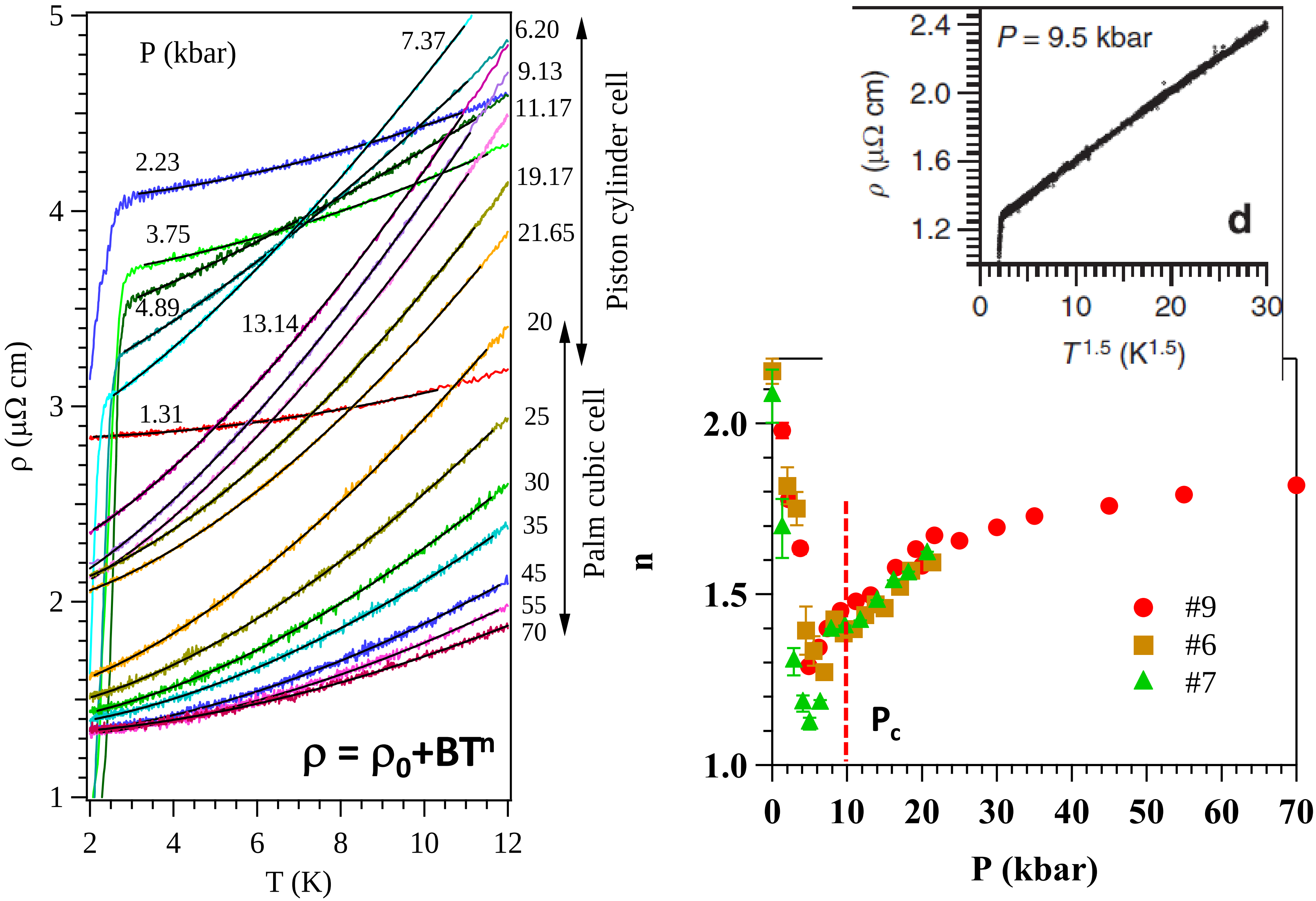
NNN AFM correlations

Evidence for quantum criticality: Enhanced m*

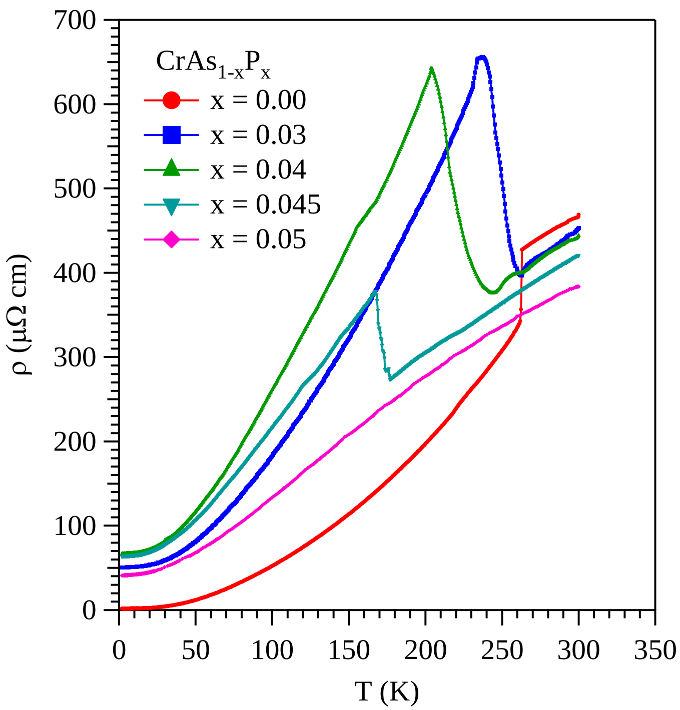


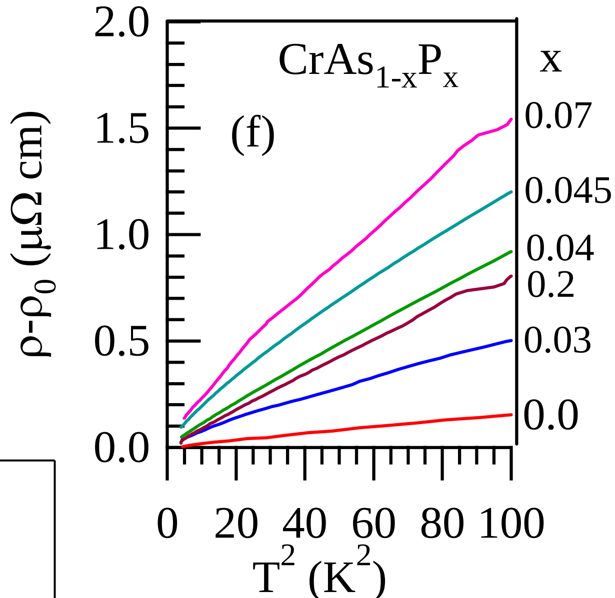
Enhancement of A coefficient near P_c; $A \propto (m^*/m_0)^2$

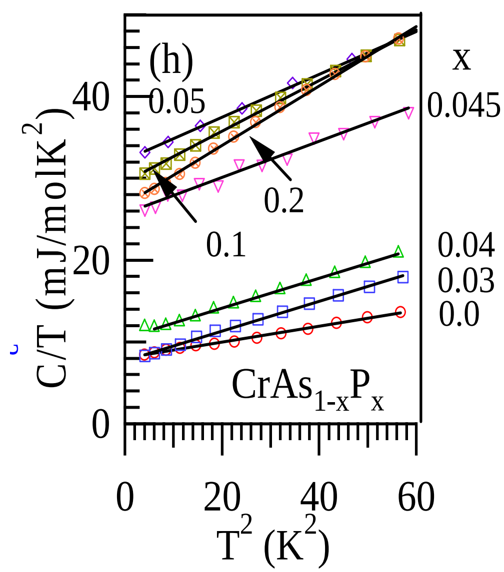
Evidence for quantum criticality: nFL

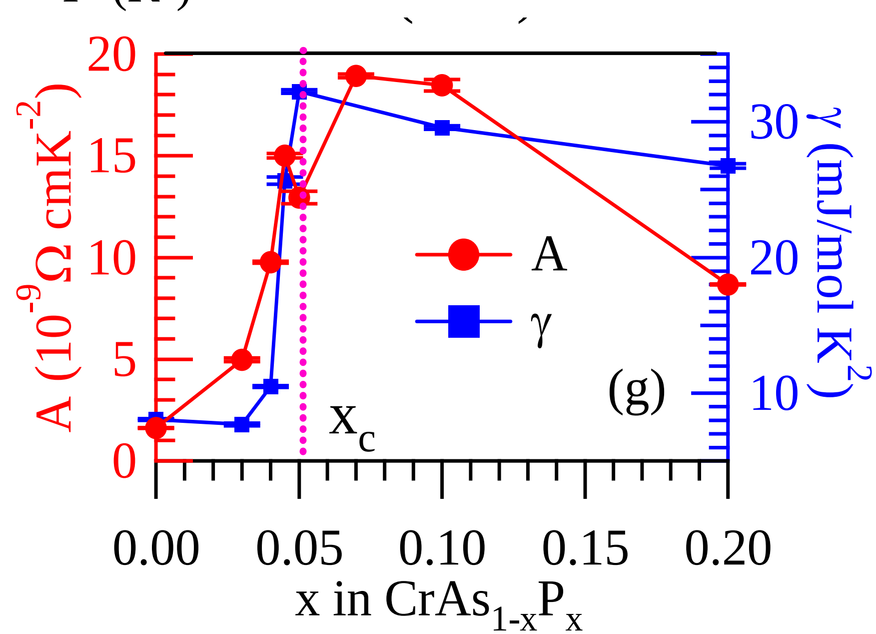


Further evidences for quantum criticality









Mn-based superconductor?

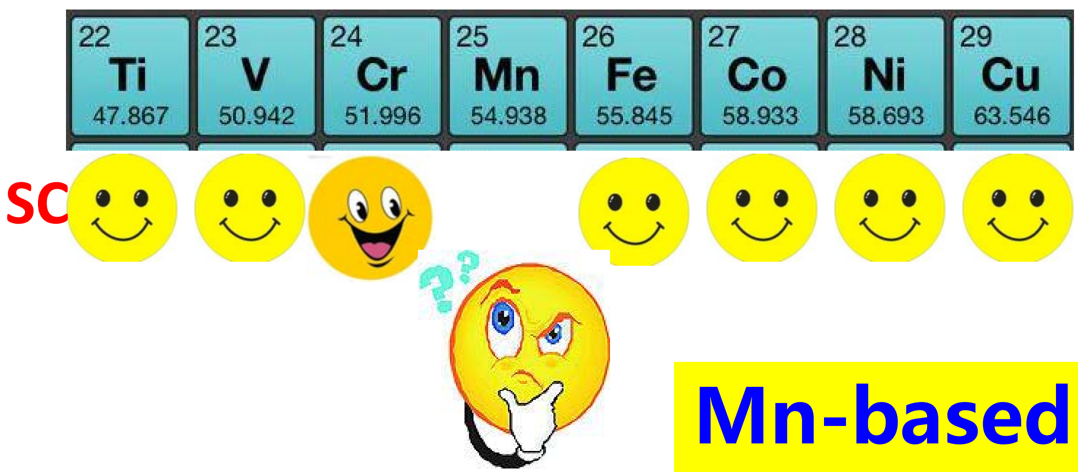
nature
COMMUNICATIONS

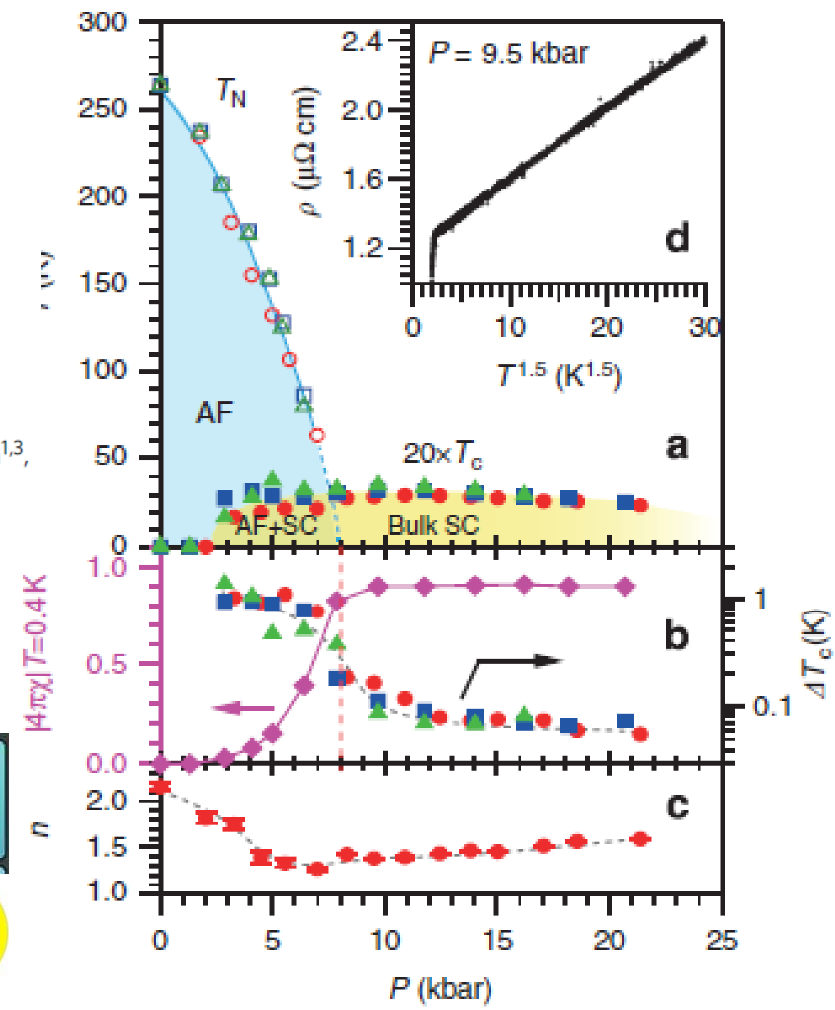
Received 16 Jun 2014 | Accepted 8 Oct 2014 | Published 19 Nov 2014
DOI: 10.1038/ncomms6508

Superconductivity in the vicinity of antiferromagnetic order in CrAs

Wei Wu[1,*], Jinguang Cheng[1,2,*], Kazuyuki Matsubayashi[2], Panpan Kong[1], Fukun Lin[1], Changqing Jin[1,3], Nanlin Wang[1,3,4], Yoshiya Uwatoko[2] & Jianlin Luo[1,3]

Nat. Comm. 5, 5508 (2014)

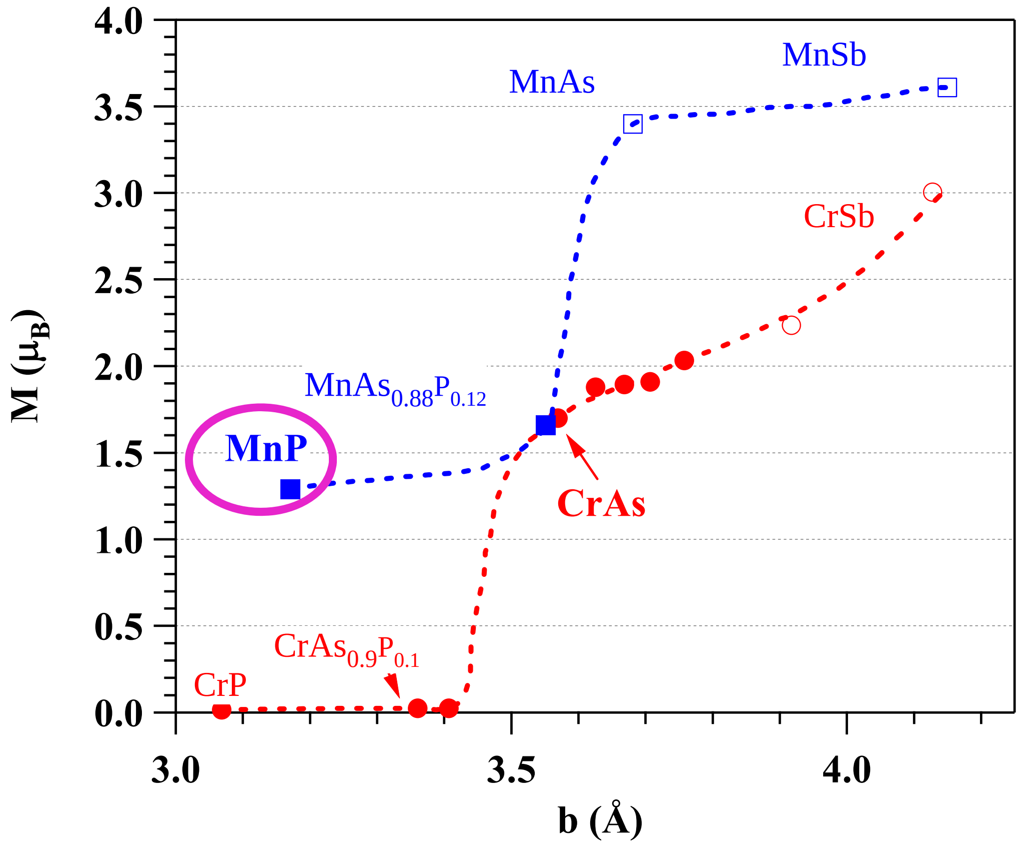


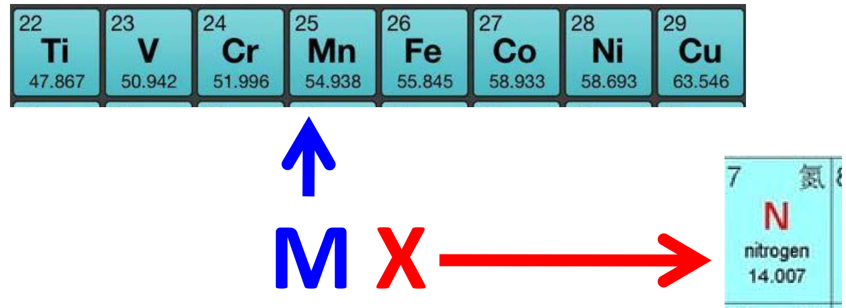


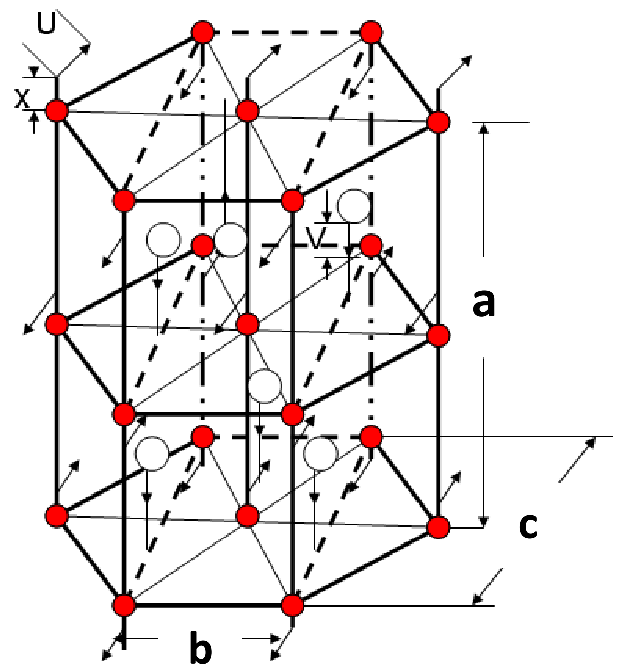
Mn-based superconductor?

Strategy

Magnetic moment vs. b-axis length



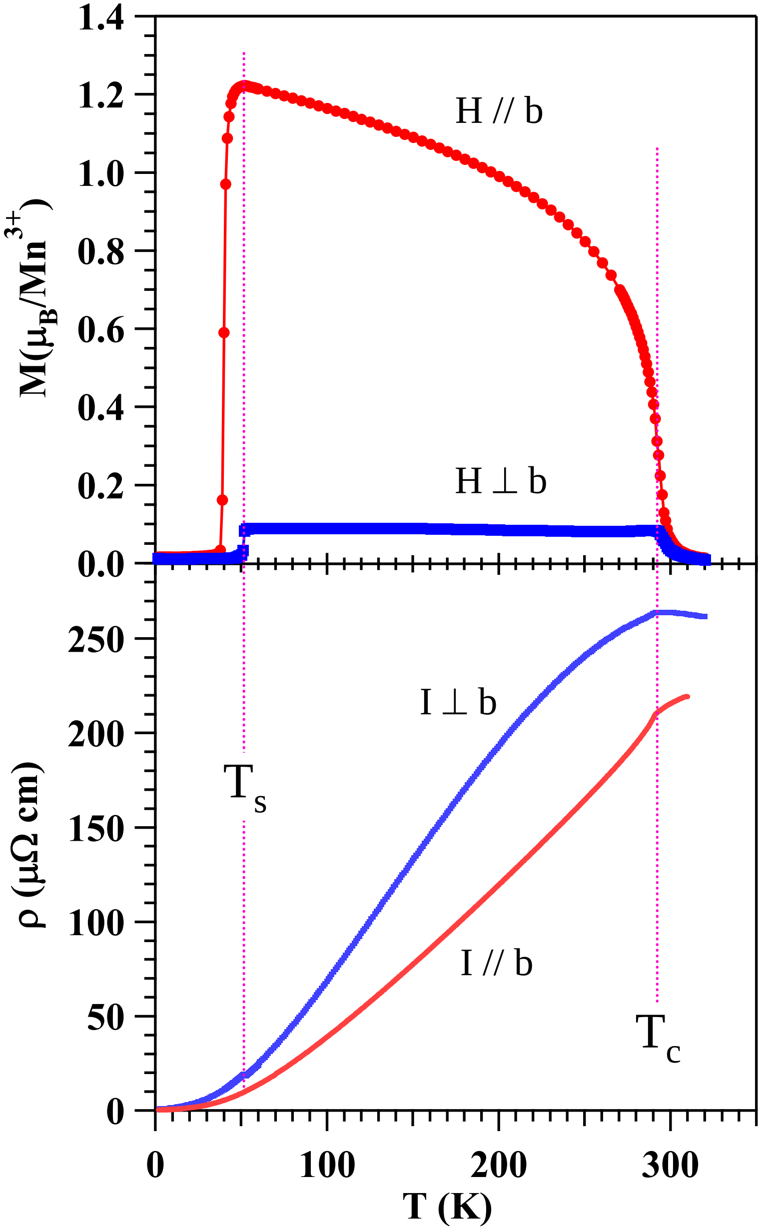


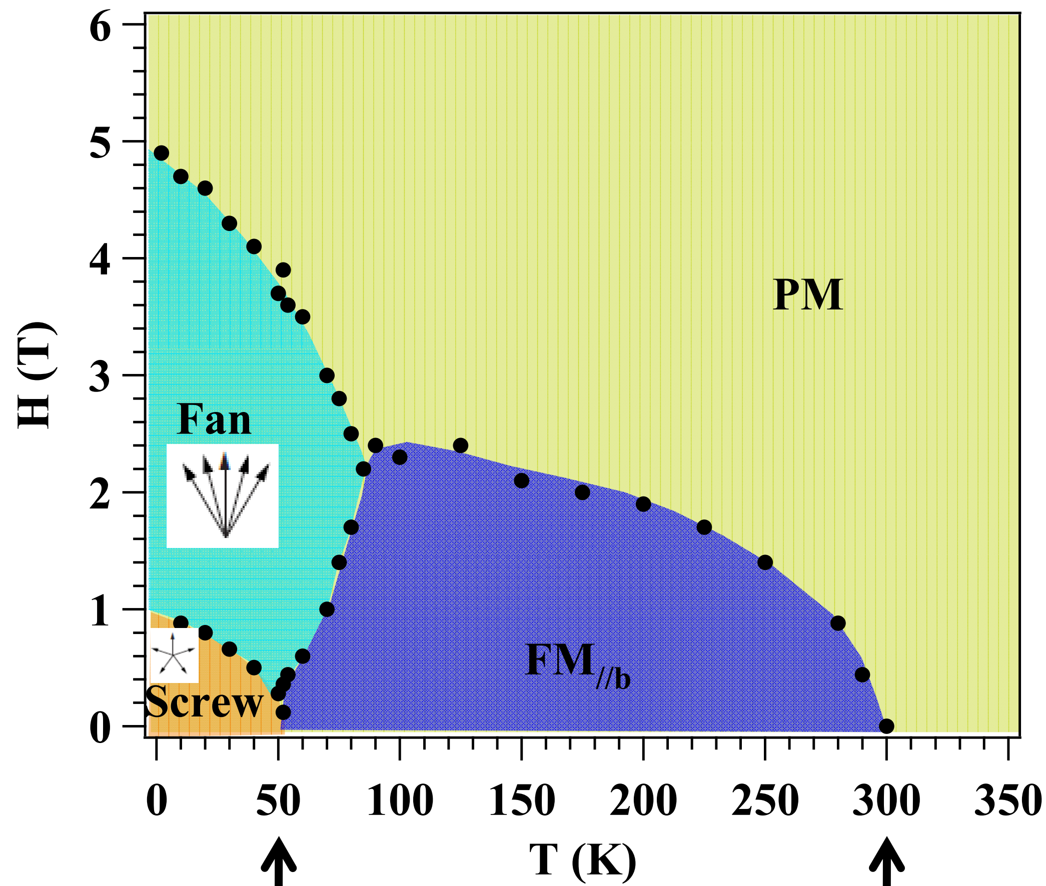


MnP would be the a good start point to approach a magnetic instability by the application of high pressure!!!

Hexagonal NiAs (solid line)
Orthorhombic MnP (dash lines)

Physical properties of MnP at ambient pressure



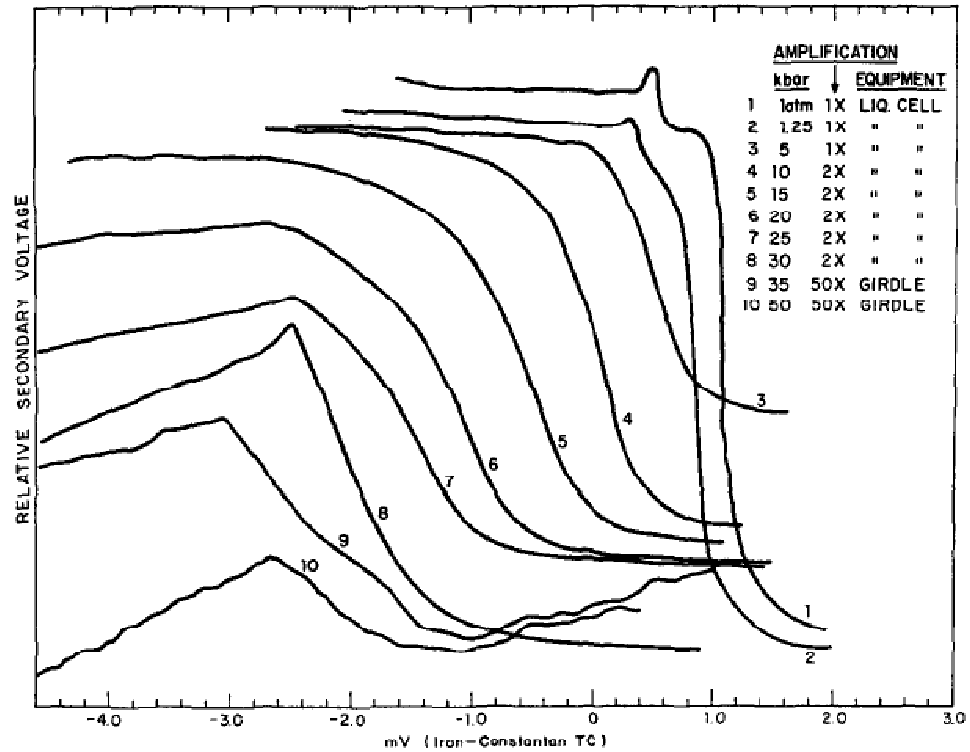


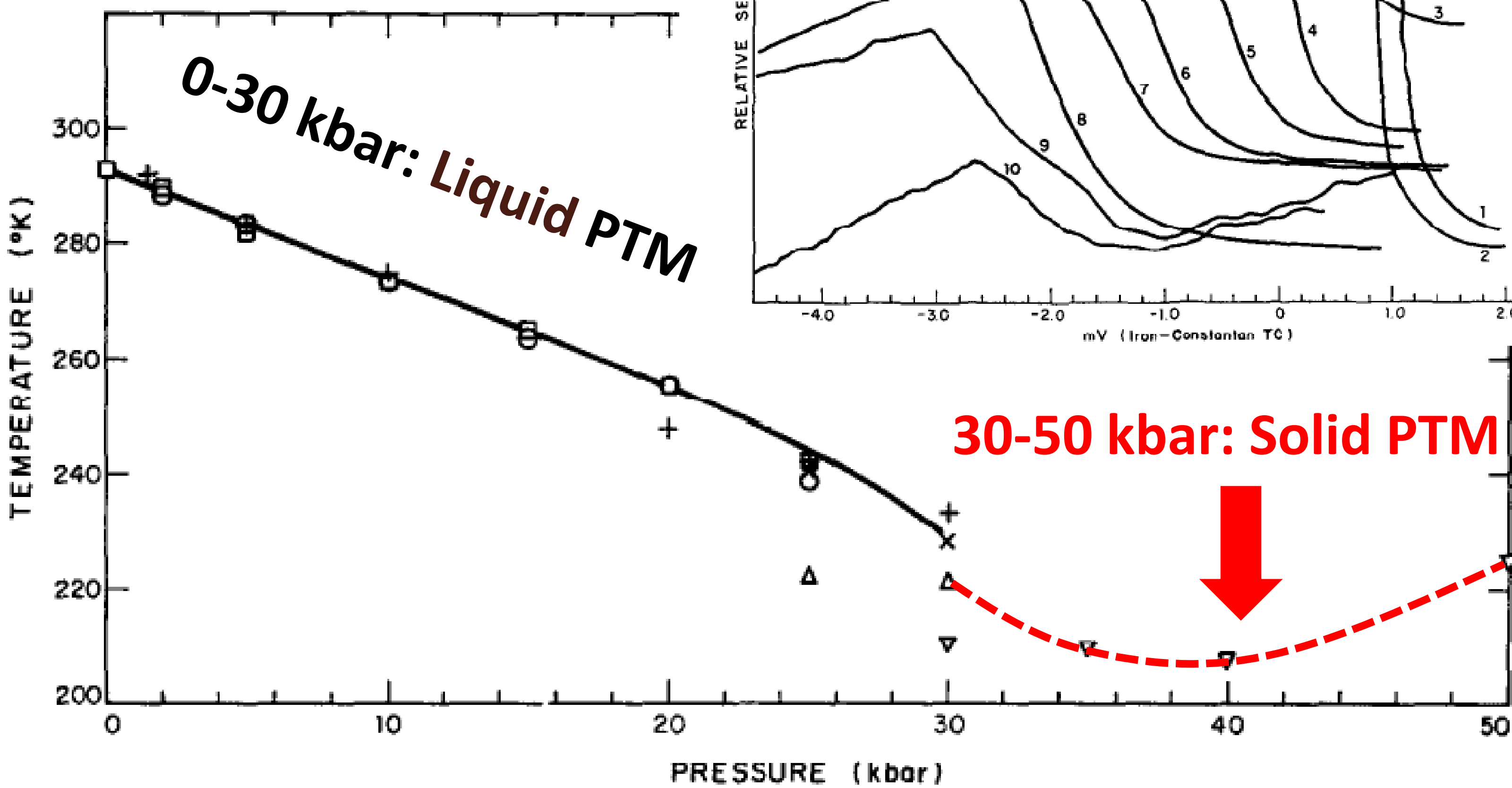
$T_s \approx 50$ K

$T_c = 291.5$ K

Earlier high-pressure studies

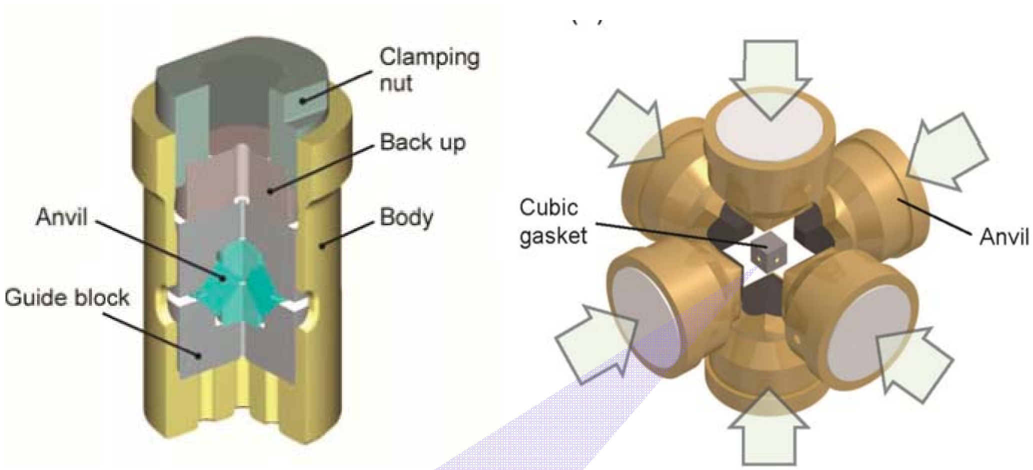
J. Solid State Chem. 4, 391 (1972)

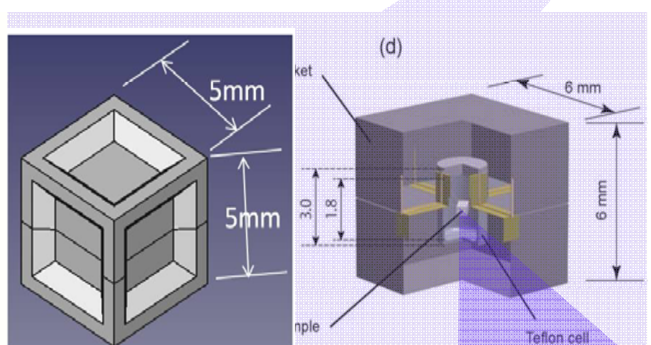




HP techniques with extended pressure capacity

Cubic anvil cell

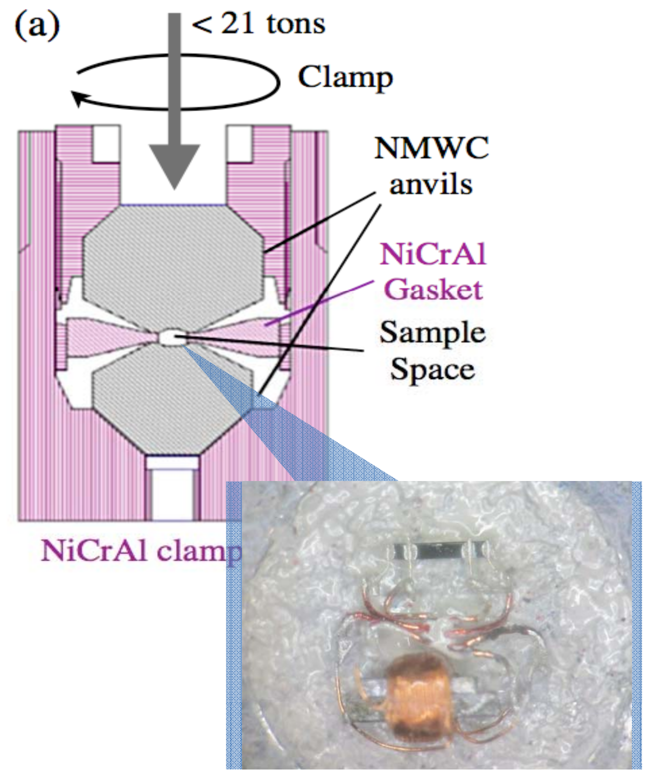




P_{max} : 15 GPa
P-medium :
Glycerol

Cheng JG, RSI (2014)

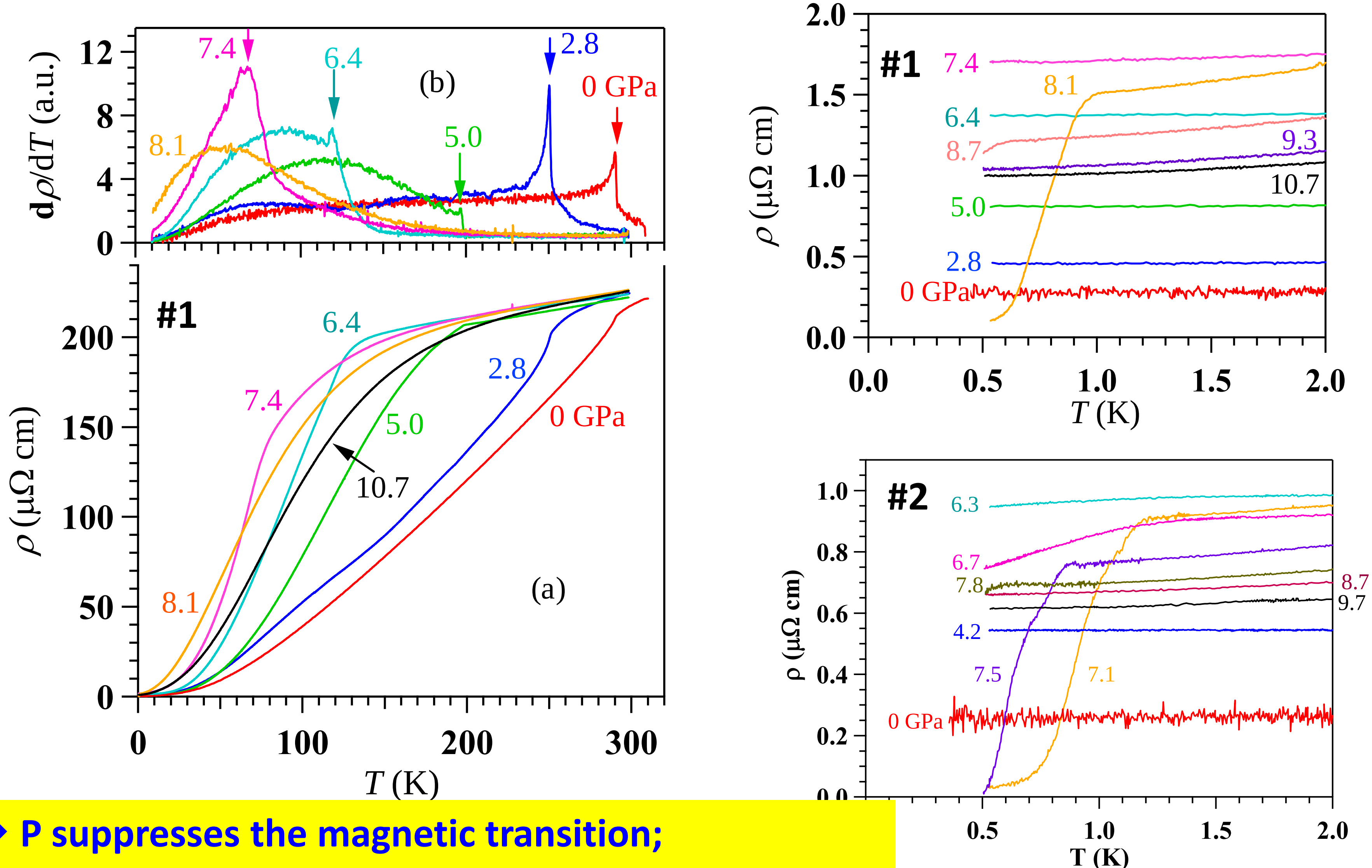
Opposed-Anvil Cell



P_{max} : 12 GPa
P-medium : Ar

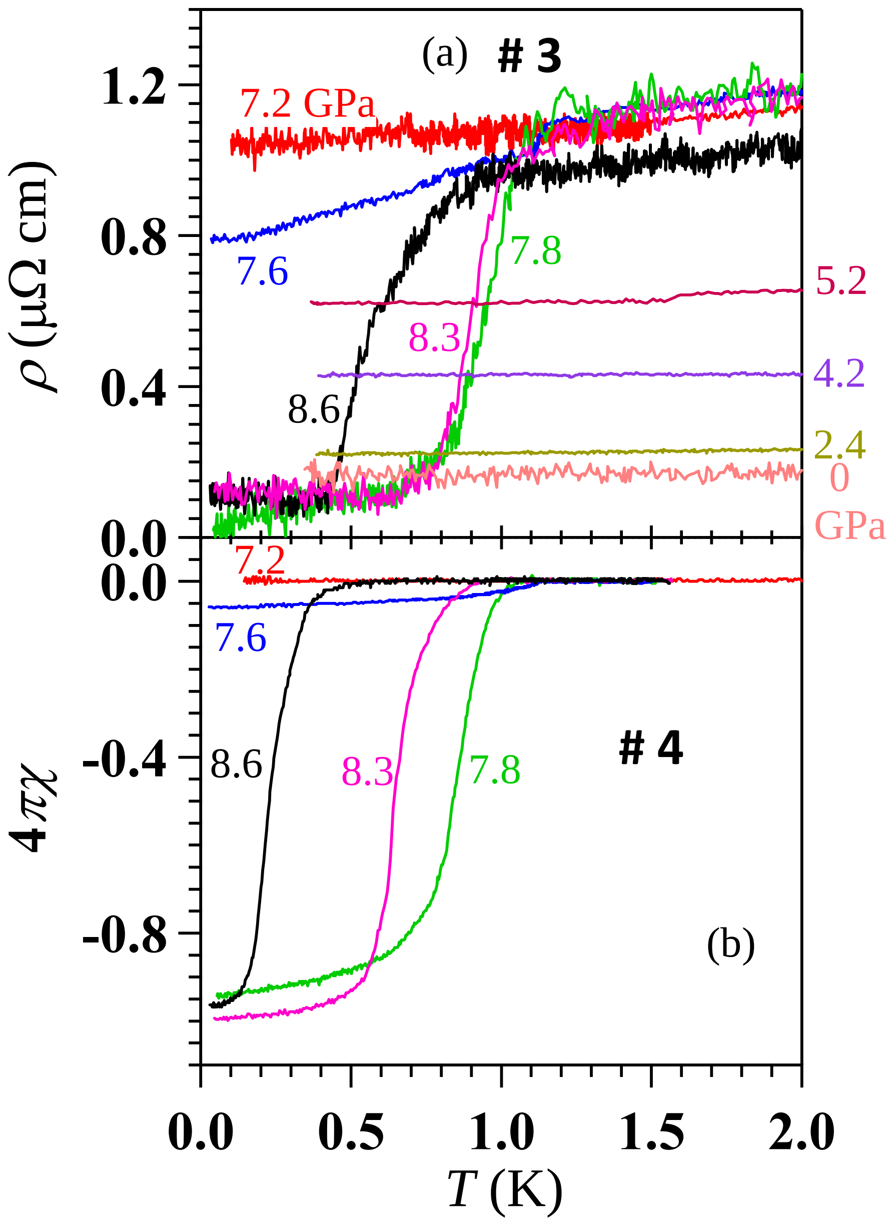
Kitagawa, JPSJ (2010)

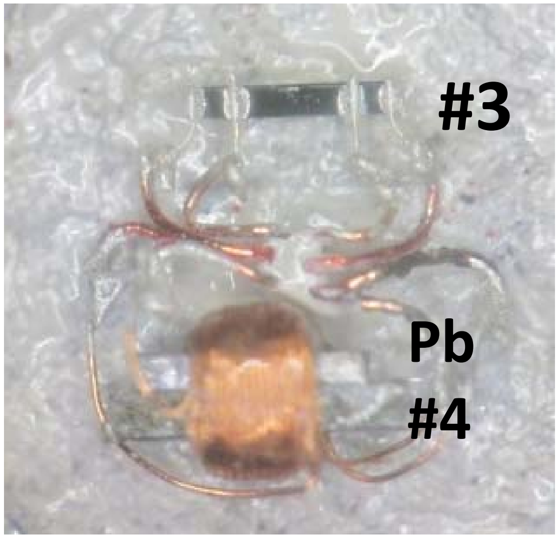
R(T) @HP: Cubic anvil cell



- ◆ **P suppresses the magnetic transition;**
- ◆ **Possible SC appears near the magnetic instability;**
- ◆ **P may alter the nature of magnetic transition**

R(T) @ HP: Opposite anvil cell

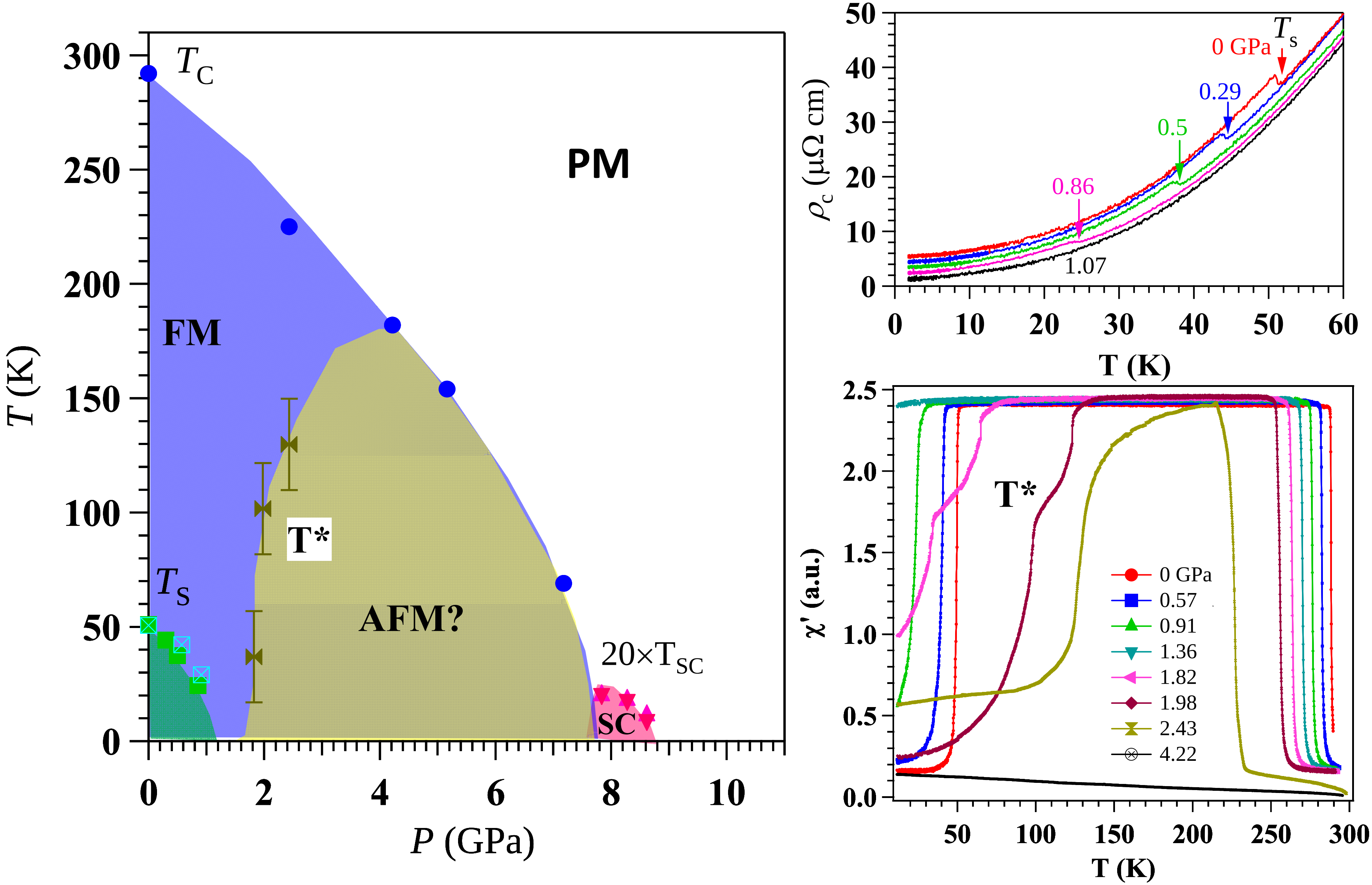




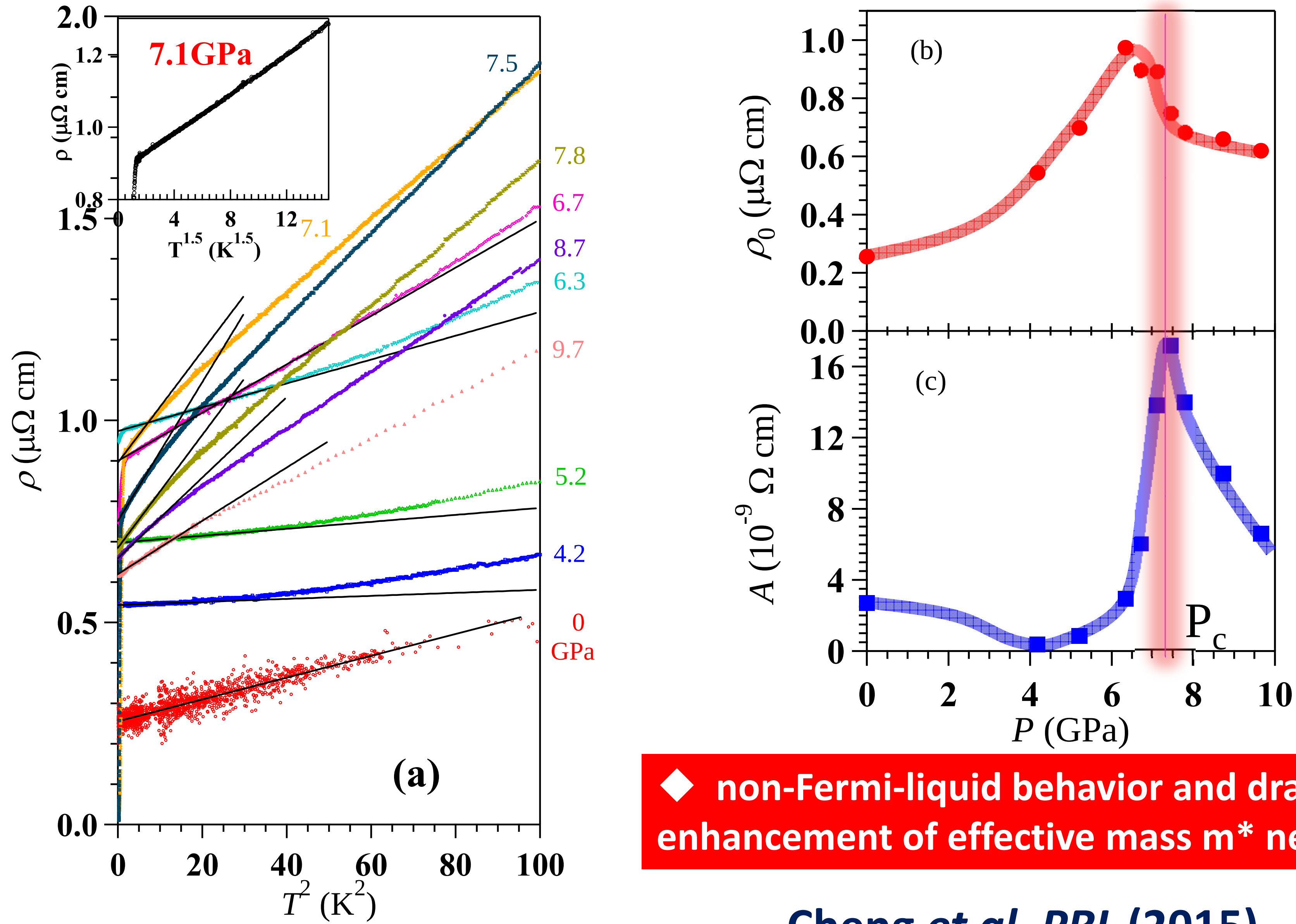
◆ Nearly perfect diamagnetic signal confirms the P-induced SC with a $T_{SC} \approx 1K$ in MnP;

◆ SC exists within a narrow pressure range where the magnetic transition just vanishes;

T-P phase diagram of MnP



Signatures of AFM QCP



◆ non-Fermi-liquid behavior and dramatic enhancement of effective mass m* near P_c

Cheng *et al. PRL* (2015)

Conclusion and outlooks

- P-induced magnetic QCP is an important approach to search for unconventional SC, e.g. CrAs and MnP.
- Expected to have more Cr- and Mn-based SCs….

- Open questions: What is the specialty for the helimagnetic QCP? Can we also realized SC in other helimagnets: FeP, FeAs? Nature of the AFM order in MnP?

Physics

Physics 8, 24 (2015)

Viewpoint

Superconductivity with a Twist

Michael R. Norman
Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, USA

Published March 16, 2015

The discovery of superconductivity in a manganese-based "helical" magnet opens a new path to explore the relationship between superconductivity and magnetism.