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Frank Capra's
"ARSENIC
and OLD LACE"


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RAYMOND MASSEY
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PRISCILLA LANE
JOSEPH LORRE
WARNER BROS.
FRANK CAPRA

Iron Arsenic Based Superconductors:

Three months with reduced sleep....(and counting).

Paul C. Canfield

Distinguished Professor of Physics

Senior Physicist, Ames Lab

Iowa State University

Boulder 2008 Summer School

Fe-As based superconductors part I

The end of the tyranny of copper

$RFeAs(O_{1-x}F_x)$ T_c up to 55 K

$RFeAsO_{1-x}$ T_c up to ~50 K

Hard to make, is this oxide physics, intermetallic physics, both, neither…?????

What is role of O / F?

What is the nature of the superconductivity, what is the symmetry of the gap?

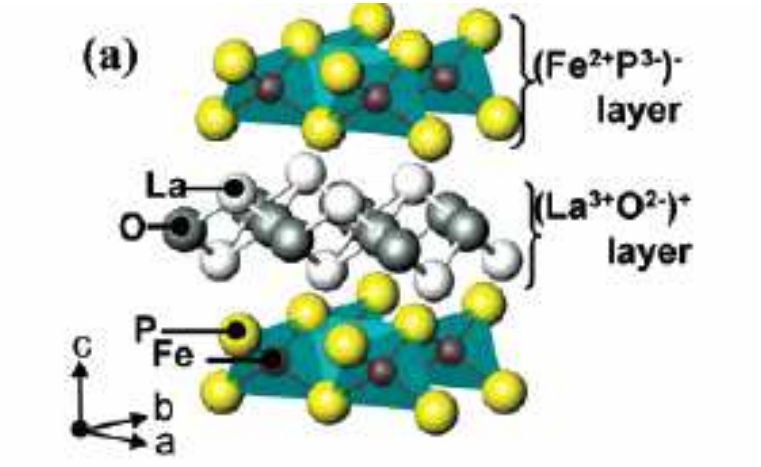
Received May 15, 2006; E-mail: hosono@msl.titech.ac.jp

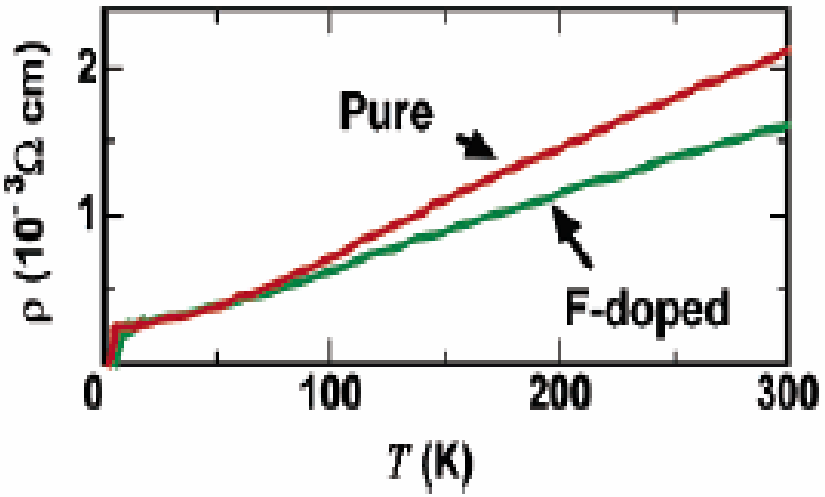
J|A|C|S COMMUNICATIONS

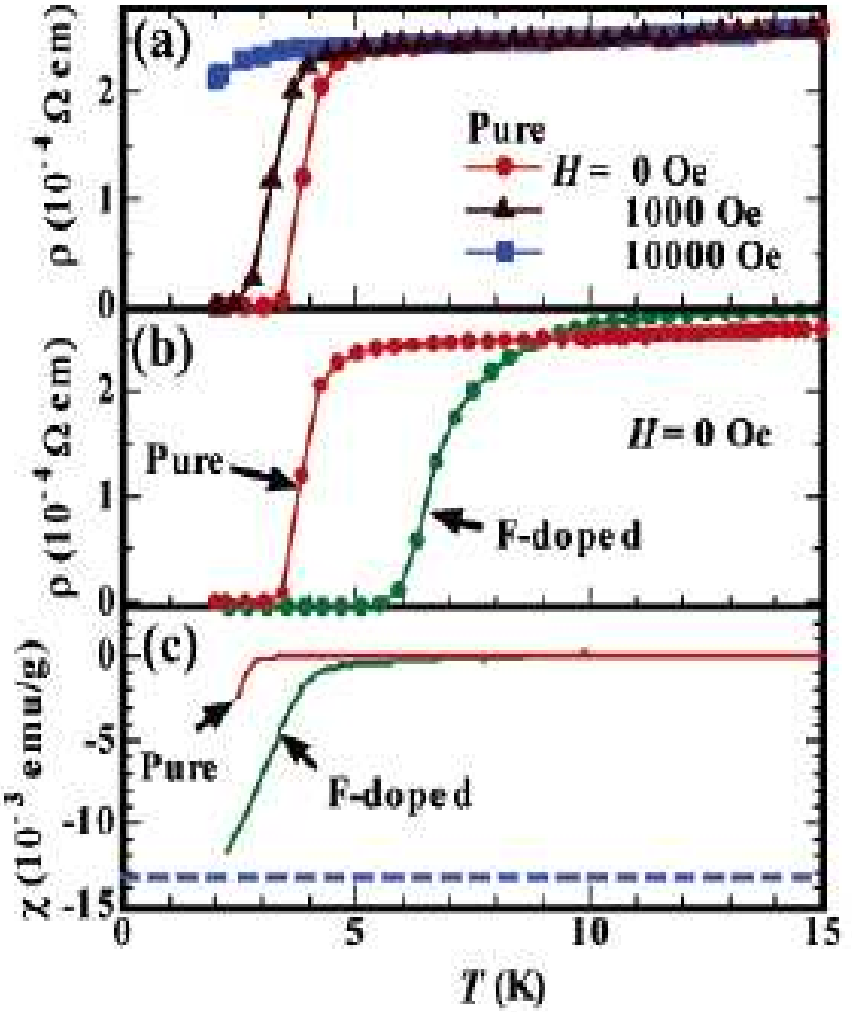
Published on Web 07/15/2006

Iron-Based Layered Superconductor: LaOFeP

Yoichi Kamihara,† Hidenori Hiramatsu,† Masahiro Hirano,†,‡ Ryuto Kawamura,§ Hiroshi Yanagi,§ Toshio Kamiya,†,§ and Hideo Hosono*,†,‡







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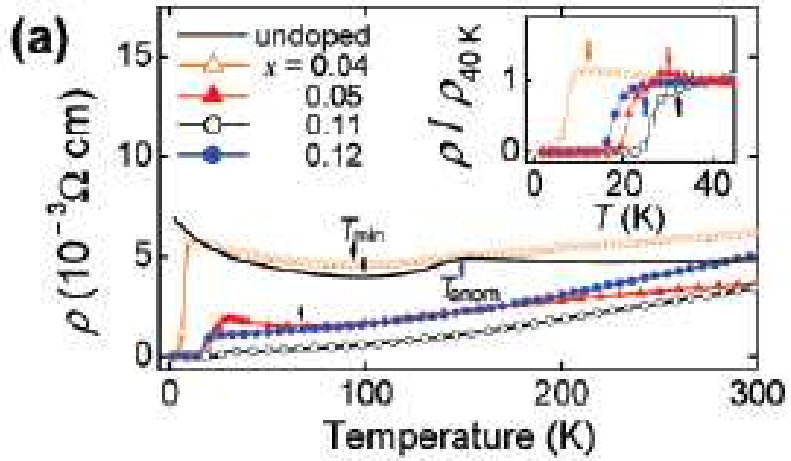
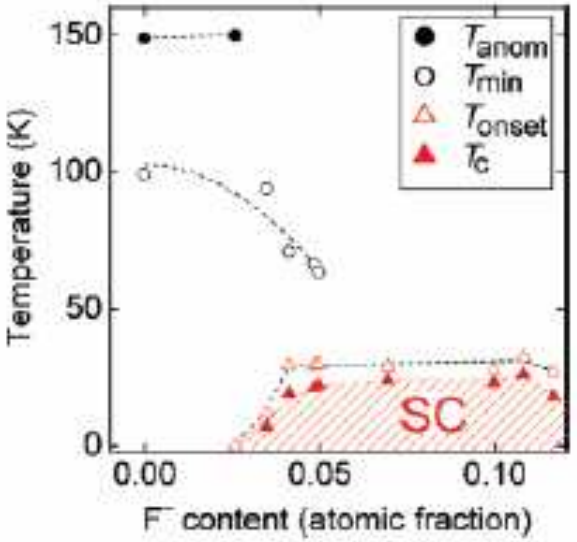
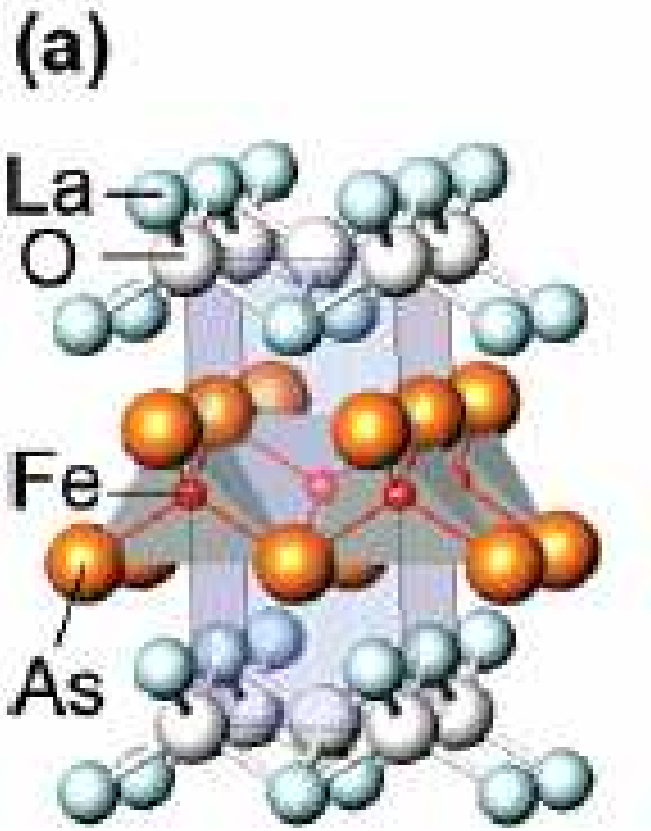
Published on Web 02/23/2008

Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05−0.12) with T_c = 26 K

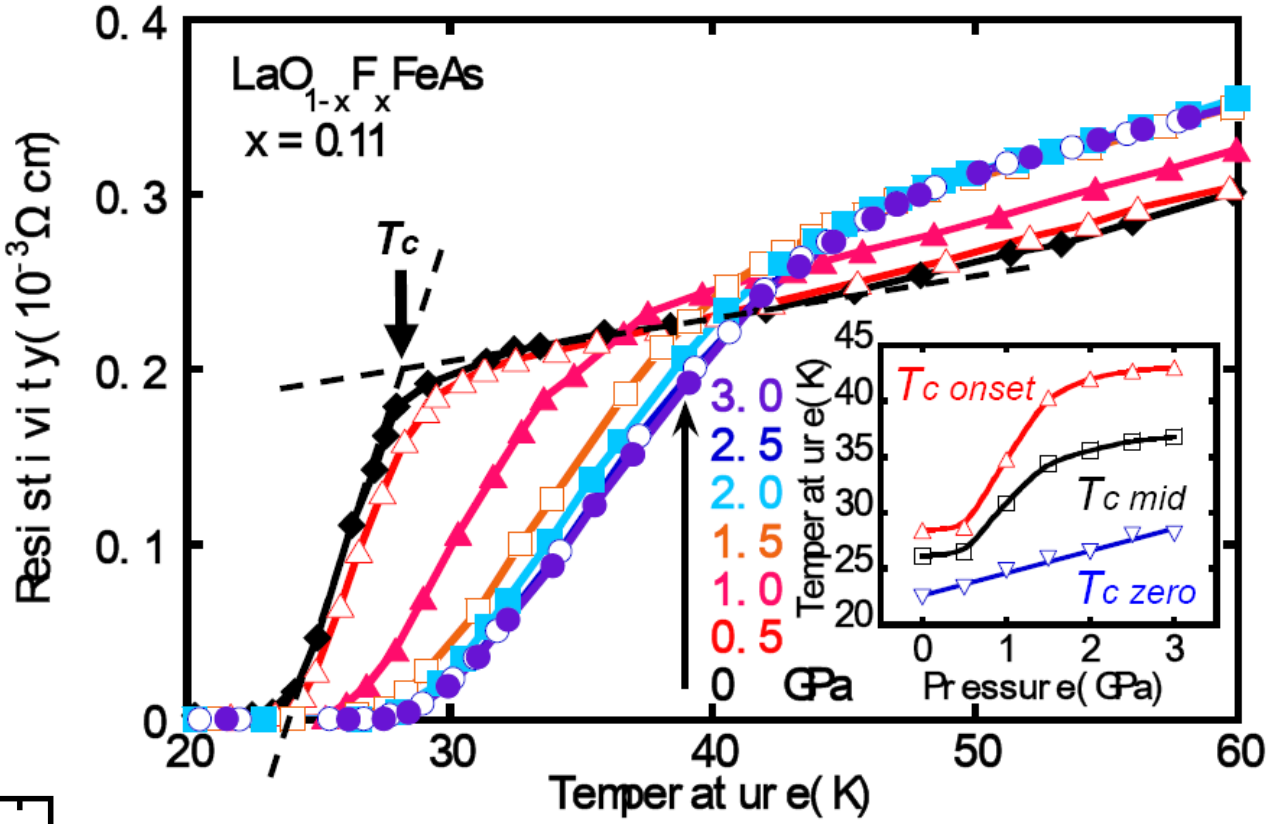
Yoichi Kamihara,*,† Takumi Watanabe,‡ Masahiro Hirano,†,§ and Hideo Hosono†,‡,§

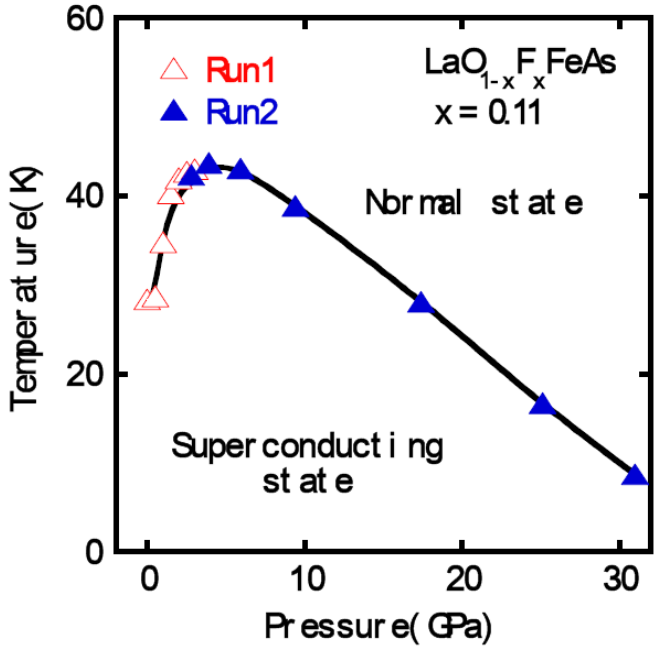






T_C can be tuned with pressure…A LOT!!





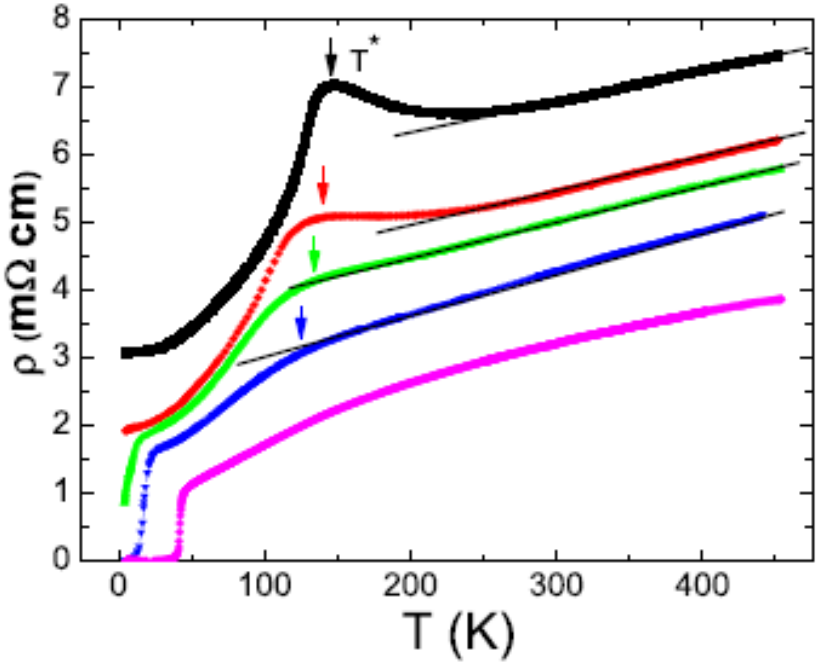
Superconductivity at 43 K in an iron-based layered compound $La[O_{1-x}F_x]FeAs$

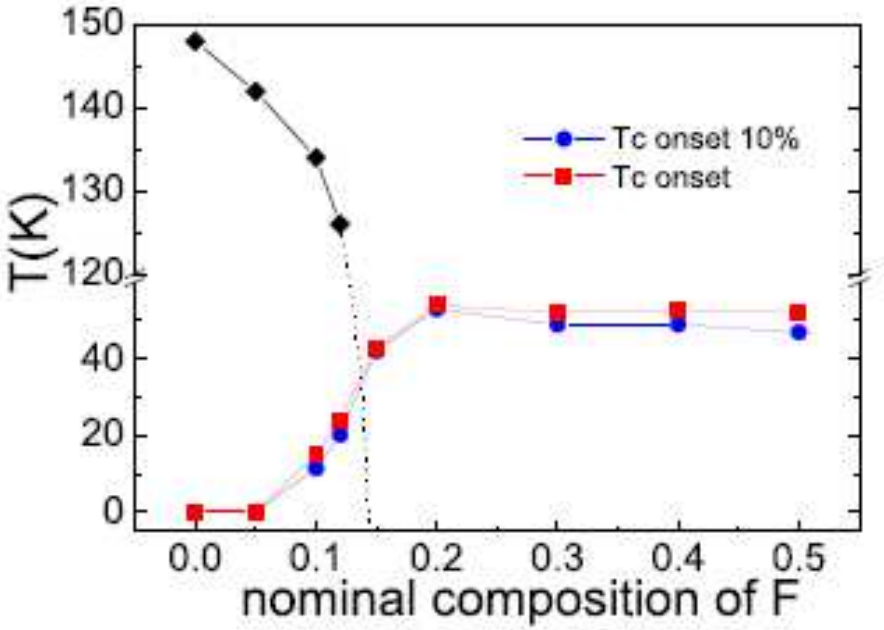
Hiroki Takahashi[1], Kazumi Igawa[1], Kazunobu Arii[1], Yoichi Kamihara[2], Masahiro Hirano[2,3], & Hideo Hosono[2,3]

An other way to change the volume of a RXY compound's unit cell is to change R….Use the lanthanide contraction.

Phase Diagram and Quantum Critical Point in Newly Discovered Superconductors: $SmO_{1-x}F_xFeAs$

R. H. Liu[1], G. Wu[1], T. Wu[1], D. F. Fang[1], H. Chen[1], S. Y. Li[2], K. Liu[1], Y. L. Xie[1], X. F. Wang[1], R. L. Yang[1], C. He[2], D. L. Feng[2] and X. H. Chen[1]*



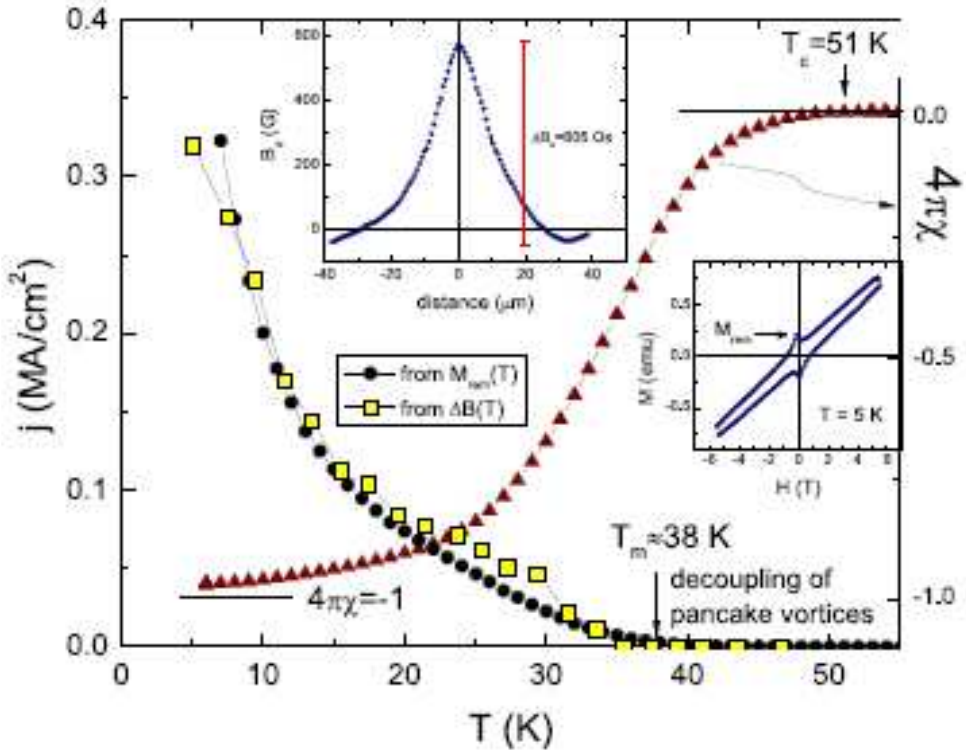


$NdFeAs(O_{0.9}F_{0.1})$

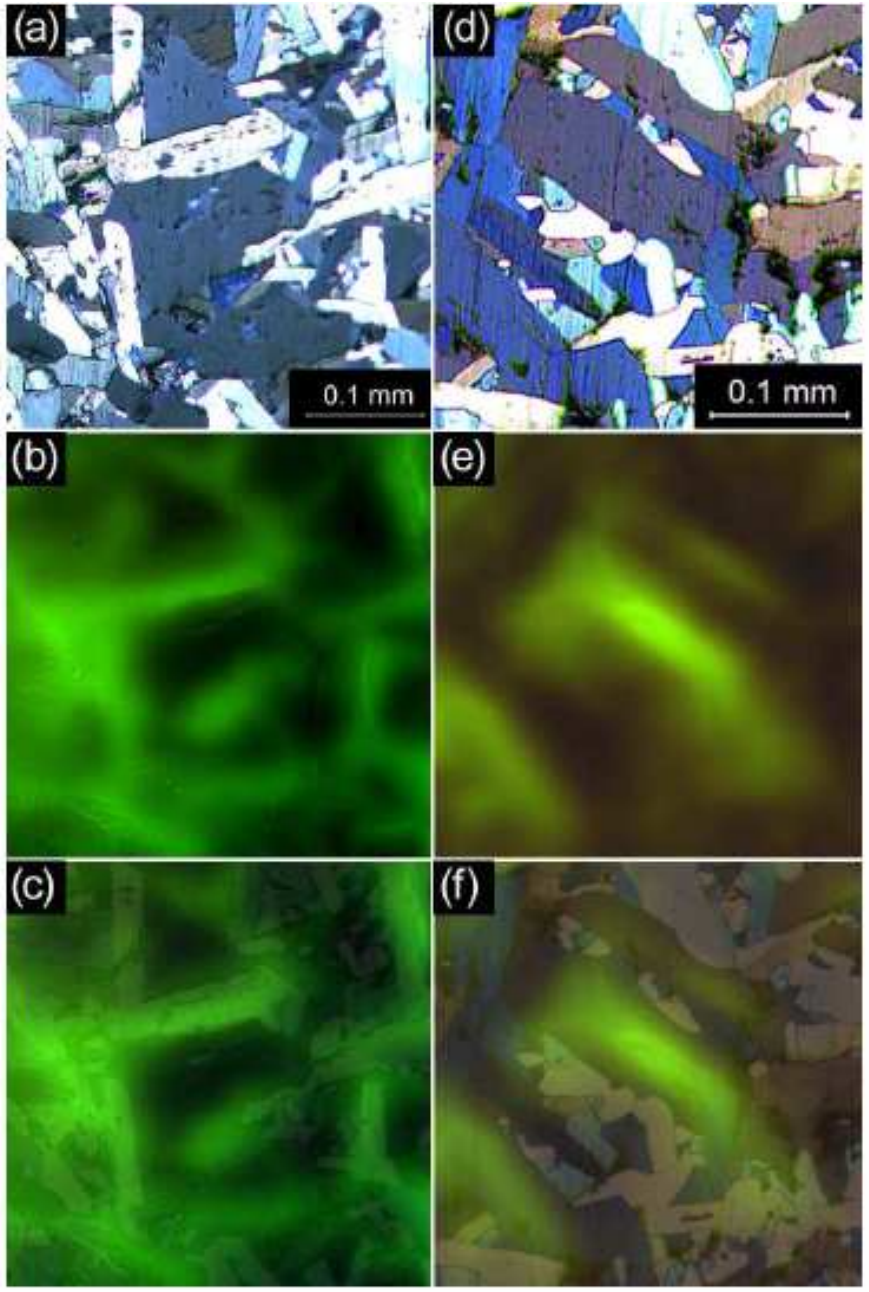
High pressure synthesis

T_C ~ 51-53 K

NOT single phased

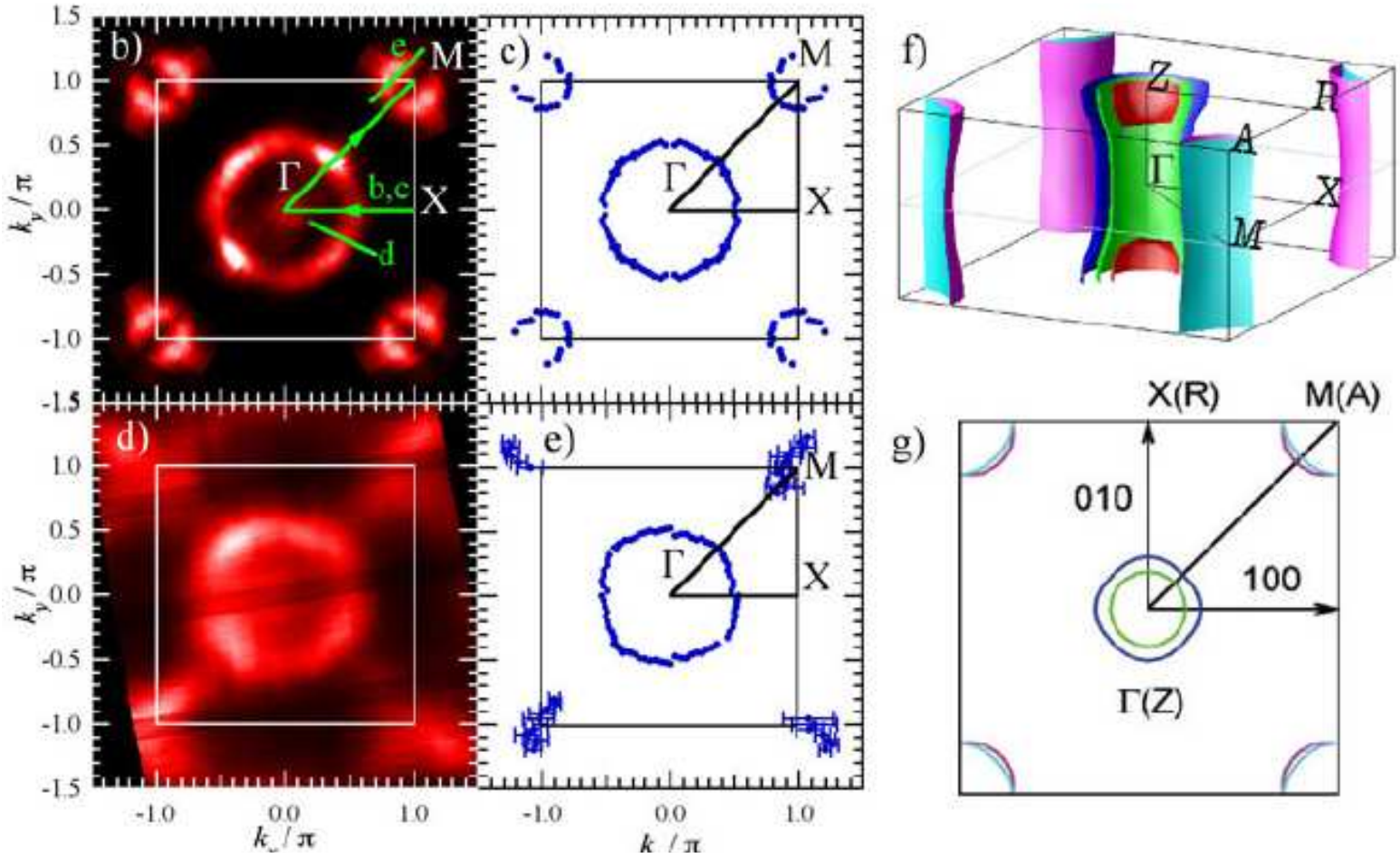


R. Prozorov,* M. E. Tillman, E. D. Mun, and P. C. Canfield
arXiv:0805.2783v2 [cond-mat.supr-con] 4 Jun 2008



Can find and isolate ~400 μm on a side plates/ grains

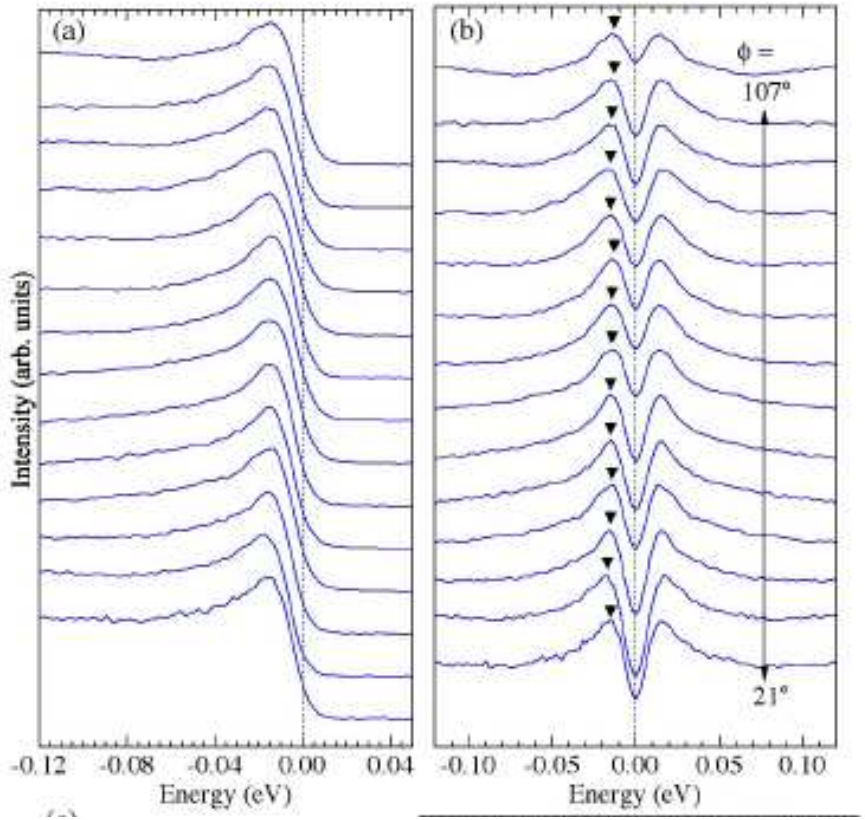
Using single grains we can perform ARPES and find Fermi surface and compare with band structure calculations....

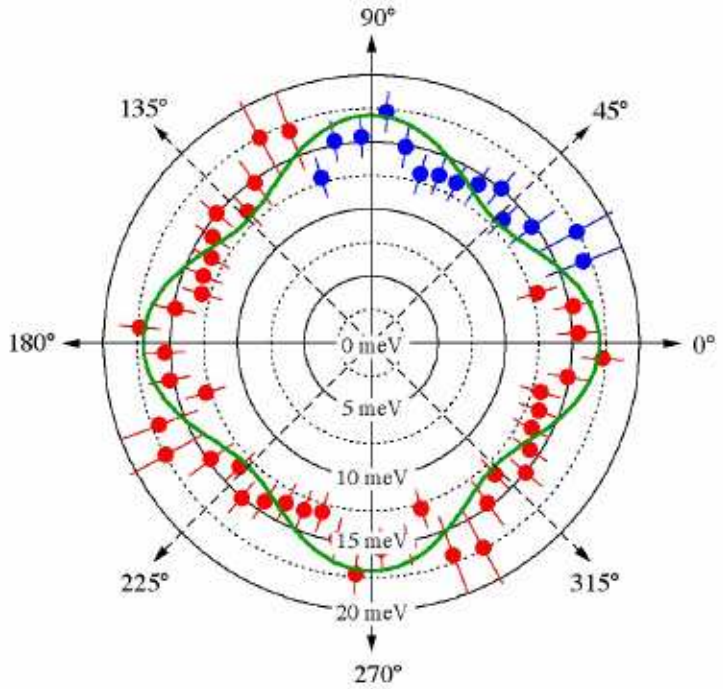


arXiv:0806.2147v3 [cond-mat.supr-con] 17 Jun 2008

C. Liu,[1] T. Kondo,[1] M. E. Tillman,[1] R. Gordon,[1] G. D. Samolyuk,[1] Y. Lee,[1] C. Martin,[1] J. L. McChesney,[2] S. Bud'ko,[1] M. A. Tanatar,[1] E. Rotenberg,[2] P. C. Canfield,[1] R. Prozorov,[1] B. N. Harmon,[1] and A. Kaminski[1]

Using single grains we can perform ARPES and find the superconducting gap and study its (lack of) anisotropy





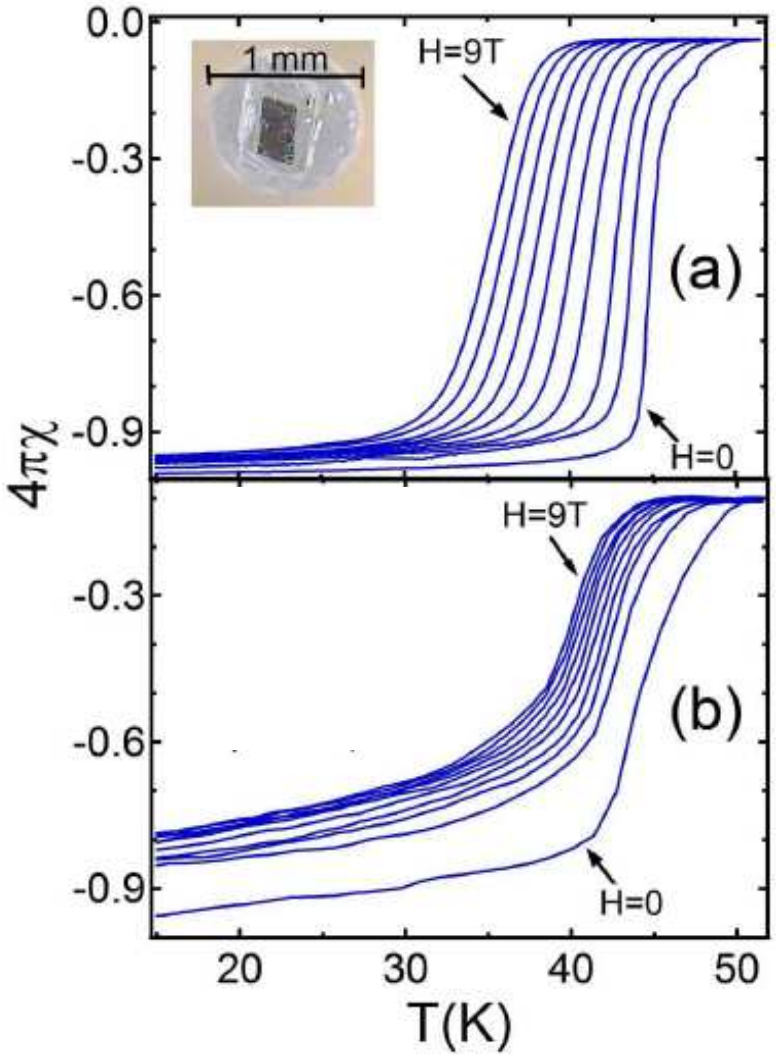
arXiv:0807.0815v1 [cond-mat.supr-con] 6 Jul 2008

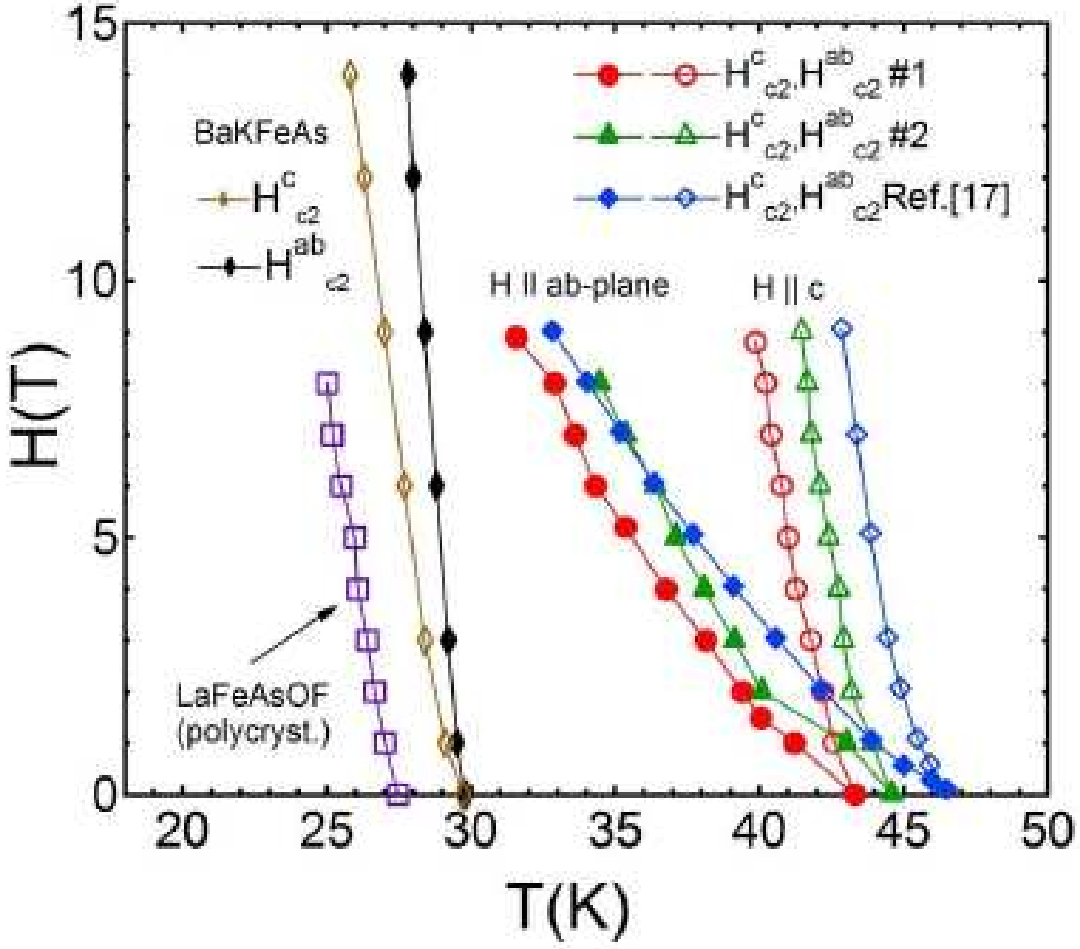
Takeshi Kondo,[1] A. F. Santander-Syro,[2,3] O. Copie,[4] Chang Liu,[1] M. E. Tillman,[1]
E. D. Mun,[1] J. Schmalian,[1] S. L. Bud'ko,[1] M. A. Tanatar,[1] P. C. Canfield,[1] and A. Kaminski[1]

Nodeless superconducting gap in $NdFeAsO_{0.9}F_{0.1}$ single crystals from anisotropic penetration depth studies

C. Martin, R. T. Gordon, M. A. Tanatar, M. D. Vannette, M. E. Tillman, E. D. Mun,
P. C. Canfield, V. G. Kogan, G. D. Samolyuk, J. Schmalian, and R. Prozorov*

arXiv:0807.0876v1 [cond-mat.supr-con] 5 Jul 2008





Nodeless superconducting gap in $NdFeAsO_{0.9}F_{0.1}$ single crystals from anisotropic penetration depth studies

arXiv:0807.0876v1 [cond-mat.supr-con] 5 Jul 2008

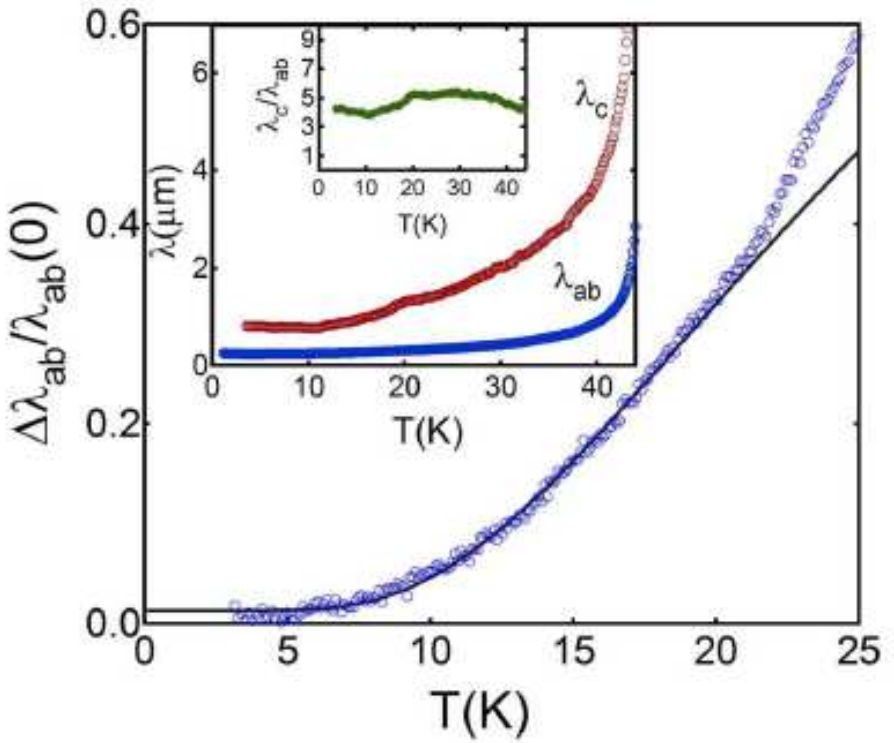


FIG. 3: (Color online)Low temperature region of $\Delta\lambda_{ab}/\lambda_0$. The solid line is the best fit to Eq. (1). The inset shows $\lambda_{ab}(T)$ and $\lambda_c(T)$. The smaller inset shows the ratio $\gamma_\lambda = \lambda_c(T)/\lambda_{ab}(T)$.

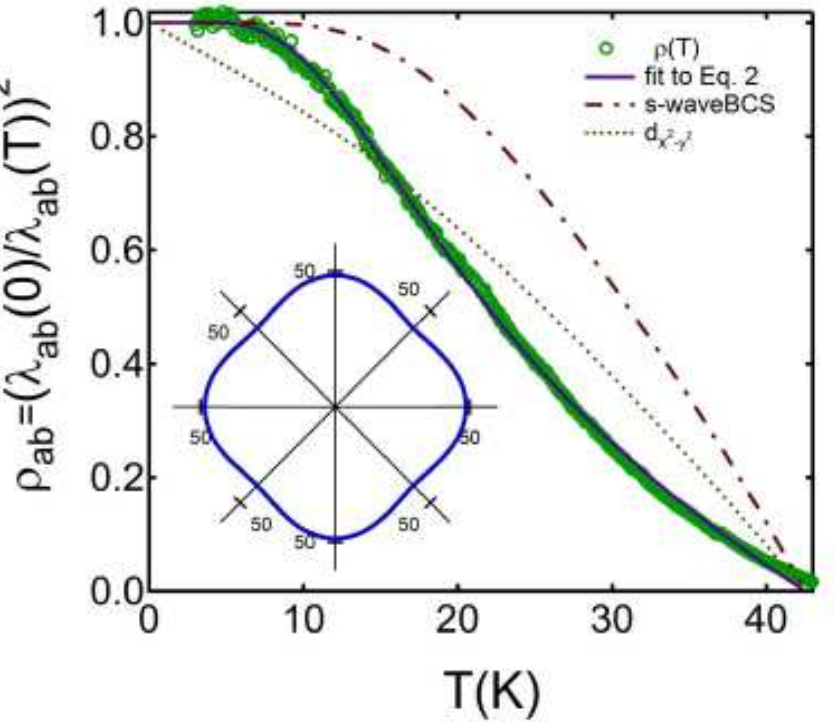


FIG. 4: (Color online)The in-plane superfluid density vs. temperature (symbols). Solid line is a fit to an anisotropic gap described by Eq. 3. The inset shows the angular dependence of the fitting gap. The s-wave BCS (lines and dots) and pure d-wave (dotted line) superfluid densities are plotted for comparison.

$$\frac{\Delta\lambda(T)}{\lambda(0)} = \sqrt{\frac{\pi\Delta_0}{2T}}\exp\left(-\frac{\Delta_0}{T}\right). \qquad (1)$$

$$\Delta(\varphi,T) = \Delta(T)\,\frac{1+\varepsilon\cos(4\varphi)}{1+\varepsilon}, \qquad (3)$$

Final comments on current state of RFeAsO samples and data.

Exact knowledge of how much F goes in or how much O is missing are qualitative at best.

All polycrystalline samples are mixed phase to some extent (in many cases to a very large extent).

Grow of the RFeAsO compounds is very complicated and controlling O or F exacerbates this problem.

Largest single crystals / single grains are on the order of 200-400 μm.

A lot of work needs to be done to get samples "under control".

There may be an intrinsic O-deficiency in these materials.

Fe-As based superconductors part II

Not even oxide physics!!!!

$(AE_{1-x}A_x)Fe_2As_2$ $T_C \sim 40$ K

AE = Ba, Sr, Ca A = K, Na, Li

Much easier to make (there are not oxides but true intermetallics)

What is role of A doping?

What is the nature of the superconductivity, what is the symmetry of the gap?

Superconductivity at 38 K in the iron arsenide $(Ba_{1-x}K_x)Fe_2As_2$

Marianne Rotter, Marcus Tegel and Dirk Johrendt*

arXiv:0805.4630v1 [cond-mat.supr-con] 29 May 2008

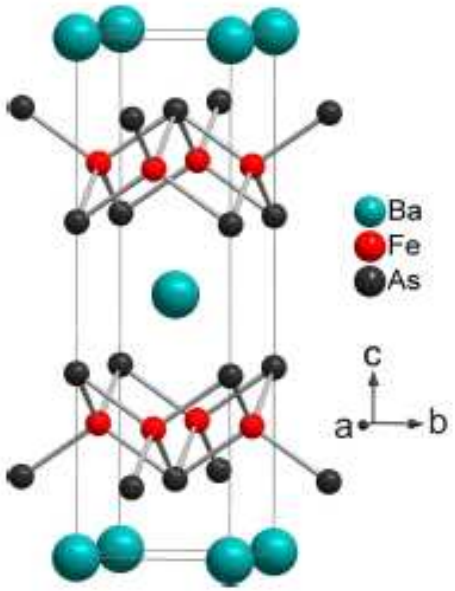
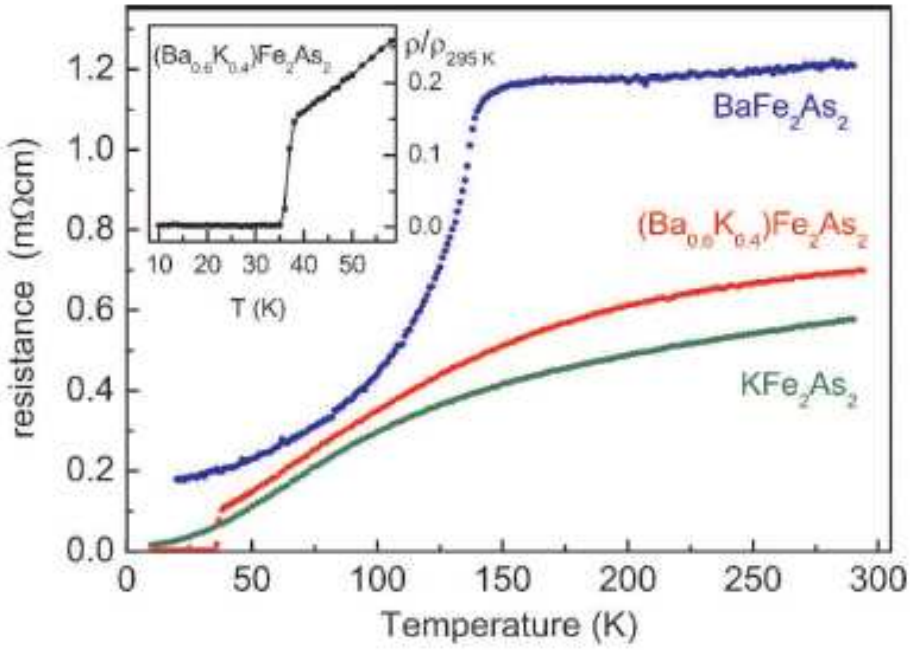
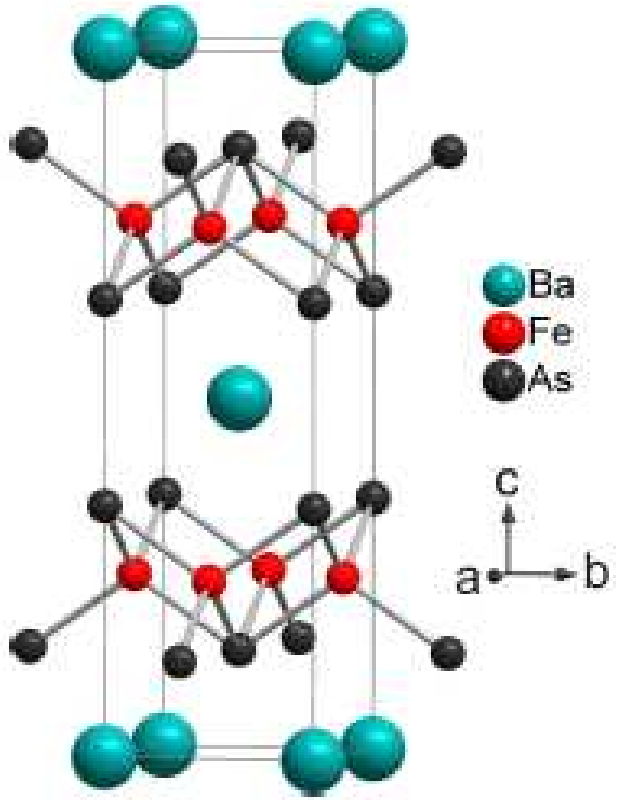


FIG. 1: Crystal structure of $BaFe_2As_2$.



In both of these structures there is a square planar sheet of Fe that is capped top and bottom with As. The A or RO layers separate these FeAs units.



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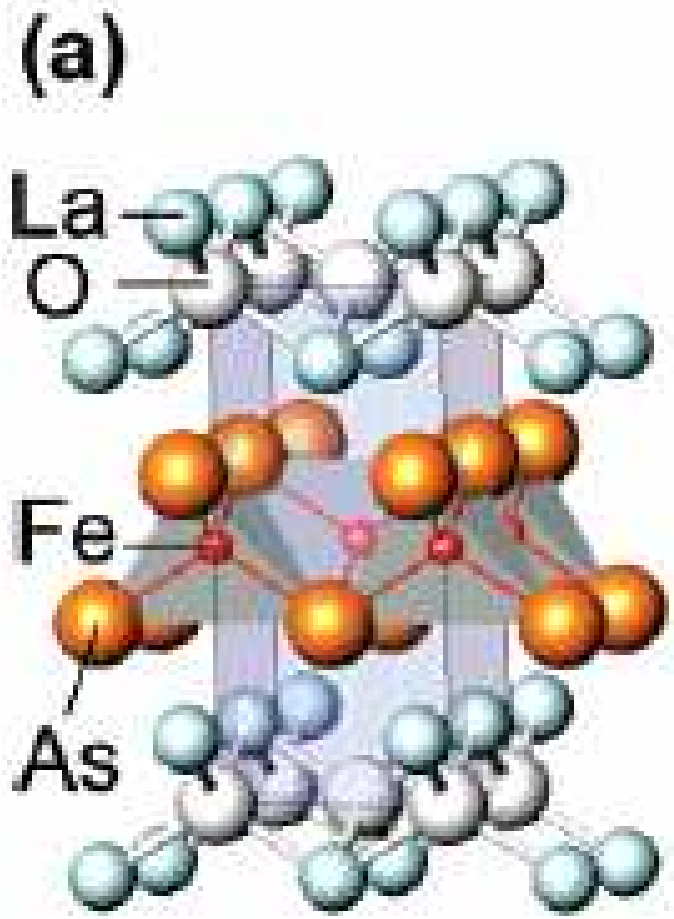
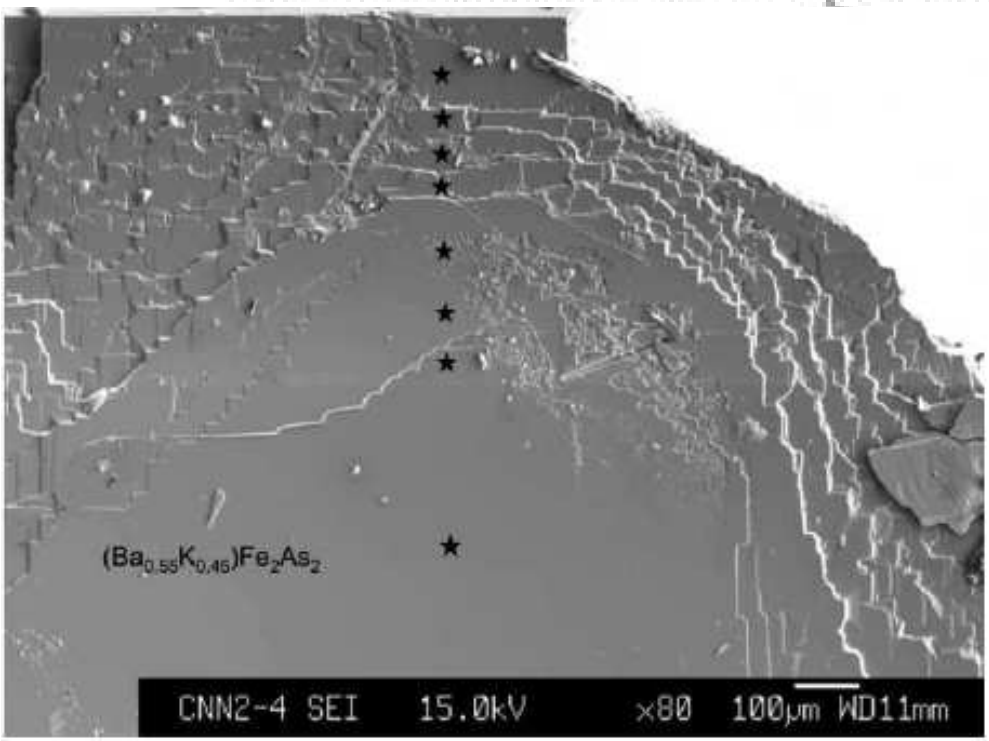


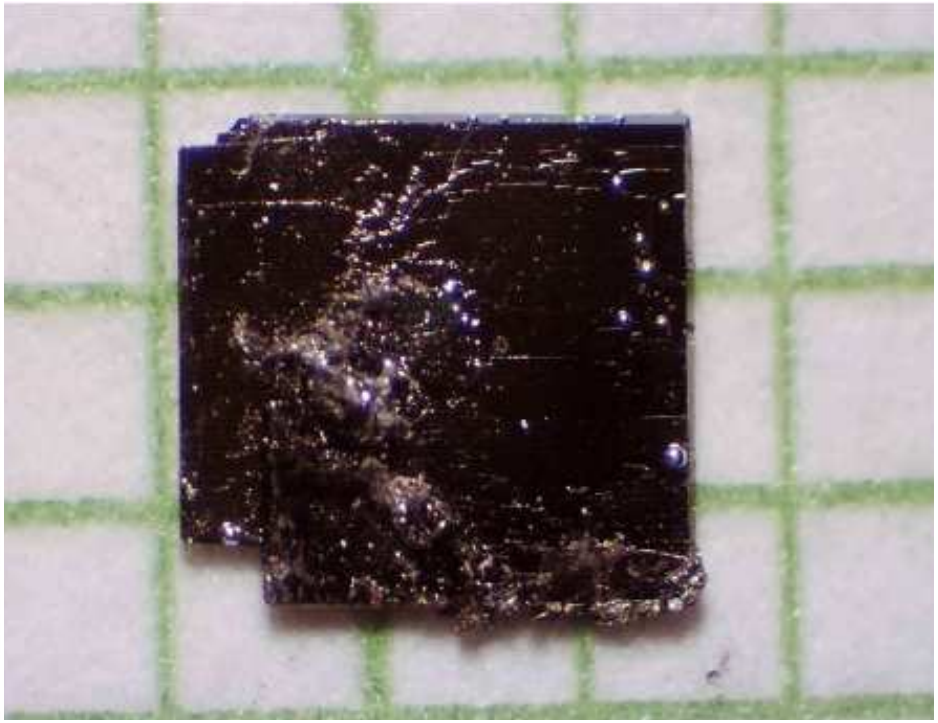
Within two days of reading Rotter's discovery we had grown large single crystals. Now single crystal work can really begin.

Anisotropic thermodynamic and transport properties of single crystalline $(Ba_{1-x}K_x)Fe_2As_2$ ($x = 0$ and 0.45).

N. Ni[1,2], S. L. Bud'ko[1,2], A. Kreyssig[1,2], S. Nandi[1,2], G. E. Rustan[1,2], A. I. Goldman[1,2], S. Gupta[1,3], J. D. Corbett[1,3], A. Kracher[1], and P. C. Canfield[1,2]

arXiv:0806.1874v1 [cond-mat.supr-con] 11 Jun 2008





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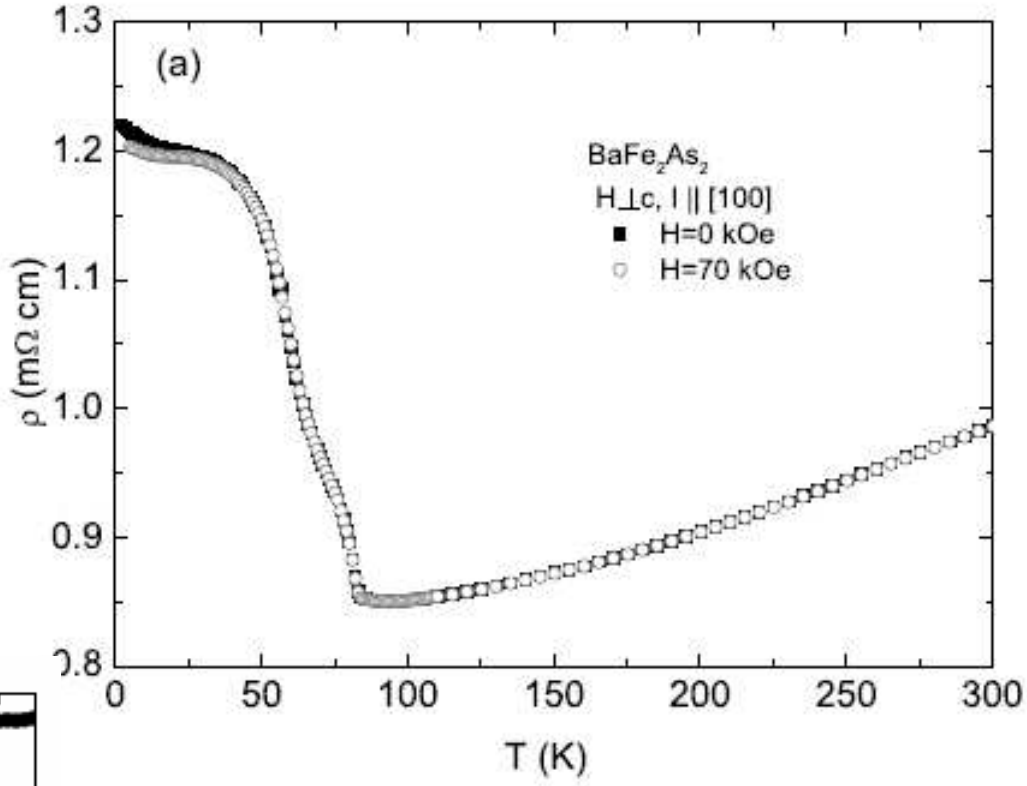
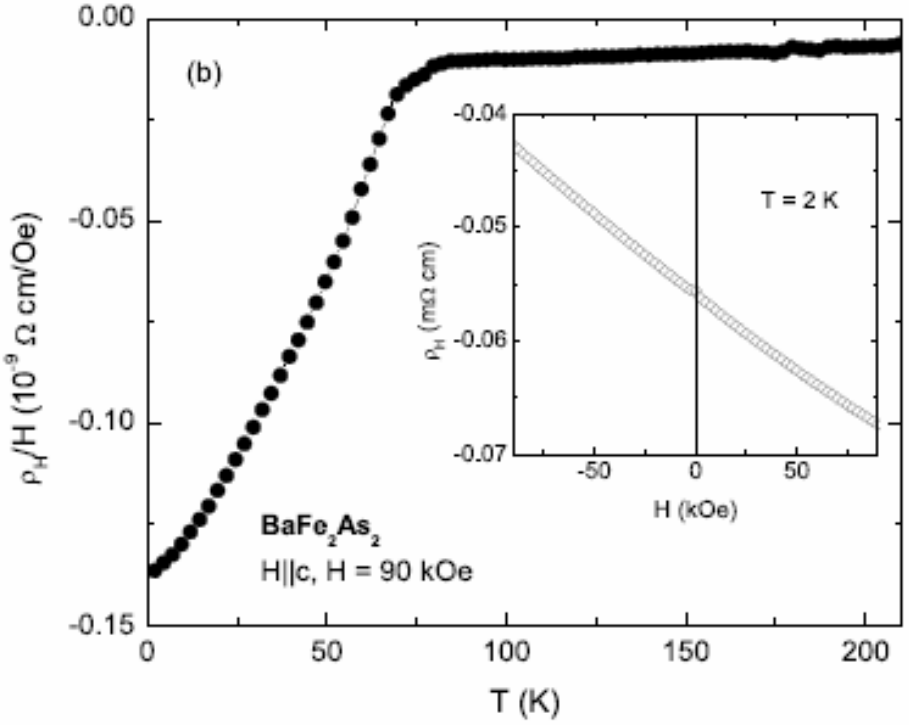
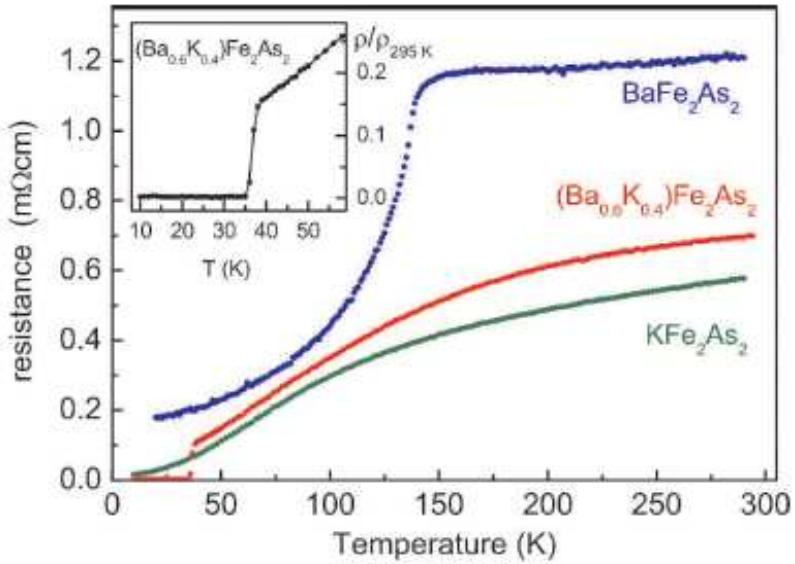
arXiv:0806.1874v1 [cond-mat.supr-con] 11 Jun 2008

$BaFe_2As_2$ has ~1% Sn substituted for As. Phase transition at ~ 80 K



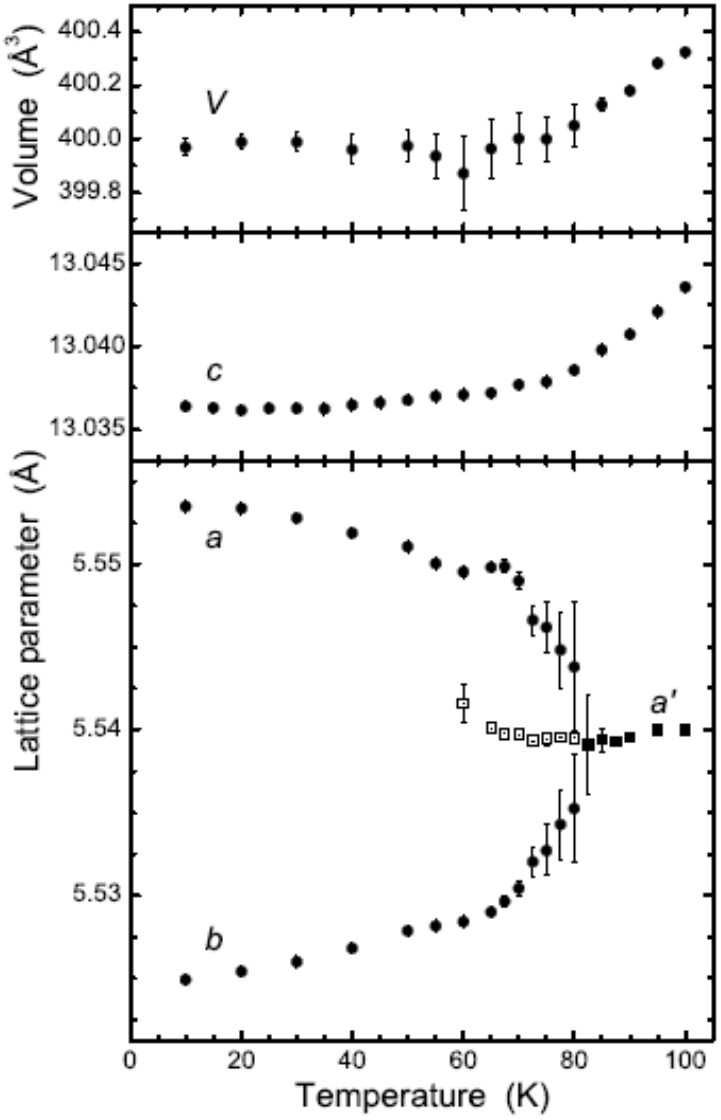


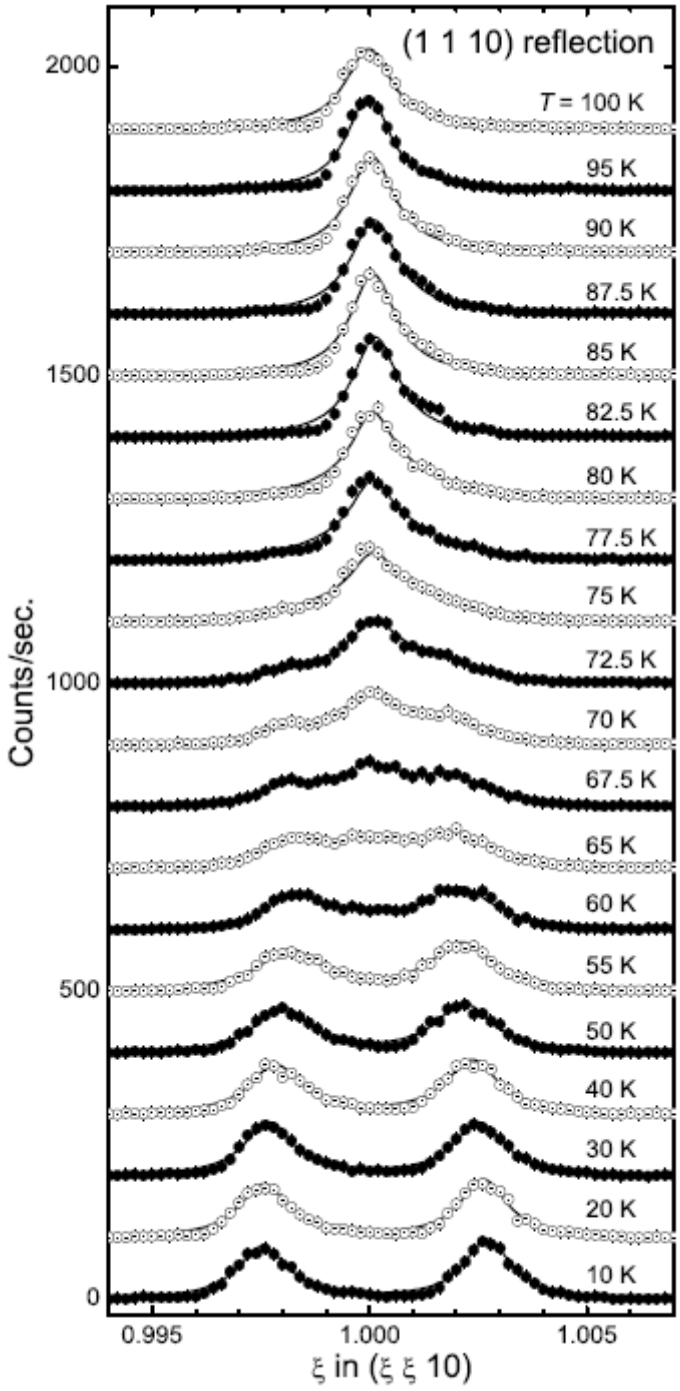


Clear tet –ortho transition and probably may be first order

Anisotropic thermodynamic and transport properties of single crystalline $(Ba_{1-x}K_x)Fe_2As_2$ ($x = 0$ and 0.45).

N. Ni[1,2], S. L. Bud'ko[1,2], A. Kreyssig[1,2], S. Nandi[1,2], G. E. Rustan[1,2], A. I. Goldman[1,2], S. Gupta[1,3], J. D. Corbett[1,3], A. Kracher[1], and P. C. Canfield[1,2]





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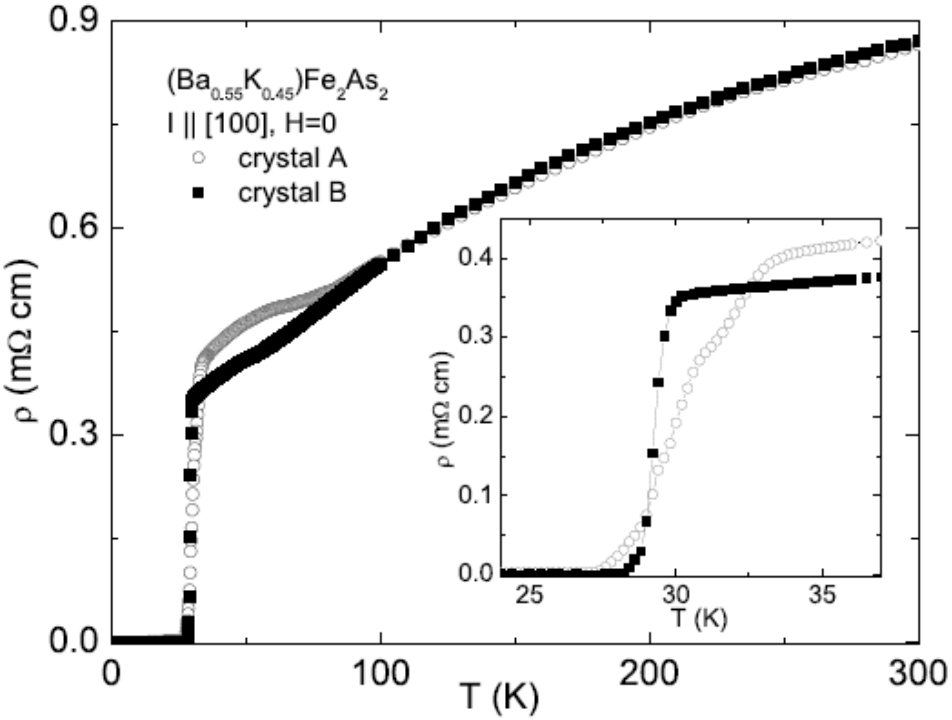

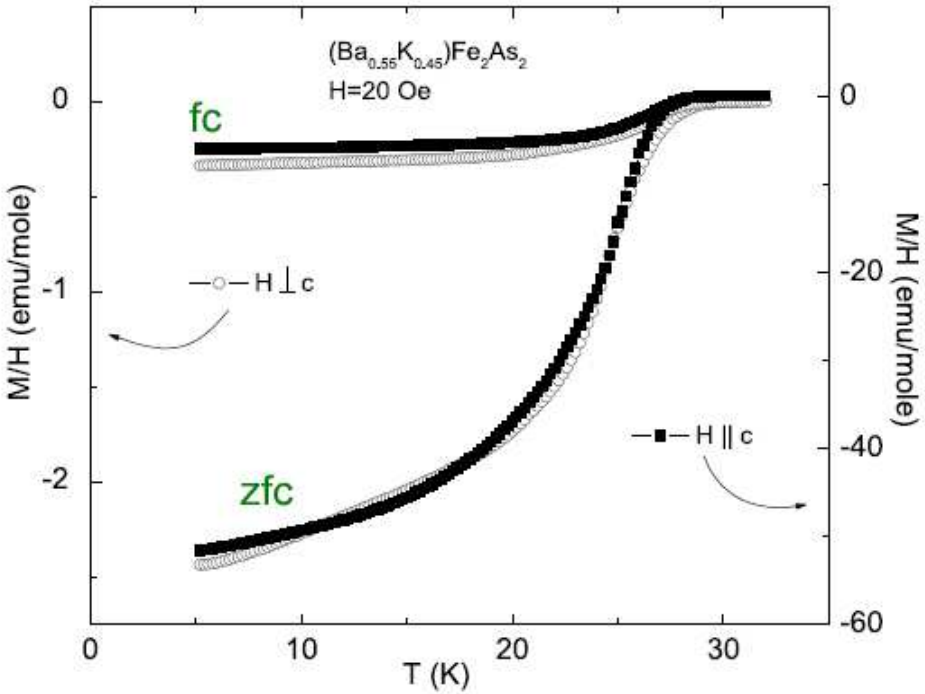

When K is substituted for Ba we get T_C of 30 K for ~40% K.

NOTE: from elemental analysis K values vary from plane to plane 40 +- 7 %

Anisotropic thermodynamic and transport properties of single crystalline $(Ba_{1-x}K_x)Fe_2As_2$ ($x = 0$ and 0.45).

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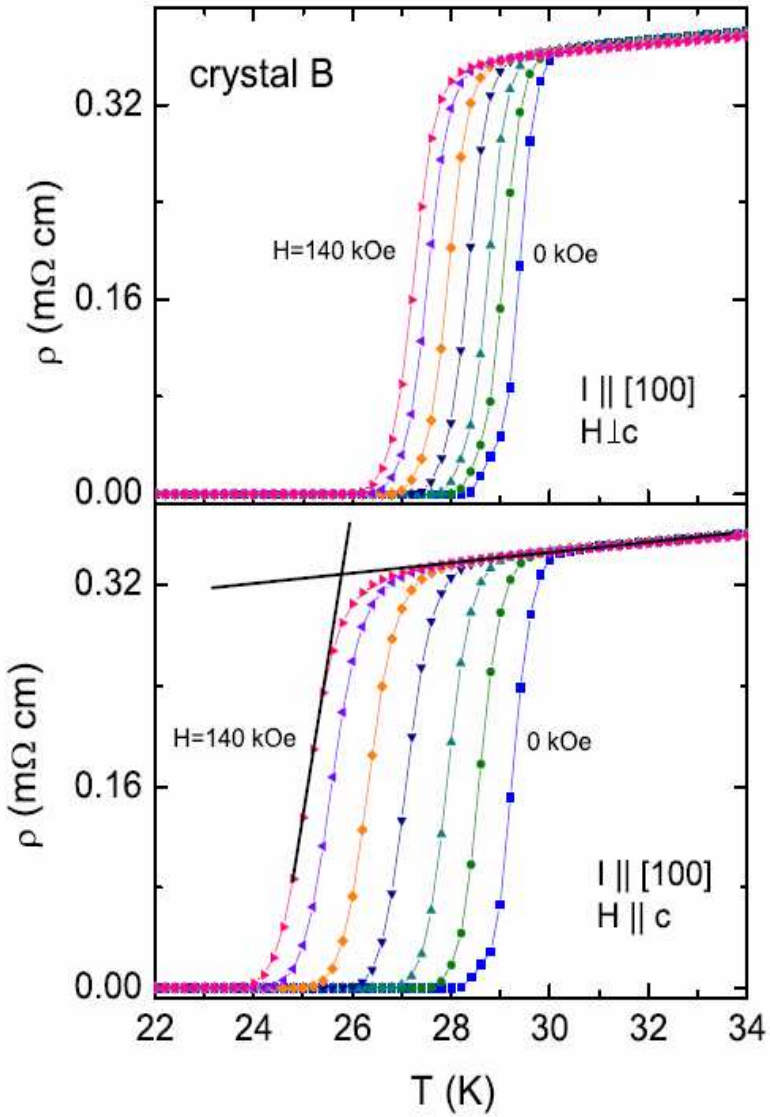
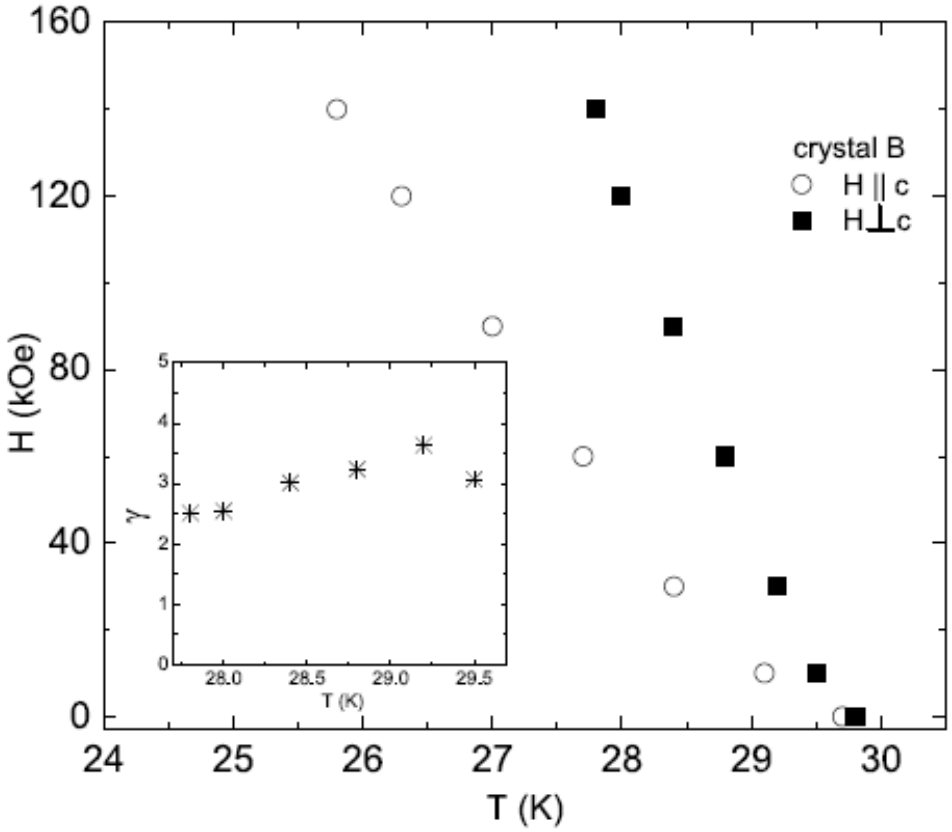
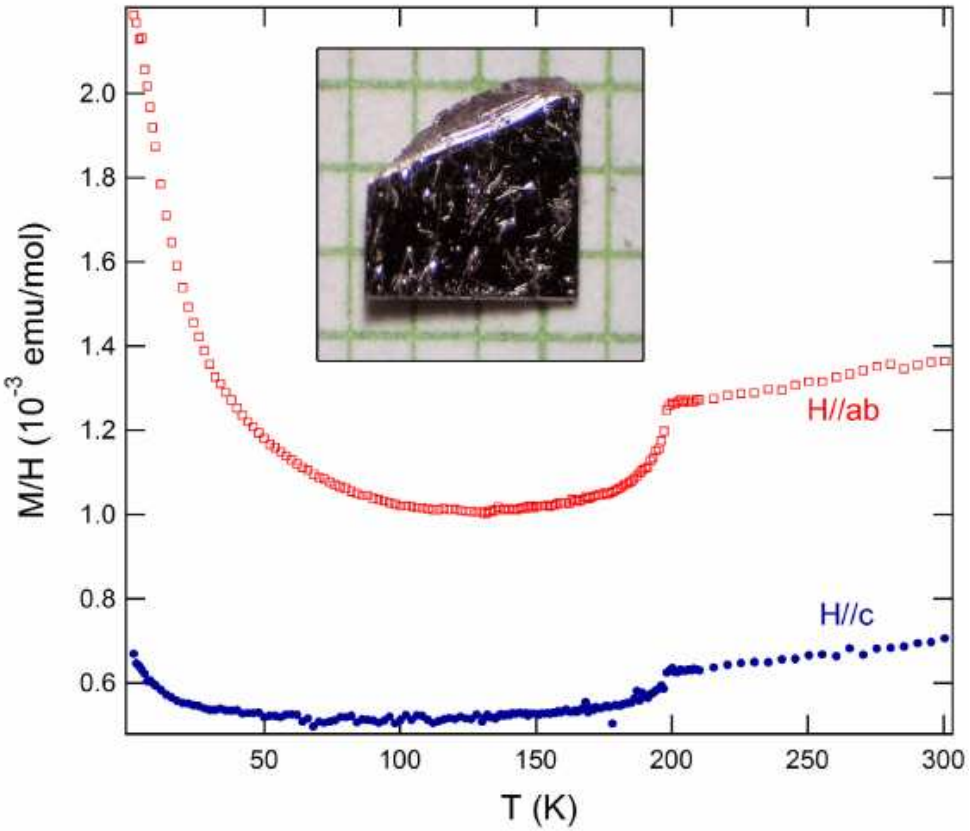
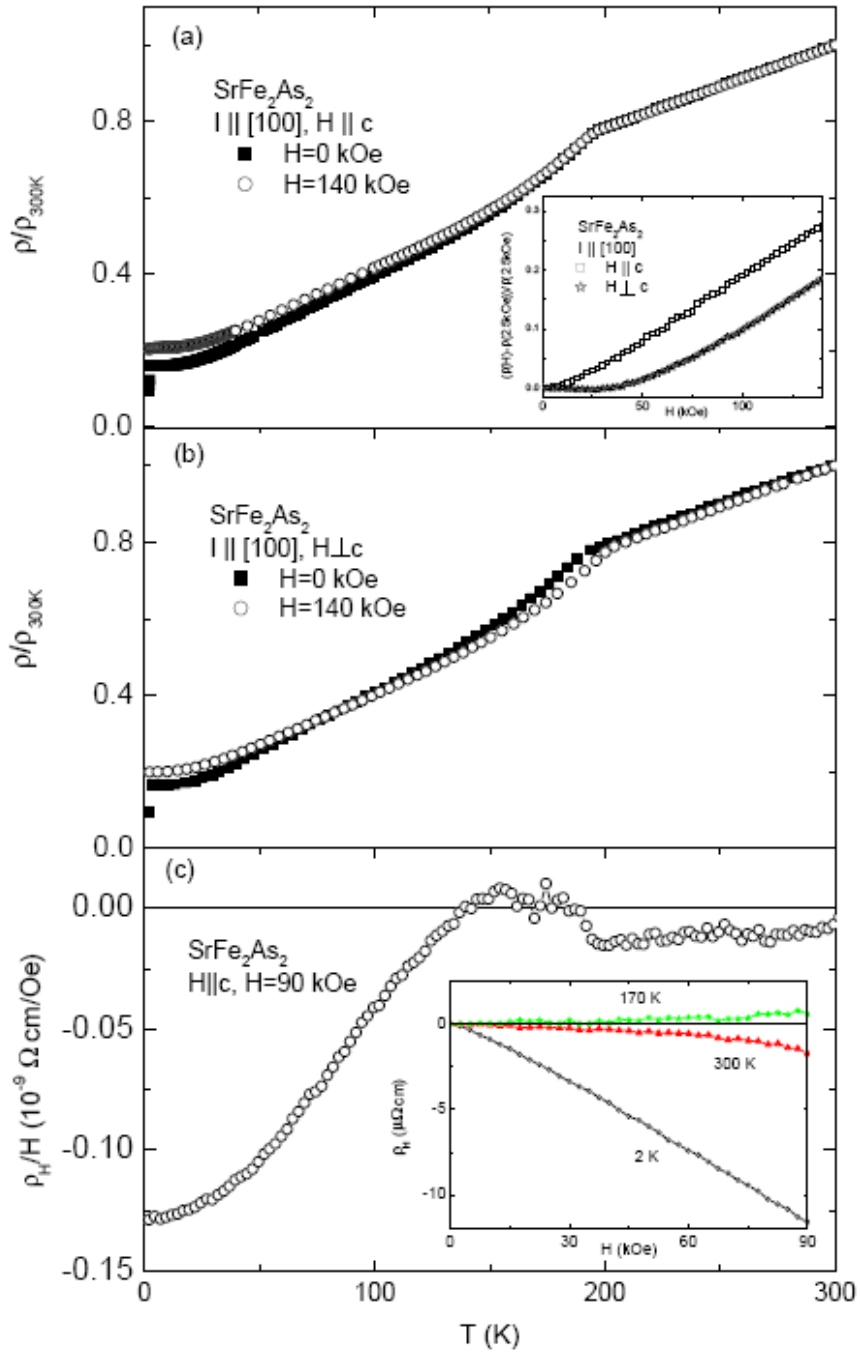




Structural transition and anisotropic properties of single crystalline $SrFe_2As_2$

J.-Q. Yan,[1] A. Kreyssig,[1,2] S. Nandi,[1,2] N. Ni,[1,2] S. L. Bud'ko,[1,2] A. Kracher,[1] R. J. McQueeney,[1,2] R. W. McCallum,[1,3] T. A. Lograsso,[1] A. I. Goldman,[1,2] and P. C. Canfield[1,2]





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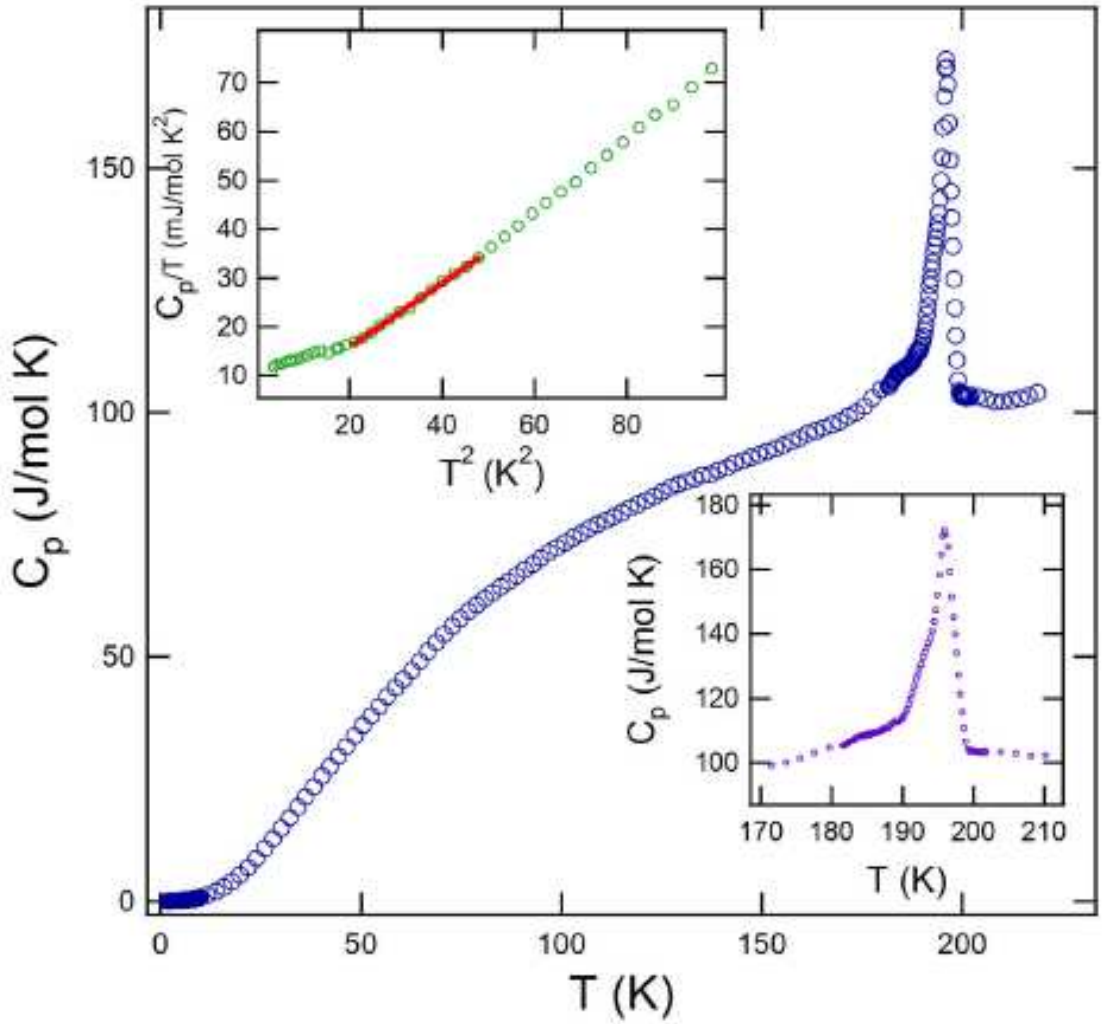
and P. C. Canfield[1,2]



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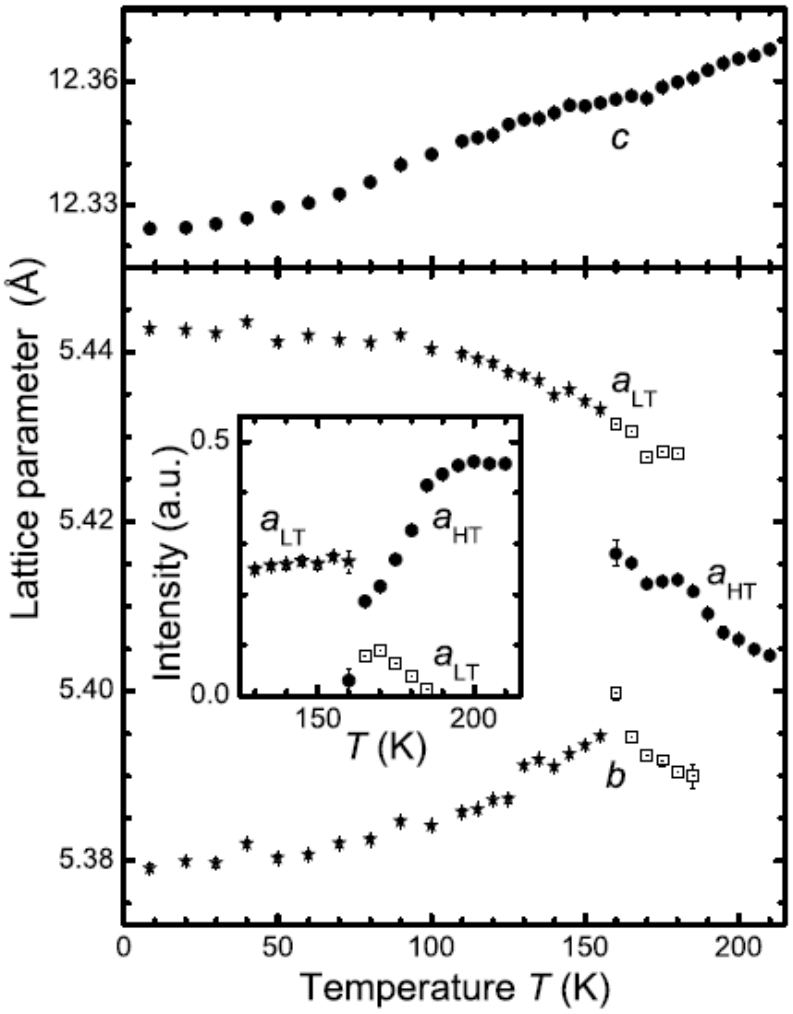
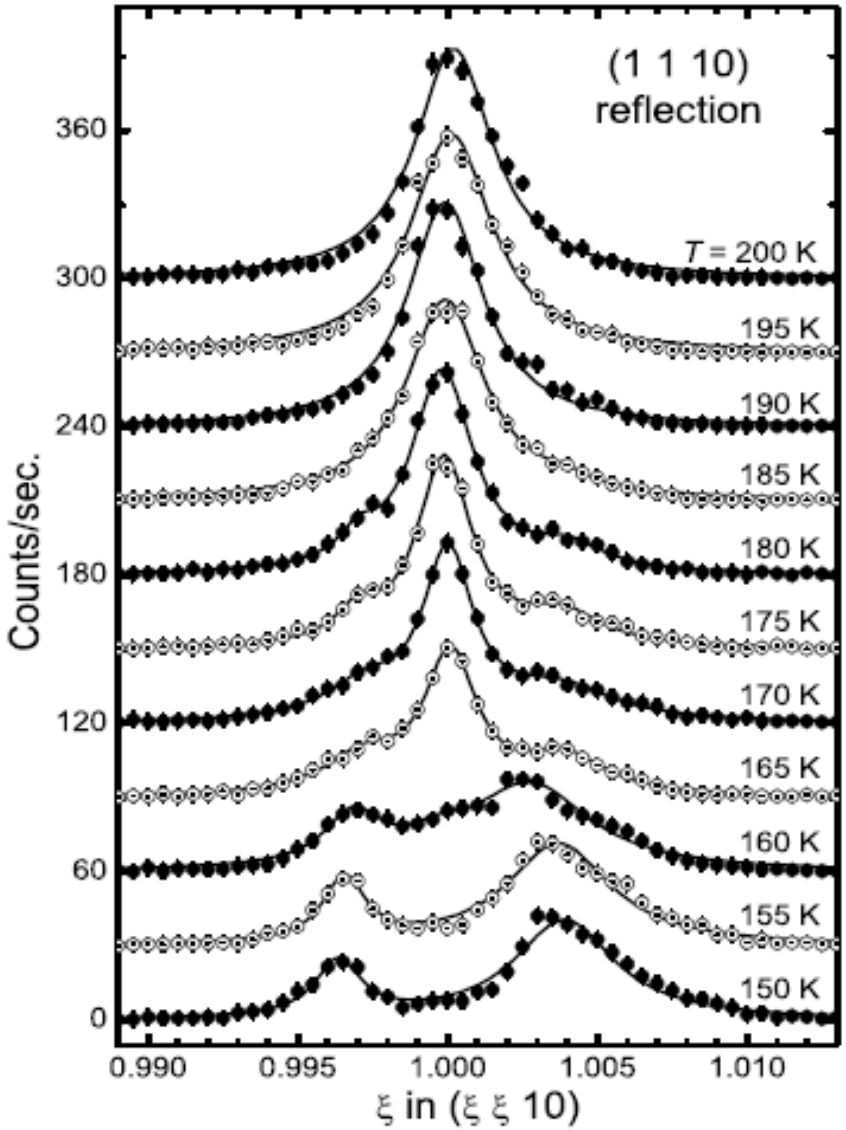
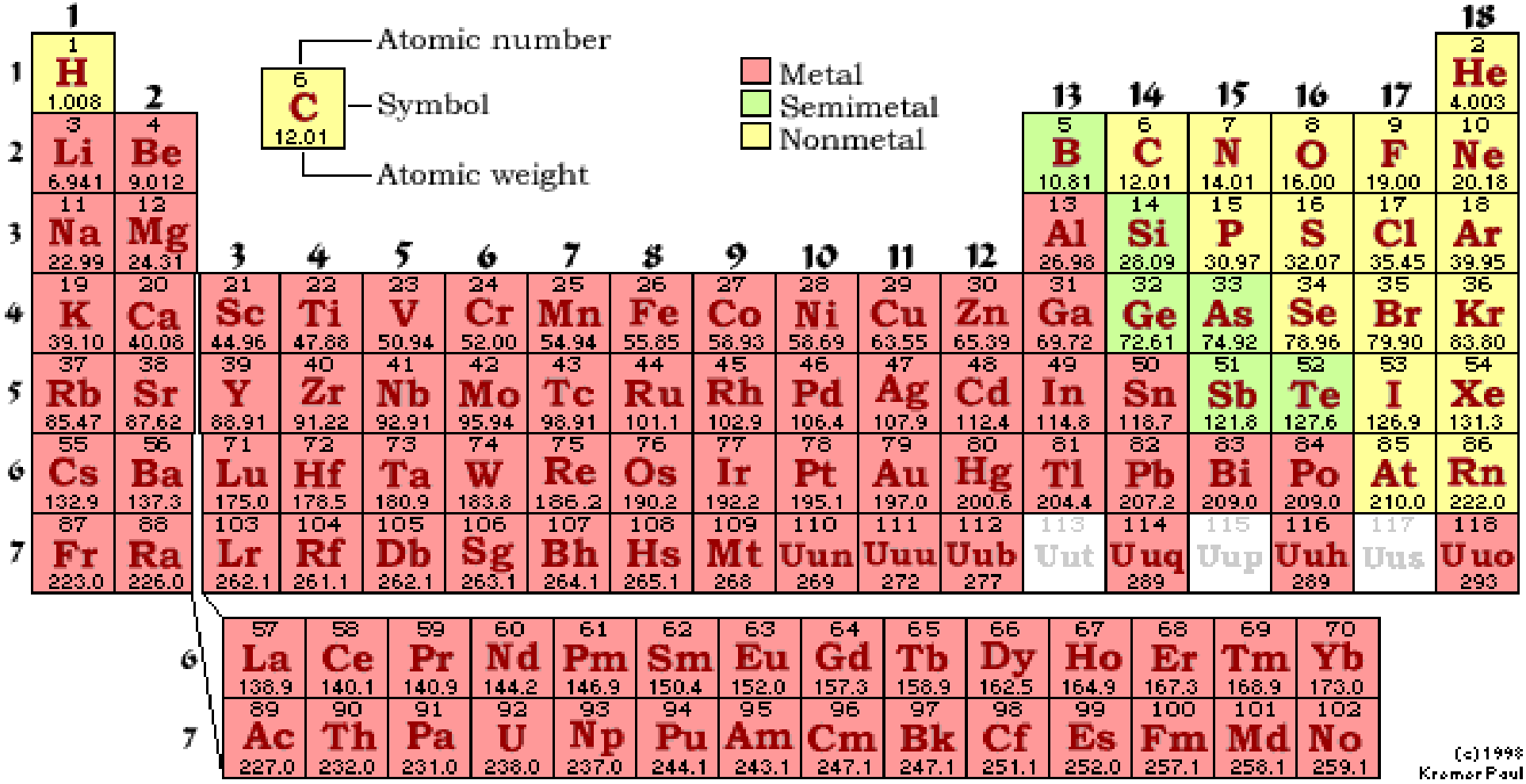




Both $BaFe_2As_2$ and $SrFe_2As_2$ were both know members of this structure….We decided to see if a new member could be found (and explored)

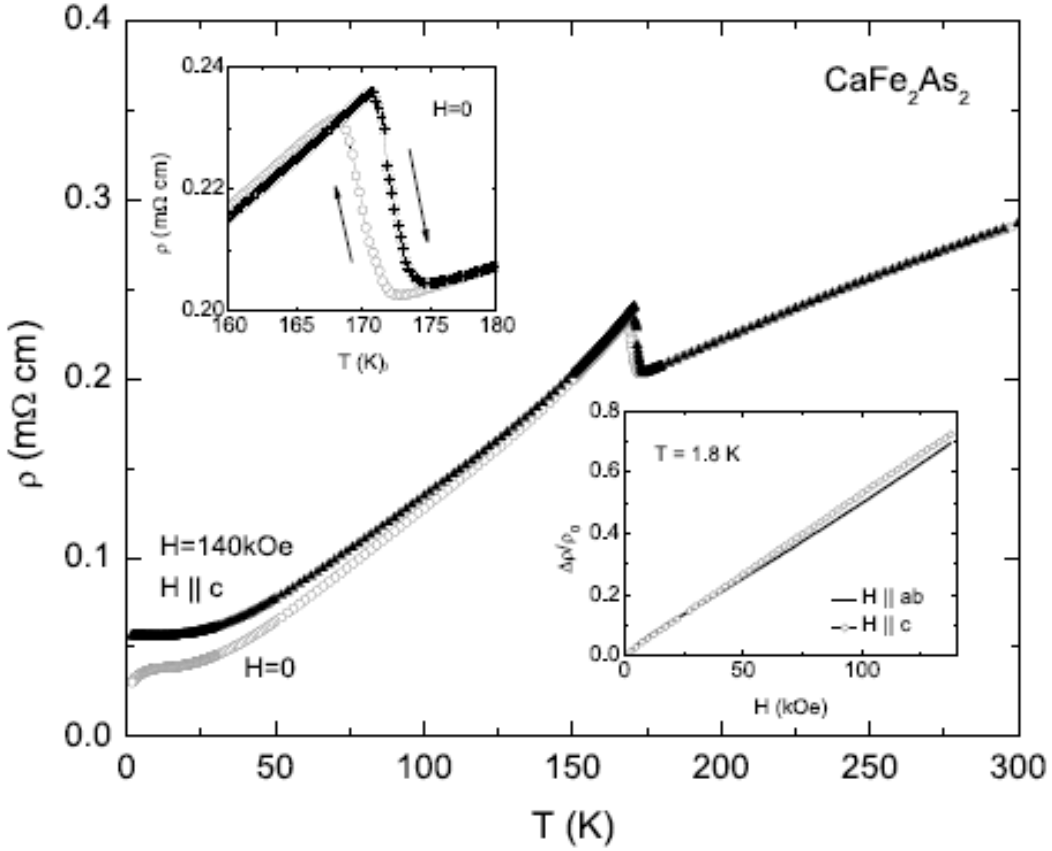
Both Ba and Sr members, when substituted with K suppressed the high temp, structural (magnetic) phase transition and became superconductors….

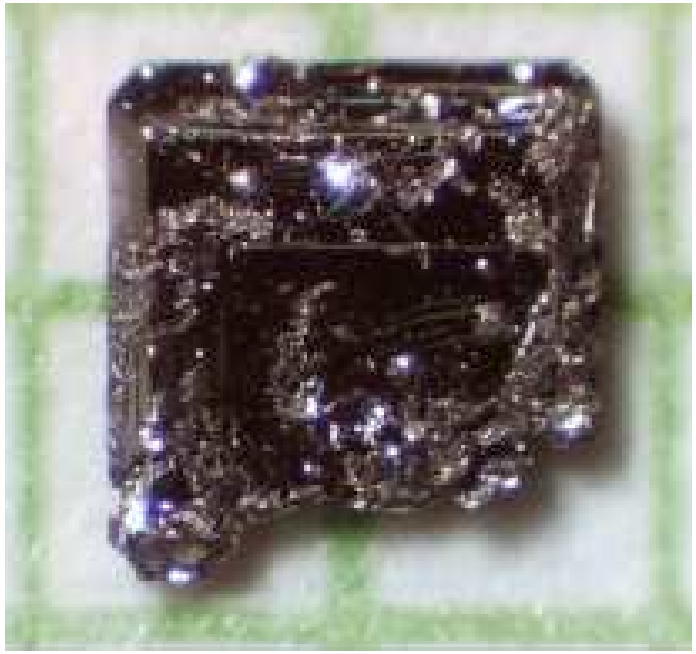


First order structural phase transition in $CaFe_2As_2$.

N. Ni, S. Nandi, A. Kreyssig, A. I. Goldman, E. D. Mun, S. L. Bud'ko, and P. C. Canfield

arXiv:0806.4328v1 [cond-mat.str-el] 26 Jun 2008





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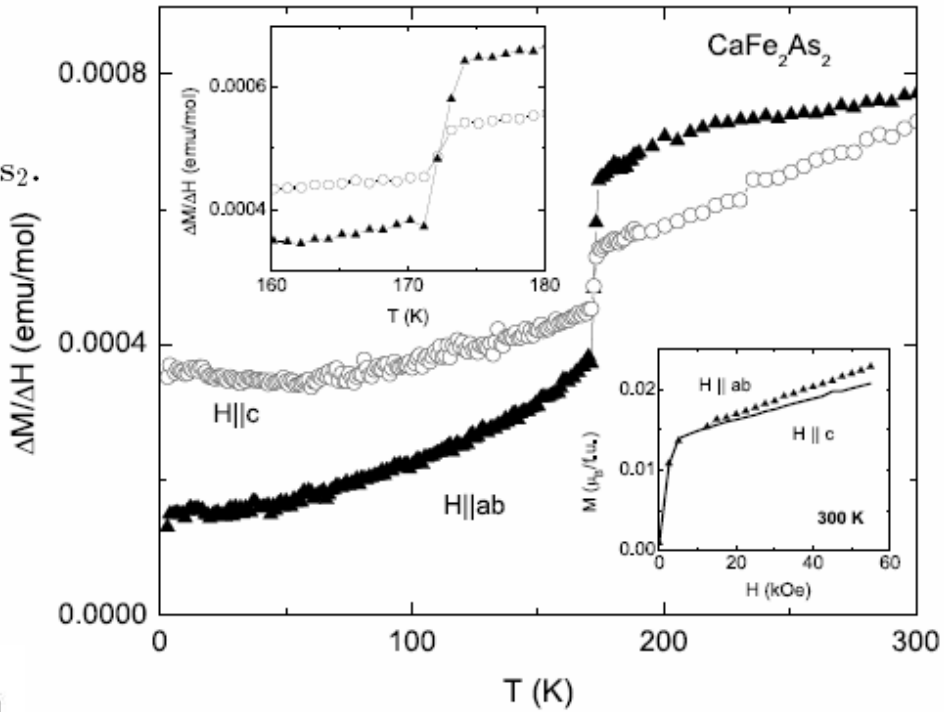

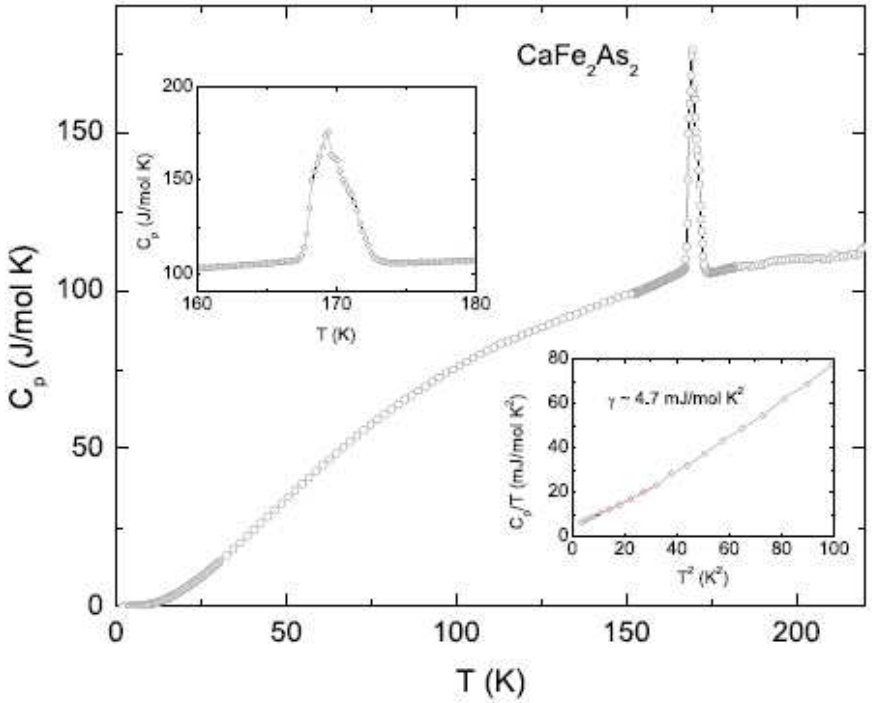

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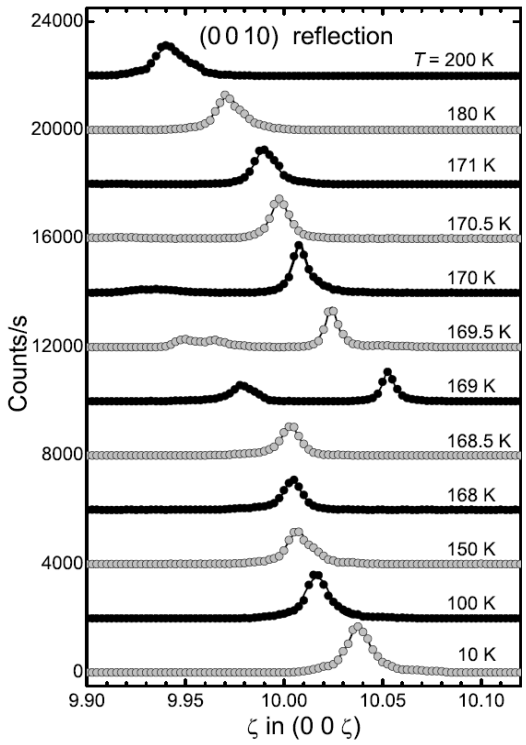
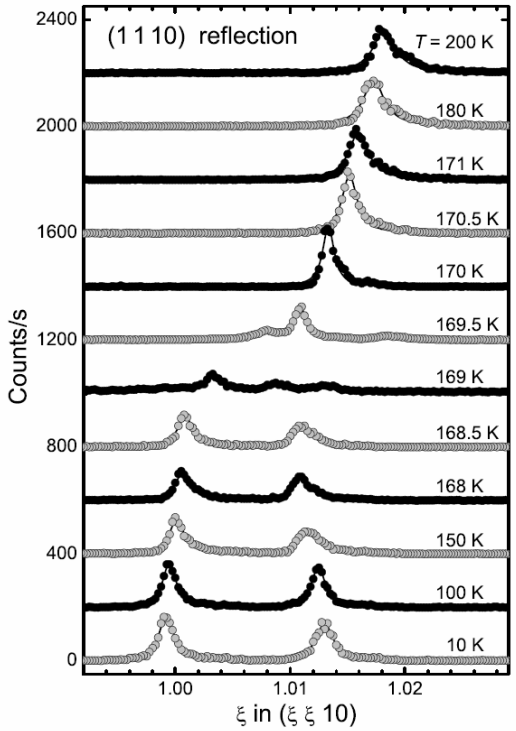
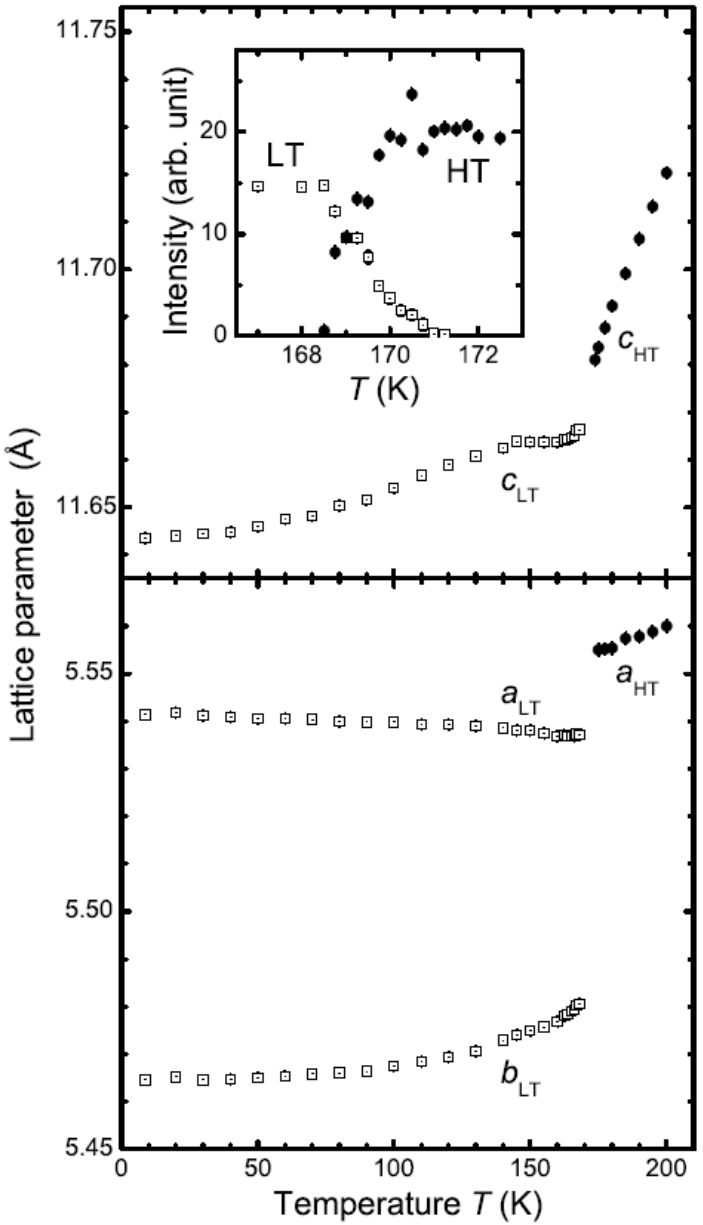
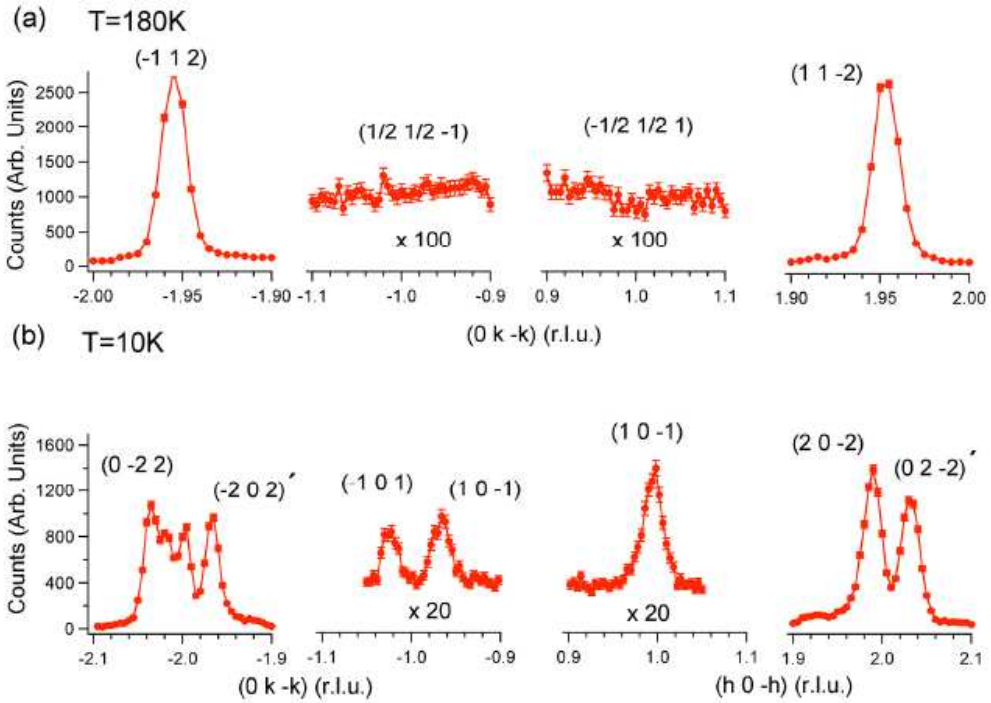


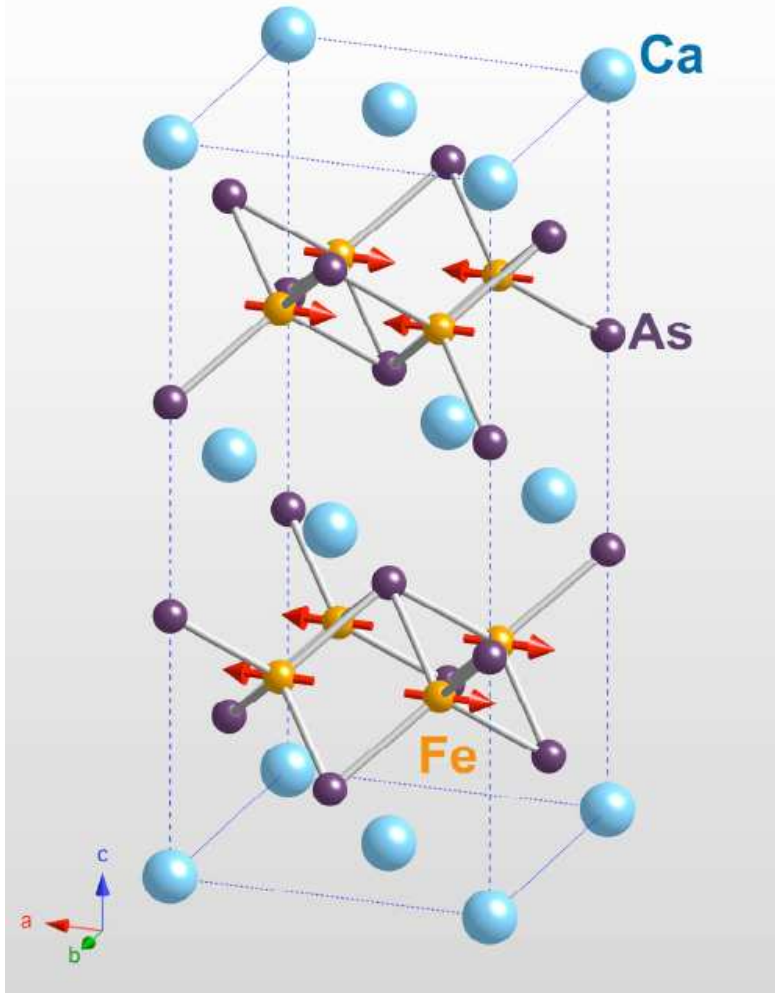




Lattice and magnetic instabilities in $CaFe_2As_2$: A single crystal neutron diffraction study

A.I. Goldman[1,2], D.N. Argyriou[3], B. Ouladdiaf [4], T. Chatterji[5], A. Kreyssig[1,2], S. Nandi[1,2], N. Ni[1,2], S. L. Bud'ko[1,2], P.C. Canfield[1,2] and R. J. McQueeney[1,2]





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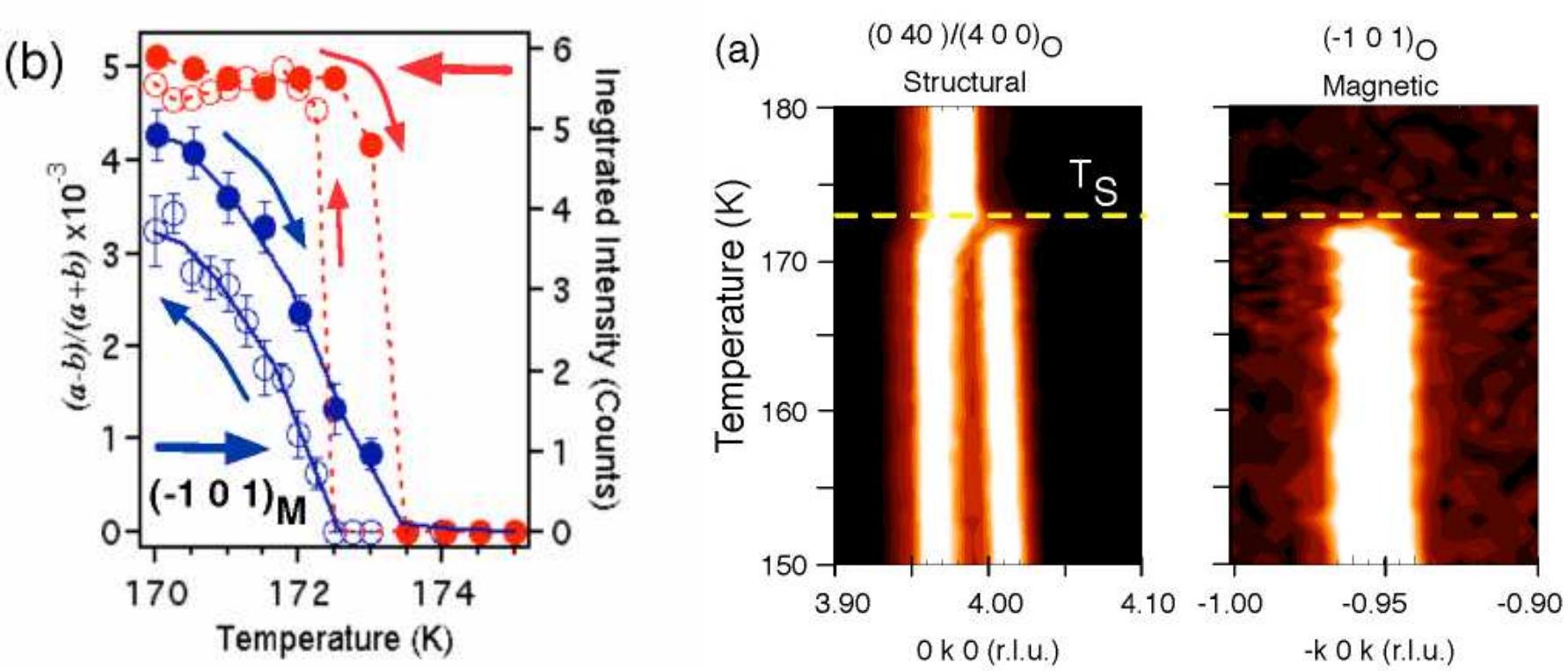


Observations and wishes about $CaFe_2As_2$

$CaFe_2As_2$ appears to be similar to $SrFe_2As_2$ and $BaFe_2As_2$.

It is much softer

It has a smaller lattice parameter (Ca is smaller than Sr or Ba)

Pressure was useful in enhancing T_C in LaFeAs(O/F)

It would be wonderful to have a pure compound that could manifest all of the salient features of this system.

Pressure induced superconductivity in $CaFe_2As_2$.

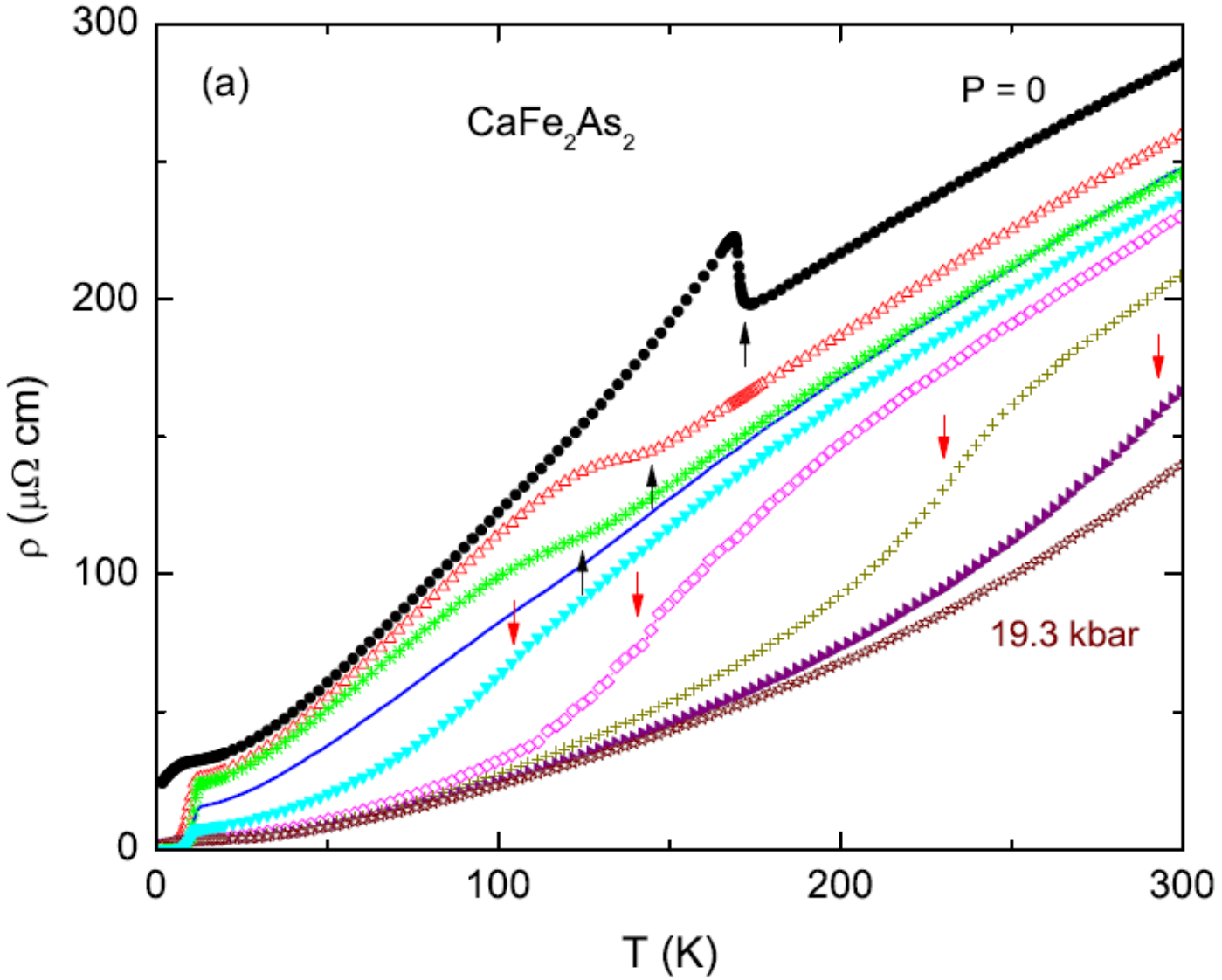
Milton S. Torikachvili
Sergey L. Bud'ko, Ni Ni, and Paul C. Canfield

arXiv:0807.0616v1 [cond-mat.supr-con] 3 Jul 2008

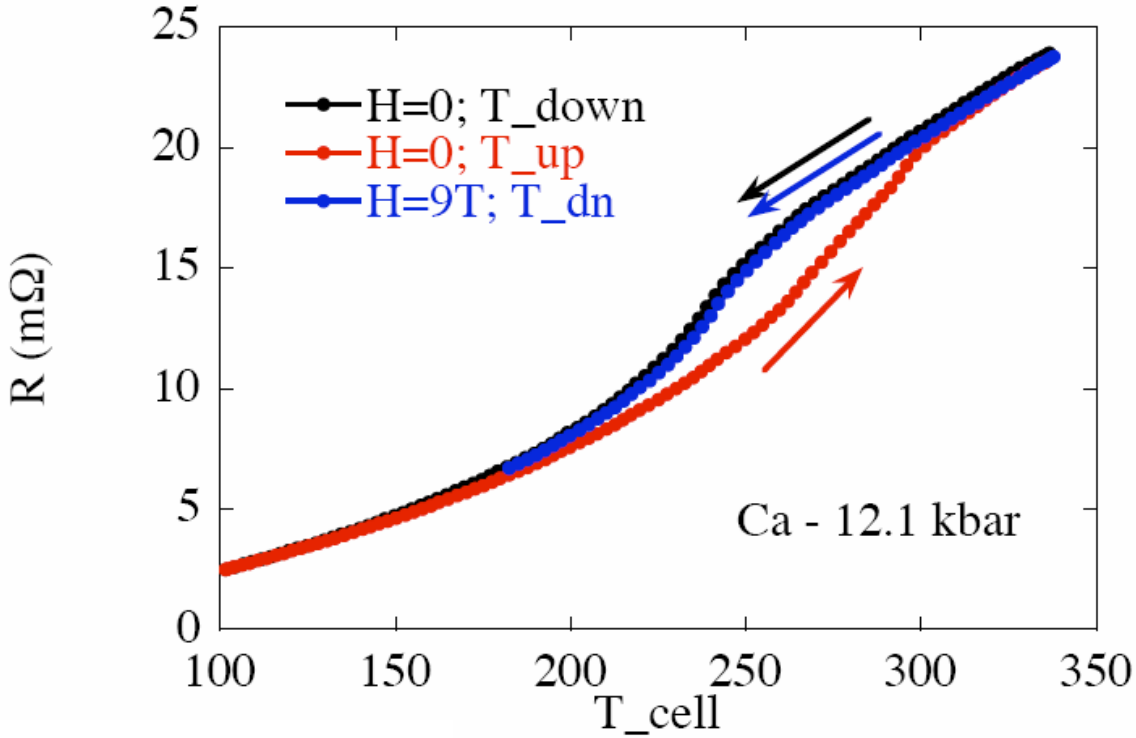
Pure compound

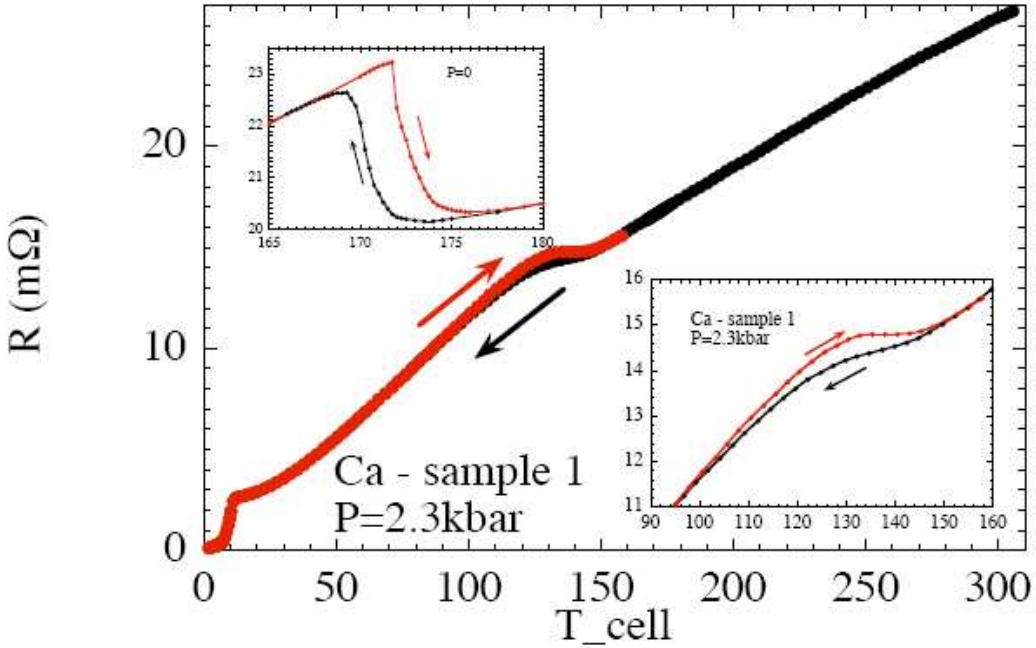
No doping

No disorder



$CaFe_2As_2$ under pressure





Both of these high temperature transitions are first order in nature (as assessed via hysterisis in transport data).

Pressure induced superconductivity in $CaFe_2As_2$.

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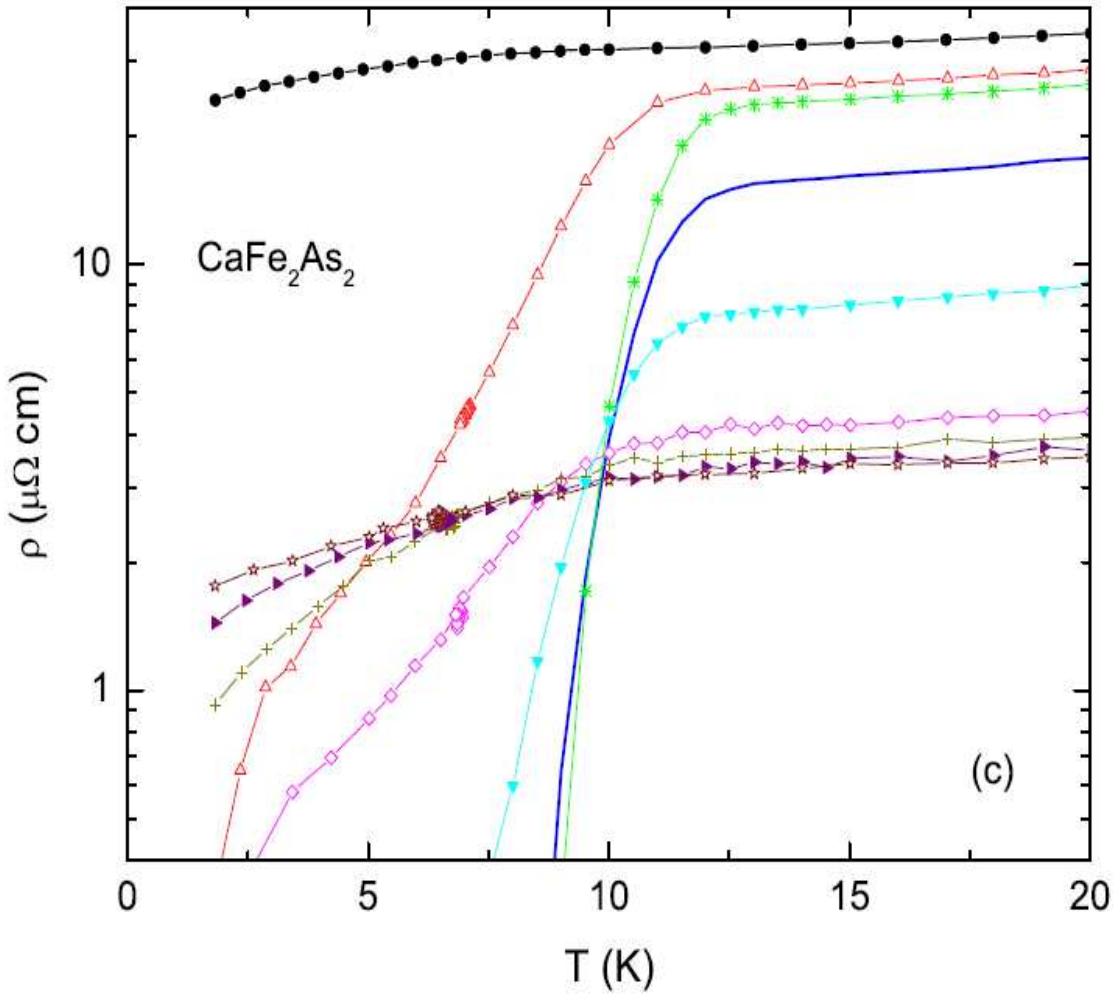
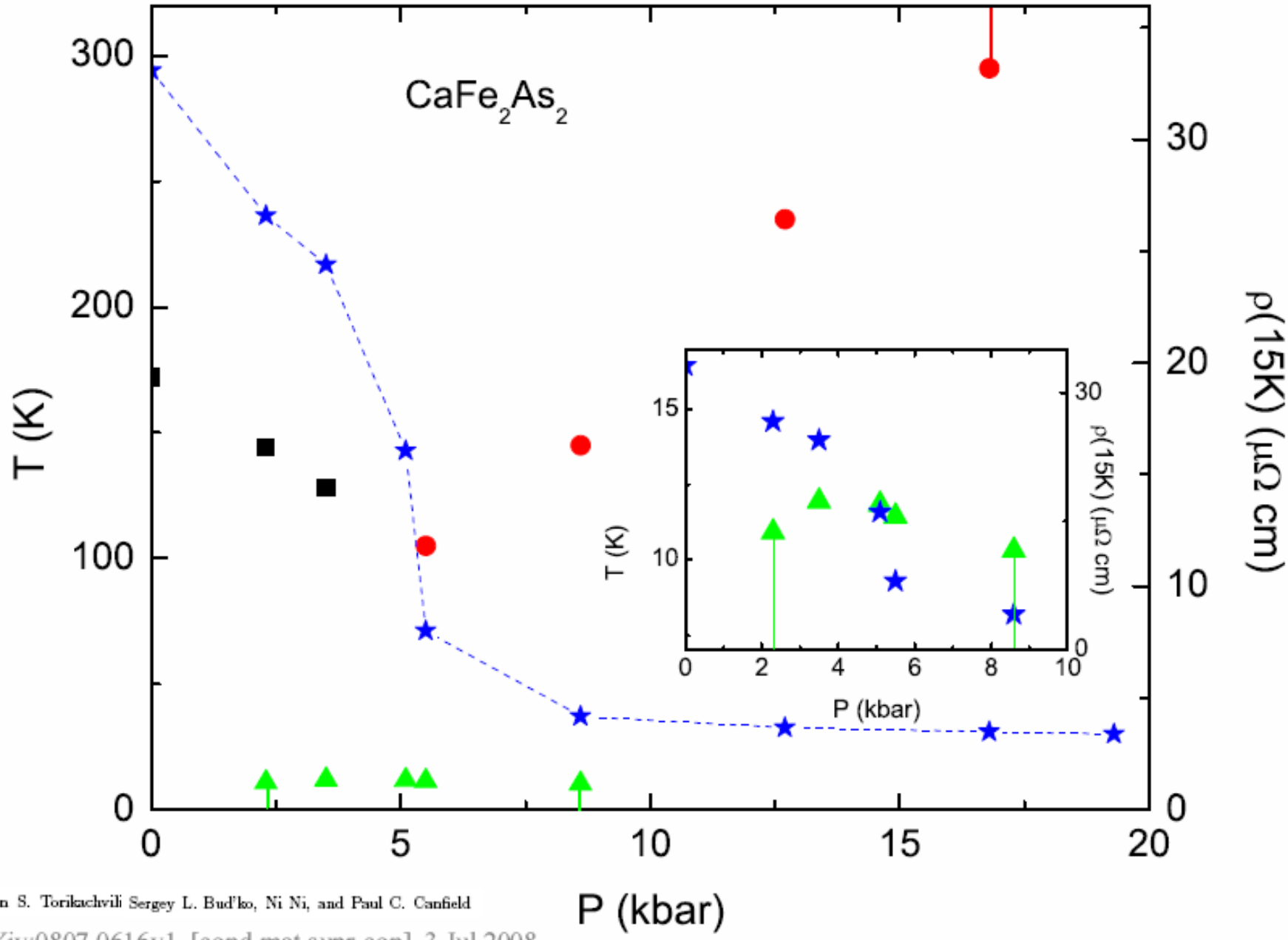


For low and high pressures there is no detectable superconductivity

For pressures centered about 5 kbar there are sharp SC transitions

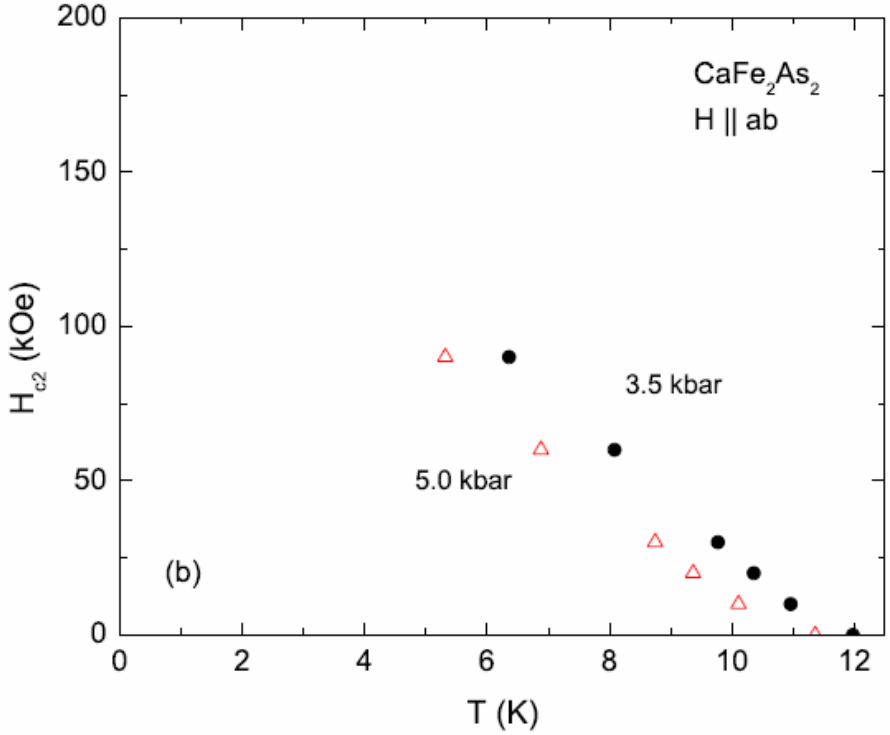
There is a dramatic reduction of residual resistivity, r(15K), as pressure passes through the 5 kbar region.

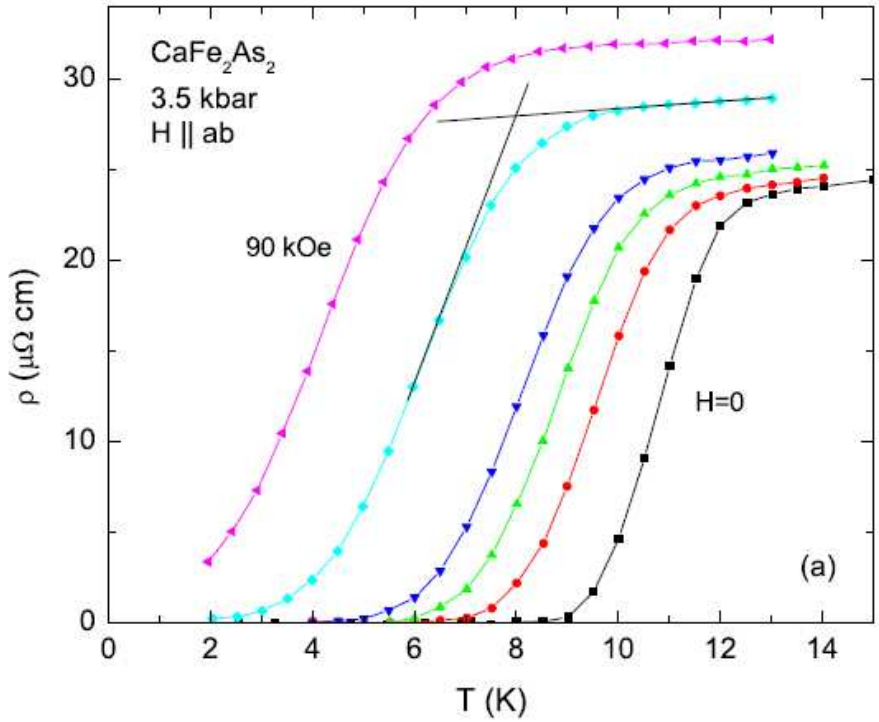


Milton S. Torikachvili Sergey L. Bud'ko, Ni Ni, and Paul C. Canfield

arXiv:0807.0616v1 [cond-mat.supr-con] 3 Jul 2008

Reasonable H_{c2} curves for SC region.



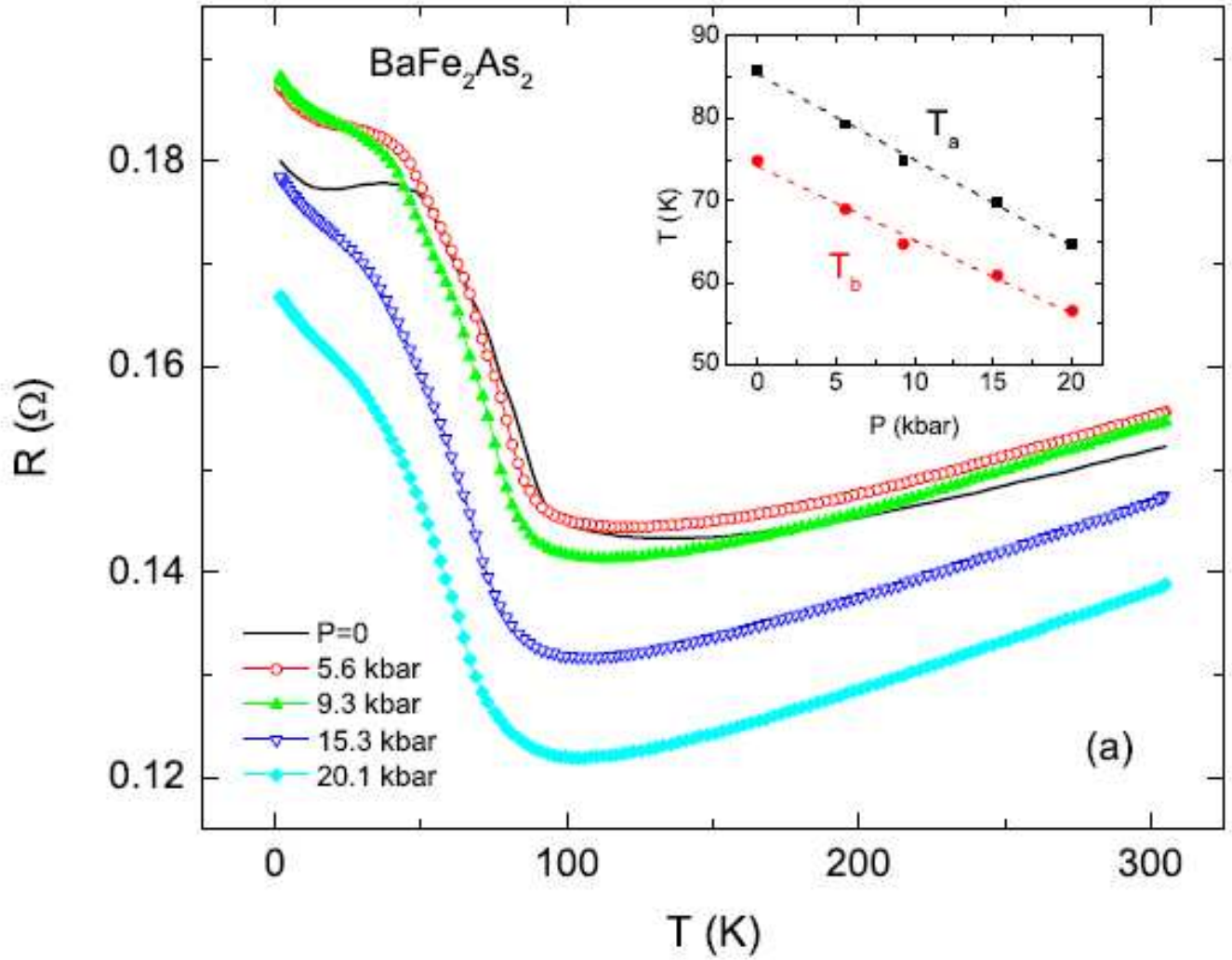


$BaFe_2As_2$ far less pressure dependent.

Effect of pressure on the structural phase transition and superconductivity in $(Ba_{1-x}K_x)Fe_2As_2$ ($x = 0$ and 0.45) single crystals.

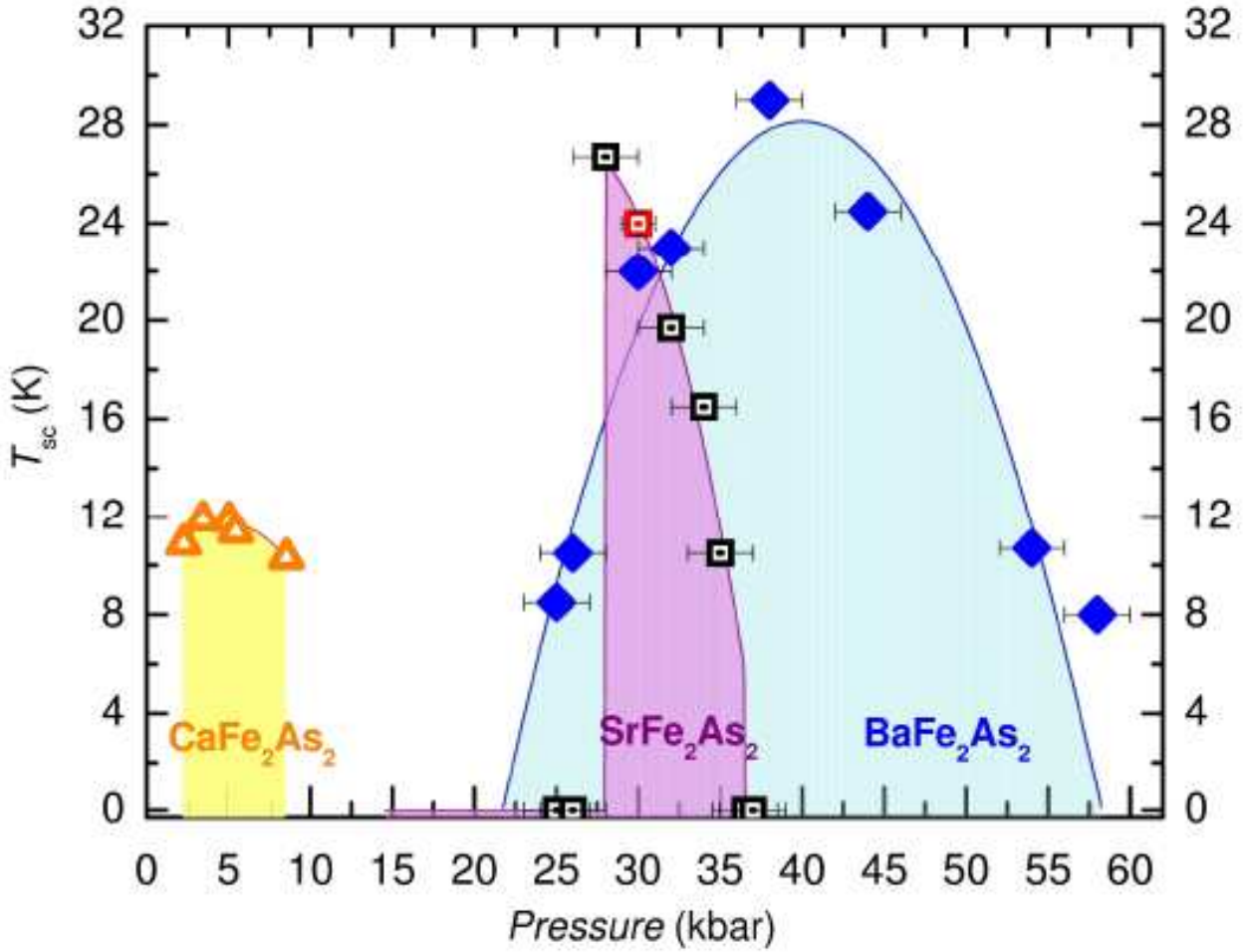
M. S. Torikachvil N. Ni, S. L. Bud'ko, and P. C. Canfield

arXiv:0807.1089v1 [cond-mat.supr-con] 7 Jul 2008

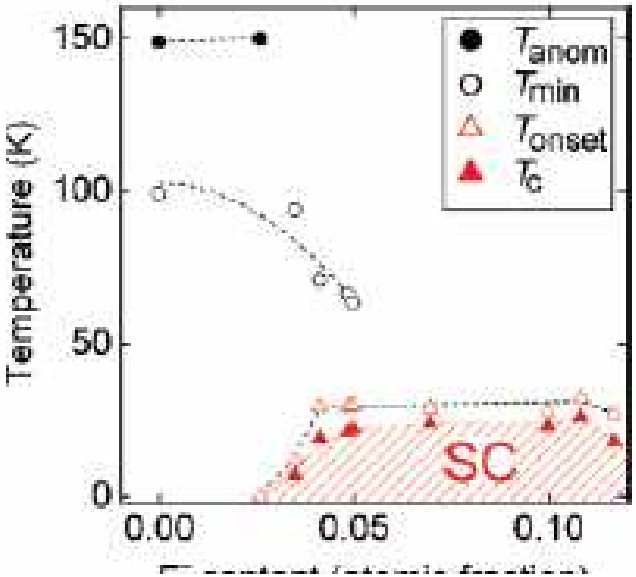


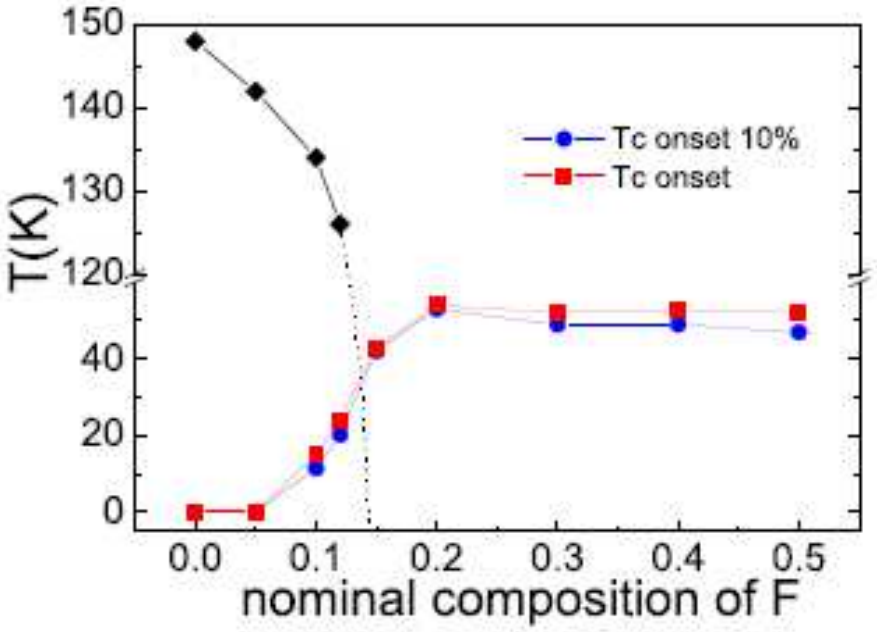
Superconductivity up to 29 K in $SrFe_2As_2$ and $BaFe_2As_2$ at high pressures

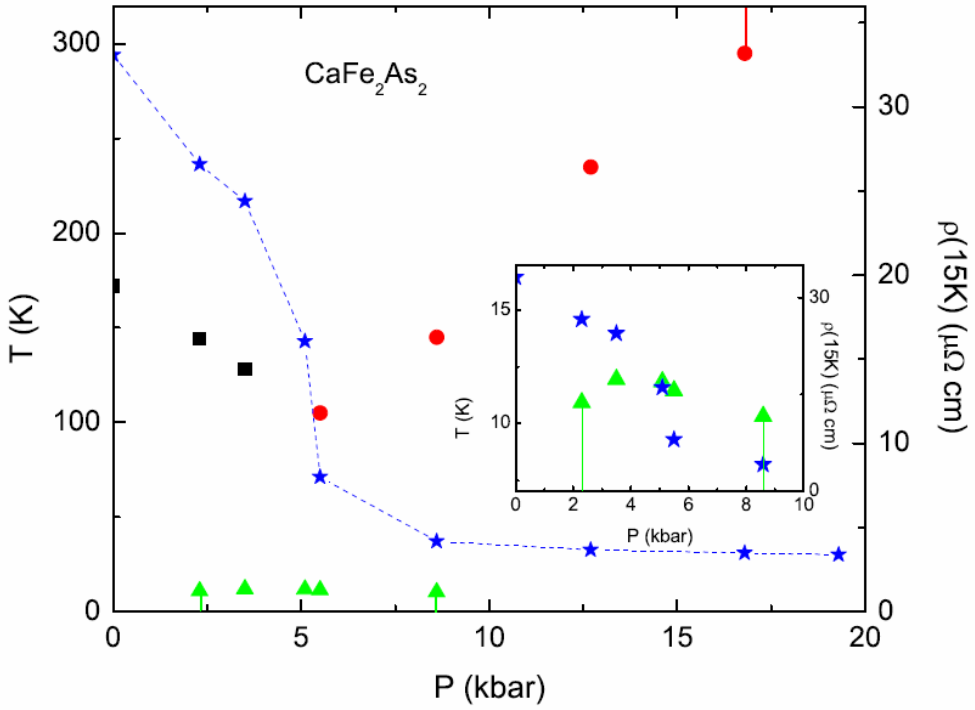
Patricia L. Alireza, Jack Gillett, Y. T. Chris Ko, Suchitra E. Sebastian[1], and Gilbert G. Lonzarich



The phase diagrams that have been mapped out for F-doped La and Sm RFeAs(O/F) bear a remarkable resemblance to what we have found in pure $CaFe_2As_2$ under accessible pressures.







Common features and hints from the data so far

Three classes of FeAs compounds with square planar Fe capped top and bottom with As and with Fe^{2+} via gross / formal counting.

In cases of RFeAsO and AFe_2As_2 a combined structural (and magnetic) phase transition needs to be suppressed for SC to emerge. This transition seems to disappear suddenly.

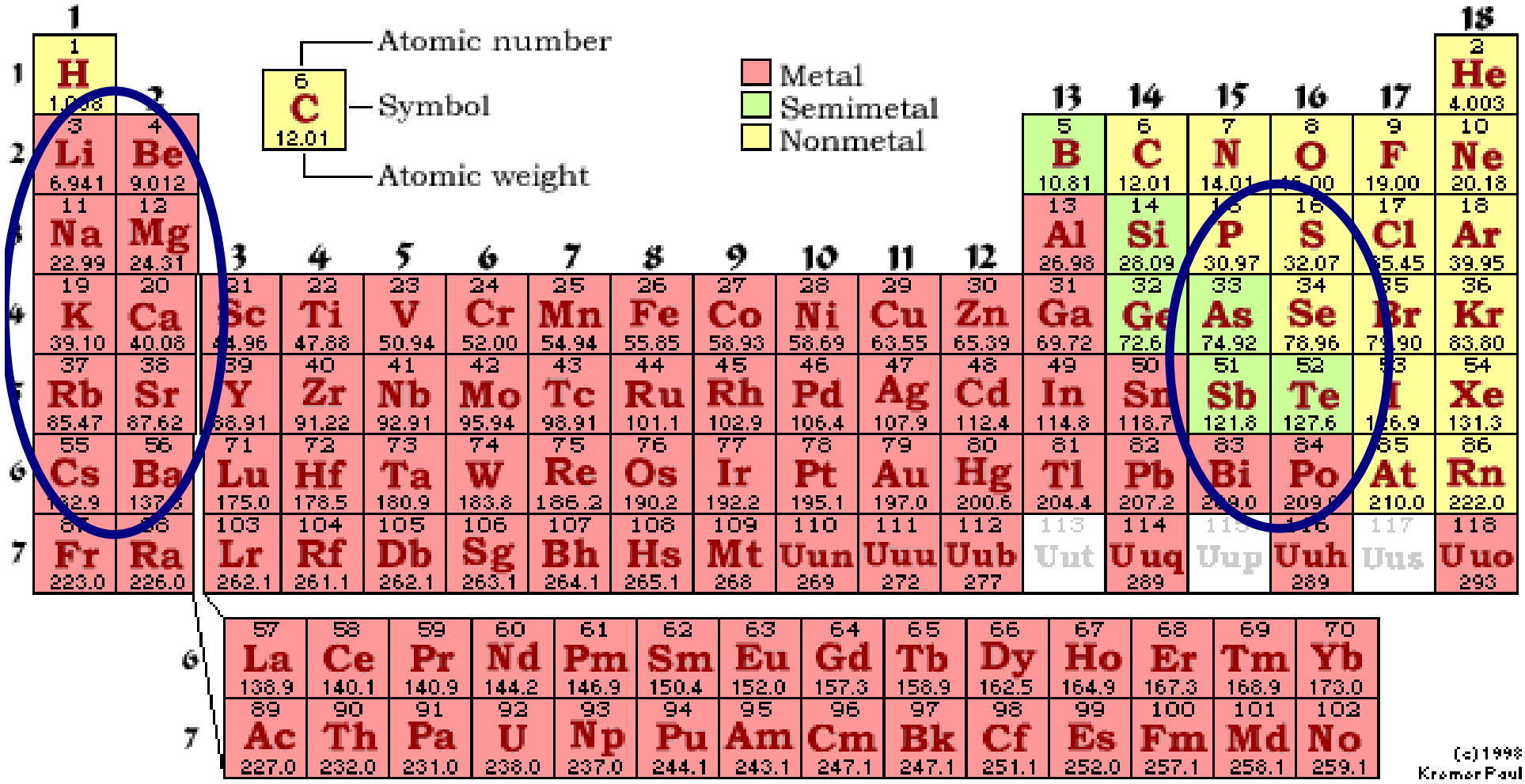
Single crystals of the AFe_2As_2 compounds are VERY soft. The $CaFe_2As_2$ can be rolled into a spiral with fine tweezers. Not at all hard.

All of the salient features associated with these compounds can be found in pure $CaFe_2As_2$ under pressure. This may allow for a clean sorting out of what is going on.

More FeAs compounds are being found and more ways of "doping" them are being developed.

Hopefully this can be generalized to other transition metals and other semi-metals as well.

Compounds with these elements have been avoided due to the difficulty in making them. These are precisely the compounds that will show properties that bridge between oxide and intermetallic physics.



Much More to Come