Magnetism and superconductivity in iron-pnictides superconductors: a status report

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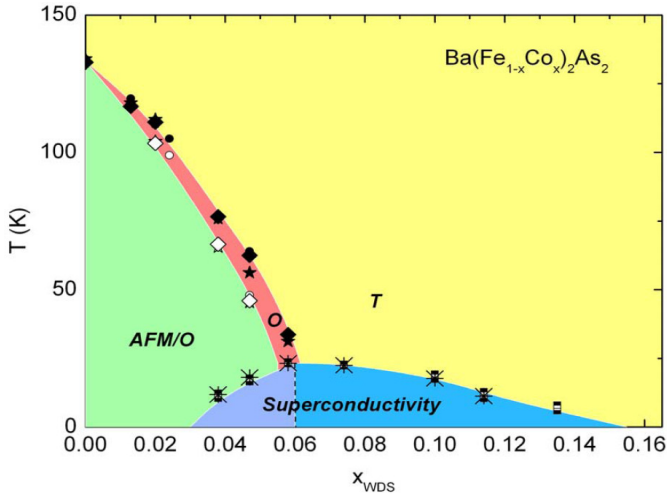
Université Paris Diderot

Outline



- Iron pnictide superconductors: families and phase diagrams
- Magneto-structural coupling
- Superconducting gap structure and pairing mechanism
- Coexistence between Spin Density Wave and Superconductivity

2008: discovery

J|A|C|S COMMUNICATIONS

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

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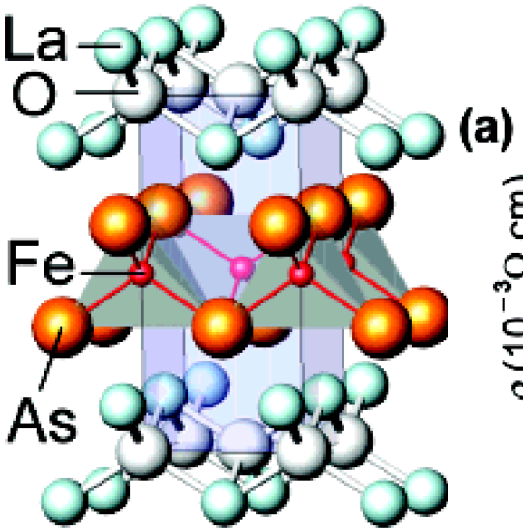
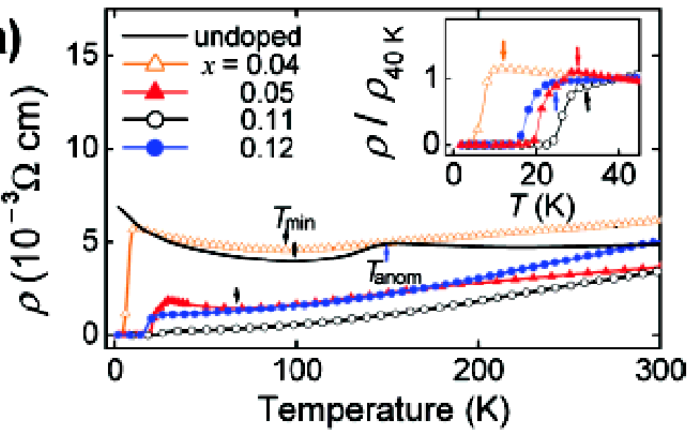
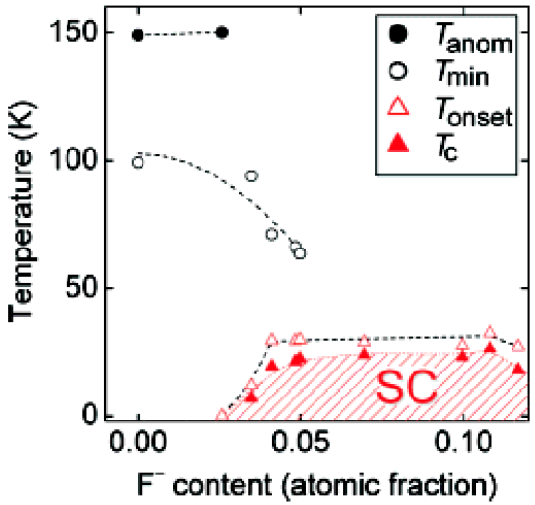
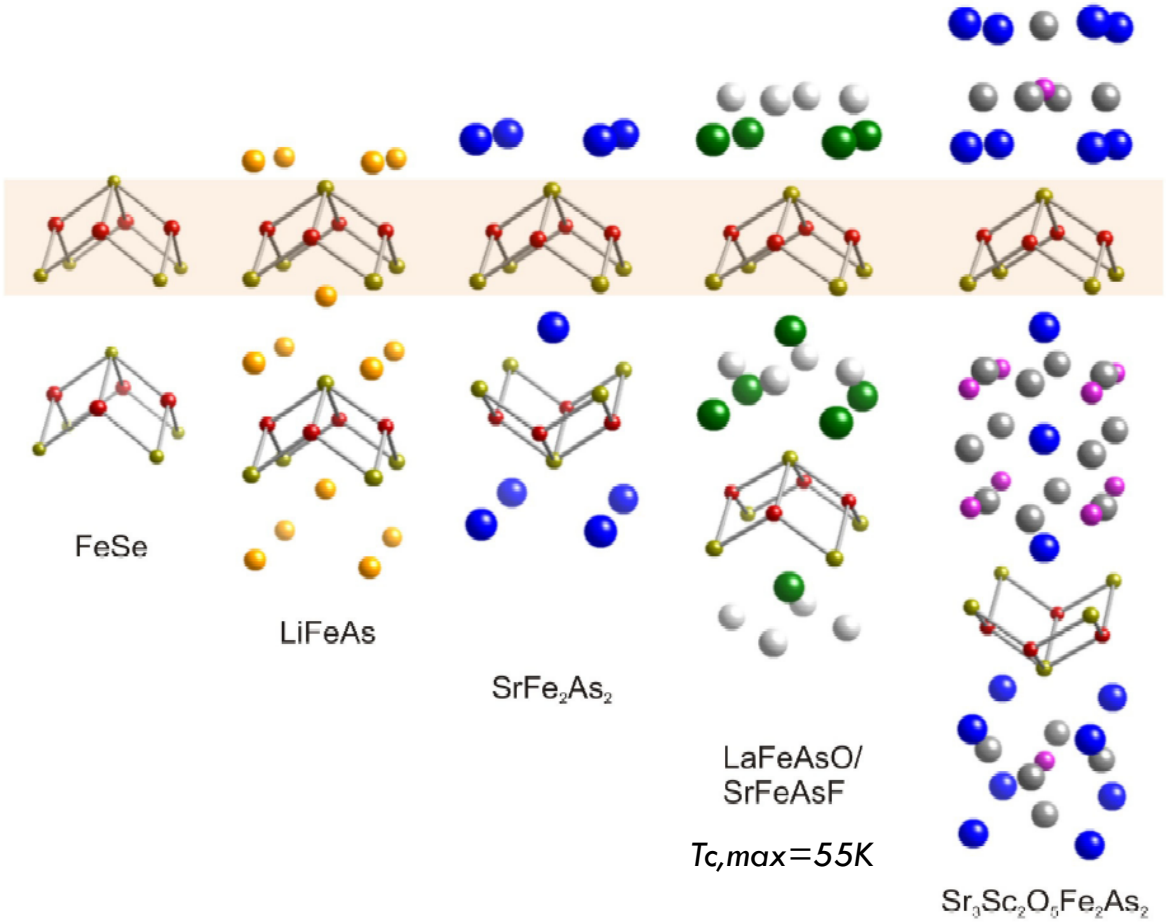


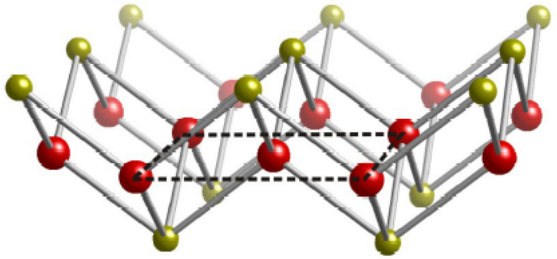




dopage électrons

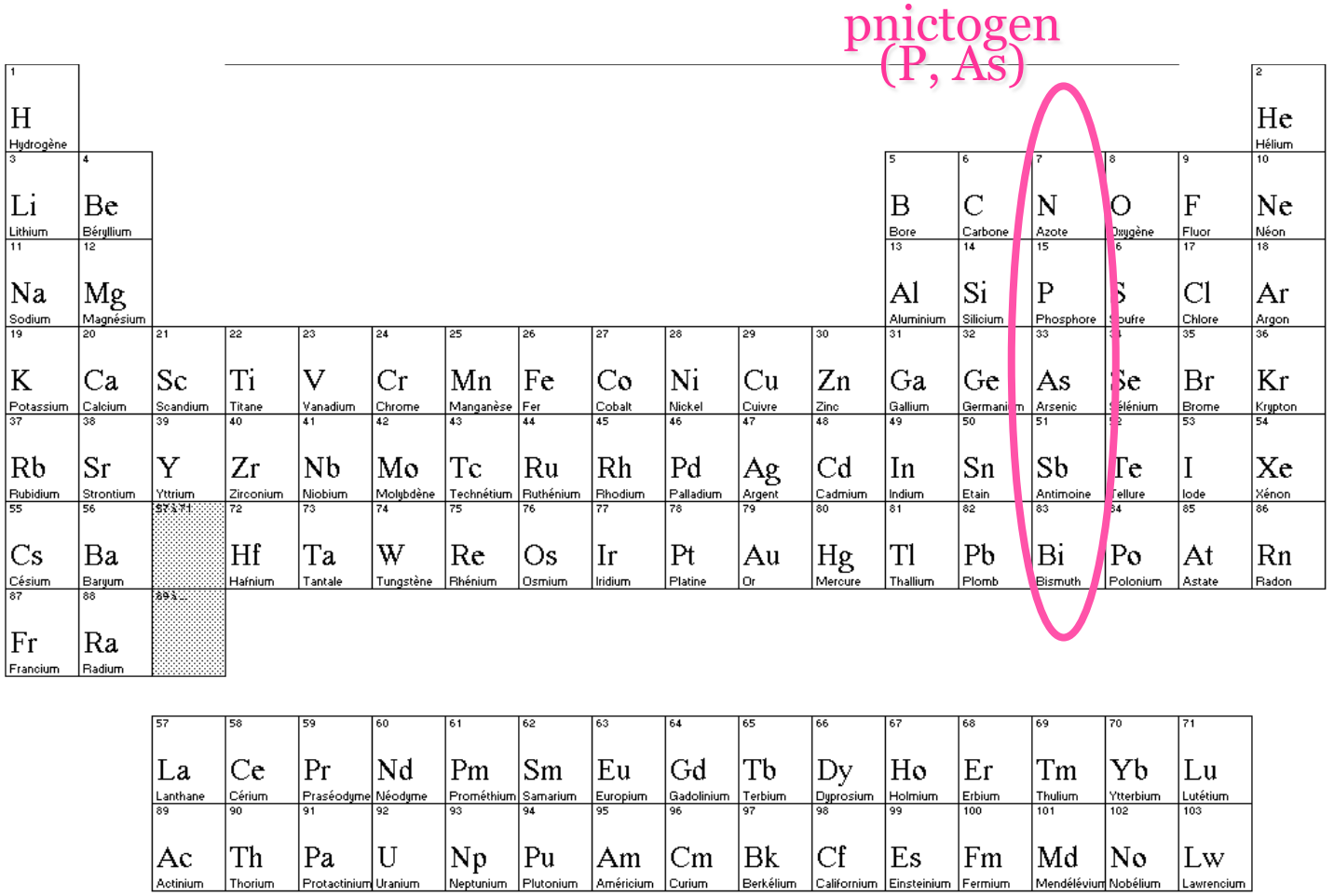
Structure and families





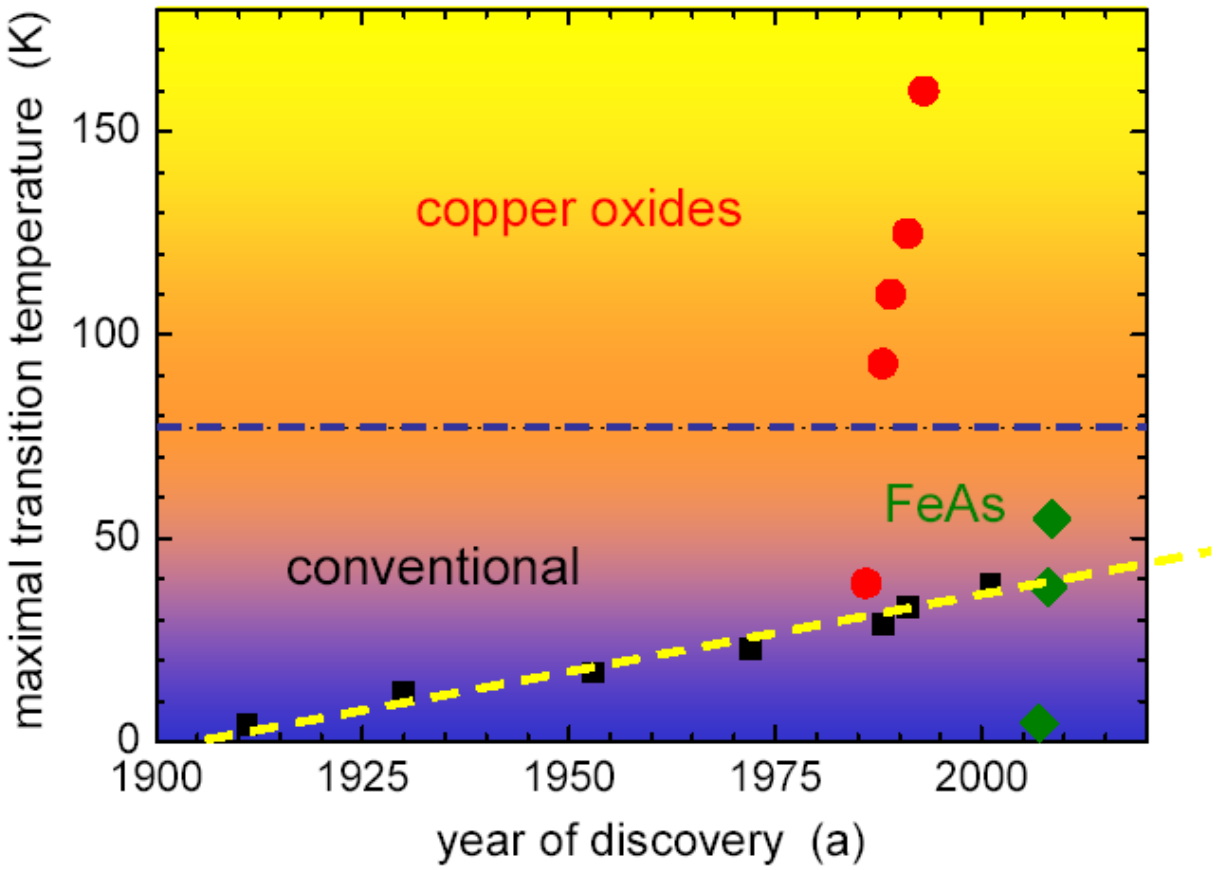
Common building block:
Fe square lattice
FeAs plane except FeSe

Pnictides



exception: FeSe…

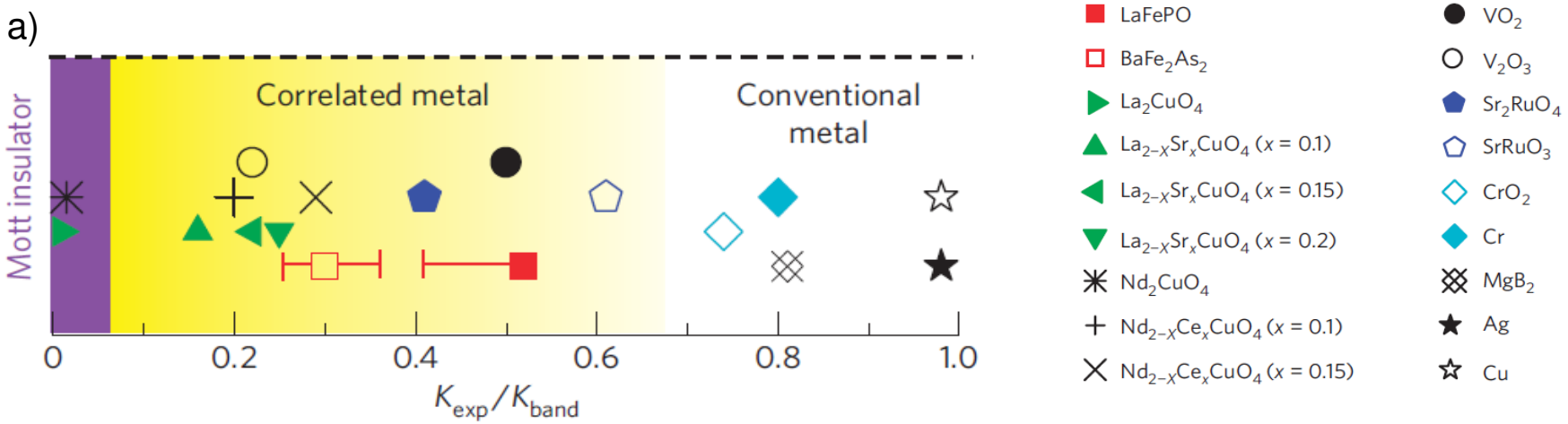
Tc vs time



A new route to high Tc superconductivity?

Electron correlations?

Comparaison between kinetic energy from optics and from band structure calculations



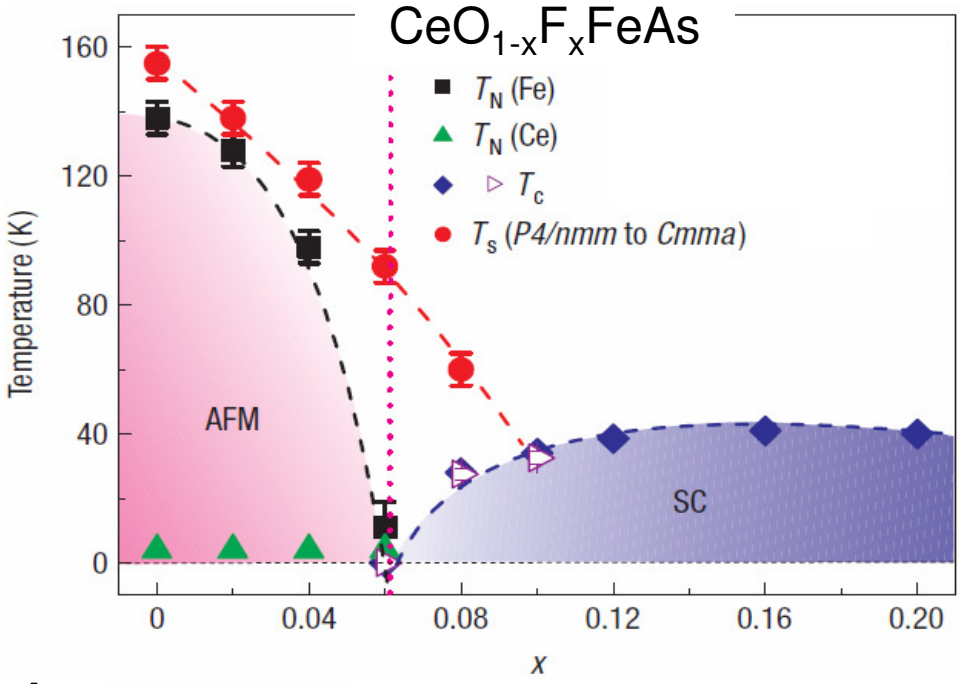
Qazilbash et al. Nature Physics 5, 647 (2009)

- Iron-pnictides further away from Mott insulator than cuprates (DMFT…)
- Ab-initio calculations (DFT) predict magnetism (but not the correct Fe moment) and gross features of band structure

K. Haule et al. Phys. Rev. Lett. 100, 226402 (2008).
D.J. Singh, M.H. Du, Phys. Rev. Lett. 100, 237003 (2008)

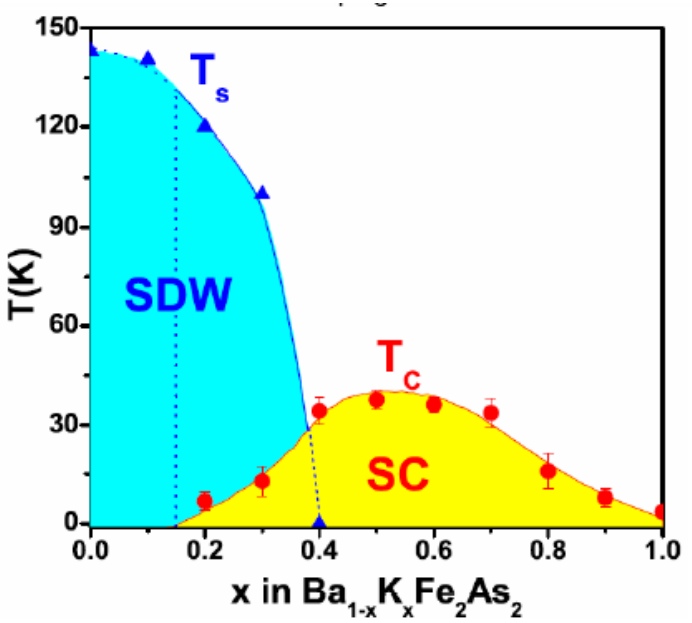
Phase diagrams and families

1111



J. Zhao et al. Nature Materials 7, 953-959 (2008)

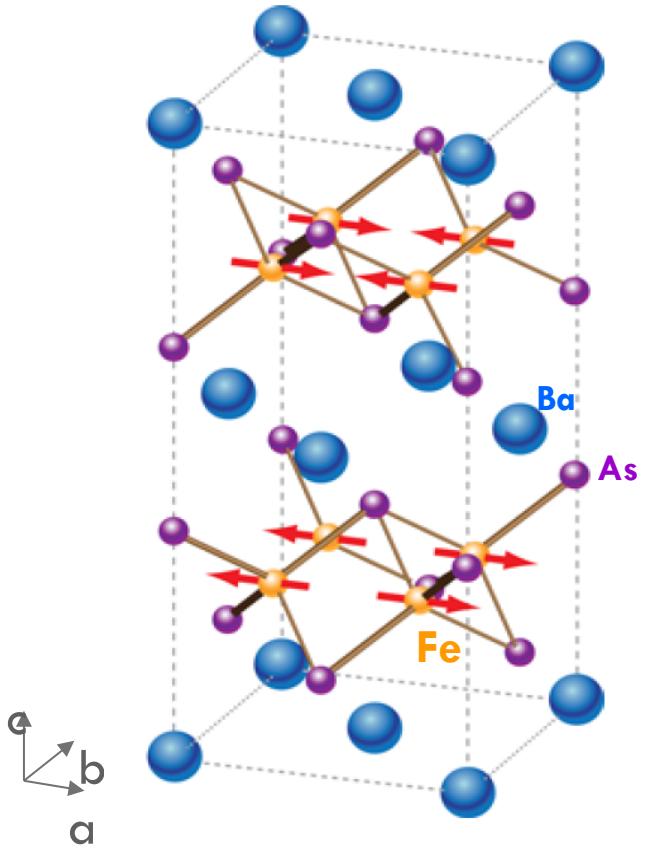
122

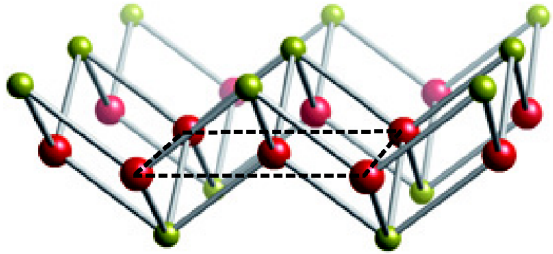


H. Chen et al. Europhys. Lett. 85, 17006 (2009)

- close proximity of SC phase with magnetism (heavy fermions, cuprates)
- coexistence (or not) between magnetism and superconductivity
- magnetic and structural transitions

Crystal structure $BaFe_2As_2$

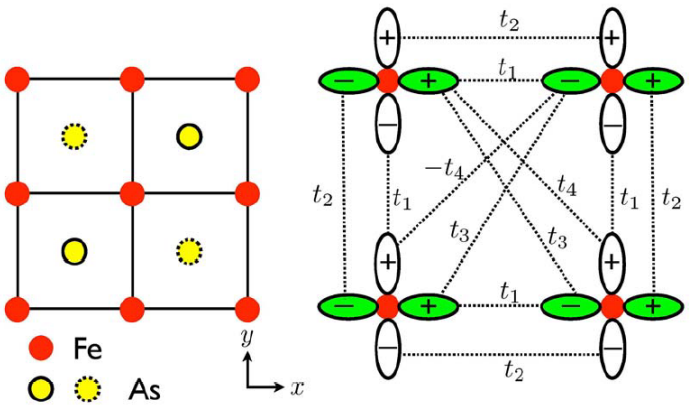




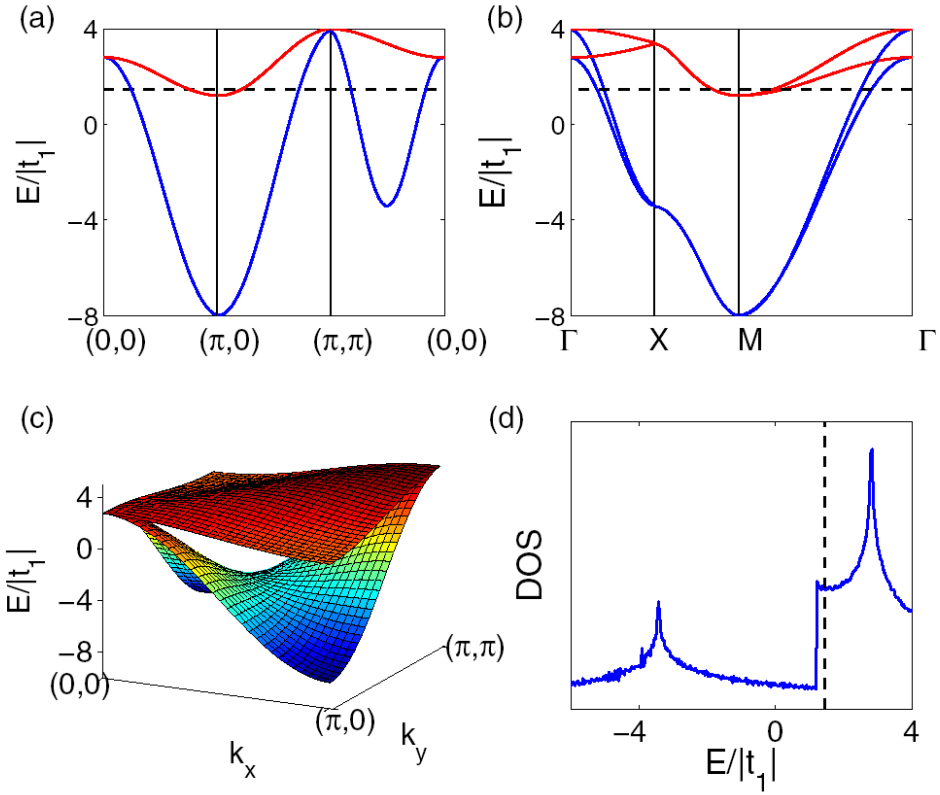
- Square plane of Fe (d^6)
- As alternating above and below Fe planes
- $FeAs_4$ tetrahedra
- Ba blocking layer

- FeAs plane: 2 Fe/cell
- BZ sometimes defined with 1 Fe/cell (extended BZ)

A multi-orbital system



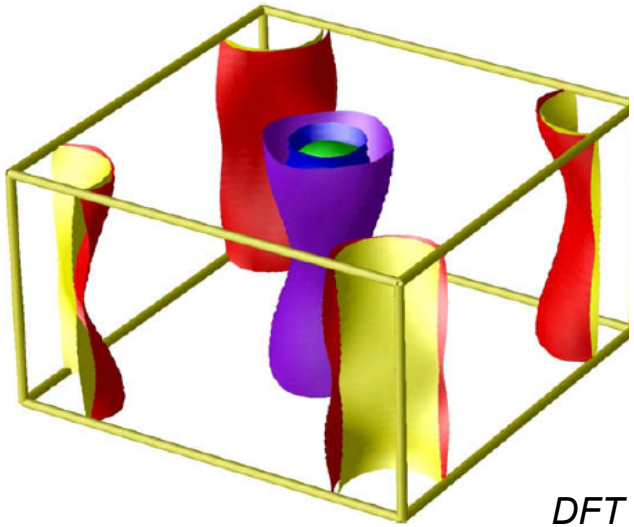
Minimal two-orbital model: $\mathbf{d_{xz}}$, $\mathbf{d_{yz}}$

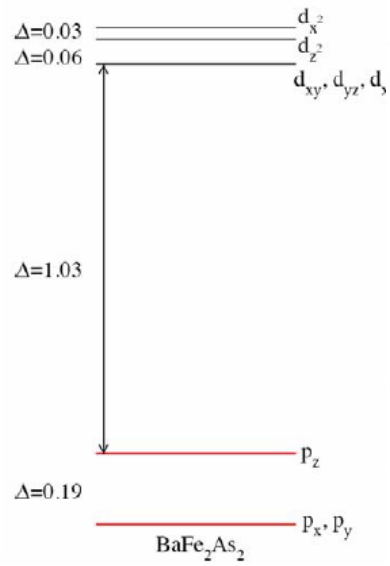


Hole and electron Fermi surfaces

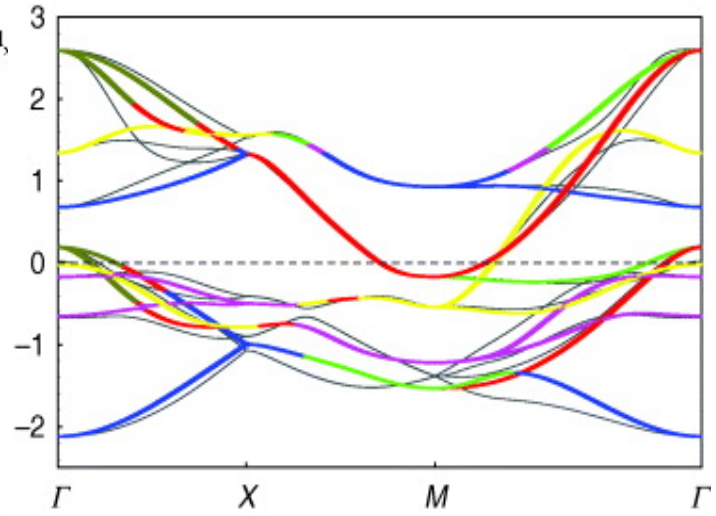
5 orbital models

3D Fermi surfaces

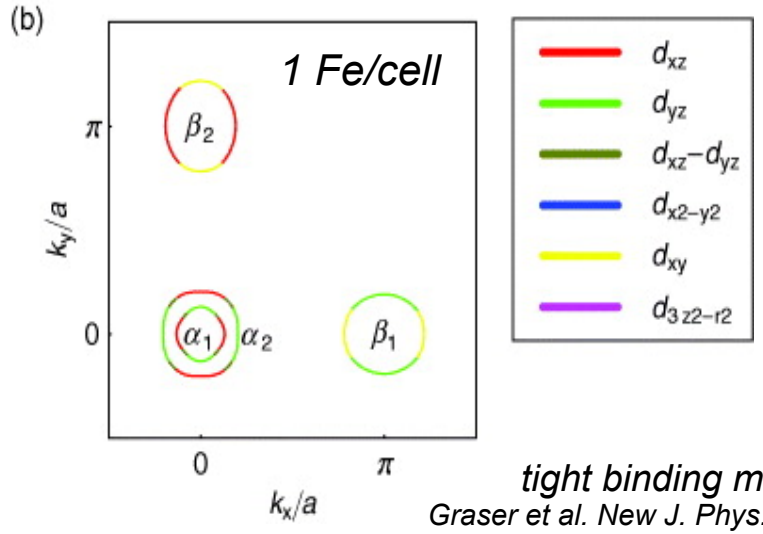




Orbital content of Fermi surfaces



DFT calculations
Mazin, *Physica C* ***469***, *614 (2009)*

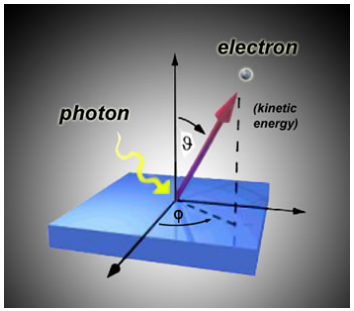


tight binding model
Graser et al. New J. Phys. 2009

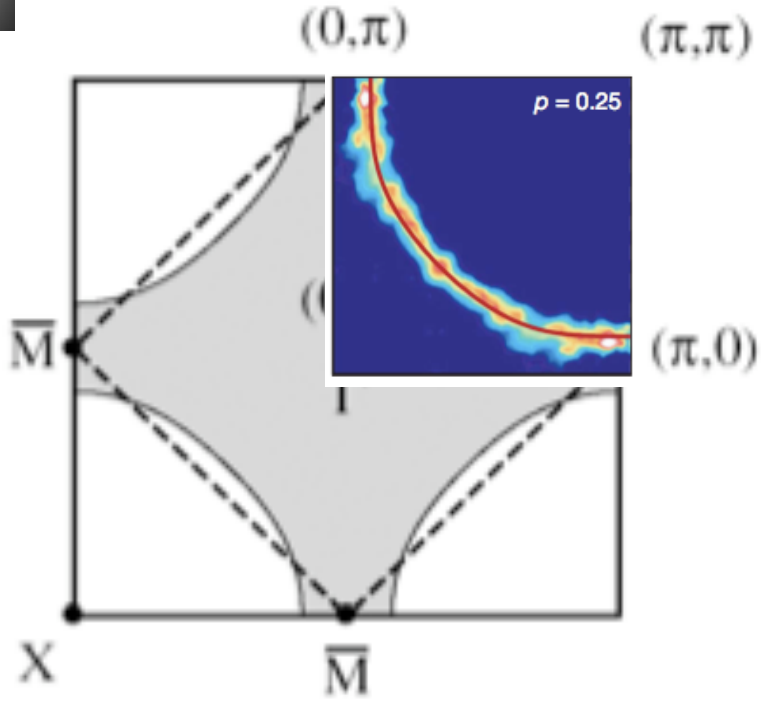
- Up to 5 Fe derived bands cross the Fermi level: 3 hole-like and 2 electron-like
- As derived bands are 2eV below Fermi level
- relatively 2D electronic structure

- **physics is governed by Fe orbitals**
- **importance of Fe-As-Fe hopping**
- **orbital physics: Hund coupling**

Fermi surfaces

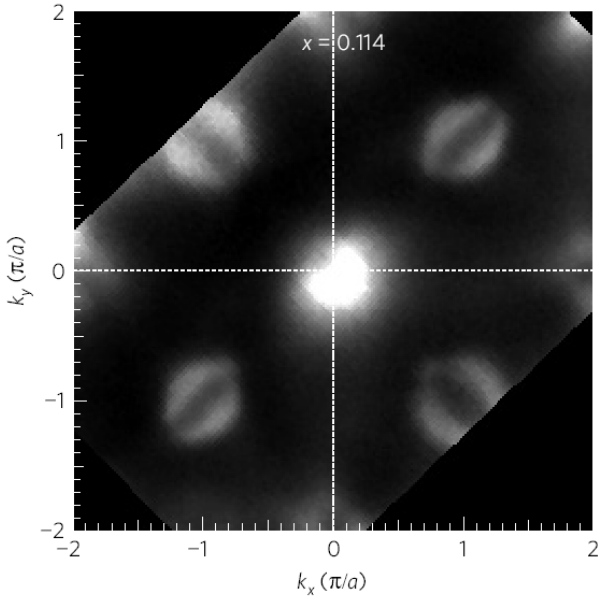


Cuprates: 1 FS



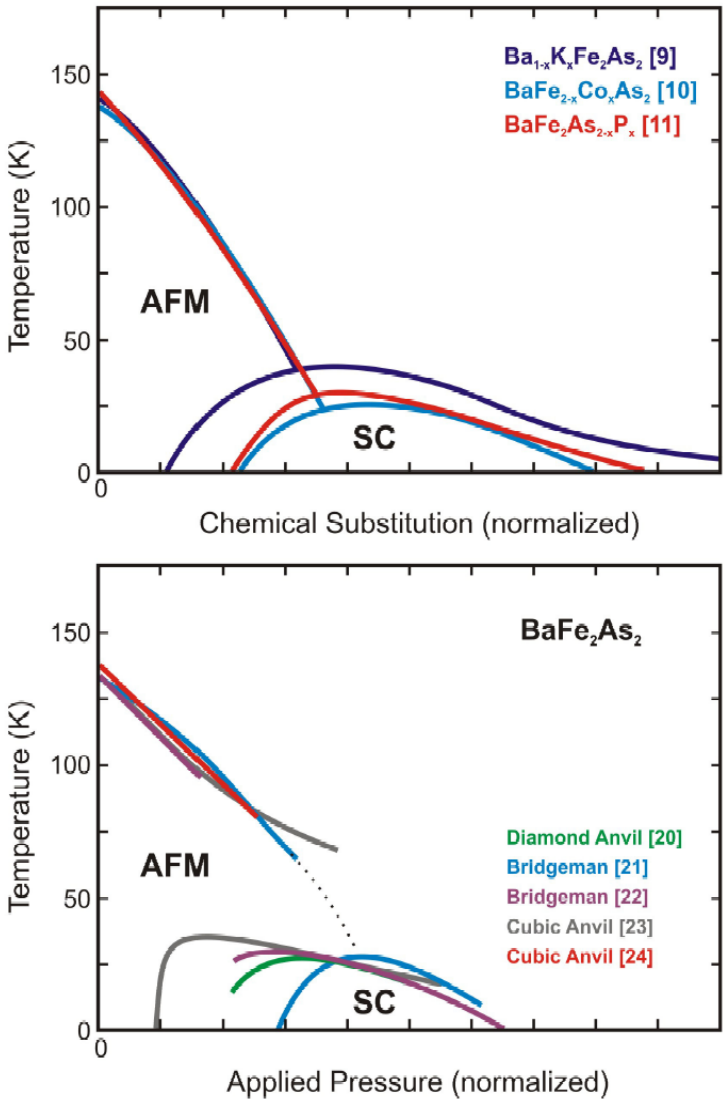
Doiron-Leyraud et al. Nature 2007

Pnictides: multiple FS

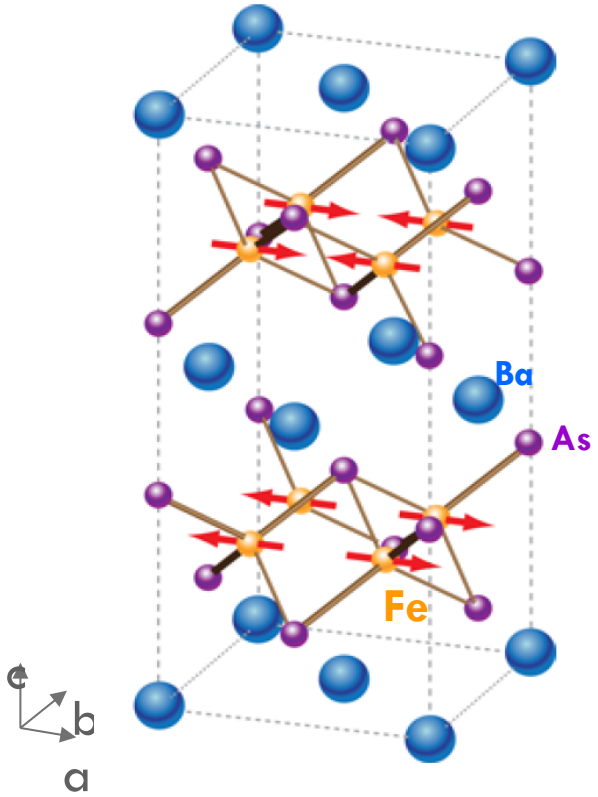


Liu et al. Nature Phys. 2010

the x parameter: tuning magnetism and superconductivity



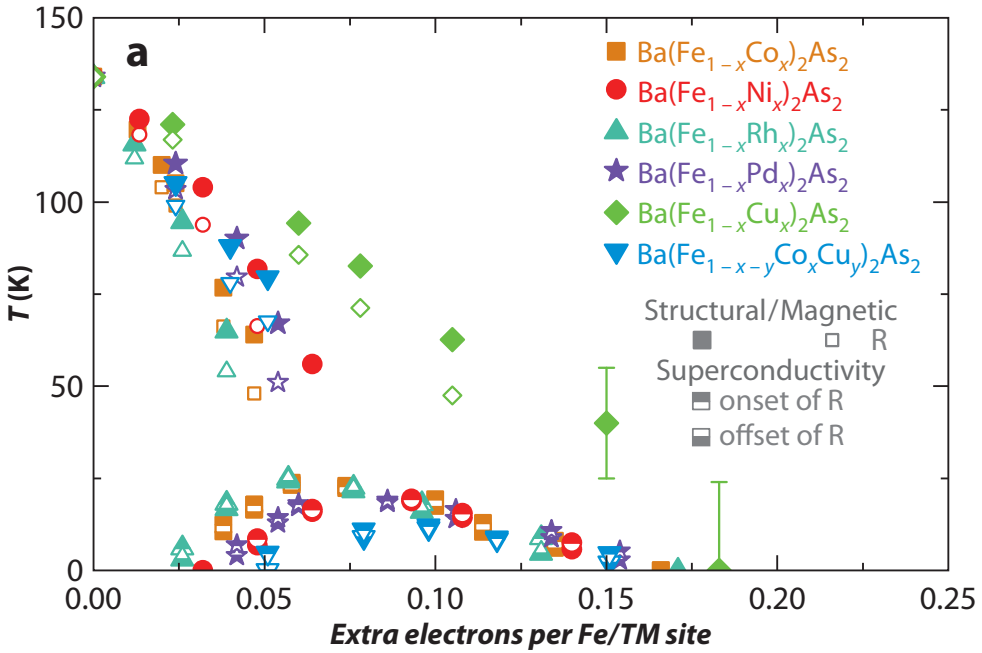
J. Paglione et R. Greene. Nature Physics 2010



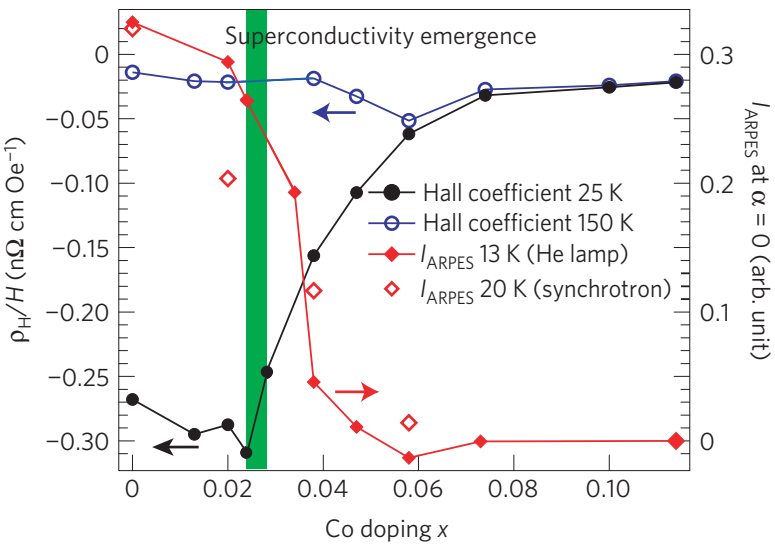
Different ways of tuning magnetism and SC

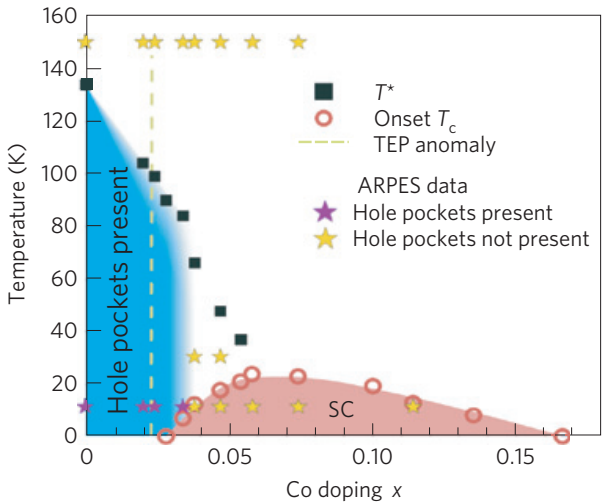
- Hole, electron, isovalent doping
- pressure
- doping in the FeAs plane is not detrimental to Tc

the x parameter: tuning magnetism and superconductivity



Canfield and Budko, Annu. Rev. Condens. Matter Phys. 1, 27-50 (2010)



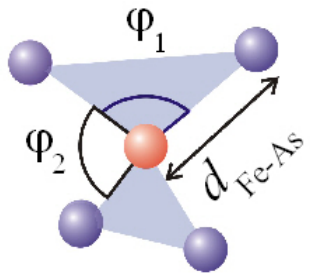


- « universal » T_c (e) phase diagram in overdoped Ba-122
- T_c is correlated with $T_{N/S}$ in underdoped Ba-122
- electronic parameter: FS topology ?

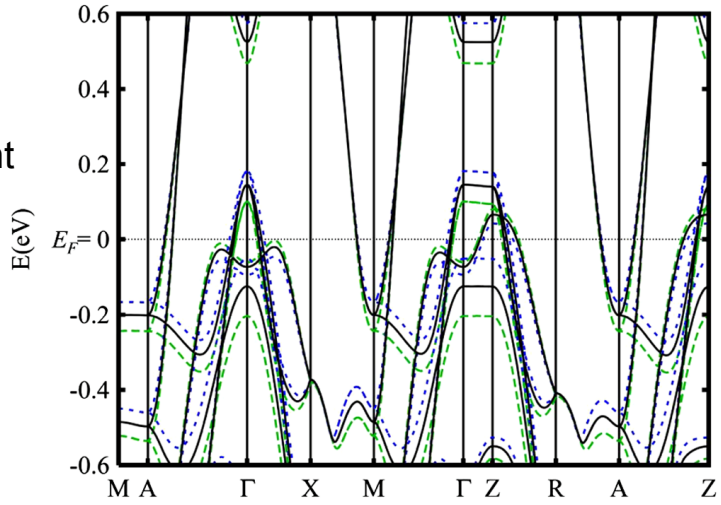
Liu et al. Nat. Phys. (2010)

What is controling T_c ?

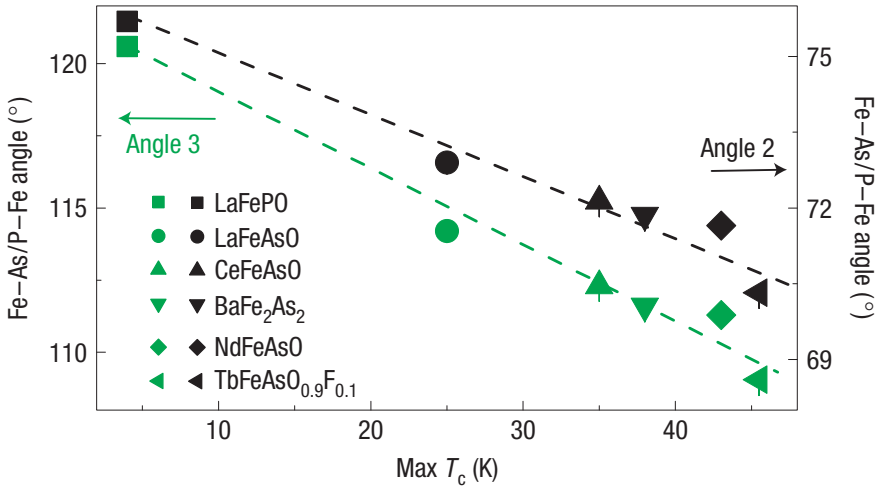
- Fe-As-Fe bond angle controls bandwidth and nesting
- Sensitivity of the band structure and calculated Fe moment with As position



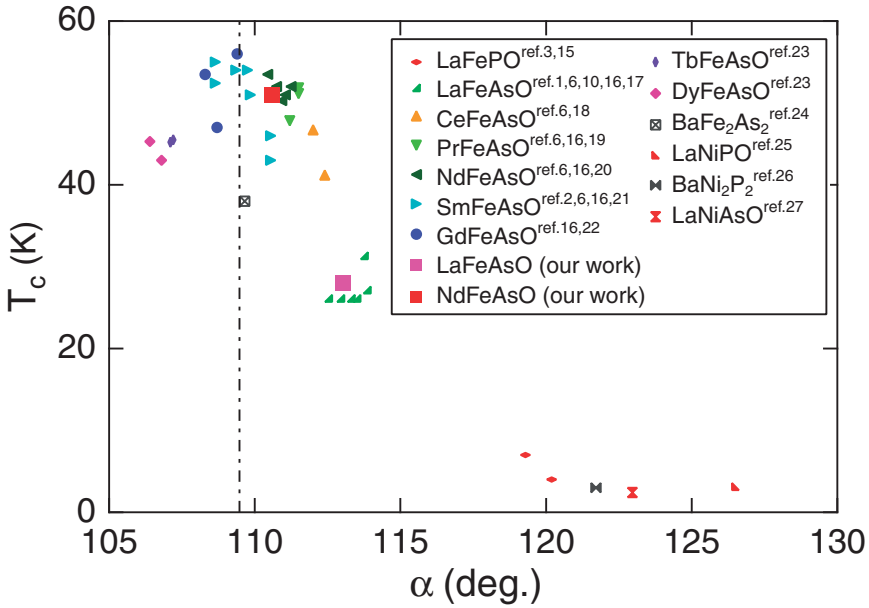
$FeAs_4$ tetrahedra



Singh et al. Phys. Rev. Lett. 100, 237003 (2008)



de la Cruz et al. Nature Mat. 7, 953 (2008)

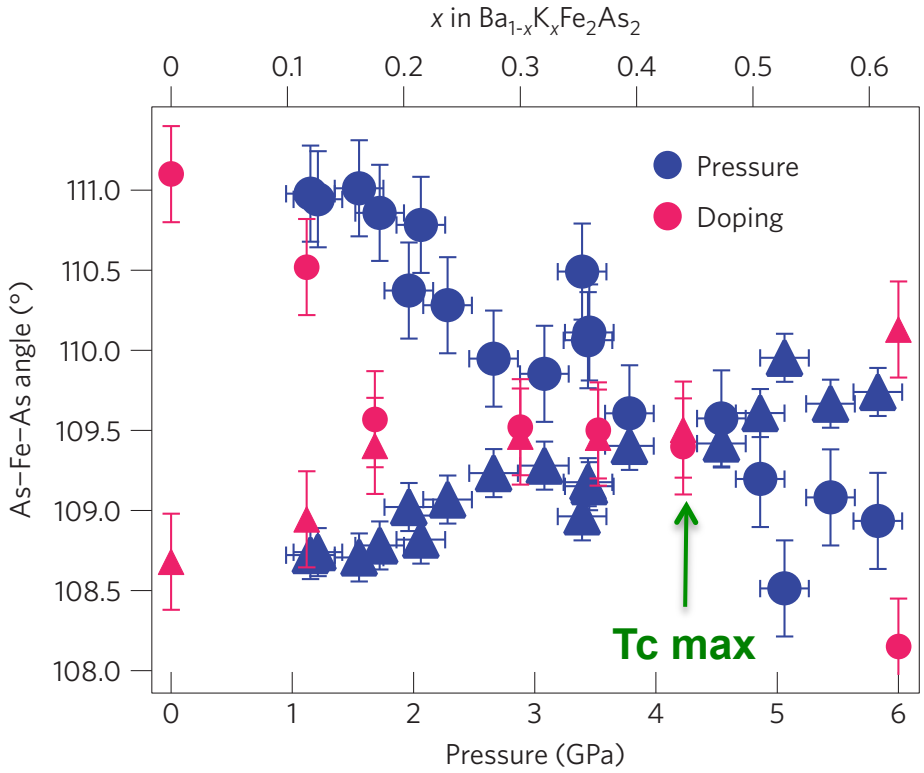


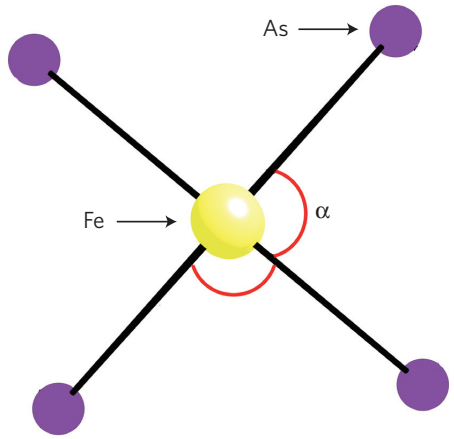
T_c is max for perfect tetrahedra: « magic » angle at 109°

C.H. Lee et al. JPSJ 77, 083704 (2008)
Garbarino et al. EPL 96 5 (2011) 57002

x: structural tuning

K (hole) doping vs pressure



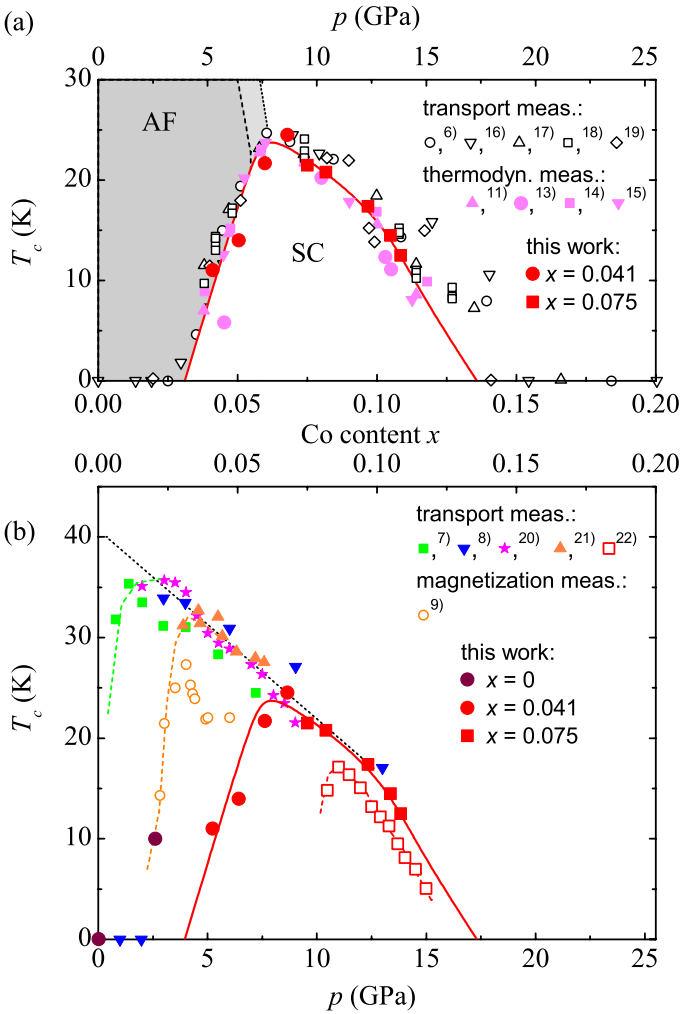


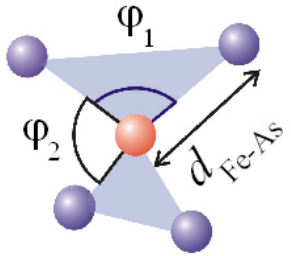
S. Kimber et al. Nature Mat. 8, 471 (2009)

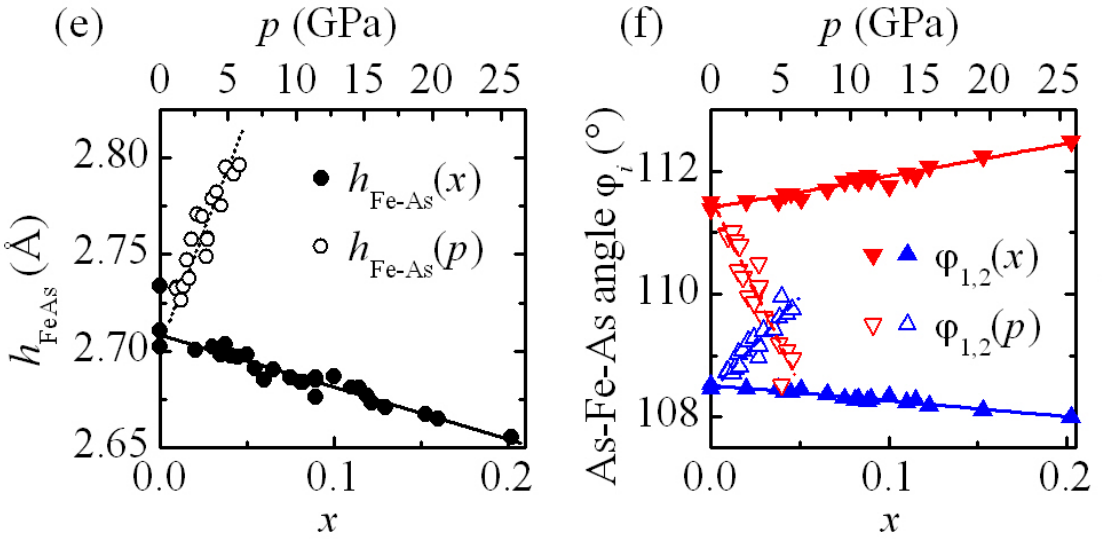
- pressure and hole doping have a similar effect on bond angle (chemical vs physical pressure)
- T_c is max around « magic » angle (but uncertainty in pressure dependance of T_c)

x parameter in $BaFe_2As_2$ (122)

Co doping vs pressure





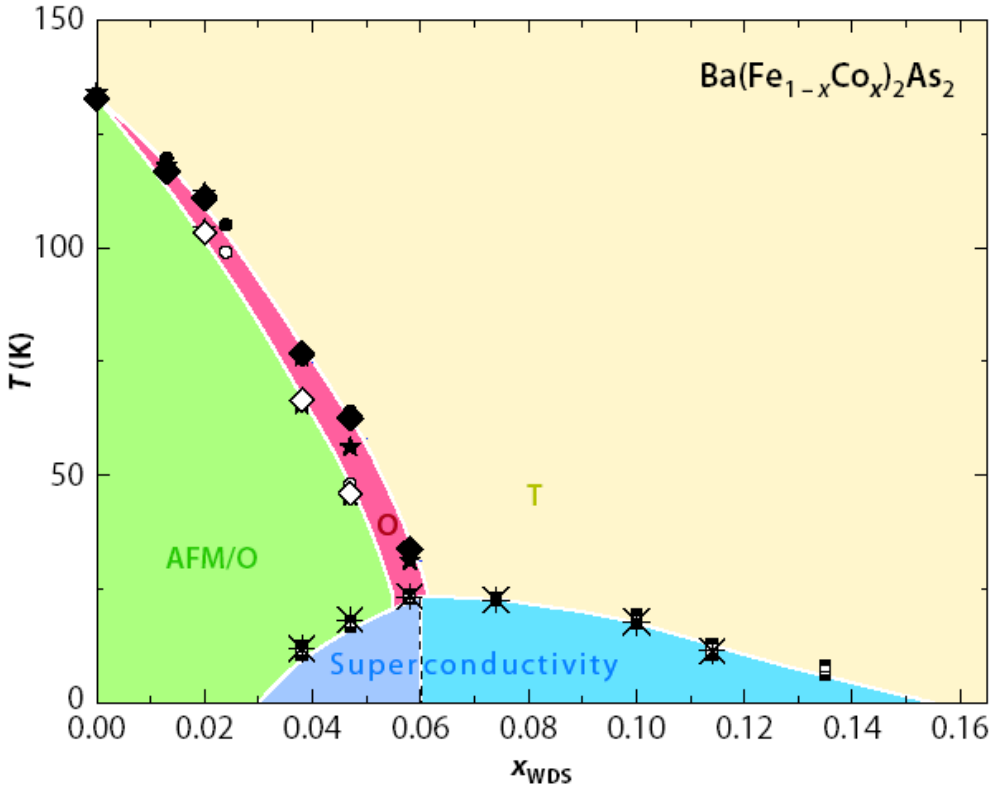


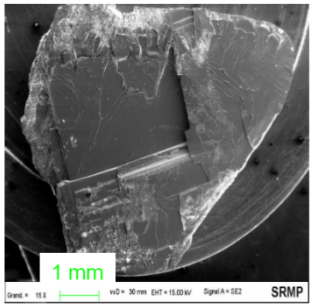
S. Drotziger et al. JPSJ. 79, 124705 (2010)

- No clear structural trends between Co and pressure
- x is not just structural tuning

Phase diagram of $Ba(Fe_{1-x}Co_x)_2As_2$

Co electron doped Ba122: most studied system



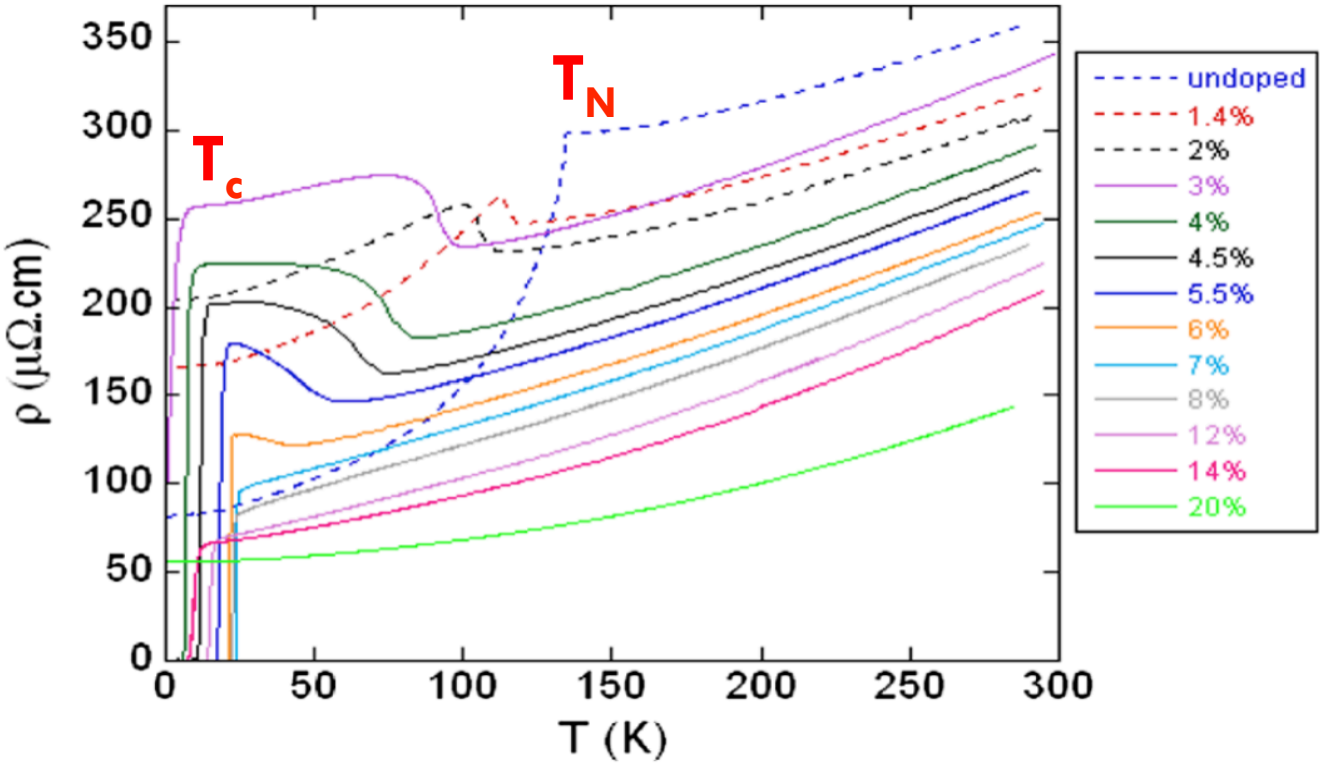


- Relatively large and good quality single crystals
- Homogeneous Co doping (no segregation)
- Fine control of Co

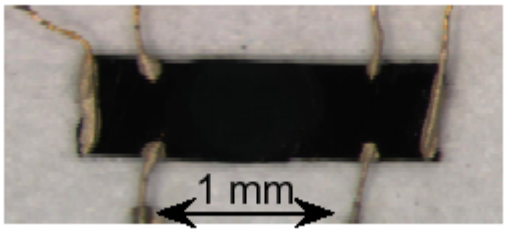
Canfield and Budko, Annu. Rev. Condens. Matter Phys. 1, 27-50 (2010)

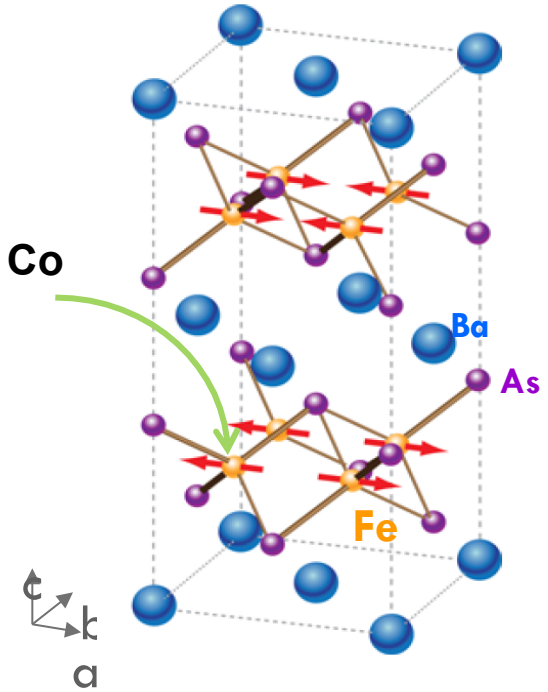
F. Rullier-Albenque & al, Phys. Rev. Lett. ***103****, 057001 (2009)*

Transport in $Ba(Fe_{1-x}Co_x)_2As_2$



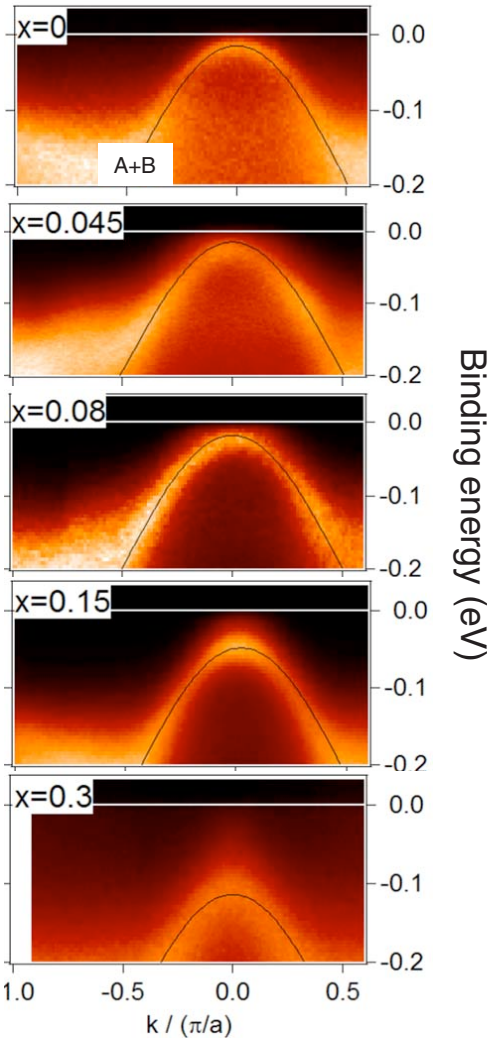
F. Rullier-Albenque & al, *Phys. Rev. Lett.* ***103***, *057001 (2009)*





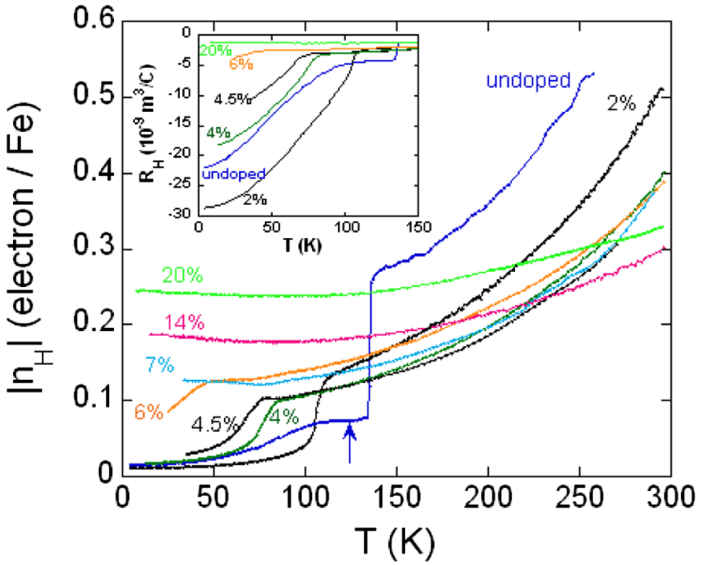
Electron doping: Co^{3+} replaces Fe^{2+}

Electron doping in $Ba(Fe_{1-x}Co_x)_2As_2$



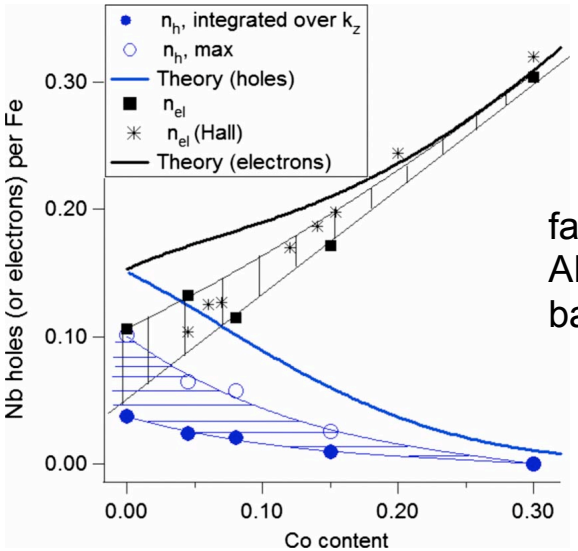
V. Brouet et al, *Phys. Rev. B* ***80****, 165115 (2009)*

ARPES: hole band sinks below E_F



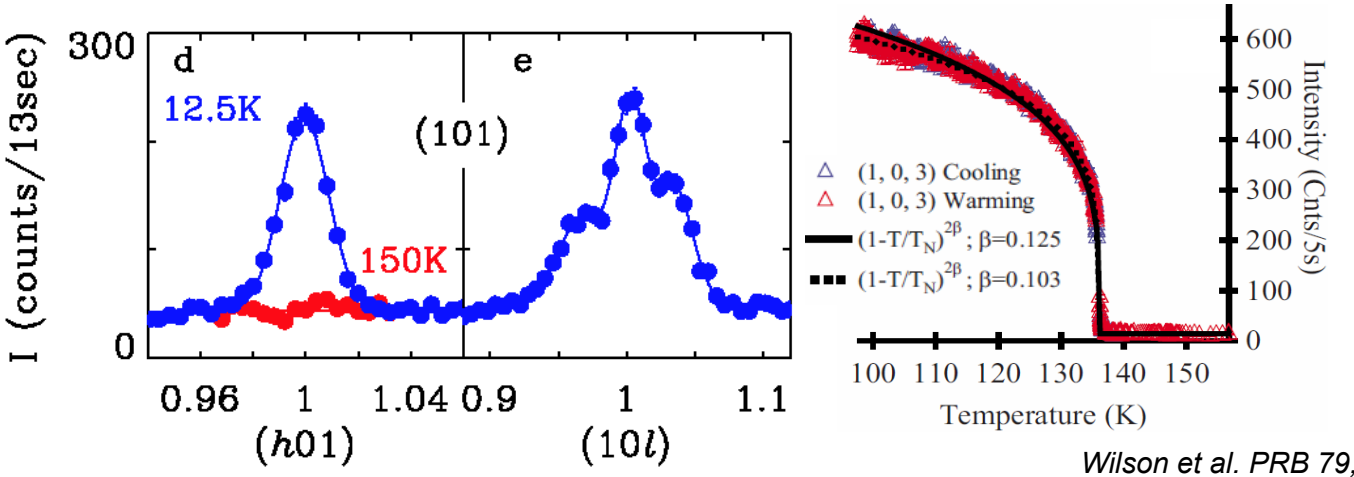
Hall effect: increase in electron-like carrier

F. Rullier-Albenque & al, *Phys. Rev. Lett.* ***103****, 057001 (2009)*



fair agreement between Hall and ARPES (Luttinger theorem): rigid band picture

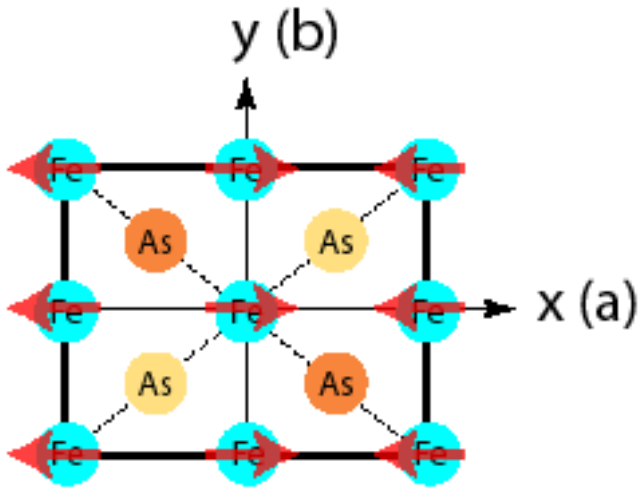
$BaFe_2As_2$: magnetic transition



Neutron diffraction: new Bragg peaks below 135K

Wilson et al. PRB 79, 184519 (2009)

Huang et PRL 2008



- transition second (Ba-122) or first (Ca-122) order
- stripe-like AF order: in-plane magnetic anisotropy

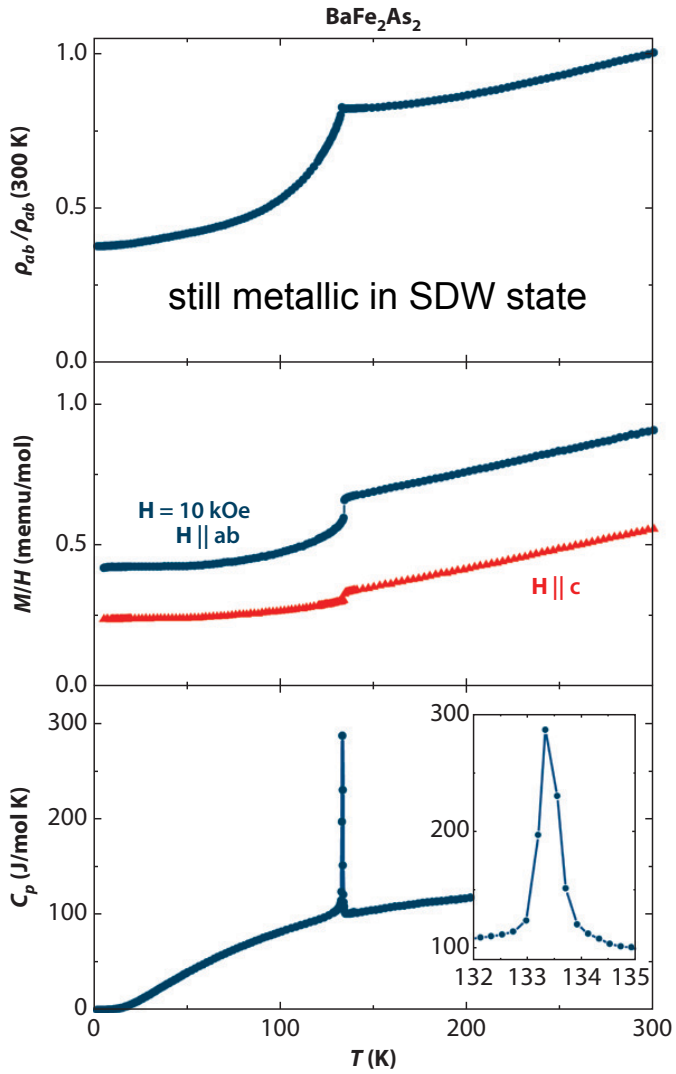
itinerant magnetism, not Mott magnetism

Spin Density Wave transition

transport

magnetization

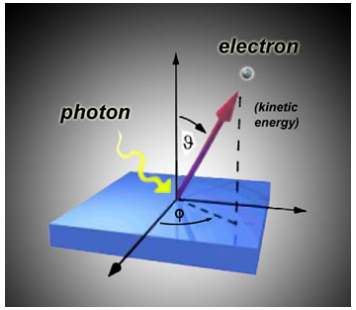
specific heat

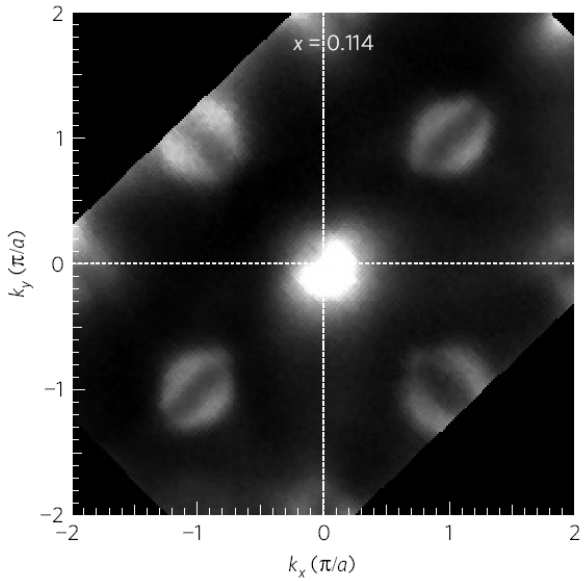


itinerant magnet: SDW transition

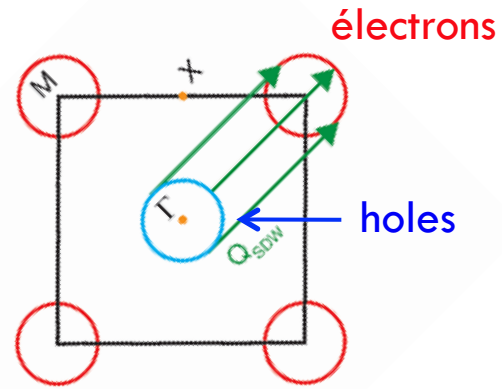
Canfield and Budko Annu. Rev. Condens. Matter Phys. 1, 27-50 (2010)

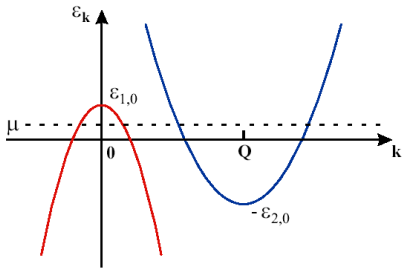
SDW and Fermi surface nesting



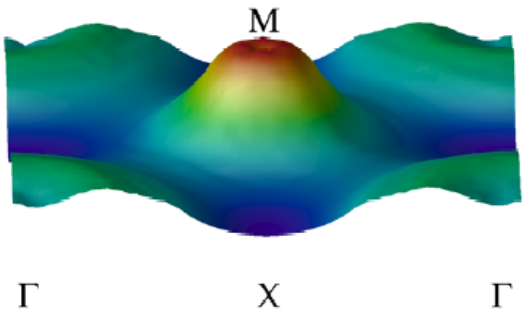


ARPES: Liu et al. Nature Phys. 2010



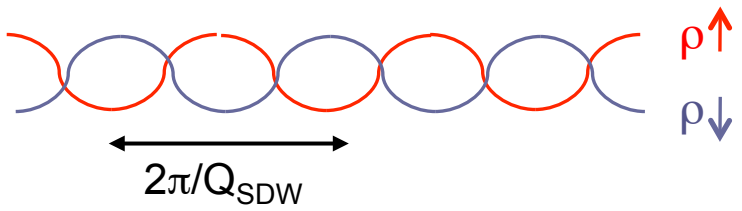


k-space susceptibility



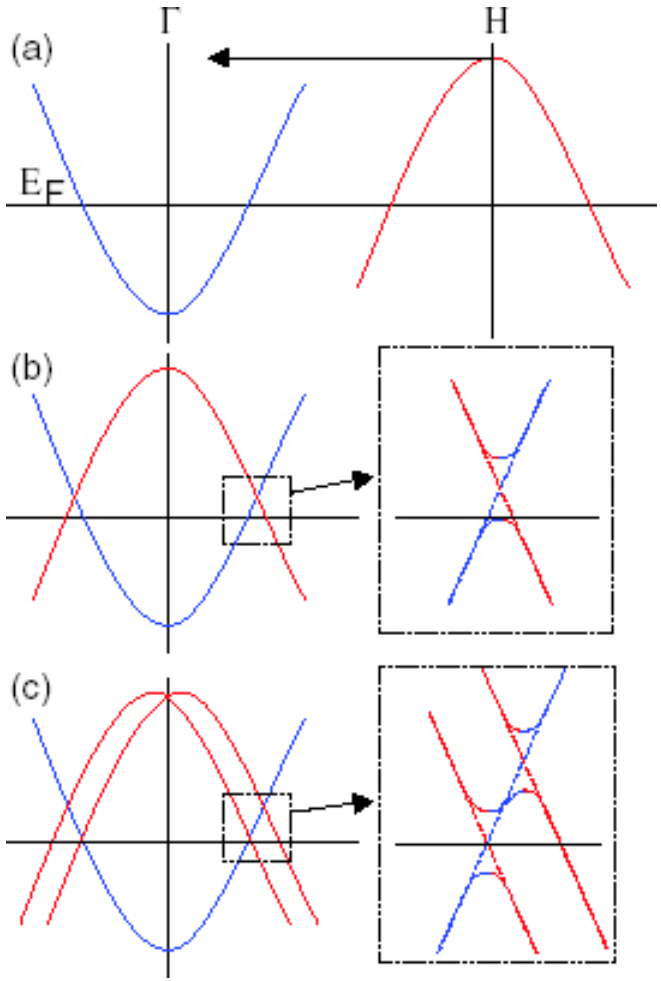
Mazin et al. PRL 2008

r-space



- approximate Fermi surface nesting $\mathbf{Q_{SDW}}$ between holes and electrons pockets
- enhancement of susceptibility at $Q_{SDW}=(\pi,\pi)$: instability
- DFT correctly predicts magnetism but over-estimate magnetic moment

Fermi surface reconstruction in the SDW state

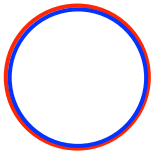


- Backfolding of the band
- Spin density wave gap at E_F (anticrossing)

- Perfect nesting: insulator
- Imperfect nesting: SDW metal

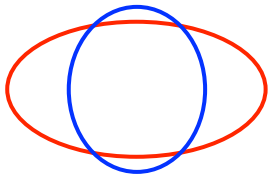
perfect nesting

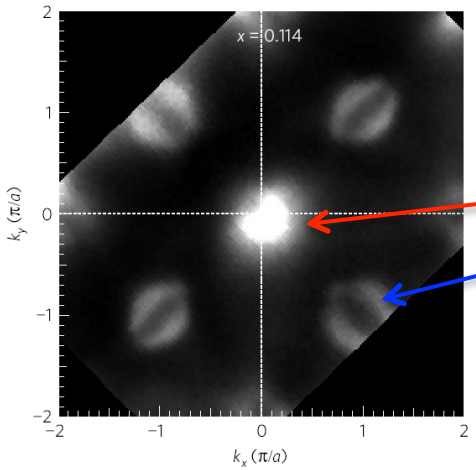
$m = m_x = m_y$



ellipticity

$m \neq m_x \neq m_y$

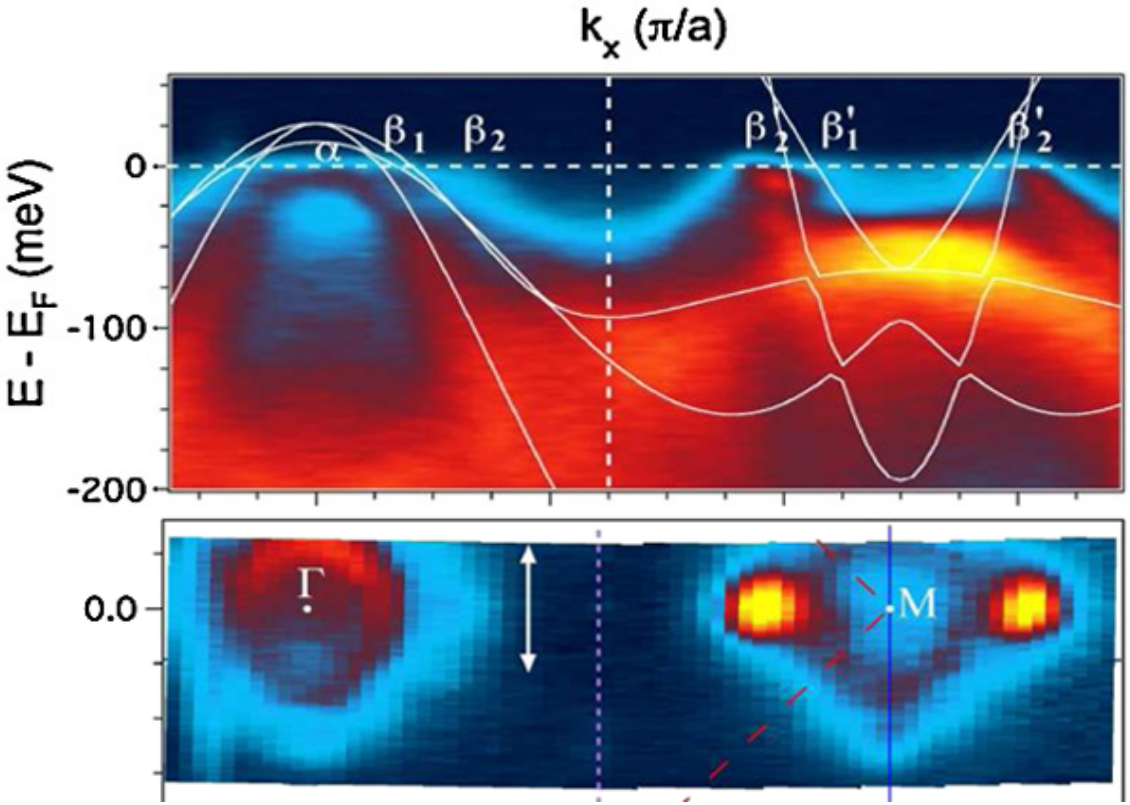


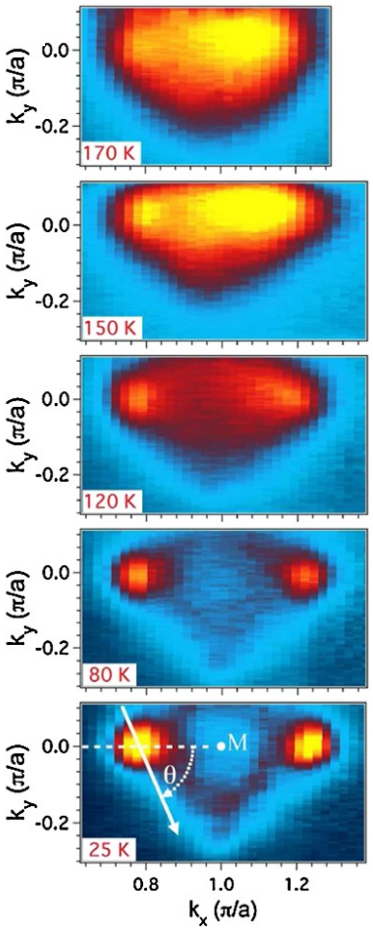


hole FS: circular
electron FS: elliptic

ARPES: Liu et al. Nature Phys. 2010

Fermi surface reconstruction





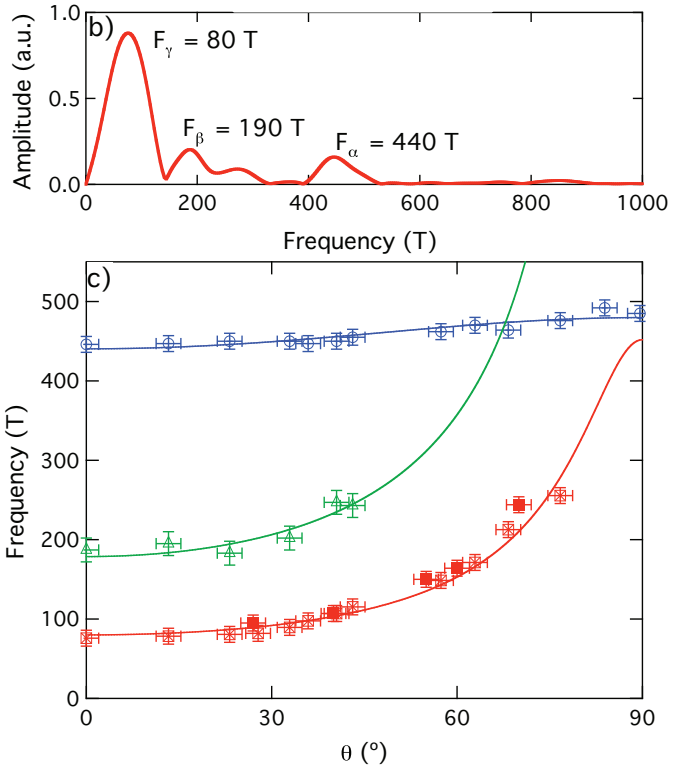
- imperfect nesting: residual Fermi surfaces
- Not all the bands are clearly resolved
- SDW gaps unclear
- More than simple band folding ?

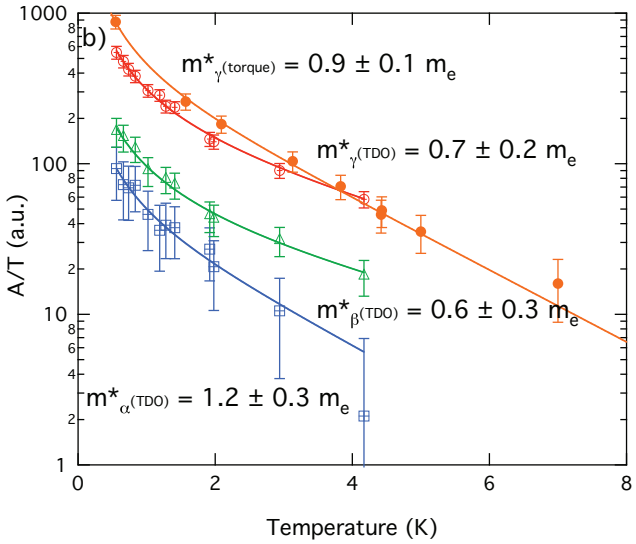
Richard et al. , Phys. Rev Lett. 104, 137001 (2010)

Liu et al. Nature Phys. 6, 419 (2010)

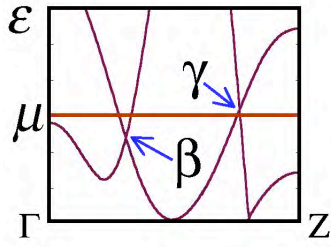
Ran et al. Phys. Rev. B 79, 014505 (2009)

Fermi surface reconstruction: quantum oscillations (SdH)





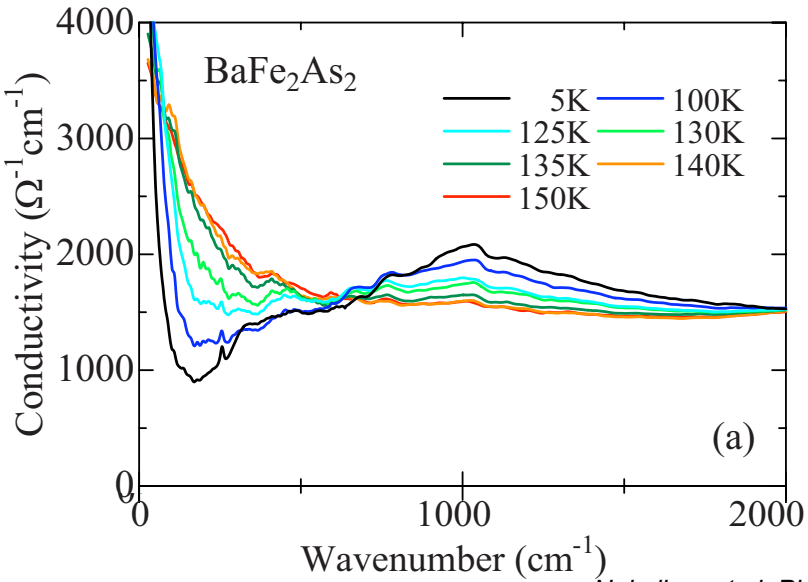
Analytis et al. Phys. Rev. B 80, 064507 (2009)



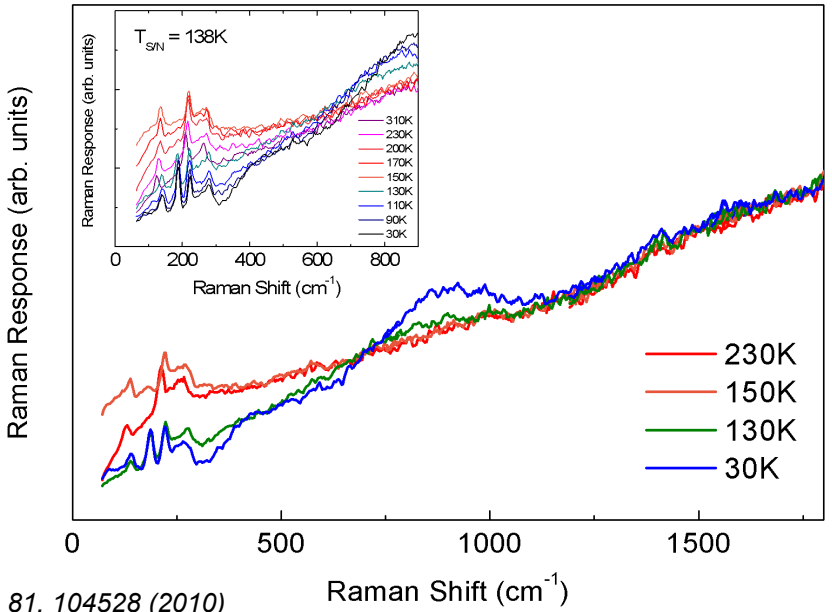
- very small FS area in the SDW phase (1.7%, 0.7% et 0.3% de ZB para): FS reconstruction
- one FS is isotropic and the other 2 anisotropic (cigar-shaped: Dirac point)

Spin density wave gaps

optical conductivity



Raman scattering

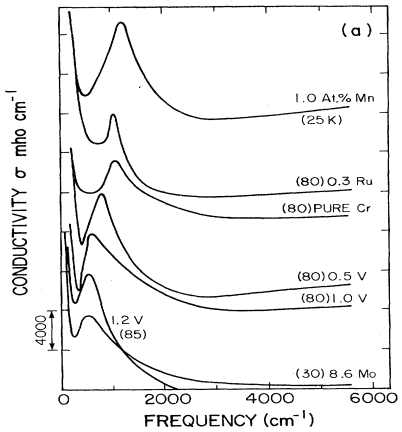


Nakajima et al. Phys. Rev. B 81, 104528 (2010)

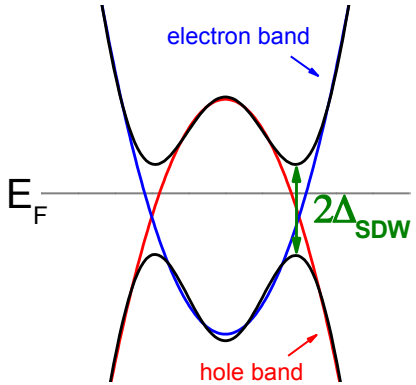
Akrap et al, Phys. Rev. B 80, 180502(R) (2009)

Chauvière et al. Phys. Rev. B 84, 104508 (2011)

Cr alloys

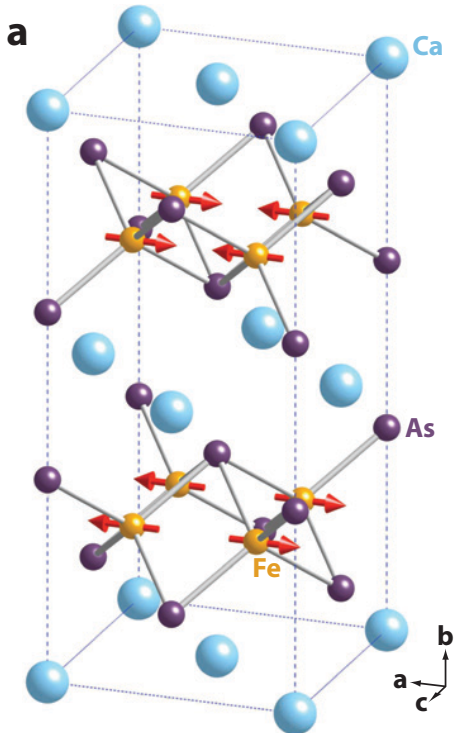


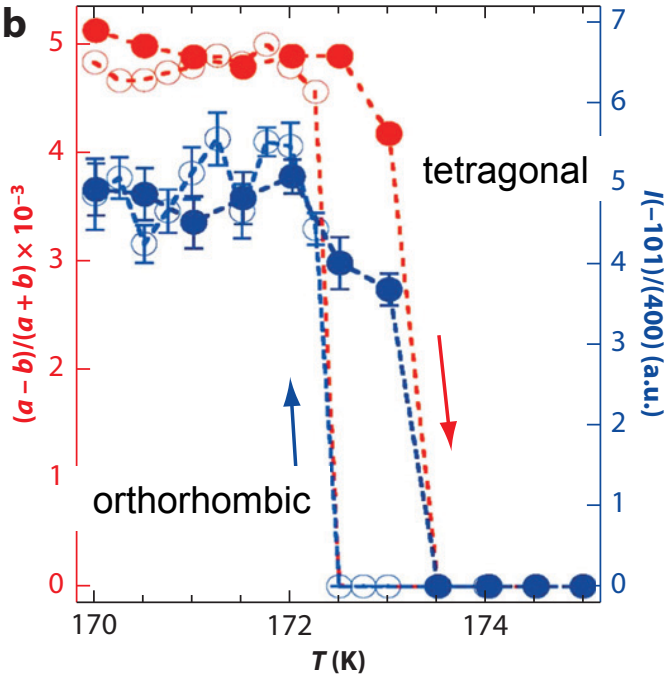
Barker et al. Phys. Rev B 1, 4378 (1970)

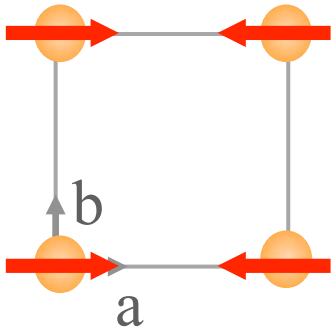


- opening of SDW gaps consistent with band folding
- residual Drude weight in the SDW state: incomplete gap

Magneto-structural transition







a>b

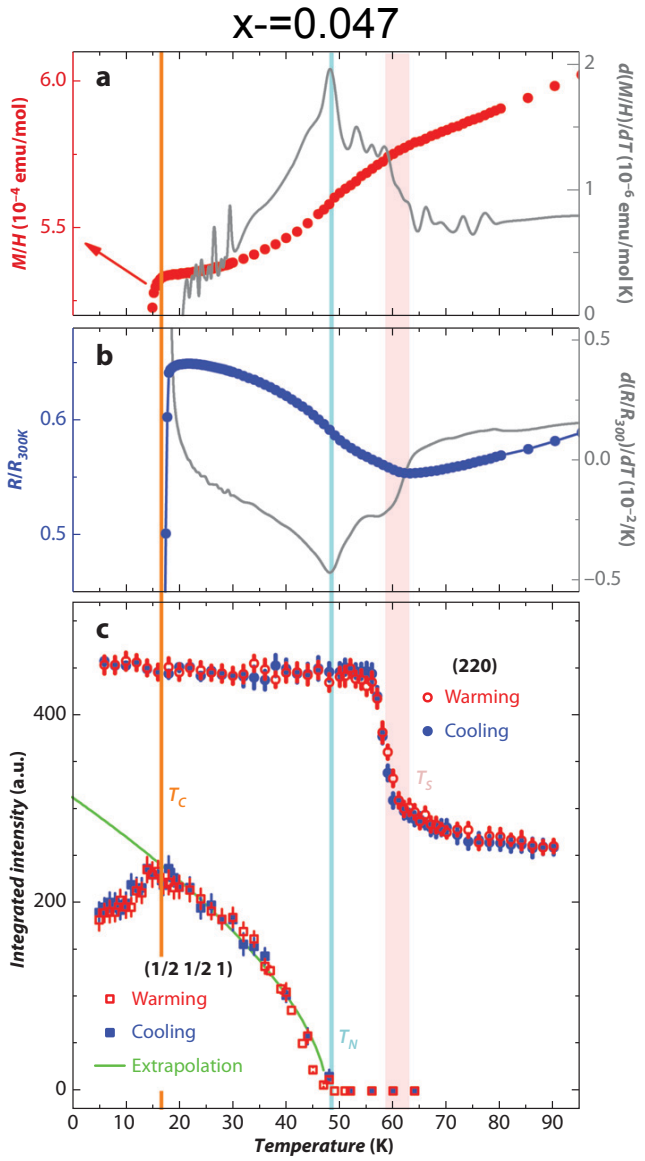
- first order in (Ca,Sr)-112 but second order in Ba-122
- orthorhombic distorsion is less than 0.5%
- Spin driven structural transition ?

Splitting of the transition in $Ba(Fe_{1-x}Co_x)_2As_2$

magnetization

transport

neutrons



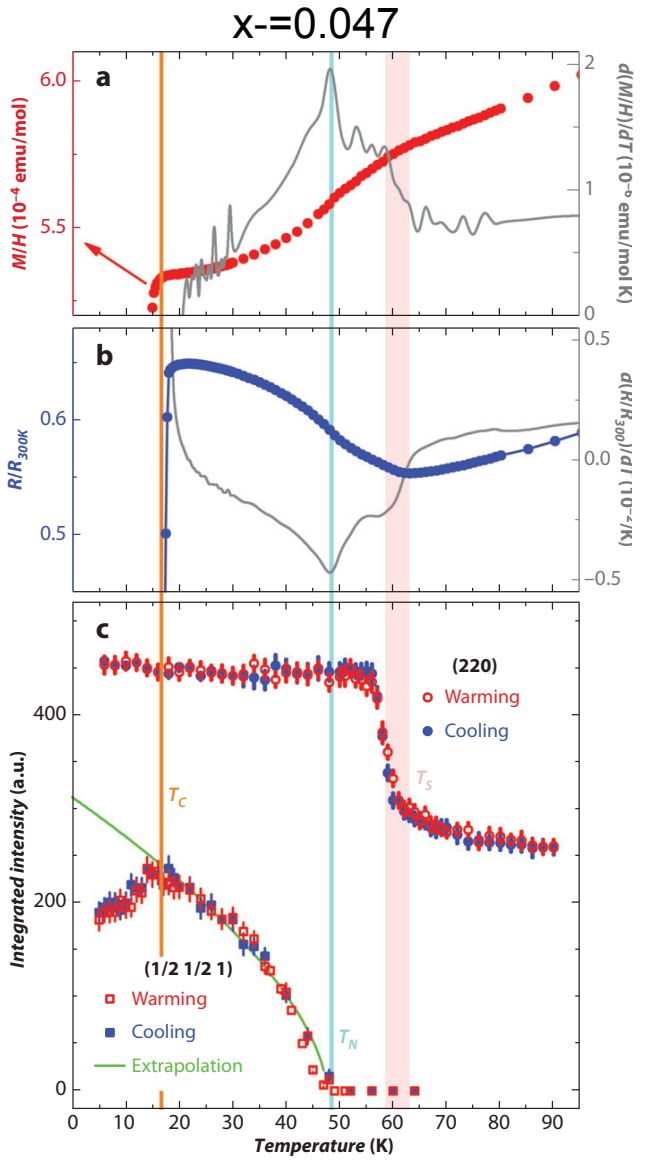
- magnetic and structural transitions split upon Co doping
- not observed in all systems (disorder?)
- fluctuating magnetic domains ?

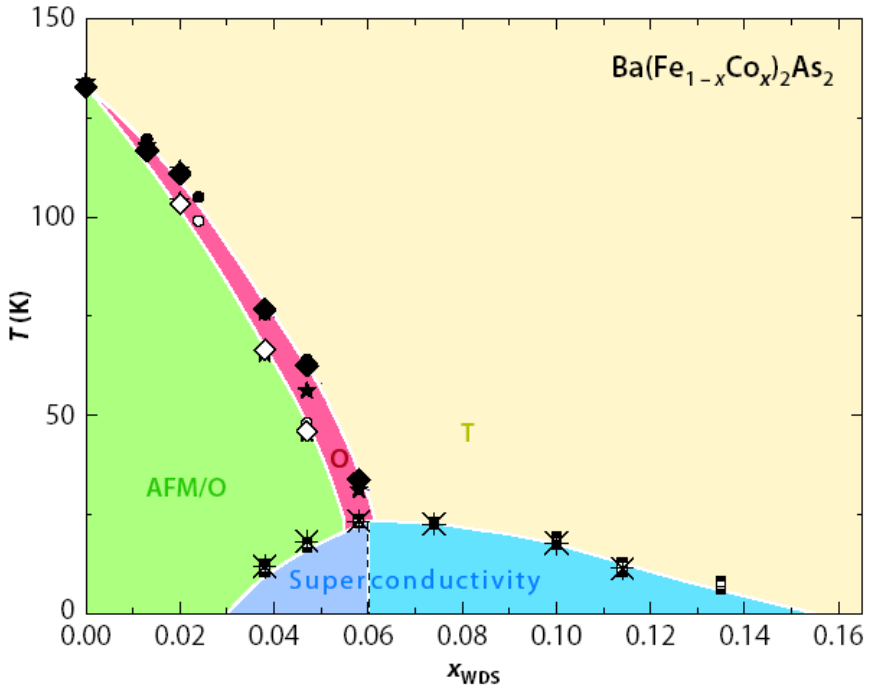
Splitting of the transition in $Ba(Fe_{1-x}Co_x)_2As_2$

magnetization

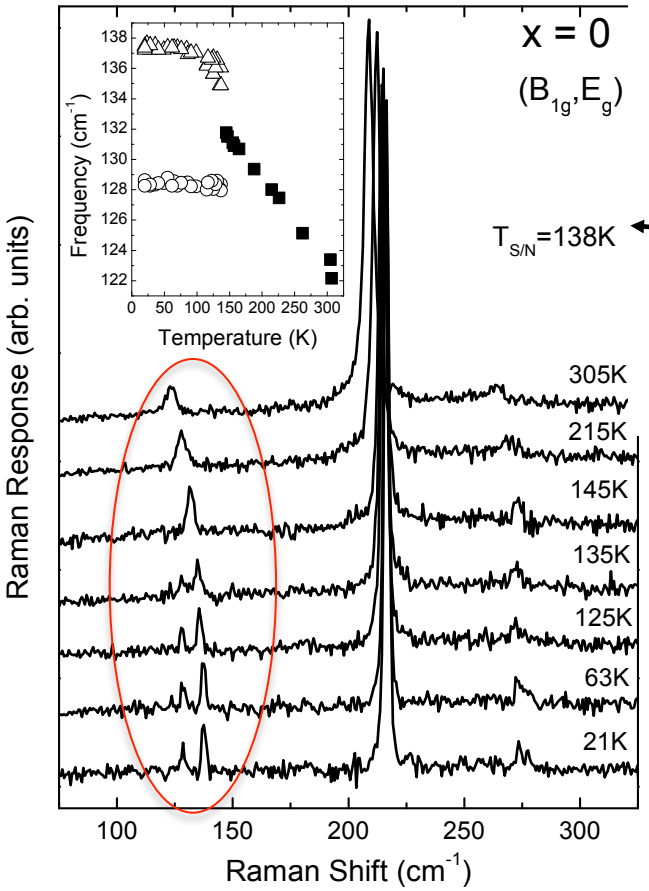
transport

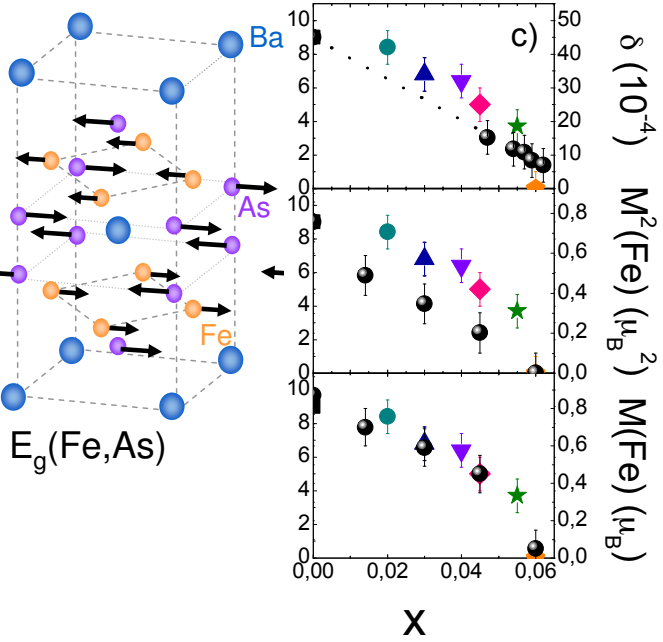
neutrons





Spin-lattice coupling



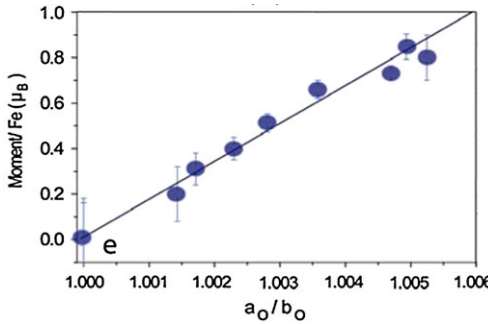


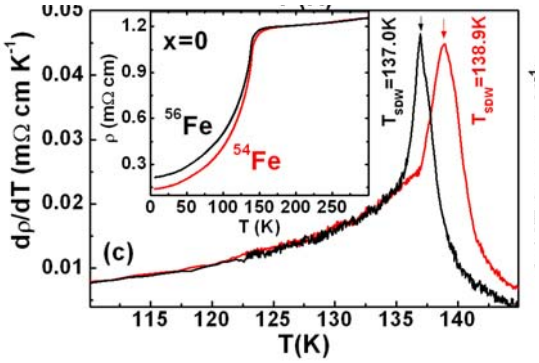
Chauvière et al. Phys. Rev. B 80, 094504 (2009)

de la Cruz et al., Phys. Rev. Lett. 104, 017204 (2010)

Liu et al. Nature 459, 64-67 (2009)

CeFeAs1-xPxO



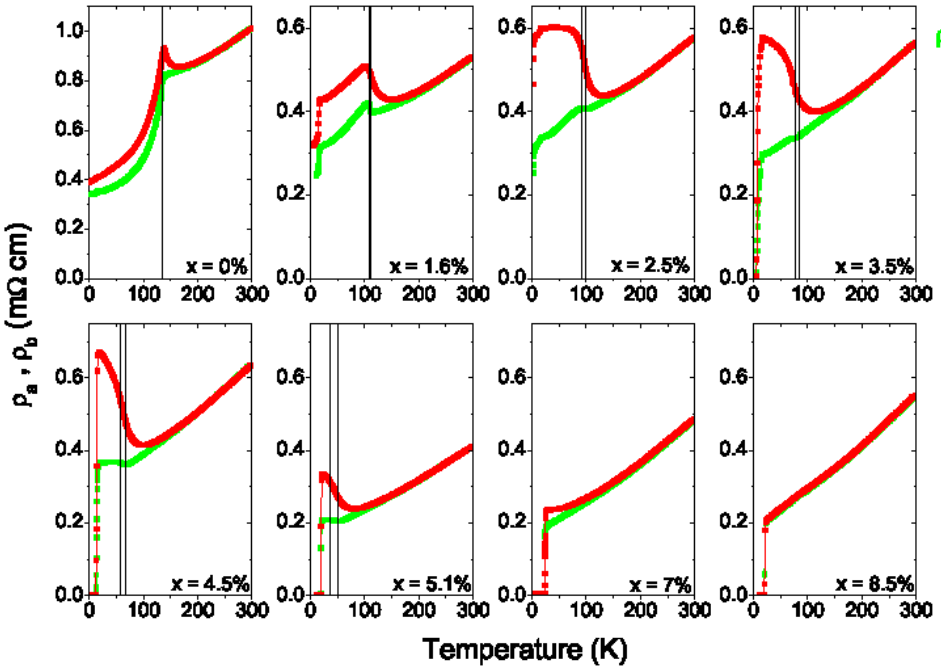


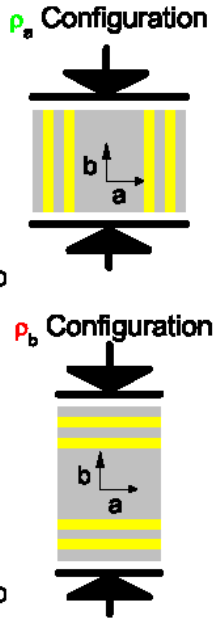
isotope effect on T_N

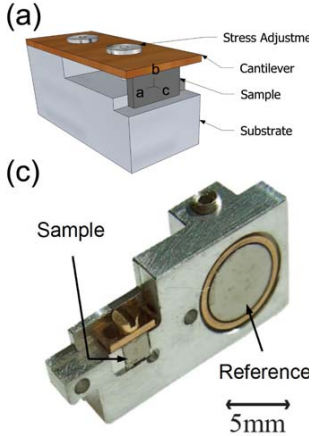
- phonon splitting much larger than expected from lattice distorsion alone
- strong spin-phonon coupling: modulation of the exchange constant by atomic motion
- linear relation between lattice distorsion, phonon splitting and magnetic moment

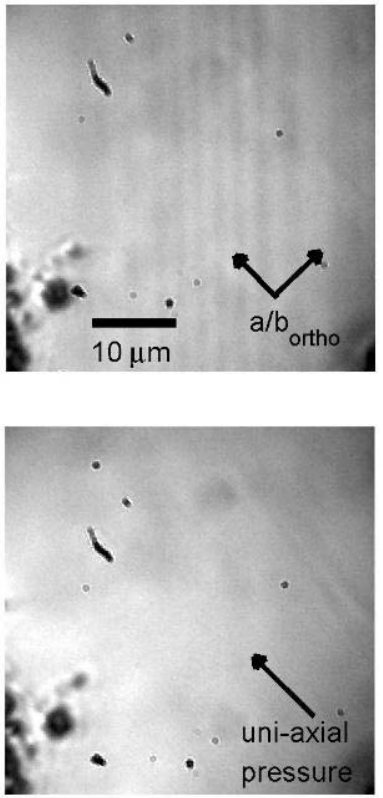
Anisotropic transport

transport in mechanically detwinned crystals







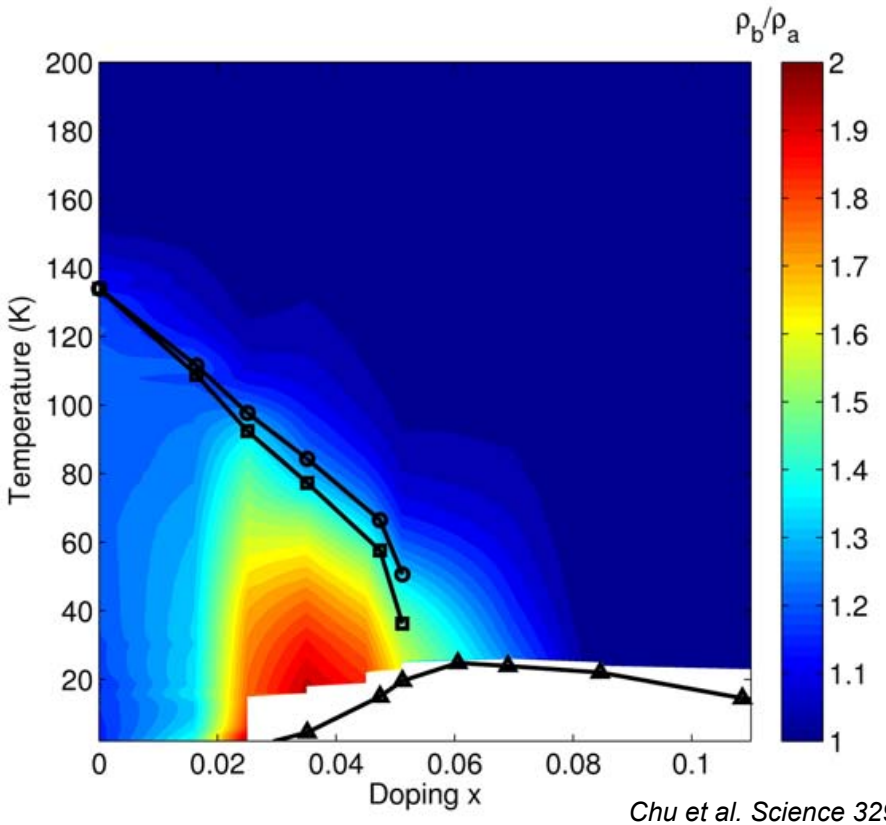


Chu et al. Science 329, 824 (2010)

- very large transport anisotropy at low temperature
- extremely strong sensitivity of properties to stress above T_S: nematic susceptibility

Nematic order ?

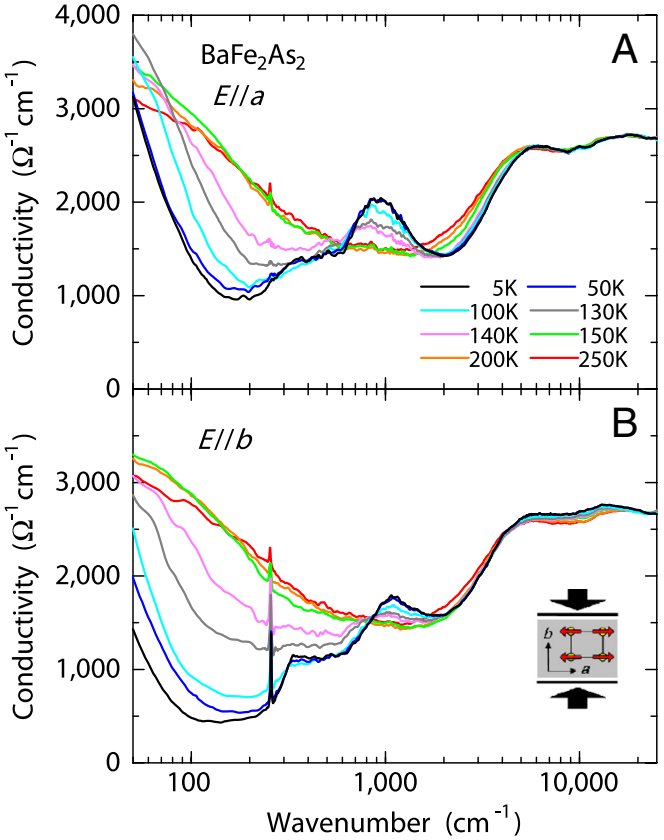
transport in mechanically detwinned crystals



Chu et al. Science 329, 824 (2010)

anisotropy (or nematic susceptibility?) is maximum around onset of SC order

optical conductivity

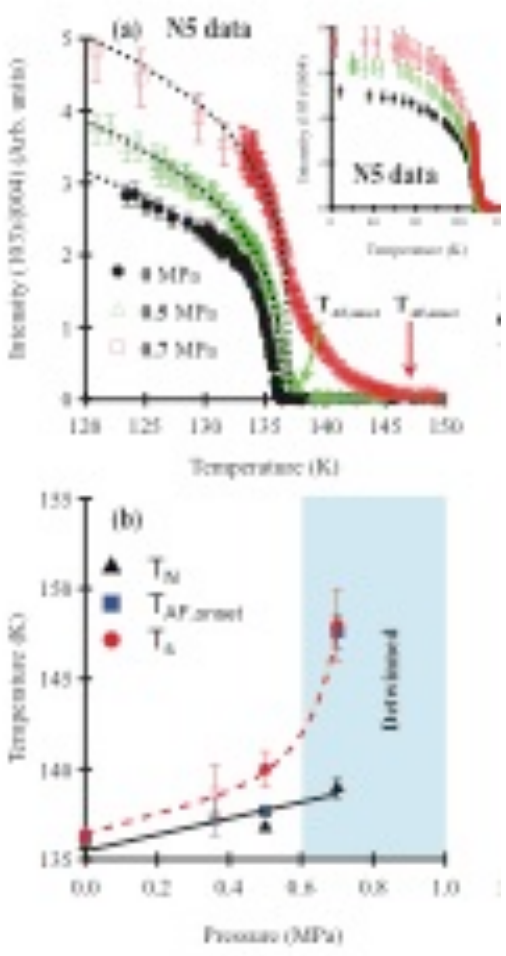


Nakajima et al. PNAS 108, 12238 (2011)

strong reduction of Drude weight along b-direction only

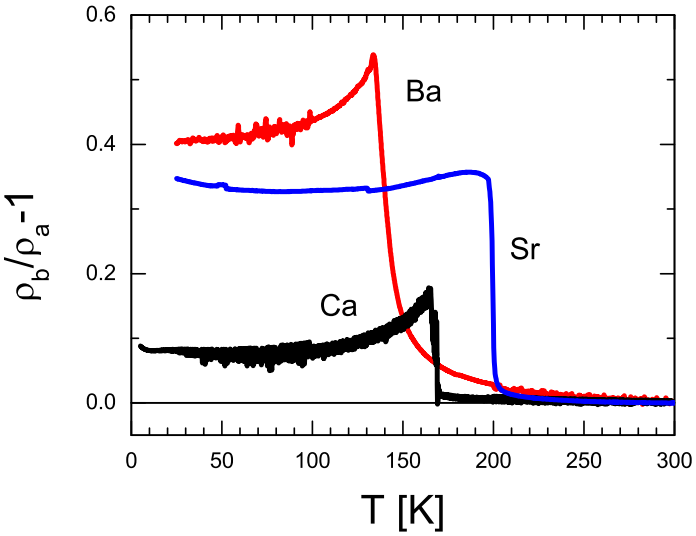
strong in-plane anisotropy of the electronic properties

Nematic order ?



Dhital et al. arXiv (2011)

small stress induced large shift of $T_{S,N}$

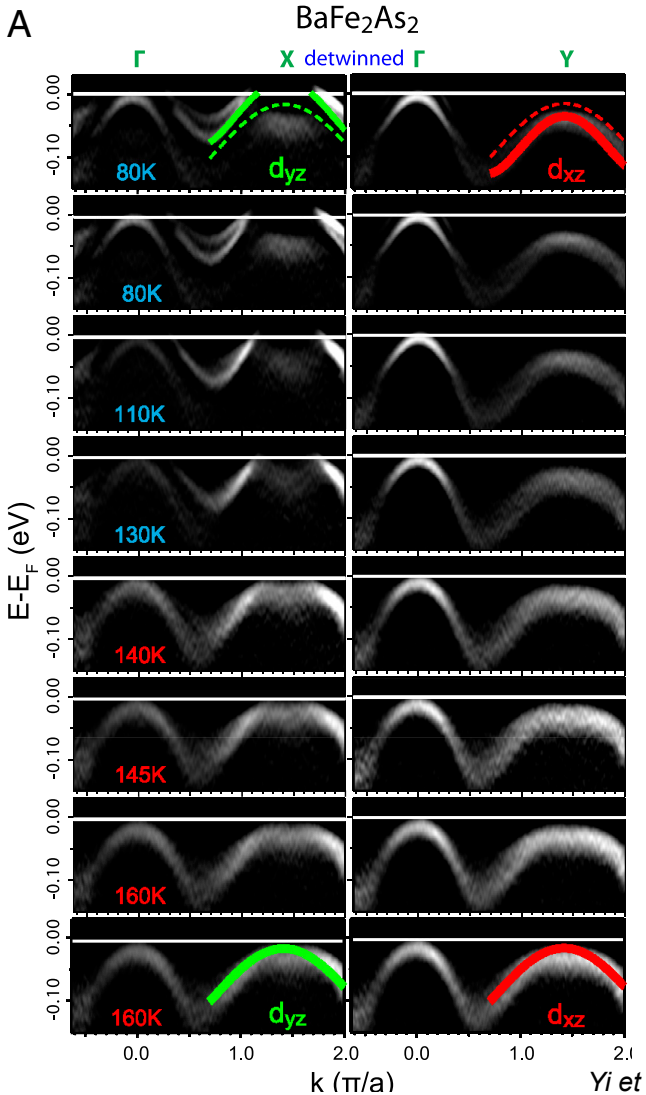


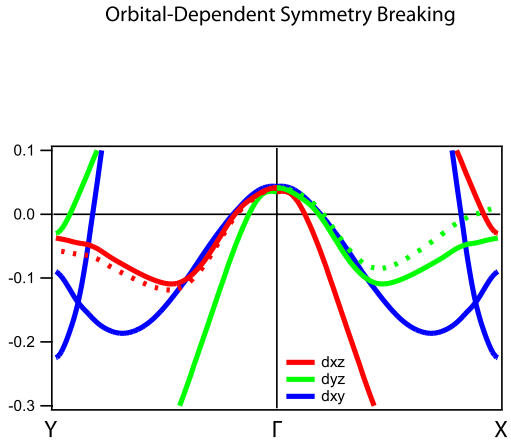
Blomberg et al. Phys. Rev. B 83, 134505 (2011)

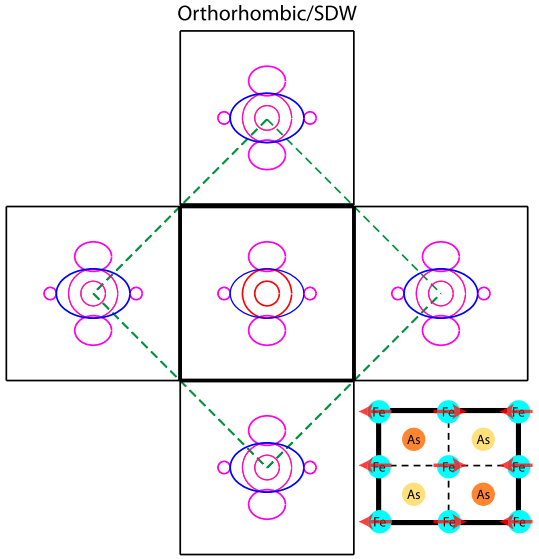
- no anisotropy above Ts for Ca122 and Sr122
- first order vs second order transition
- nematic phase above T_S is not generic
- Fluctuating magnetic domain

Orbital dependent band splitting

ARPES on detwinned crystals







- C_4 symmetry is broken
- splitting larger than expected from structural distorsion
- orbital degrees of freedom may play a role in the magneto-structural transition

Yi et al. PNAS 108, 6878 (2011)

Magneto-structural coupling

what is the driving force behind the M/S transition? a chicken and egg problem

1. **Magnetic driven structural distorsion**: magnetic fluctuations drive the distorsion via magneto-elastic coupling or via Ising nematic fluctuations that break C_4 symmetry above T_S (φ=$\mathbf{m_1}.\mathbf{m_2}$) (« nemato-elastic » coupling)

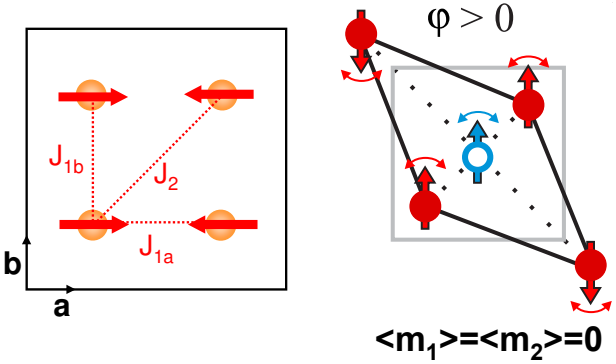
T. Yildirim. Phys. Rev. Lett. 101, 057010 (2008)

Fernandes et al., Phys. Rev. Lett. 105, 157003 (2010)

Chandra et al., Phys. Rev. Lett. 64, 88 (1990)

A. Cano et al., Phys. Rev. B 82, 020408(R) (2010)

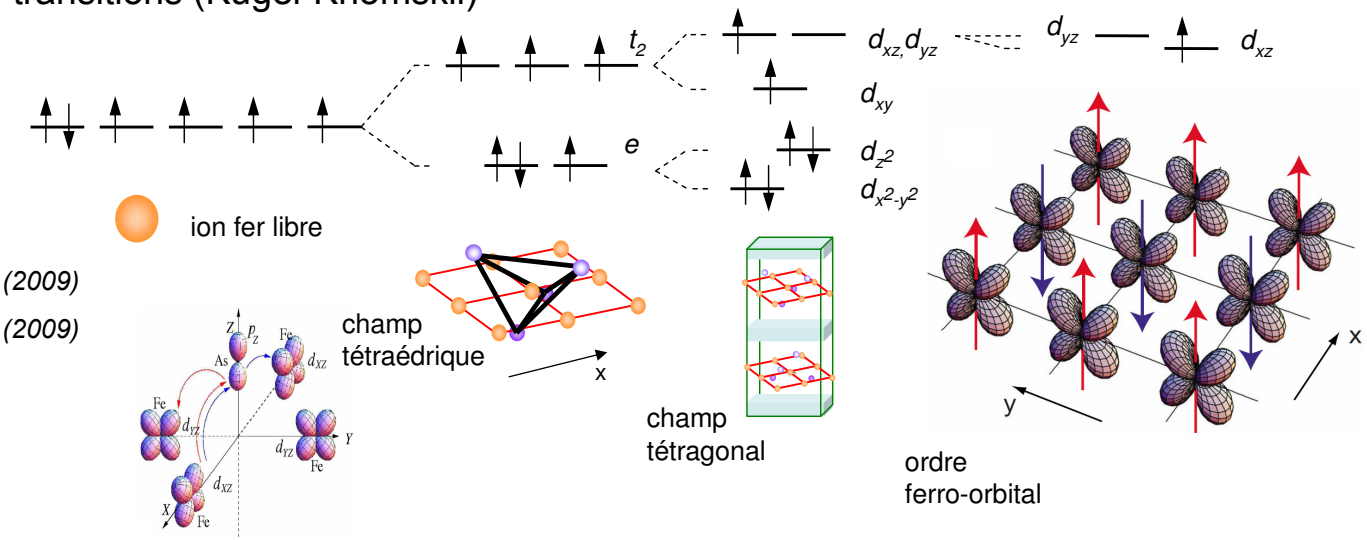
I. Paul, Phys. Rev. Lett. 107, 047004 (2011)



2. **Orbital ordering**: difference in d_{xz} and d_{yz} occupation drives both magnetic and structural transitions (Kugel-Khomskii)

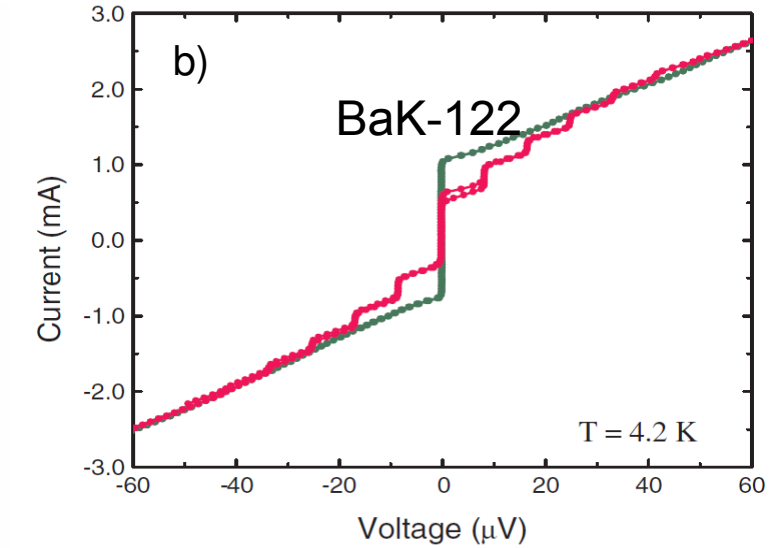
Kruger et al. Phys. Rev. B 79, 054504 (2009)

Lv et al. Phys. Rev. B 80, 224506 (2009)



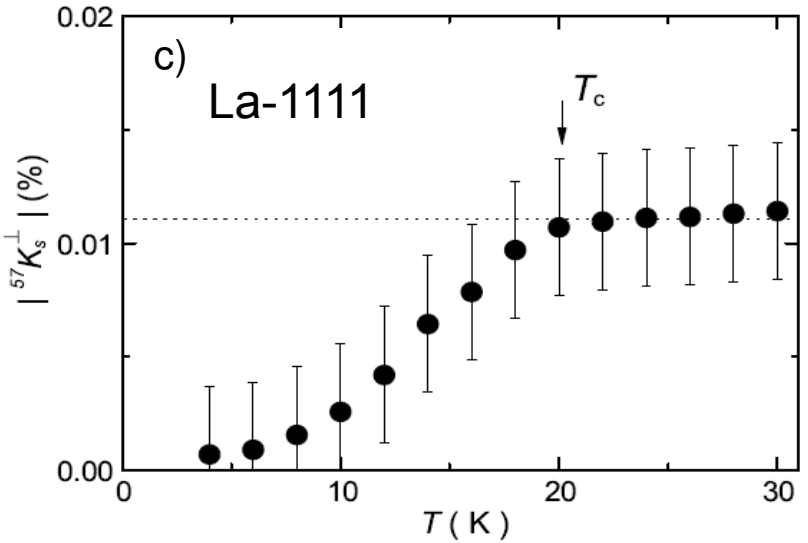
Superconducting state

AC Josephson effect: charge 2e



Zhang et al. Phys. Rev. Lett. 102, 147002 (2008)

NMR: spin-singlet



Teresaki et al. JPSJ 78, 13701 (2008)

Electron-phonon coupling too weak to explain T_c>10K

Boeri et al. Physica C 469, 628-634 (2009)

Gap structure and spin fluctuation pairing

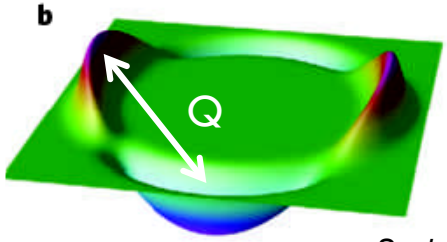
- weak electron-phonon coupling
- proximity of AF order suggests spin fluctuation pairing

$$\Gamma_s(\boldsymbol{k},\boldsymbol{k}') = \frac{3}{2}U^2\frac{\chi_0(\boldsymbol{q})}{1-U\chi_0(\boldsymbol{q})}$$ singlet repulsive interaction (Stoner-Hubbard)

$$\Delta_{\boldsymbol{k}} = -\sum_{\boldsymbol{k}'}{}'\Gamma_s(\boldsymbol{k},\boldsymbol{k}')\frac{\Delta'_{\boldsymbol{k}}}{2E'_{\boldsymbol{k}}}\tanh\frac{E'_{\boldsymbol{k}}}{2T},$$ solution allowed if Δ changes sign

Berk and Schrieffer. Phys.Rev.Lett. 17, 433 (1966)
Scalapino et al., Phys. Rev. B 34, 8190 (1986)

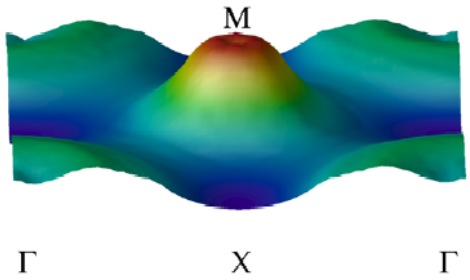
In cuprates: susceptibility is peaked at Q=(π,π)



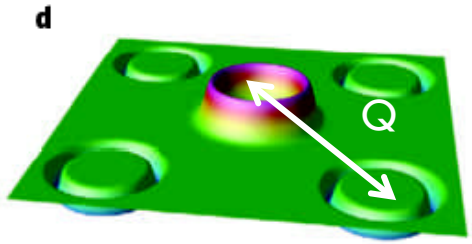
d-wave gap

Scalapino. Phys. Rep. 250, 329 (1995)

In pnictides: susceptibility is peaked at Q=(π,0)



$$\Delta_i = \sum_j \Lambda_{ij}\Delta_j F(\Delta_j, T)$$



s^{+-} gap

Suhl et al. Phys. Rev. Lett. 3, 552 (1959)
Kuroki et al. Phys.Rev.Lett. 101, 087004 (2008)
Mazin et al. Phys. Rev. Lett. 101, 057003 (2008)

alternative model: orbital fluctuations theory predicts s^{++}

Saito et al. Phys.Rev. B 82, 144510 (2010)

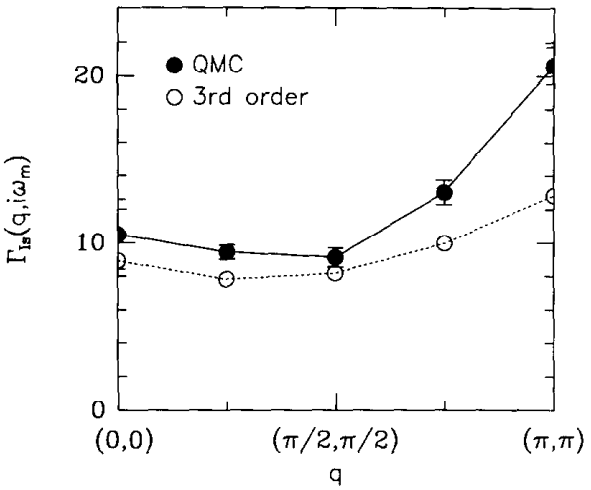
Gap structure and spin fluctuation pairing

- weak electron-phonon coupling
- proximity of AF order suggests spin fluctuation pairing

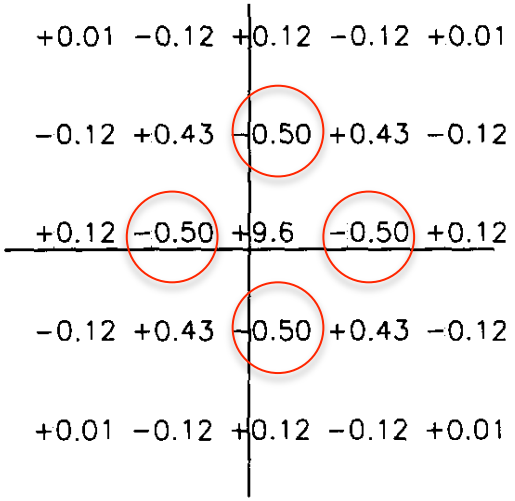
$$\Gamma_s(\boldsymbol{k},\boldsymbol{k}') = \frac{3}{2}U^2\frac{\chi_0(\boldsymbol{q})}{1-U\chi_0(\boldsymbol{q})}$$

singlet repulsive interaction (Stoner-Hubbard)

Berk and Schrieffer. Phys.Rev.Lett. 17, 433 (1966)
Scalapino et al., Phys. Rev. B 34, 8190 (1986)



$$\Gamma_{ls}(\boldsymbol{l}) = \frac{1}{N}\sum e^{iq\cdot l}\Gamma_{ls}(q).$$



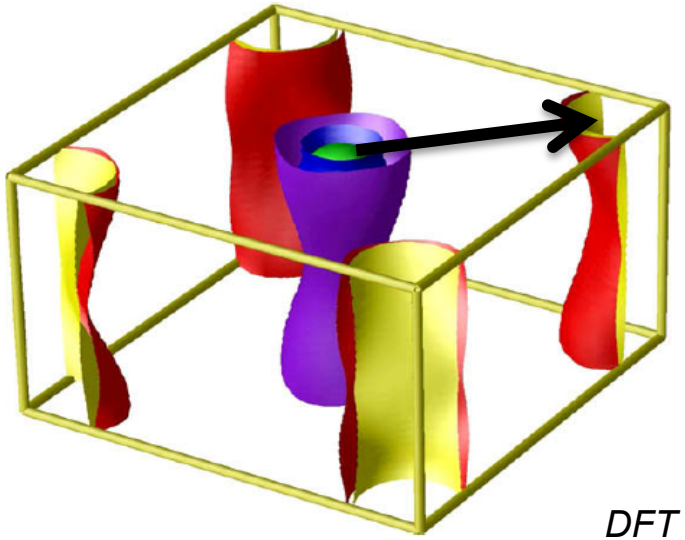
Pairing interaction for cuprates
(Monte Carlo and 3rd order perturbation theory)
Repulsive!

Pairing interaction is attractive for specific regions in real space

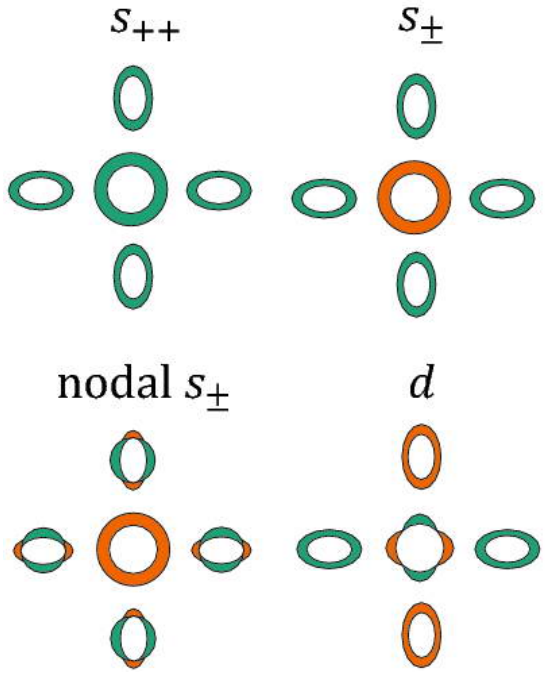
Scalapino. Phys. Rep. 250, 329 (1995)

Gap symmetry vs gap structure

- spin fluctuation pairing naturally leads to s^{+-} symmetry in pnictide
- Coulomb interband interaction is responsible for both SDW and SC phase
- gap symmetry does not tell much about presence of nodes



DFT calculations
Mazin, *Physica C* ***469***, *614 (2009)*

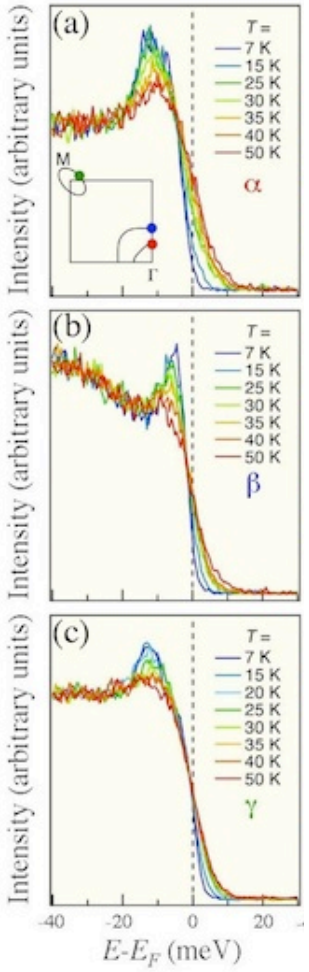


same symmetry but different gap structure!

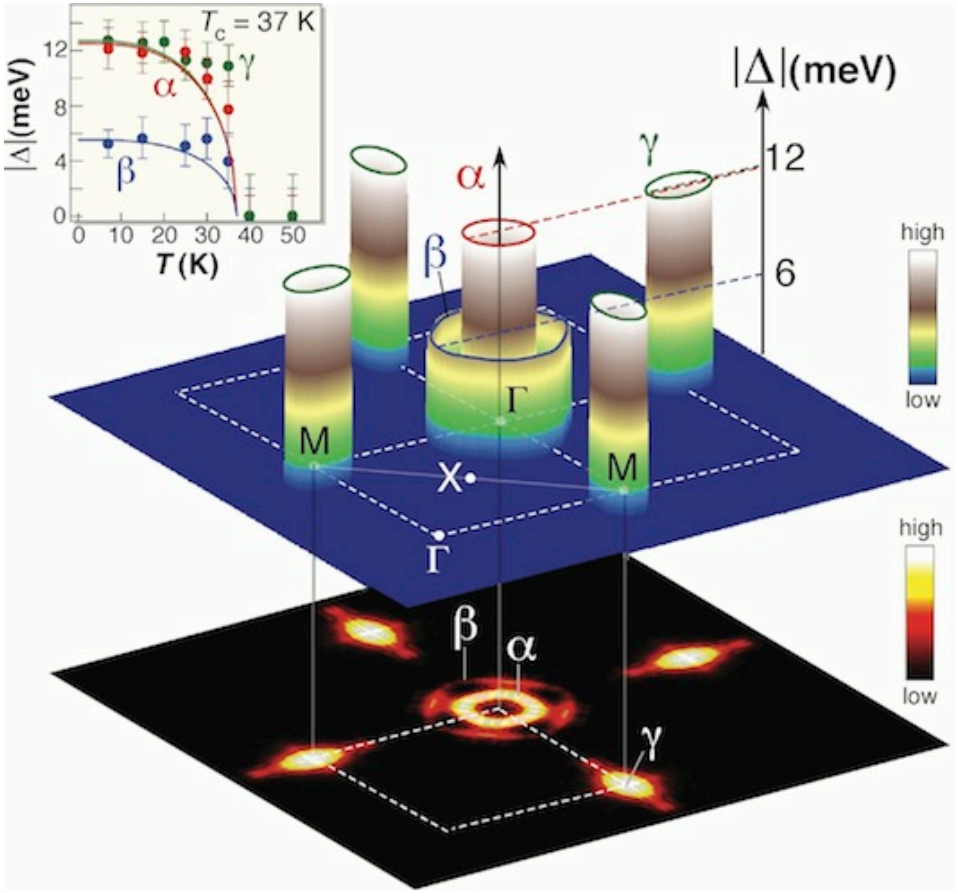
- possible source of anisotropy around FS: orbital content, intraband interaction, FS topology
- crucial role of nesting properties

Maier et al. Phys.Rev. B 79, 224510 (2009)
Kuroki et al. Phys. Rev. B 79, 224511 (2009)

Multiple gaps in optimally-doped K-Ba122



T_c=37K



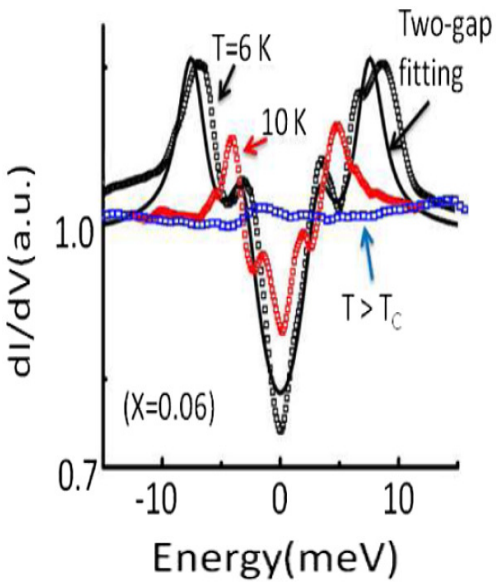
Ding et al. Europhys. Lett. 83, 47001 (2008)

FS dependent pairing strength (3.5 - 7 $k_B T_c$)

Multiple gaps in optimally-doped Co-Ba122

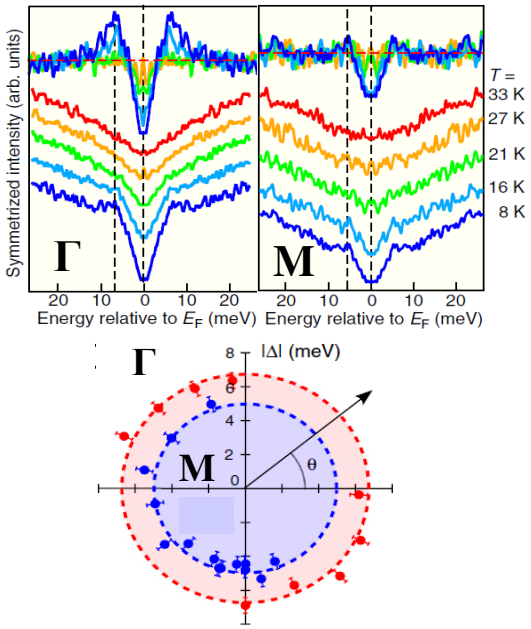
T_c=25K

STM



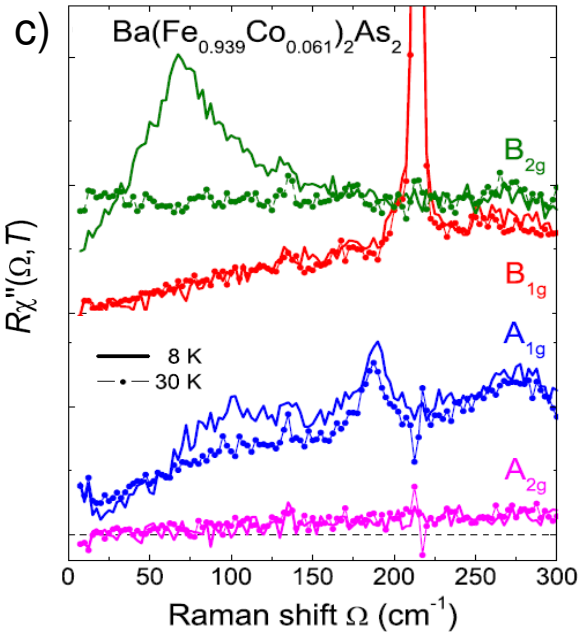
Teague et al. Phys. Rev. Lett. 106, 087004 (2011)

ARPES



Terashima et al. PNAS 106, 7330 (2009)

Raman

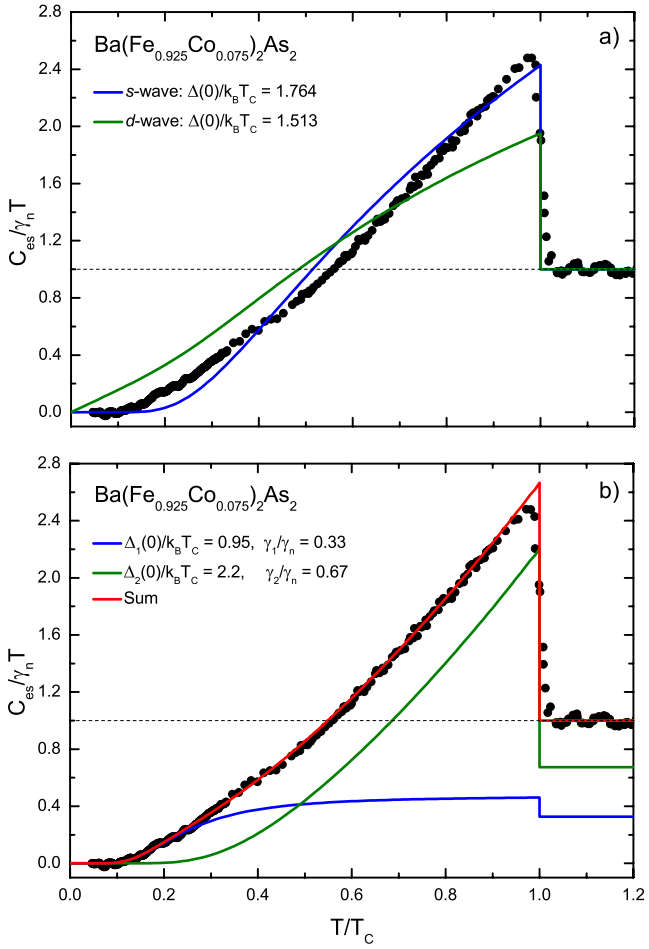


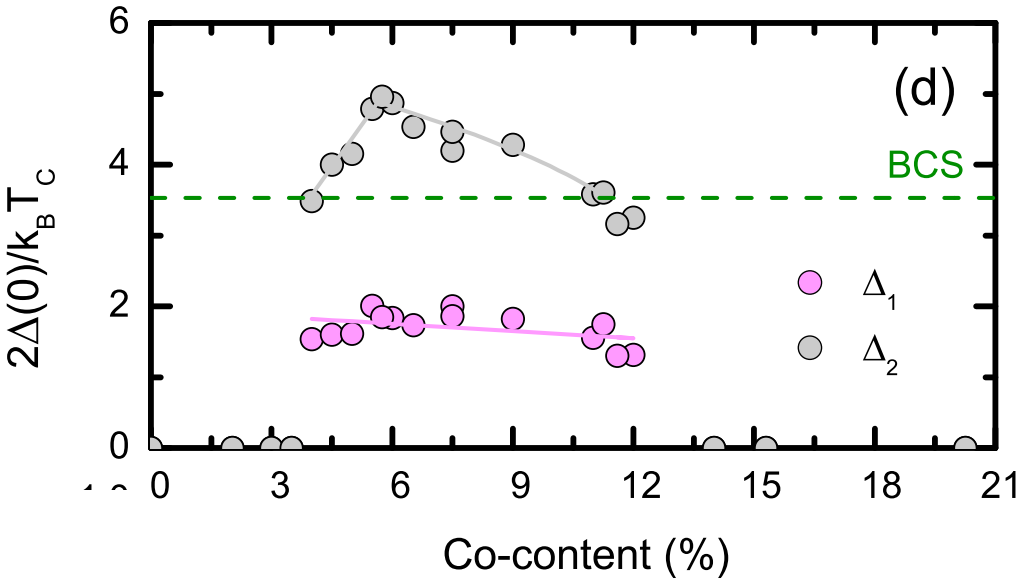
Muschler et al. Phys. Rev. B 80, 180510 (2009)

- at least 2 gaps around electron and hole pockets
- up to three different gaps have been reported

$$\frac{2\Delta_e}{k_B T_c} \approx 4 \qquad \frac{2\Delta_h}{k_B T_c} \approx 6$$

Specific Heat in Co-Ba122

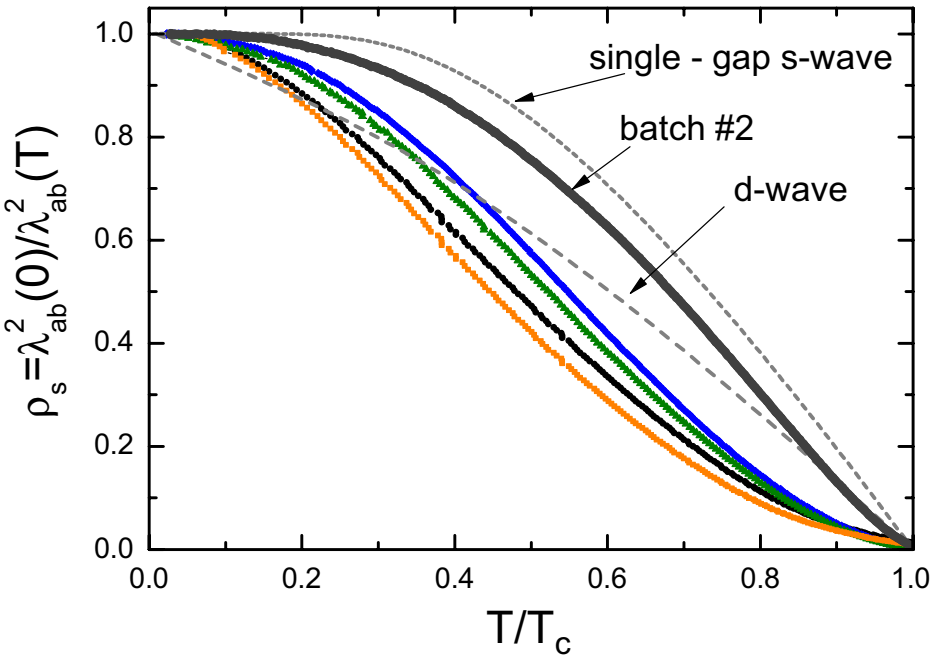


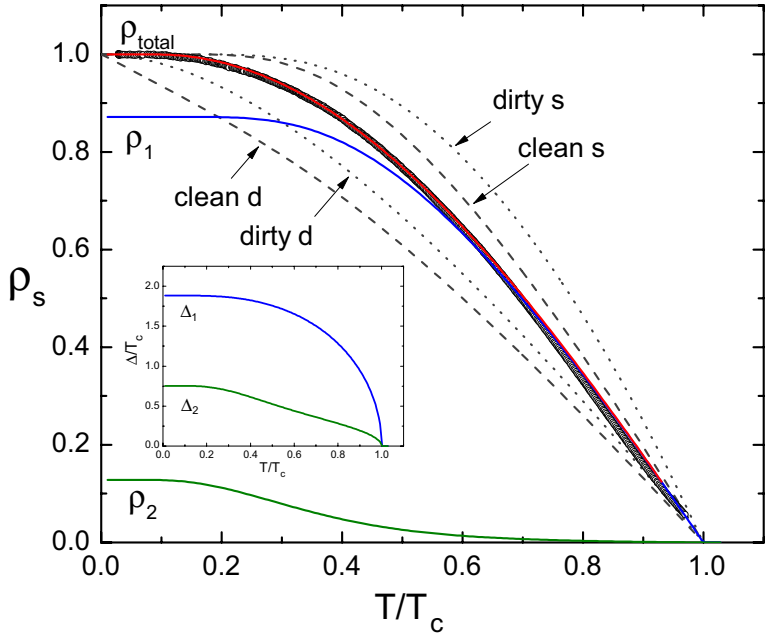


Hardy et al. Phys. Rev. B 81, 060501 (2010)
Hardy et al. Europhys. Lett. 91, 47008 (2010)

- significantly smaller gaps: one smaller than BCS weak coupling ratio one bigger
- role of anisotropy?

London penetration depth in Co-Ba122

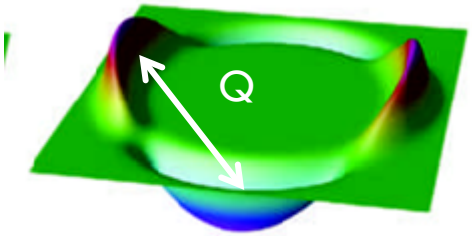


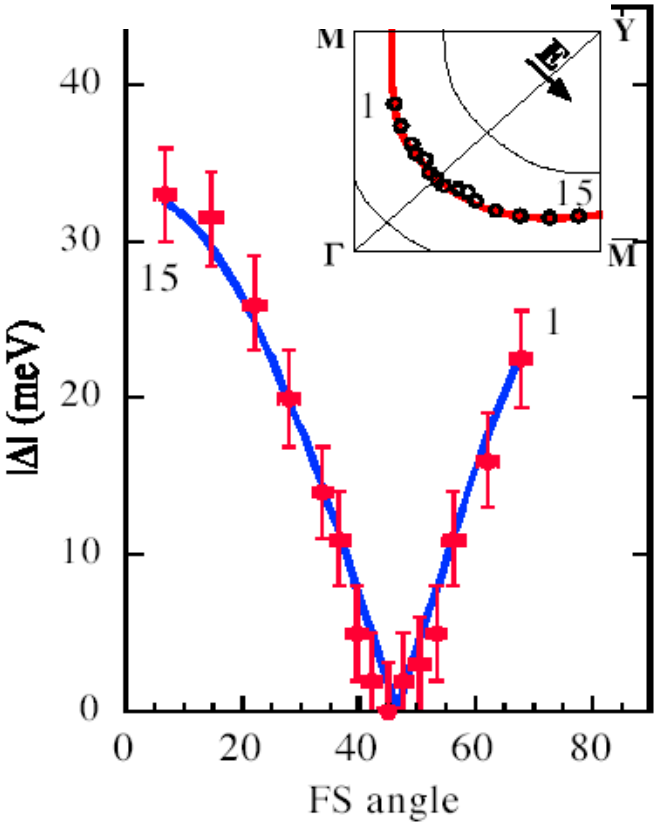


Prosorov et al. Rep. Prog. Phys.. 74, 124505 (2011)

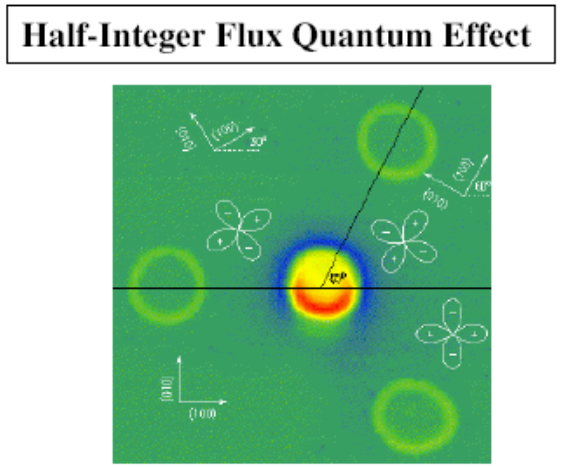
- significantly smaller gaps: one smaller than BCS weak coupling ratio one bigger
- fit must be done self-consistently: one cannot assume two independent BCS T dependences
- different techniques may be sensitive to different FS (effective mass, Fermi velocity….)

Probing the phase - Cuprates: reminder

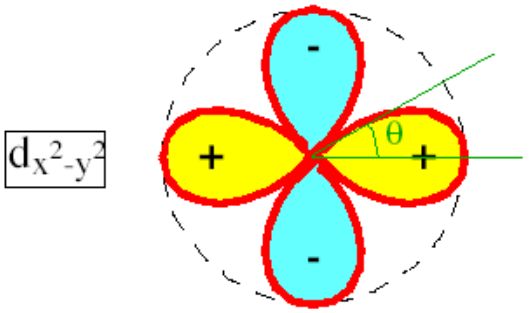


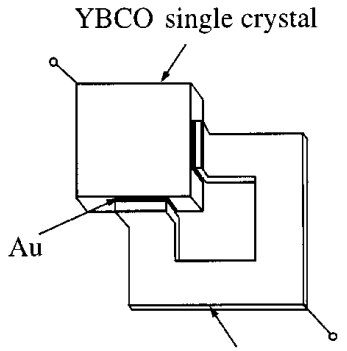


tricristal experiment



cristal orientations: π ring



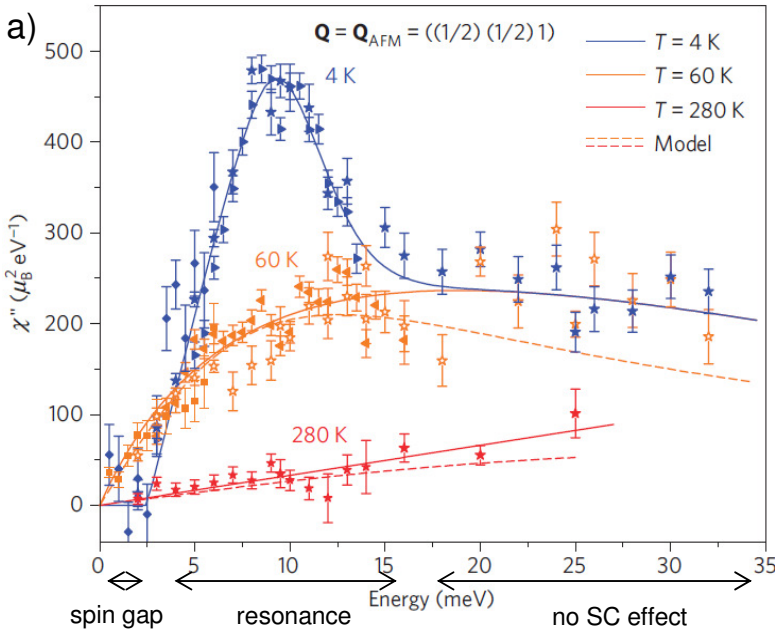


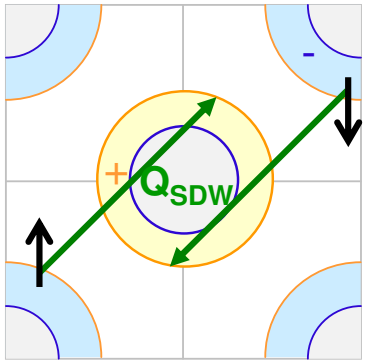
Tsuei et al. Rev. Mod. Phys. 72, 969 (2000)

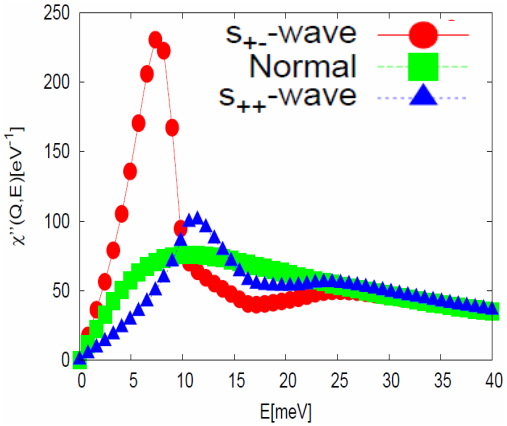
Neutron resonance in Co-Ba122

T_c=25K

Spin excitation spectrum in SC state





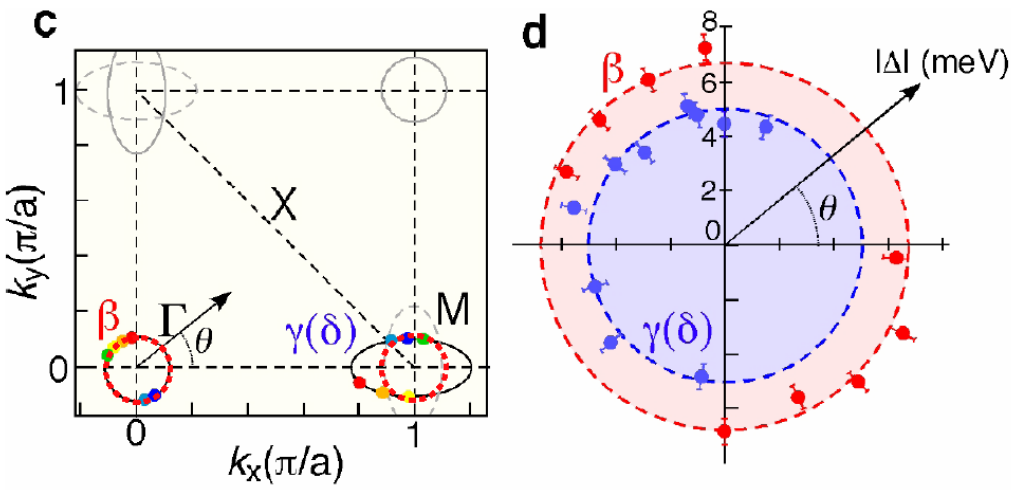


Christianson et al. Nature 456, 930 (2008)
Isonov et al. Nature Phys. 6, 178 (2010)

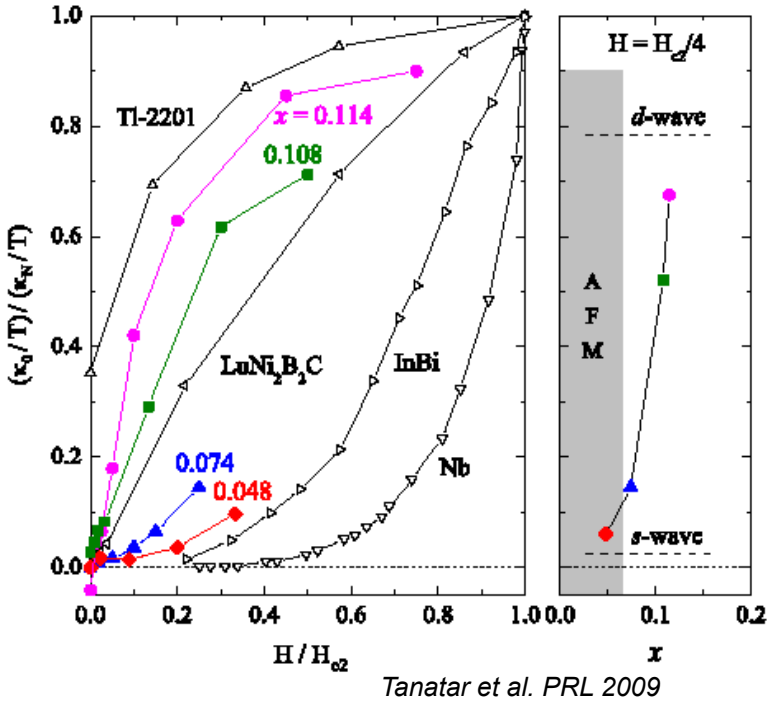
Korshunov et al. Phys.Rev.B 81, 024511 (2009)
Mazin et al. Phys. Rev. Lett. 101, 057003 (2008)

- collective spin excitation below 2Δ at Q_{AF}
- fingerprint of a sign changing gap and residual AF fluctuations
- observed in various families (11, 122, 1111…) and other SC: cuprates; heavy fermions…
- no truely conclusive phase sensitive test up to now (phase shift in Josephson loops, qp interferences…)

Gap anisotropy in Co-Ba122



Terashima et al. PNAS 2009



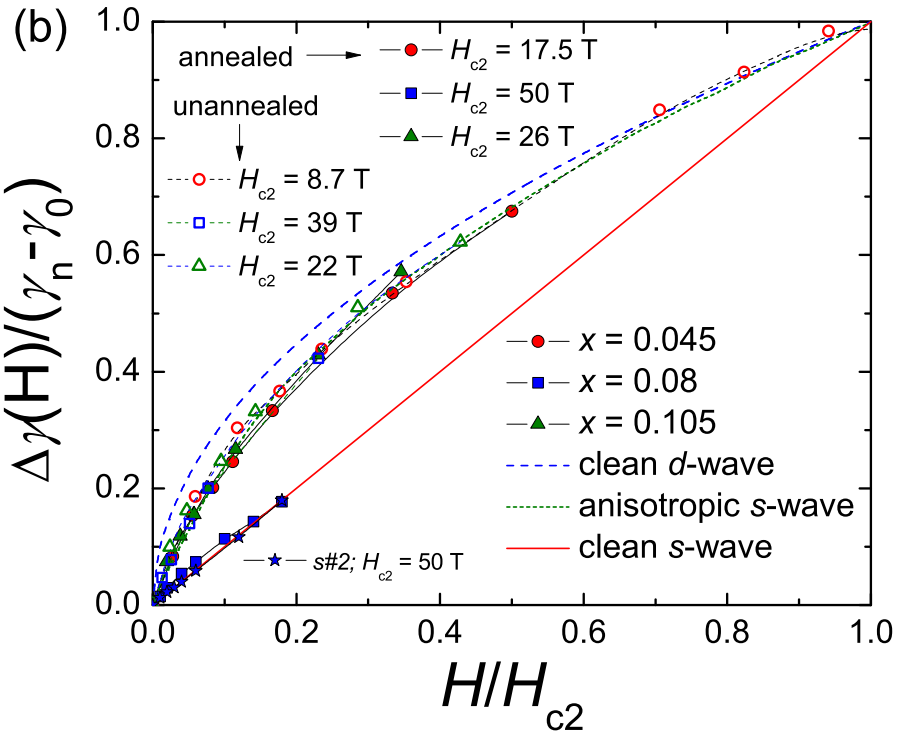
Tanatar et al. PRL 2009

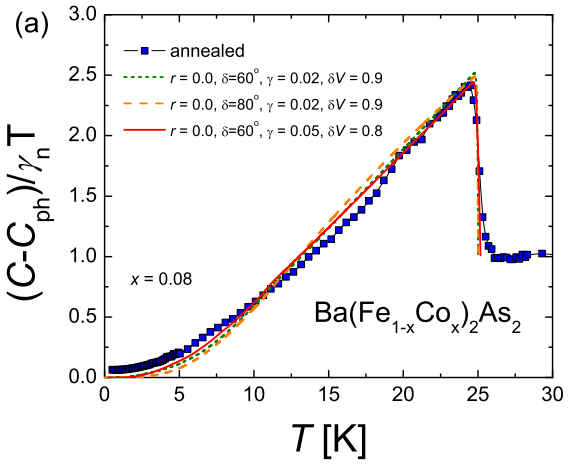
ARPES sees isotropic and large gaps

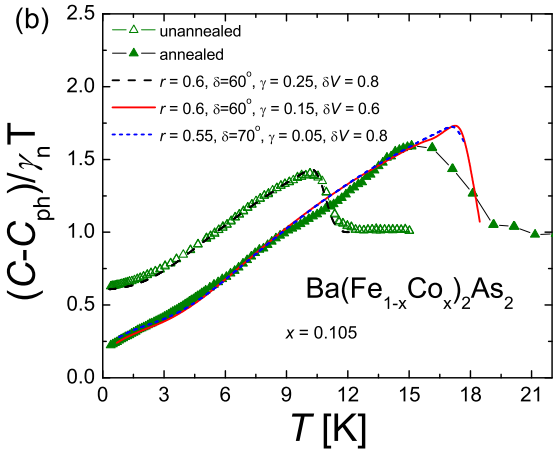
Thermal conductivity: anisotropic gap or very small gap (but no nodes)

- **Surface vs bulk issue?**
- **ARPES resolution?**

Gap anisotropy in Co-Ba122



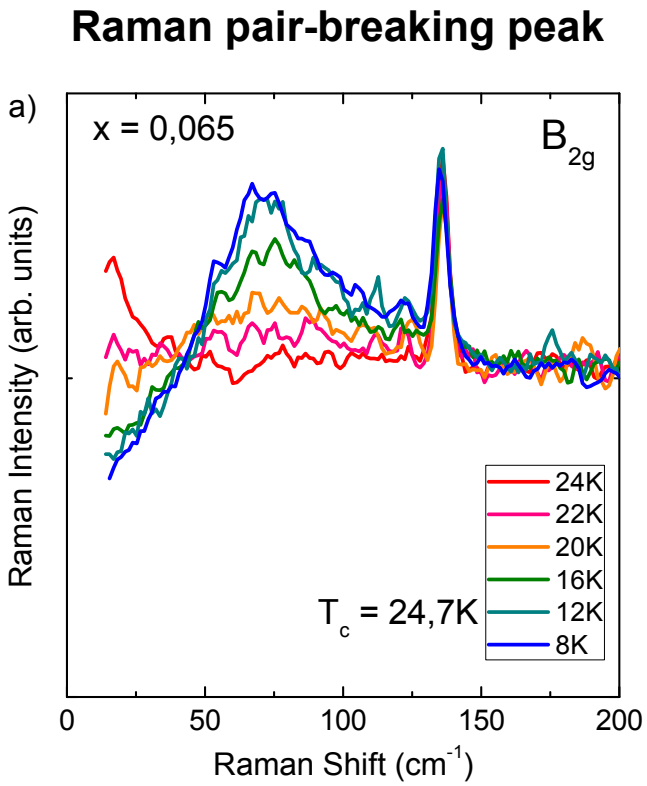




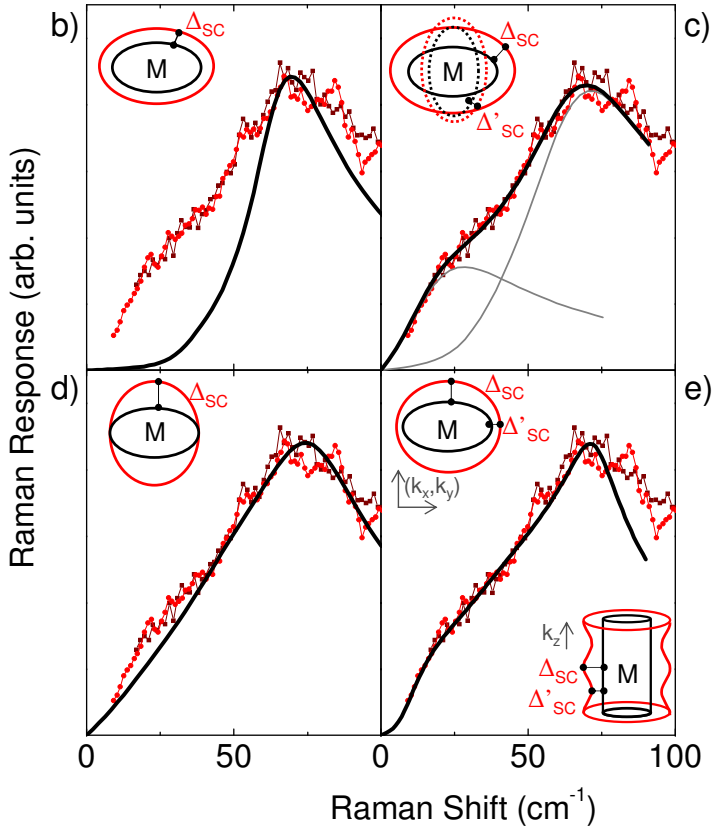
Gofryk et al. Phys. Rev. B 83, 064513 (2011)

- Field dependence of the low temperature residual term of electronic specific heat: anisotropic gap but doping dependent!
- Optimal doping: full gaps
- Under and overdoped: siginficant anisotropy

Gap anisotropy in Co-Ba122



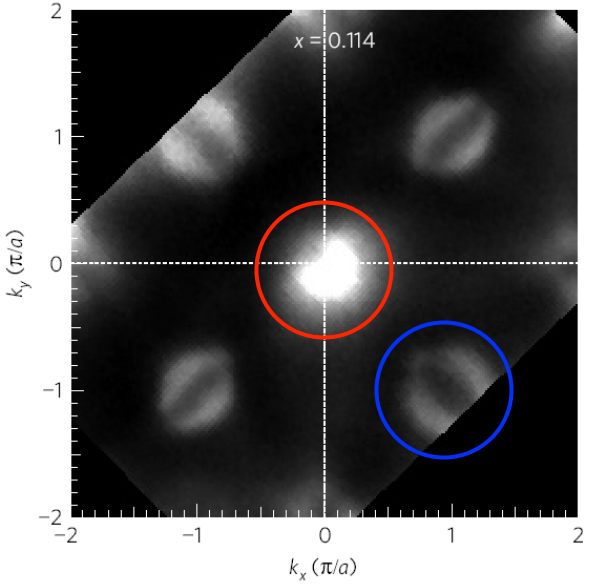
L. Chauvière et al. Phys. Rev. B 82, 180521 (2010)



- significant anisotropy around electron pocket: Δ_{max}=6-7 Δ_{min}
- in-plane or out of plane anisotropy

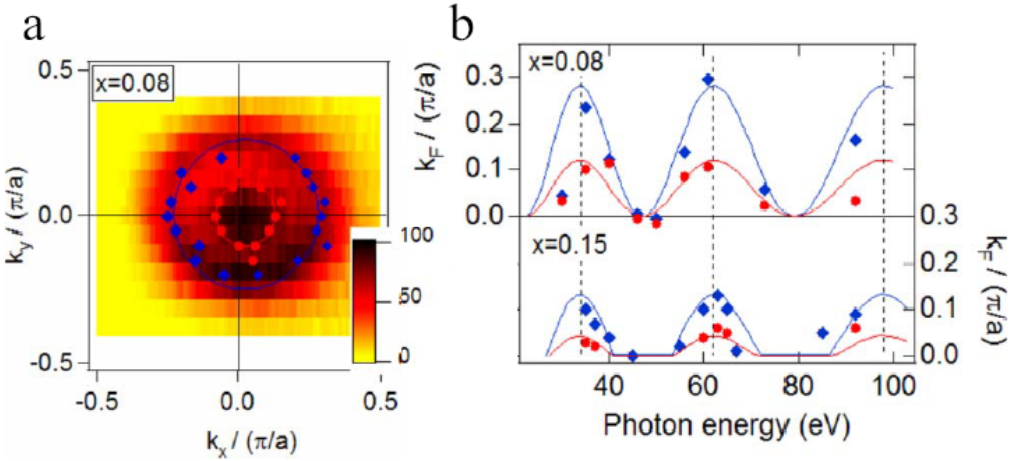
2D vs 3D Fermi surfaces

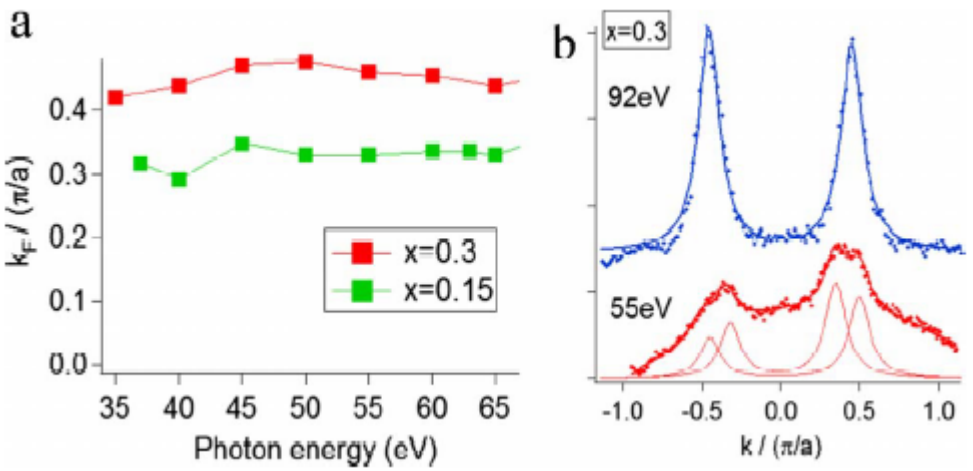
k_z is tuned via incident photon energy



Hole FS

Electron FS

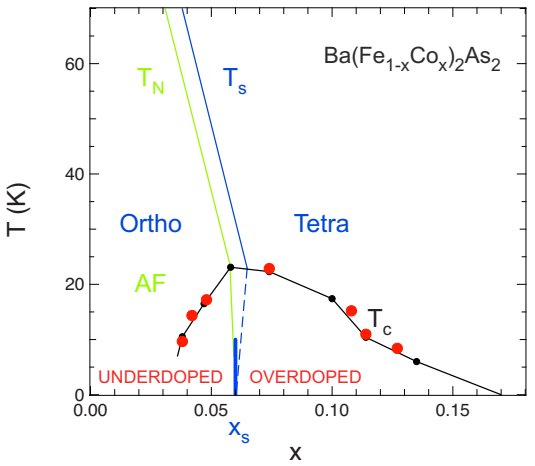




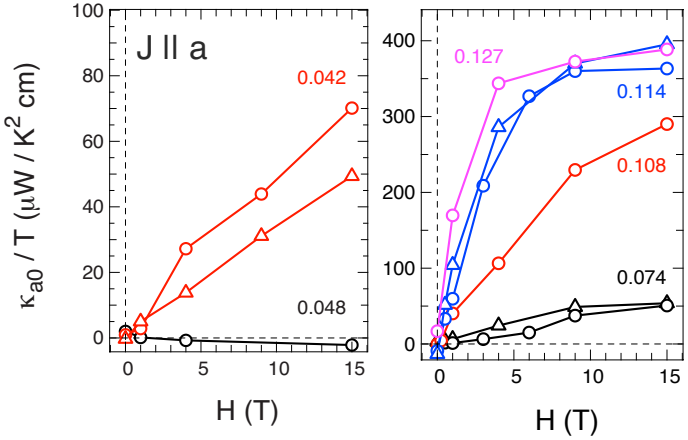
Note: 11 and 1111 families are more 2D

Brouet et al. PRB 80, 165115 (2009)

Directionnal thermal conductivity in Co-Ba122

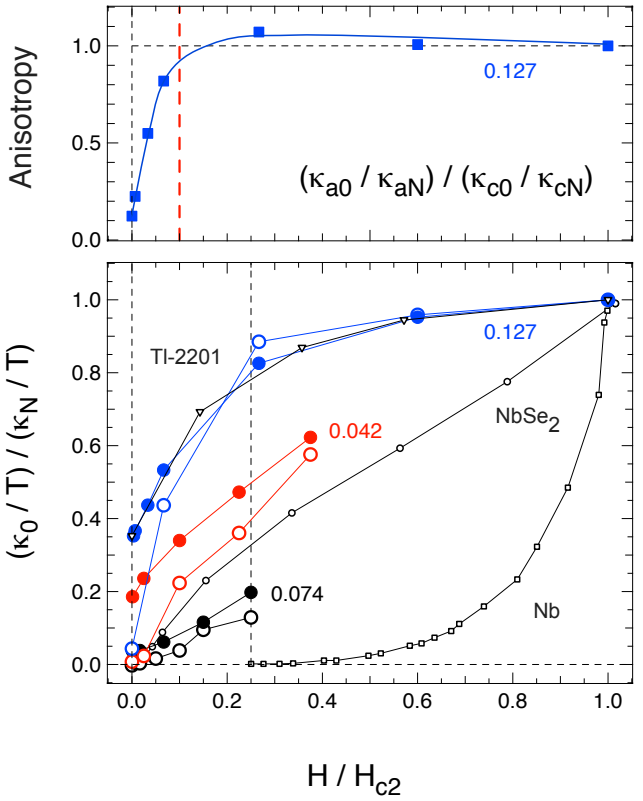


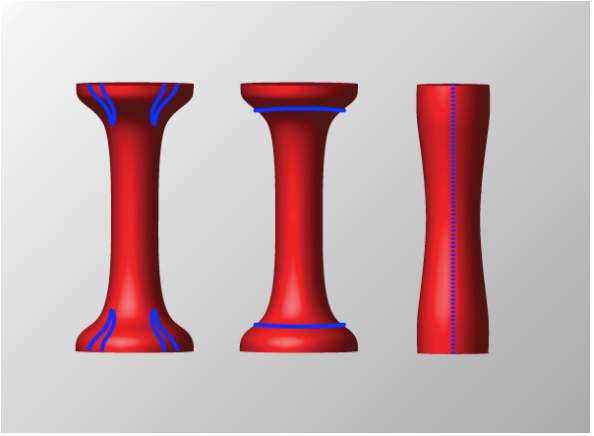
a-axis: no residual linear term



Reid et al, Phys. Rev. B 82, 064501 (2010)

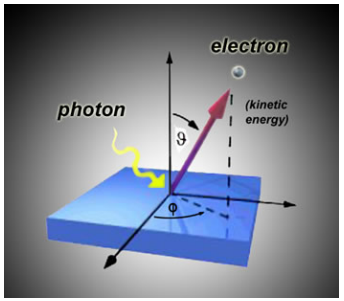
c-axis: residual linear term



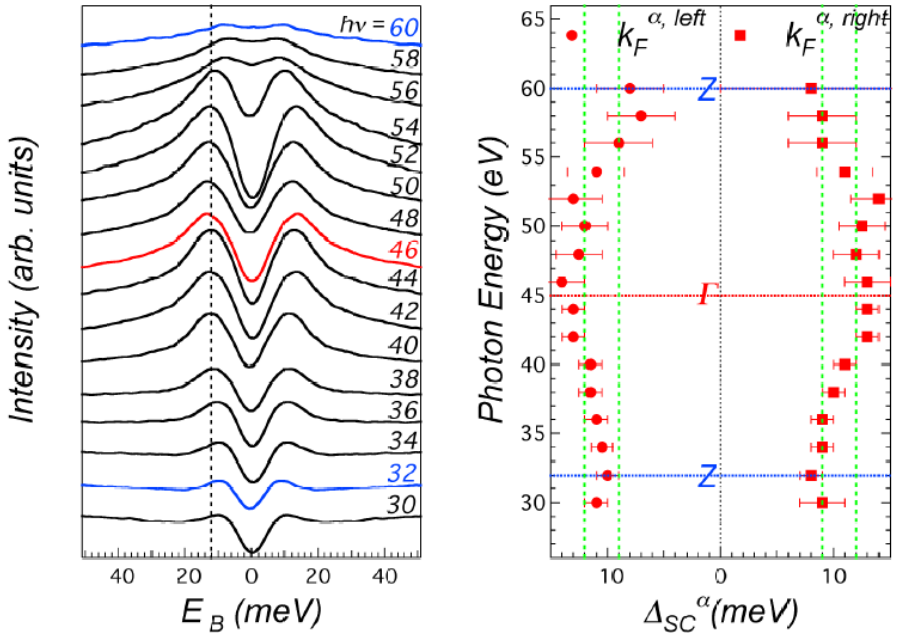


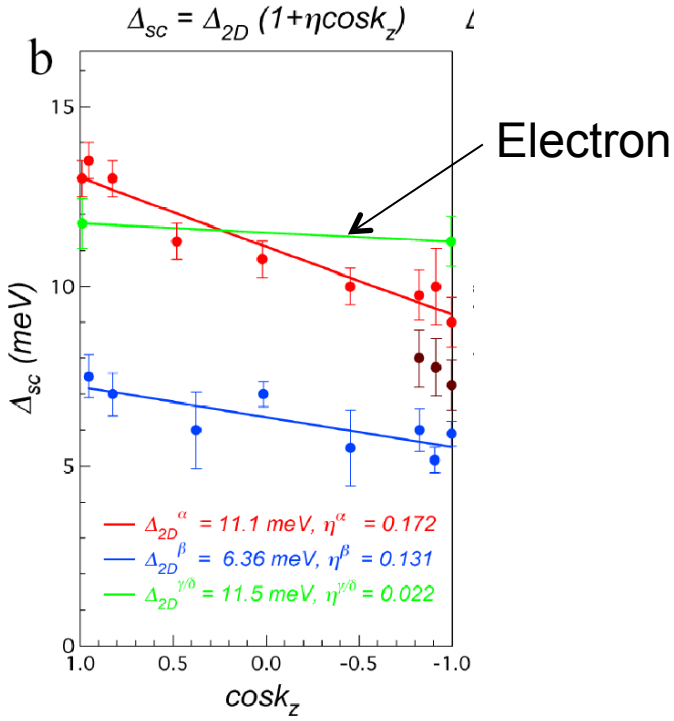
- nodes on FS part with high v_F along c-axis
- penetration depth shows similar behavior
- strong doping dependence

k_z dependence of the gap via ARPES



$(BaK)Fe_2As_2$ (hole doped)



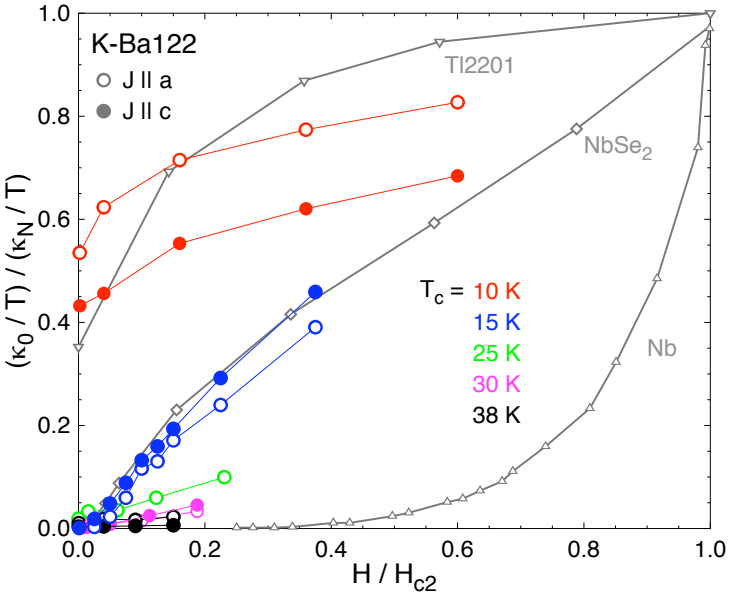


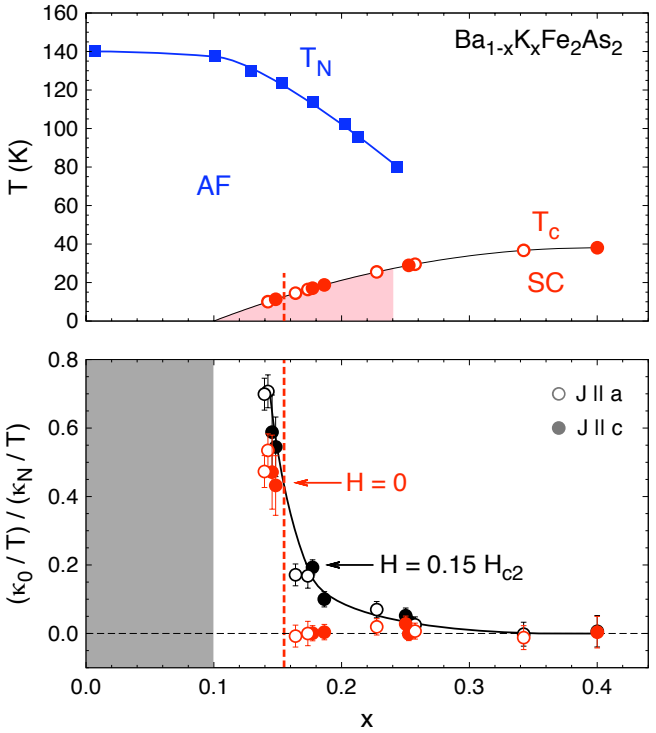
Xu et al. arXiv:1006.3958 (2010)

- Hole FS strong k_z dependence (3D): c axis κ_{th}
- Electron FS weak k_z dependence (2D): Raman

k_z is tuned via incident photon energy

Directionnal thermal conductivity in K-Ba122

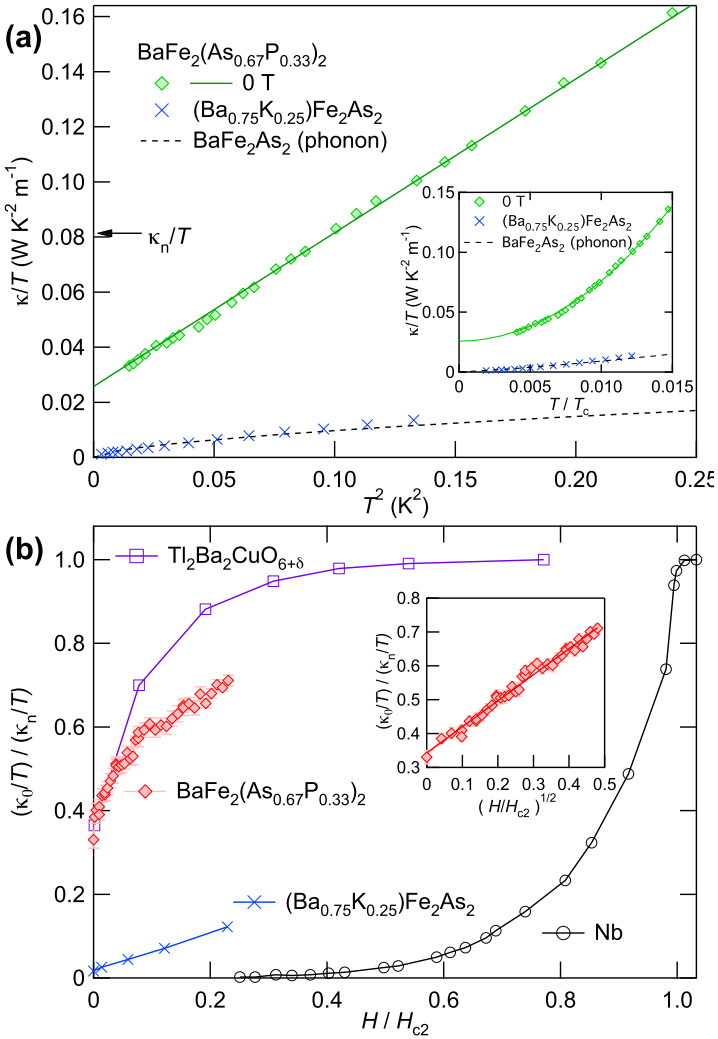




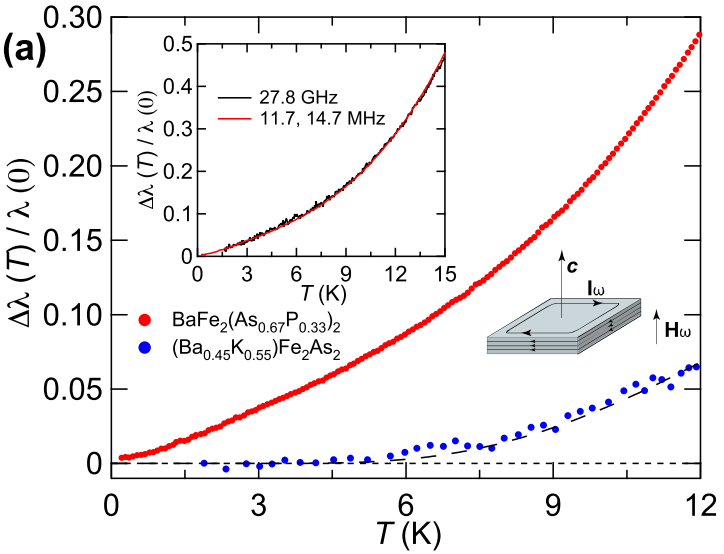
the structure of the gap is strongly doping dependent

Substitution dependence of the gap anisotropy

κ_{th}: isovalent versus hole doping



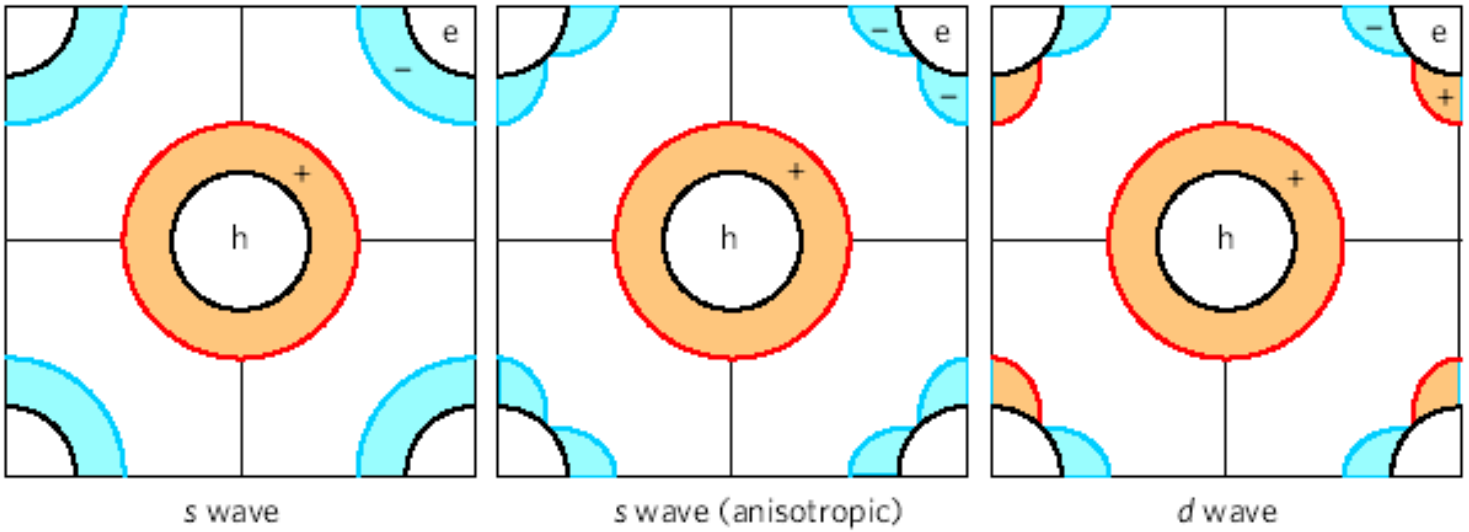
London penetration depth: isovalent vs hole doping



Hashimoto et al, Phys. Rev. B 81, 220501(R) (2010)

- $BaFe_2(As_{1-x}P_x)_2$ shows clear indication of nodes
- gap structrure is not universal

Gap structure in Ba122



Interband pair interaction ⟶ Intra and interband pair interaction

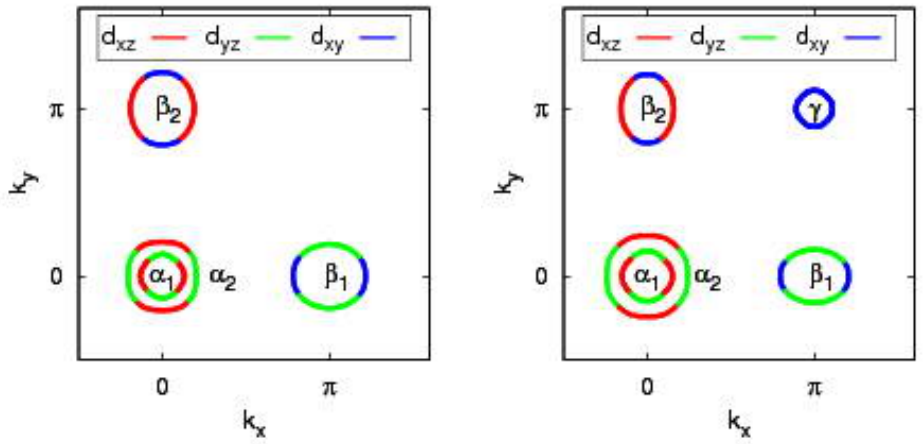
- **plus** k-dependence of interaction (nesting) + orbital dependence
- doping dependent ! fine tuning

Maier et al. PRB 79, 224510 2010

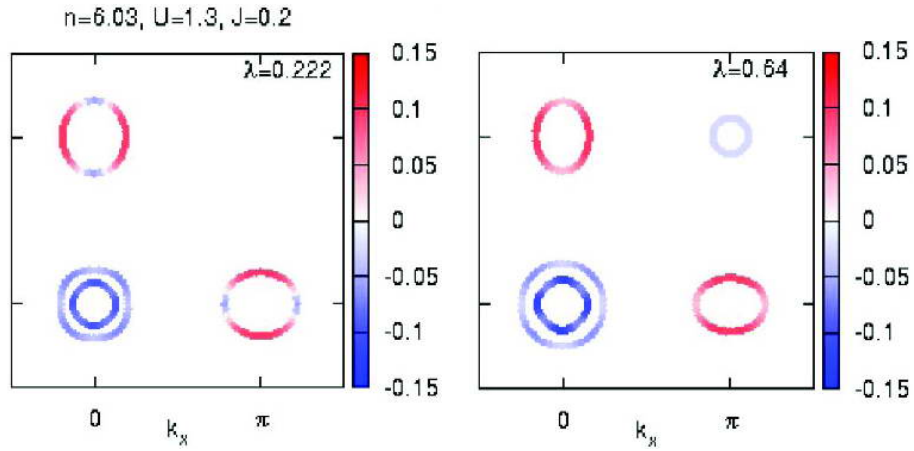
Role of orbital content

Fermi surfaces

Electron doping **Hole doping**



gap structures

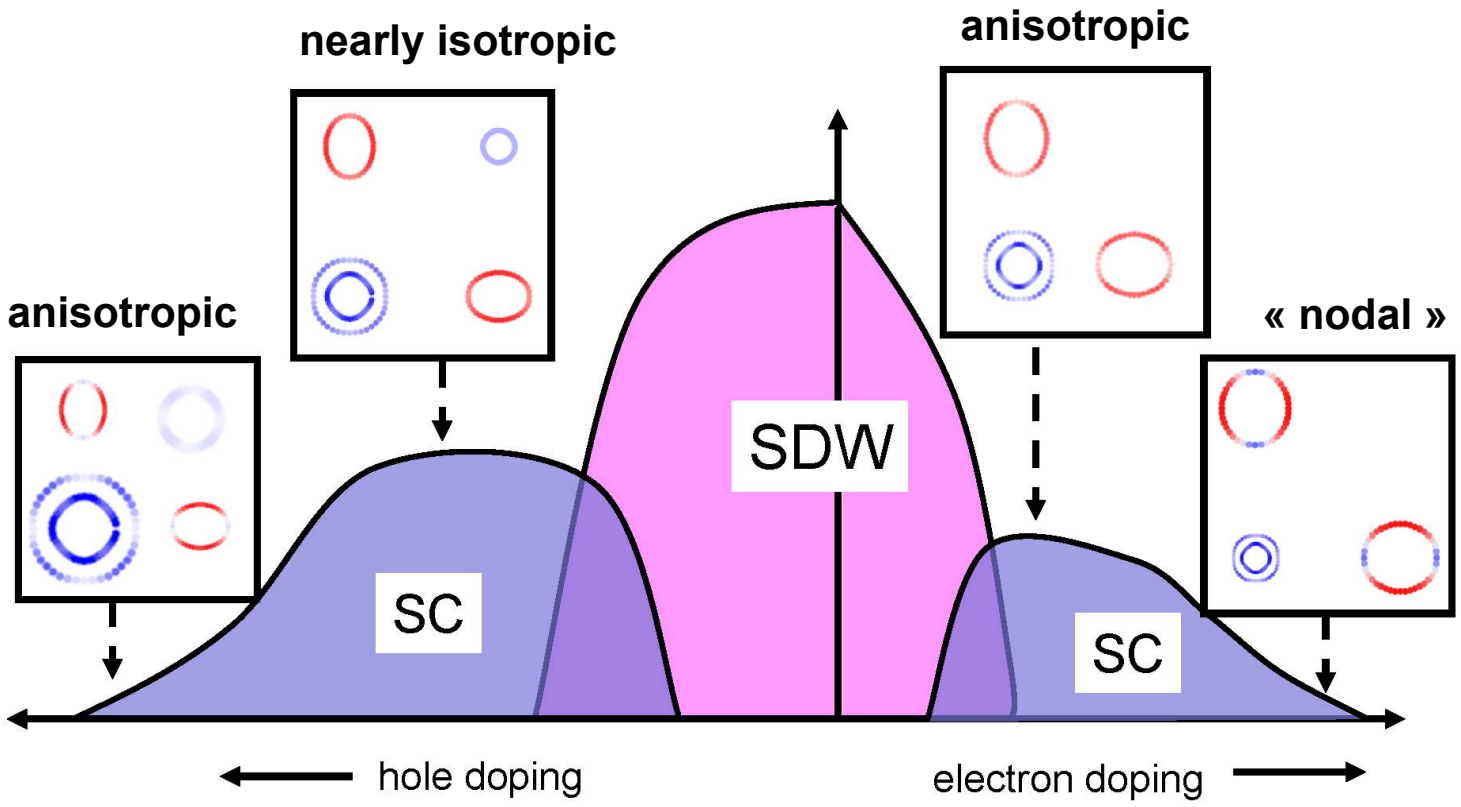


- orbital dependent FS leads to modulation of interband interaction matrix: intra-orbital scattering dominates
- d_{yz}/d_{xz} scattering between electron and hole pocket lead to s^{+-} pairing
- d_{xy} scattering between electron pocket frustrates s^{+-} pairing: anisotorpy
- additional hole pocket stabilizes isotropic s^{+-}

Kuroki et al. PRB 79, 224511 (2009)
Maier et al. PRB 79, 224510 (2010)

Strong sensitivity to FS topology (doping, As height…)

Doping dependant gap and interband spin fluctuations

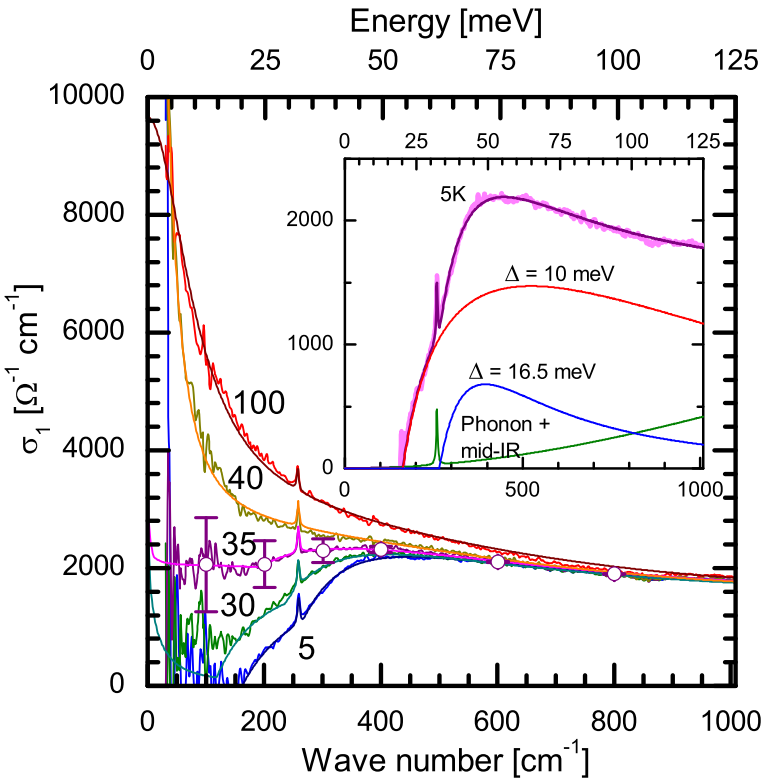


Hirschfeld et al. arXiv:1106.3712 (2011)

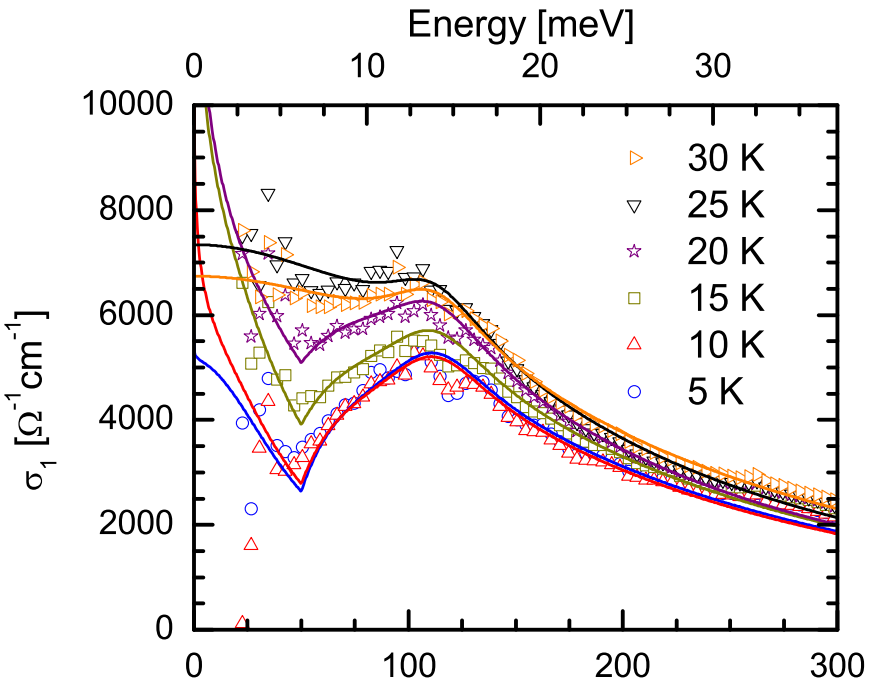
Phase diagram of the gap structure in Ba122 from spin fluctuation theory

Role of disorder: optical conductivity

K-Ba122: out of plane substitution



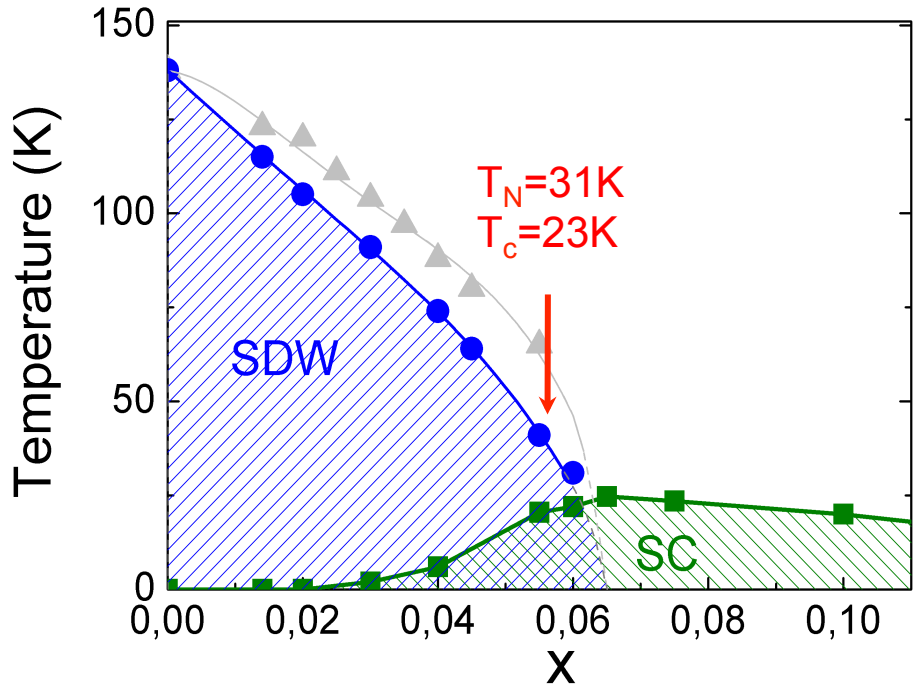
Co-Ba122: in plane substitution



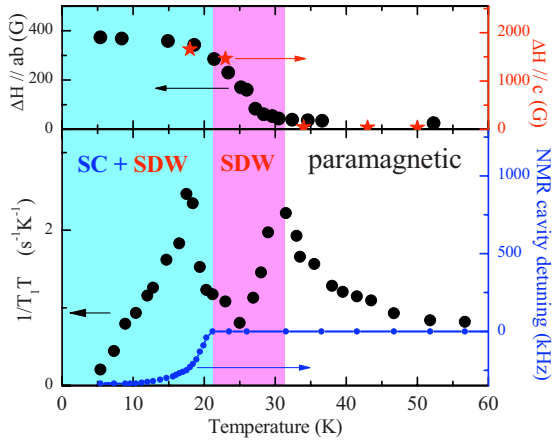
Lobo et al. Phys. Rev. B 82, 100506(R) (2010)

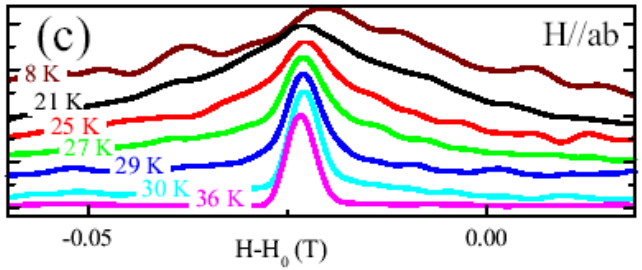
- subgap absorption in Co-Ba122: anisotropy or pair-breaking?
- interband impurity scattering is pair-breaking for s^{+-}
- importance of interband versus intraband impurity scattering ?

SDW + SC orders



^{75}As NMR





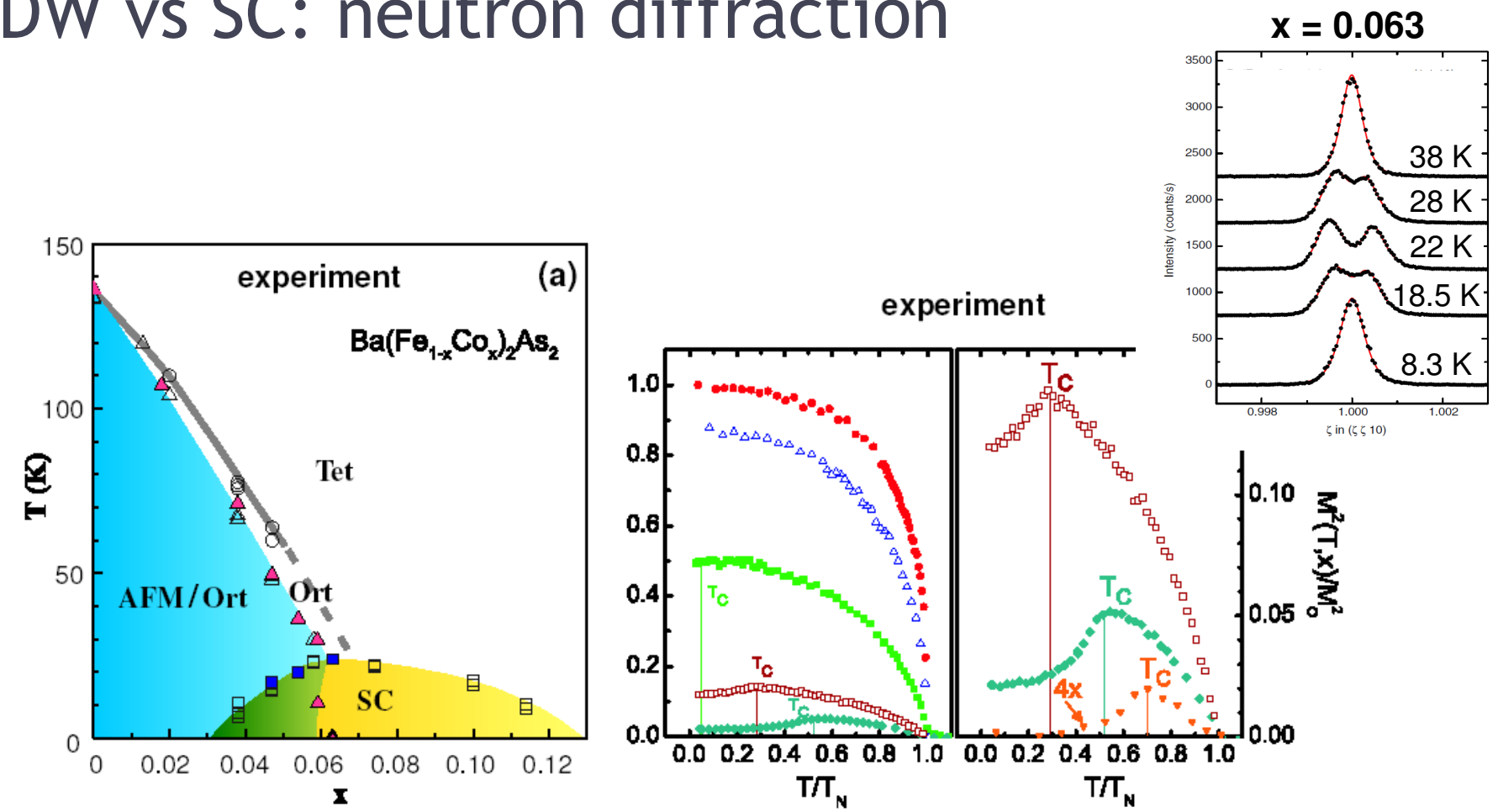
*Laplace et al. PRB **80**, 140501 (2009)*
Julien et al. EPL 87, 37001 (2009)

NMR spectra homogeneously broadened
All Fe involved in SDW order

- SDW+SC: atomic coexistence (NMR, muSr…) for Co-Ba122: situation less clear in other systems
- Fe conduction electrons are involved in both orders: competition
- s^{+-} gap and incommensurablility favor coexistence

Vorontsov and Chubukov Phys. Rev. B 81, 174538 (2010)
Fernandes and Schmalian Phys. Rev. B 82, 014521 (2010)

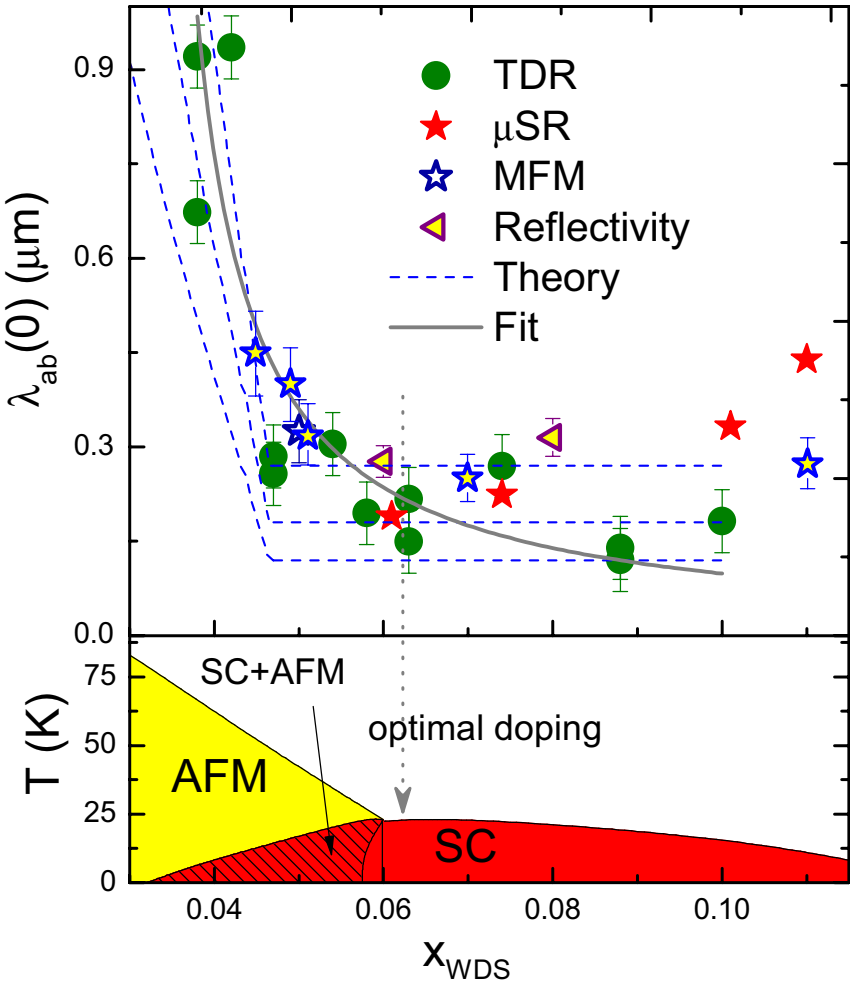
SDW vs SC: neutron diffraction

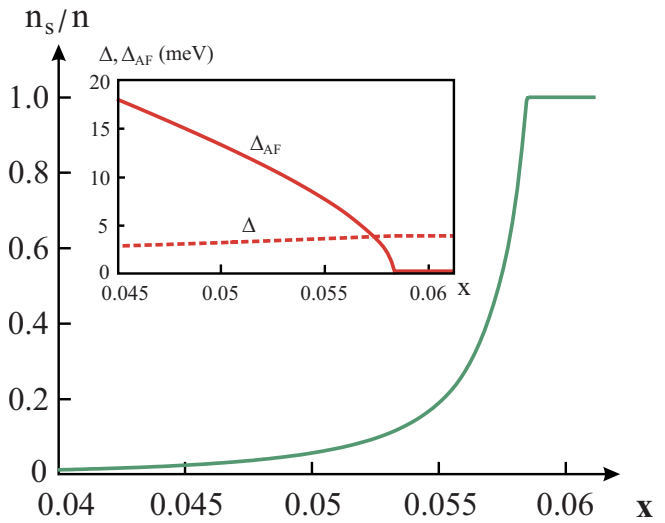


- reduction of Fe moment below T_c
- SC affects SDW
- interplay/competition around the FS
- re-entrance of the tetragonal phase!

Fernandes et al. Phys. Rev. B 81, 140501 (2010)
Nandi et al. Phys. Rev. Lett. 104, 057006 (2010)

SDW vs SC





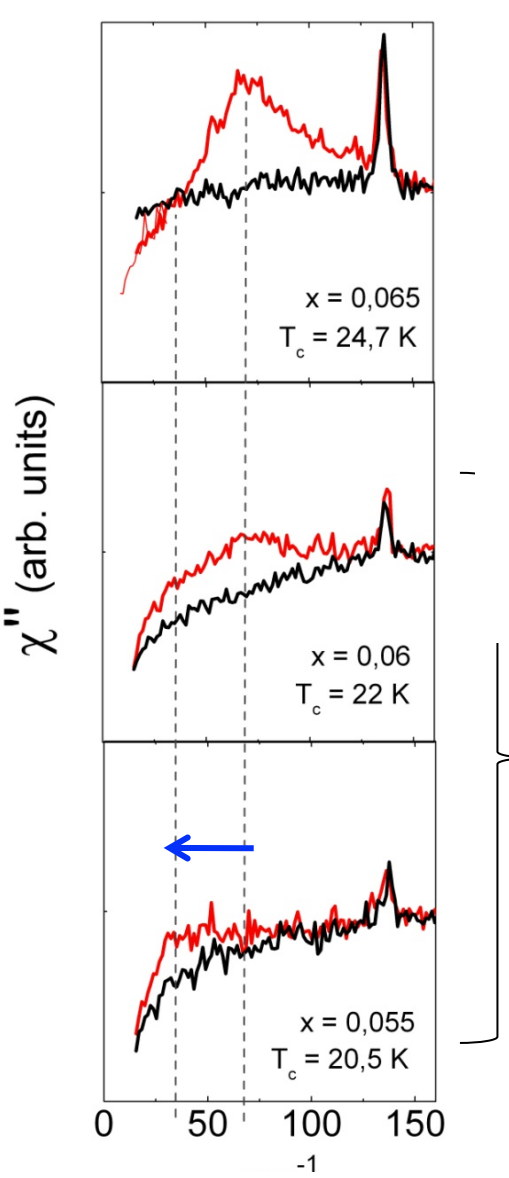
$$\lambda_{ab}^{SC+SDW}(0) = \lambda_{ab}^{0}(0)\sqrt{1+\frac{\Delta_{AF}^2}{\Delta_0^2}}$$

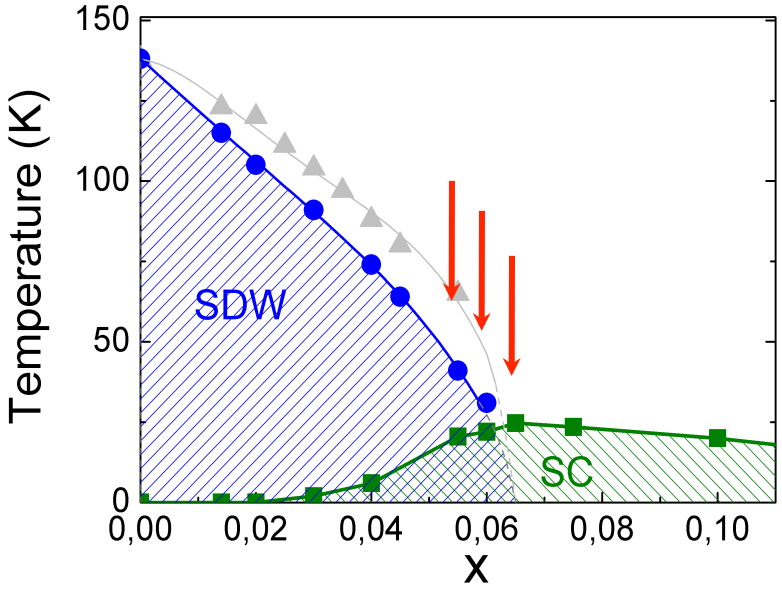
Prosorov et al. Rep. Prog. Phys.. 74, 124505 (2011)
Fernandes et al. Phys. Rev. B 82, 014520 (2010)

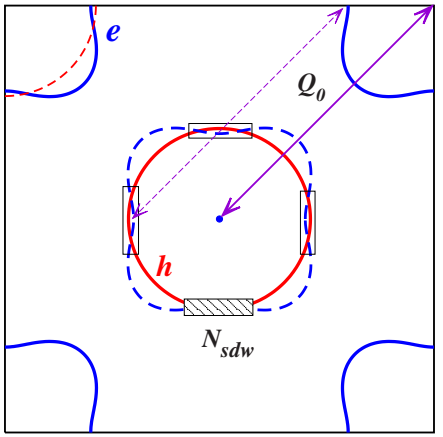
- **drastic increase of penetration depth in the coexistence regime**
- **drop in the superfluid density**

SDW vs SC: Raman

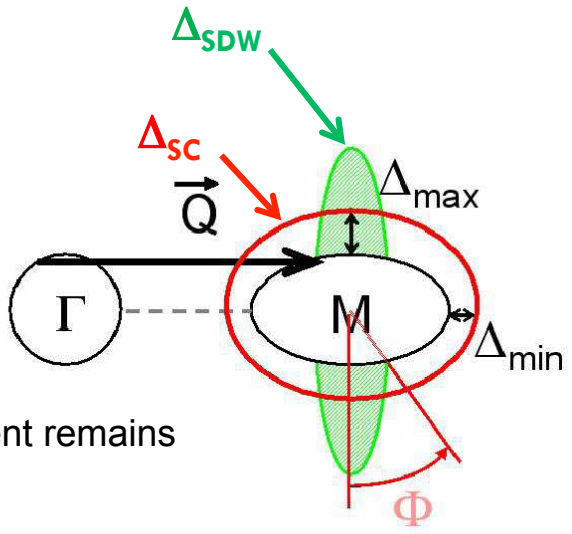
Vorontsov and Chubukov Phys. Rev. B 81, 174538 (2010)







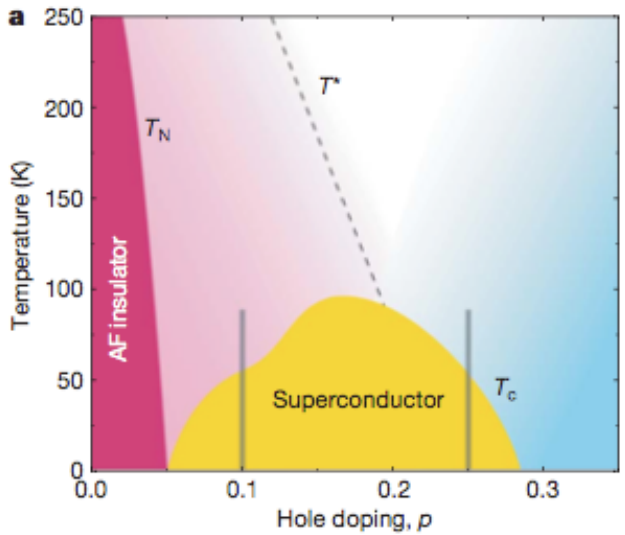
Coexistence SDW + SC

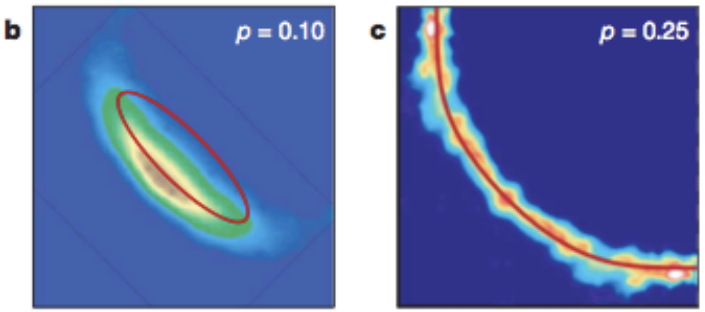


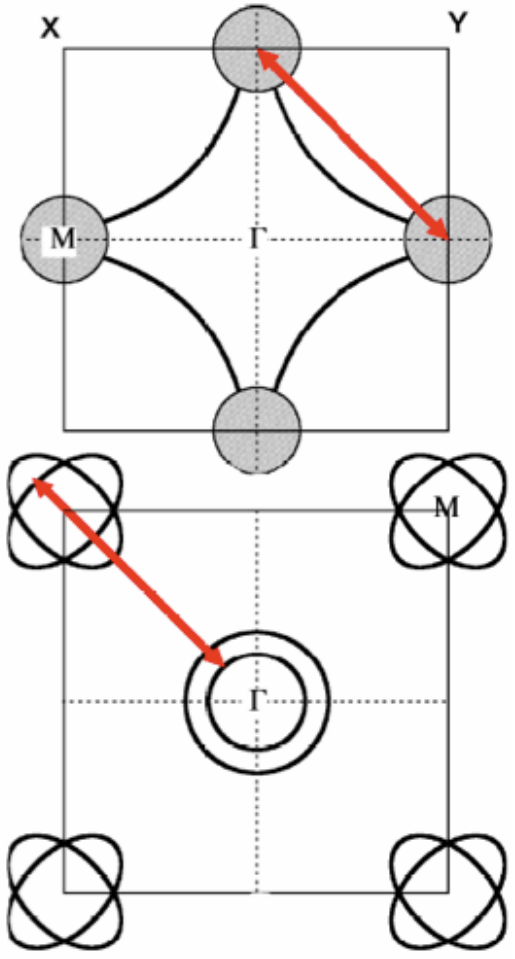
- The $2\Delta_{max}$ component is suppressed
- At x=0.055 only a low energy component remains

L. Chauvière et al. Phys. Rev. B 82, 180521 (2010)

Hot spots in underdoped cuprates and pnictides



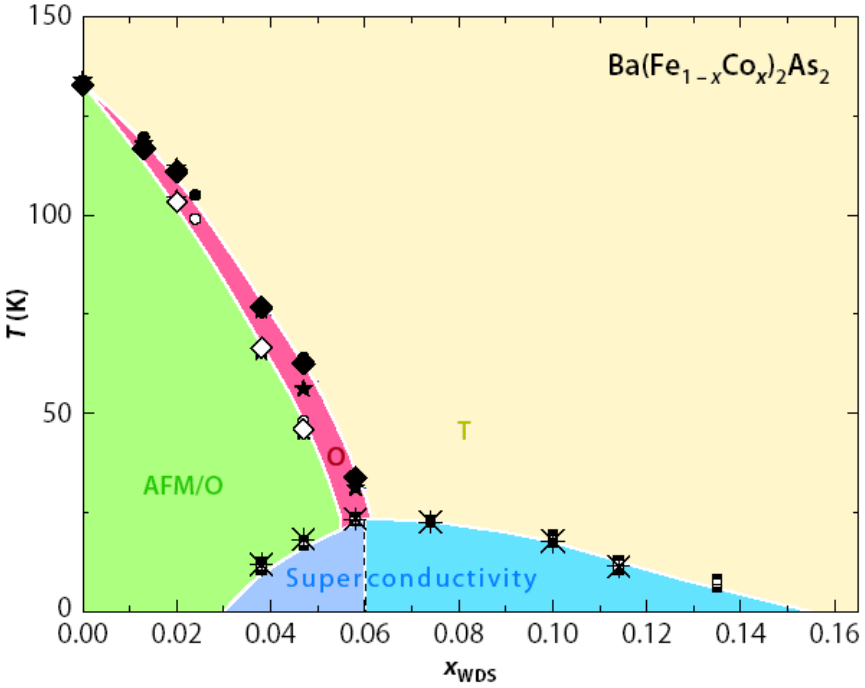




Doiron-Leyraud et al. Nature 2007

Superconductivity is confined in k-space in both systems close to competing order

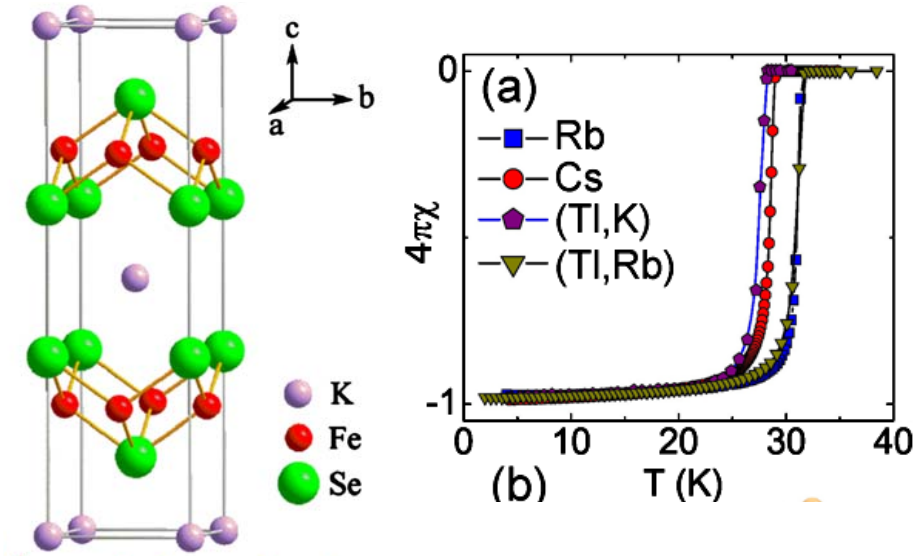
Summary



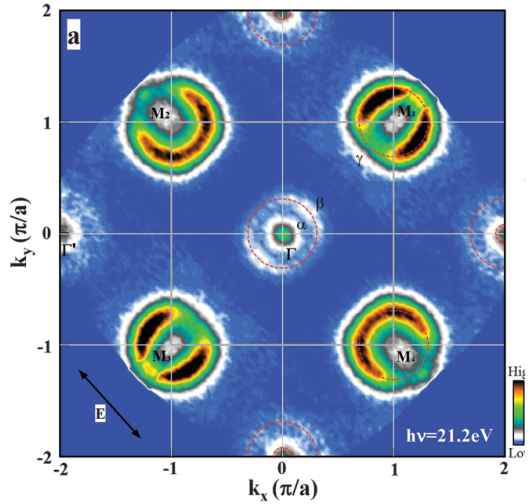
- key role of magnetic fluctuations
- interband Coulomb interaction drive both SC and SDW
- gap structure is not universal (but gap symmetry is s-wave)
- maximum T_c: optimum nesting <u>without</u> magnetism

- need to confirm s+- gap !
- is their a role for structural degrees of freedom ?

The case of $A_2Fe_4Se_5$

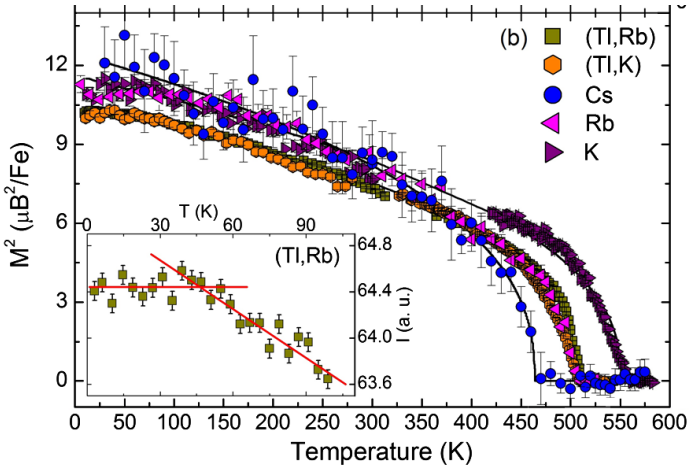


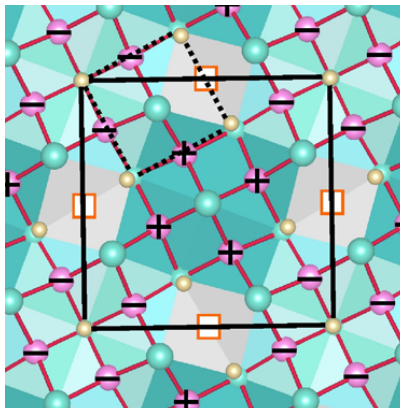
J. Guo et al., Phys. Rev. B 82, 180520(R) (2010)



D. Mou et al., Phys. Rev. Lett. 106, 107001 (2011)

absence of electron-hole nesting





T_N=560K !!! (Fe ordered vacancies)
local magnetism?

coexistence or phase separation?

F. Ye et al., Phys. Rev. Lett. 107, 137003 (2011)

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