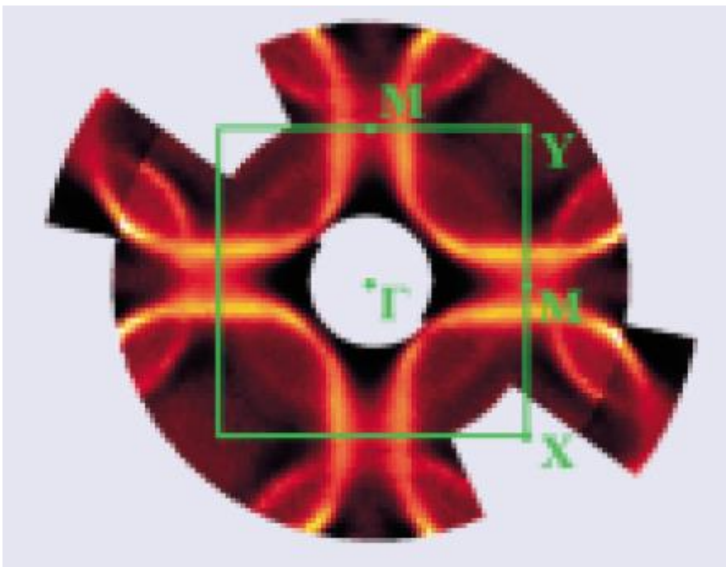
15 Jahre Hochtemperatur-Supraleitung

Erste Anwendungen sind in Sicht, verstanden sind die Hochtemperatur-Supraleiter trotz großer Fortschritte aber noch nicht

Helmut Eschrig, Jörg Fink und Ludwig Schultz

Physik Journal
1 (2002) Nr. 1

Fermi surface of cuprates



▶ b) Die mit winkelaufgelöster Photoemission gemessene Fermi-Oberfläche des Hochtemperatur-Supraleiters $Bi_2Sr_2CaCu_2O_8$ stimmt gut mit Rechnungen überein [9]. **[9] Kordyuk PRL 2002**

Energy gap at the FS in the sc state

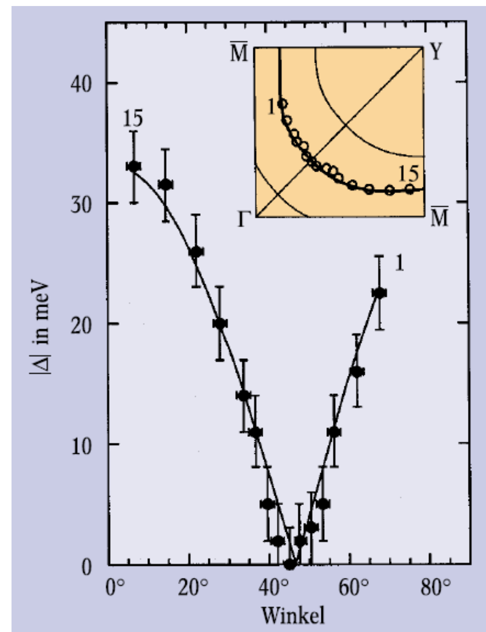
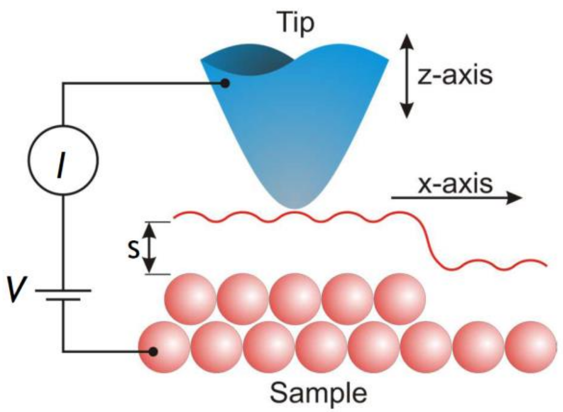
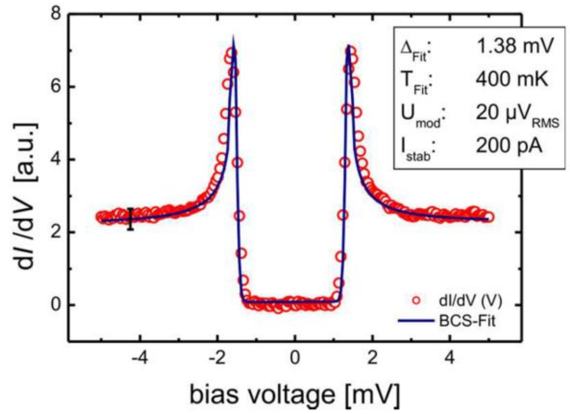


Abb. 6:
Die Energielücke der Supraleitung von $Bi_2Sr_2Ca\,Cu_2O_8$ weist die für d-Wellen-Symmetrie charakteristische Nullstelle auf. Gemessen wurde als Funktion des Winkels entlang der Fermi-Oberfläche (siehe Einschub) mit winkel-aufgelöster Photoemission bei $T = 13$ K [10].

[10] *H. Ding* et al., Phys. Rev. B **54**, R 9678 (1996).

Scanneling tunneling spectroscopy

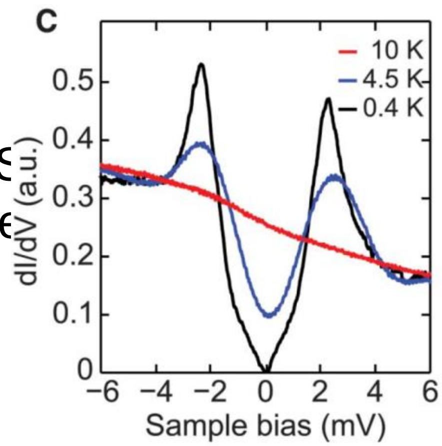




Superconducting gap of a Nb-tip on W(110), T= 378 mK, D. Baumann, PhD thesis (2011), IFW Dresden

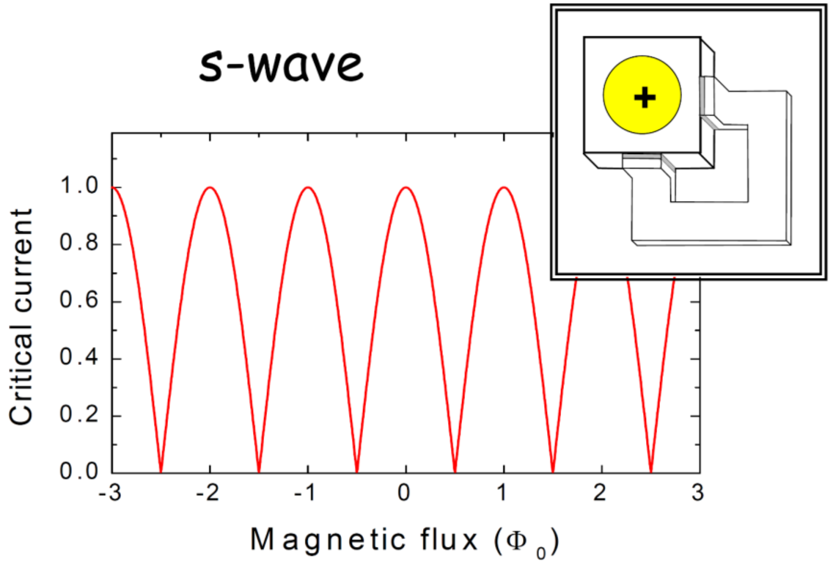
$I_t = I_t(z)$ → topography maps (S

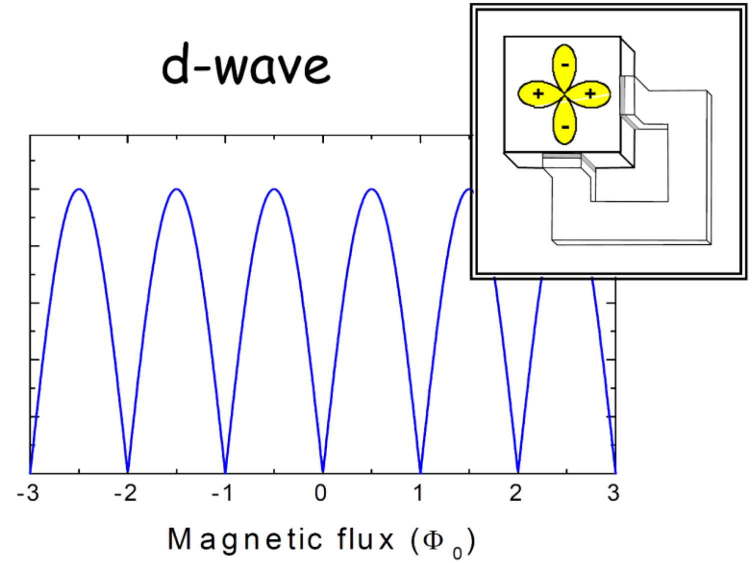
dI/dV ~ LDOS → local density of state

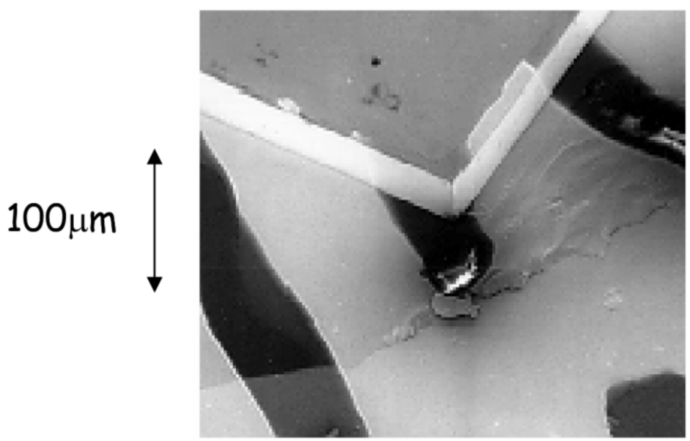


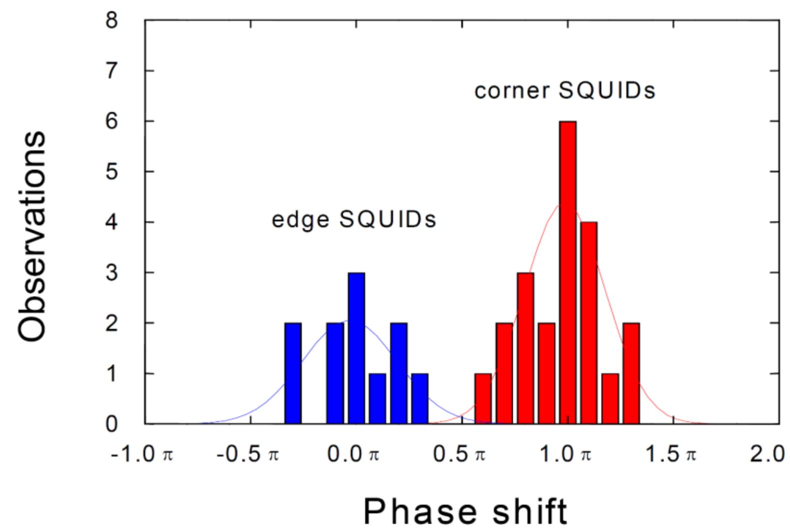
Superconducting gap of FeSe: nodes lead to finite DOS in the gap.
Song et al. Science 2011

The corner SQUID experiment



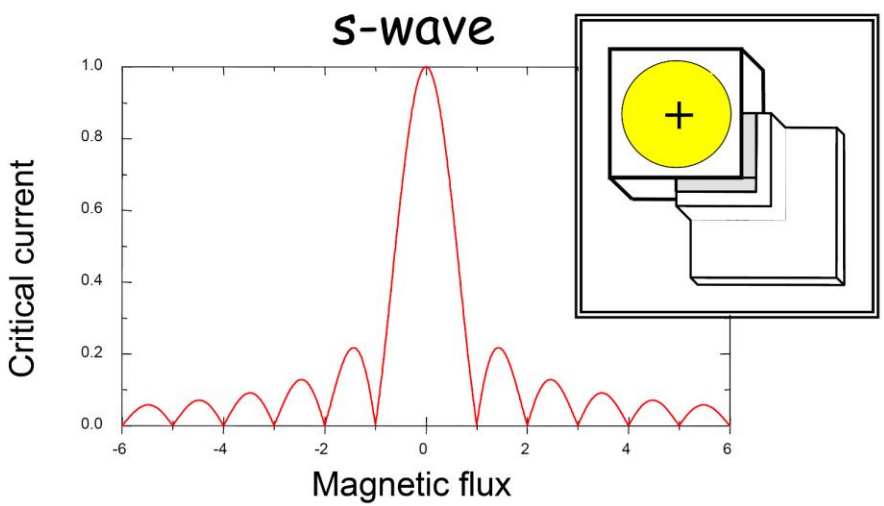


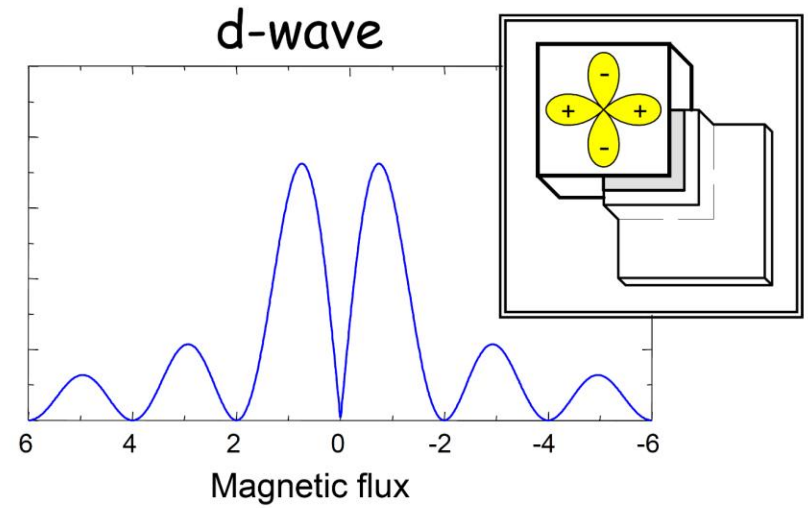


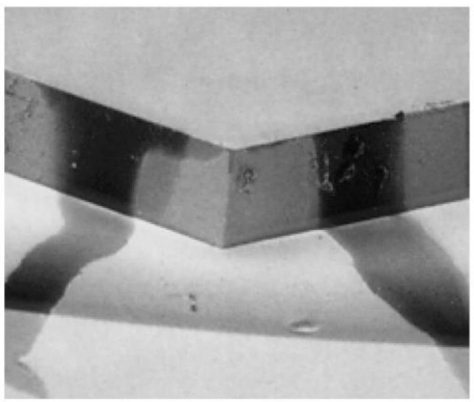


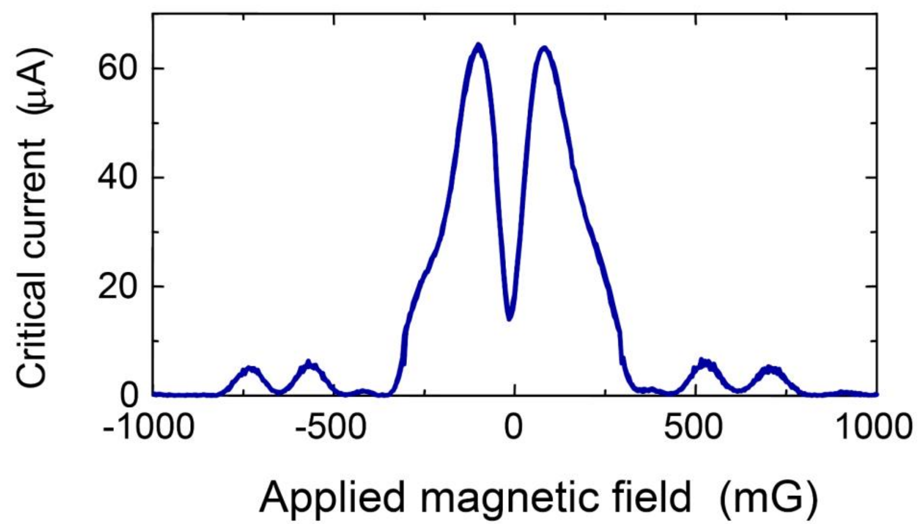
D. A. Wollman, D. J. Van Harlingen, W. C. Lee, D. M. Ginsberg, and A. J. Leggett, Phys. Rev. Lett. **71**, 2134 (1993)

The corner junction experiment



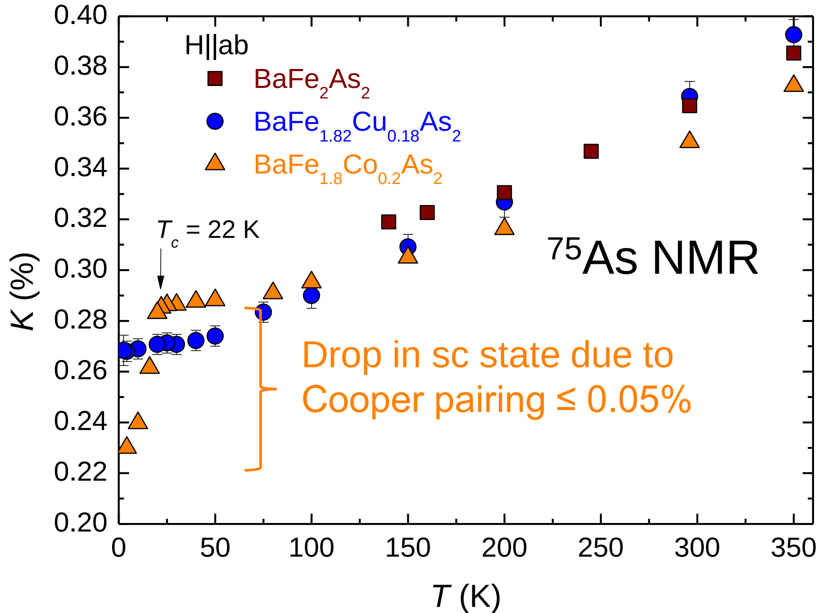


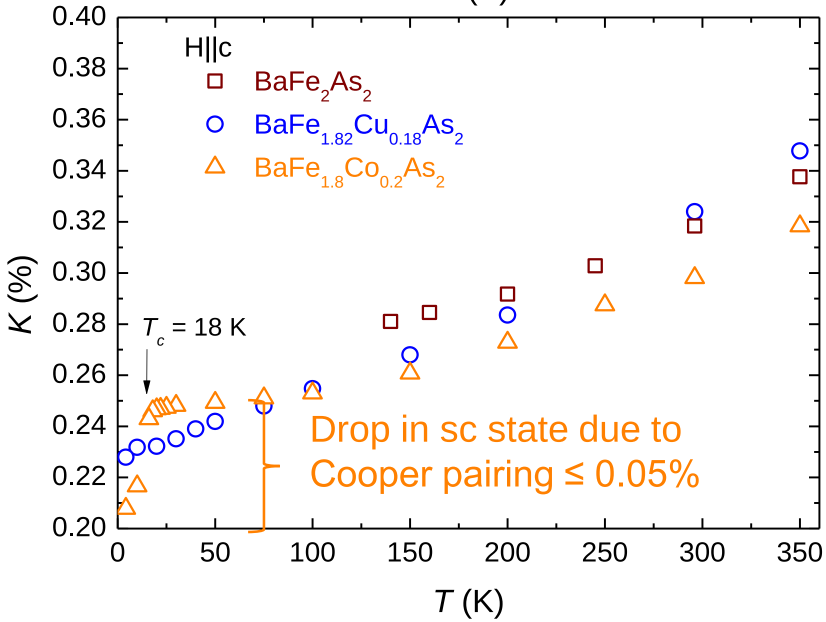




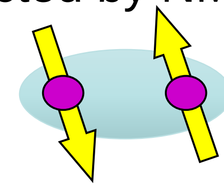
D. A. Wollman, D. J. Van Harlingen, J. Giapintzakis, and D. M. Ginsberg, Phys. Rev. Lett. **74**, 797 (1995)

S=0 superconductivity detected by NMR





H.-J. Grafe et al. Phys. Rev. B **90**, 094519 (2014)



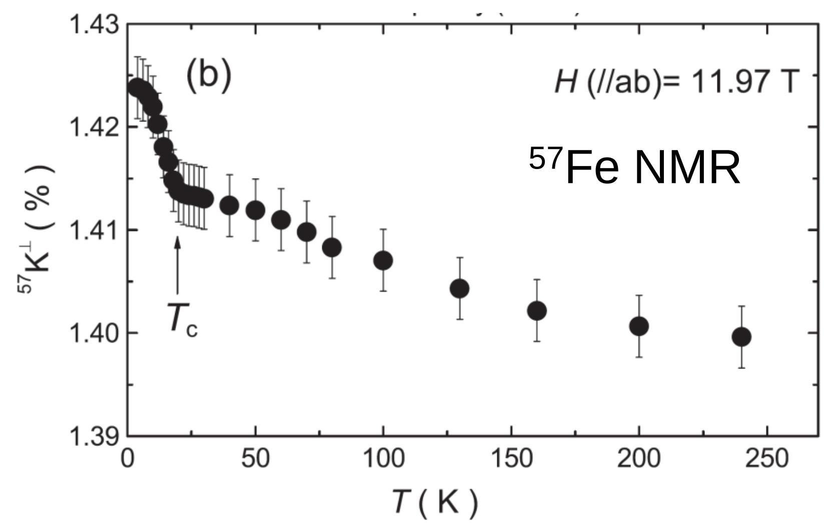
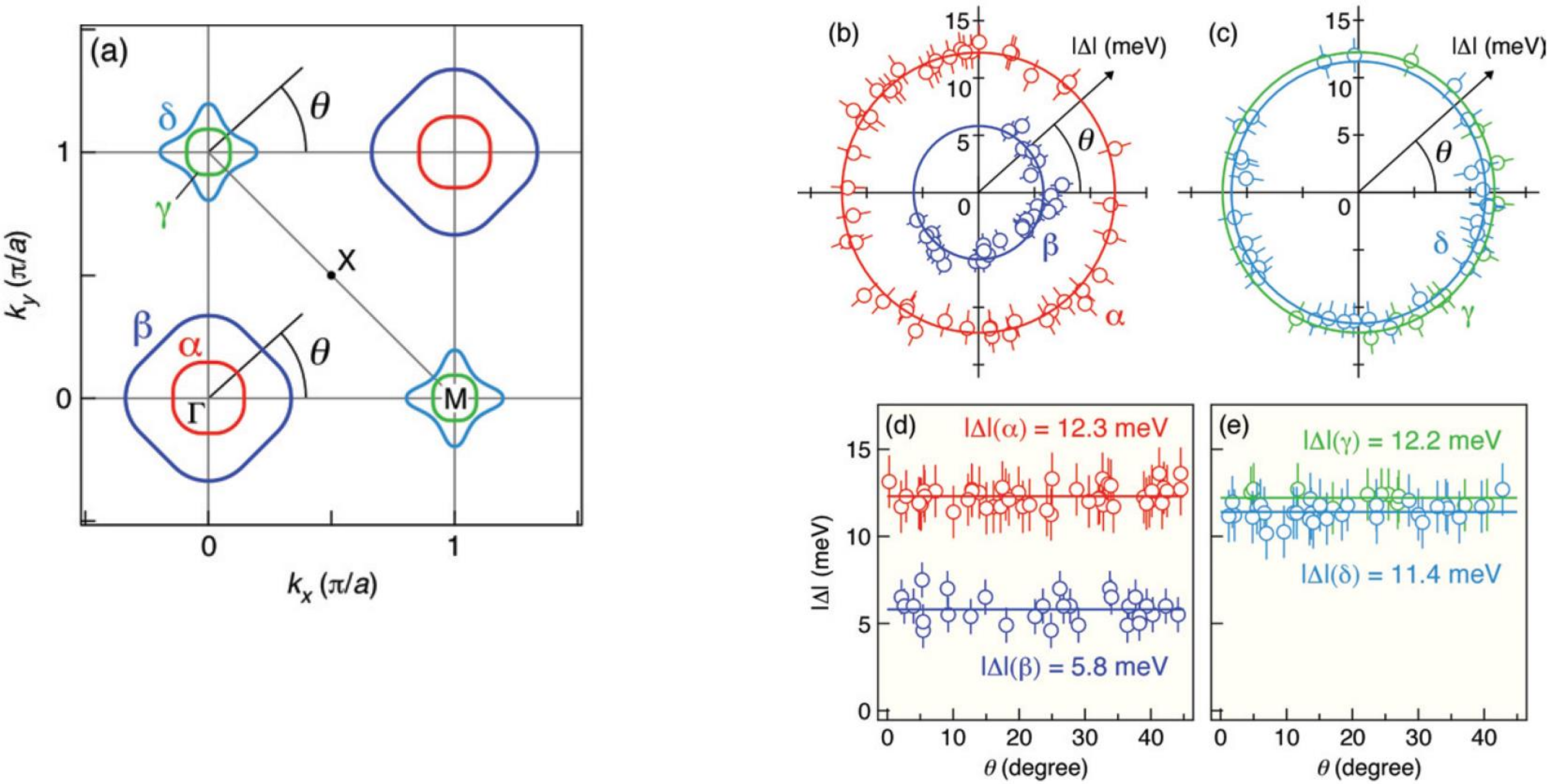


Fig. 1. (a) ^{57}Fe-NMR spectra at $H = 11.97$ T and 30 K for $LaFeAsO_{0.7}$ in the field parallel (●) and perpendicular (○) to the orientation direction. (b) T dependence of $^{57}K^{\perp}$ at $H = 11.97$ T [$T_c(H) \sim 20$ K]. It is noteworthy that the T dependence of $^{57}K^{\perp}$ is opposite to those of ^{75}As and ^{19}F sites,[9,11,12] indicating that the hyperfine-coupling constant is negative at the Fe site, originating from the inner core-polarization.

Terasaki et al. J. Phys. Soc. Jap. 78, 013701 (2009)

SC gap symmetry determined by ARPES in $Ba_{0.6}K_{0.4}Fe_2As_2$



K. Nakayama et al EPL, 85 (2009) 67002

Fig. 2: (Colour on-line) (a) Schematic view of the four FS sheets with a definition of the FS angle (θ). (b), (c) SC gap size at 15 K extracted from the symmetrized spectra shown on polar plots for the (b) α, β and (c) γ, δ FSs as a function of θ. (d) and (e), Same as (b) and (c) but the data points have been shifted (reduced) into the $0^\circ \leqslant \theta \leqslant 45^\circ$ region, by assuming a four-fold symmetry. Thick lines show the averaged SC gap values on each FS.

Thermal conductivity in sc state of $Ba(Fe_{1-x}Co_x)_2As_2$

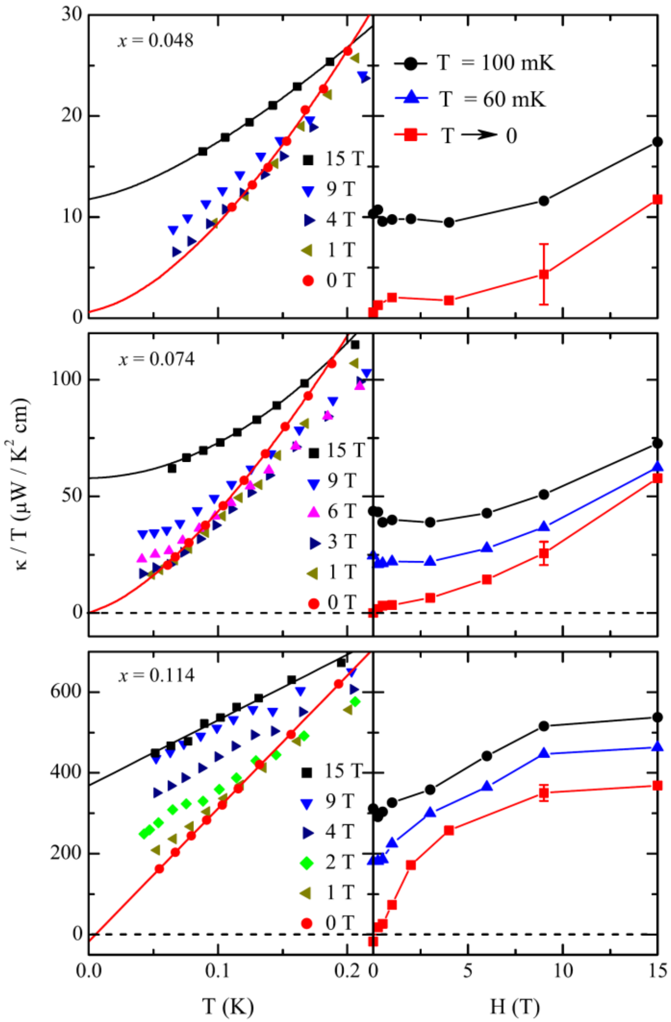


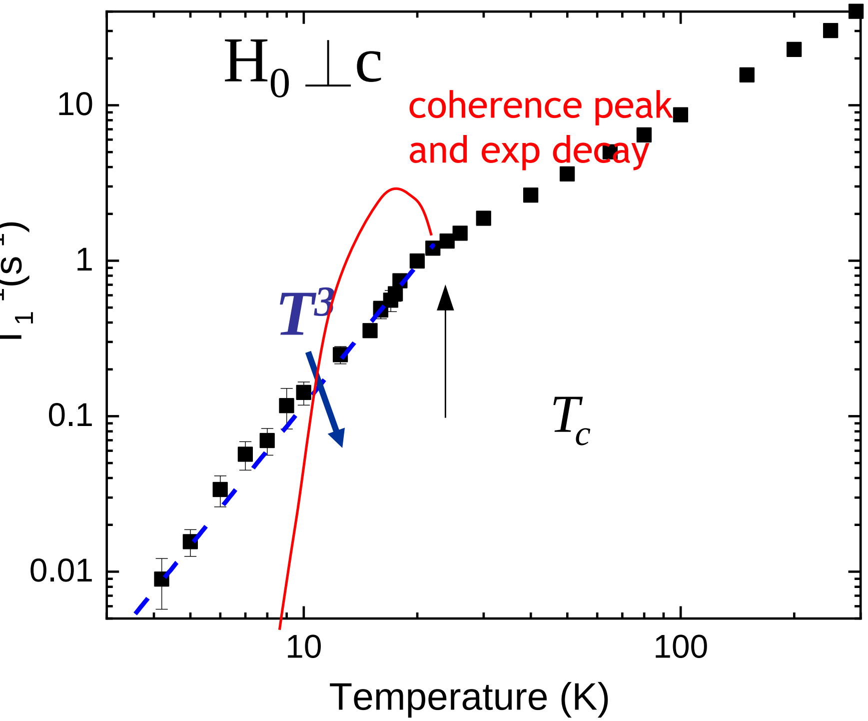
FIG. 2 (color online). Left panels: Temperature dependence of the thermal conductivity, plotted as κ/T vs T, for three Co concentrations, each measured in magnetic fields as indicated. The lines are a power-law fit of the form $\kappa/T = a + bT^{\alpha}$ to the $H = 0$ and $H = 15$ T data, used to extract the residual linear term $\kappa_0/T \equiv a$ in the $T \to 0$ limit (see text). Right panels: field dependence of κ/T plotted for three temperatures, as indicated. The $T \to 0$ data (red squares) are obtained from the power-law extrapolations, with a typical error bar as shown.

Tanatar et al PRL 104, 067002 (2010)

Spin lattice relaxation rate, T_1^{-1}, superconducting state

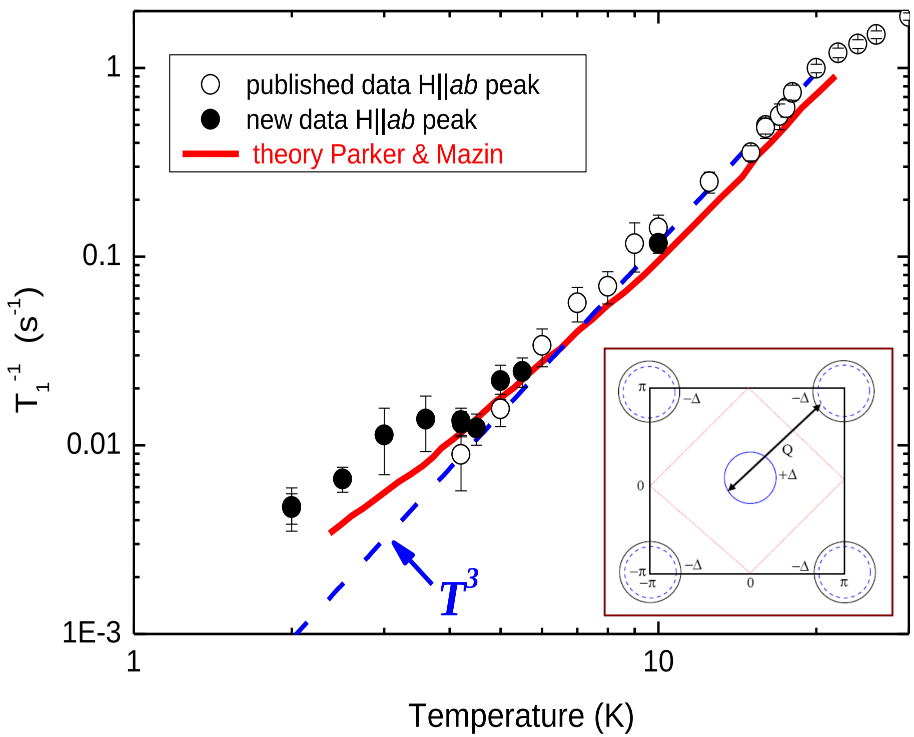
$LaO_{0.9}F_{0.1}FeAs$

- No Hebel Slichter coherence peak, no expon. decay
- T^3 dependence below T_c is indicative for line nodes



⇒ suggestive of d-wave superconductivity

H.-J. Grafe *et al*. PRL **101**, 047003 (2008)



extended s+/- wave scenario including impurities

Mazin et al., PRL **101**, 057003 (2008)

Neutron scattering – resonance peak below 2Δ

$BaFe_{1.85}Co_{0.15}As_2$, Δ = 6 +- 1 meV, T_c = 25 K

The "plus-minus" gap is the best candidate

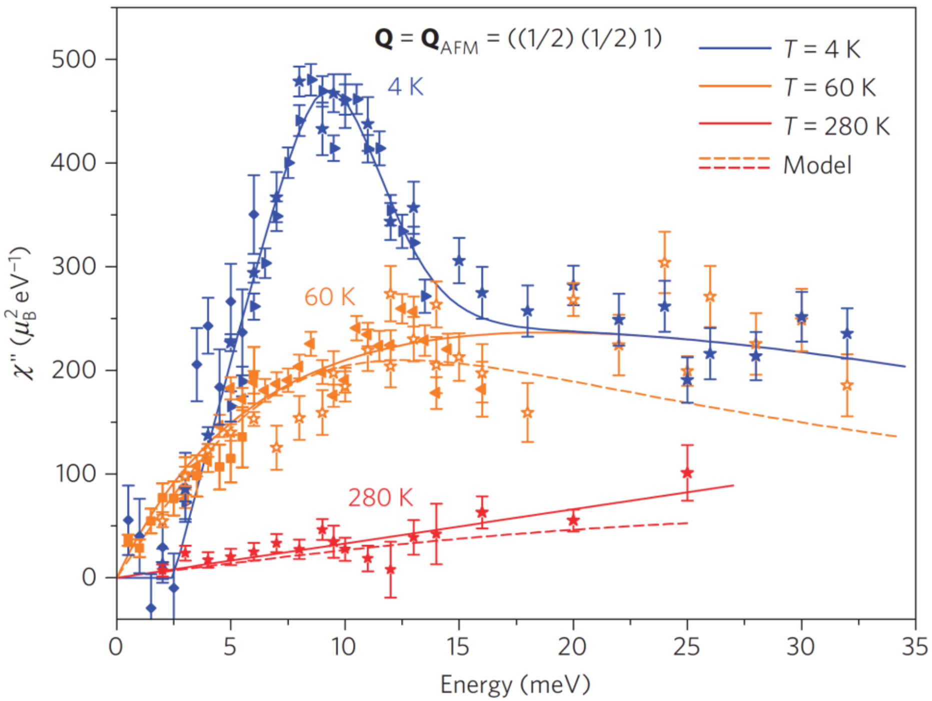
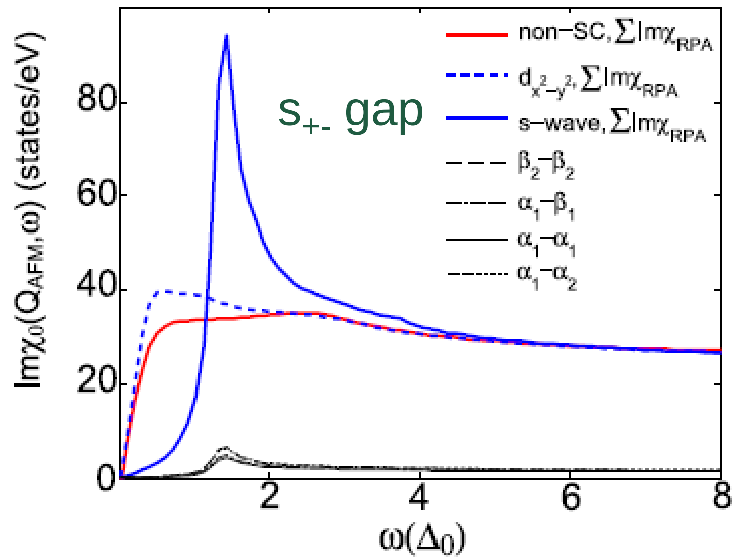


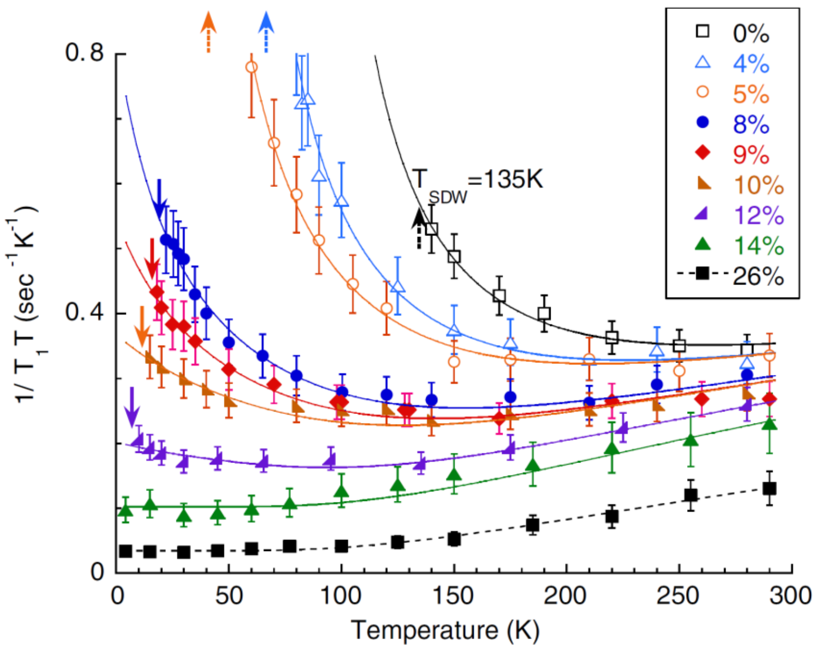
Figure 2 | Imaginary part of the spin susceptibility $\chi(\mathbf{Q}_{\mathbf{AFM}}, \omega)$ in the superconducting ($T = 4$ K) and the normal state ($T = 60$ and 280 K).

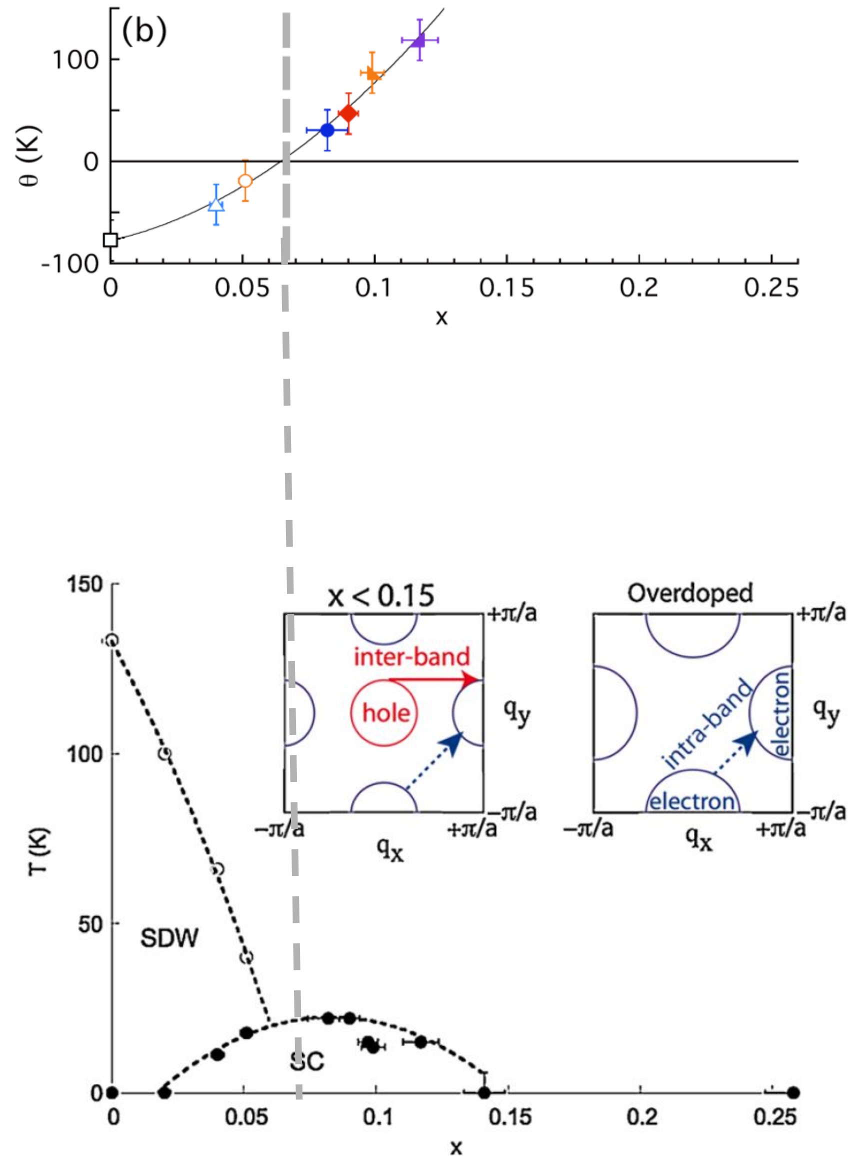
Inosov Nat Phys 6, 178 (2009



Eremin &
Korshunov
Scalapino &
Maier

Quantum critical point?





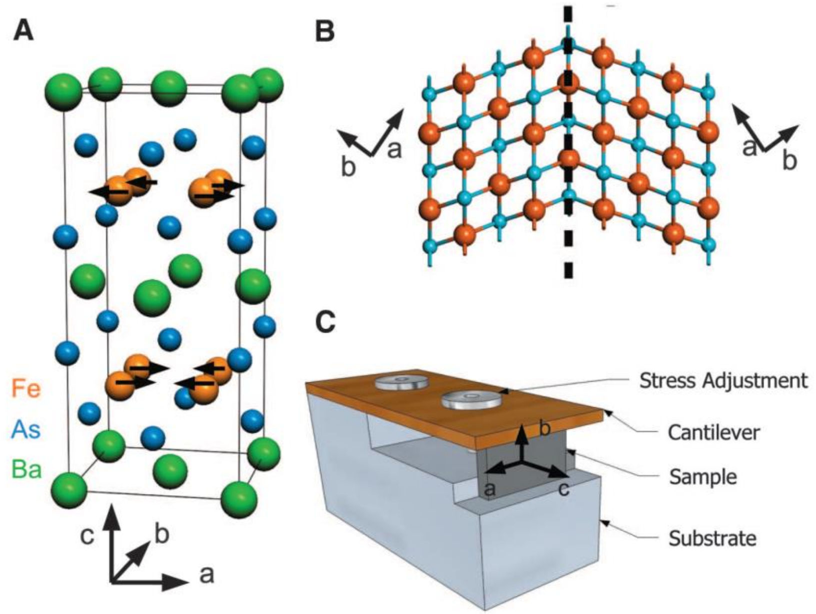
Fit $(T_1T)^{-1}$ to Curie Weiss:

$(T_1T)^{-1} \sim C/(T+\Theta)$

$\Rightarrow$ $\Theta = 0$ when T_c=max, and T_N->0: indication of QCP

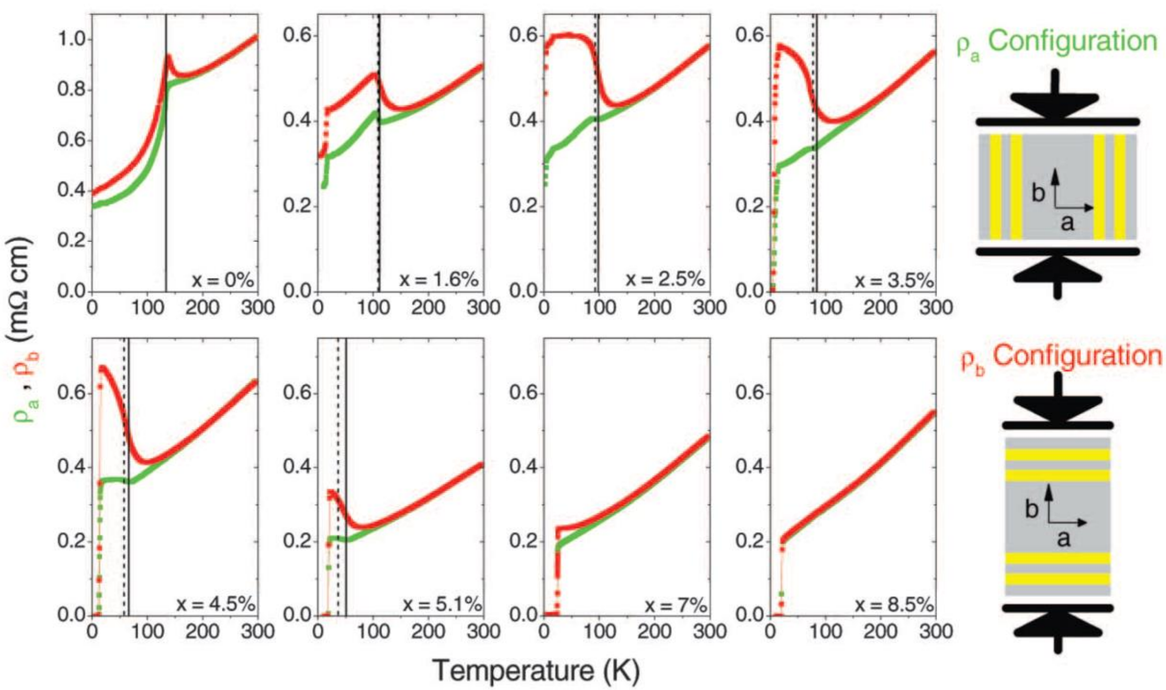
Ning PRL 104, 037001 (2010)

Nematicity



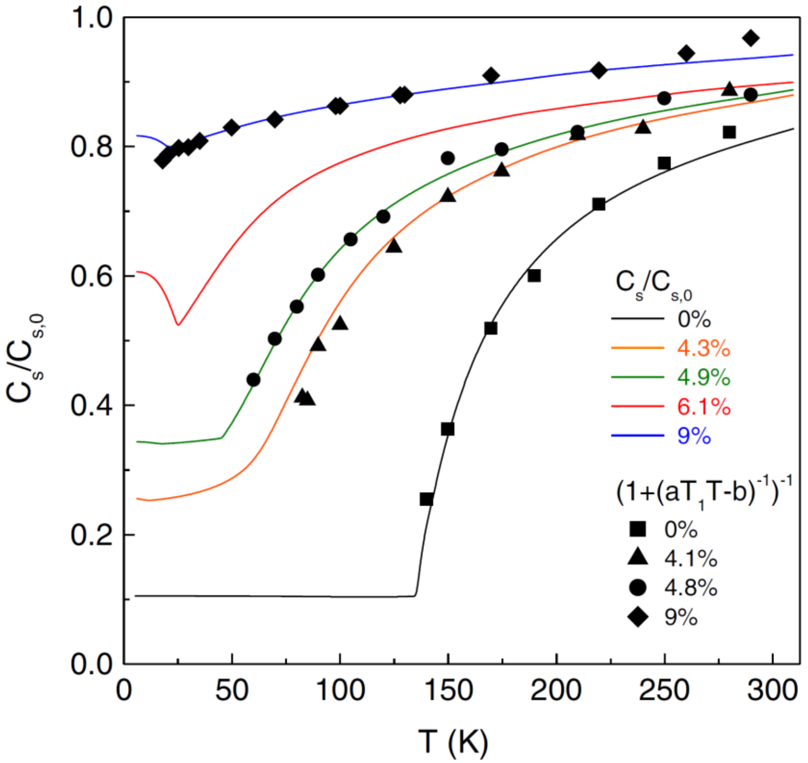
Apply uniaxial strain to detwin the samples.
Resistivity anisotropy already above T_S: nematic fluctuations.

Chu et al. Sience 329, 824 (2010)

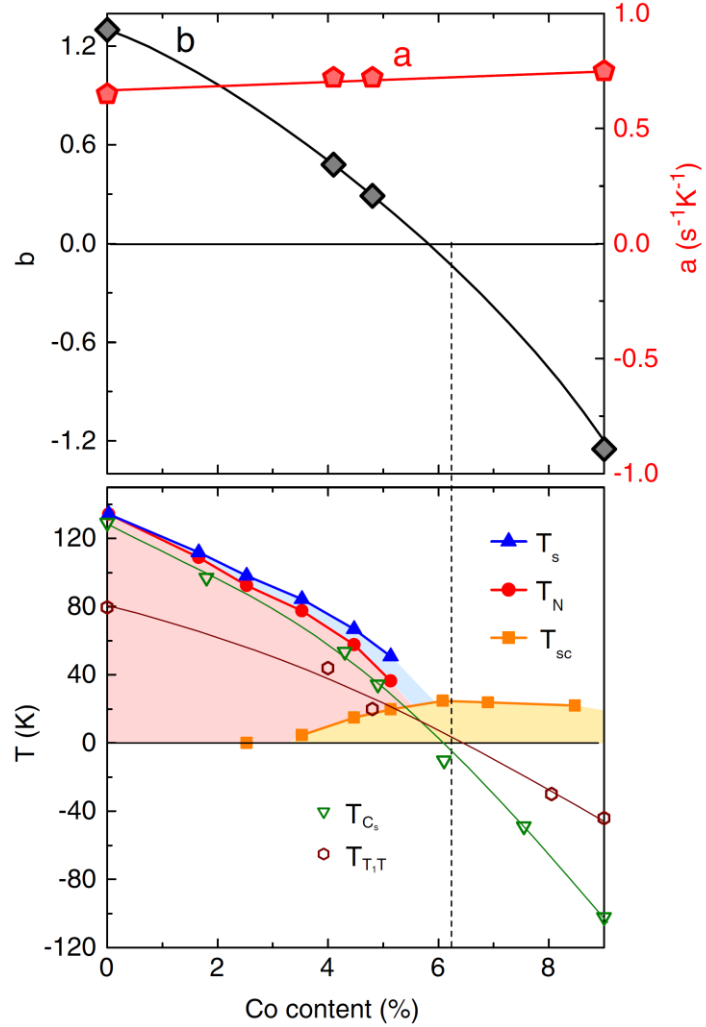


Nematicity

Scaling of shear modulus C66 (softening of the lattice at and above T_S) and NMR $(T_1T)^{-1}$ (spin fluctuations) indicates magnetically driven nematicity.



$$\frac{C_s}{C_{s,0}} = \frac{1}{1 + [a(T_1T) - b]^{-1}}$$



nematic QCP at optimal doping?

Fernandes et al. PRL 111, 137001 (2013)

Nematicity

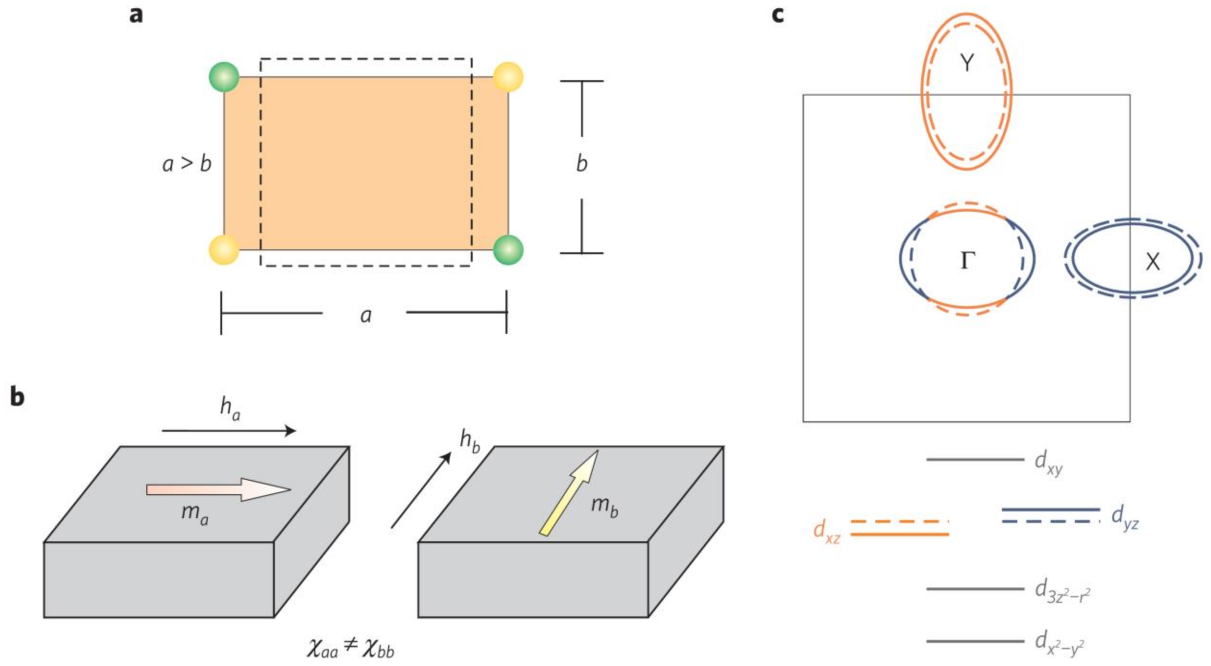


Figure 2 | Manifestations of nematic order in the iron pnictides. a, Structural distortion from a tetragonal (dashed line) to an orthorhombic (solid line) unit cell[5]. **b**, Anisotropy in the uniform spin susceptibility $\chi_{ij} = m_i/h_j$, where m_i denotes the magnetization along the *i* direction induced by a magnetic field h_j applied along the *j* direction[7]. **c**, Splitting of the d_{xz} and d_{yz} orbitals (orange and blue lines, respectively)[15]. The corresponding distortion of the Fermi surface is also shown (see also Fig. 5a).

The susceptibilities of the structural transition, of the spin order (anisotropy in magnetic susceptibility) and of the orbital order (splitting of the d_{xz} and d_{yz} bands) are all non-zero in nematic phase and are intertwined: meaningless which drives the nematic instability.

Fernandes Nature Physics 10, 97, (2014):