Pnictides at high magnetic fields

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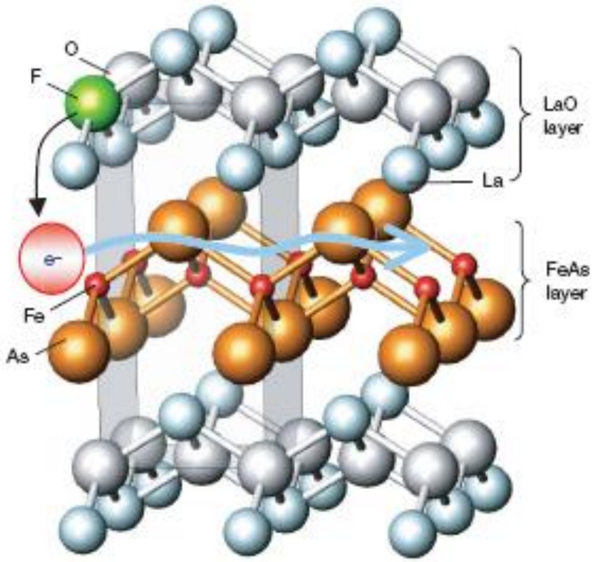
A diverse superconducting/magnetic family

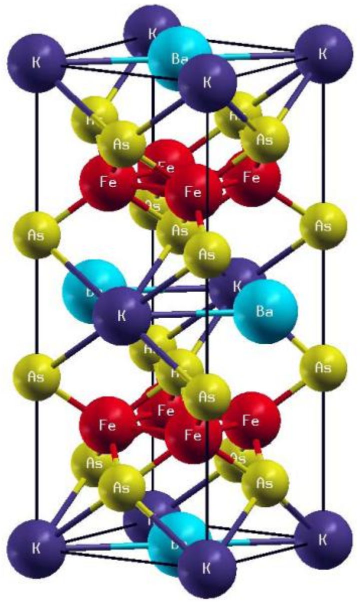
- Oxypnictide base
- ReOMPn
  - M = Fe, Co, Ni
  - Pn = As or P
  - Re = La, Nd, Sm, Pr



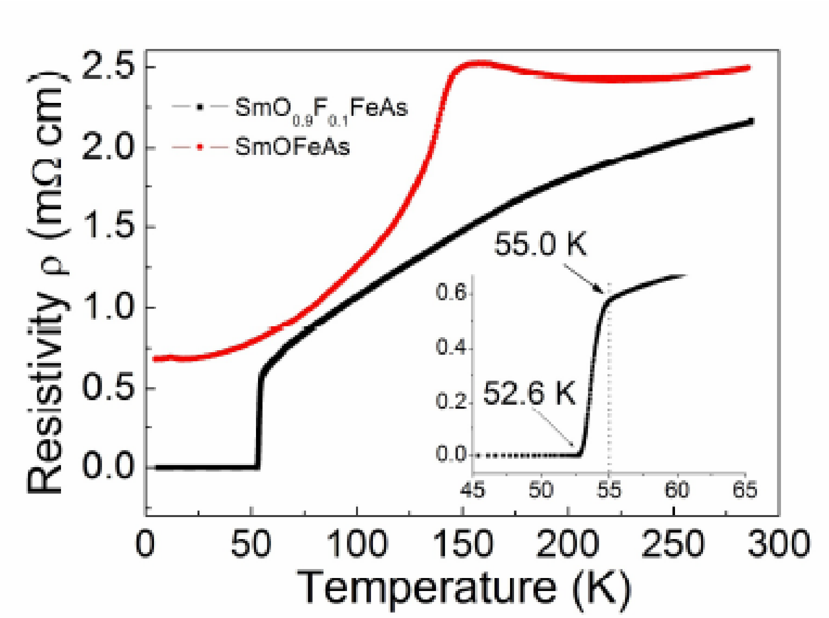
- Superconducting AsFe layers and charge reservoir ReO layers

- Superconductivity occurs on the FeAs layer with magnetic pairbreaking Fe^{2+} ions

- Main families: ReOMPn based (1111)
  $Ba_{1-x}K_xFe_2As_2$ based (122)
  $FeSe_xTe_{1-x}$ based (11)

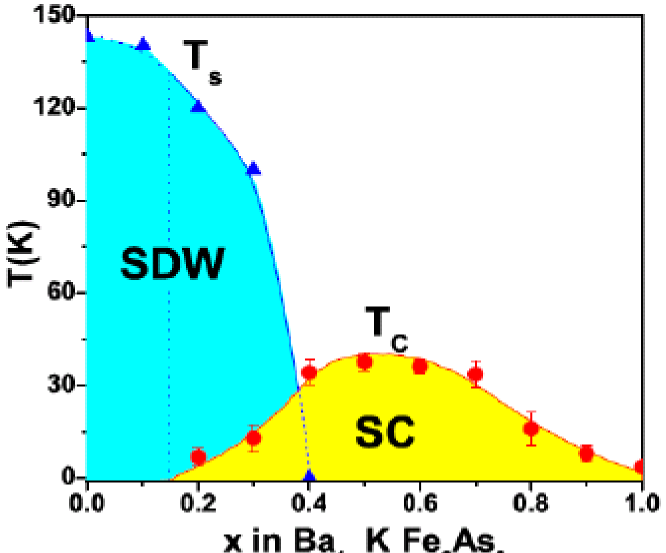


Supercondutivity upon doping



Undopped parent compound: anisotropic semi-metal. Antiferromagnetic transition at 150K and tetragonal – orthorhombic structural transition

Becomes superconducting upon doping with F, or in the oxygen deficient form without F



- $LaO_{0.89}F_{0.11}FeAs$: $T_c \cong$ 26K (43K under pressure)
- $NdO_{1-x}F_xFeAs$: $T_c \cong$ 52K
- $SmO_{1-x}F_xFeAs$: $T_c \cong$ 55K
- $PrO_{1-x}F_xFeAs$: T_c = 52K
- $CeO_{1-x}F_xFeAs$: T_c = 40K

- $Ba_{1-x}K_xFe_2As_2$: T_c = 38K

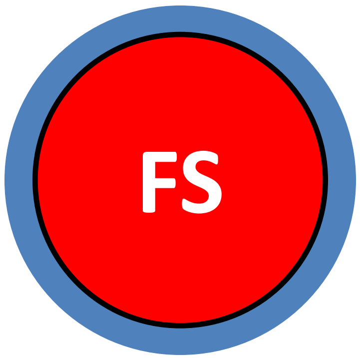
Coexistence of AF and SC

What makes oxypnictides special?

- High T_c up to 55K in a very broad family of materials (up to several hundreds compounds)
- A hope of discovering new higher-T_c pnictides and a pathway for understanding cuprates
- Superconductivity resulting from magnetic Fe ions: coexistence of superconductivity and antiferromagnetism (elemental Fe has T_c = 2K under 20 Gpa)
- Extremely high $H_{c2}(0)$ > 100T, grossly exceeding what would be normally expected from a SC with T_c = 20-50K (well above the Pauli paramagnetic limit)
- Anomalous temperature dependence of $H_{c2}(T)$ consistent with multiband pairing
- Small sizes of the Cooper pairs (2-3 nm): sensitivity to materials defects and strong current blocking by grain boundaries
- Competing SC/AF orders, low carrier density, strong fluctuation effects
- Rich vortex dynamics and pinning: vortex melting/vortex glass zoology + multiband-band physics + interaction of vortices with magnetic structures. Some pnictides behave like HTS, some behave like LTS

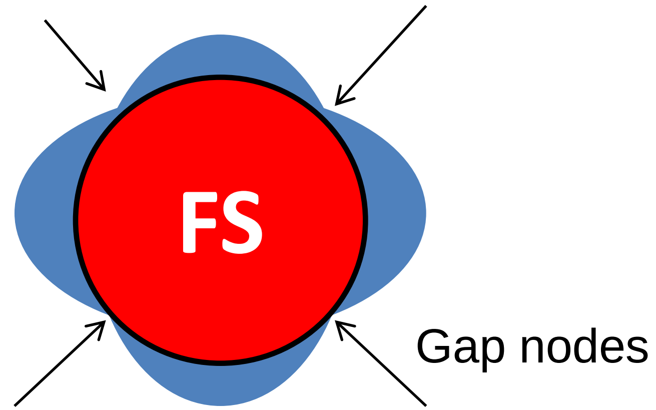
Pairing gap symmetries

s-wave



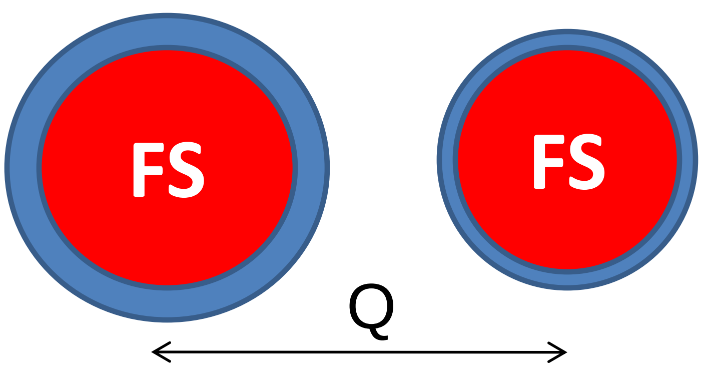
Most traditional SC:
Nb, Pb, NbTi, Nb_3Sn

d-wave



High-T_c cuprates,
heavy fermion SC, pnictides?

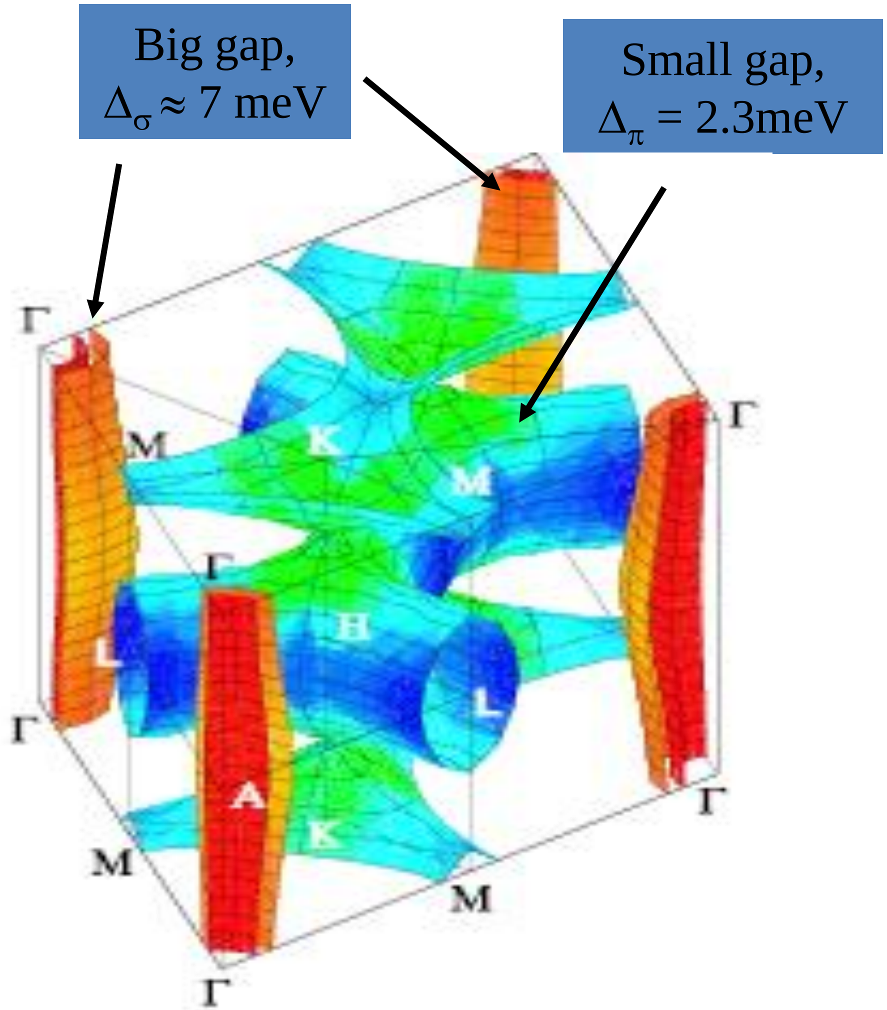
Multi-gap:

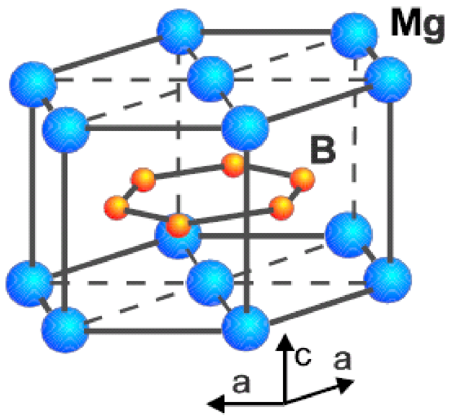


- **Multiband superconductors (MgB_2, oxypnictides**
- **Different superconducting gaps on disconnected pieces of FS**
- **s-wave gaps with either same or opposite signs ($s^{\pm}$ pairing)**
- **Line nodes?**

Two-gap superconductivity in MgB_2

J. Akimitsu et al, Nature 410, 63 (2001)





- 2D big gap for in-plane σ-orbitals of B and 3D small gap for out-of-plane π-orbitals of B
- Weak interband coupling
- Conventional electron-phonon pairing

Multicomponent s-wave order parameter

Interband phase excitations

Critical temperature

Suhl, Mattias, Walker PRL 3, 552 (1959); Moskalenko, FMM 8, 25 (1959):

$$T_{c0} = 1.14\omega_D \exp[-(\lambda_+ - \lambda_0)/2w],$$

$$\lambda_\pm = \lambda_{11} \pm \lambda_{22}, \qquad \lambda_0 = \sqrt{\lambda_-{}^2 + 4\lambda_{12}\lambda_{21}},$$

$$w = \lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21},$$

Pairbreaking interband impurity scattering

$$\psi\left(\frac{1}{2} + \frac{g}{t}\right) - \psi\left(\frac{1}{2}\right) = -\frac{(\lambda_0 + w\ln t)\ln t}{p + w\ln t},$$

$$2p = \lambda_0 + [\gamma_- \lambda_- - 2\lambda_{12}\gamma_{21} - 2\lambda_{21}\gamma_{12}]/\gamma_+$$

Interband coupling increases T_c

Golubov, Mazin, PRB 55, 15146 (1997);
AG, PRB 67, 184515 (2003)

- **Weak interband pairing** in MgB_2, $\lambda_{12}\lambda_{21} << \lambda_{11}\lambda_{22}$
- **Strong interband pairing** in pnictides, $\lambda_{12}\lambda_{21} > \lambda_{11}\lambda_{22}$

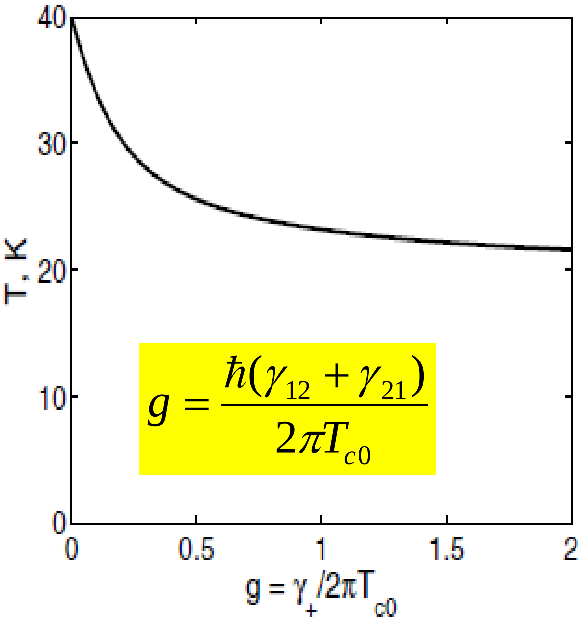
$$T_c \simeq T_{c0} - \frac{\pi\gamma_{12}}{8}\left(1 \mp \sqrt{\frac{N_1}{N_2}}\right)^2$$

T_c suppression is much weaker for the two-gap s^{++}(-) than for $s^{\pm}$ (+)

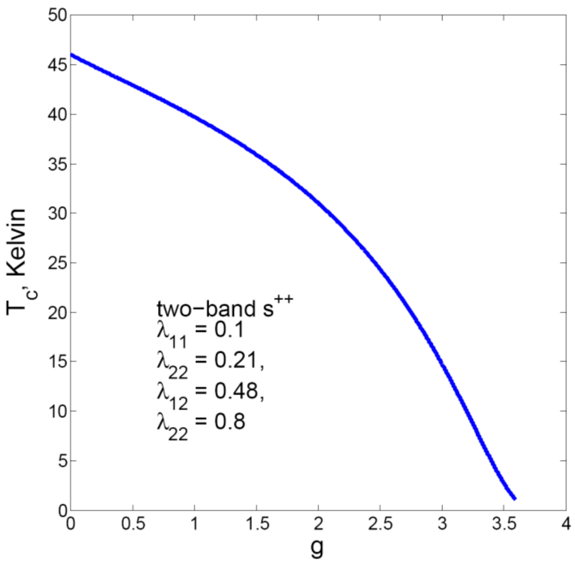
Effect of interband scattering on T_c

Possible scenarios

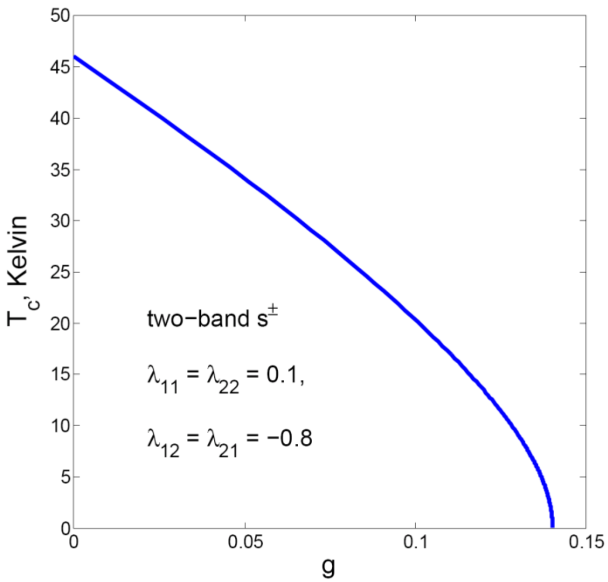
s^{++} weakly coupled bands



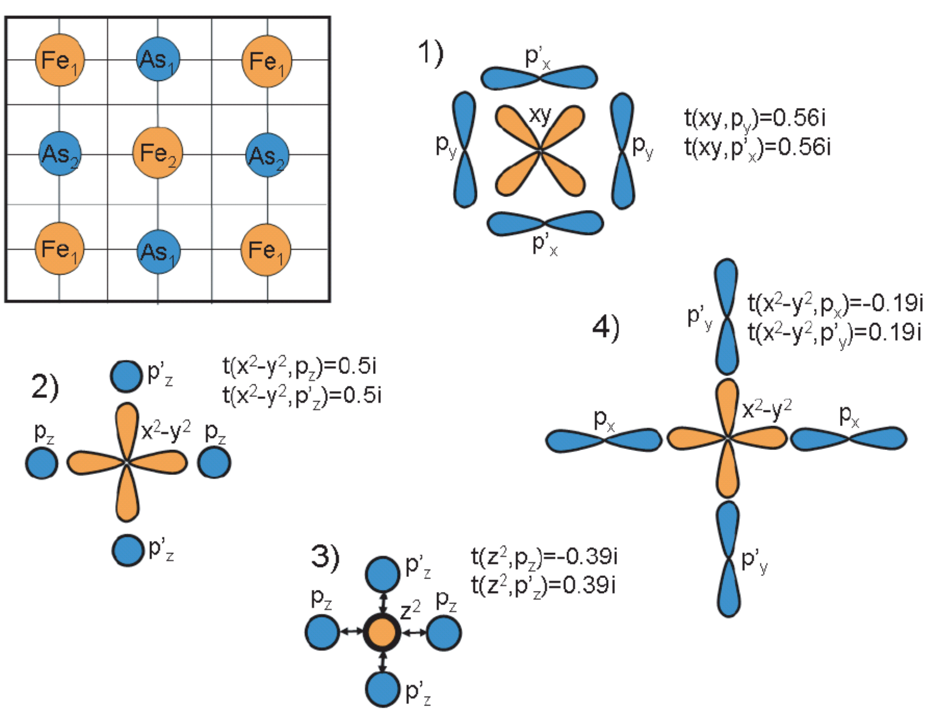
s^{++} strongly coupled bands

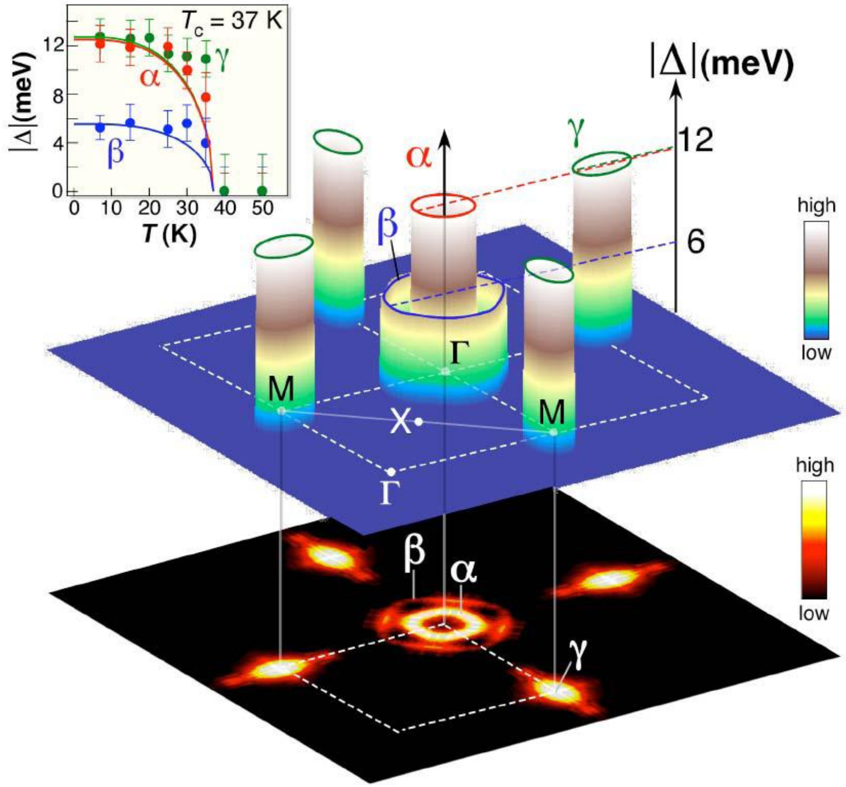


s^{+-} two-band pairing



Multiband superconductivity in oxypnictides





Haule and Kotliar, NJP 025021 (2009)

Five d-orbitals of Fe hybridized with p-orbitals of As

Several disconnected pieces of FS

Multiple superconducting gaps

ARPES and tunneling: $Ba_{0.6}K_{0.4}Fe_2As_2$

Ding et al, EL 83, 47001 (2008)

Electron spectrum from ab-initio calculations and ARPES

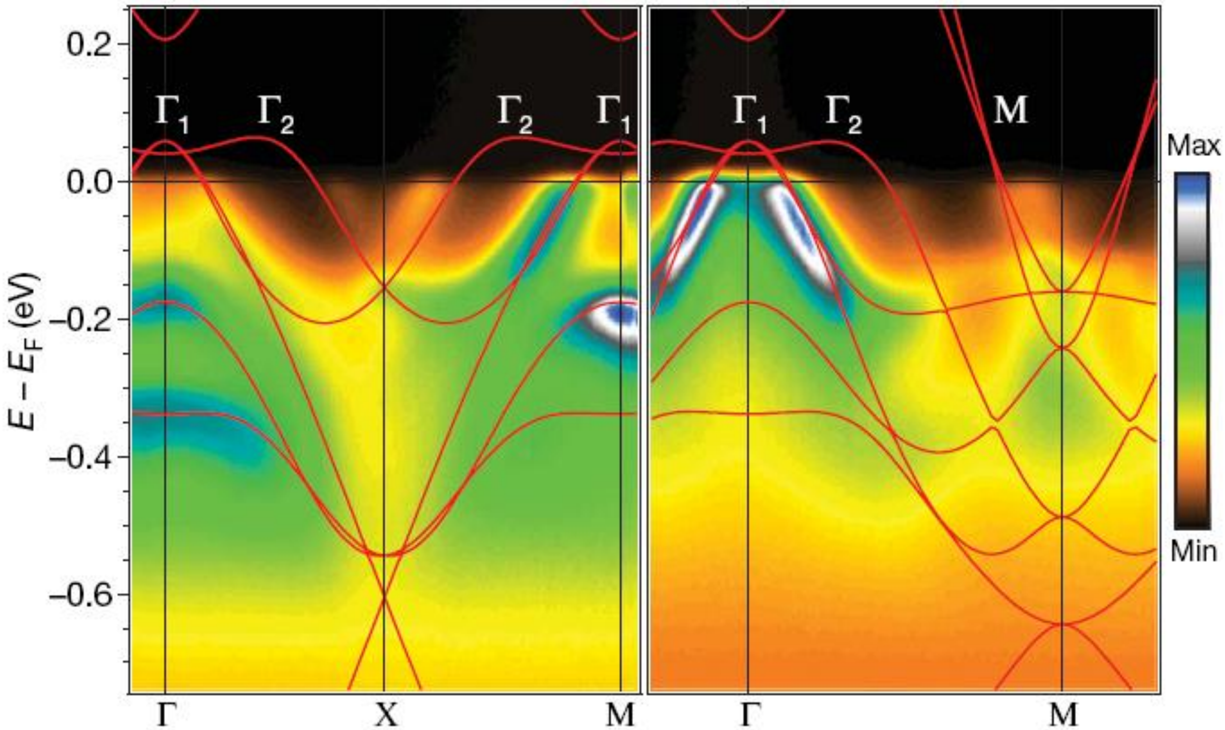


Figure 2 | Comparison between angle-resolved photoemission spectra and LDA band structures along two high-symmetry lines. ARPES data from LaOFeP (image plots) were recorded using 42.5-eV photons with an energy resolution of 16 meV and an angular resolution of 0.3°.

- multiple bands crossing the Fermi level
- qualitative consistency of ARPES and ab-initio calculations
- two hole pockets at Γ and two electron pockets at M

Vol 455|4 September 2008|doi:10.1038/nature07263 nature

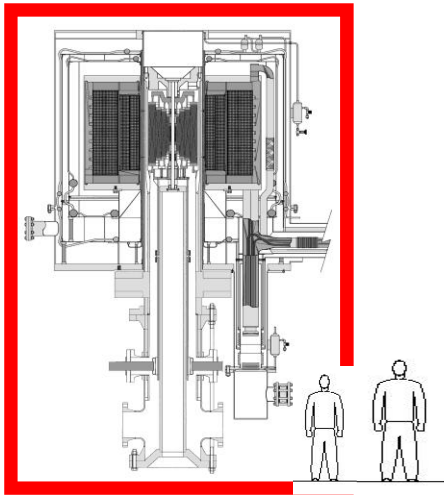
LETTERS

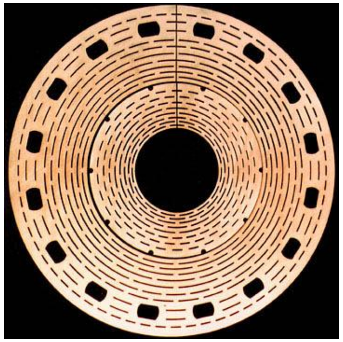
Electronic structure of the iron-based superconductor LaOFeP

D. H. Lu[1], M. Yi[1], S.-K. Mo[1,2], A. S. Erickson[3], J. Analytis[3], J.-H. Chu[3], D. J. Singh[4], Z. Hussain[2], T. H. Geballe[3], I. R. Fisher[3] & Z.-X. Shen[1]

High-field measurements at NHMFL

45T Hybrid Magnet
Highest DC Magnetic Field

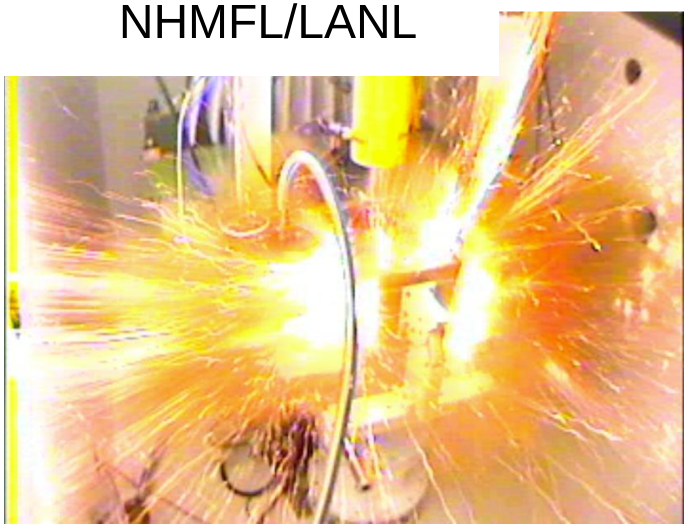




"world's highest steady-field resistive (35 T) and hybrid (45 T) magnets"

200T, 1 microsecond
One pulse per hour

NHMFL/LANL



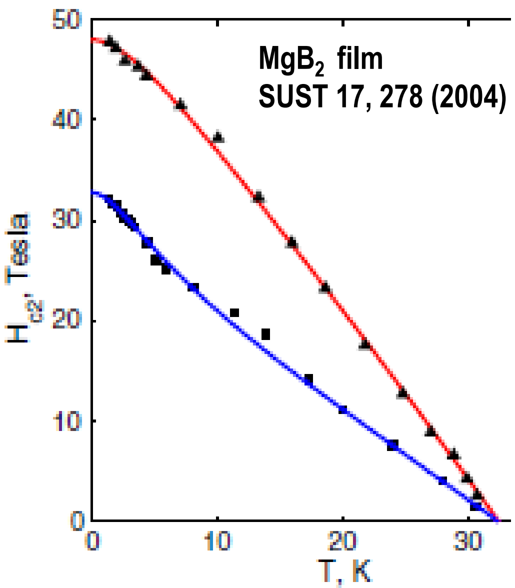
First signs of huge upper critical fields

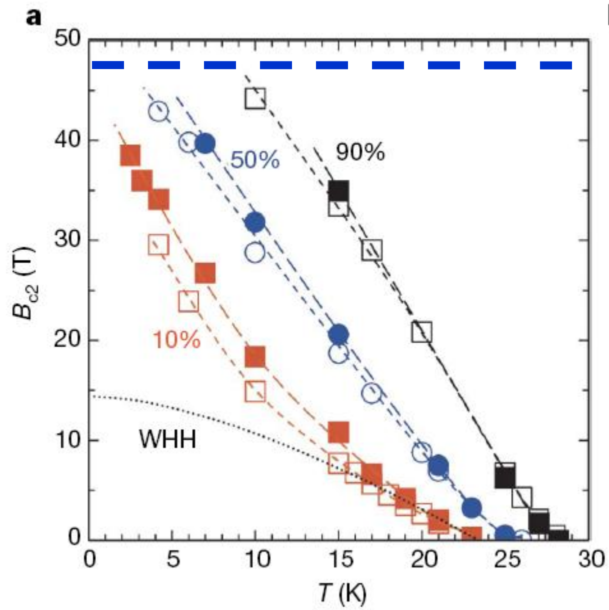
Vol 453|12 June 2008|doi:10.1038/nature07058 nature

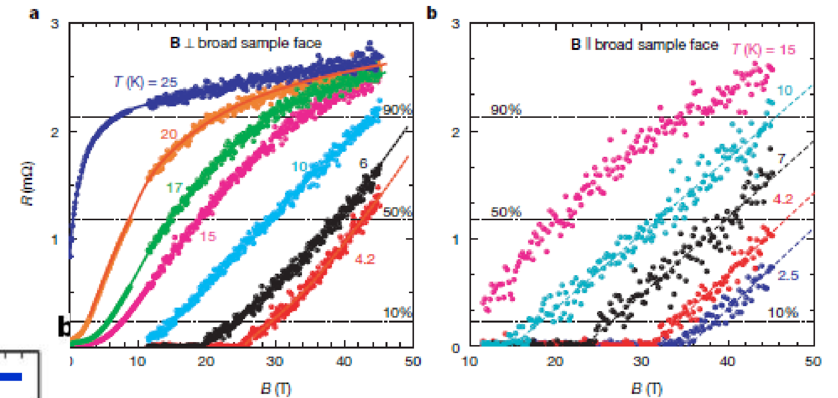
LETTERS

Two-band superconductivity in $LaFeAsO_{0.89}F_{0.11}$ at very high magnetic fields

F. Hunte[1], J. Jaroszynski[1], A. Gurevich[1], D. C. Larbalestier[1], R. Jin[2], A. S. Sefat[2], M. A. McGuire[2], B. C. Sales[2], D. K. Christen[2] & D. Mandrus[2]







- Very high dH_{c2}/dT = 3-10 T/K; extrapolation to low T suggests: $H_{c2}(0) \approx 70$ T, well above WHH and the BCS paramagnetic limit

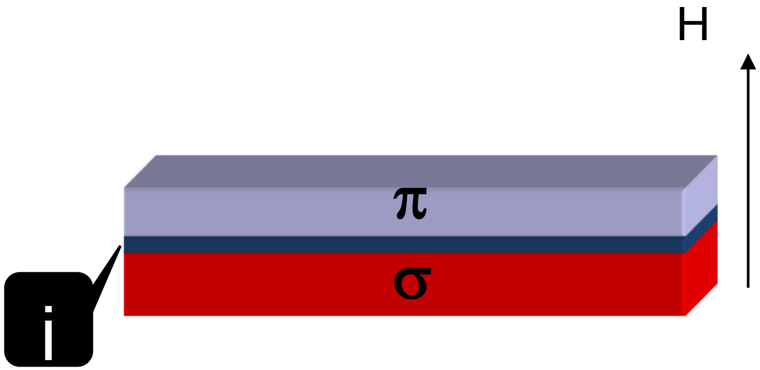
- Upward curvature of $H_{c2}(T)$ for H||c, similar to MgB_2

- Anisotropic H_{c2} in randomly-oriented grains

- Onset of SC transition: highest H_{c2} || ab

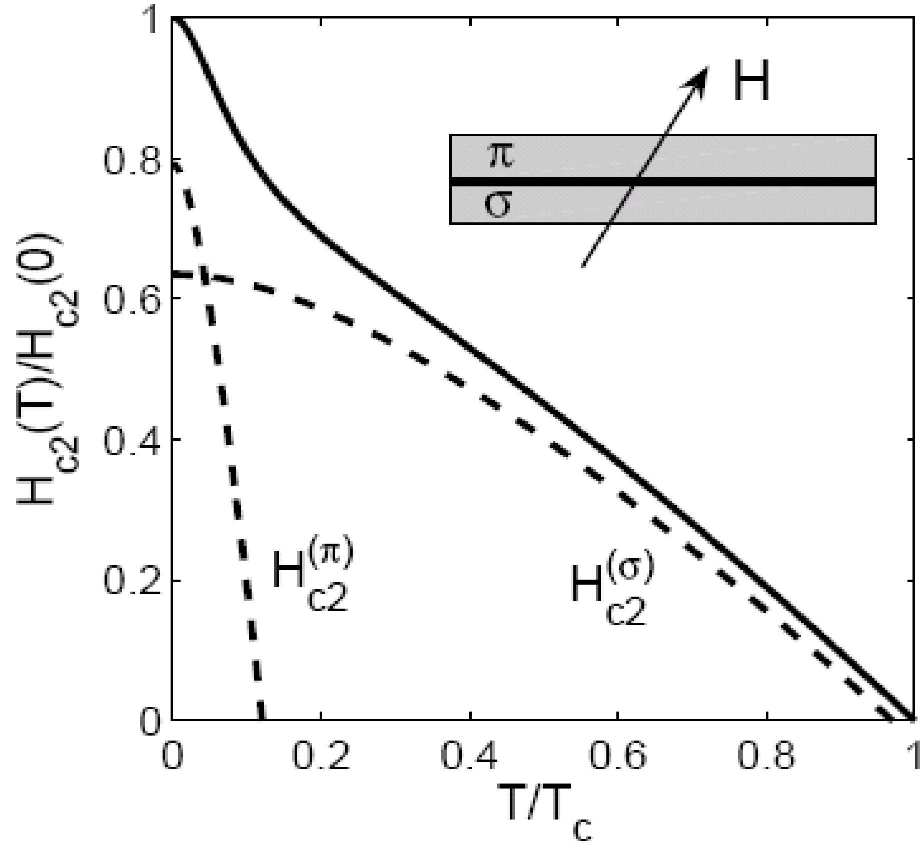
- Onset of resistivity: percolative transition for the grains with the smallest H_{c2} || c

Bilayer toy model for H_{c2} in a two-band superconductor



- Two coupled films (σ and π): $T_c^{(\sigma)} > T_c^{(\pi)}$
- Josephson interface junction mimics interband coupling
- Breakdown of the GL angular scaling: temperature dependent anisotropy
- Model-independent behavior

Cleaner σ: upward curvature of $H_{c2}(T)$



$$H_{c2} = \frac{H_{c2}(0)}{\sqrt{\cos^2\theta + \gamma^{-2}\sin^2\theta}},$$

applied separately for each films

Two-gap superconductivity in the dirty limit

Two-gap Usadel eqs.

$$(\omega + i\mu_B H)f_1 - \frac{D^{(1)}_{\alpha\beta}}{2}[g_1\Pi_\alpha\Pi_\beta f_1 - f_1\nabla_\alpha\nabla_\beta g_1] = \Delta_1 g_1 + (f_2 g_1 - f_1 g_2)\gamma_{12}$$

$$(\omega + i\mu_B H)f_2 - \frac{D^{(2)}_{\alpha\beta}}{2}[g_2\Pi_\alpha\Pi_\beta f_2 - f_2\nabla_\alpha\nabla_\beta g_2] = \Delta_2 g_1 + (f_1 g_2 - f_2 g_1)\gamma_{21}$$

Here $D_{\alpha\beta}$ are intraband electron diffusivities, $\Pi = \nabla + 2\pi i A/\phi_0$, γ are interband scattering rates, λ_{nm} is 2×2 matrix of BCS coupling constants.

- Gap equations:

$$\Delta_m = 2\pi T \sum_{\omega>0}^{\omega_D} \sum_{s=1,2} \lambda_{ms} f_s(\omega, \Delta_s)$$

Equation for H_{c2} including inter and intraband scattering, and paramagnetic effects in the dirty limit

AG, PRB 67, 184515 (2003); Physica C546, 160 (2007)

$$2wF_+F_- + (\lambda_0 + \tilde{\lambda})F_+ + (\lambda_0 - \tilde{\lambda})F_- = 0,$$

$$F_\pm = \ln t + \mathrm{Re}\,\psi\left(\frac{1}{2} + \frac{\Omega_\pm + i\mu_B H}{2\pi T}\right) - \psi\left(\frac{1}{2}\right),$$

$$2\Omega_\pm = \omega_+ + \gamma_+ \pm \sqrt{\omega_-^2 + \gamma_+^2 + 2\gamma_-\omega_-},$$

$$\gamma_\pm = \gamma_{12} \pm \gamma_{21}, \qquad \omega_\pm = (D_1 \pm D_2)\pi H/\phi_0,$$

$$\tilde{\lambda} = [(\omega_- + \gamma_-)\lambda_- - 2\lambda_{12}\gamma_{21} - 2\lambda_{21}\gamma_{12}]/\Omega_0$$

- Can be used for different pairing mechanisms
- Application to MgB_2: weak interband pairing: $\lambda_{12}\lambda_{21} \ll \lambda_{11}\lambda_{22}$
- Application to pnictides: strong interband pairing: $\lambda_{12}\lambda_{21} > \lambda_{11}\lambda_{22}$

Nd-1111 single crystal

PHYSICAL REVIEW B **78**, 174523 (2008)

Upper critical fields and thermally-activated transport of $NdFeAsO_{0.7}F_{0.3}$ single crystal

J. Jaroszynski, F. Hunte, L. Balicas, Youn-jung Jo, I. Raičević, A. Gurevich, and D. C. Larbalestier
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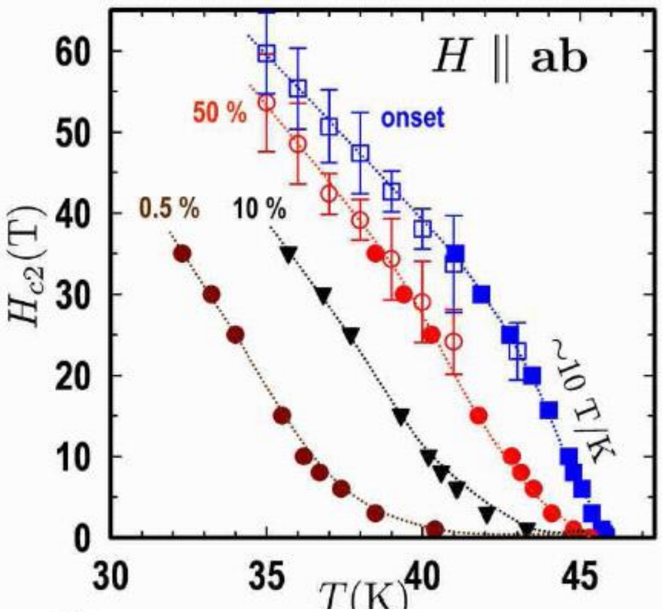
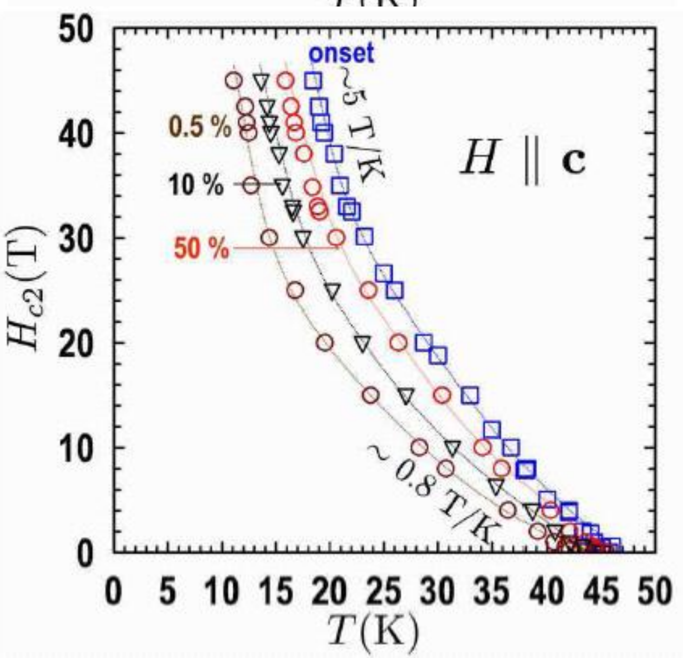
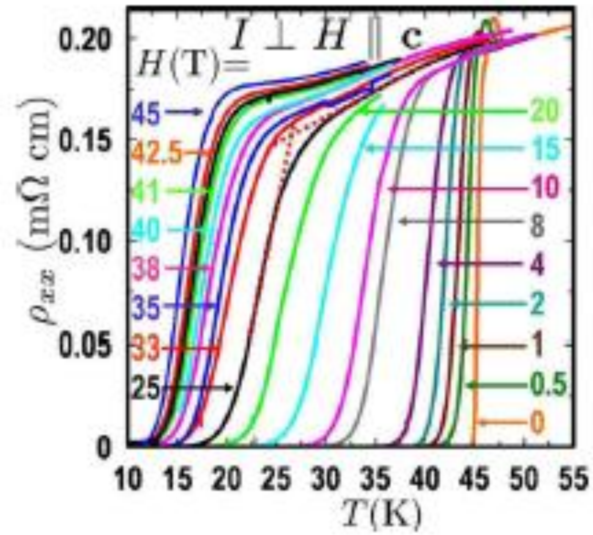
(Received 14 October 2008; published 21 November 2008)

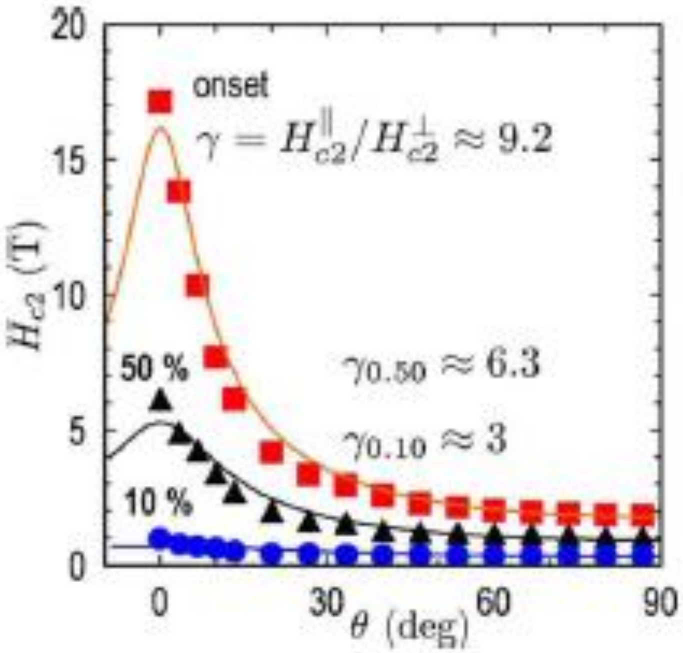


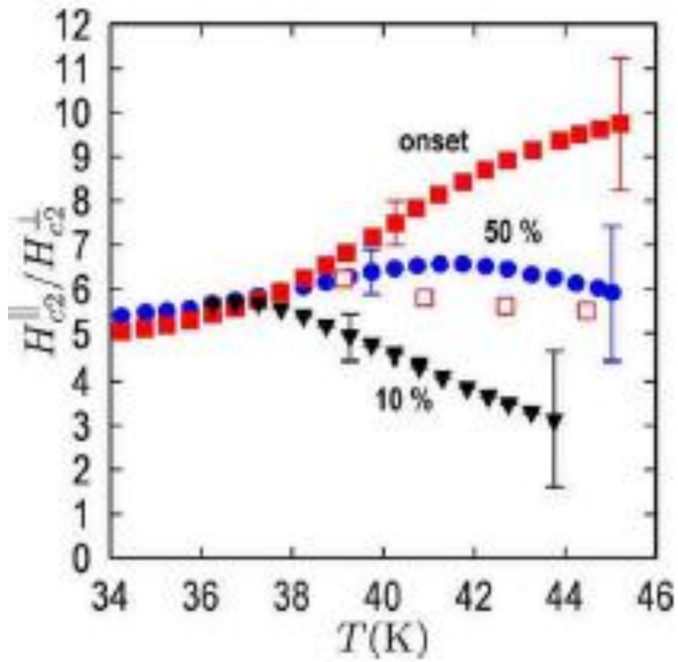




- Combined dc (Tallahassee) and pulse (LANL) fields
- The same multiband behavior of $H_{c2}(T)$ as on La-1111 polycrystals
- Naïve extrapolation to T=0 suggests $H_{c2}||ab \approx$ 200-300 T

Nd-1111 single crystals: temperature-dependent anisotropy





$$H_{c2}(\theta) = \frac{H_{c2}(0,T)}{\sqrt{\cos^2\theta + \gamma^{-2}(T)\sin^2\theta}}$$

- **Two-band angular scaling for H_{c2}:**
  $D_m \Rightarrow D_m(\theta) = [D^2_m{}^{(ab)}\cos^2\theta + D_m^{(c)}D_m^{(ab)}\sin^2\theta]^{1/2}$

- **GL single-band scaling is not too bad**
- **Temperature-dependent γ(T) indicates multiband superconductivity**
- **Different dependencies of γ(T) for H_{c2} (onset) and irreversibility field (10%)**

Nd-1111 single crystals: clean or dirty?

- GL coherence lengths $\xi_{ab}(0)$ and $\xi_c(0)$ estimated from the observed $H_{c2}(T)$ slopes near T_c:

$$\xi_{ab} = \left(\frac{\phi_0}{2\pi T_c \,|\, H'_{c2} \,|} \right)^{1/2} \cong 2-3nm, \qquad \xi_c = \frac{\xi_{ab}}{\gamma} \cong 0.3-0.4nm$$

for H_{c2}' = 2-4 T/K, γ = 7-10

- the numbers are similar to those for YBCO

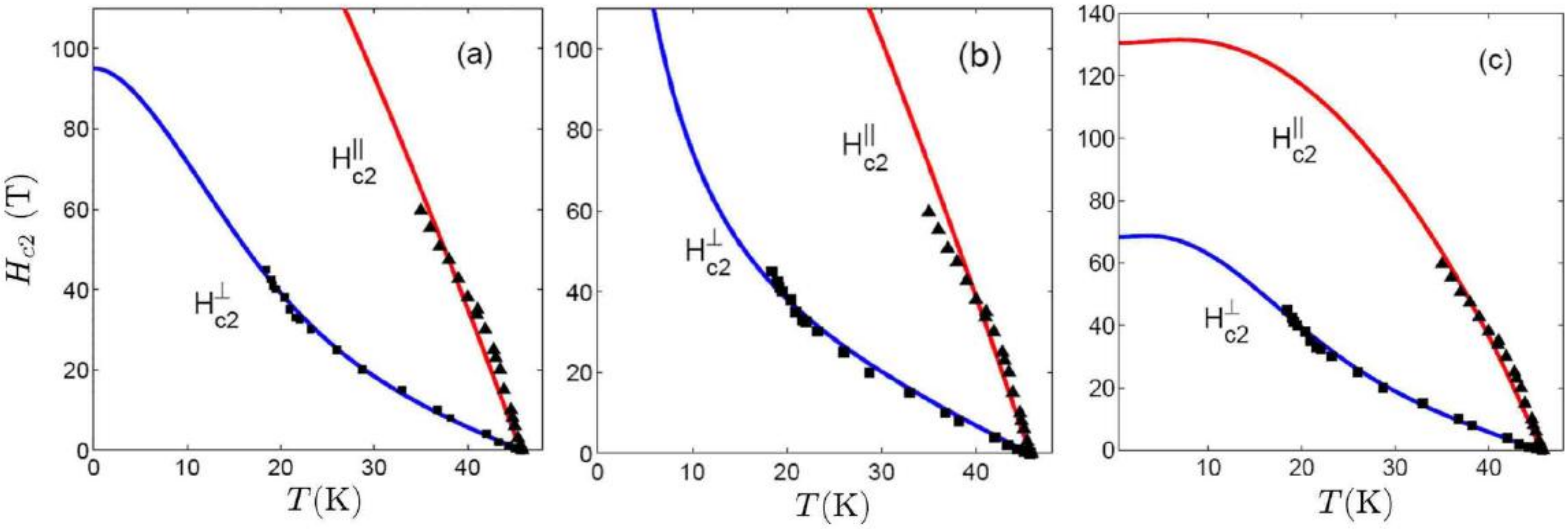
- Drude mean-free path estimated from $\rho_n(T_c)$:

$$\ell = \frac{m^* v_F}{\rho_n n e^2} = \frac{\lambda_L^2 v_F \mu_0}{\rho_n} \cong 2-3nm$$

$\rho_n(T_c) \approx$ 0.2-0.3 mΩcm, $\lambda_L \approx$ 200 nm,
v_F = 1.3*10^7 cm/s

- Moderately dirty limit, $\xi_{ab}(0) \approx \ell$.
- Dirty limit is applicable
- Unclear what part of $\rho_n(T_c)$ comes from nonmagnetic impurity scattering

Two-band analysis of H_{c2} in Nd-1111 single crystal

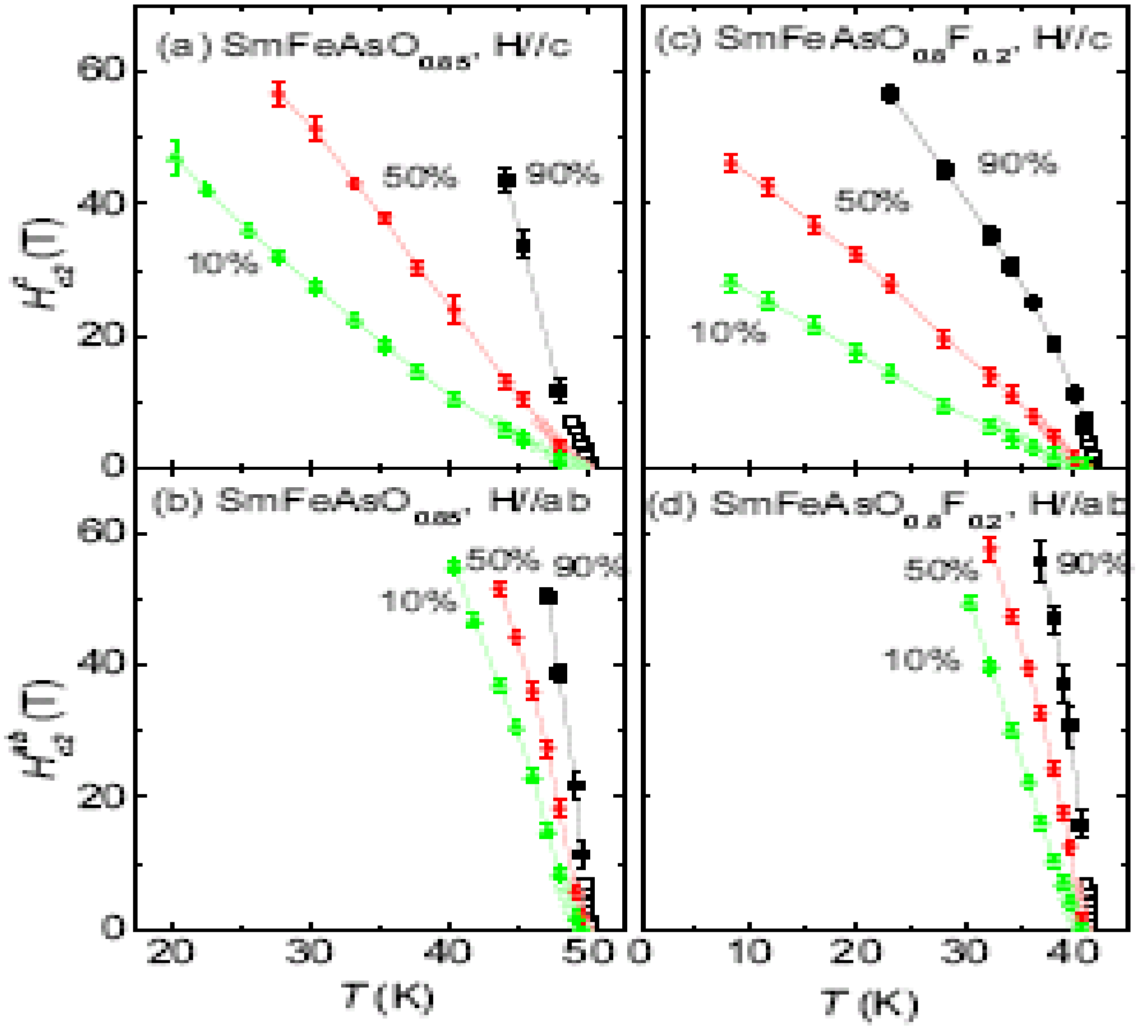


s^{++} no PM terms $\quad$ $s^{\pm}$ no PM terms $\quad$ s^{++} & PM terms

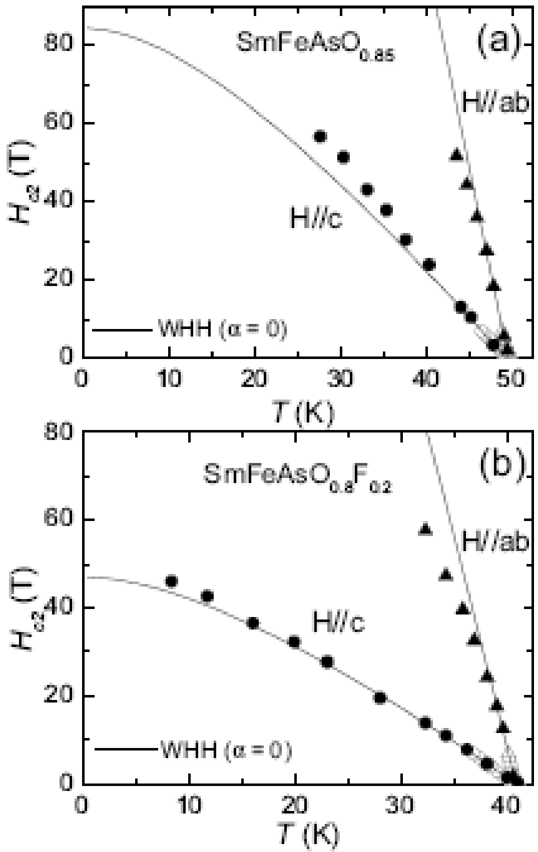
- Reproducing the observed upward curvature of $H_{c2}(T)$ requires a significant difference in the band diffusivities D_1 and D_2
- s^{++} two-band pairing: $D_2 \approx 0.1D_1$ (a)
- $s^{\pm}$ pairing requires $D_2 \approx 0.01D_1$ (b)
- Pauli pairbreaking reduces the extrapolated $H_{c2}(0)$ from 200-300 T down to 60-120T

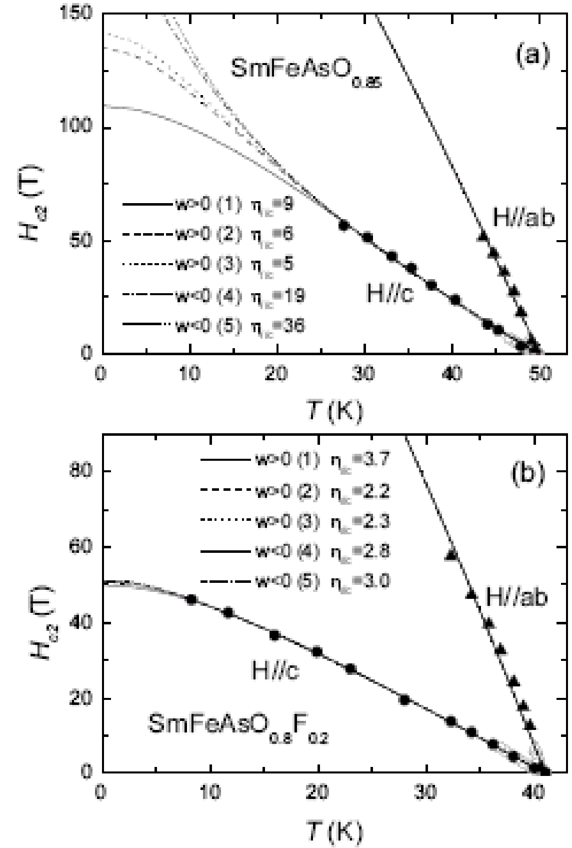
60 T pulse measurements on Sm-1111 crystals

H.-S. Lee et al, arXiv: 0908.1287



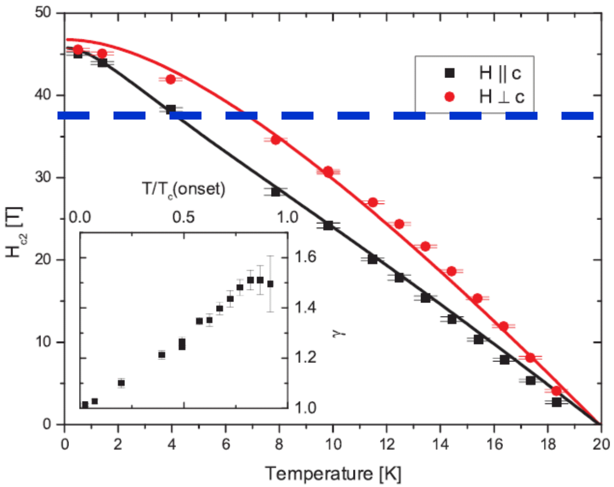
Single band versus multiband analysis



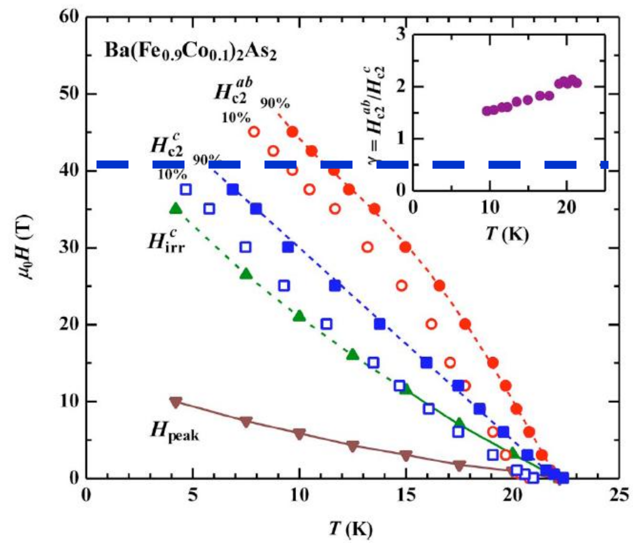


60 T is not enough to distinguish between different scenarios

PM limit in pnictides is greatly exceeded

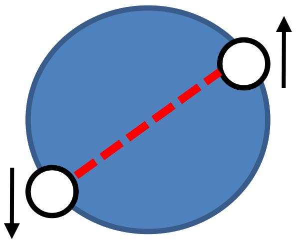


SrFe$_2$As$_2$ epitaxial films.
Baley et al, PRL 102, 117004 (2009)

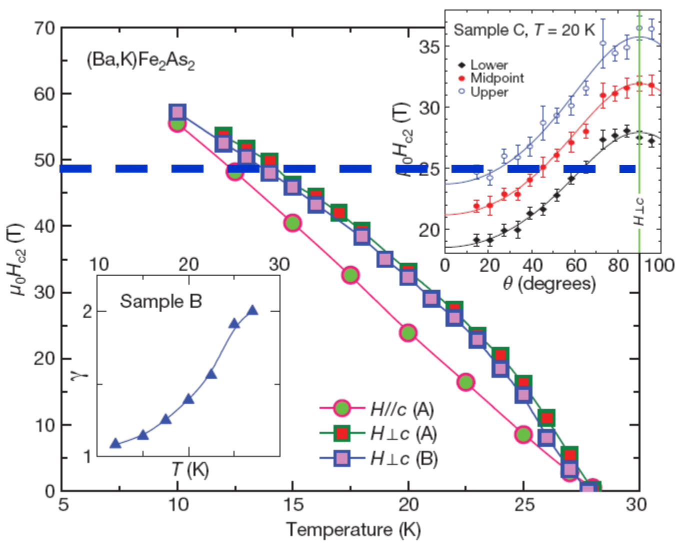


Yamamoto et al, APL 94, 062511 (2009)

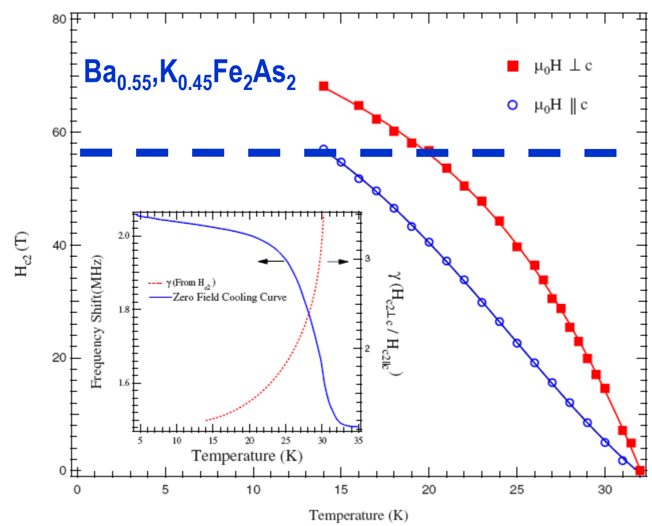
$\mu_B H_p \cong \Delta/\sqrt{2}$



H_p [T] = 1.84 T_c [K]



Yuan et al, Nature 457, 565 (2009)



Altarawneh et al, PRB 78, 220505 (R) (2008).

Nearly isotropic H_{c2}

Paramagnetic limit is exceeded by the factor ~ 2

How can it be in a seemingly layered compound?

Paramagnetic limitations of H_{c2}

- BCS one-gap paramagnetic limit **(Chandrasekhar; Klogston (1962); Maki (1964));**

$$\mu_B H_p = \Delta / \sqrt{2} \quad \longrightarrow \quad B_p[T] = 1.84 T_c[K]$$

- Which gap in multiband superconductors?

- For T = g = 0 , both D_σ and D_π should be replaced by effective diffusivities

$$\tilde{D}_\sigma = \sqrt{D_\sigma^2 + D_0^2}, \qquad \tilde{D}_\pi = \sqrt{D_\pi^2 + D_0^2}$$

- Quantum diffusivity: $$D_0 = \hbar / 2m$$

(diffusion relation and the energy uncertainty principle $L^2 = Dt$ and $\hbar/t = \hbar^2/2mL^2$)

How dirty should it be to reach the PM limit?

- Impurity diffusivity = quantum diffusivity: $\ell v_F/3 = \hbar/2m$
- Fermi-Compton mean free path:

$$\ell \cong \frac{\hbar}{m v_F}$$ H||c

$$\ell \cong \frac{\hbar}{m\sqrt{v_{F\sigma}^{(ab)} v_{F\sigma}^{(c)}}}$$ H||ab

For $v_F \sim 10^7 - 10^8$ cm/s (depending on the orientation), we get $\ell \sim 2 - 20$ Å

Easier to reach in pnictides because of their small Fermi velocities
$v_F \cong 10^7$ cm/s

PM limit in two-gap superconductors

- Maximum possible field H_p in the extreme dirty limit $D_1 << D_0$ and $D_2 << D_0$:

$$\mathbf{H_p^{(max)} = \frac{\pi T_c}{2\gamma\mu_B}}$$

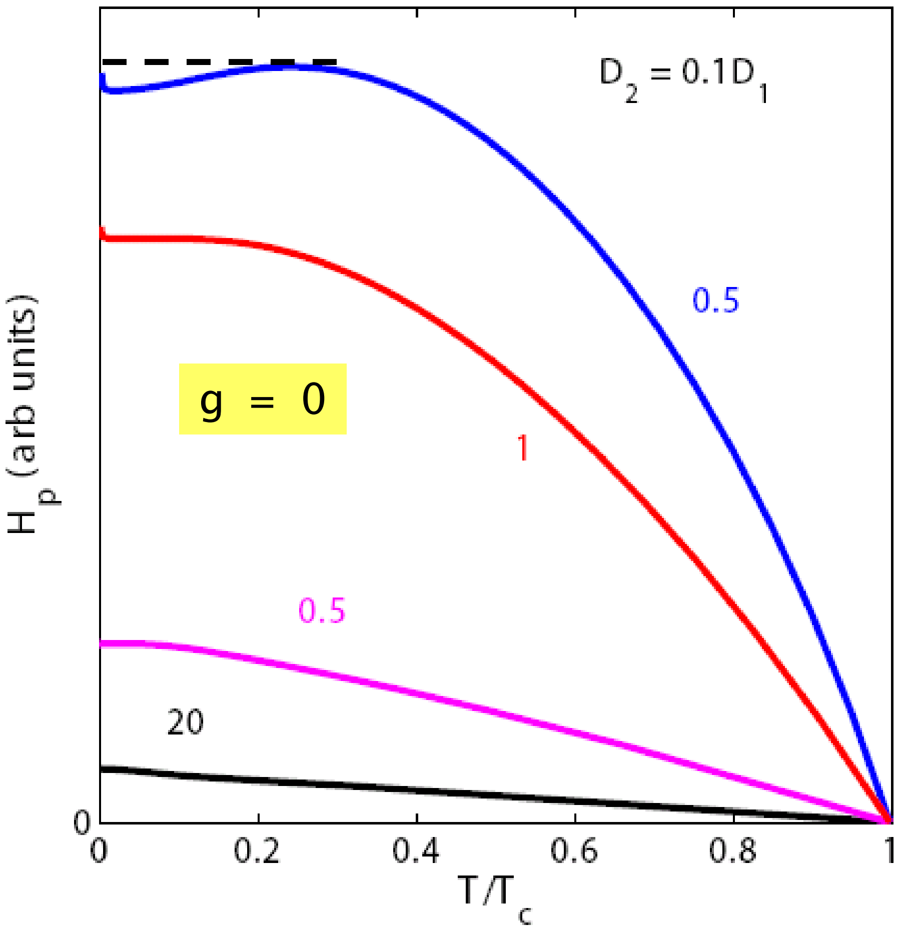
Same as in one-gap SC

- Two more limiting cases:

$$\mathbf{H_p = \frac{\pi T_c}{2\gamma\mu_B} \exp\left(-\frac{\lambda_- + \lambda_0}{2w}\right) << H_p^{(max)},} \qquad \mathbf{D_0 << D_1 \exp(-\lambda_0 / w)} \qquad \text{(dirty 2)}$$

$$\mathbf{H_p = \frac{\pi T_c}{2\gamma\mu_B} \exp\left(\frac{\lambda_- - \lambda_0}{2w}\right) \approx H_p^{(max)},} \qquad \mathbf{D_0 << D_2 \exp(-\lambda_0 / w)} \qquad \text{(dirty 1)}$$

PM first order phase transition induced by strong disorder

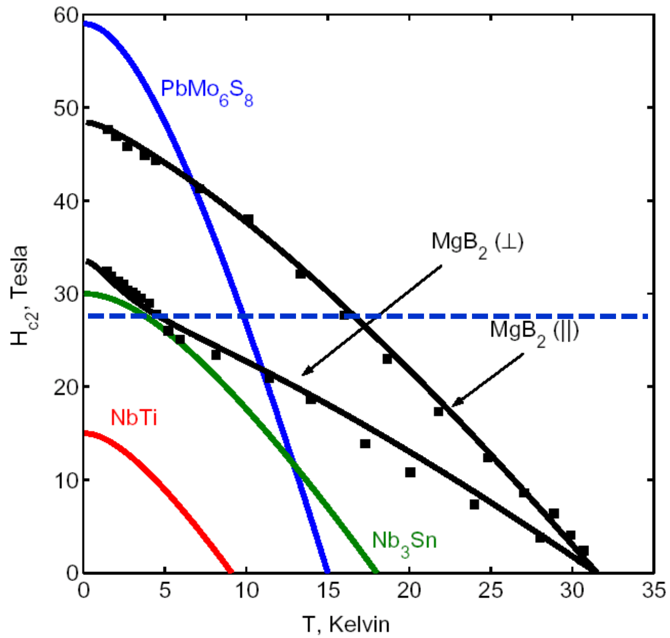


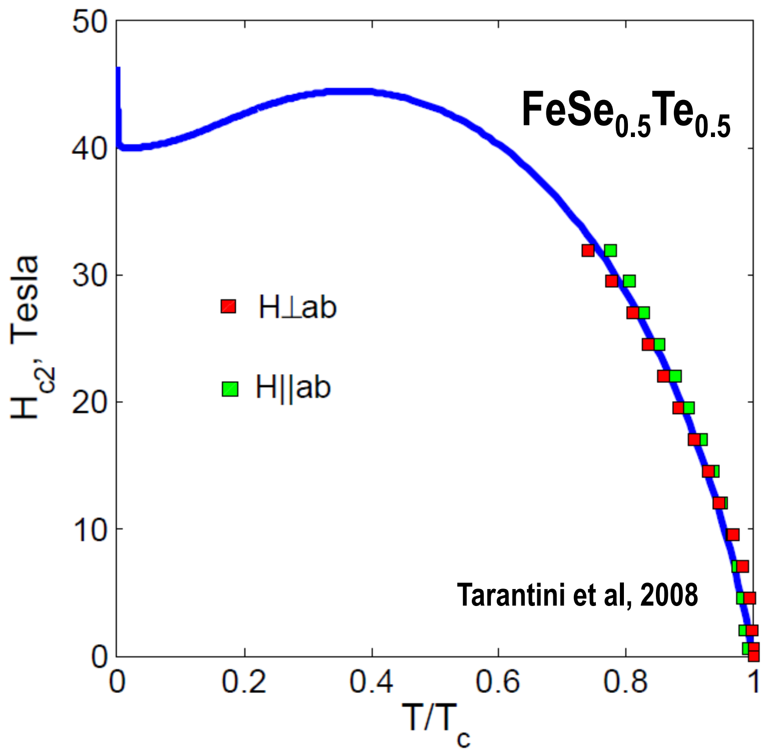
Nonmonotonic $H_p(T)$ for small values of the control parameter D_σ/D_0

First order phase transition between N and S state at low T

Similar to the paramagnetic first order transition in the one-gap BCS theory (Sarma, 1963, Maki, 1964)

Crossover from orbital to paramagnetically limited H_{c2}





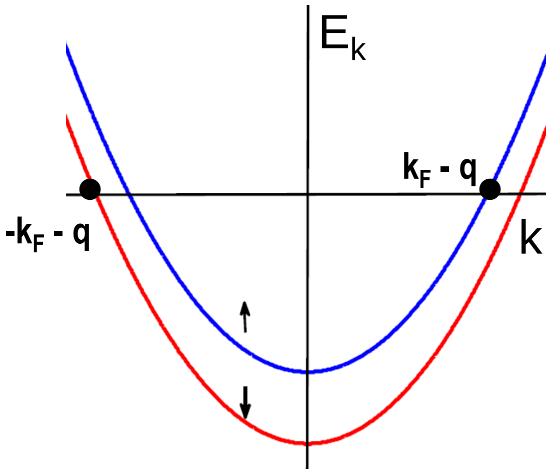
- **Pnictides are not exceptional: for $PbMo_6S_8$ $H_{c2}(0) > 2H_p^{BCS}$**
- **Enhancement of H_p by spin-orbit interaction and strong coupling effects**

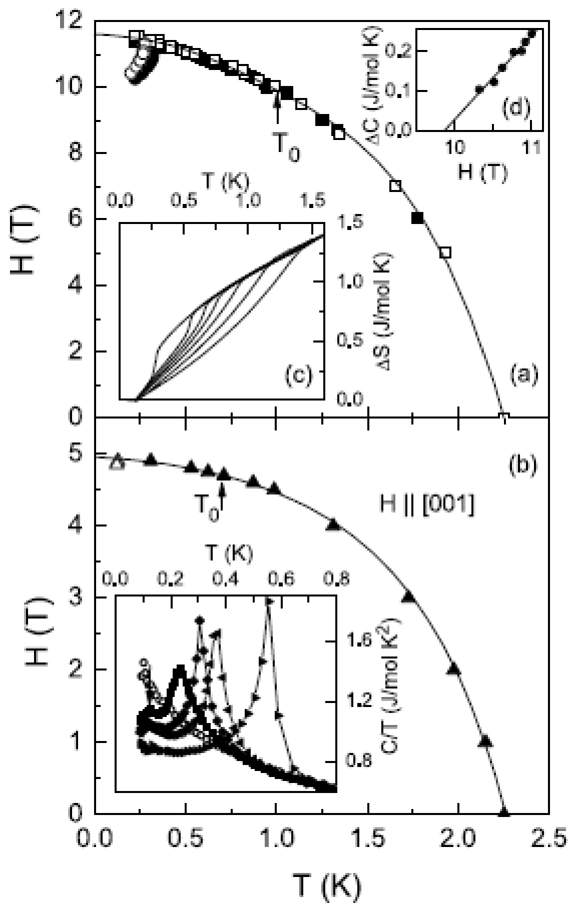
- **Quasi-isotropic $H_{c2}(T)$ might reflect the crossover from anisotropic orbital to isotropic Pauli pairbreaking**

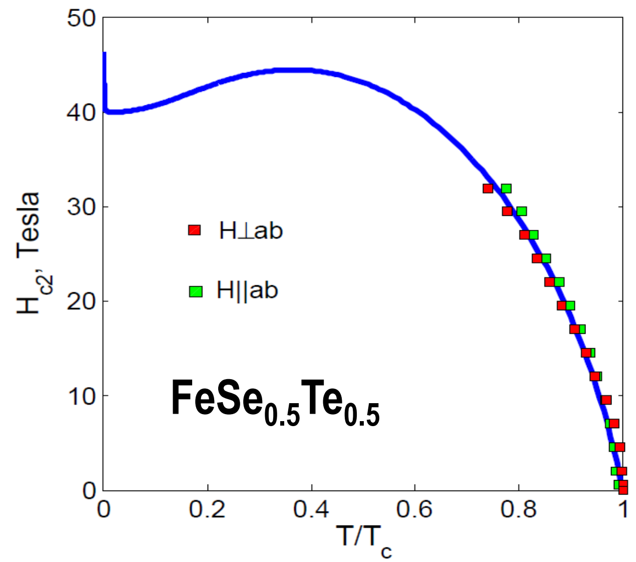
$$H_p = (1+\lambda)H_p^{BCS}$$

Werthammer, Helfand, Hohenberg, Phys. Rev. 147, 291 (1966)
Orlando, McNiff, Foner, Beasley, PRB 19, 4545 (1979)
Schlossman, Carbotte, PRB 39, 4210 (1989)

Can FFLO state occur in pnictides?





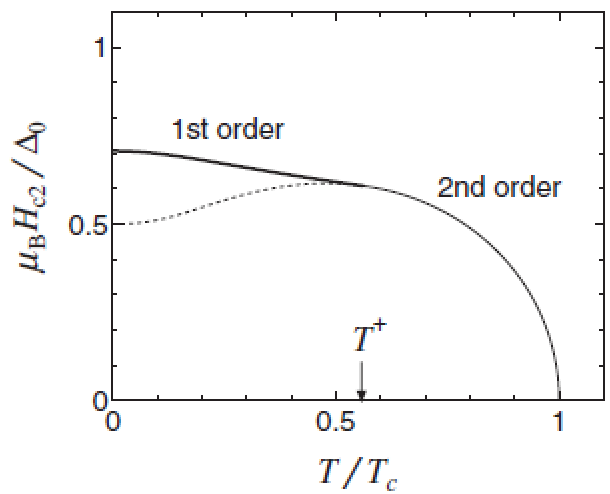


Paramagnetic depairing: in-plane modulation of the order parameter for H||ab

$\Delta(x) = \Delta_0 \cos(2qx)$

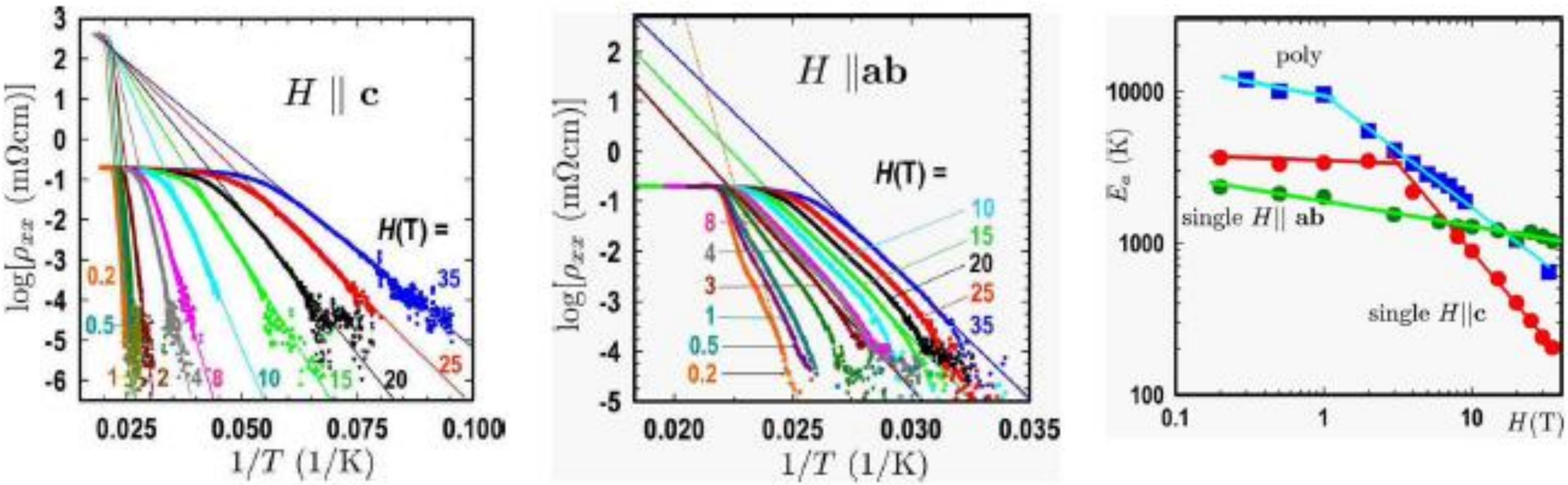
Similar to $CeCoIn_5$

Bianchi et al, PRL 91, 187004 (2003)



FFLO in pnictides requires very high fields

Nd-1111 single crystal: thermally-activated vortex dynamics



- Thermally-activated TAFF resistivity over 4-5 decades in ρ:

$$\rho = \rho_0 \exp[-E_a(T,B)/T]$$

- TAFF activation energy:

$$E_a = \frac{E_0(1-T/T_c)^{\alpha}}{[1+B/B_0(T)]^{\beta}}\left[1-\frac{B}{B_{c2}(T)}\right]^{\gamma}$$

- $E_0 \sim 10^2 - 10^3$ K, $B_0 \cong 3$T, $\alpha \approx 1$, and $\beta = 1.1$, B||c, and $\beta = 0.17$ B||ab

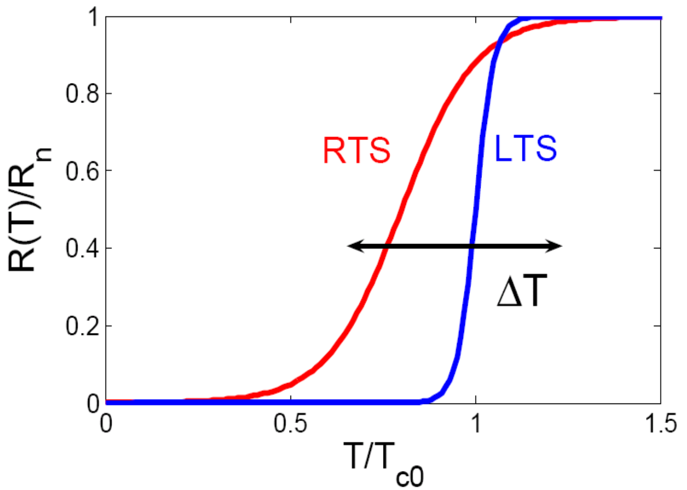
  Similar to YBCO

J. Jaroszynski et al, PRB 78, 174523 (2008)

Strong thermal fluctuations in 1111-pnictides

- **Critical fluctuation region:** $\Delta T = T_c - T < T_c Gi$

- **Ginzburg parameter:** $$Gi = \frac{\gamma^2}{2}\left(\frac{k_B T_c}{H_c^2 \xi^3}\right)^2 \propto \left(\frac{T_c^2 m\gamma}{v_F n}\right)^2$$



- **Anisotropy parameter and the London penetration depth in a uniaxial superconductor:**

$$\gamma = \left(\frac{m_c}{m_{ab}}\right)^{1/2} = \frac{\lambda_c}{\lambda} = \frac{\xi}{\xi_c}$$

$$\lambda = \left(\frac{mc^2}{4\pi e^2 n_s}\right)^{1/2}$$

$$\Delta T_c \propto T_c^5 \gamma^2 / n^3$$

- LTS: $Gi \sim 10^{-8}$, $\Delta T \sim 10^{-7}$ K
- YBCO: $Gi \sim 0.1\text{-}10^{-2}$, $\Delta T \sim 1\text{-}10$ K
- 122 pnictides: $Gi \sim 10^{-4}$ -10^{-3}
- 1111 pnictides: $Gi \sim 10^{-2}$
- T_c reduction by phase fluctuations
- Melting of the vortex lattice. Reduced irreversibility field, $H^*(T) < H_{c2}(T)$. Numerous vortex glasses

Melting of the vortex lattice

- **Lindemann criterion:** (Nelson et al; Hougtion, Pelcovits, Sudbo; Blatter et al, Brandt et al)

$$\langle u^2 \rangle = c_L^2 \phi_0 / B, \qquad c_L \approx 0.15\text{-}0.17$$

- Upper branch of the melting field $B_{c1} << B_m << B_{c2}$:

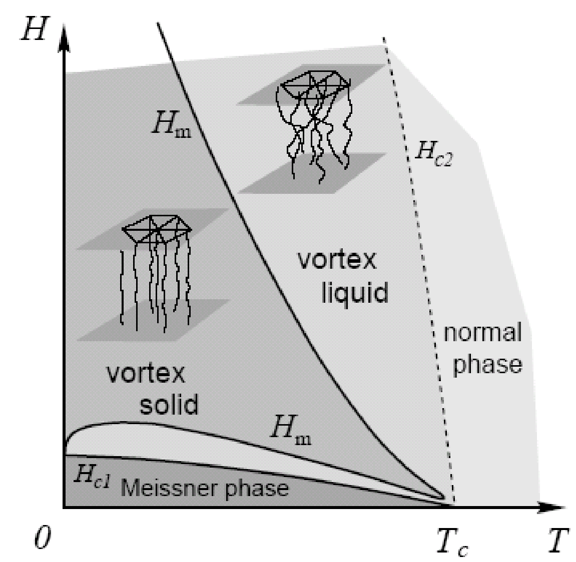
$$\frac{B_m}{B_{c2}(0)} \approx \alpha \left(1 - \frac{T_c}{T}\right)^2, \qquad \alpha = \frac{\pi^2 c_L^4}{Gi}$$

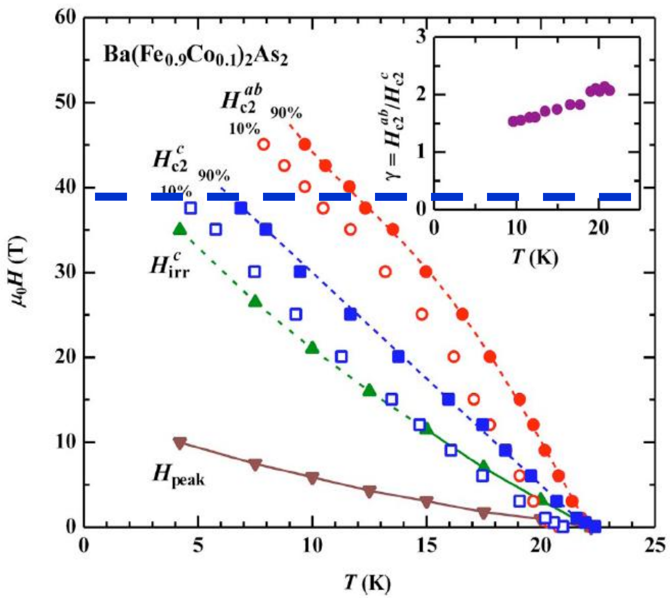
- For Nd-1111, $\gamma = 7$, Gi = 0.01, $c_L = 0.15$, $\kappa = \lambda/\xi \sim 10^2$ we get $\alpha \approx 0.5$

- Low carrier density and strong anisotropy in Nd-1111 reduce the melting field well below H_{c2}

$$B_m \propto \frac{1}{\gamma^2 \lambda_L^4 T_c^2}$$

- Effect of thermal fluctuations is much weaker in 122

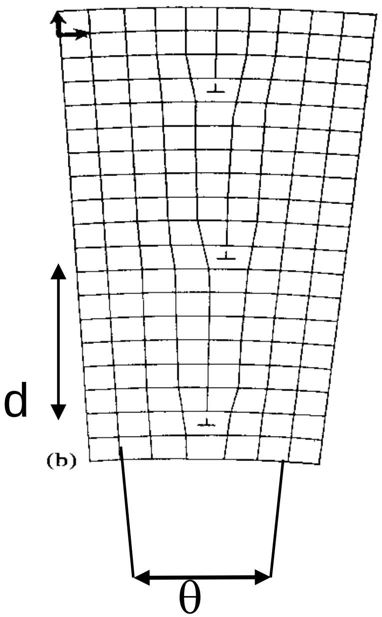




Yamamoto et al, APL 94, 062511 (2009)

Types of grain boundaries

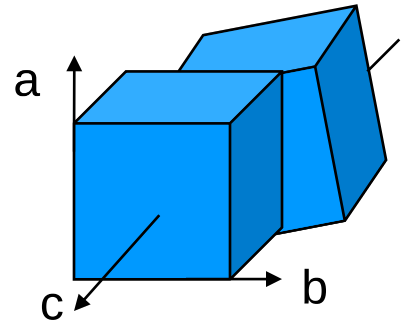
[001] tilt GB (parallel c-axis)

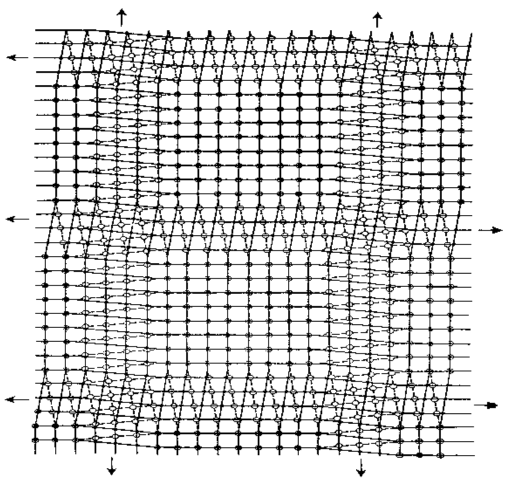


Chain of edge dislocations spaced by

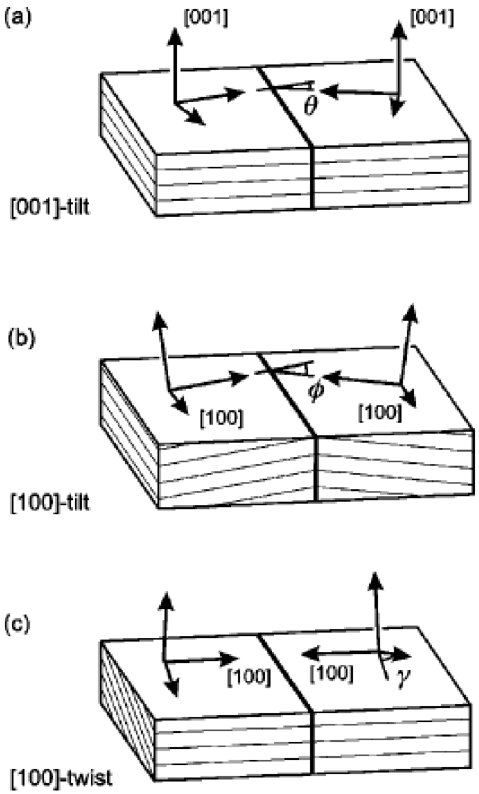
$d = b/2\sin(\theta/2)$

Twist GB



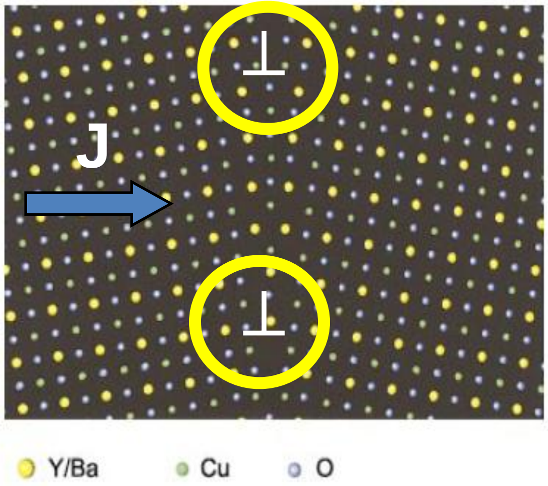


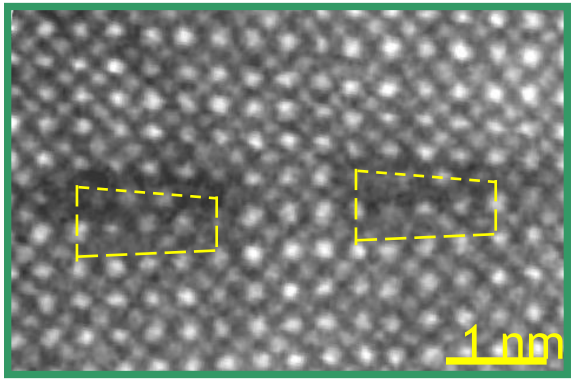
Cellular structure of twist dislocations in the ab plane



The grain boundary problem in cuprates

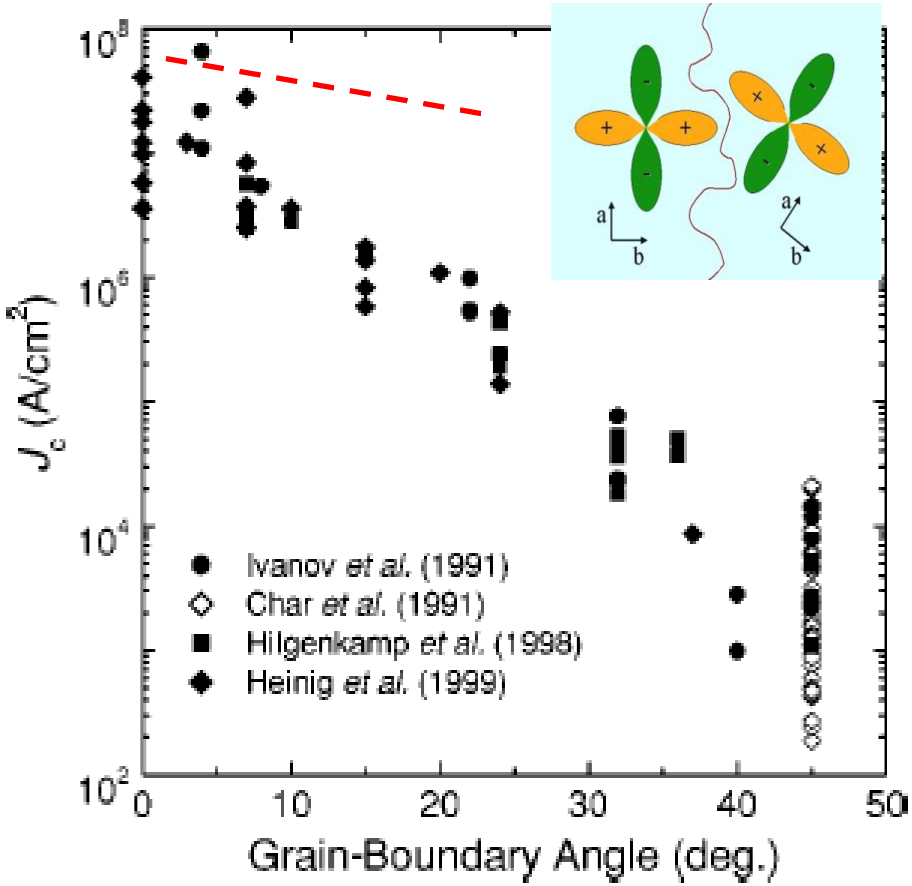
16^{O} [001] tilt grain boundary in YBCO



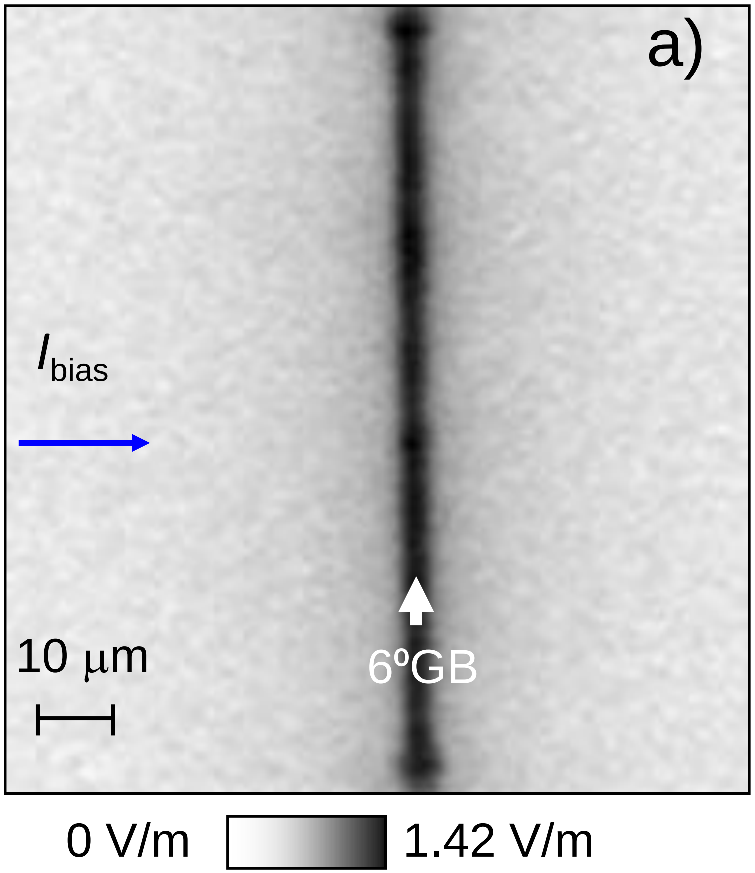


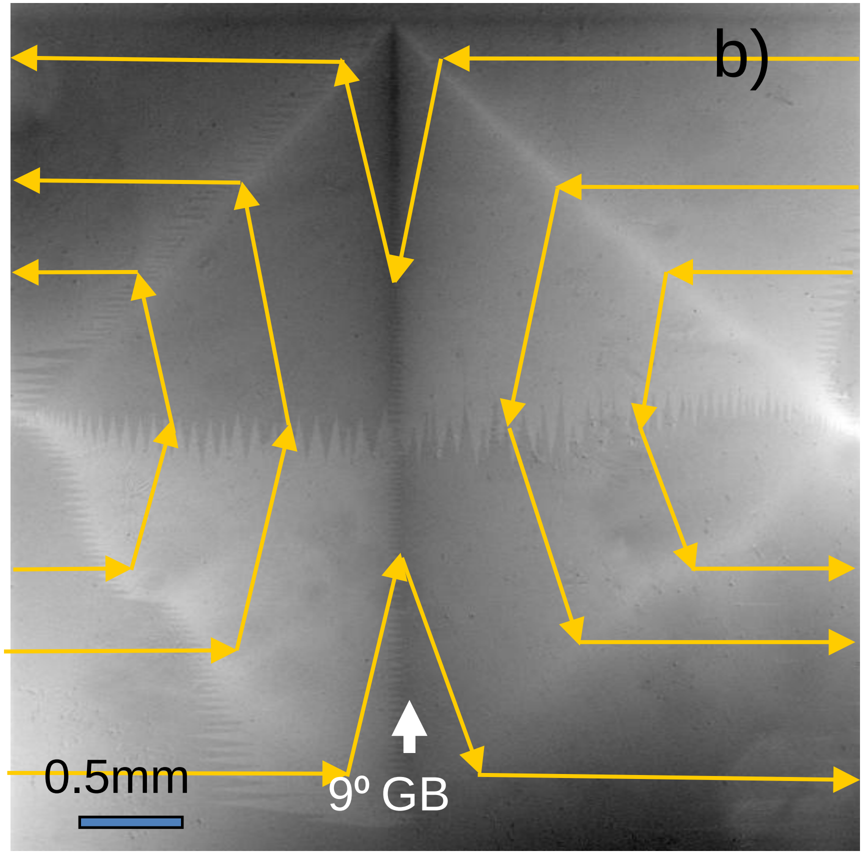
X. Song et al. Nature Mat. 4, 470 (2005)

$J_c(\theta) = J_0\cos^2 2\theta$ - pure d-wave scenario is too weak to explain the observed exponential decrease of $J_c(\theta)$



Current blocking revealed by scanning laser micrscopy and magneto-optical imaging in $Ba(Fe_{1-x}Co_x)_2As$ bicrystals (x=0.16)

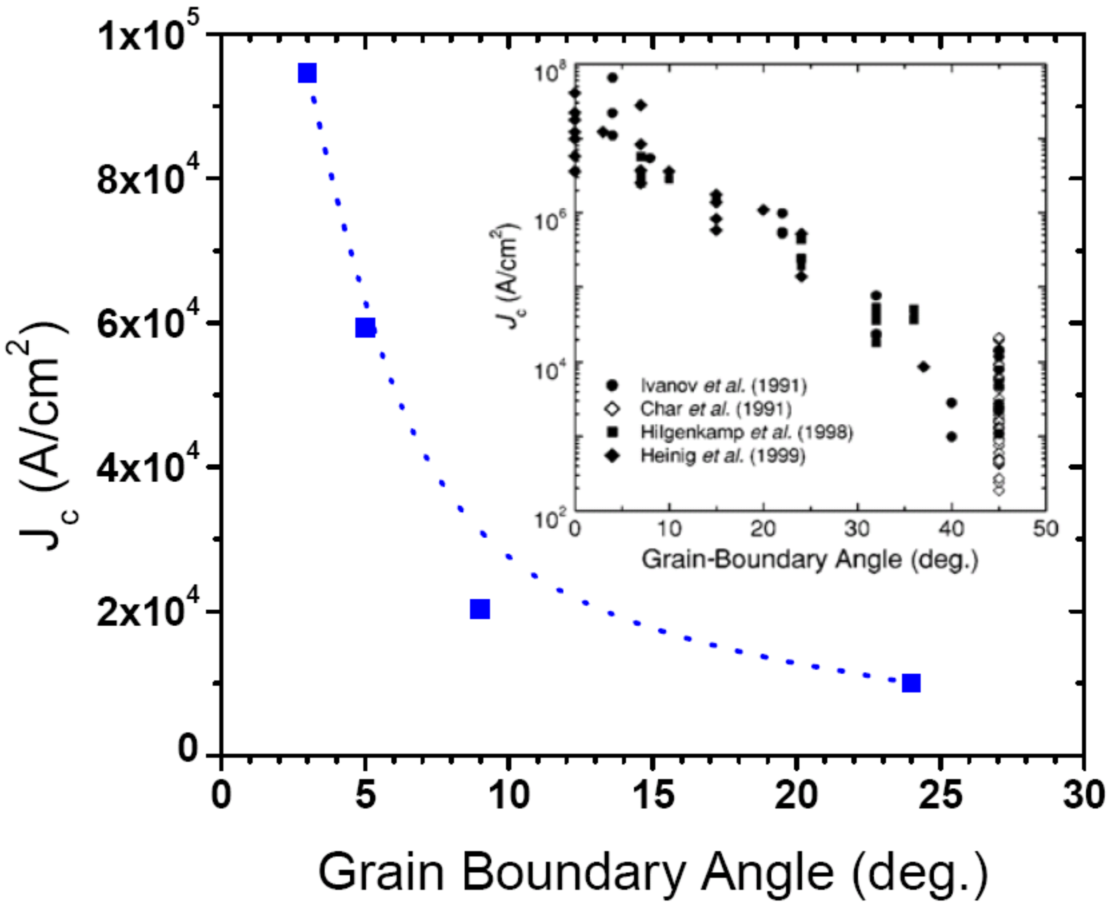




D. Abraimov, 2009

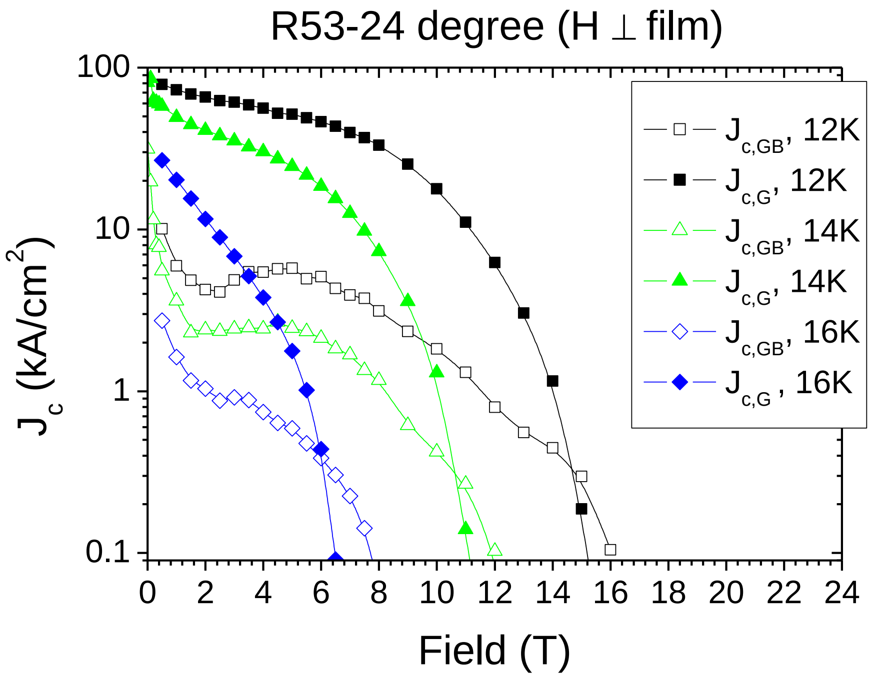
A. Polyanskii, 2009

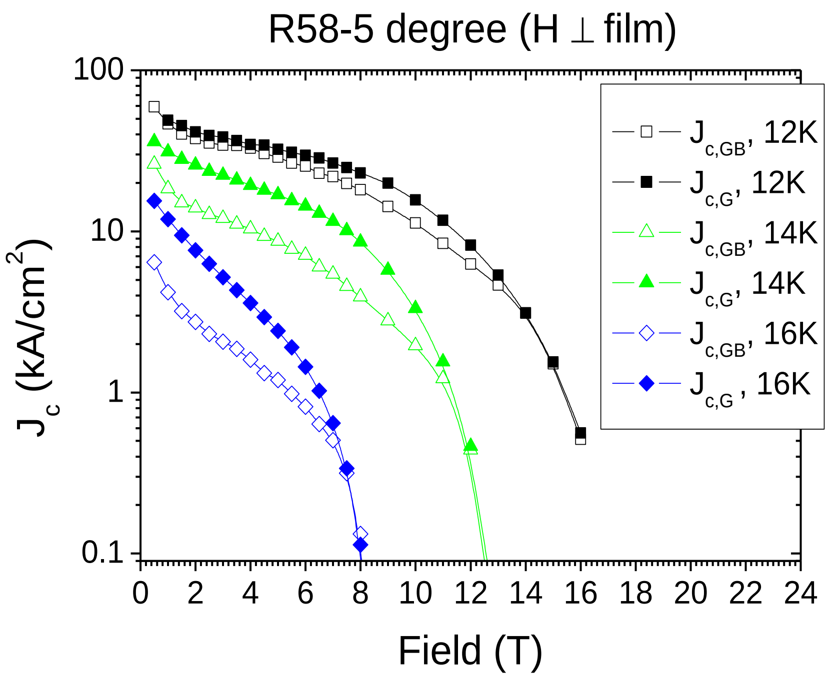
Rapid drop of J_c with the misorientation angle measured by transport (S. Lee et al, arXiv: 0907.3741)



Similar ratio of J_c (24°)/J_d ~ 2×10^{-4} indicates similar suppression of the OP on grain boundaries in YBCO and 122 pnictides

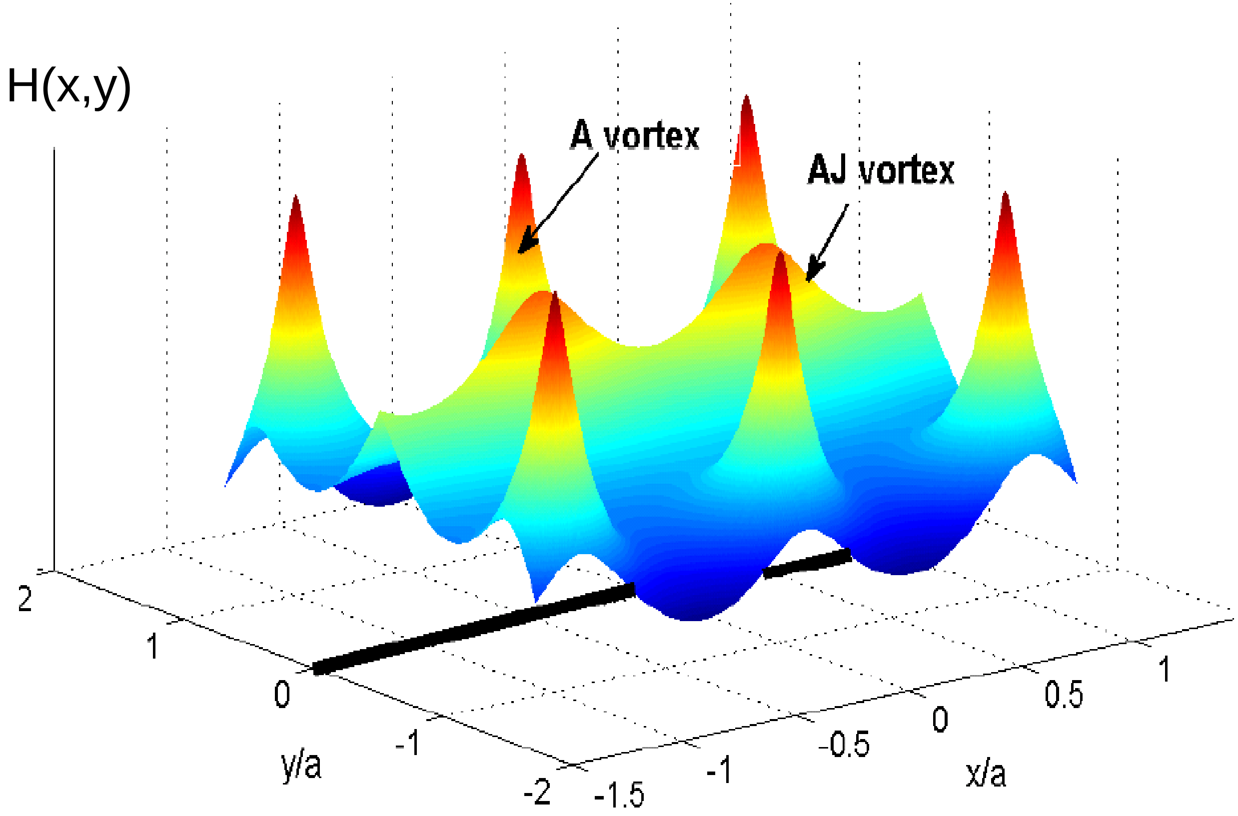
Critical currents of GBs in magnetic field





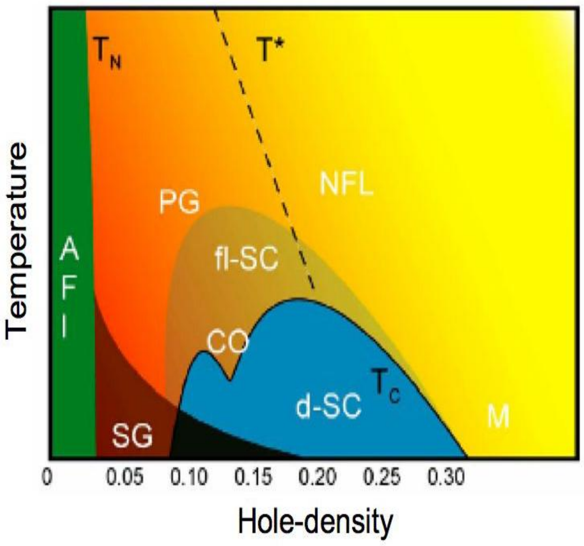
Very similar to the behavior observed on YBCO grain boundaries

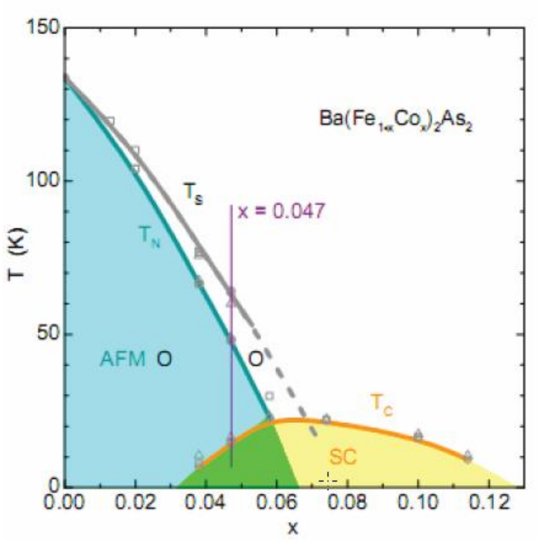
Vortices on grain boundaries

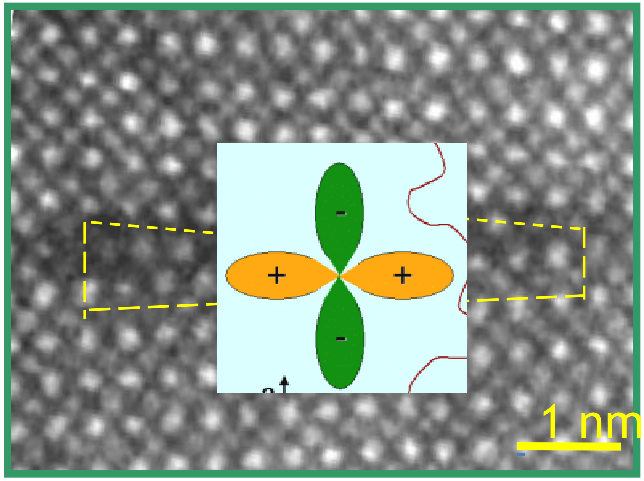


Pinning of vortices on GB by vortices in the grains

Similarities of cuprates and pnictides



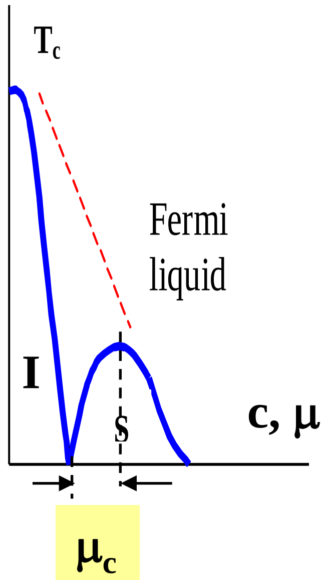


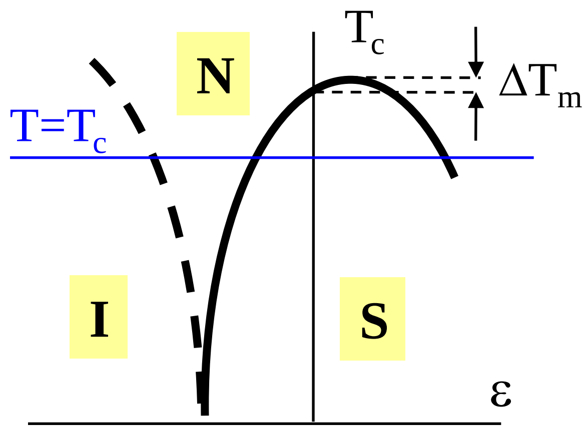


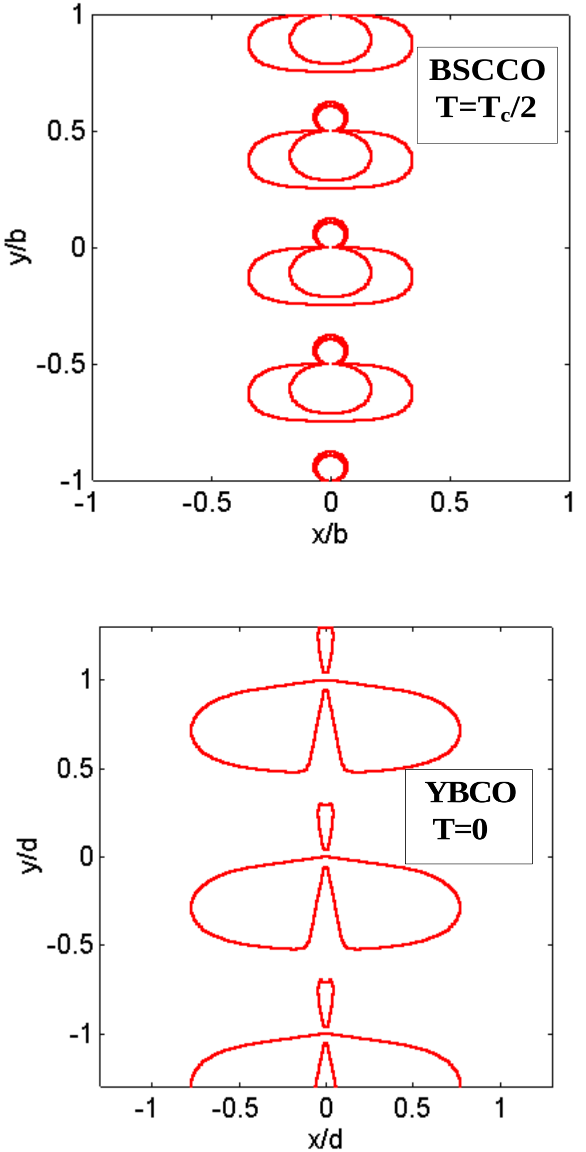
- short coherence length, $\xi \approx$ 1-2 nm
- charging and strains effects of dislocation cores
- competing orders: nonsuperconducting AF phase precipitates on GB
- low carrier density $\Rightarrow$ long Thomas Fermi screening length $l_{TF} \approx$ 1-2 nm

Strain effects at grain boundaries

AG and E. Pashitskii, PRB, 56, 6213 (1987).



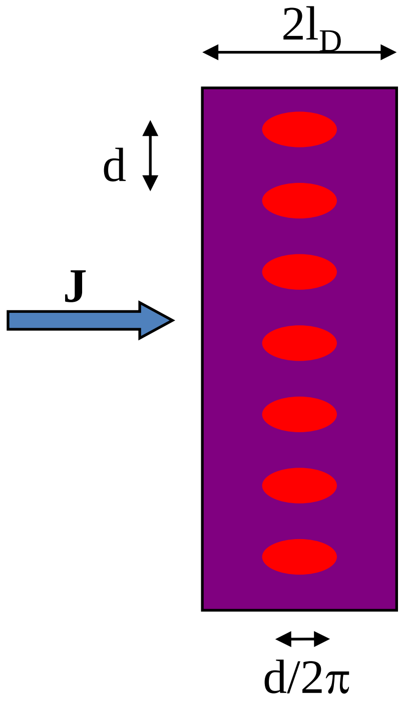




$$T_c = T_{c0} - C_a\varepsilon_a - C_b\varepsilon_b - R_{iklm}\varepsilon_{ik}\varepsilon_{lm}$$

- Strain-induced dielectric and normal regions near dislocation cores.
- Anisotropic $T_c(\varepsilon)$ for YBCO ($C_a \approx - C_b \sim 300K$). Isotropic $T_c(\varepsilon)$ for BSCCO ($C_a \approx C_b \sim 300K$)

Current Channels and Charging Effects



- Charged coupling of dielectric/metallic core regions of size ~ b

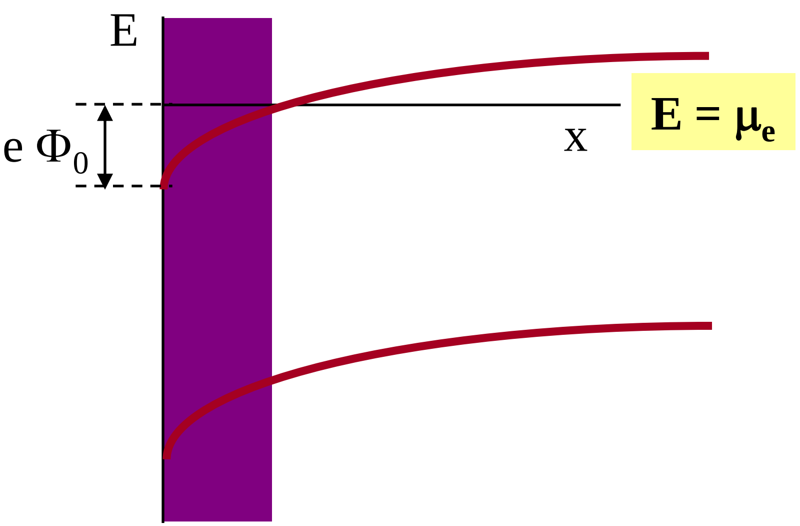
- Superconductivity suppression in the space charge layer of thickness $2l_D \sim \xi_0$

AG and E. Pashitskii, PRB 57, 13875 (1998);

H. Hilgenkamp and J. Mannhart, APL 73, 265 (1998); RMP 74, 485 (2002)

- "Transistor" model of GB: $\mu + e\Phi = const$

$$\Phi_0 \cong -\frac{ZN_0\zeta b(1-2\sigma)^2 l_D \ln(d/r_i)}{4(1-\sigma)^2\kappa_\infty}\sin\frac{\theta}{2}$$



- Zone bending near GB: shift toward the nonsuperconducting AF state.

Peculiarities and open questions of superconductivity in oxypnictides

- Mechanism of superconductivity – the nature of the pairing glue
- Why strong magnetism does not kill s-wave superconductivity and why nonmagnetic impurities do not suppress T_c?
- How far can $H_{c2}(T)$ go and what is the behavior of $H_{c2}(T)$ at low temperatures? Any new states due to paramagnetic effects (FFLO state?).
- Vortex physics in pnictides. Pinning, critical currents and irreversibility fields. Effect of magnetism on vortex behavior.
- Proximity of SC state to AF semimetal, short coherence length, long screening length: weak linked grain boundaries block current