Change of pairing symmetry in KFe_2As_2

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International Workshop on *Recent Developments in Fe-based High-Temperature Superconductors*

Riverhead, New York – 4 September 2013

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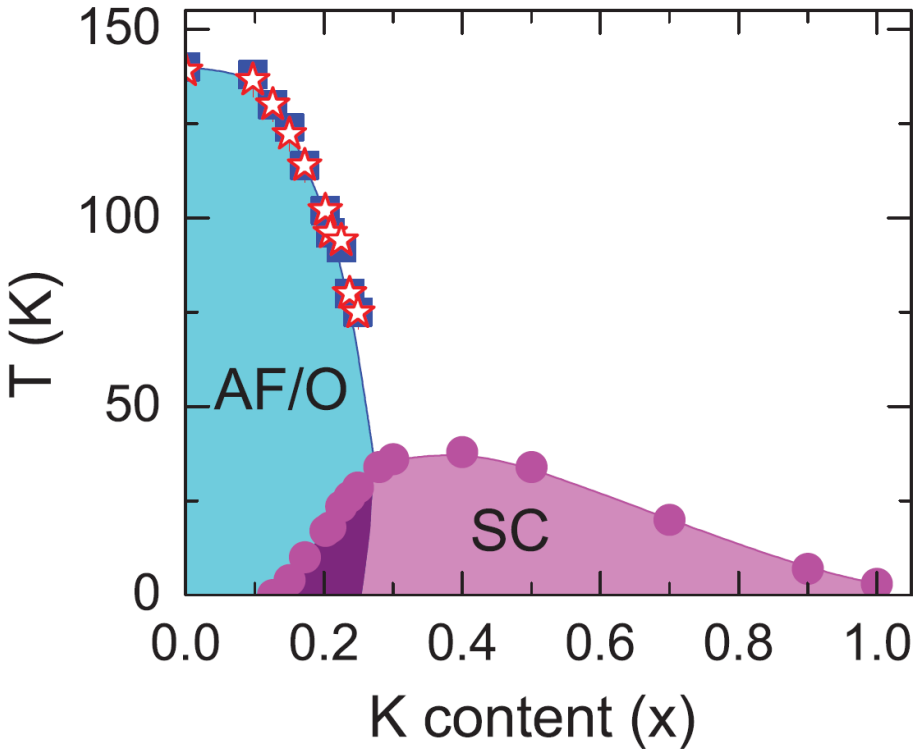
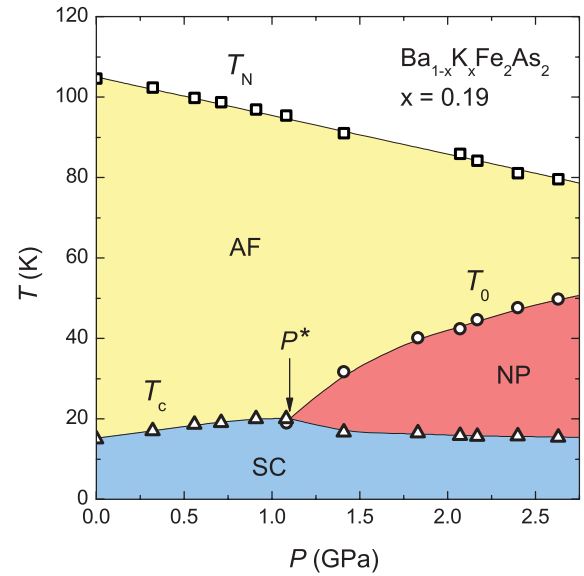
Tafti *et al*., Nature Physics **9**, 349 (2013)

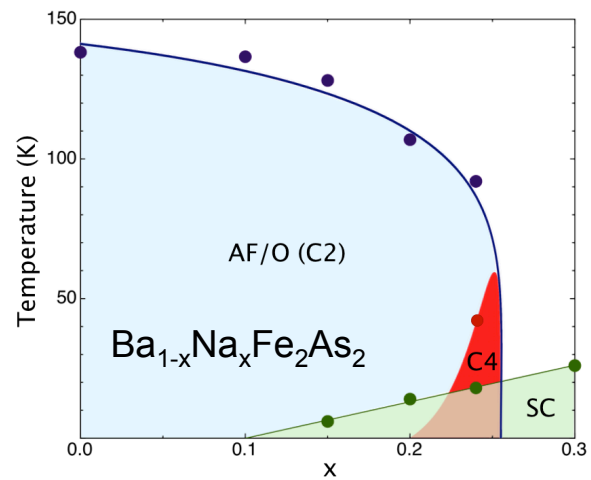
$Ba_{1-x}K_xFe_2As_2$



Avci *et al.*, PRB **85**, 184507 (2012)

Hassinger *et al.*, PRB **86**, 140502 (2012)

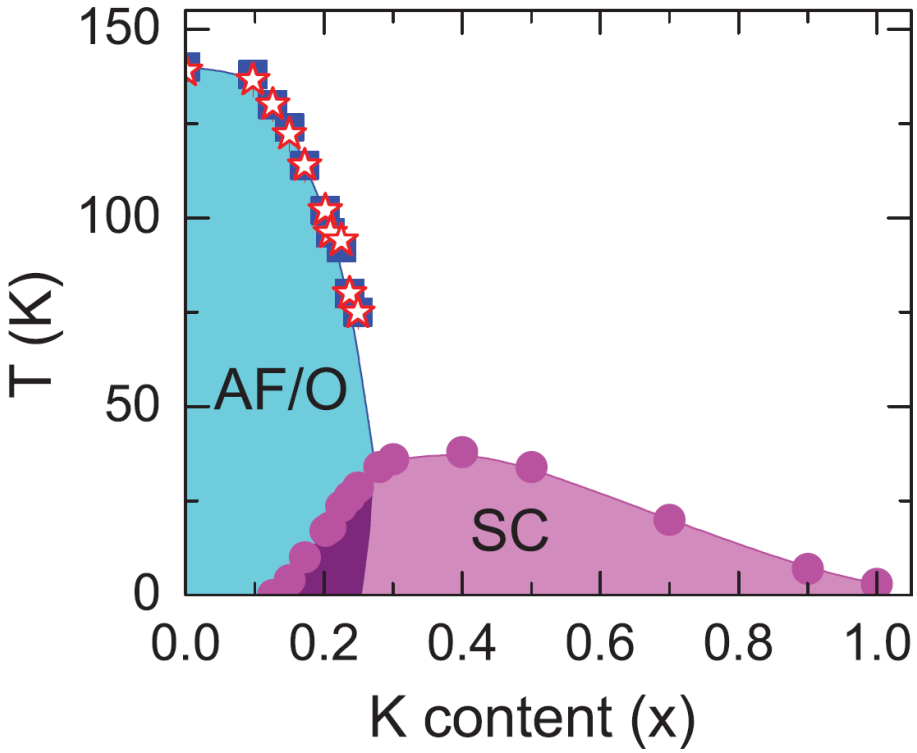


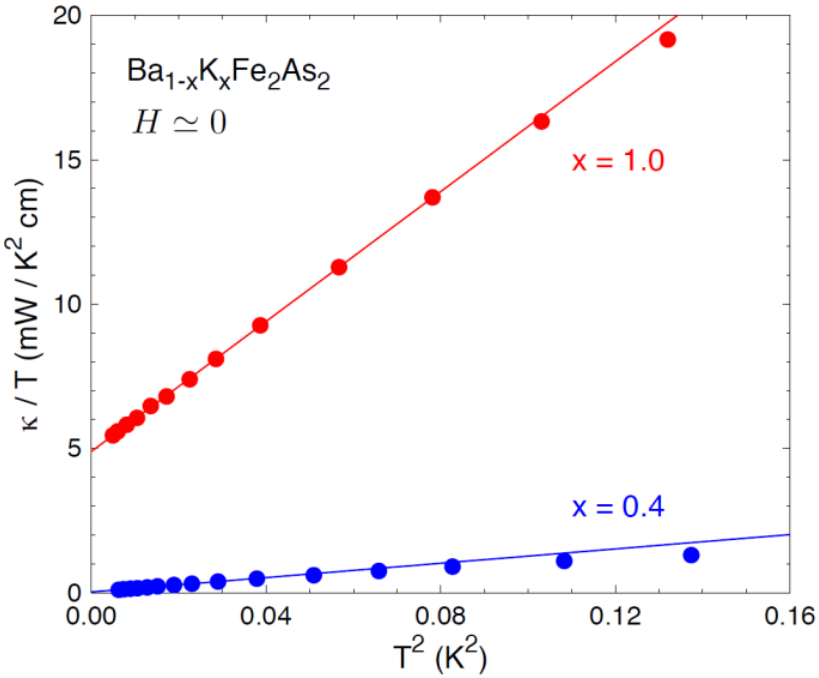


Avci *et al.*, arXiv:1303.2647

$Ba_{1-x}K_xFe_2As_2$

Change of gap structure



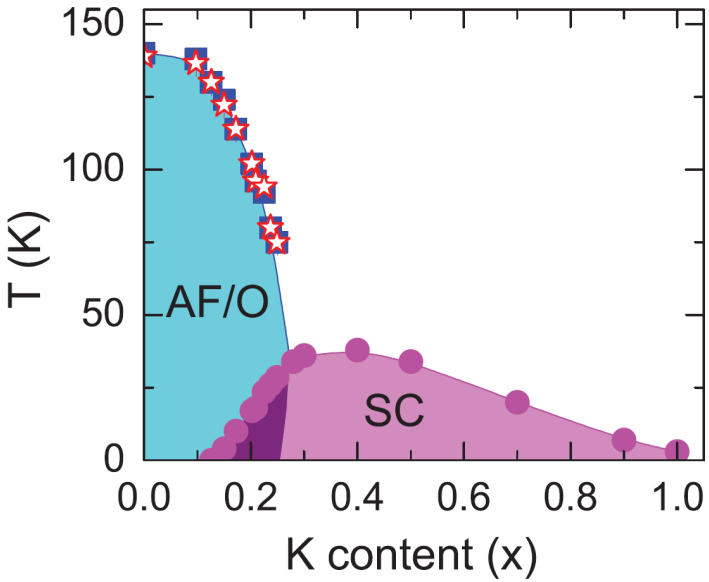


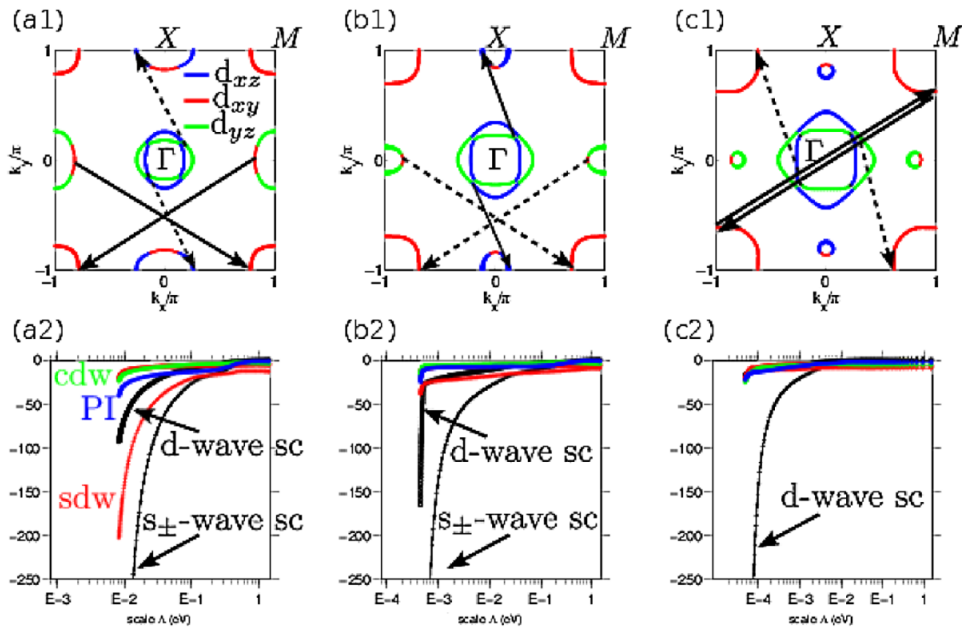
Reid *et al.*, SUST **25**, 084013 (2012)

Avci *et al.*, PRB **85**, 184507 (2012)

$Ba_{1-x}K_xFe_2As_2$

fRG calculations

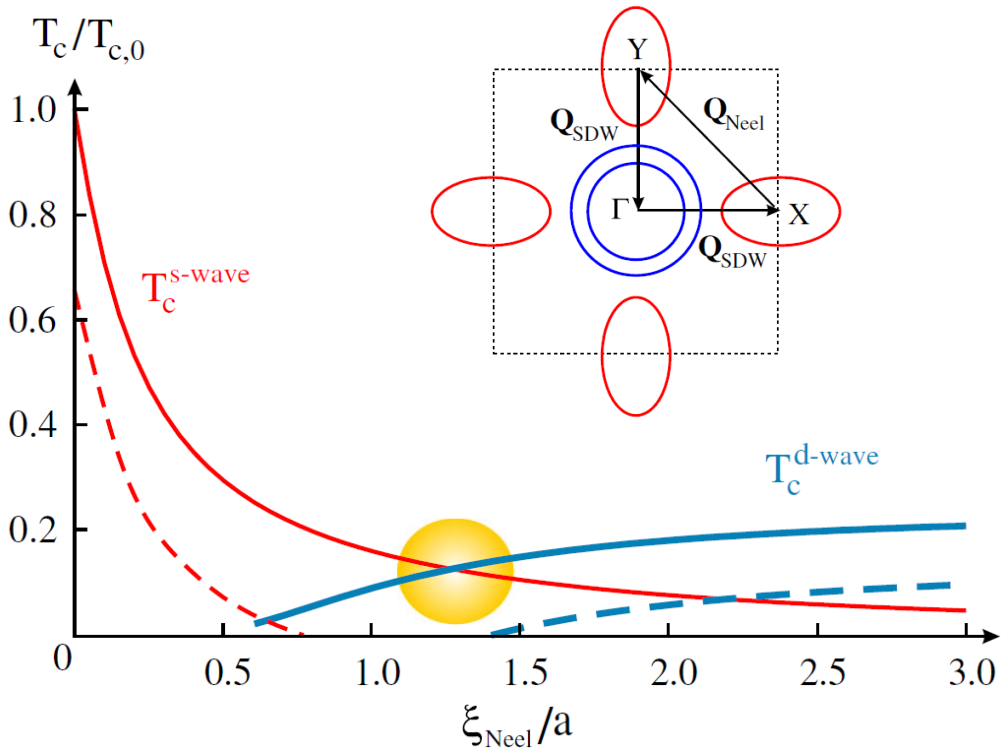




Thomale *et al.*, PRL **107**, 117001 (2012)

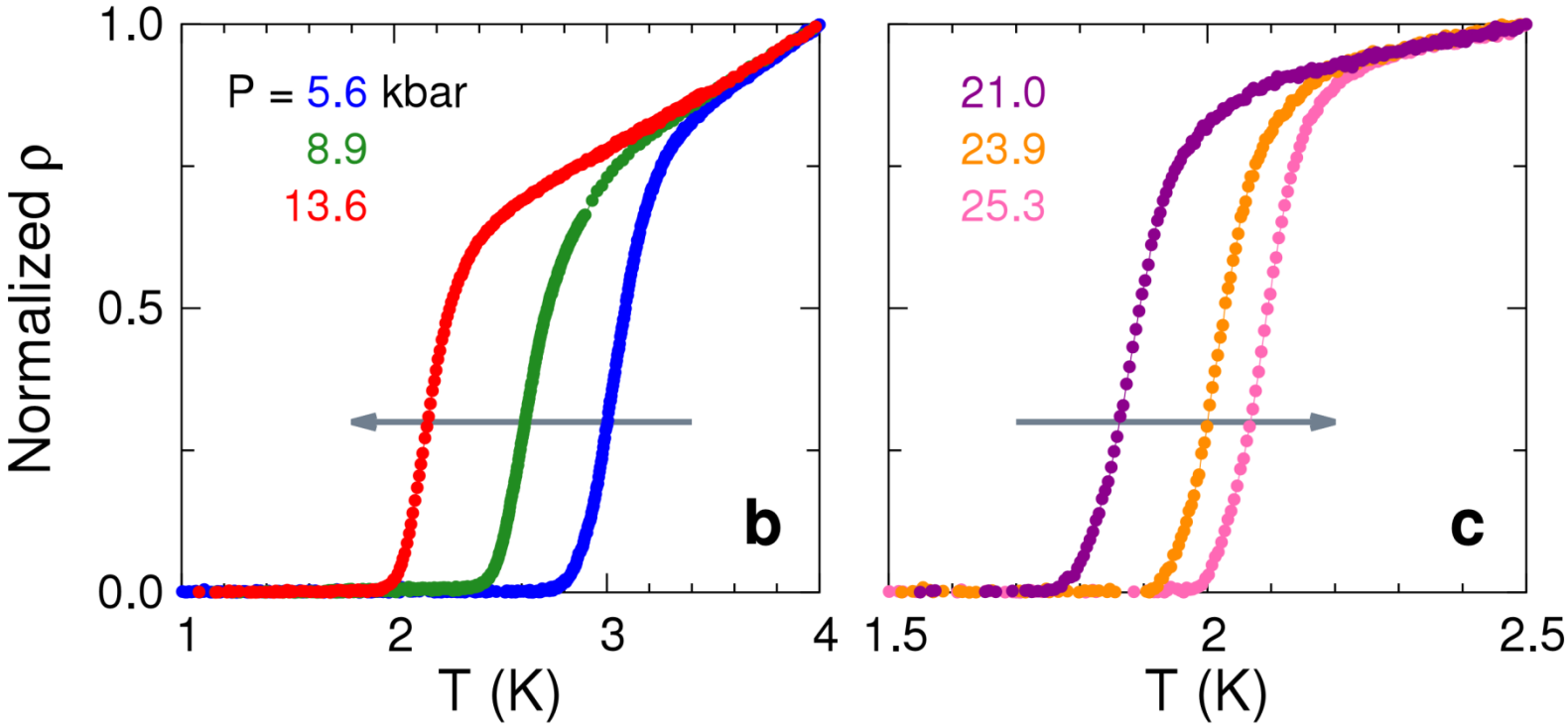
Near degeneracy of *s* and *d* pairing states

- *d*-wave and *s*-wave states are nearly degenerate Graser *et al*., NJP **11**, 025016 (2009)
- Change of pairing symmetry induced by tuning strength of different scattering processes



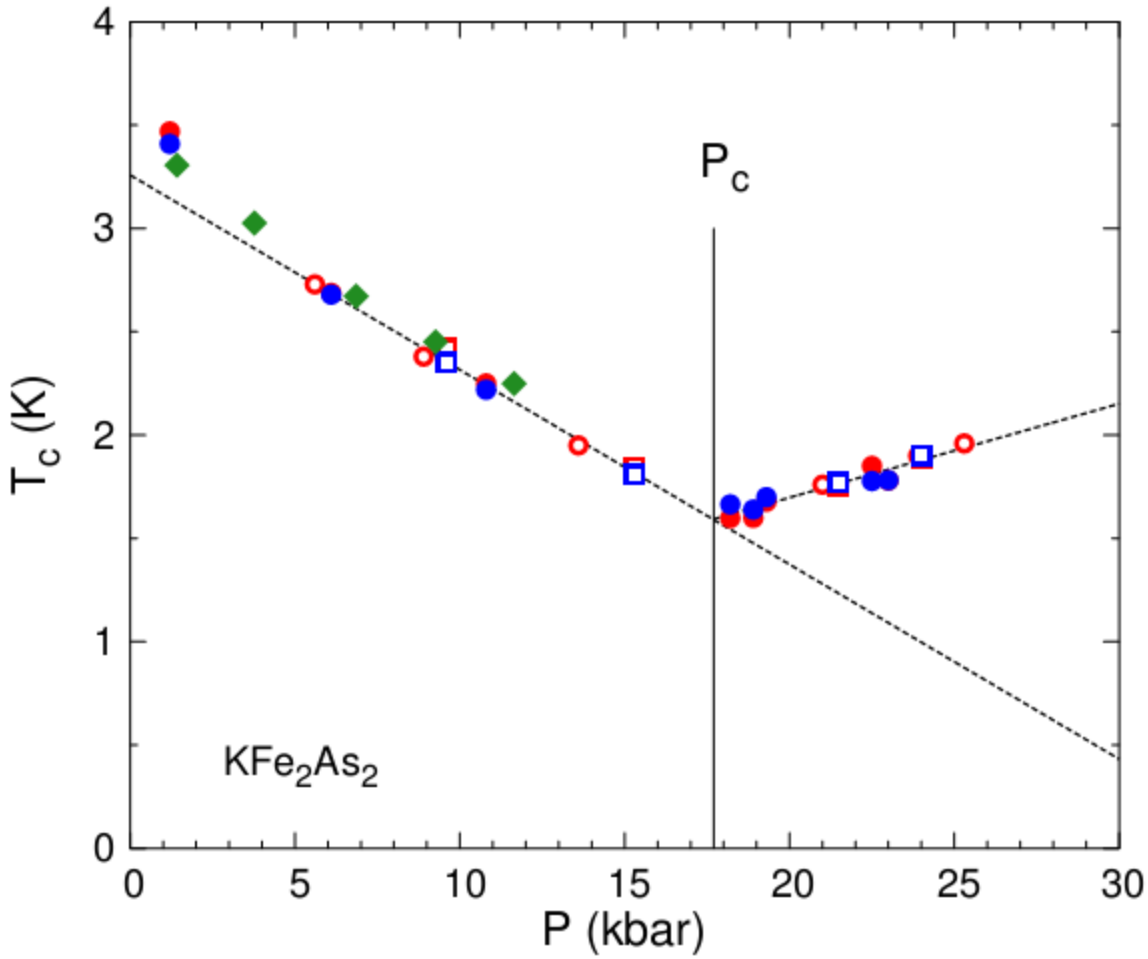
Fernandes & Millis, PRL **110**, 117004 (2013)

KFe_2As_2 Pressure dependence of T_c



Tafti *et al.*, Nature Physics **9**, 349 (2013)

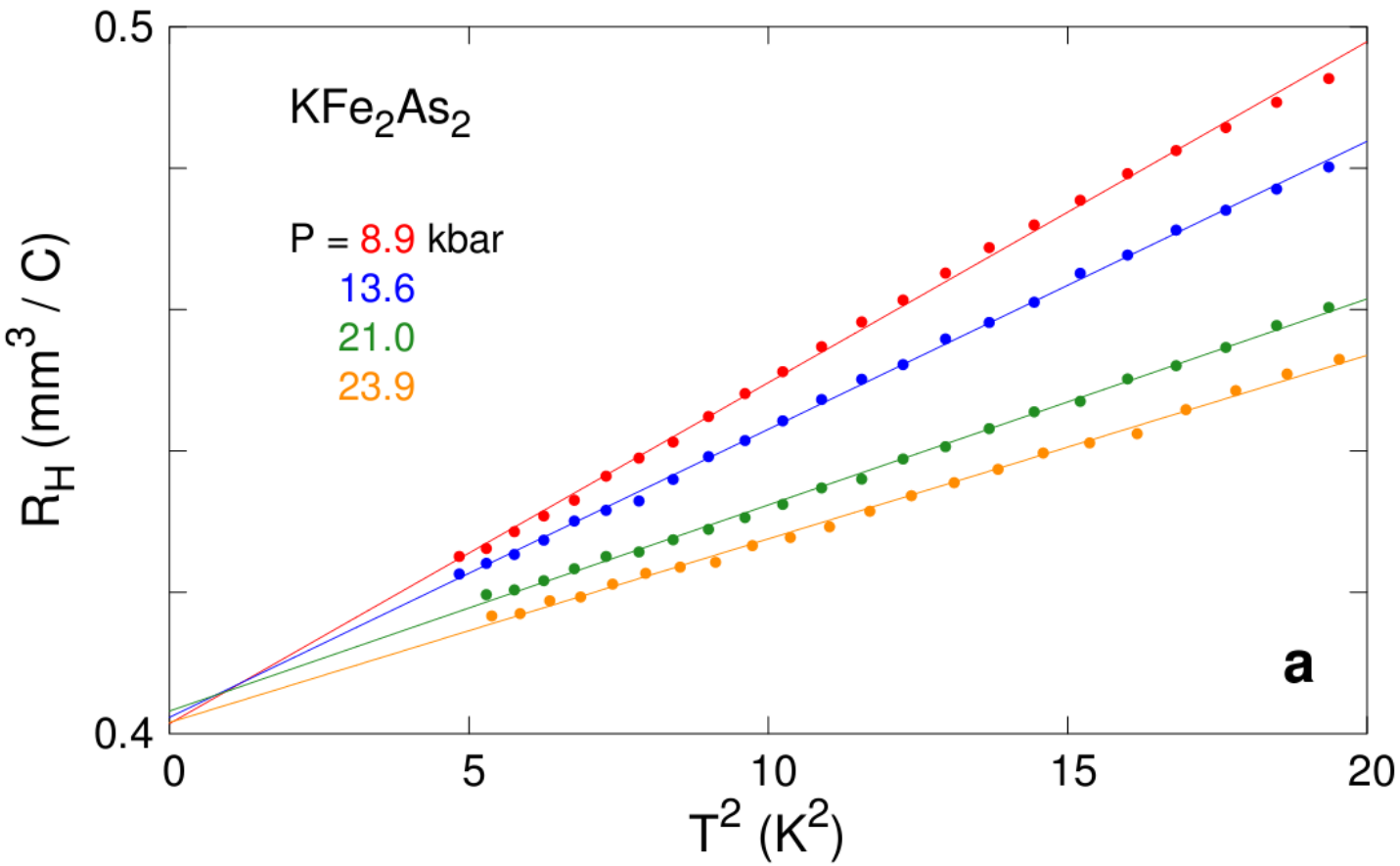
KFe_2As_2 Pressure dependence of T_c



Tafti *et al*., Nature Physics **9**, 349 (2013)

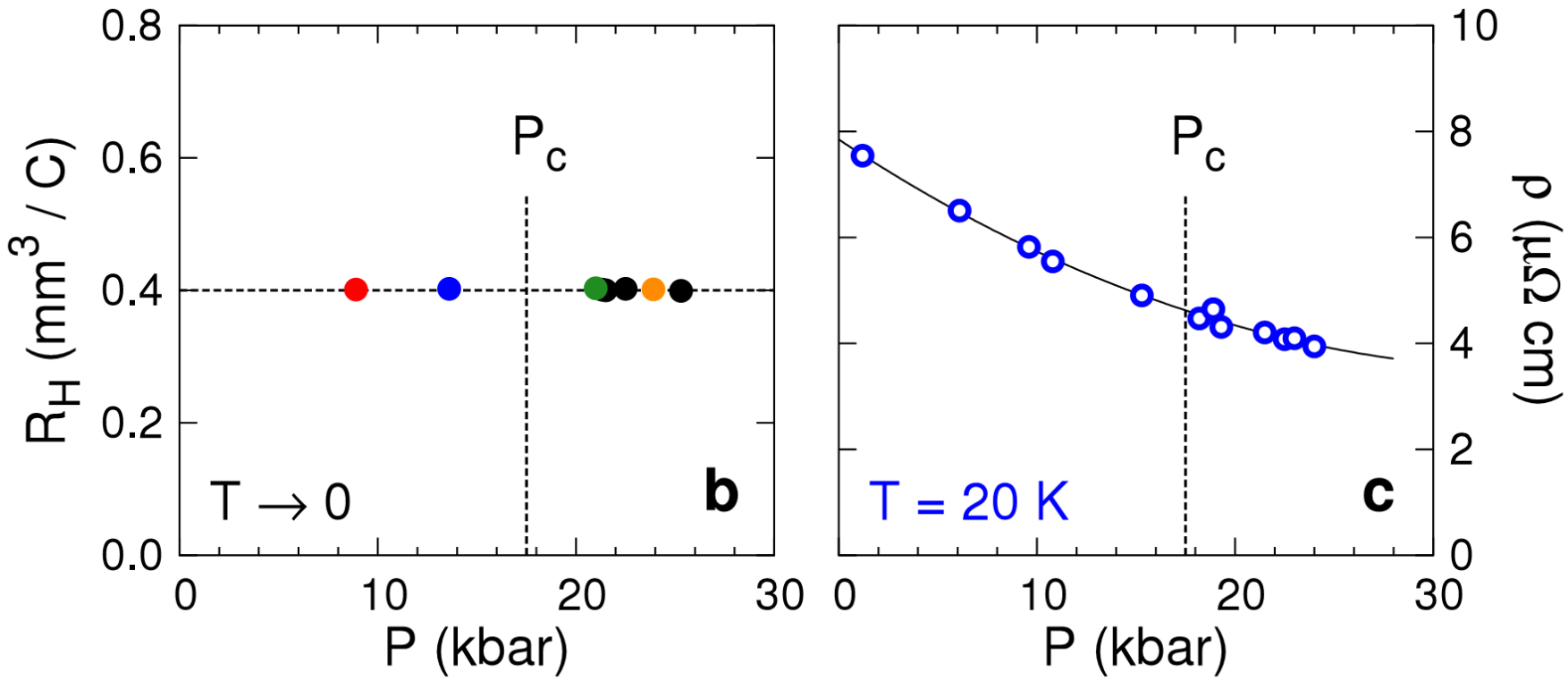
Bud'ko *et al*., PRB **86**, 224514 (2012)

KFe_2As_2 Hall effect under pressure



Tafti *et al*., Nature Physics **9**, 349 (2013)

KFe_2As_2 Normal state properties under pressure

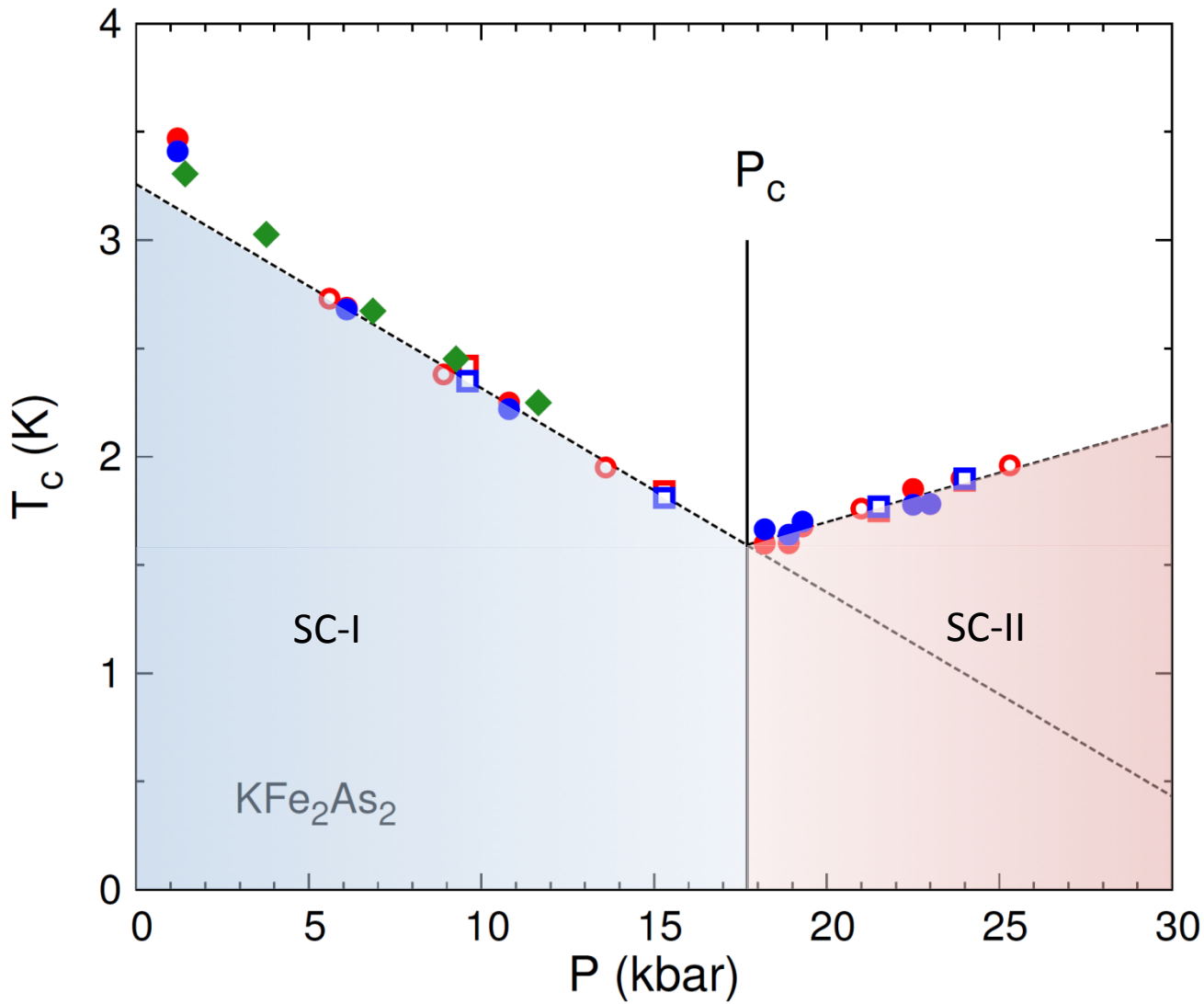


No change in normal state

Tafti *et al*., Nature Physics **9**, 349 (2013)

KFe_2As_2

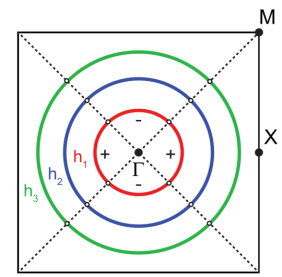
Transition between two pairing states



Tafti *et al*., Nature Physics **9**, 349 (2013)

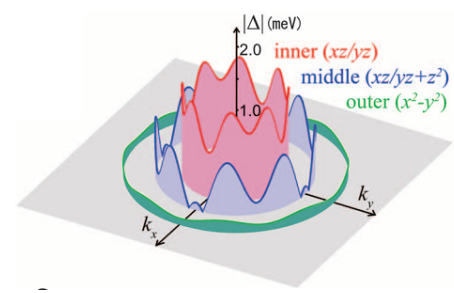
Phase I : What is the pairing symmetry ?

Two scenarios :

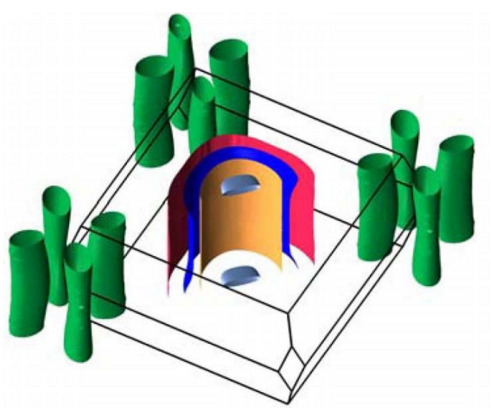


1) *d*-wave : symmetry-imposed line nodes on *all* FS

2) $s_{\pm}$: accidental line nodes on *one* FS



Okazaki *et al*., Science **337**, 1314 (2012)



Hashimoto *et al*., PRB **82**, 014526 (2010)

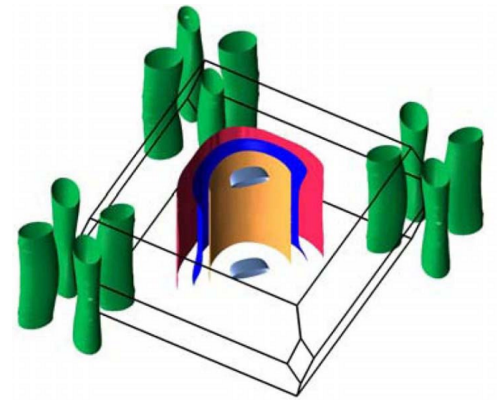
Phase I : What is the pairing symmetry ?

<u>Heat transport</u> : three tests

1) Impurity scattering

2) Anisotropy (*a* – *c*)

3) Magnetic field



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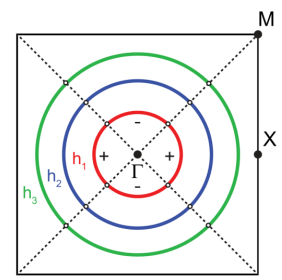
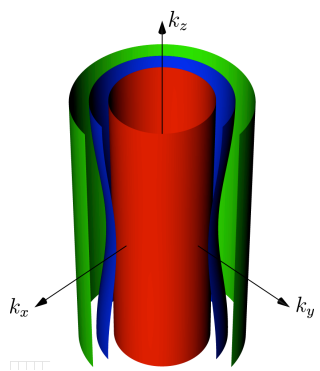
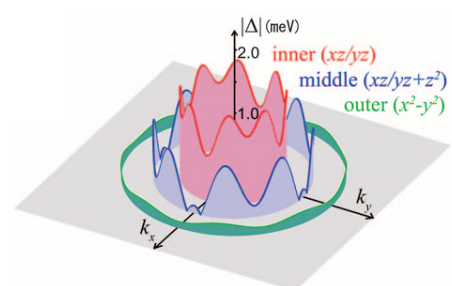


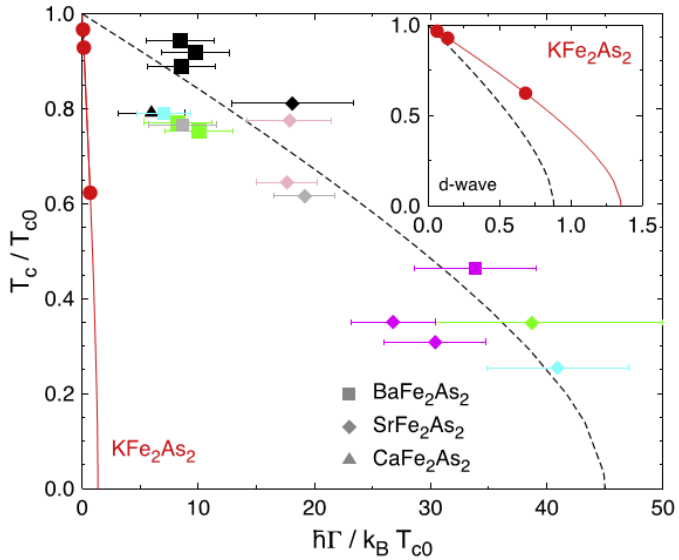


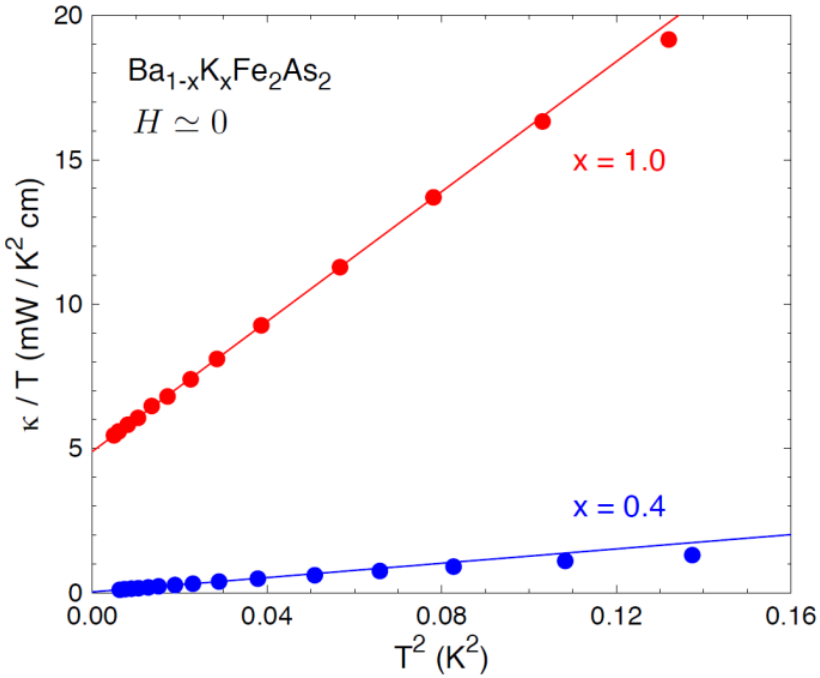


Terashima *et al*., PRB **87**, 224512 (2013)

d-wave : symmetry-imposed line nodes on *all* FS

1) Impurity scattering





Reid *et al.*, SUST **25**, 084013 (2012)

Reid *et al.*, PRL **109**, 087001 (2012)

Kirshenbaum *et al.*, PRB **86**, 140505 (2012)

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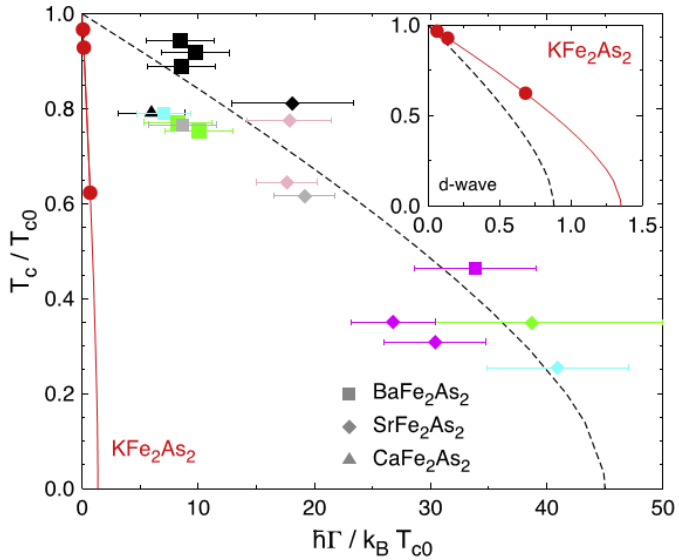
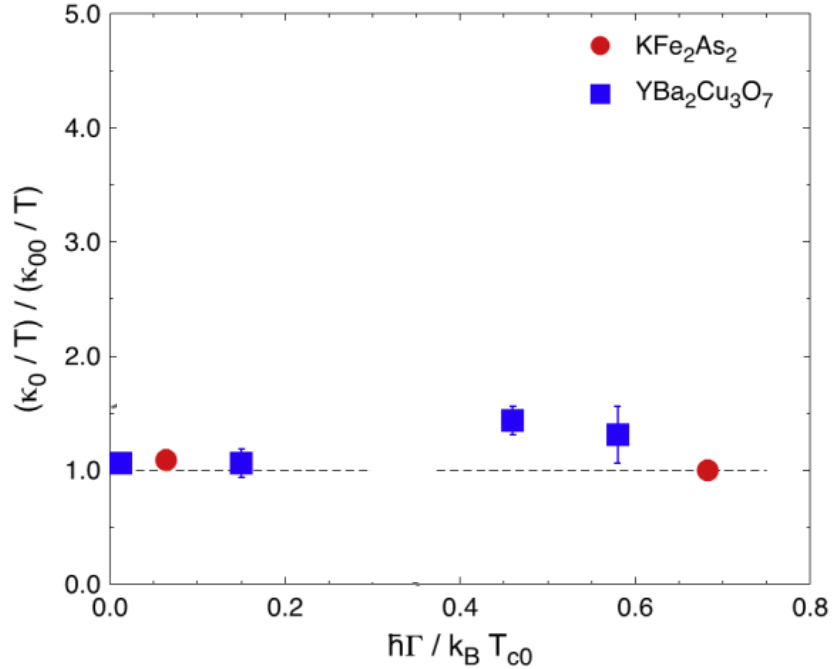




Reid *et al.*, SUST **25**, 084013 (2012)

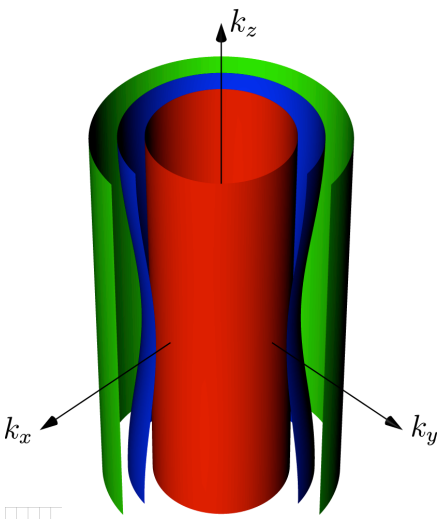
Kirshenbaum *et al.*, PRB **86**, 140505 (2012)

Reid *et al.*, PRL **109**, 087001 (2012)

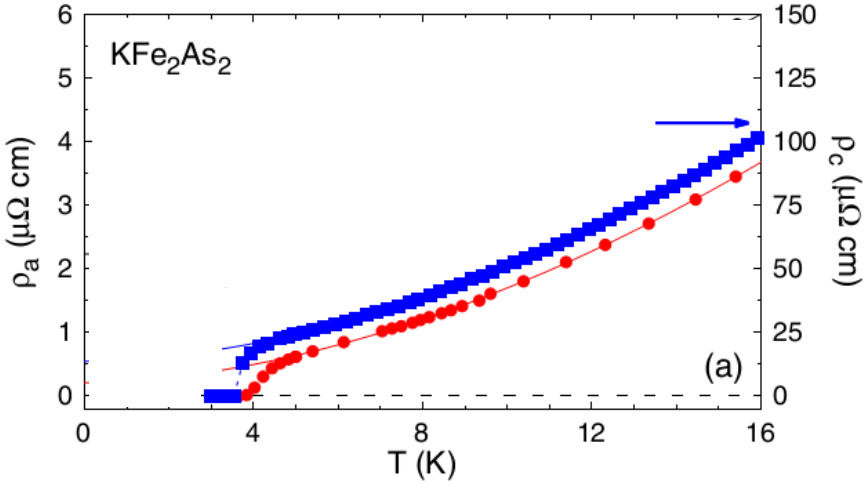
YBCO : Taillefer *et al.*, PRL **79**, 483 (1997)

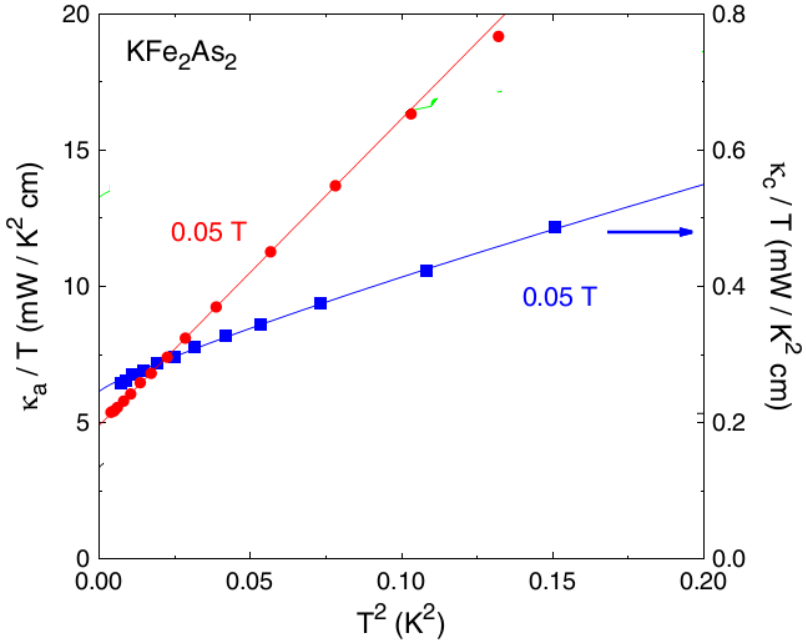
d-wave : symmetry-imposed line nodes on *all* FS

2) Anisotropy ($a - c$)



Terashima *et al.*, PRB **87**, 224512 (2013)

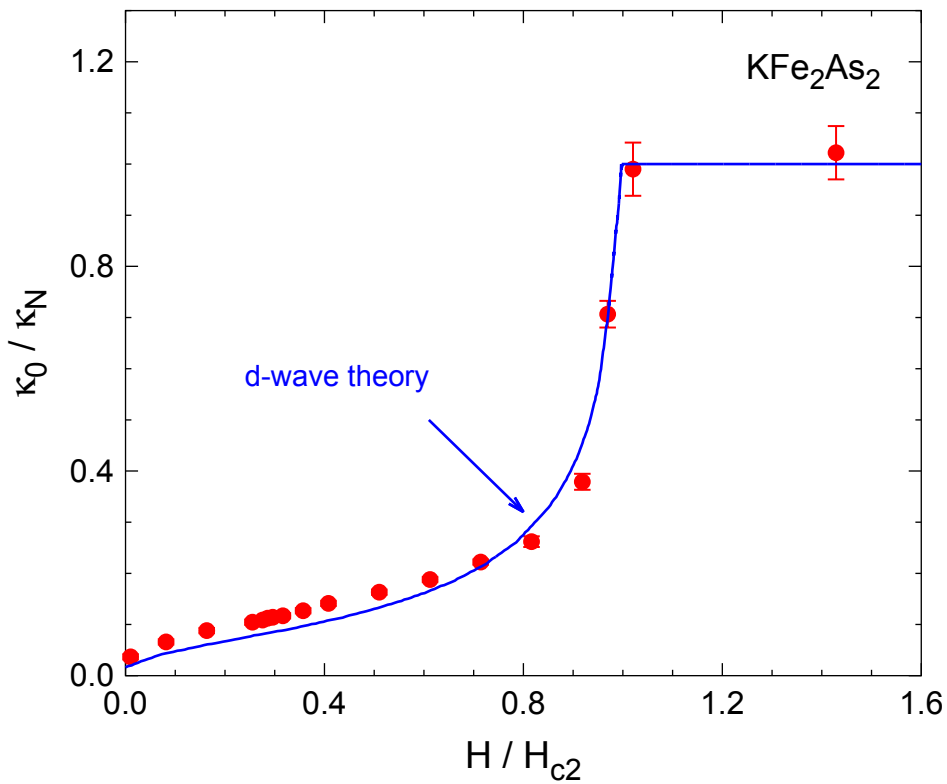




Reid *et al.*, PRL **109**, 087001 (2012)

d-wave : symmetry-imposed line nodes on *all* FS

3) Magnetic field



Experiment: Juneau-Fecteau *et al.*, to be published

Theory: Vorontsov & Vekhter, PRB **75**, 224502 (2007)

Phase I : What is the pairing symmetry ?

Heat transport – three tests :

1) Impurity scattering

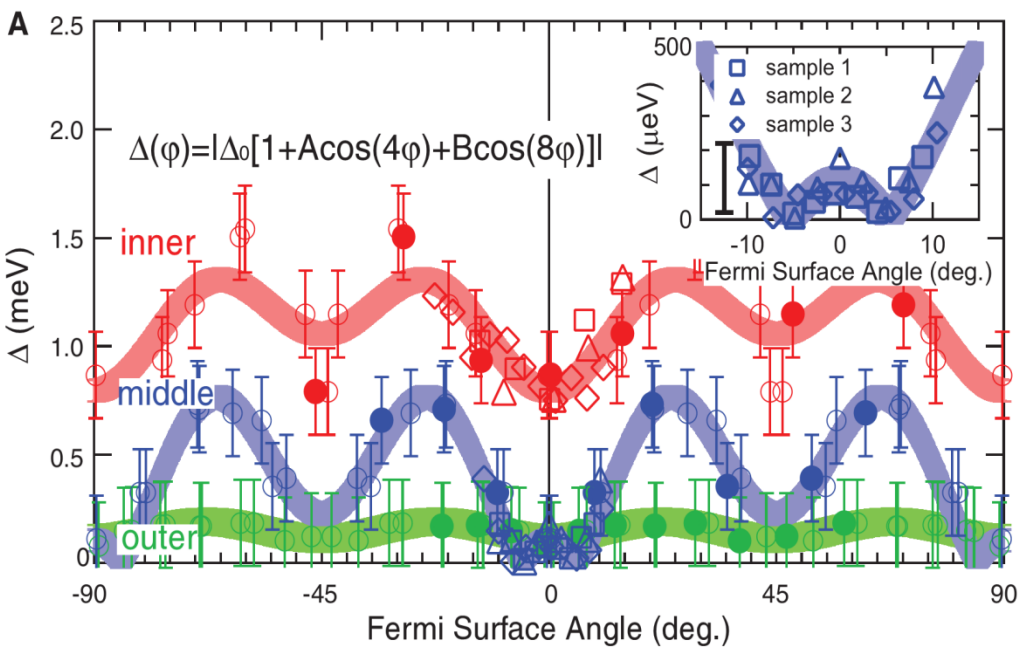
2) Anisotropy (*a* – *c*)

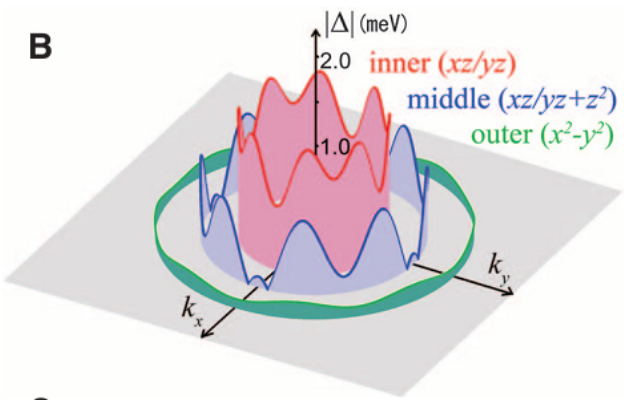
3) Magnetic field

d-wave : symmetry-imposed line nodes on *all* FS **All good**

$s_{\pm}$: accidental line nodes on *one* FS

Laser ARPES study





Okazaki *et al*., Science **337**, 1314 (2012)

$s_{\pm}$: accidental line nodes on *one* FS

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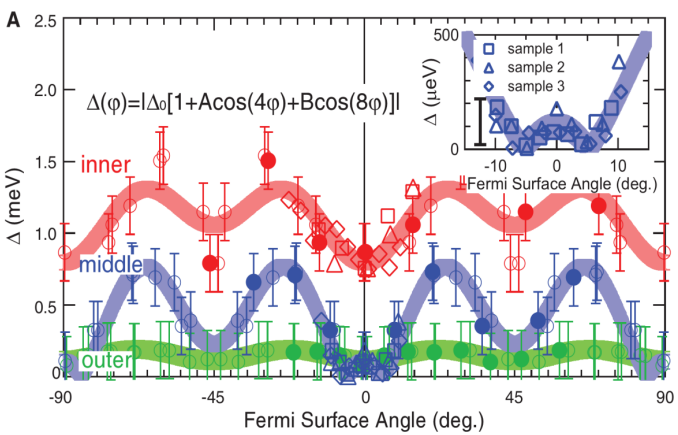

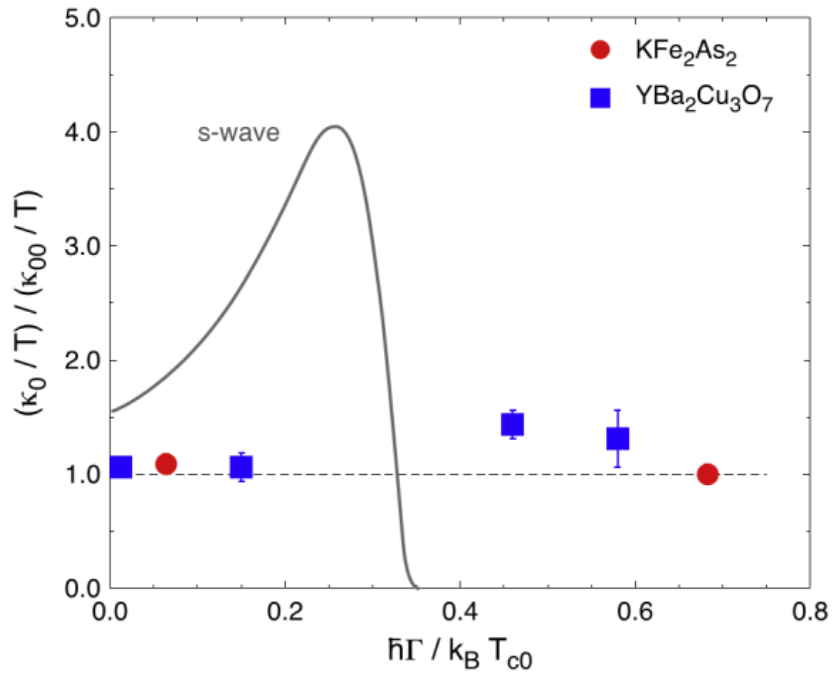

Theory: Mishra *et al.*, PRB **80**, 224525 (2009)

Reid *et al.*, PRL **109**, 087001 (2012)

Okazaki *et al.*, Science **337**, 1314 (2012)

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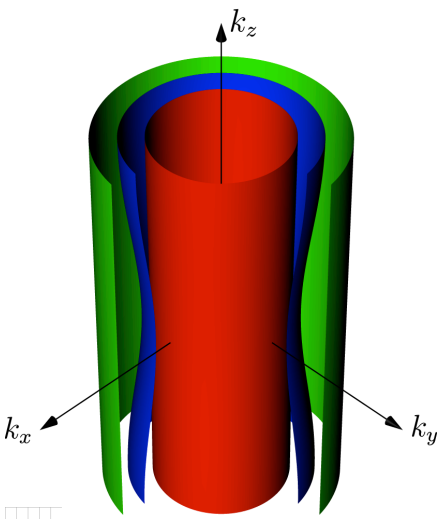
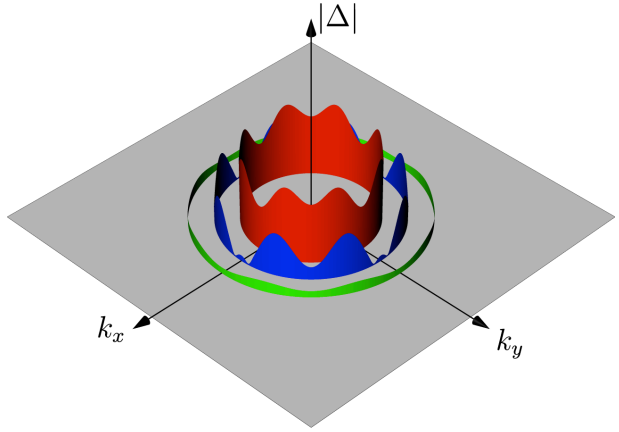
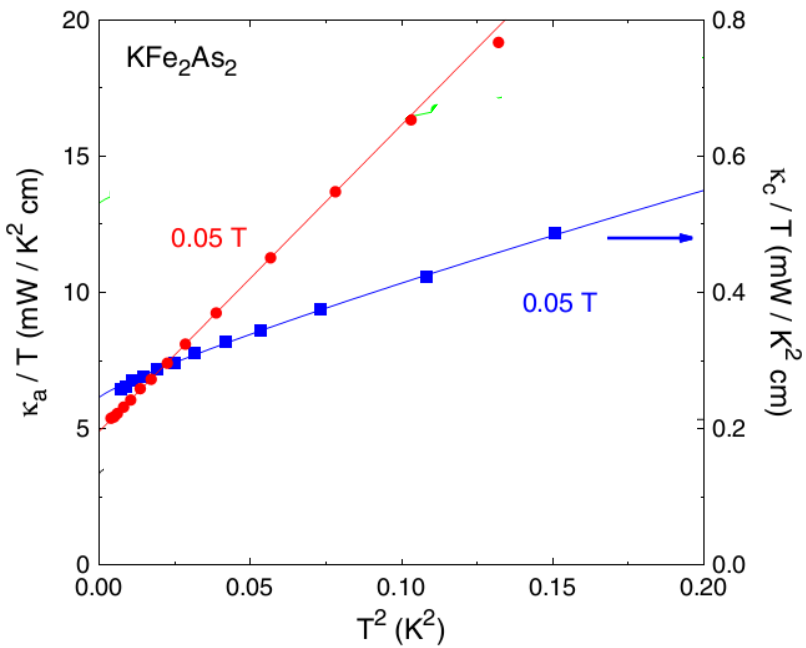
2) Anisotropy ($a - c$)



Terashima *et al*., PRB **87**, 224512 (2013)



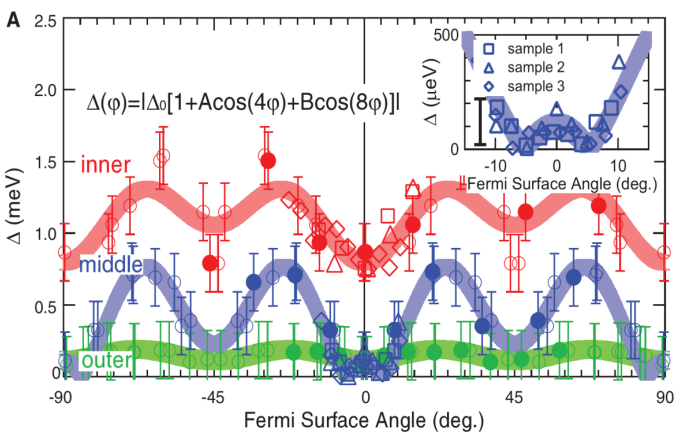
Okazaki *et al*., Science **337**, 1314 (2012)



Reid *et al*., PRL **109**, 087001 (2012)

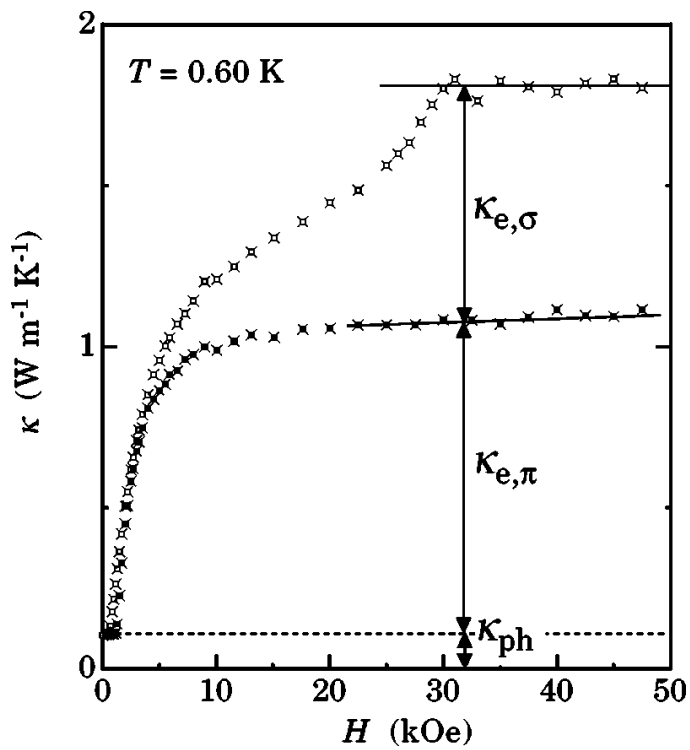
$s_{\pm}$: accidental line nodes on *one* FS

3) Magnetic field



Okazaki *et al.*, Science **337**, 1314 (2012)

MgB_2



Sologubenko *et al.*, PRB **66**, 014504 (2002)

$s_{\pm}$: accidental line nodes on *one* FS

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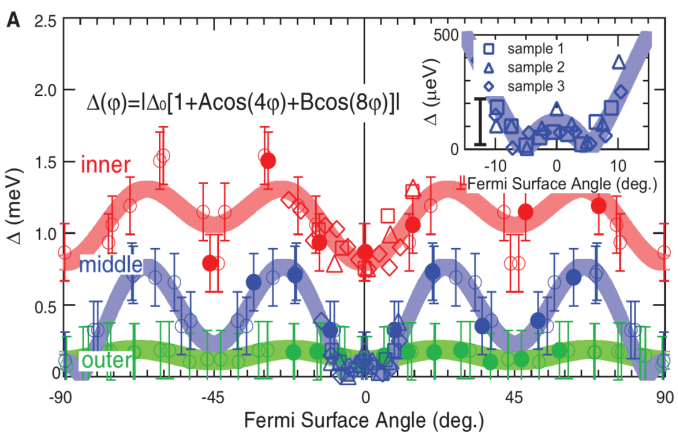

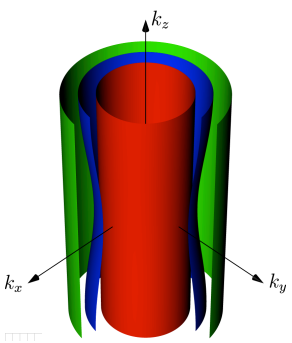

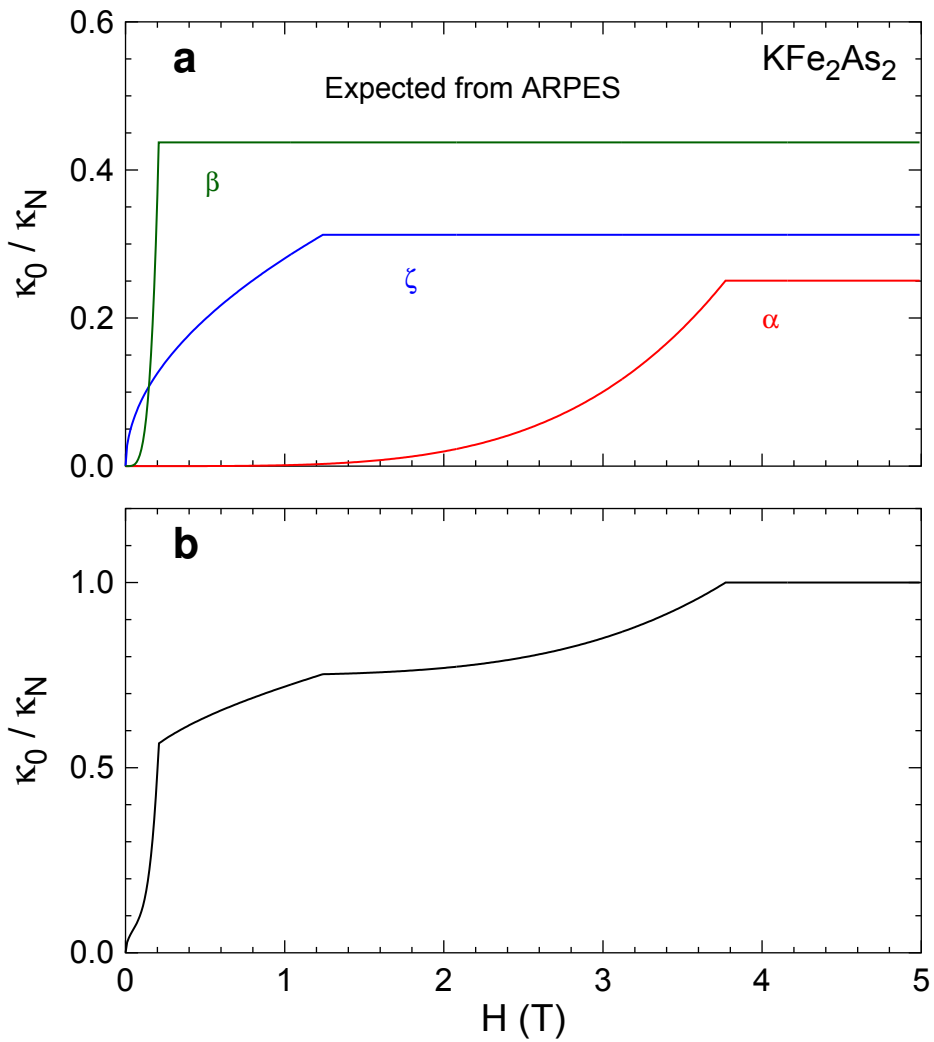

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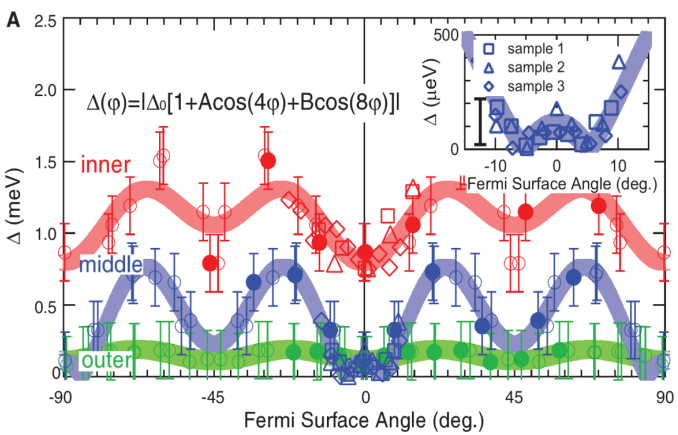
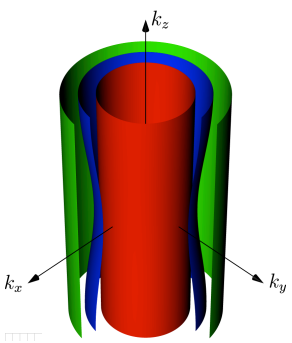
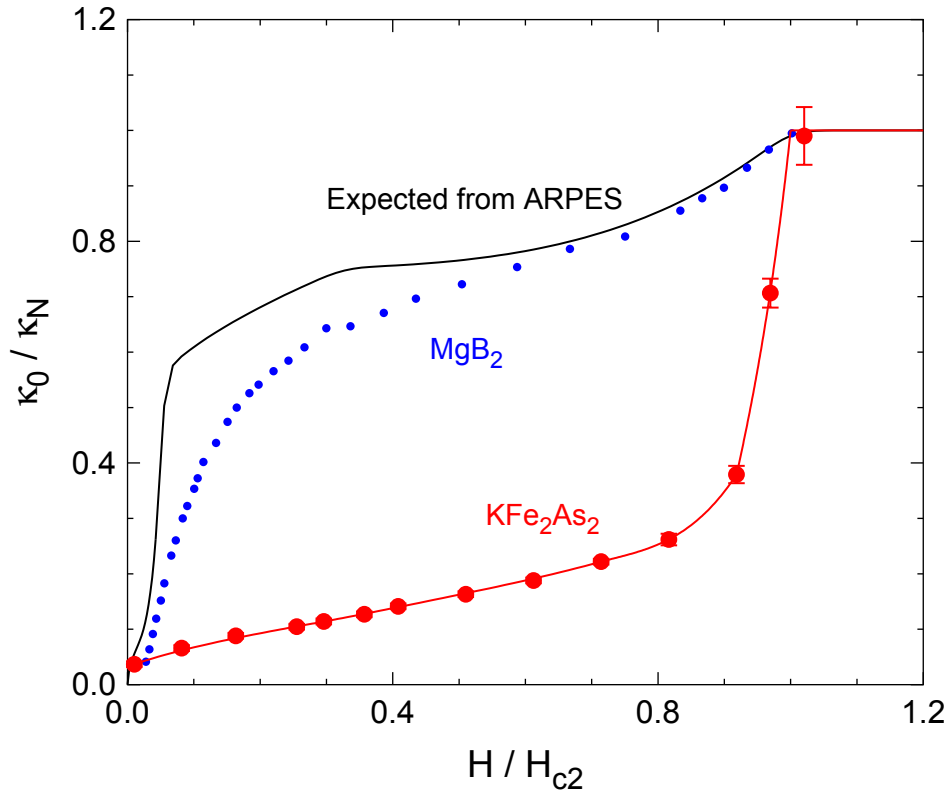




Okazaki *et al.*, Science **337**, 1314 (2012)



KFe_2As_2 : Juneau-Fecteau *et al.*, to be published

MgB_2 : Sologubenko *et al.*, PRB **66**, 014504 (2002)

Phase I : What is the pairing symmetry ?

Heat transport – three tests :

1) Impurity scattering

2) Anisotropy (*a* – *c*)

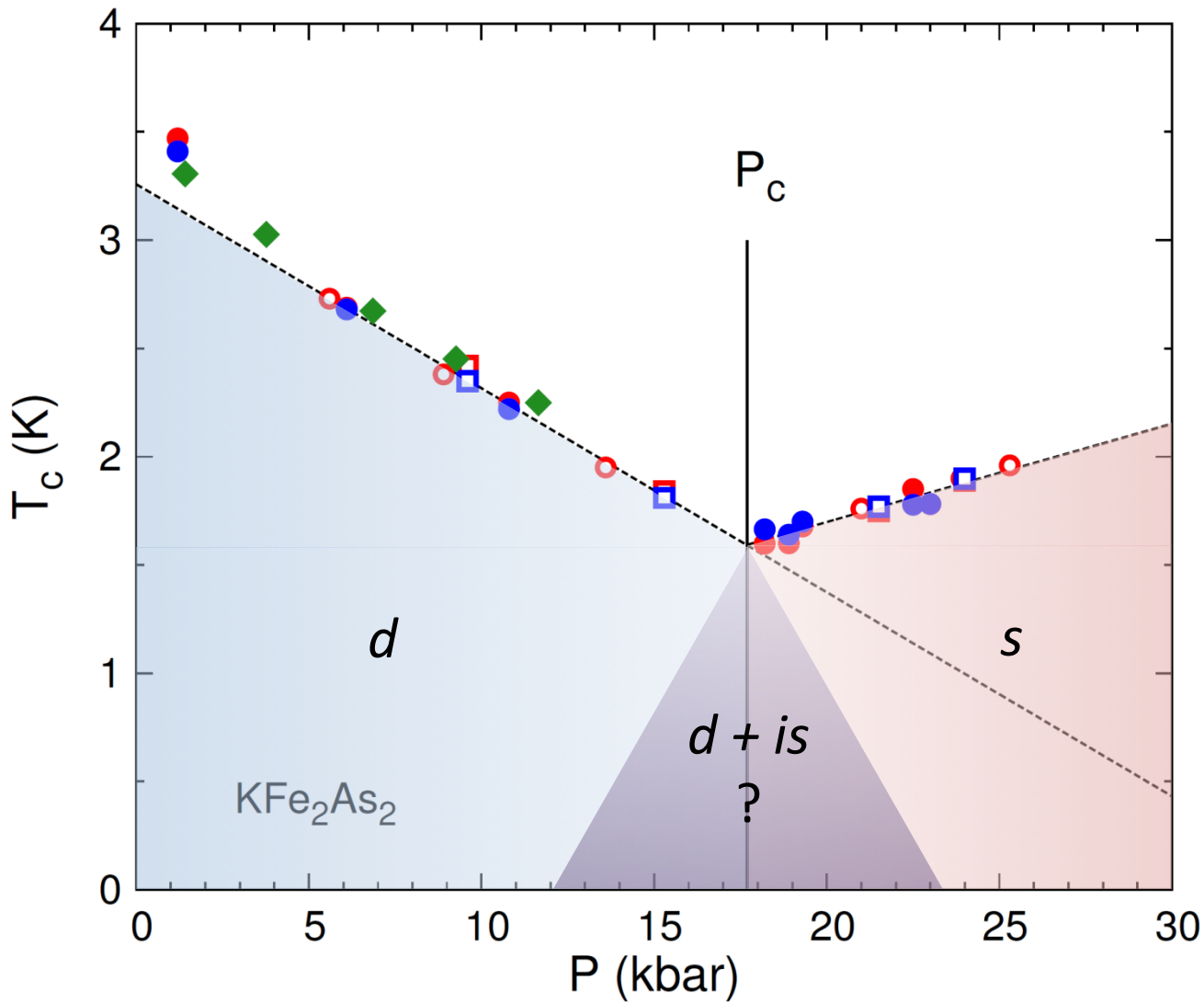
3) Magnetic field

d-wave : symmetry-imposed line nodes on *all* FS **All good**

$s_{\pm}$: accidental line nodes on *one* FS **All problematic**

KFe_2As_2

Two different pairing symmetries



Tafti *et al*., Nature Physics **9**, 349 (2013)

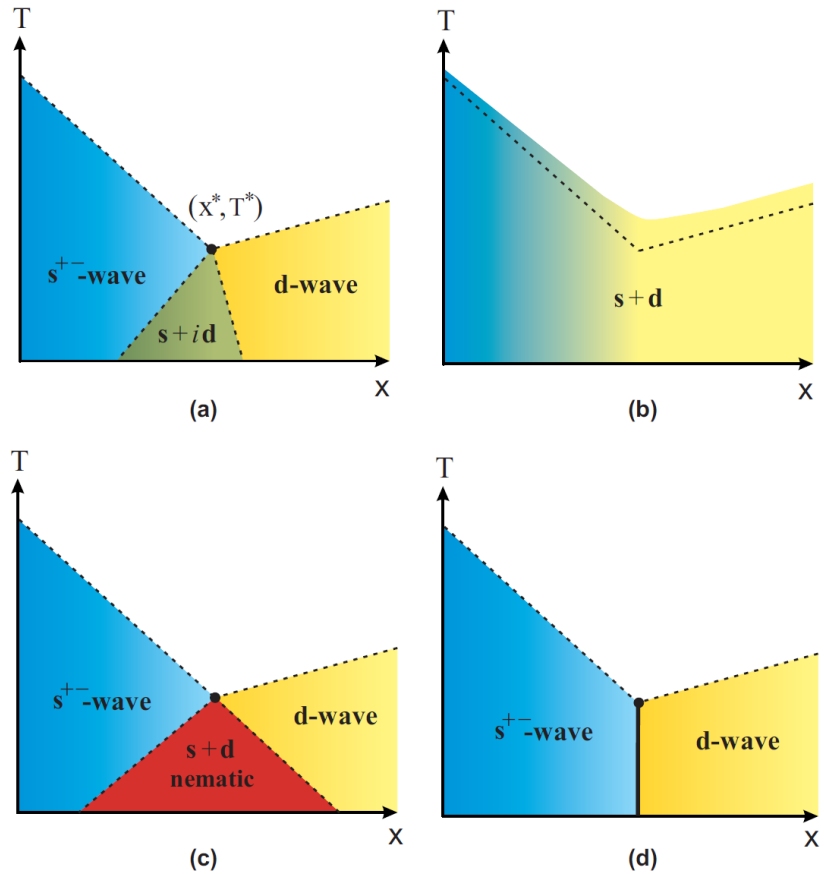
Possible phase diagrams

Fernandes & Millis, arXiv: 1306.1125

$$F_{\mathrm{SC-nem}} \propto \varphi \Delta_s \Delta_d \cos\theta$$

Weak nematic fluctuations

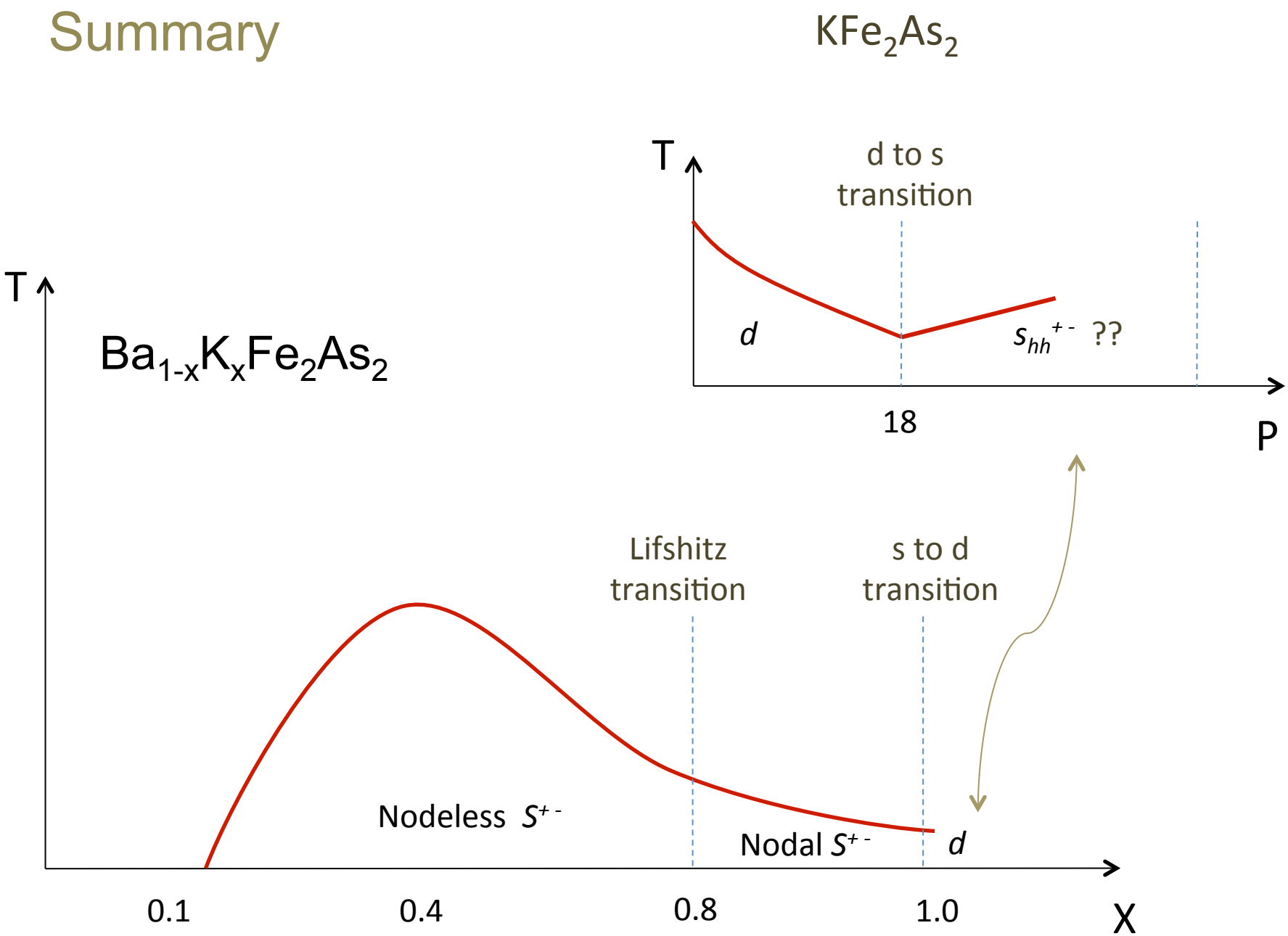
Intermediate nematic fluctuations



Pre-exising nematic order

Strong nematic fluctuations

Summary


KFe2As2
T
d to s
transition
d
shh+- ??
18
P
T
Ba1-xKxFe2As2
Lifshitz
transition
s to d
transition
Nodeless S+-
Nodal S+-
d
0.1
0.4
0.8
1.0
X

Conclusions

- V-shaped phase diagram T_c vs P in KFe_2As_2
- Transition between different pairing states
- Thermal conductivity and penetration depth favour *d*-wave at $P = 0$
- Possibility of an intermediate *d* + *is* state
- Pairing state at the surface of KFe_2As_2 may be different from the bulk

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Reid *et al*., PRL **109**, 087001 (2012)