Pseudogap and electronic ordering in 2D superconductors: ARPES approach

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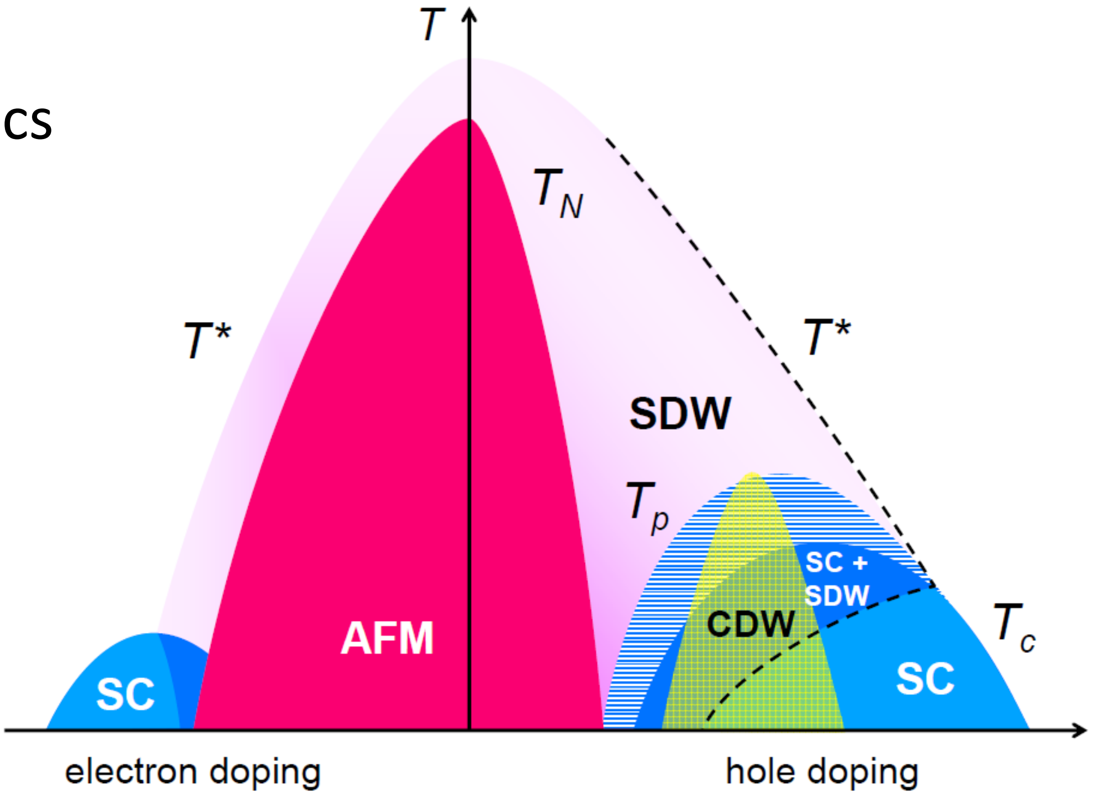


Low Temp. Phys. (2015)

Outline

1. Pseudogap history
2. **Pseudogap in cuprates and TDM**
3. Pseudogap in Fe-SC?
4. **Band structure of Fe-SC and superconductivity**
5. **Pseudogap and superconductivity**

Conclusion:

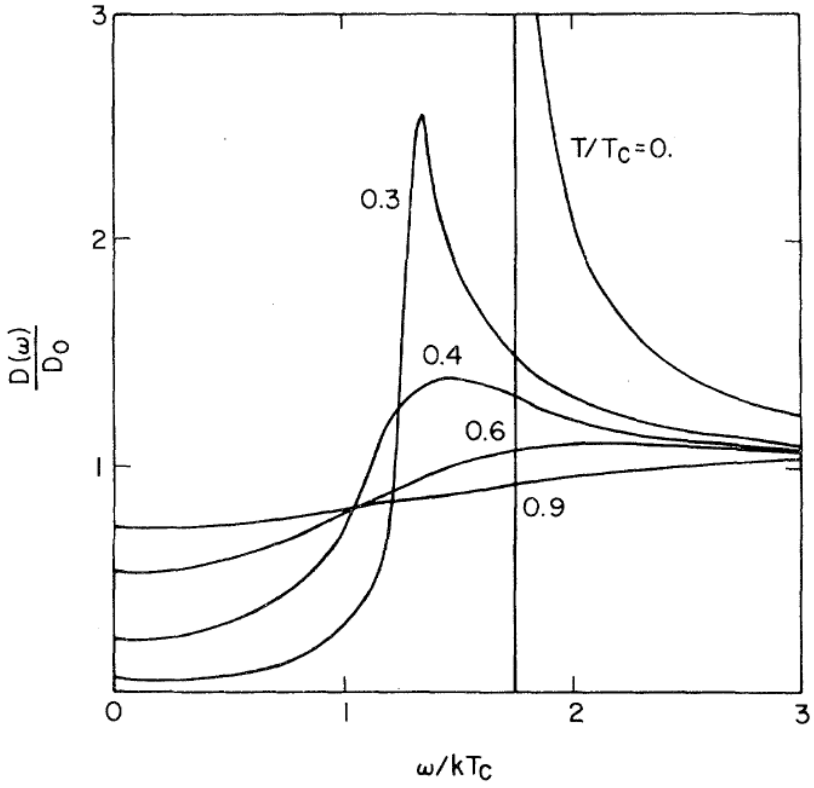
What is similar between Fe-SC and Cu-SC with maximal Tc? – proximity to Lifshitz transition

Low Temp. Phys. (2015)

Pseudogap history

The term "pseudogap" had been coined by Mott back in 1968 as a depletion of the electronic density of states at the Fermi level

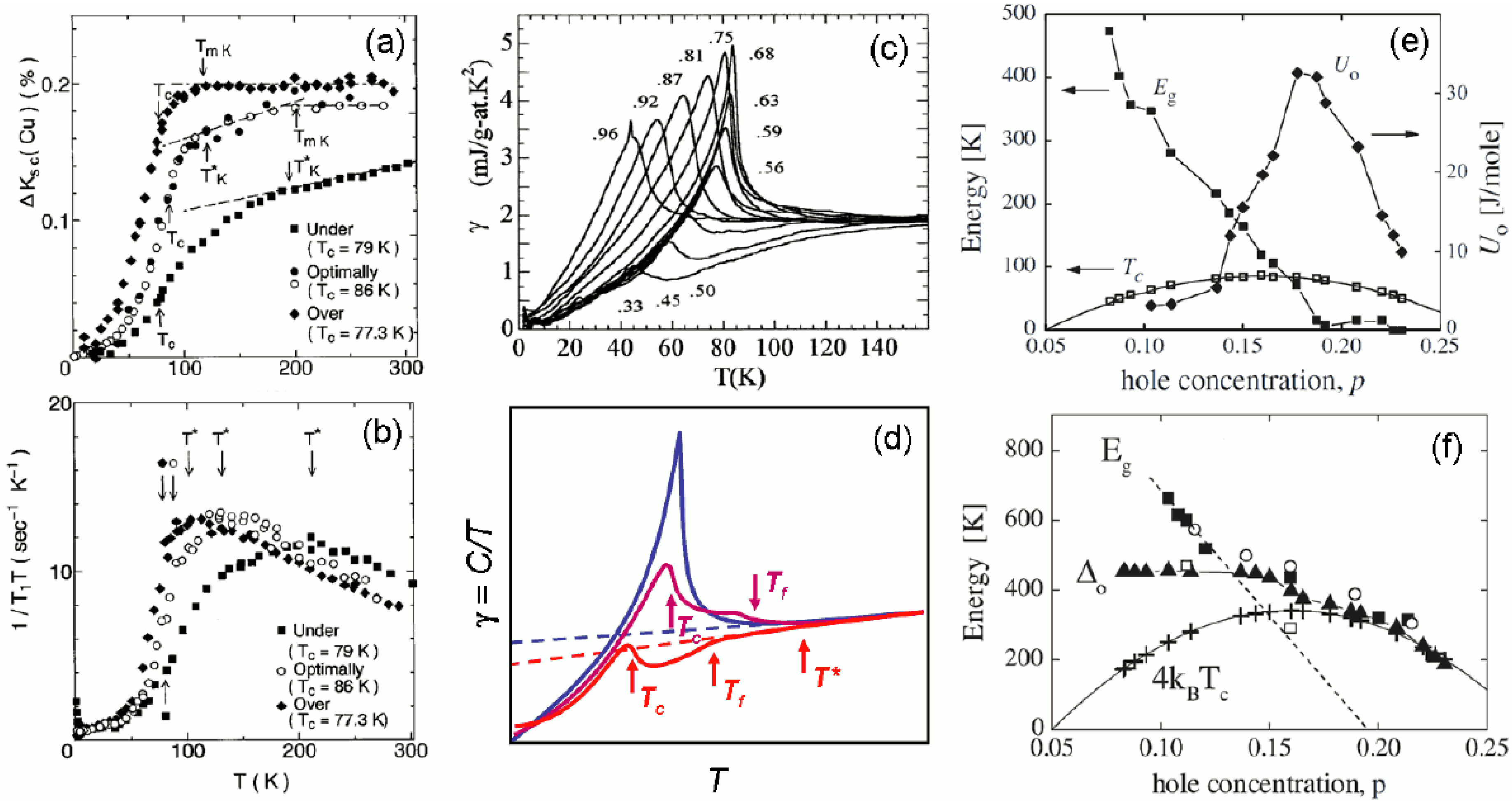
N. F. Mott, *Rev. Mod. Phys.* **40**, 677 (1968)



'Fluctuating band gap', the gap formed by uctuating CDW at a Peierls transition in quasi-1D metals

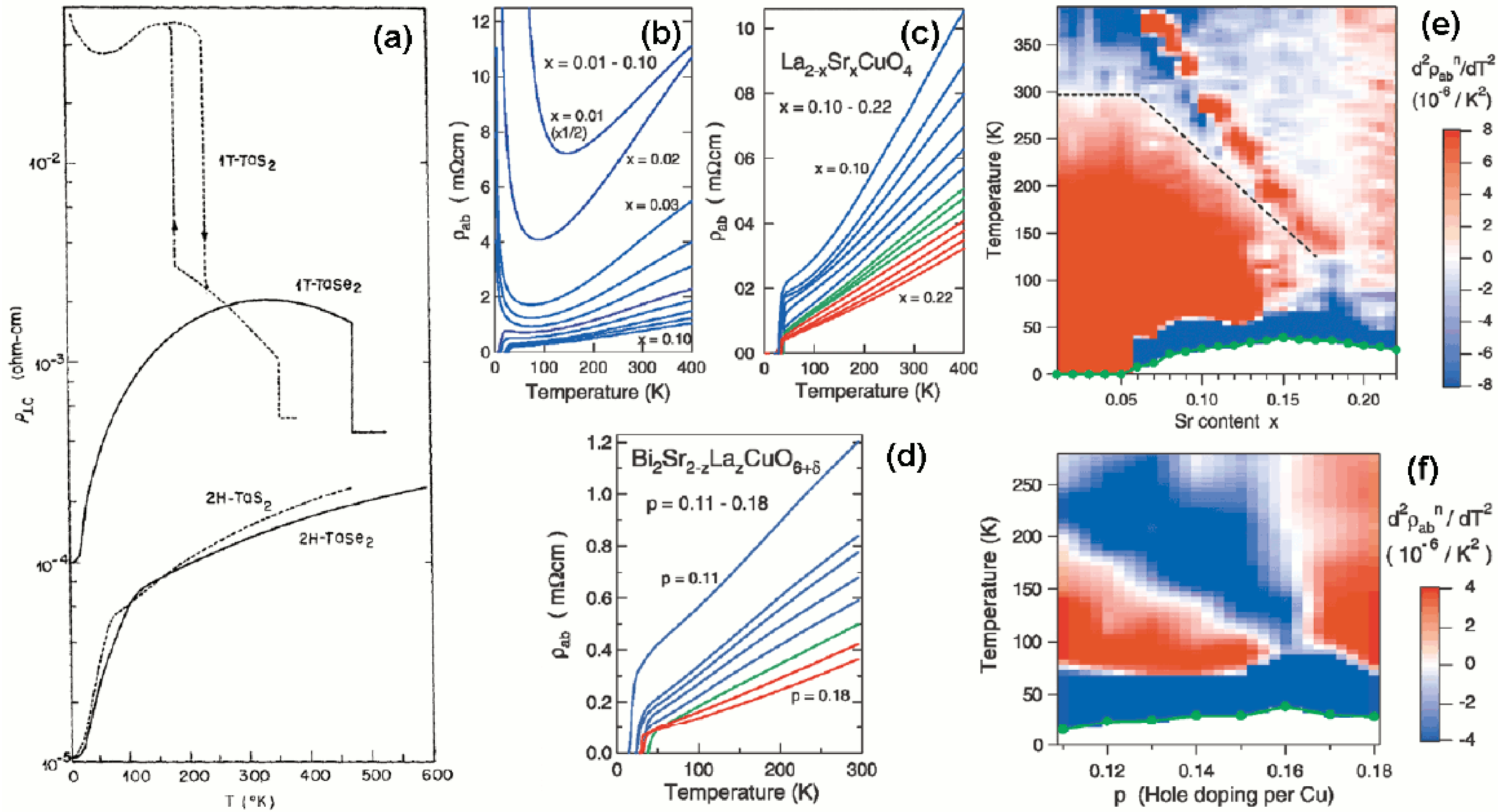
M. J. Rice & S. Strassler, *Solid State Commun.* **13**,1389 (1973)

Pseudogap in experiment



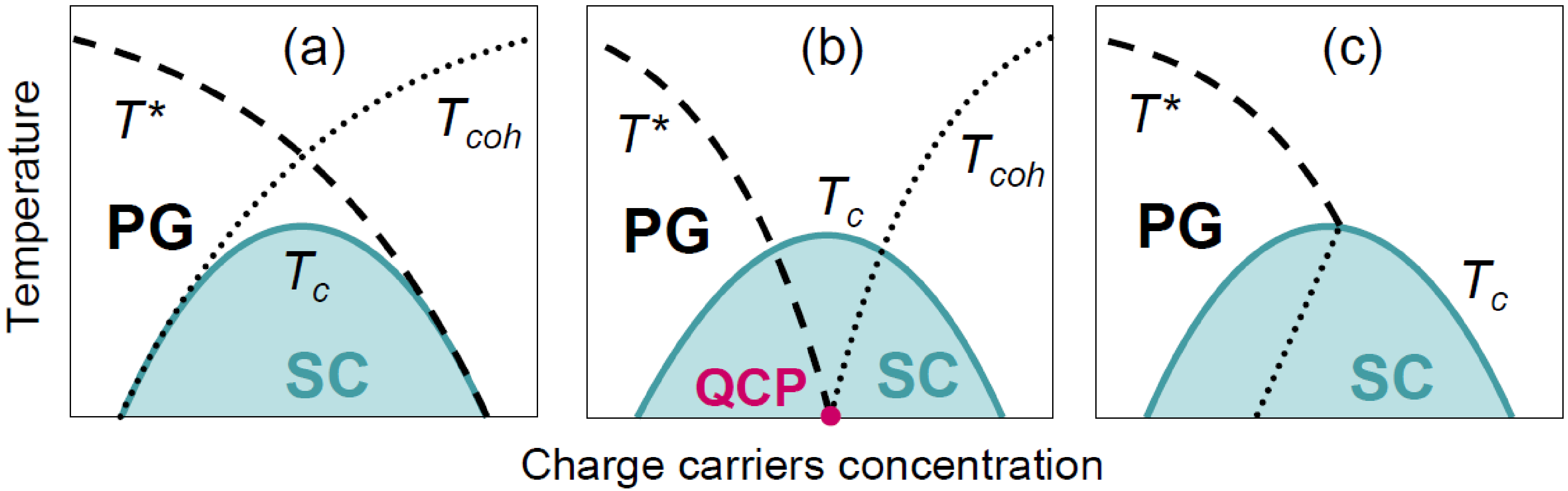
(a,b) K. Ishida et al., Phys. Rev. B 58, R5960 (1998); (c) J. W. Loram et al., Physica C 235-240, Part 3, 1735 (1994); (e,f) J. L. Tallon et al., Phys. Status Solidi (b) 215, 531 (1999).

Pseudogap in experiment



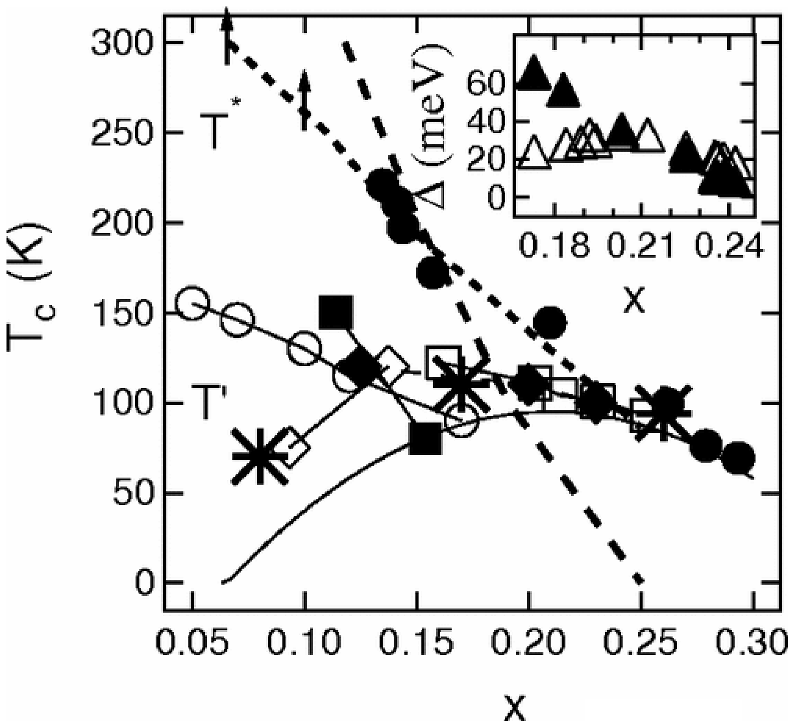
(a) J. Wilson, F. Di Salvo, and S. Mahajan, Adv. Phys. 24,117 (1975)
(b-f) Y. Ando et al., Phys. Rev. Lett. 93, 267001 (2004).

Pseudogap in theories

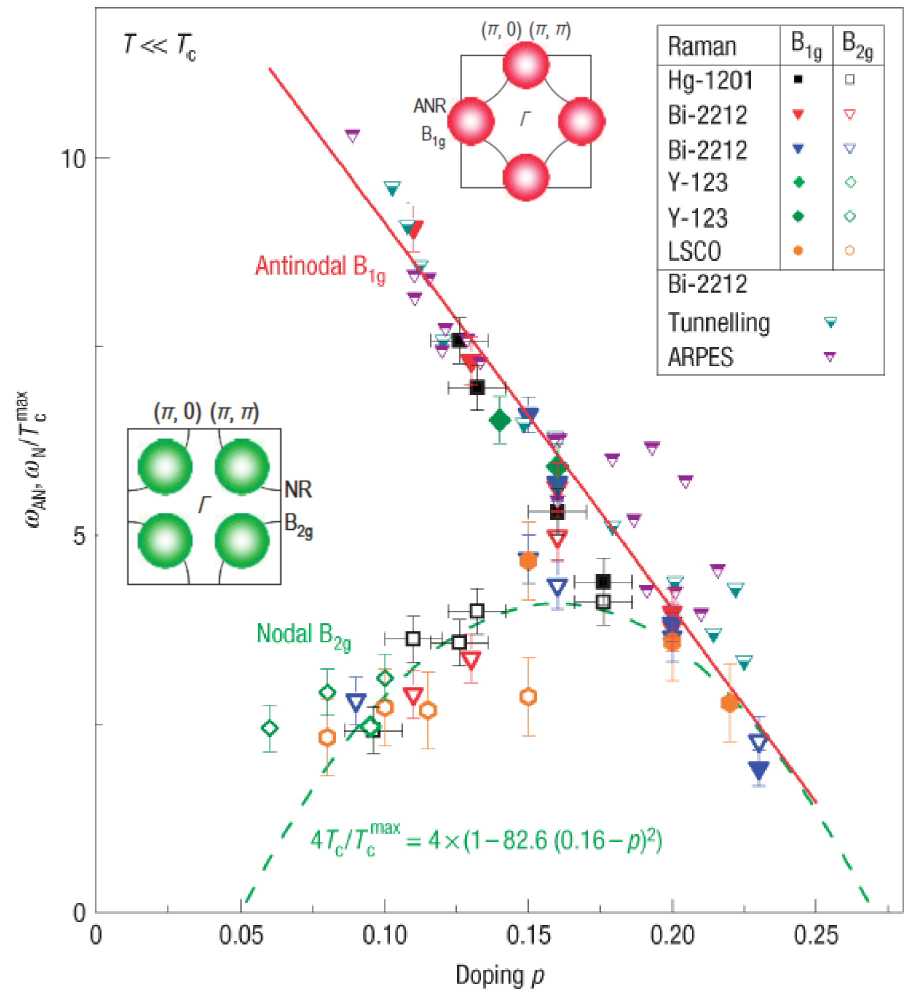


(a) the preformed pairs scenarios or spin singlet scenario
(b) quantum critical point (QCP)
(c) competition between superconductivity and another ordering

"Two gaps" scenario



J. Tallon and G. Williams, PRL (1999);
R. Markiewicz, PRL (2002).



M. Le Tacon et al., Nat. Phys. (2006).

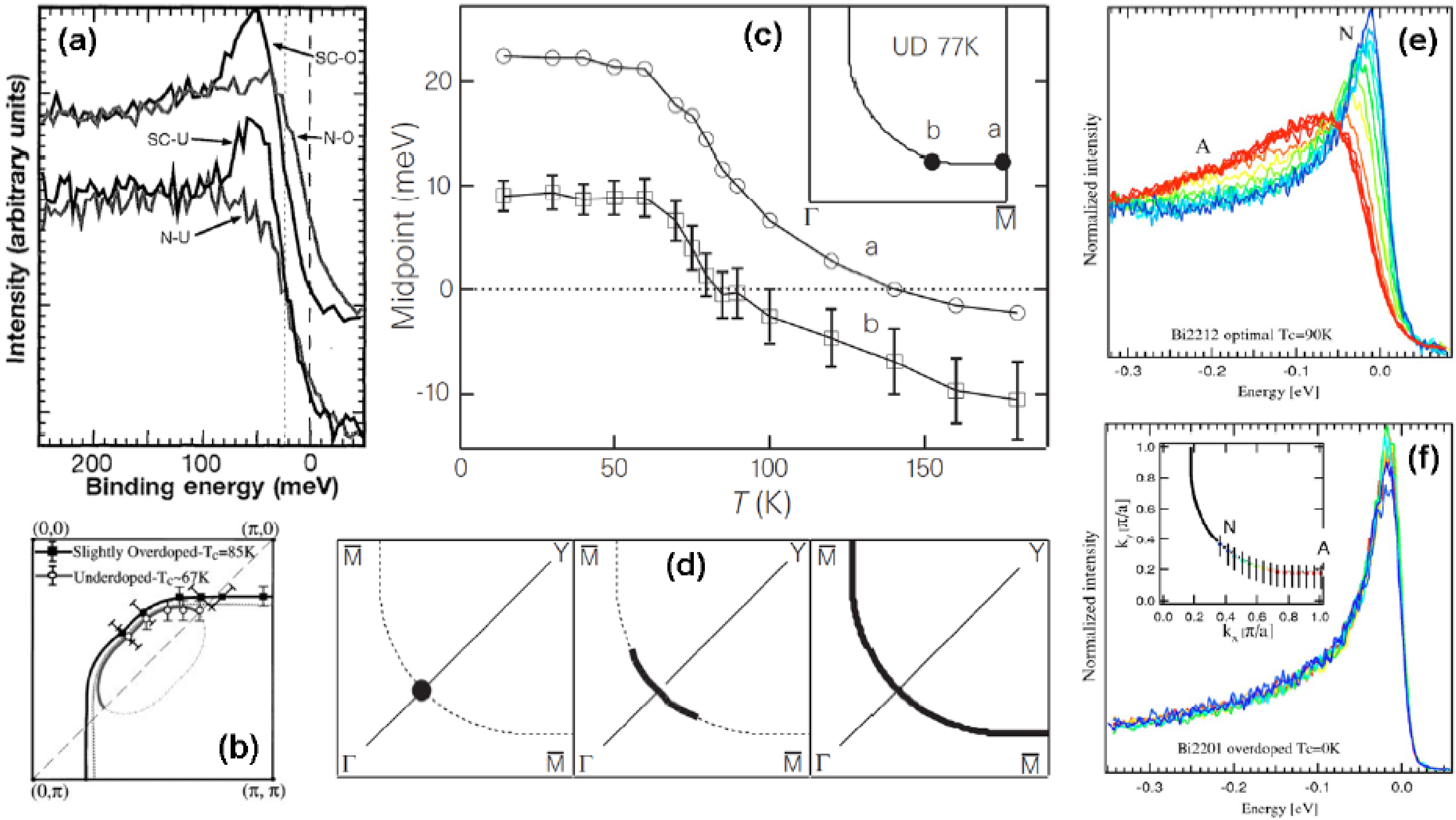
2. Pseudogap in cuprates and TMD

1. Measuring gaps in ARPES
2. Two gaps in Cu-SC
3. CDW gaps in TMD
4. CDW in cuprates
5. VHs nesting and Mott gap in TMD
6. Three gaps in Cu-SC

Conclusion: SDW+CDW+SC fluctuations

7. Two sides of the phase diagram

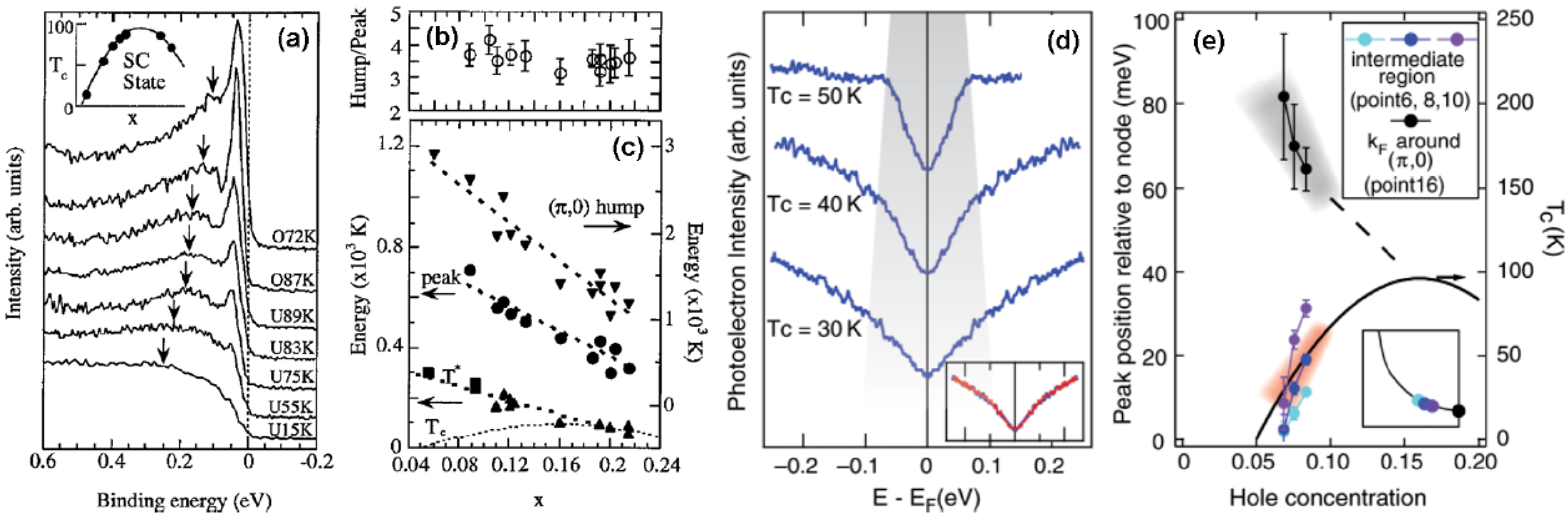
Pseudogap in cuprates by ARPES



(a) A. G. Loeser et al., Science 273, 325 (1996); (b) D. Marshall et al., Phys. Rev. Lett. 76, 4841 (1996); (c,d) M. R. Norman et al., Nature 392, 157 (1998); (e,f) A. Kaminski et al., Phys. Rev. B 71, 014517 (2005).

Pseudogap in cuprates by ARPES

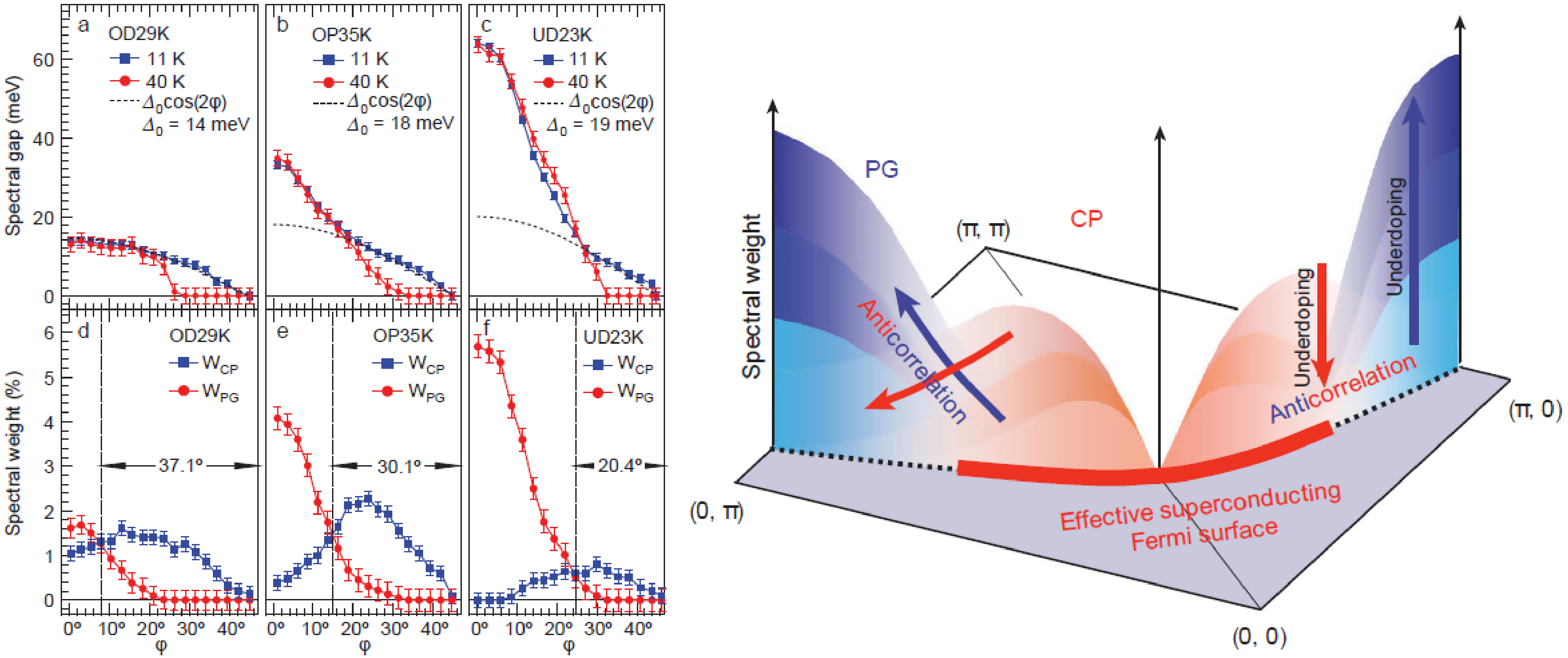
BSCCO



(a-c) J. Campuzano et al., Phys. Rev. Lett. 83, 3709 (1999);

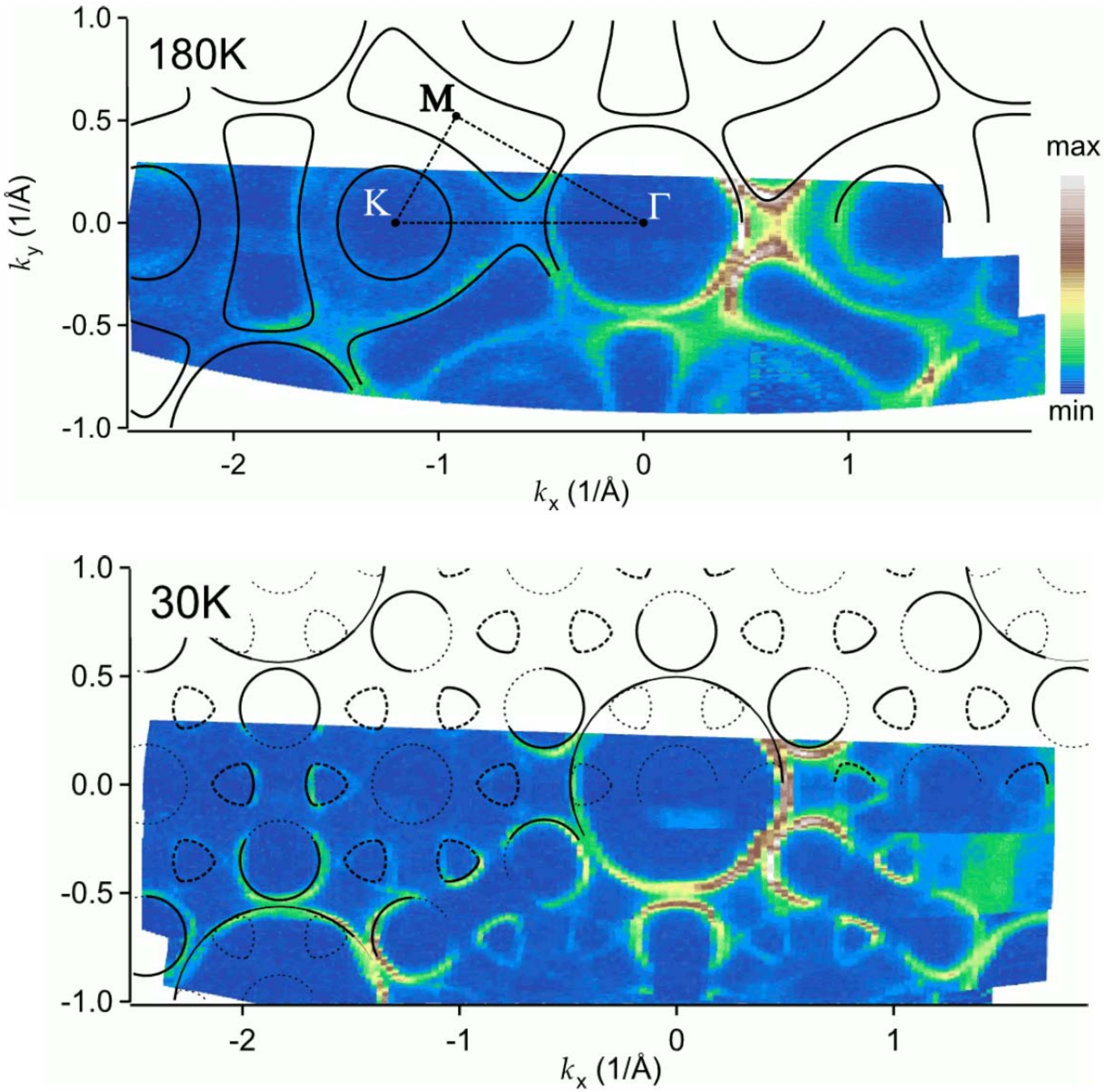
(d,e) K. Tanaka et al., Science 314, 1910 (2006)..

Two gaps by ARPES



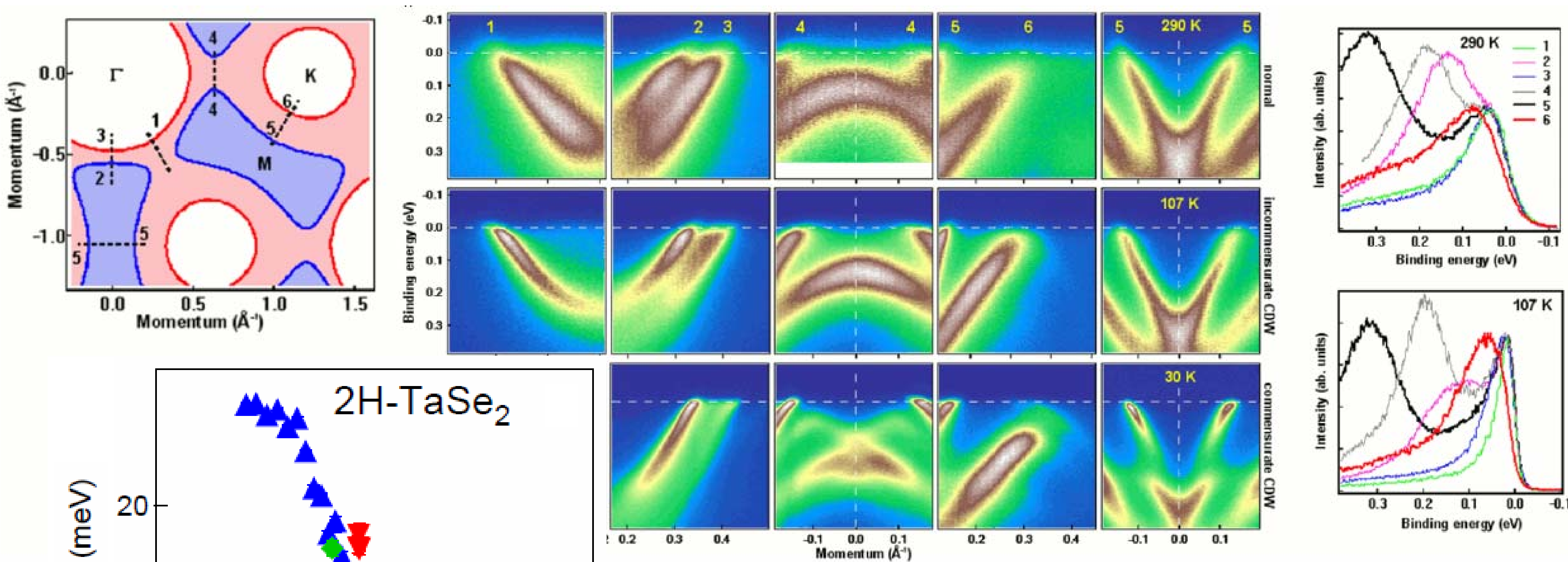
T. Kondo et al., Nature 457, 296 (2009)

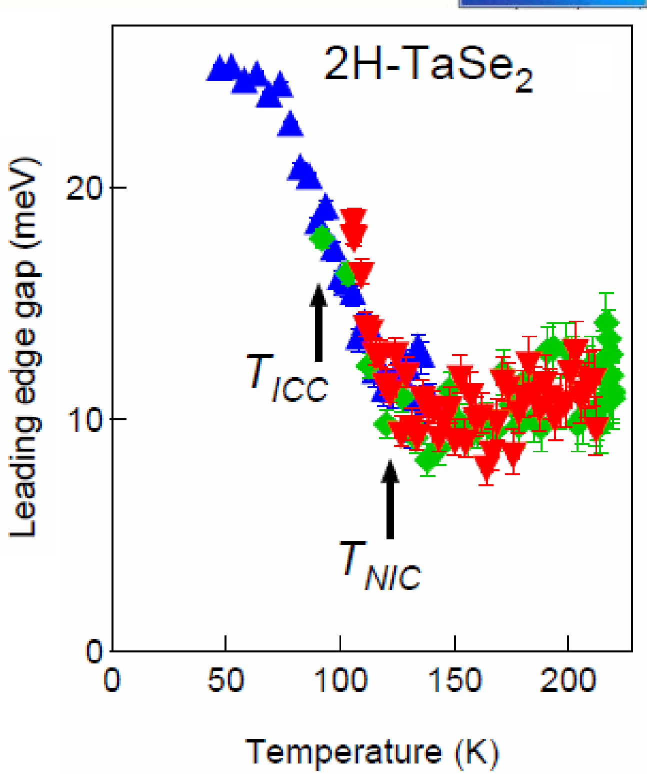
Pseudogap in TMD



Borisenko PRL 2008
Evtushinsky PRL 2008

Pseudogap in TMD



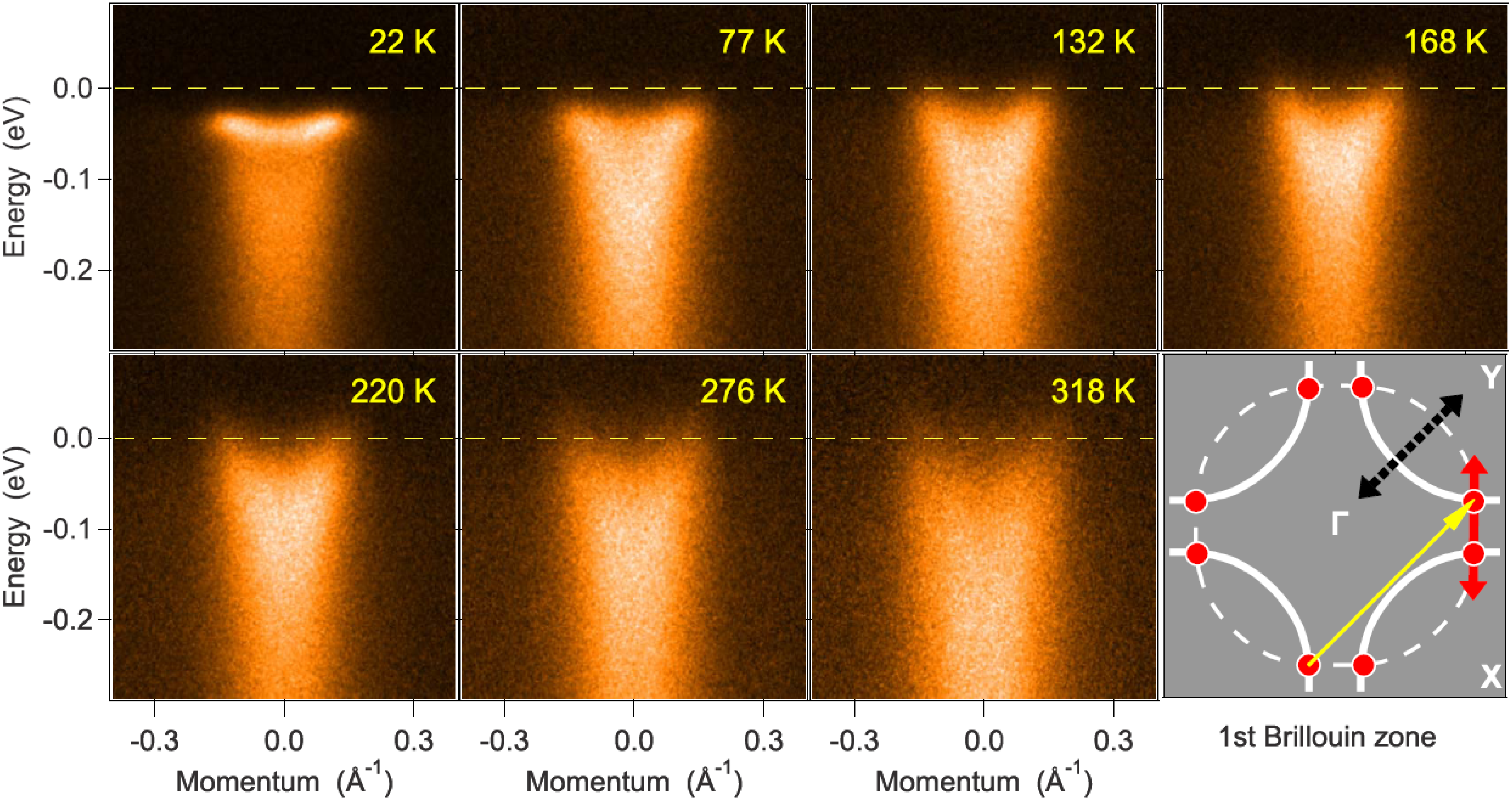


Pseudogap in TaSe2 is the incommensurate CDW gap

Borisenko PRL 2008

Pseudogap in cuprates

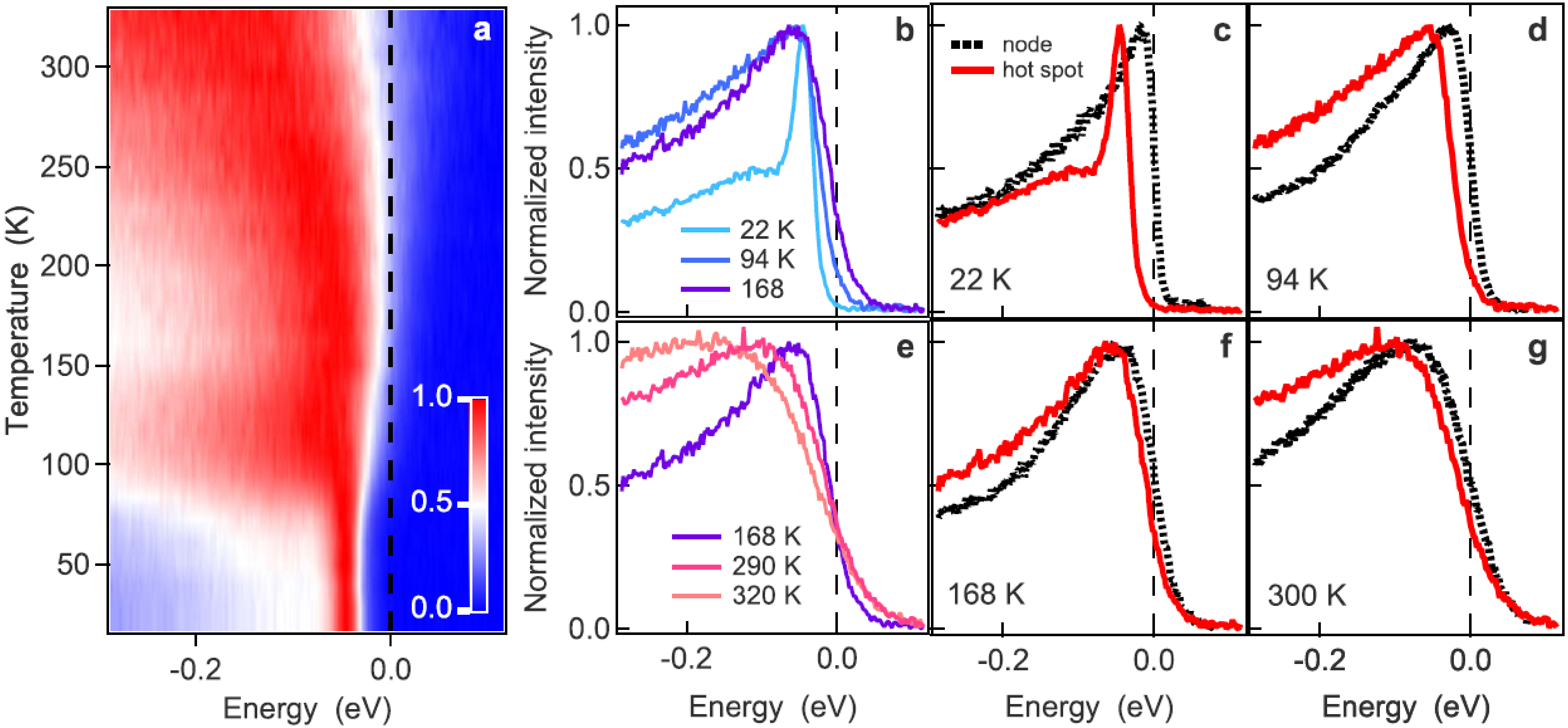
Bi(Pb)-2212 UD 77K



Kordyuk *PRB* (2009)

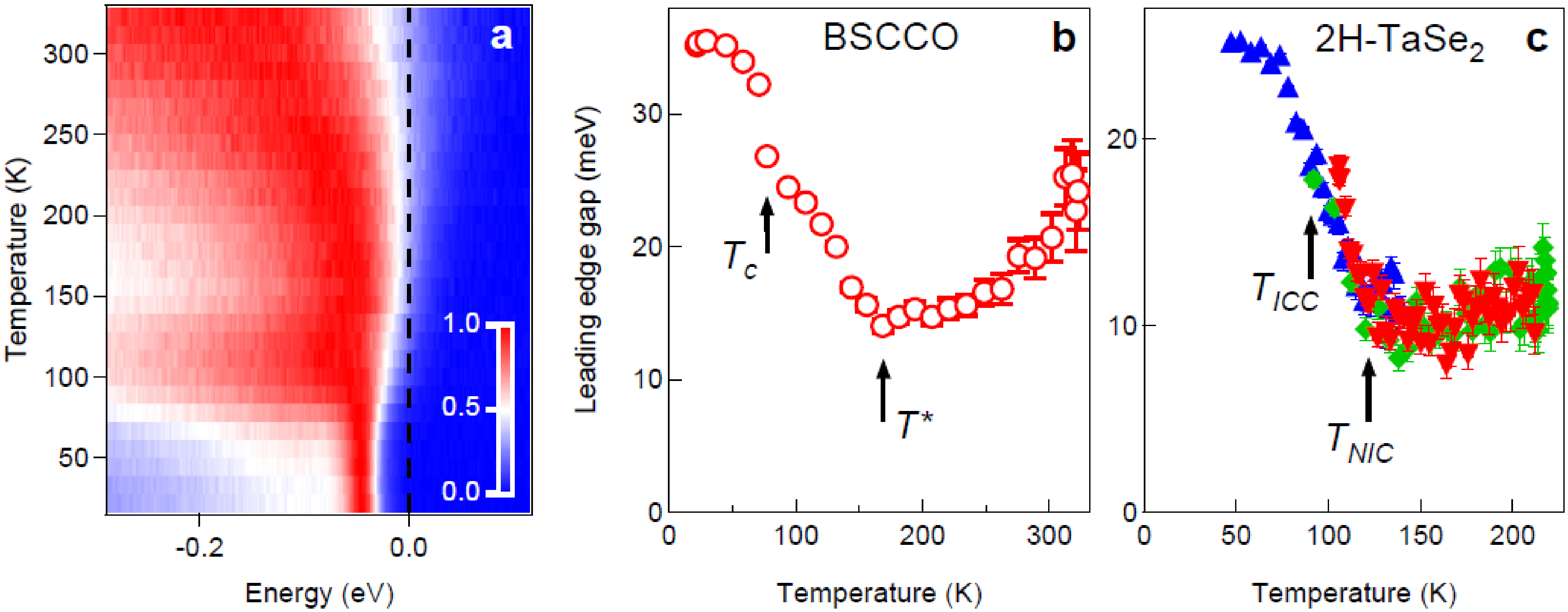
Pseudogap in cuprates

Bi(Pb)-2212 UD 77K



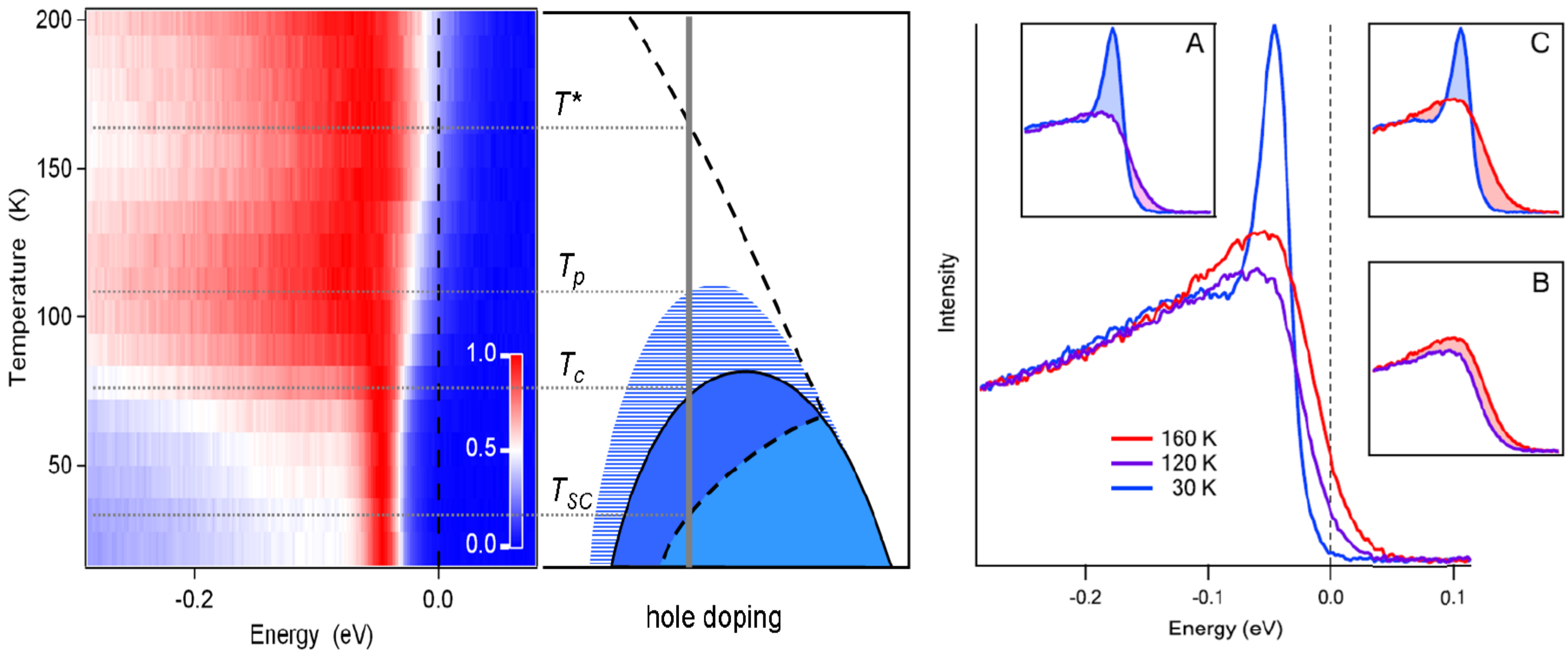
Kordyuk *PRB* (2009)

PG in cuprates = PG in TMD



Kordyuk *PRB* (2009)

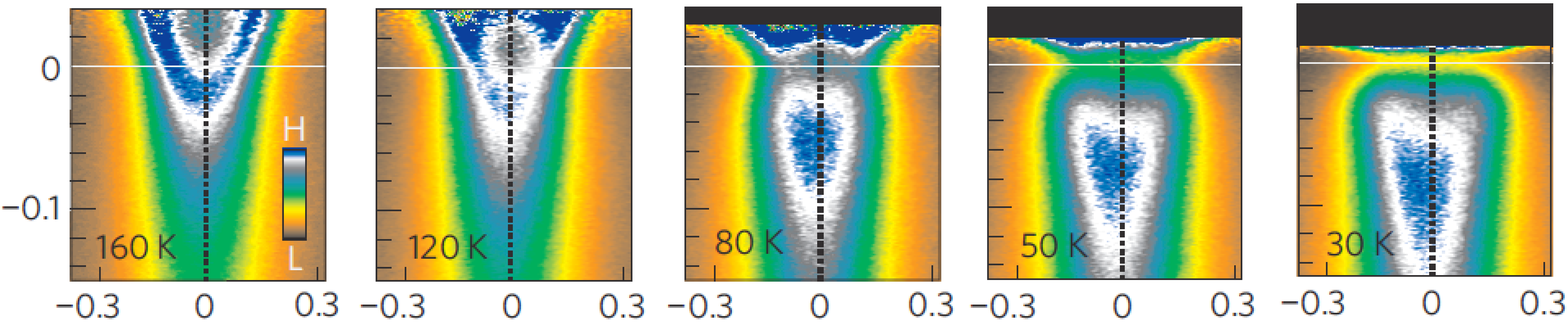
Pseudogap in cuprates

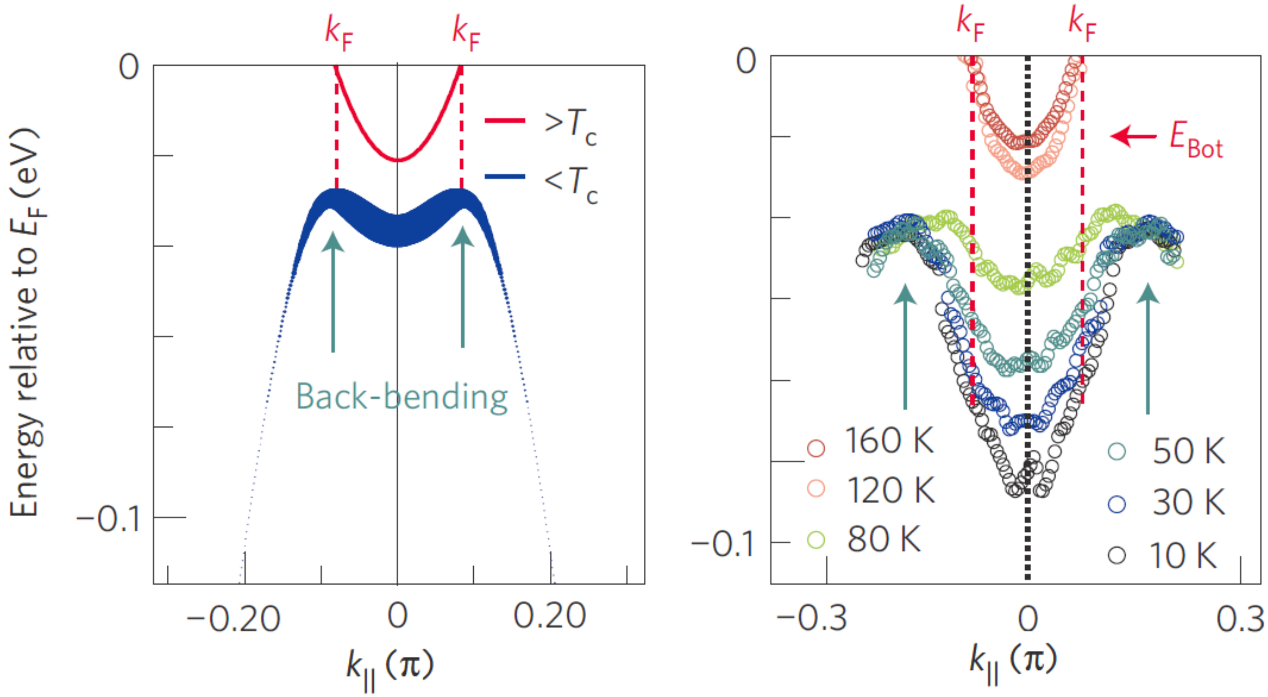


Temperature evolution of the hot spot EDC for underdoped BSCCO (*Tc* = 77 K).
T* - the pseudogap starts to increase rapidly, the spectral weight starts to decrease;
Tp - the spectral weight starts to increase;
Tc - the superconducting gap opens, the spectral weight continues to increase up to T_{SC}.
The examples of non-normalized EDC's at 160 K, 120 K, and 30 K (right) illustrate the spectral weight evolution.

(0,π) SDW

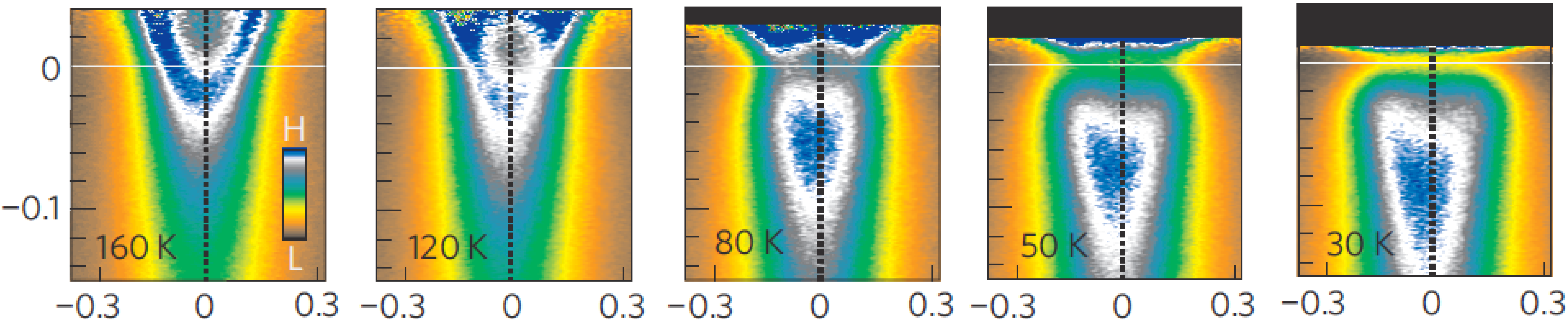
Pb–Bi2201 Tc = 34 K, T^* = 125 K

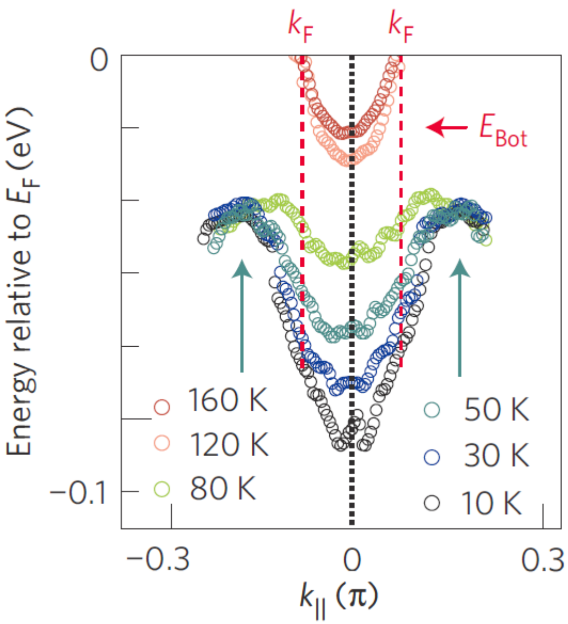


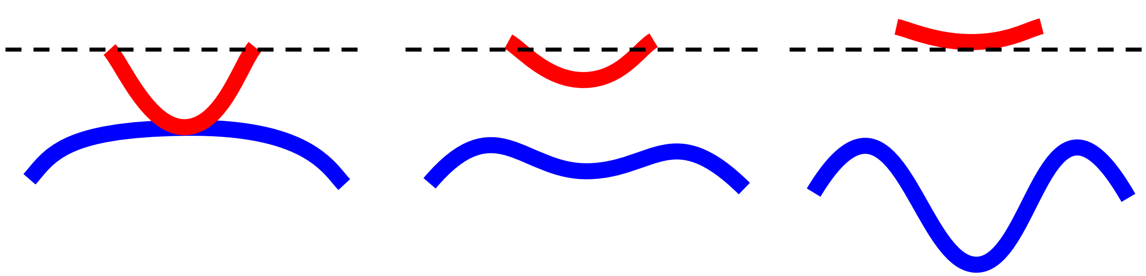


M. Hashimoto et al. *Nat. Phys.* **6**, 414 (2010)

(0,π) SDW

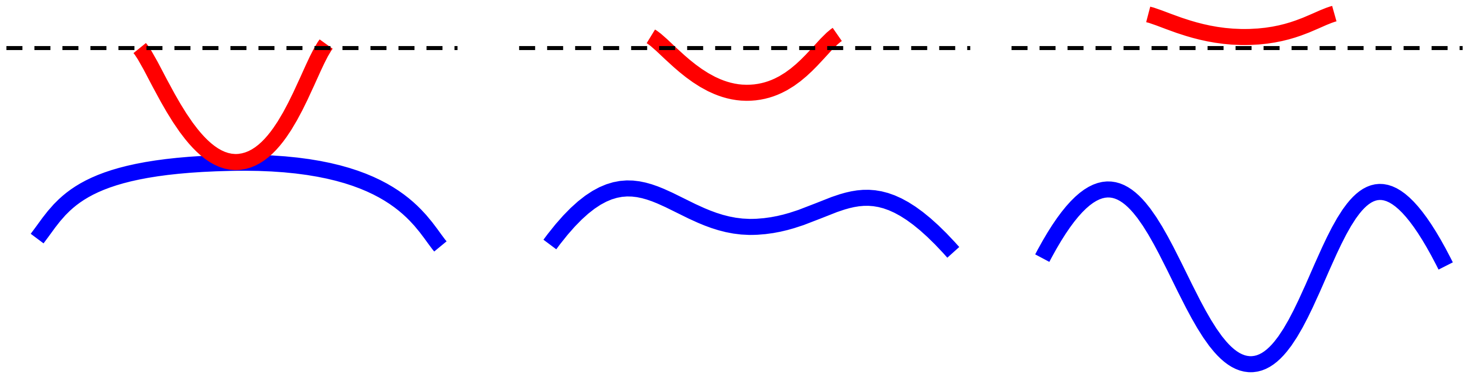




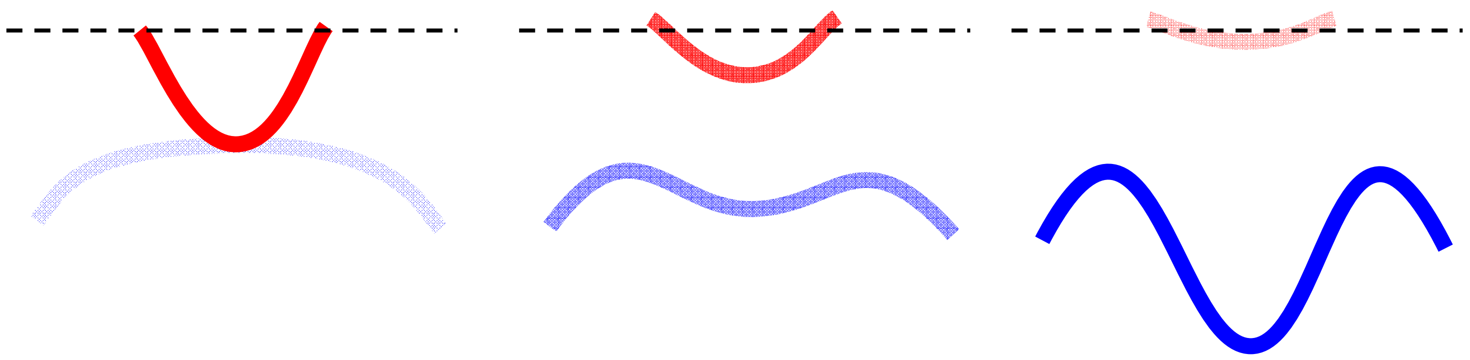


M. Hashimoto et al. *Nat. Phys.* **6**, 414 (2010)

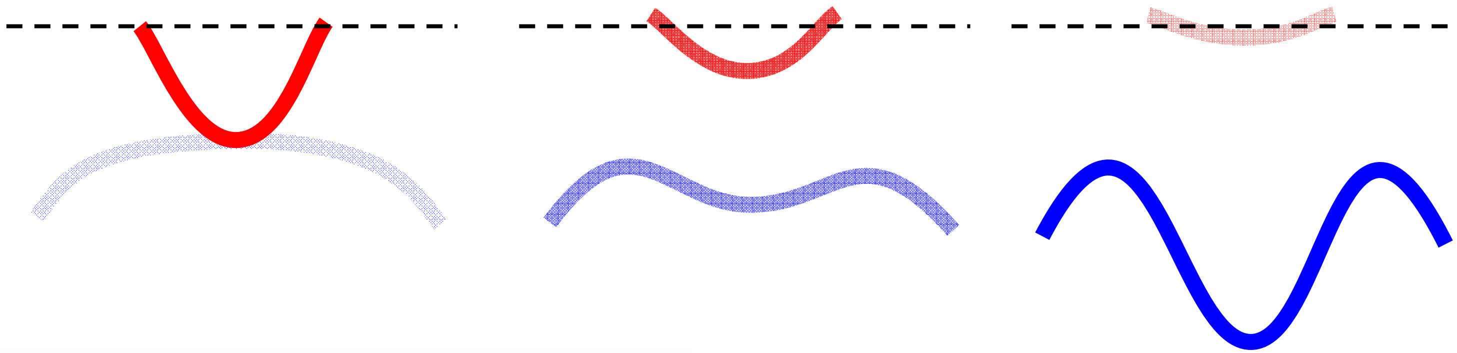
$(0,\pi)$ SDW

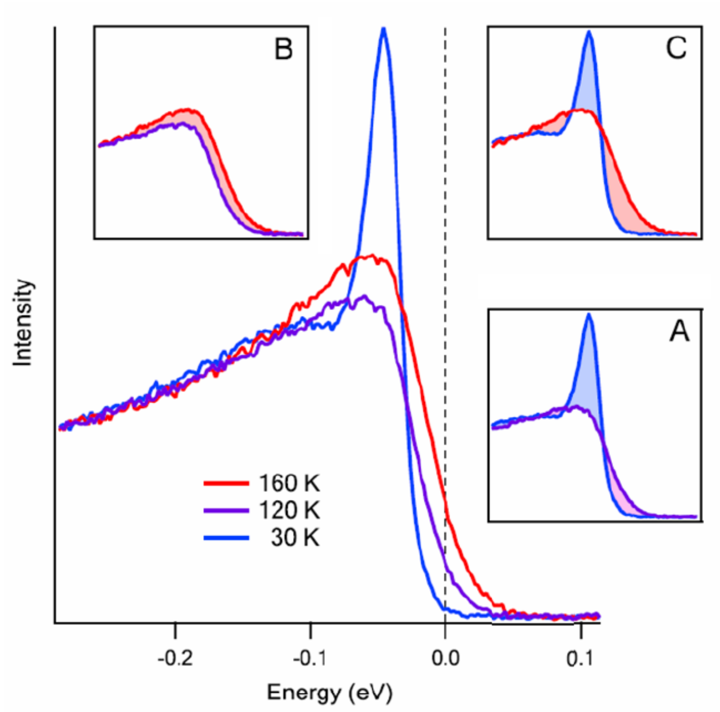


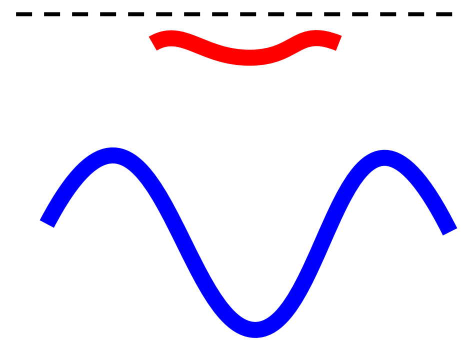
(0,π) SDW



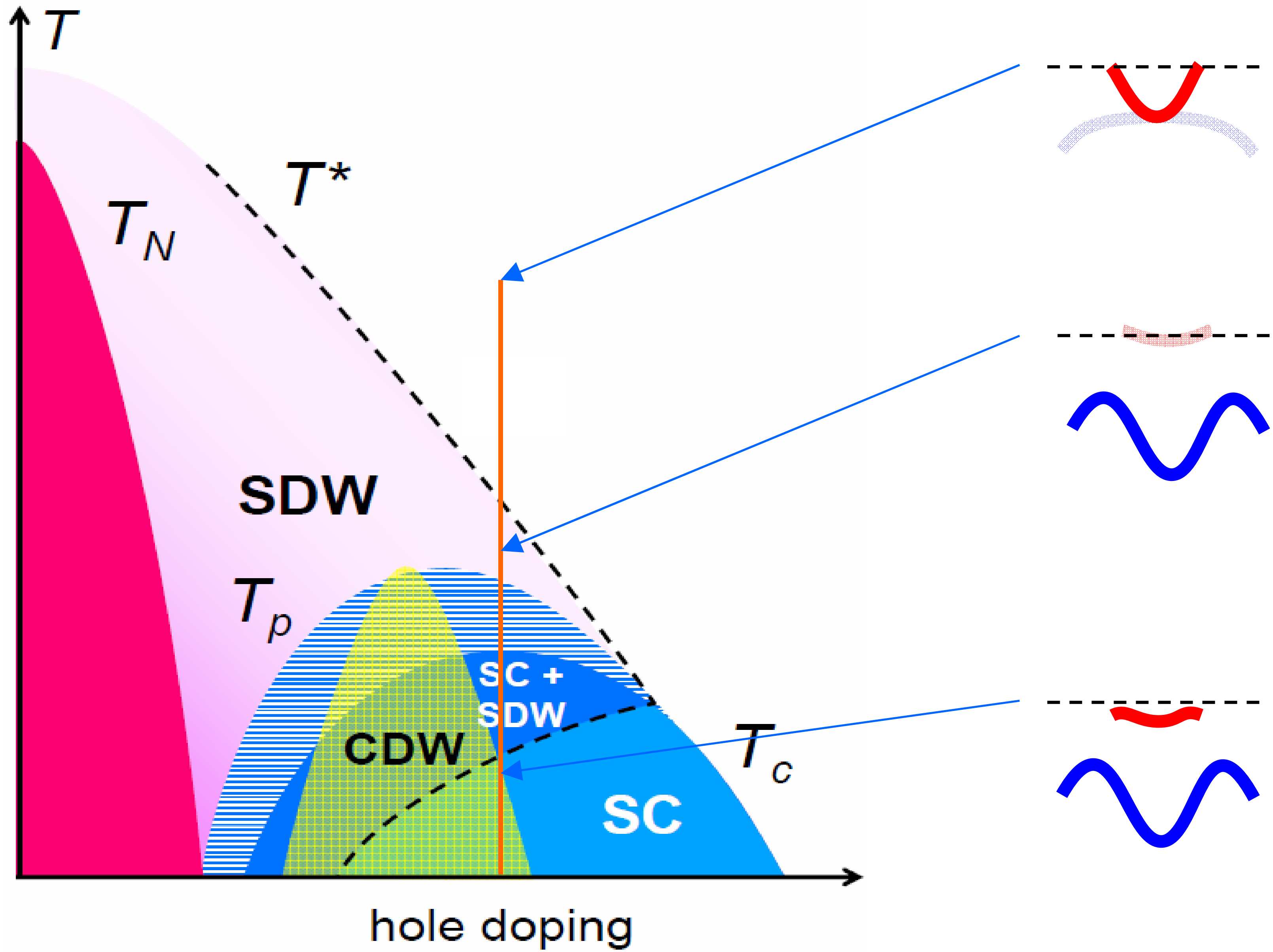
(0,π) SDW



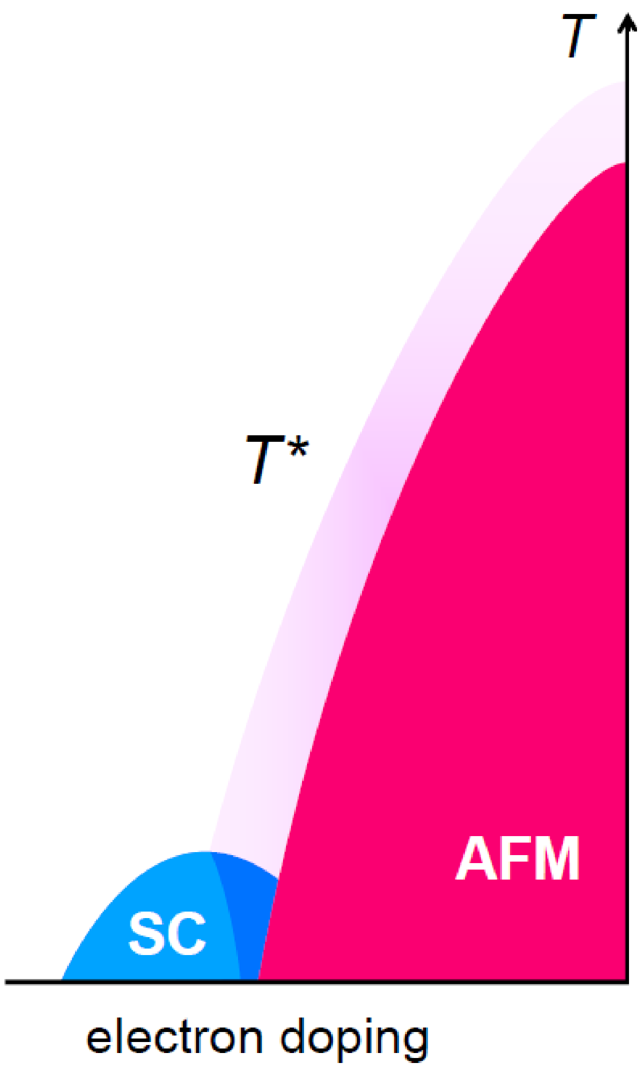


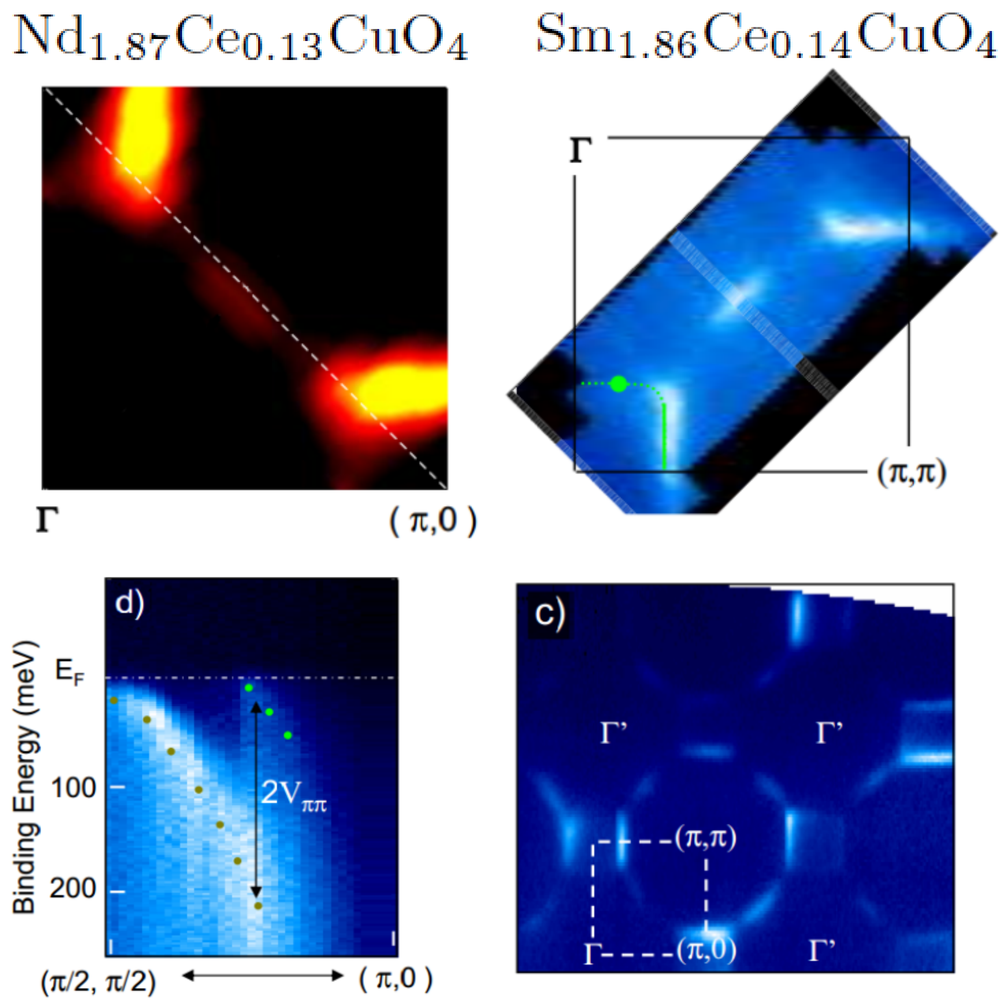


Pseudogap in hole-doped cuprates



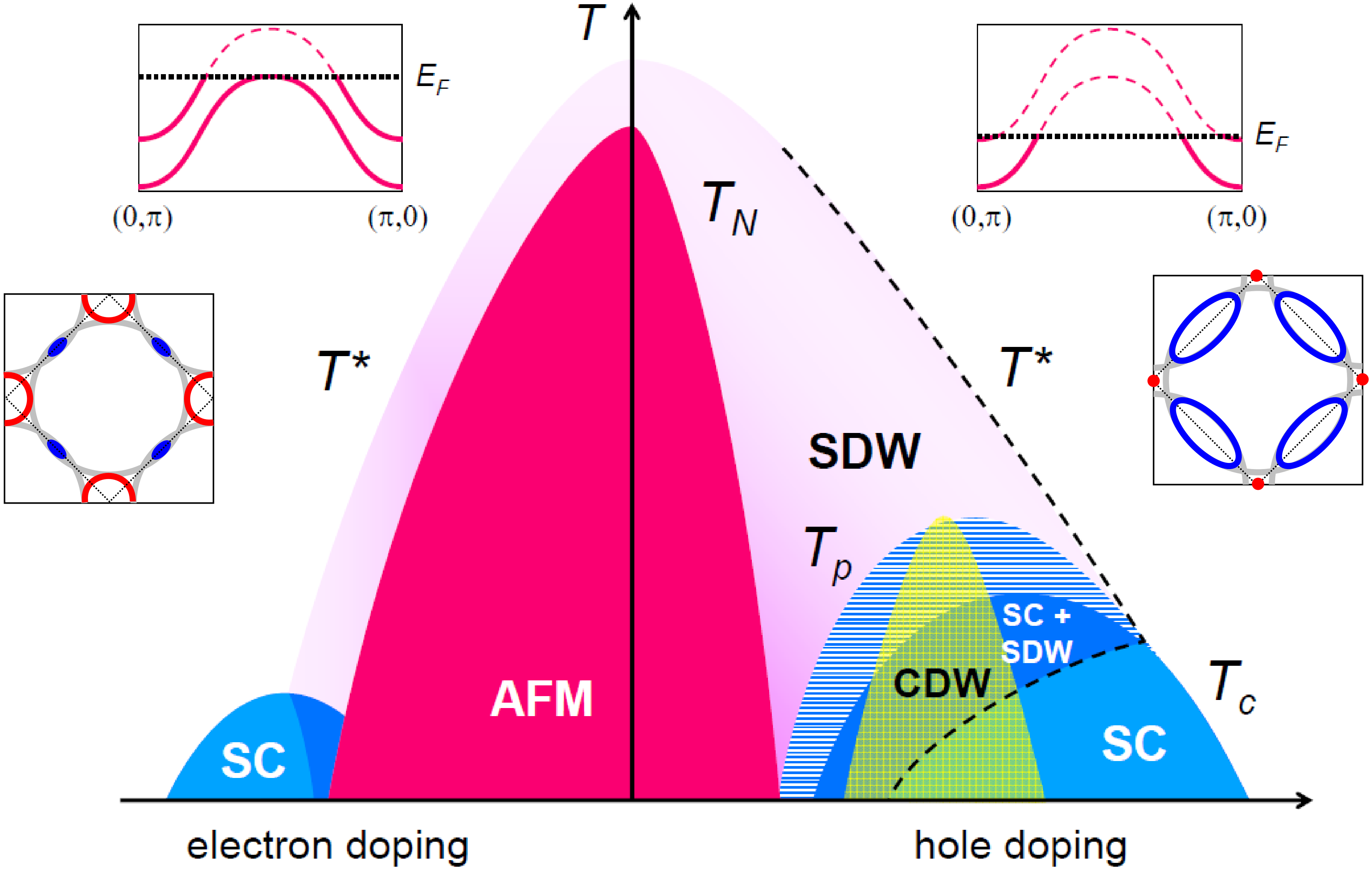
SDW in electron-doped cuprates





H. Matsui et al., *PRL* **94**, 047005 (2005)
S. R. Park et al., *PRB* **75**, 060501 (2007)

SDW and superconductivity



Pseudogap in cuprates

There are at least **three** mechanisms that form the pseudogap in the hole doped cuprates:

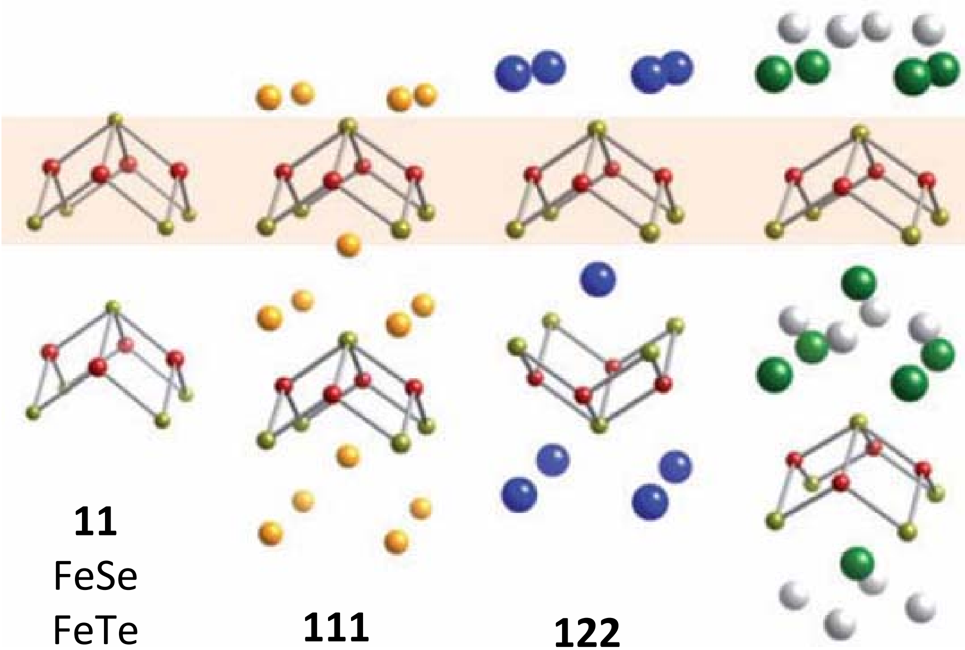
1 the preformed pairing;

2 the incommensurate CDW due to nesting of the straight parallel Fermi surface sections around (π,0) and (0,π);

3 **SDW** which is **dominant** constituent of the pseudogap assosiated with ***T**** and is either causing or caused by the Mott localization.

These phases occupy different parts of the phase diagram and gap different parts of the Fermi surface competing for it.

Iron-based superconductors (FeSC)



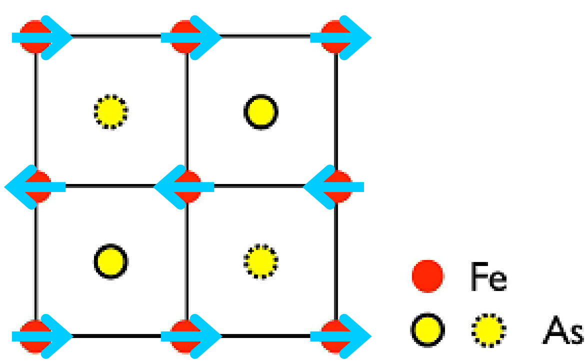
11 FeSe FeTe

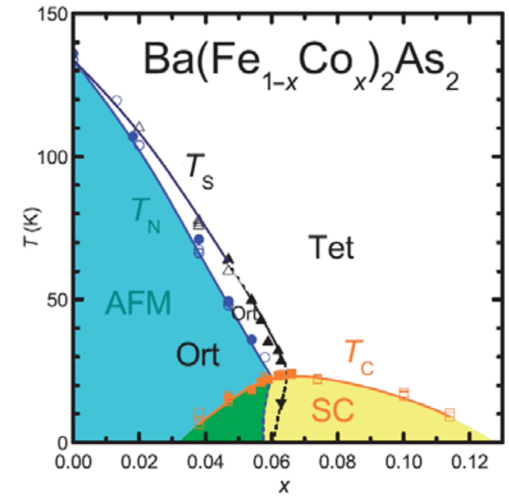
111 LiFeAs

122 $BaFe_2As_2$

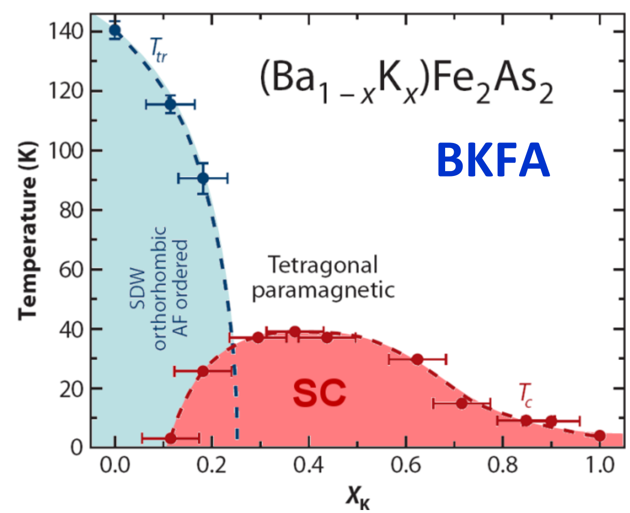
1111 LaFeAsO

Paglione & Greene, *Nat. Phys.* (2010)



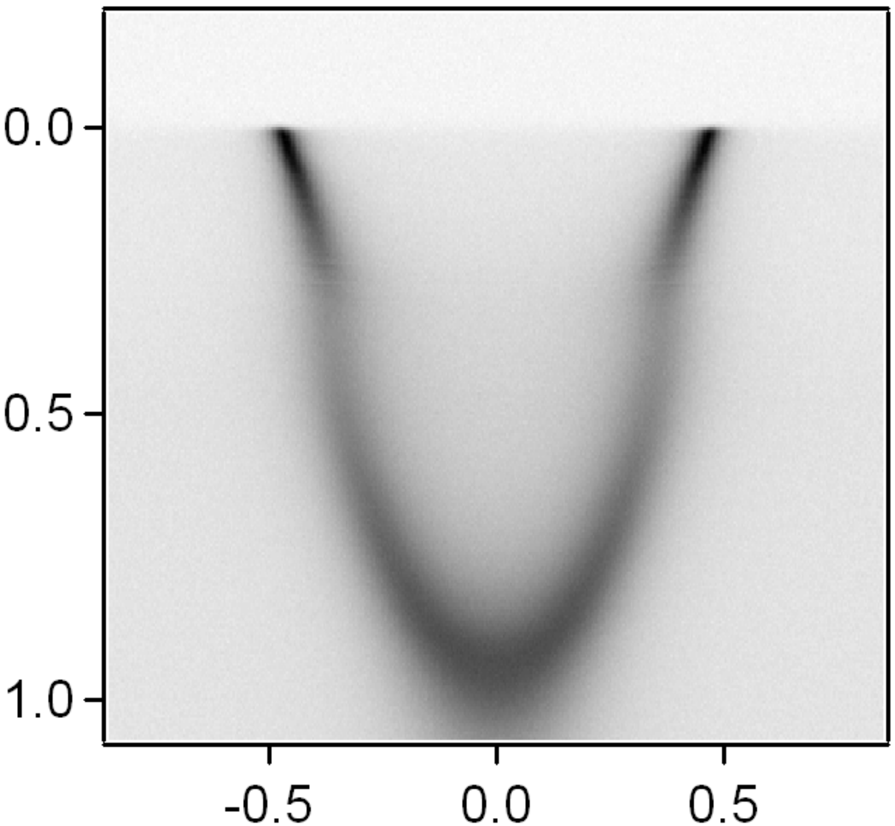


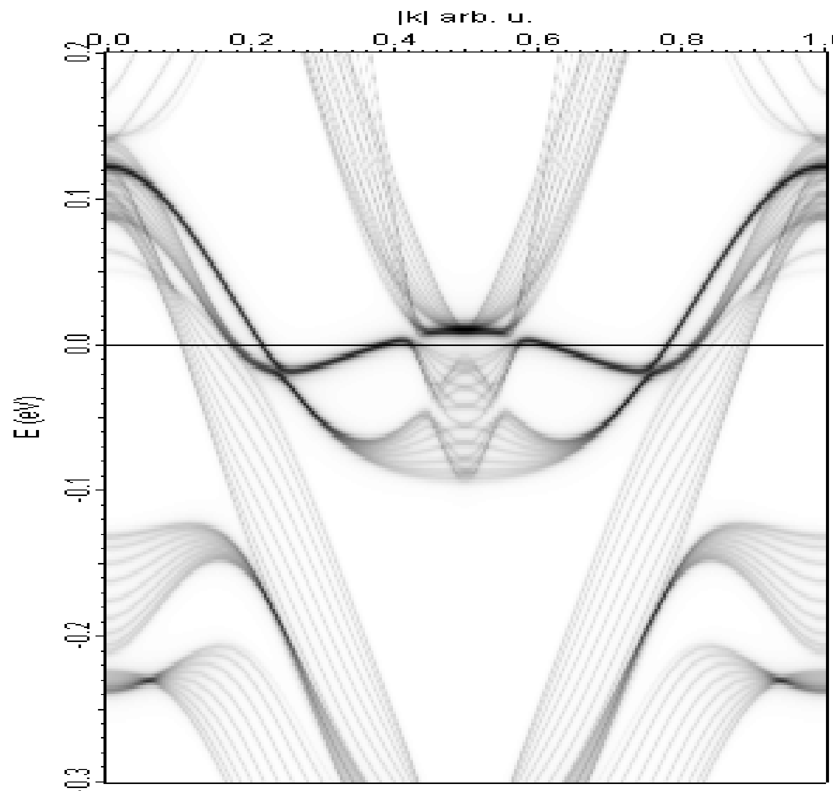
S.Nandi *et al.* PRL 2010



H.-H.Wen & S.Li Annu. Rev. Cond. Mat. Phys. 2011

Cu-SC *vs* Fe-SC

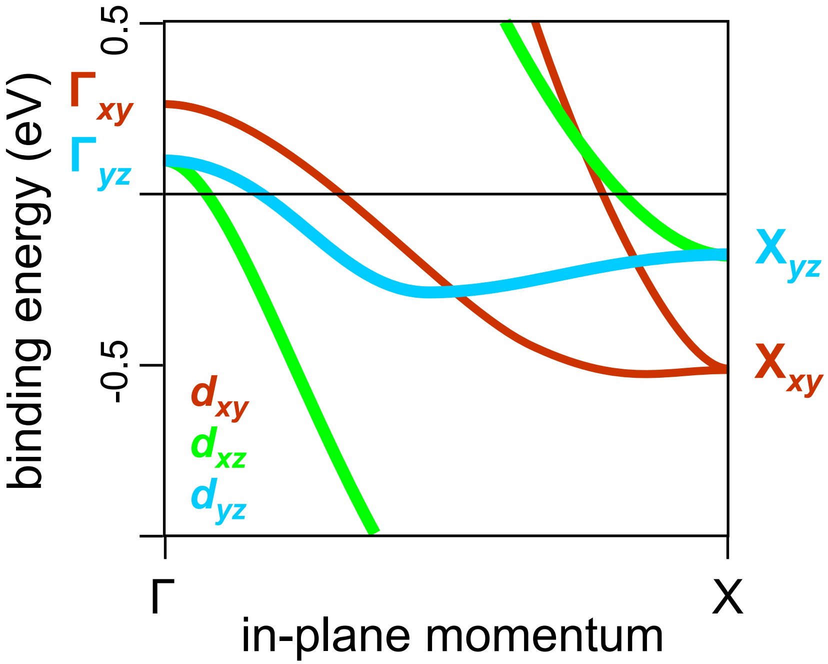


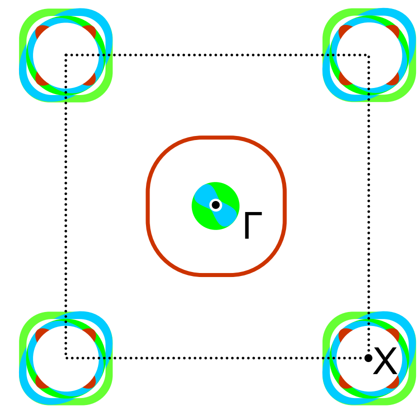


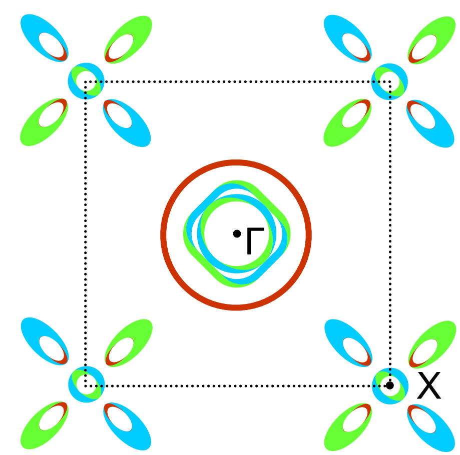
Cu-SC vs Fe-SC

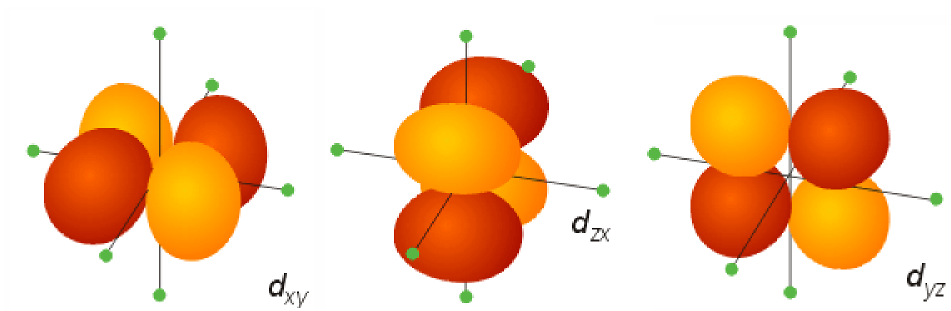
	Cu-SC	Fe-SC
band structure	simple (1 band, split)	complex (5 bands)
renormalization	k-dependent	band dependent
$1+\lambda$ (ω cutoff)	k-dependent 2 (0.5 eV)	>4 (50 meV) 3 (1.5 eV)
SC gap	k-dependent	band dependent
pseudogap	k-dependent	no?
main interaction	SF	(phonons + SF) *multi-bands

Iron-based superconductors: electronic structure

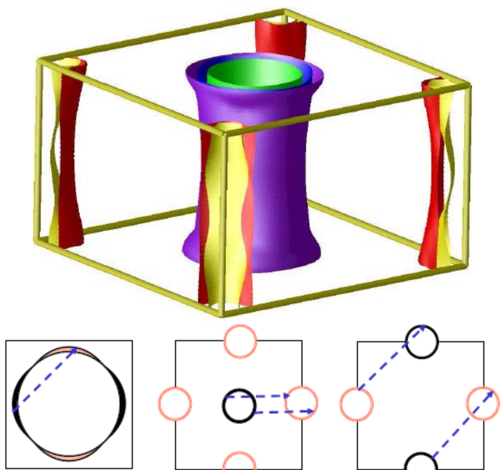




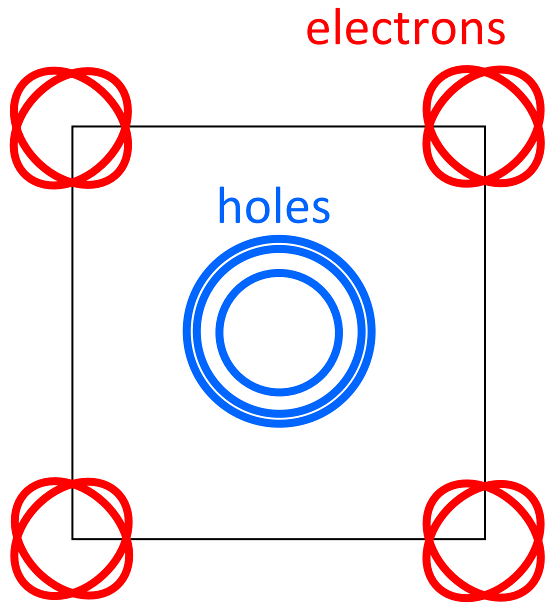


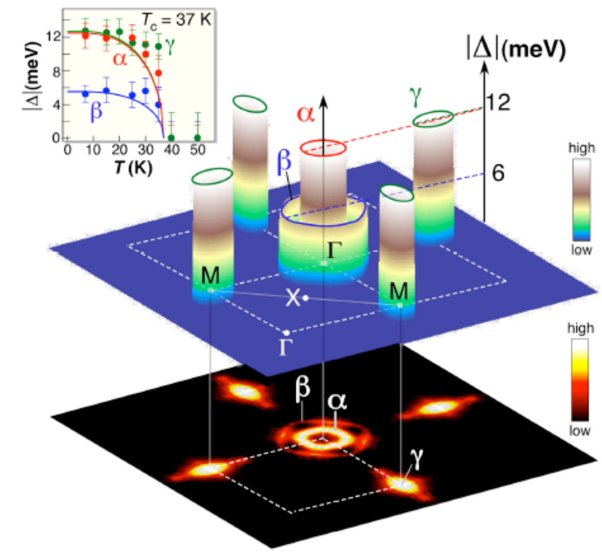


Fermi surface of BKFA

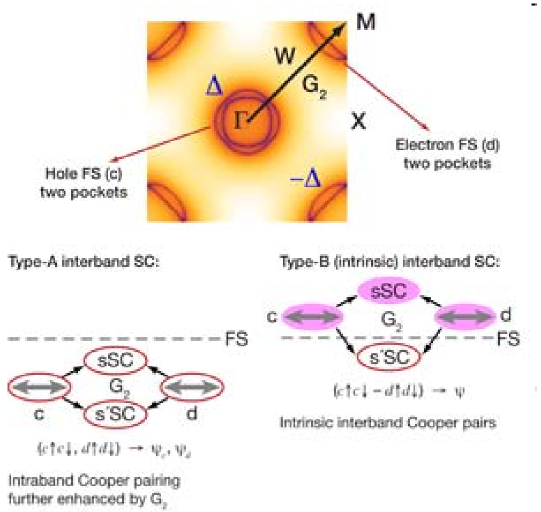


Mazin & Schmalian 2009

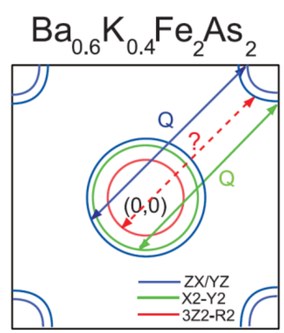




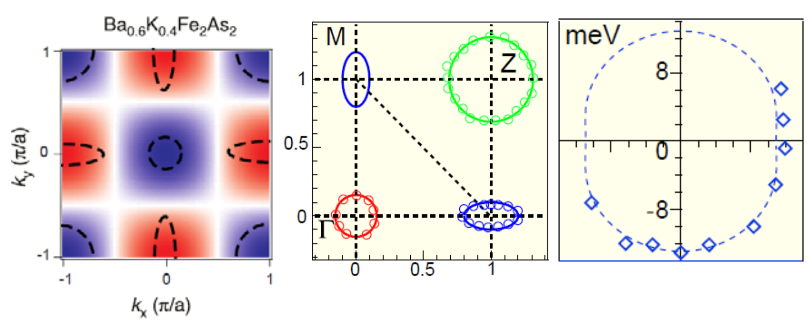
Ding *EPL* 2008



Tesanovic *Physics* 2009

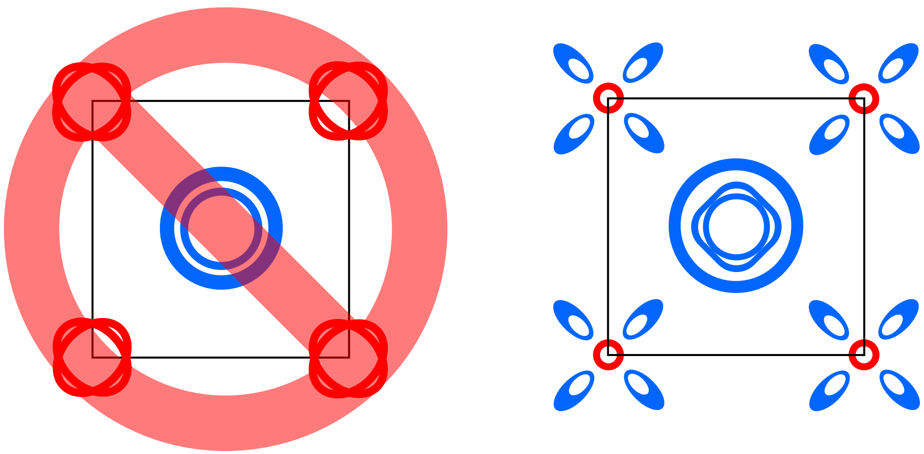


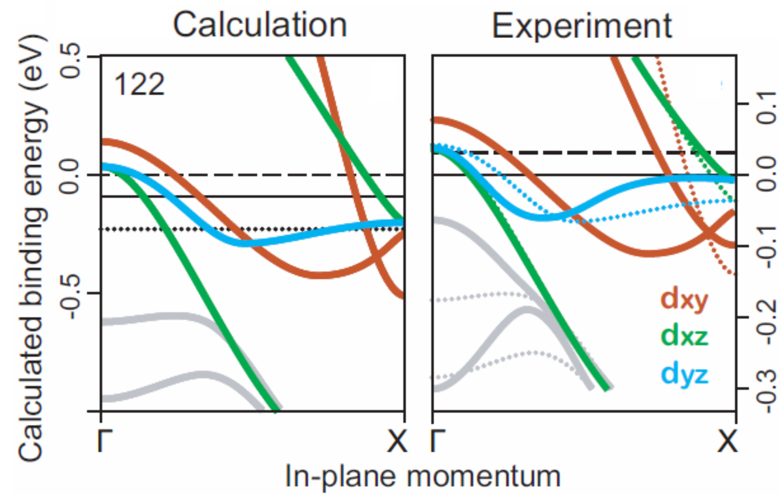
Shimojima *Science* 2011



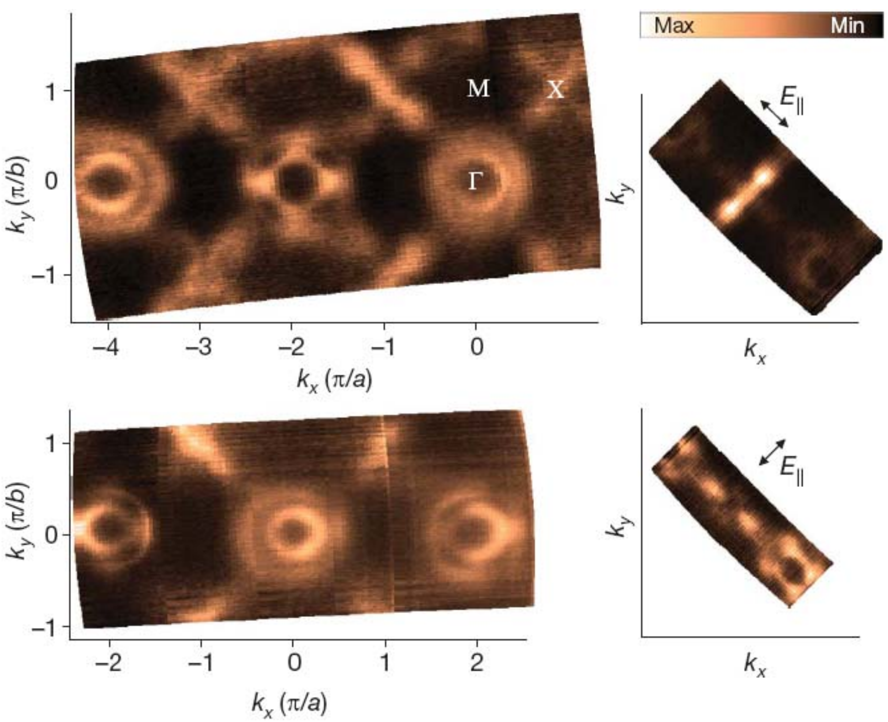
Hu & Ding arXiv:1107.1334

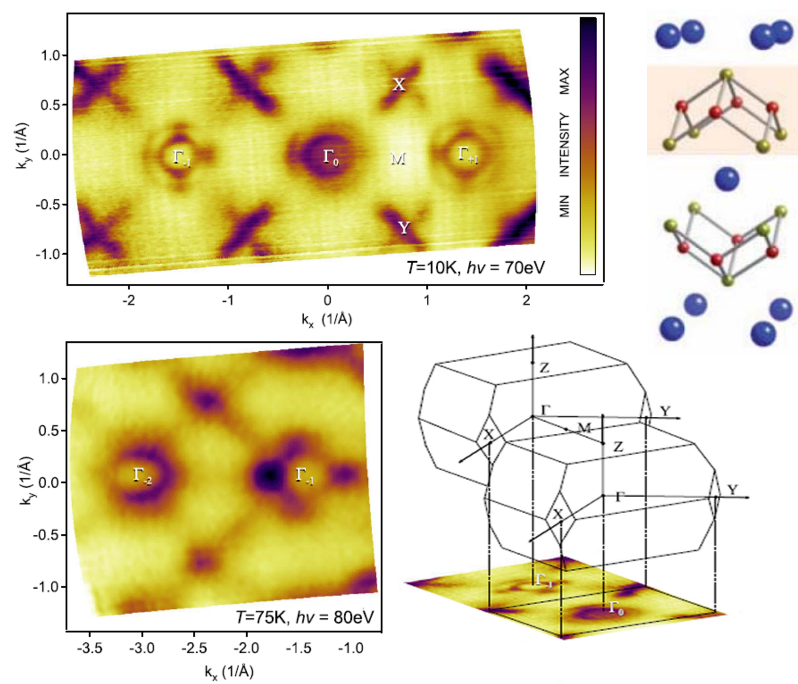
Fermi surface of BKFA





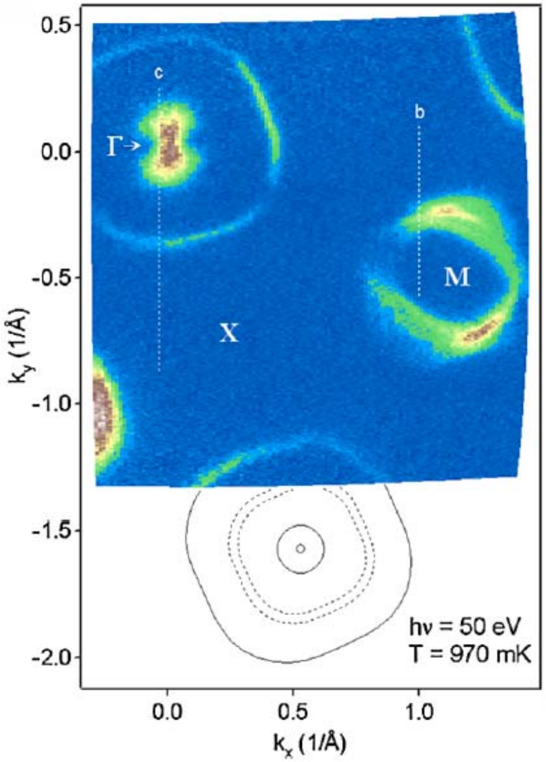
A. A. Kordyuk, *J. Supercond. Nov. Magn.* 2013

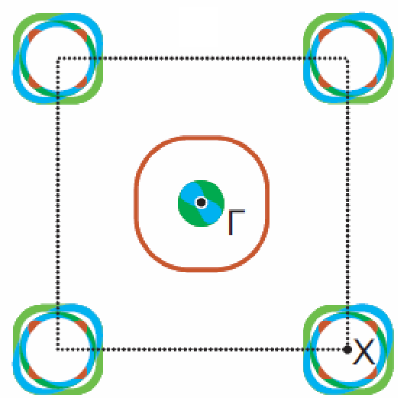


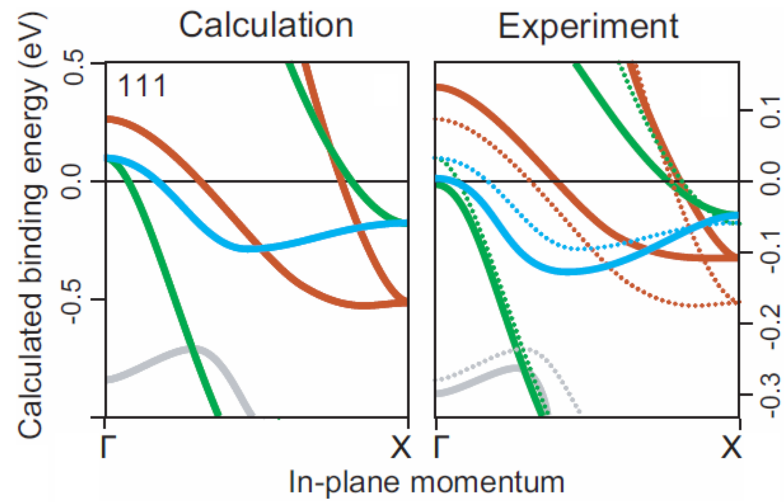


V. Zabolotnyy *Nature* 2009

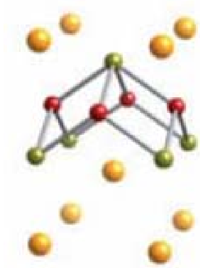
Fermi surface of LiFeAs

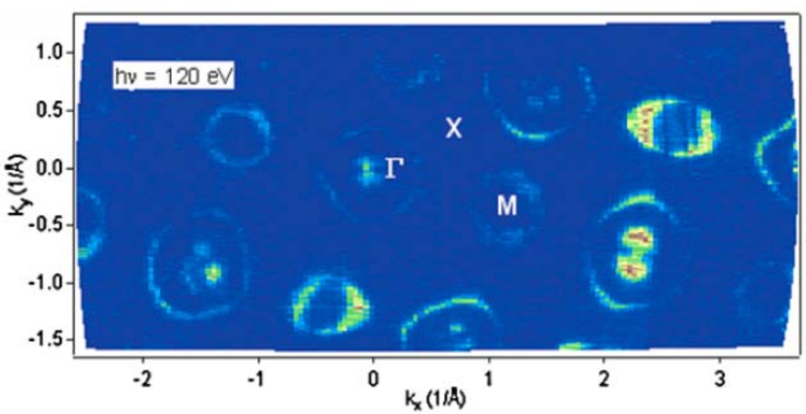




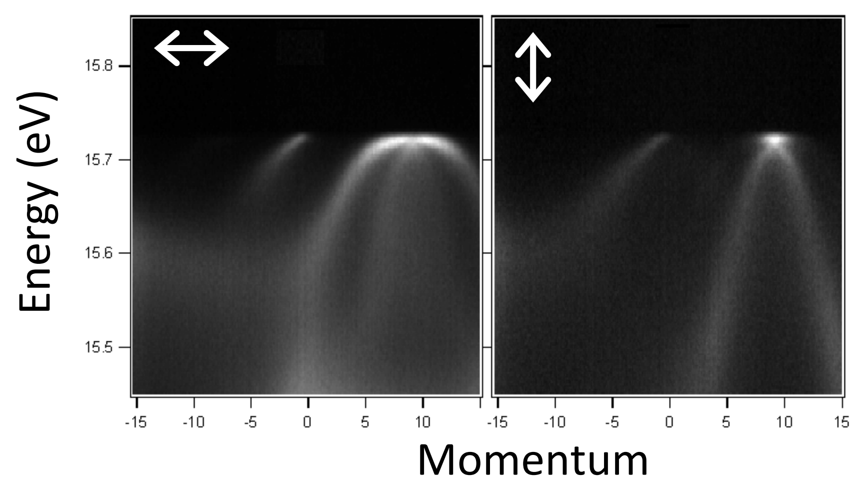


Kordyuk, *J. Supercond. Nov. Magn.* 2013





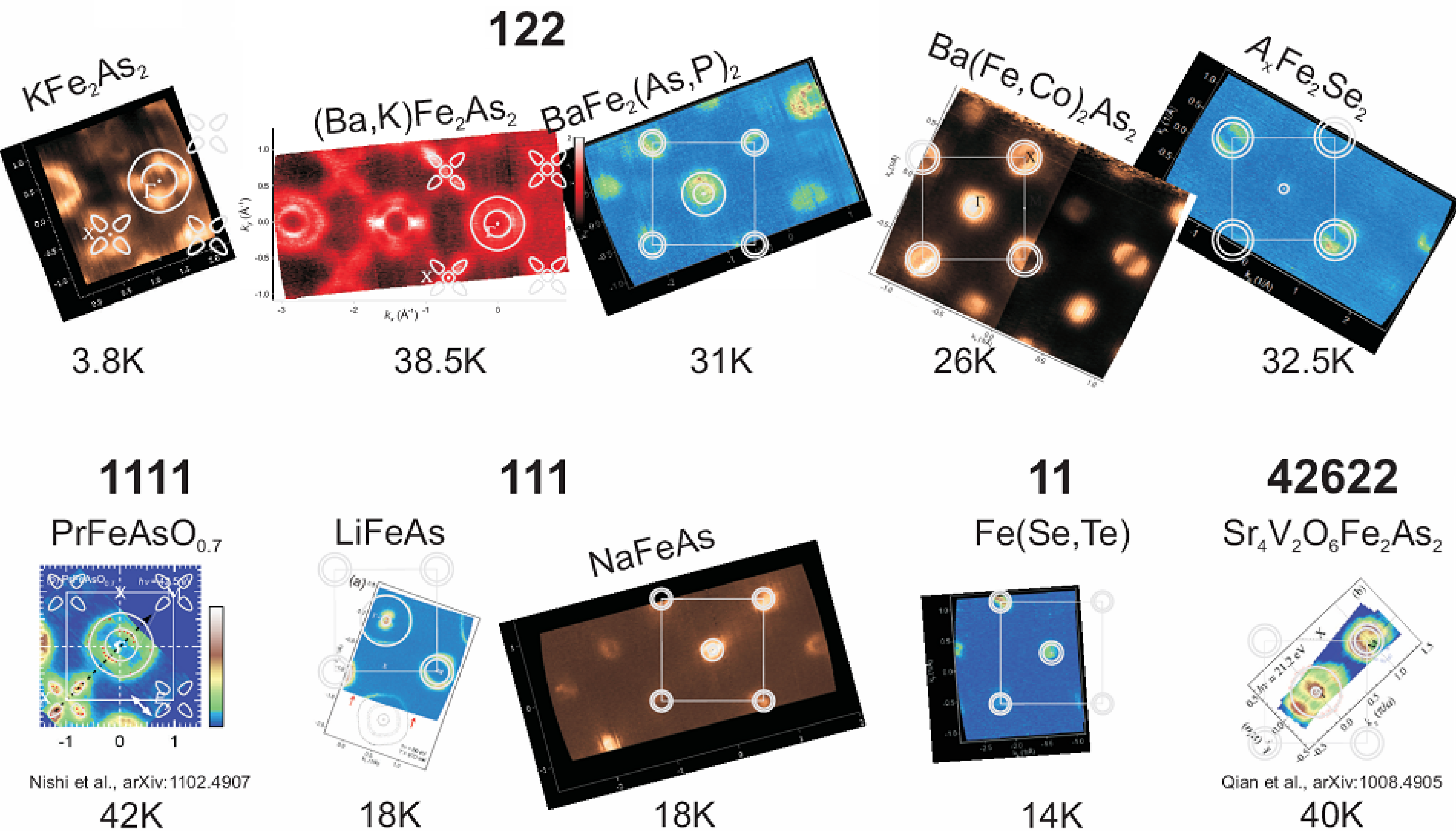
polarization



Borisenko *PRL* 2010

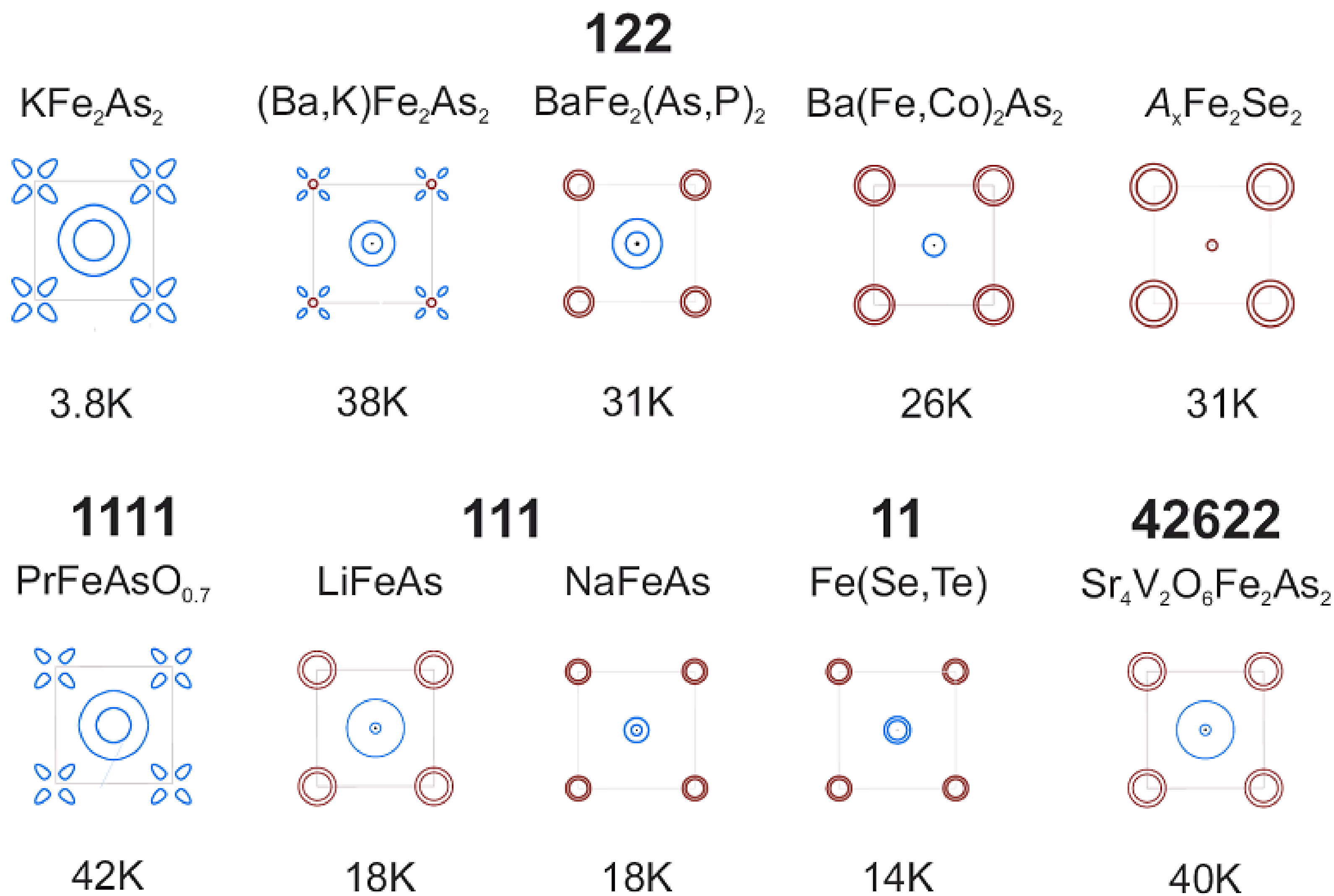
Kordyuk *PRB* 2011

FS's of iron-based superconductors



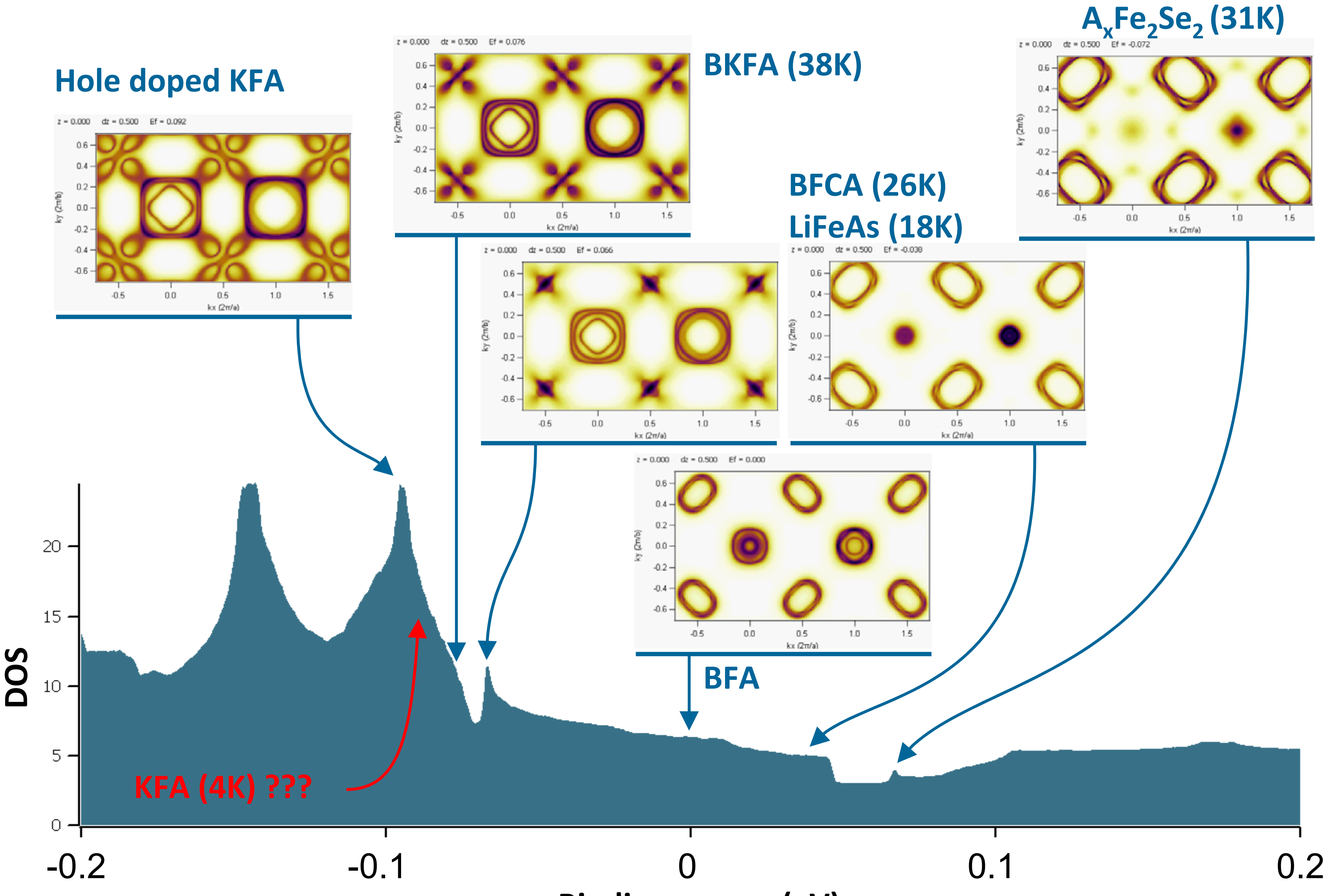
D. Evtushinsky 2011

FS's of iron-based superconductors



D. Evtushinsky 2011

BFA: density of states



Zabolotnyy 2011

"Topological" superconductivity

=

Small Fermi surfaces

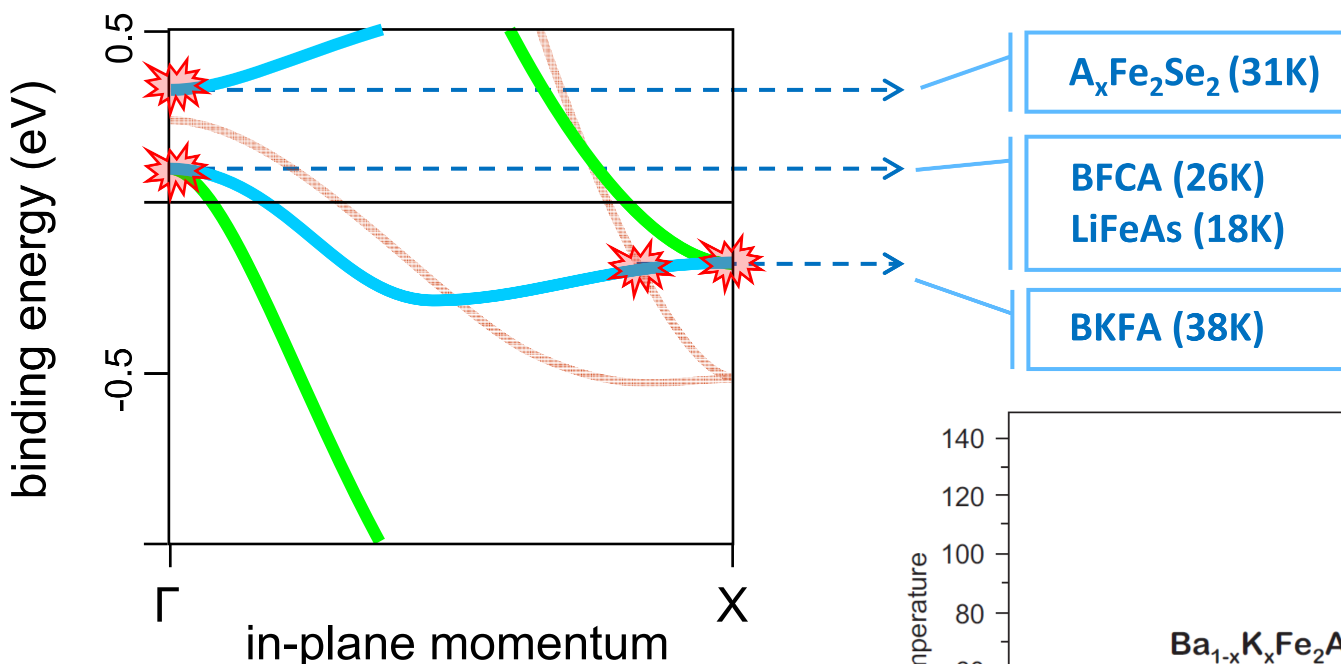
=

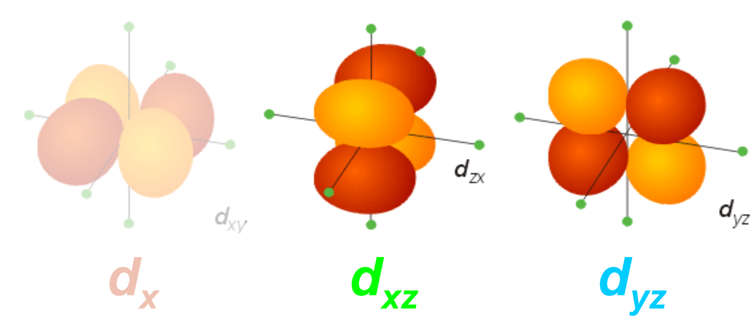
vicinity to Lifshitz transition

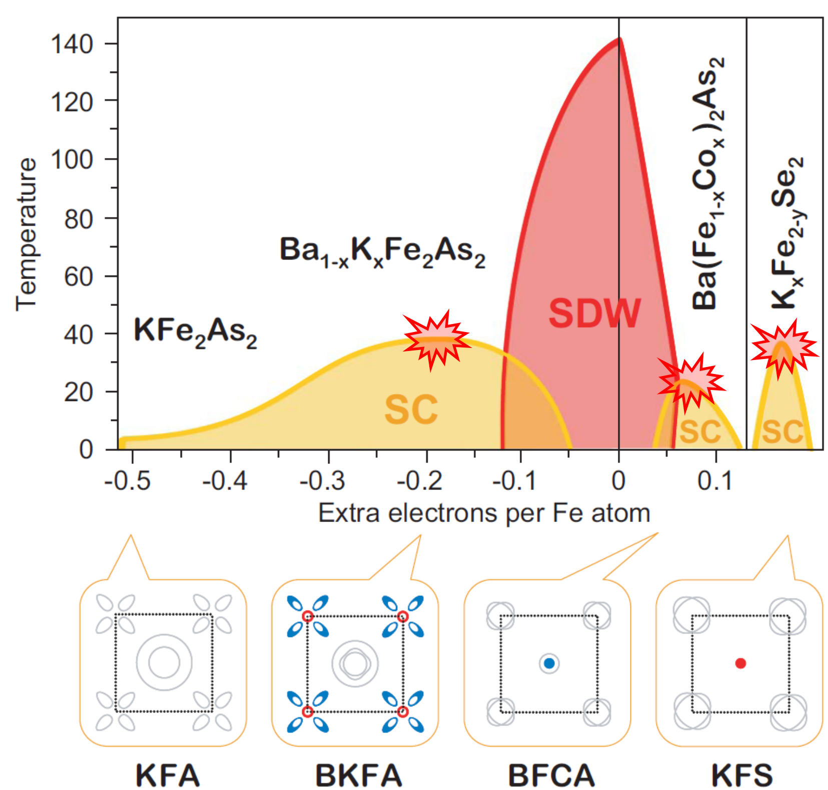
=

vicinity to 2D-3D crossover

FeSC: electronic structure and superconductivity



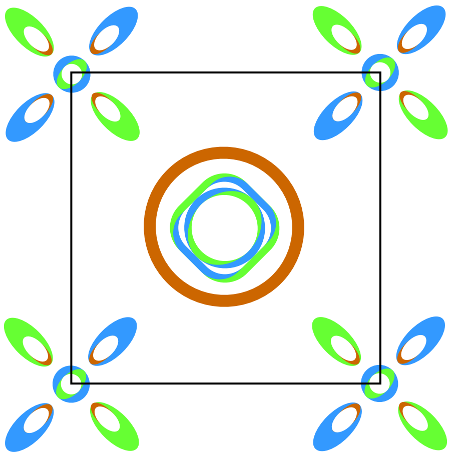


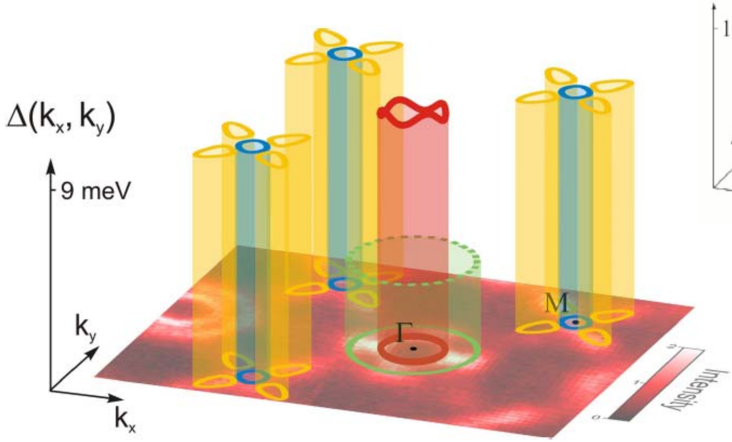


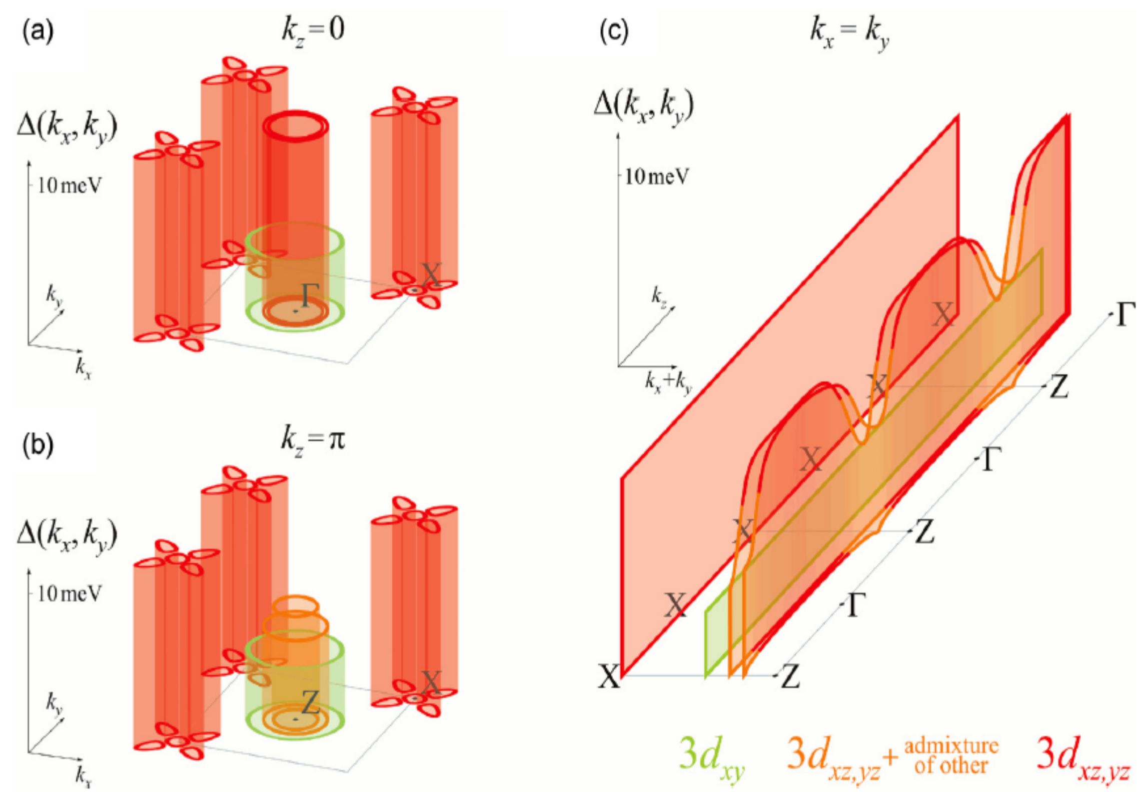
correlates with SC gap!!! - Daniil

A. A. Kordyuk, *J. Supercond. Nov. Magn.* (2013); *Low Temp. Phys.* (2012)

BKFA: Fermi surface and gaps







D. Evtushinsky PRB 2009, NJP 2009

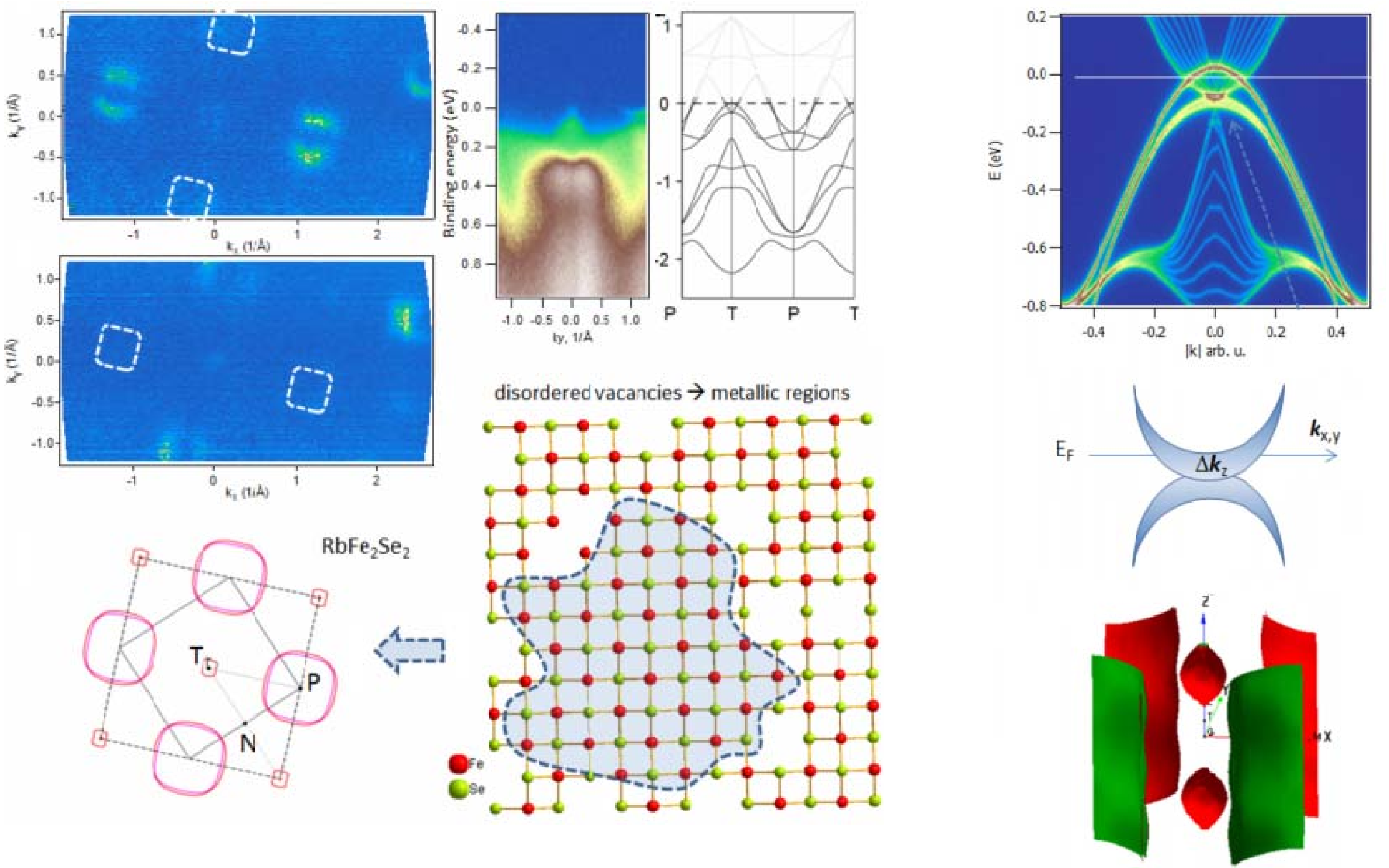
Δ correlates with the orbital composition:

Δ = 3–4 meV for 3dxy and 3dz2

Δ = 10.5 meV for 3dxz/yz.

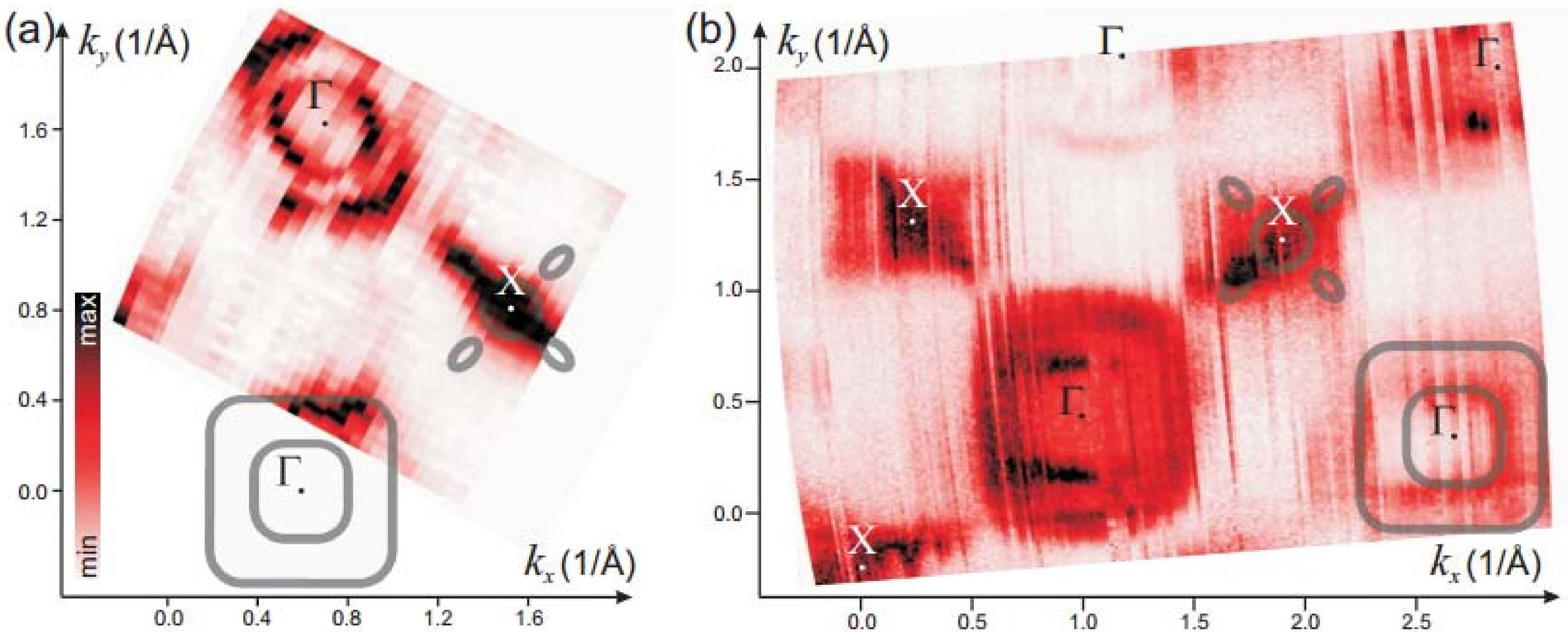
D. Evtushinsky PRB 2014

A-FeSe $Rb_{0.77}Fe_{1.61}Se_2$ $T_c = 32.6$ K



S. V. Borisenko arXiv:1204.1316 – PRB 2013

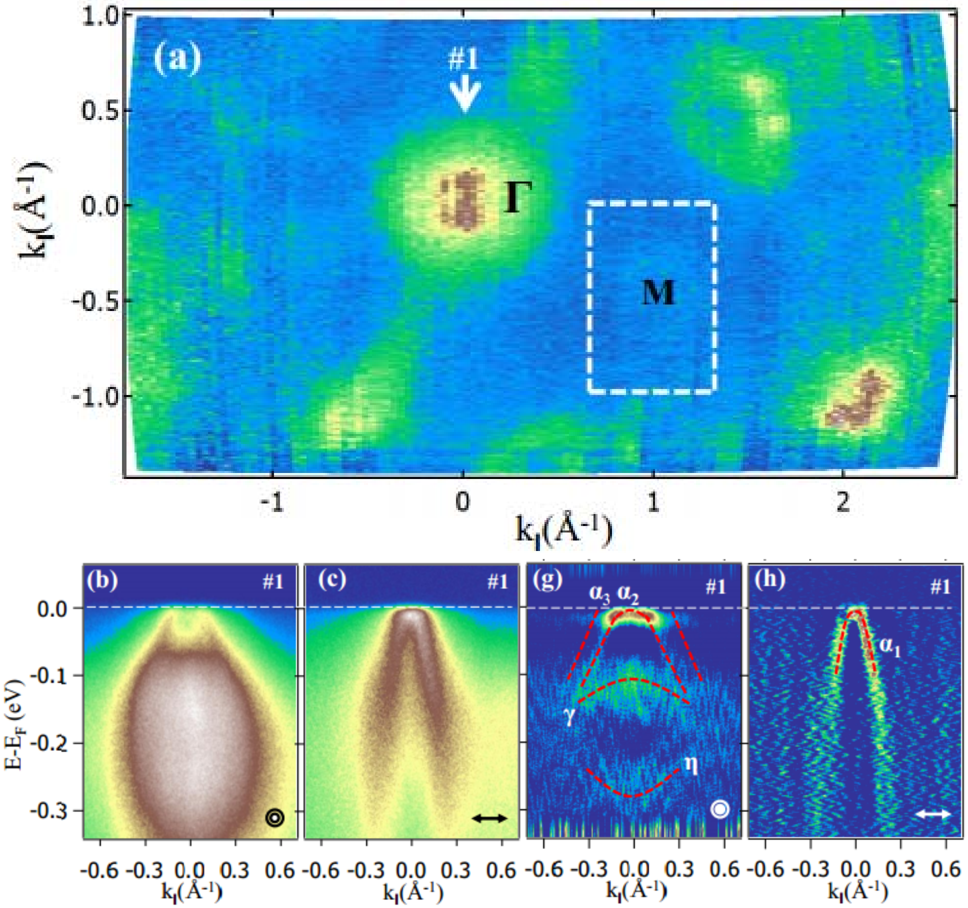
$Ca_{1-x}Na_xFe_2As_2$ **33K**

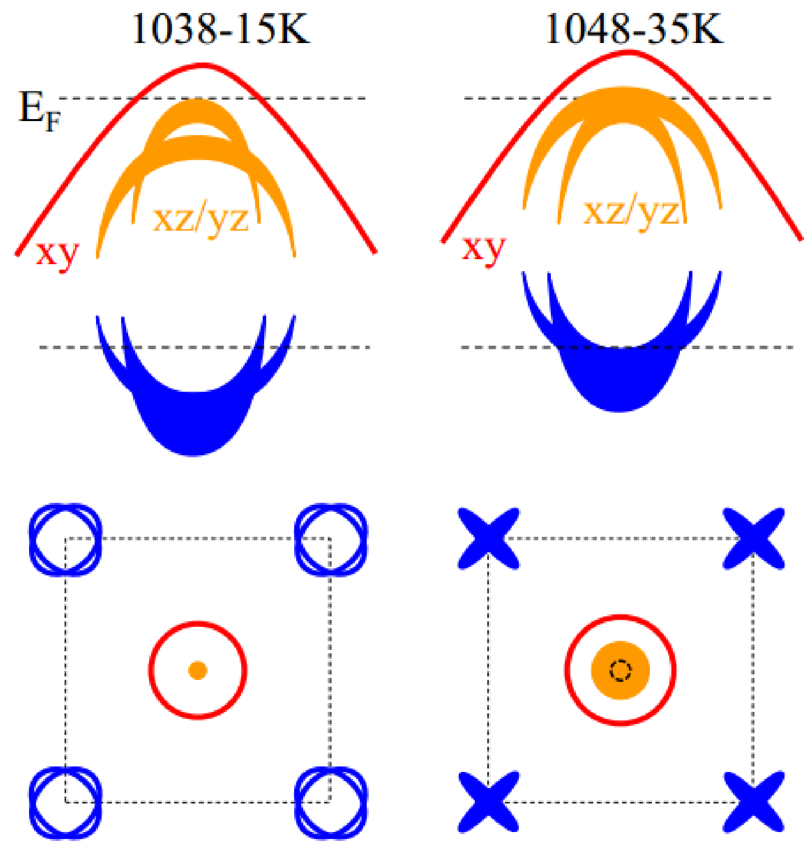


D. V. Evtushinsky arXiv:1211.4593

$(CaFe_{0.95}Pt_{0.05}As)_{10}Pt_3As_8$ **"10 3 8" – 15K**

$(CaFeAs)_{10}Pt_{3.58}As_8$ **"10 4 8" – 35K**



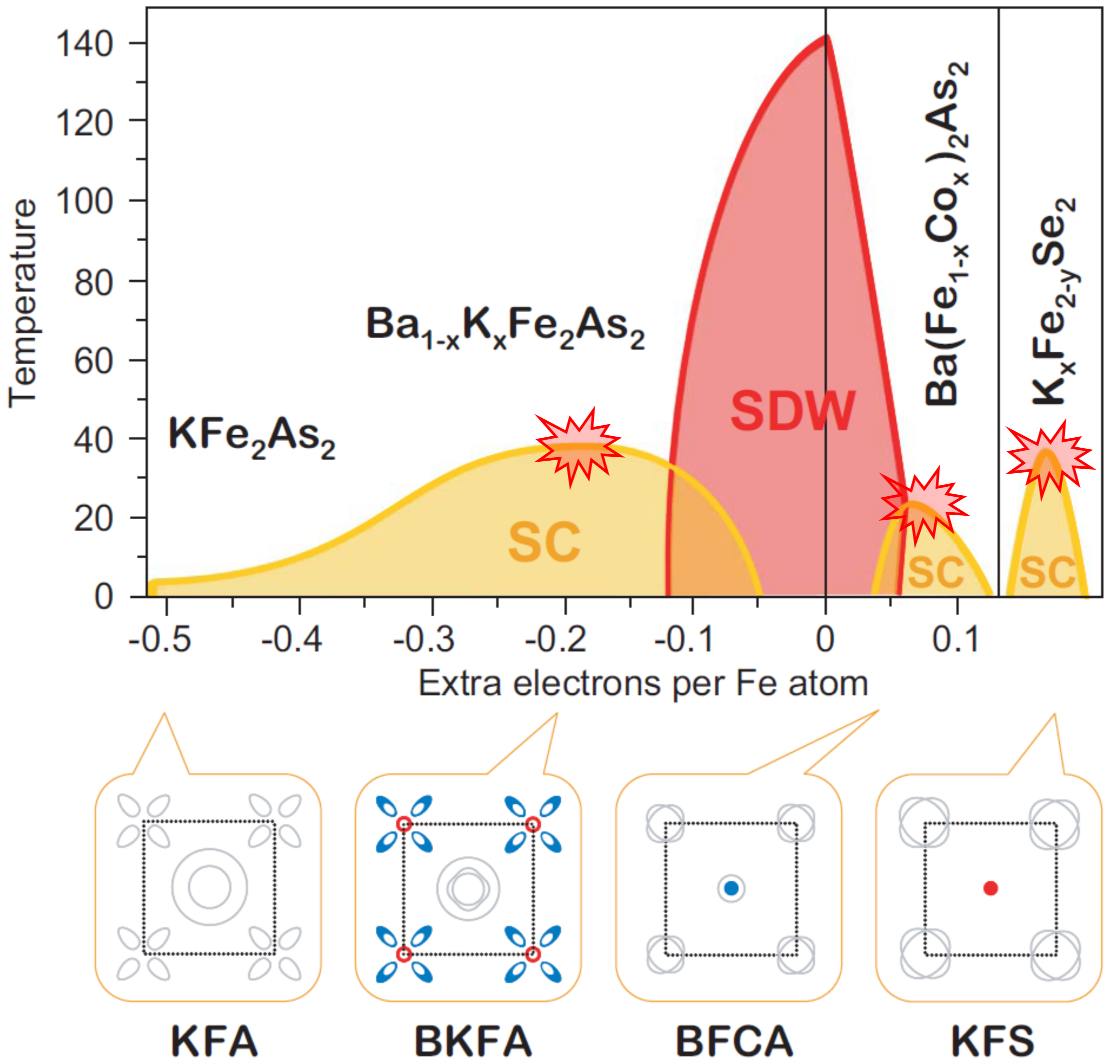


S.Thirupathaiah arXiv:1307.1608

- **The band structure of Fe-SC is well captured by LDA but do not take it too literally. The calculated Fermi surface is usually bad starting point for theory.**

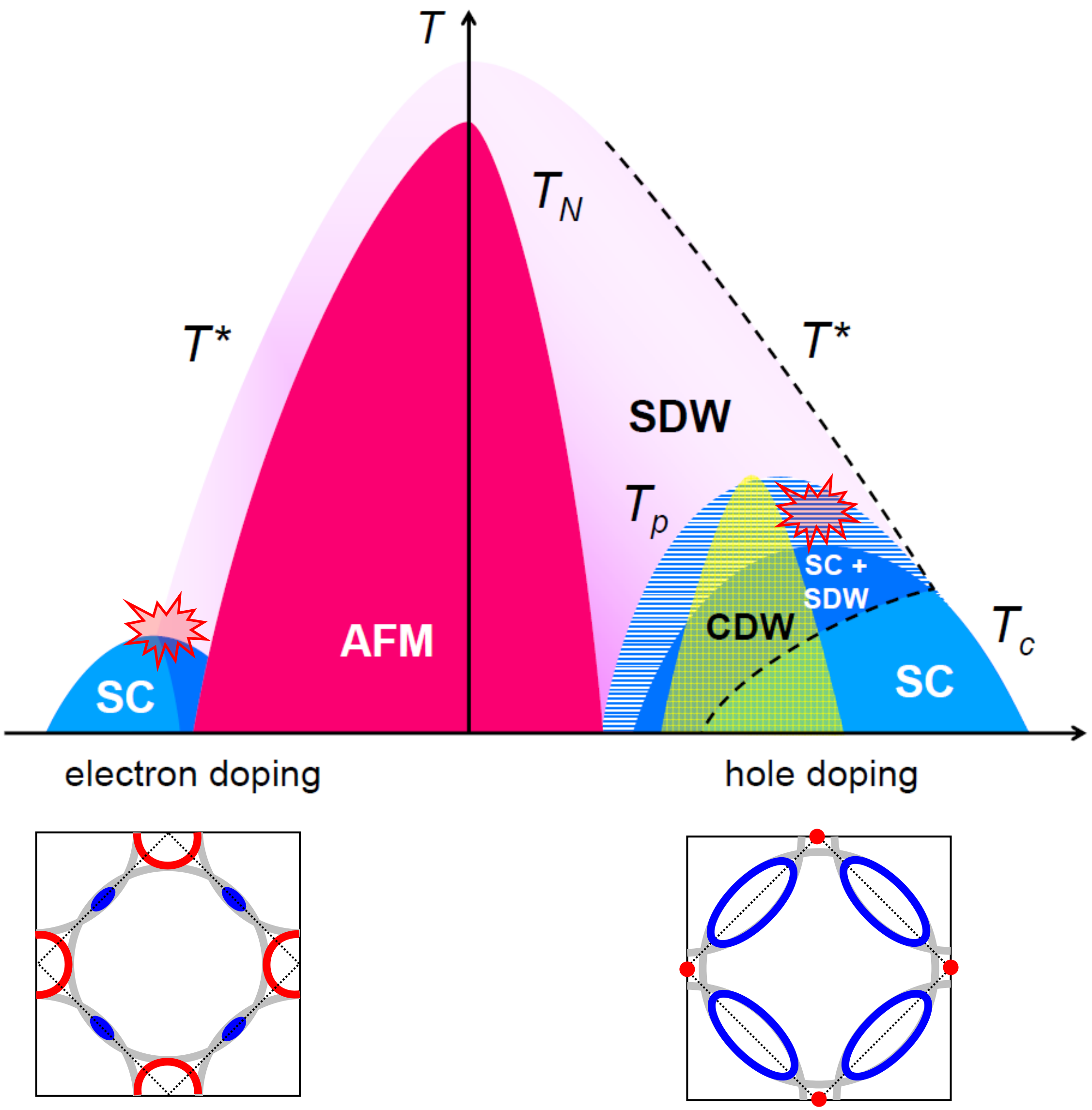
- **Main contributors to SC are dxz,yz electrons and Tc for different compounds seems to correlate with the position of the Van Hove singuliarities (Lifshitz transitions) for the xz- and yz-bands.**

"Topological" superconductivity in Fe-SC



A. A. Kordyuk, *J. Supercond. Nov. Magn.* (2013); *Low Temp. Phys.* (2012)

"Topological" superconductivity in Cu-SC



A. A. Kordyuk *Low Temp. Phys.* (2015)