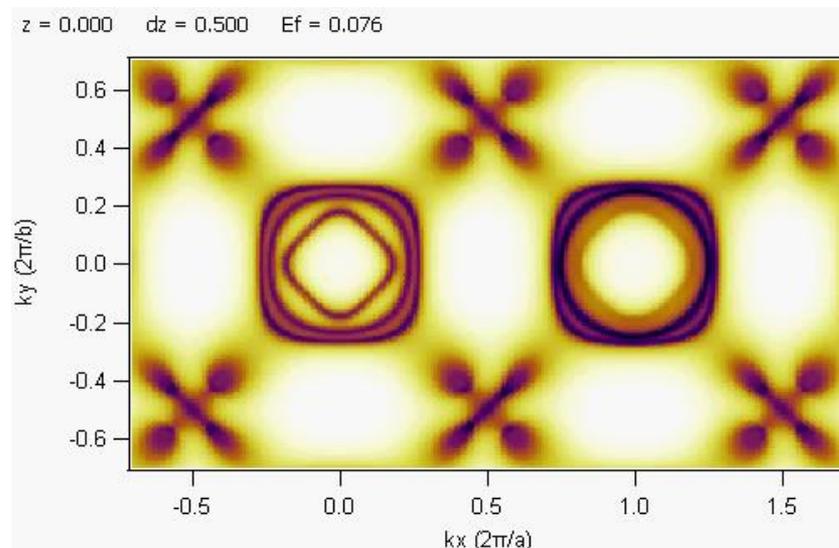
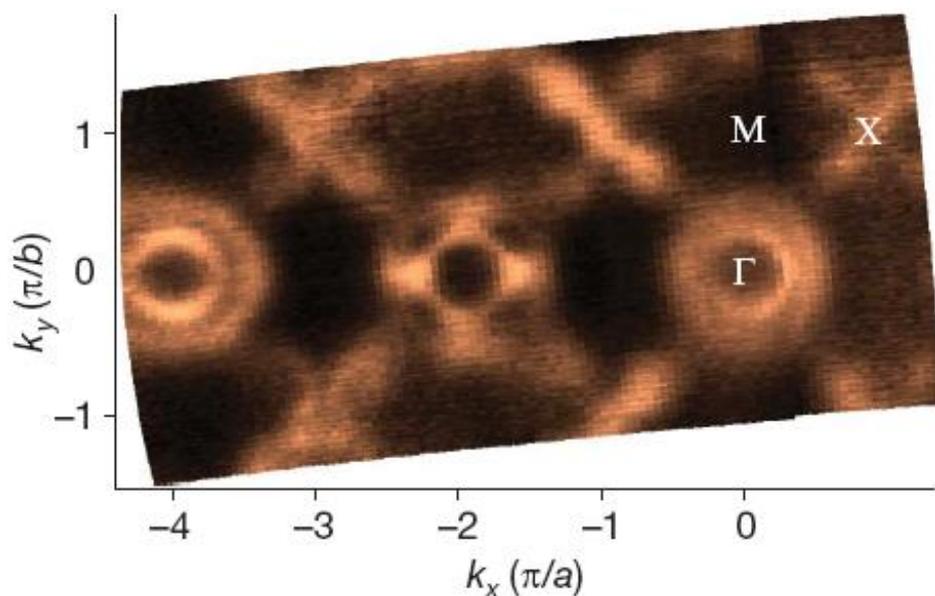


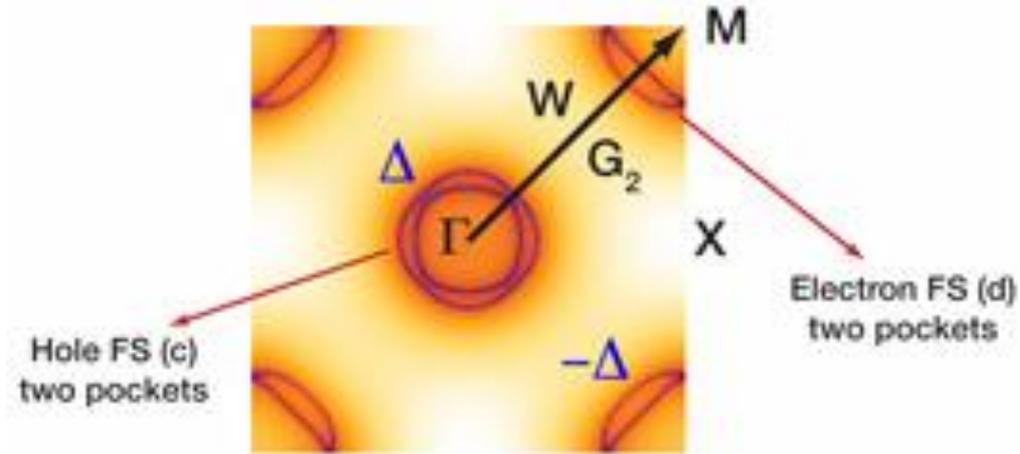
Сверхпроводники на основе железа: электронная структура и электронные свойства



А. А. Кордюк
Институт металлофизики НАН Украины

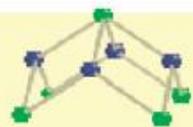
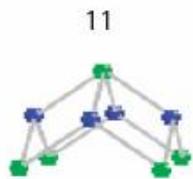
Темы

- Электронная структура
- Сверхпроводящая щель
- Собственная энергия
- Магнетизм



**Ферро-пниктиды –
сверхпроводники на основе железа**

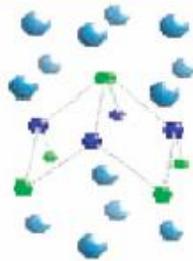
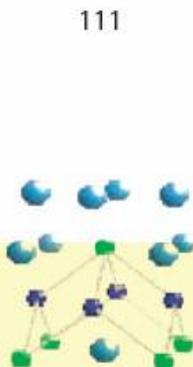
Iron-based superconductors



FeSe
FeTe

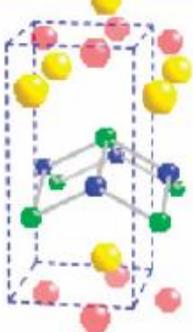
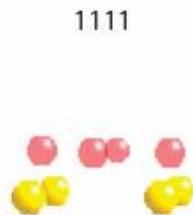
$T_c = 8 \text{ K}$

HP
 $T_c = 37 \text{ K}$



LiFeAs
NaFeAs

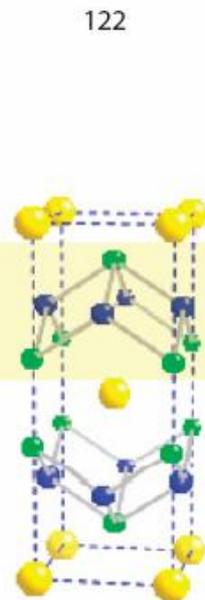
$T_c = 18 \text{ K}$



F-REFeAsO

RE-CaFeAsF

$T_c = 57 \text{ K}$

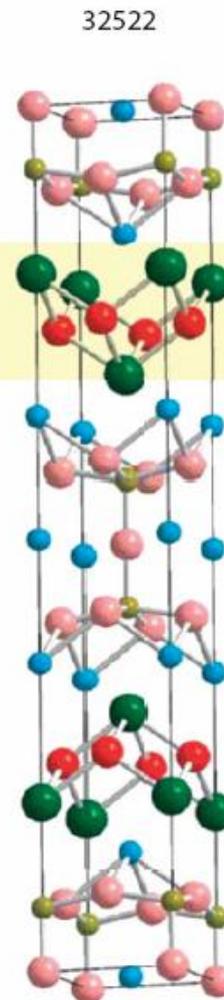


(Ba,K)Fe₂As₂

$T_c = 38 \text{ K}$

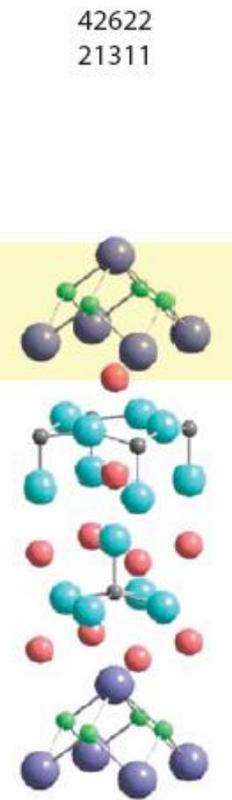
Ba(Fe,Co)₂As₂

$T_c = 26 \text{ K}$



(Sr₃Sc₂O₅)Fe₂As₂

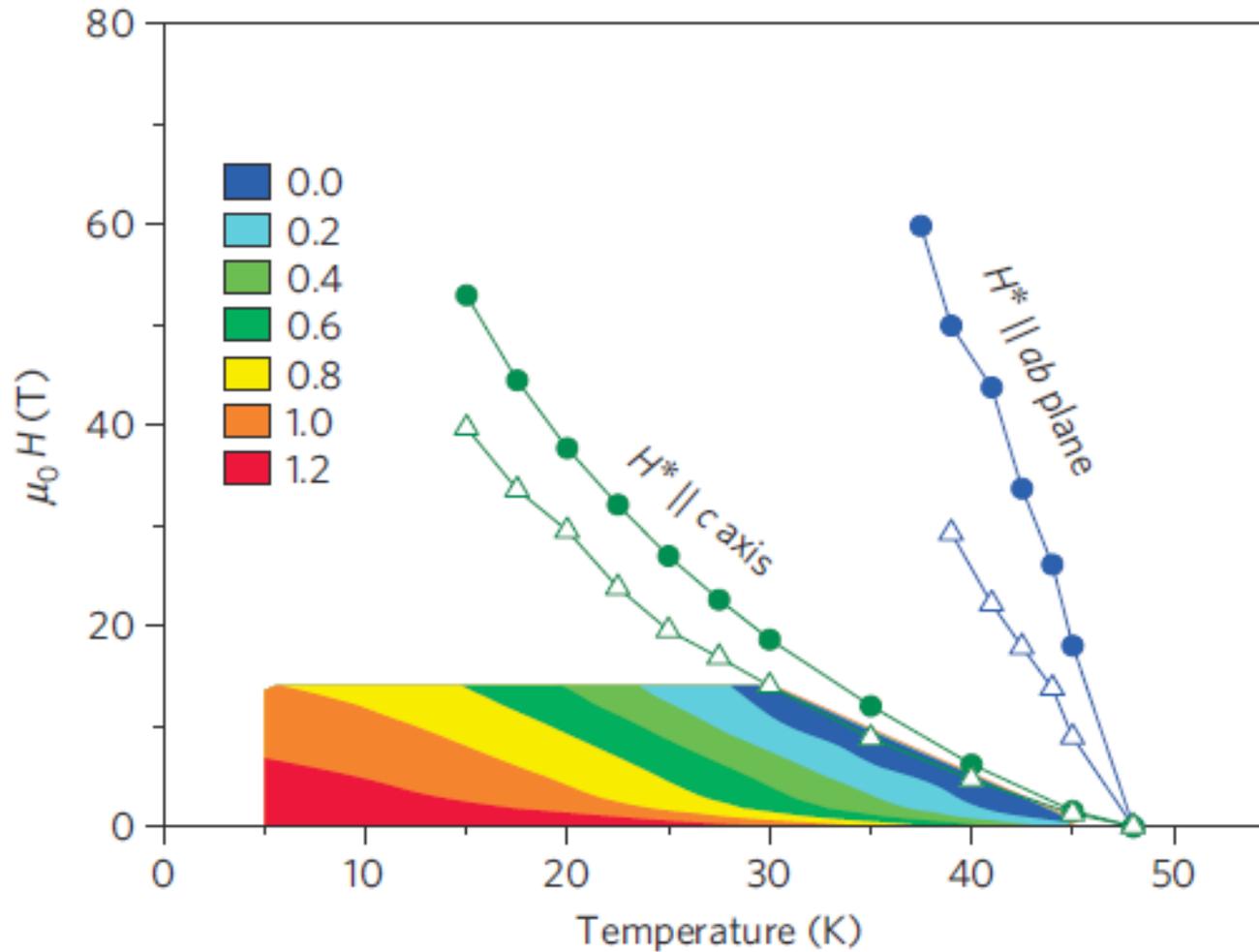
No SC



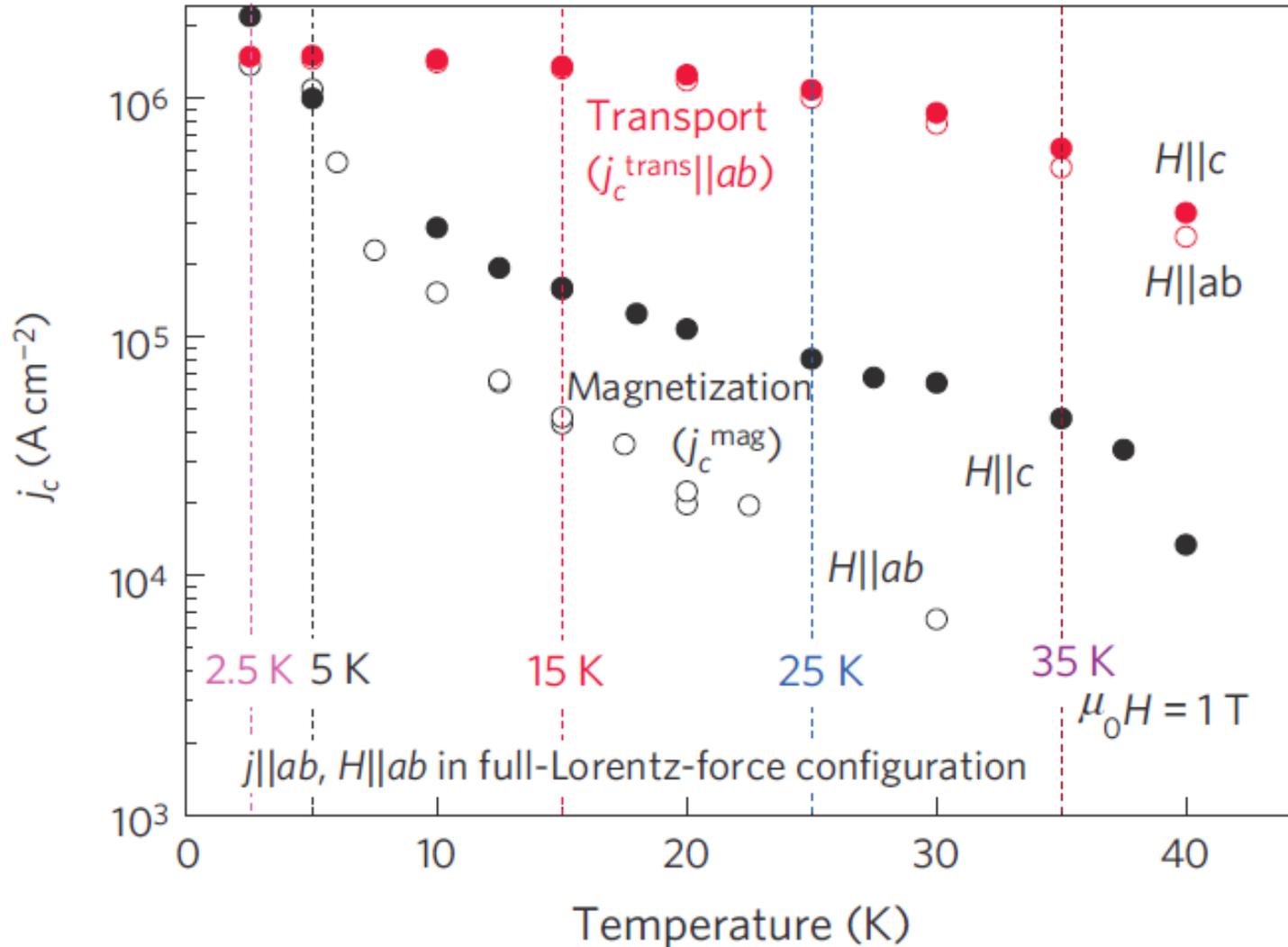
(Sr₄V₂O₆)Fe₂As₂

$T_c = 37 \text{ K}$
 $T_c = 46 \text{ K (HP)}$

Критические параметры FeSC

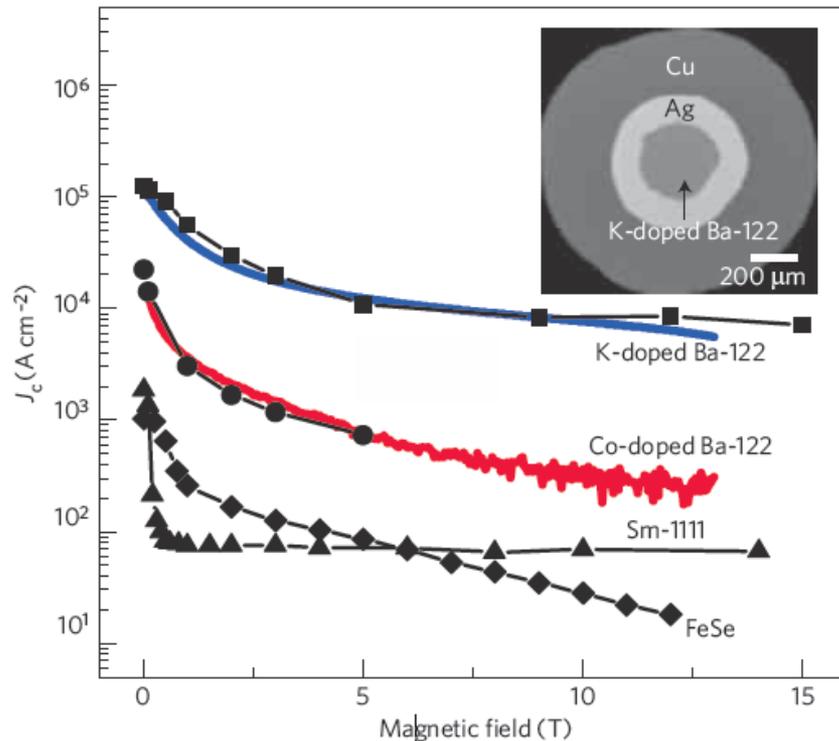
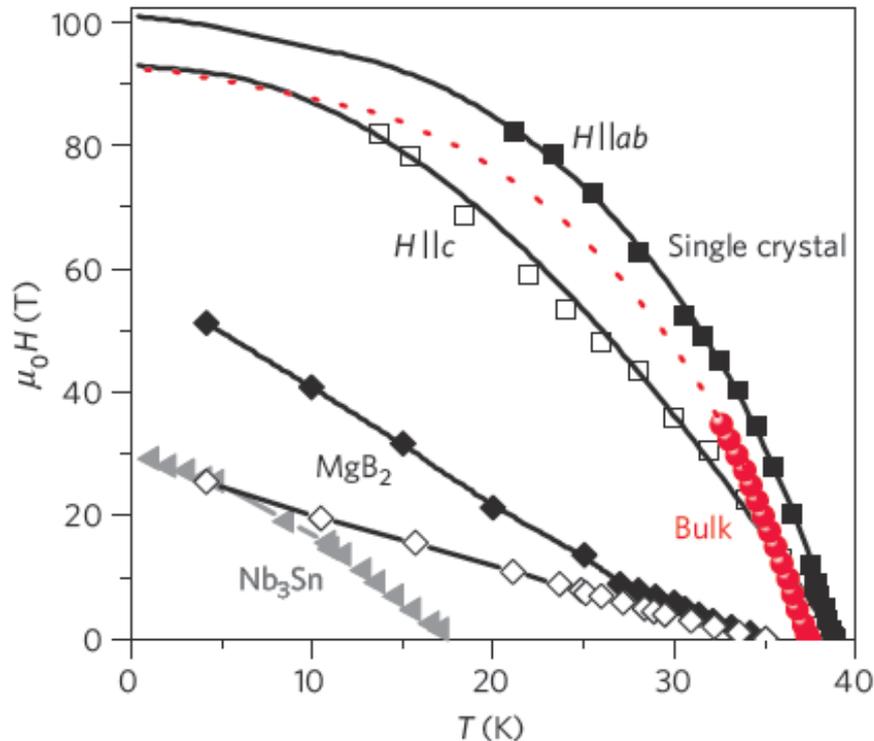


Критические параметры FeSC

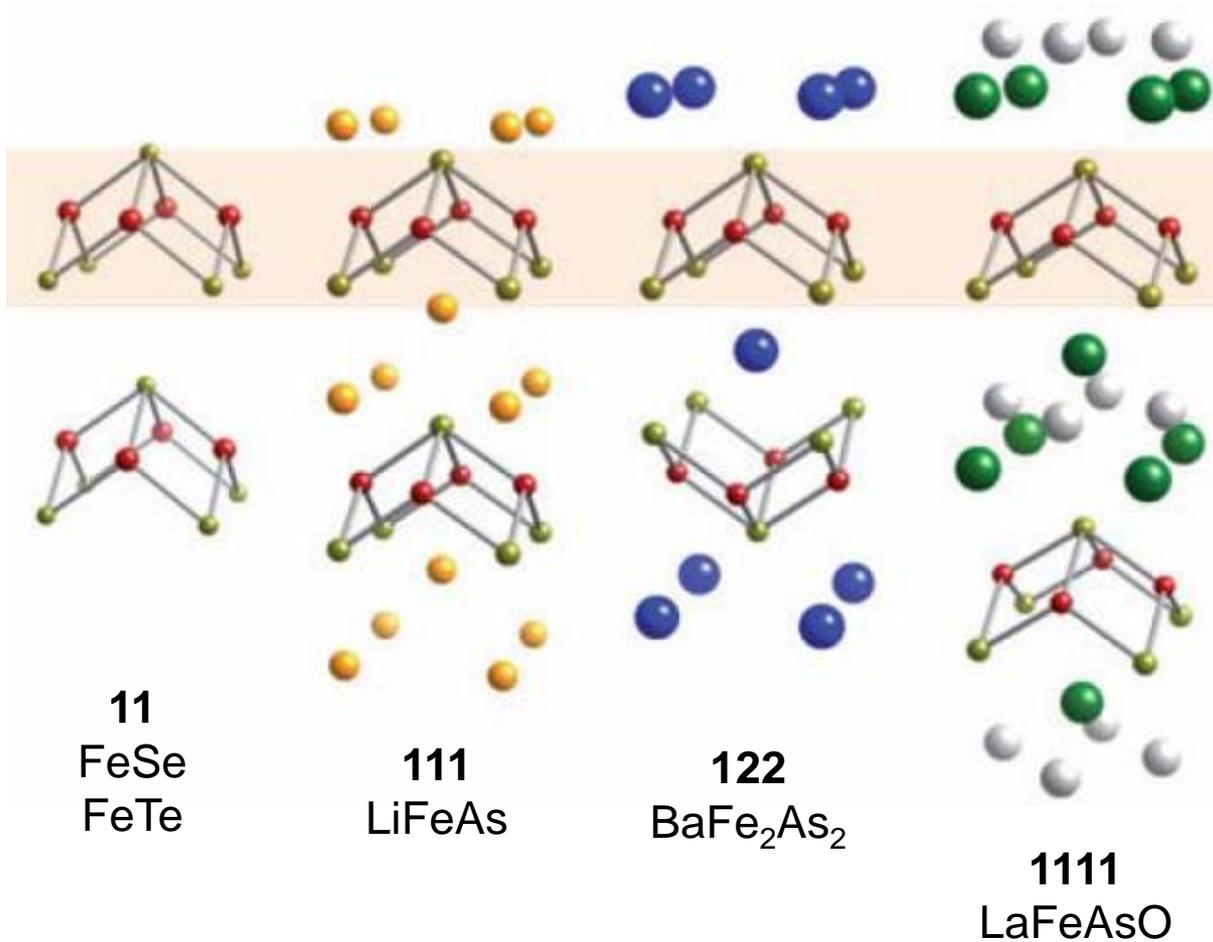


Провода на $\text{Ba}(\text{K})\text{Fe}_2\text{As}_2$

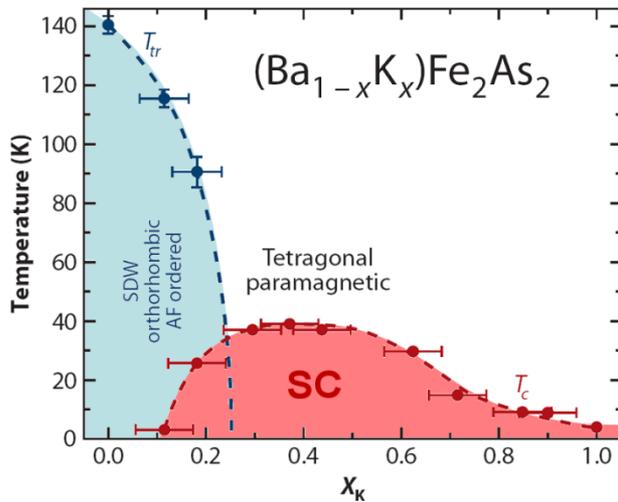
Сегодня, во всем мире, чрезвычайно активно развивается технология изготовления проводов на основе железосодержащих сверхпроводников. Очевидные перспективы: по крит. полю они значительно превосходят как Nb_3Sn так и MgB_2 , а J_c повышается день ото дня.



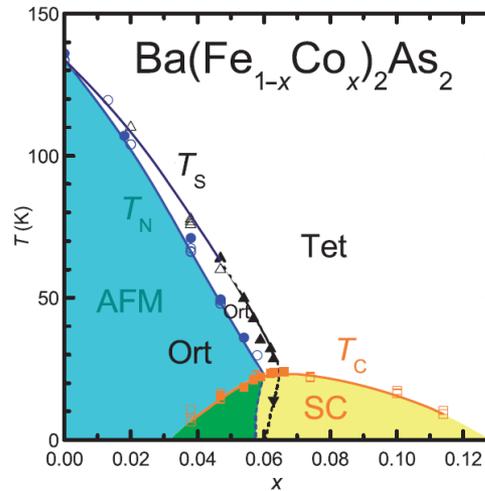
Iron-based superconductors



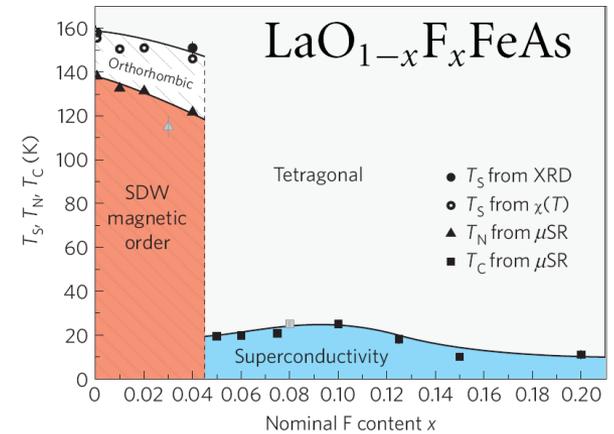
Phase diagrams



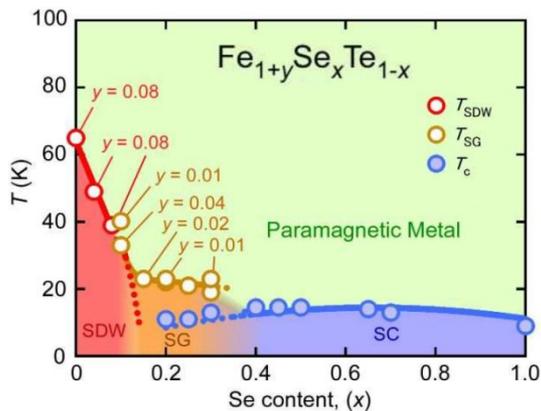
H.-H.Wen & S.Li [Annu. Rev. Cond. Mat. Phys. 2011](#)



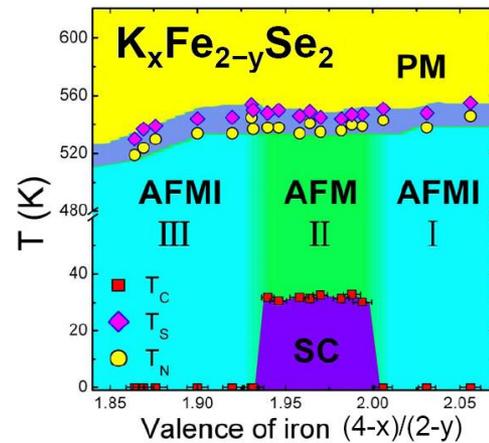
S.Nandi *et al.* [PRL 2010](#)



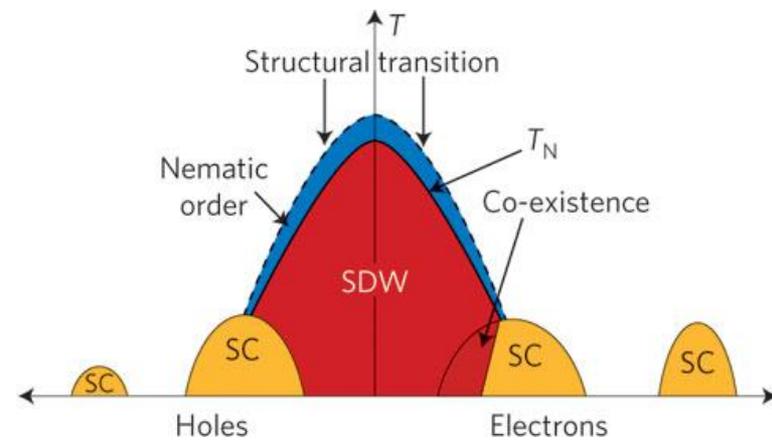
H.Luetkens *et al.* [Nature Mat. 2009](#)



N.Katayama *et al.* [arXiv:1003.4525](#)

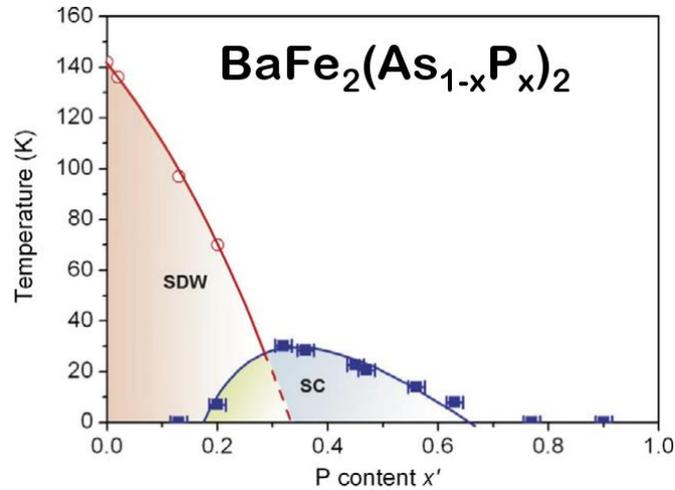


Y.J.Yan *et al.* [arXiv:1104.4941](#)

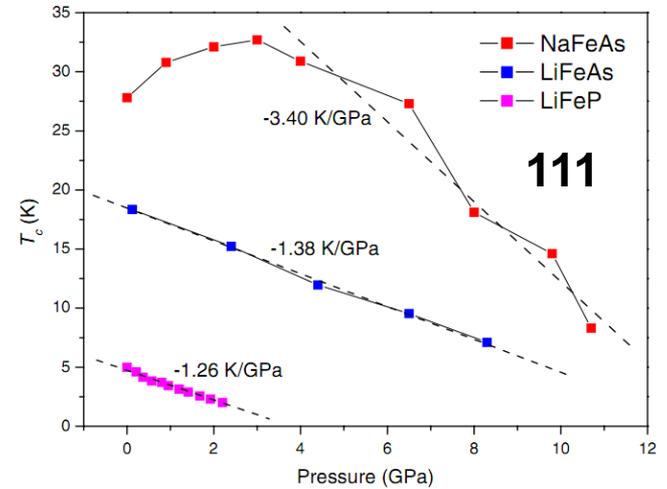


Basov & Chubukov [Nature Phys. 2011](#)

Phase diagrams



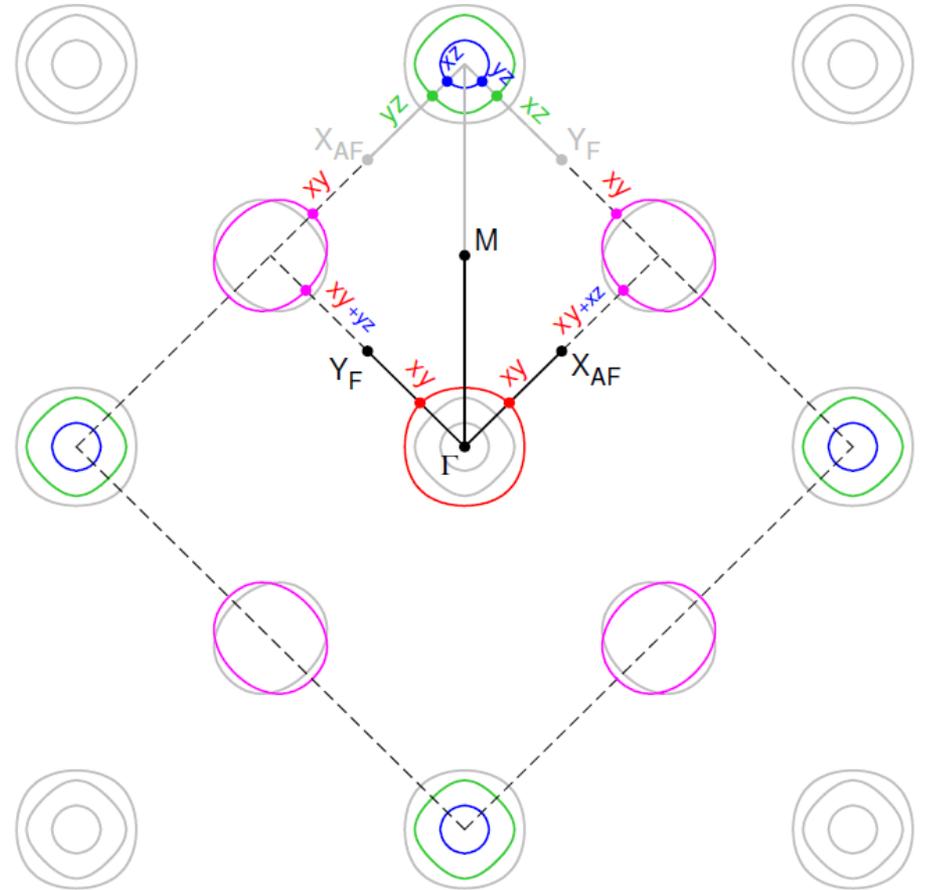
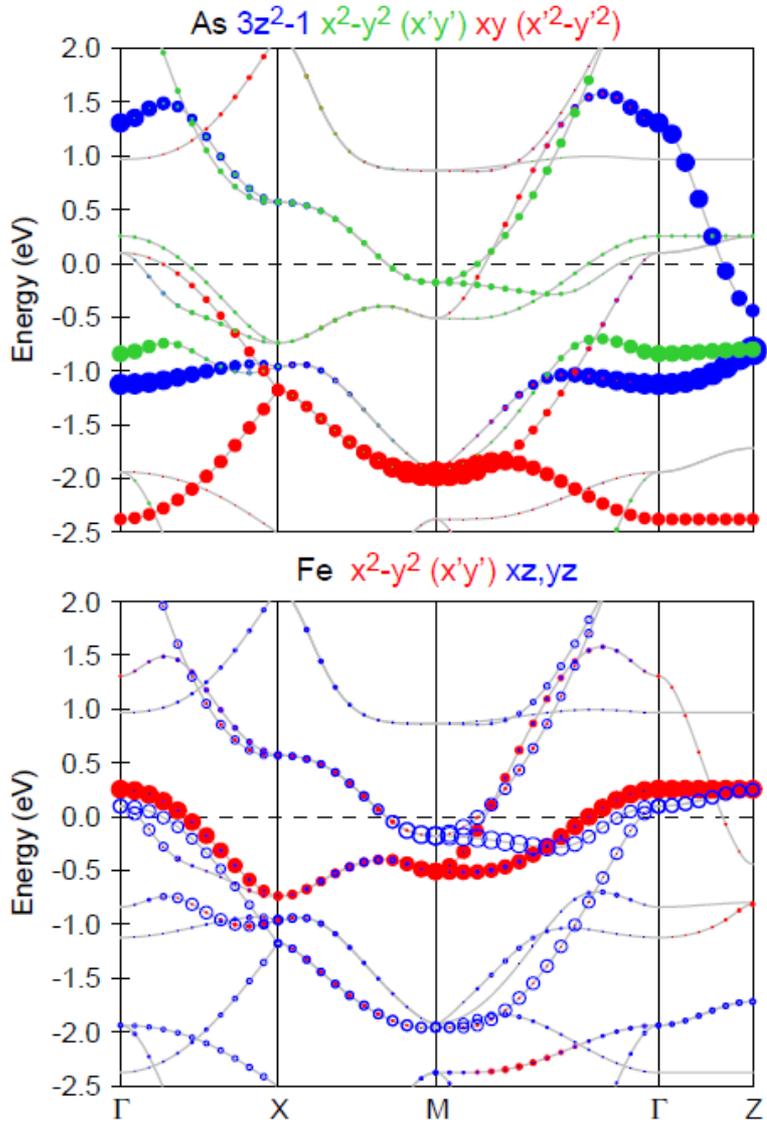
S.Jiang *et al.* [J.Phys.Cond.Matt. 2009](#)



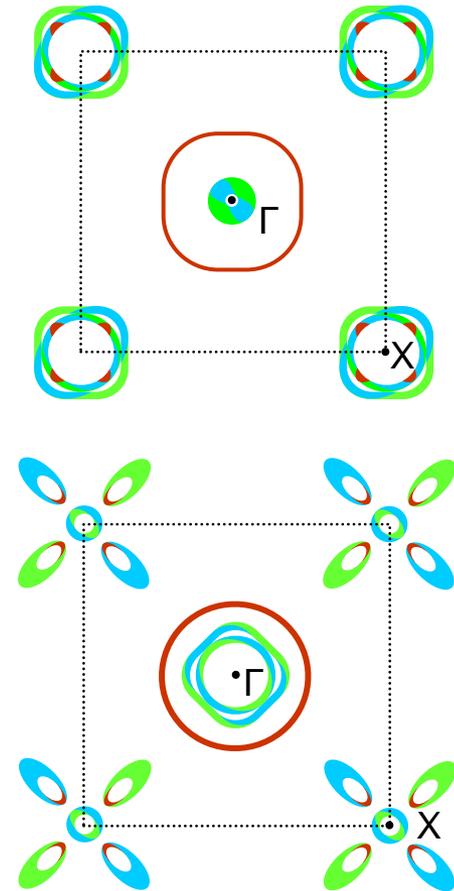
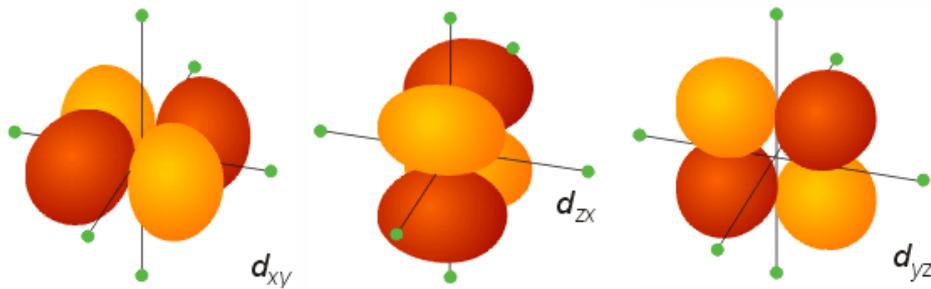
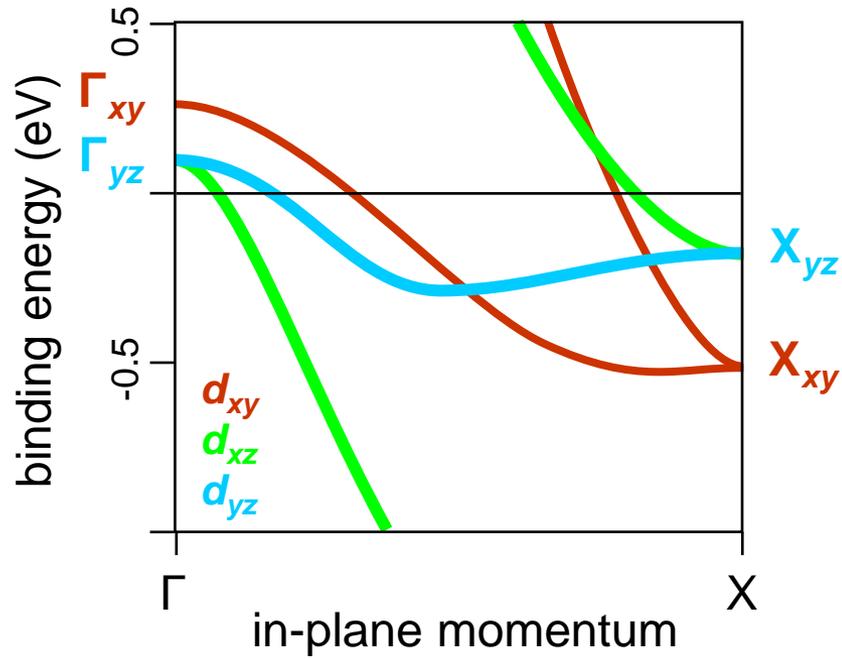
X.C.Wang *et al.* [High Pressure Research 2011](#)

Электронная структура

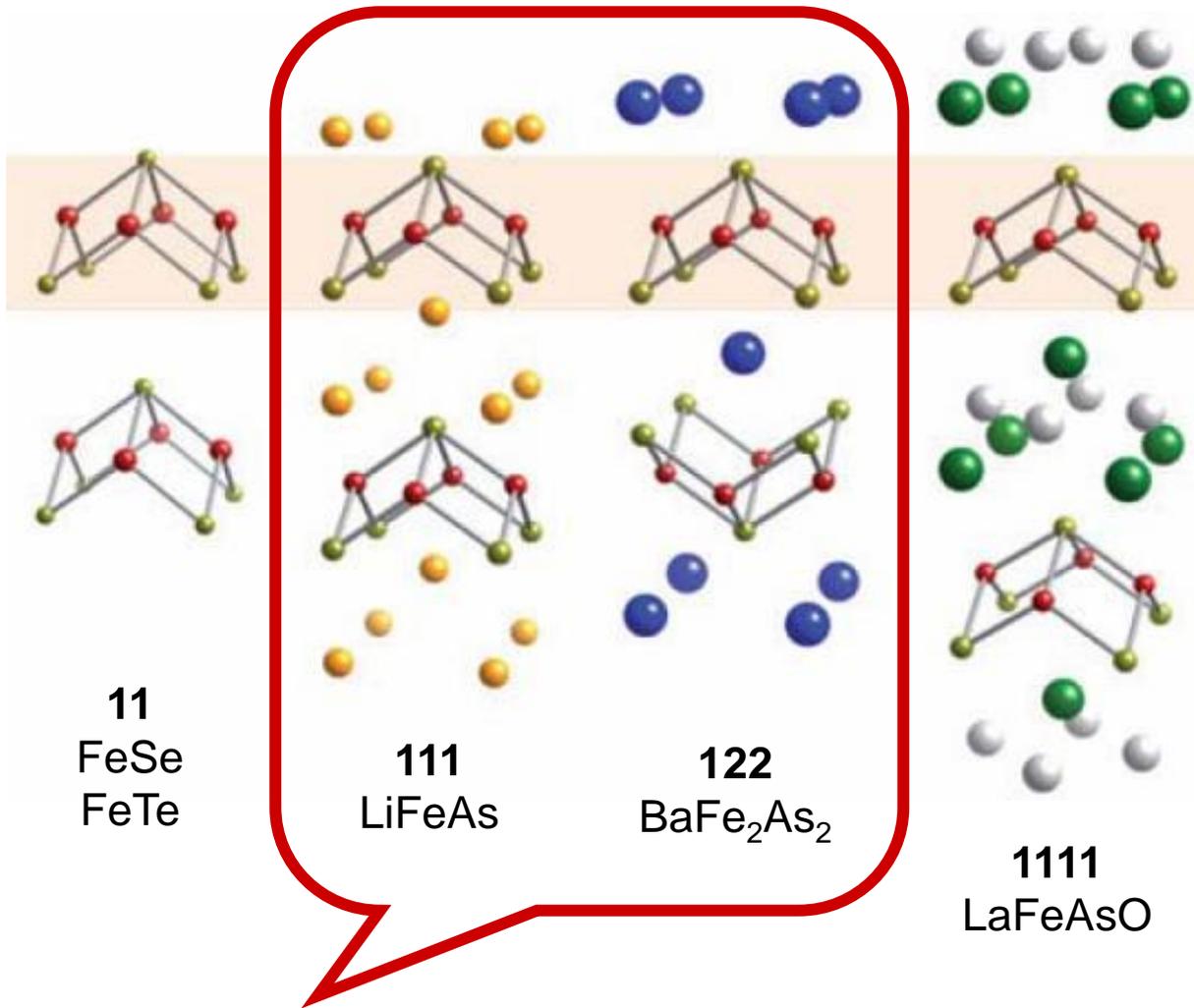
FeSC electronic band structure



FeSC electronic band structure



Iron-based superconductors

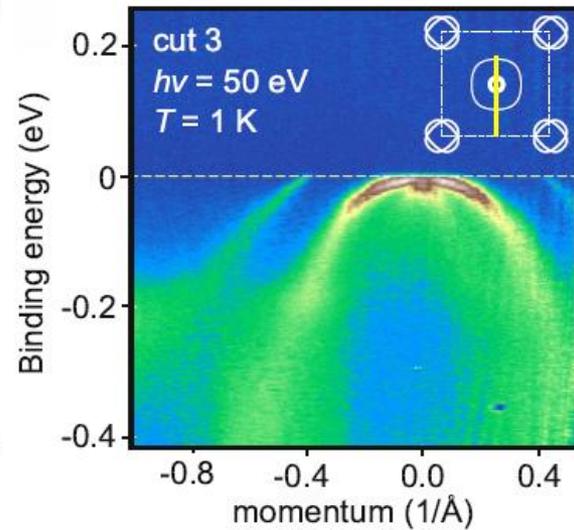
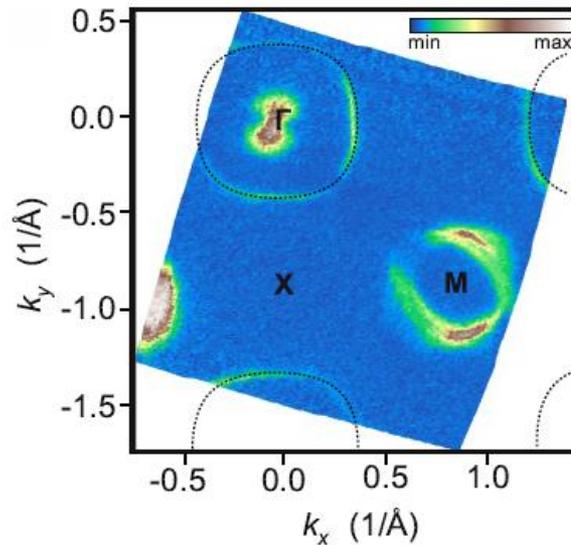
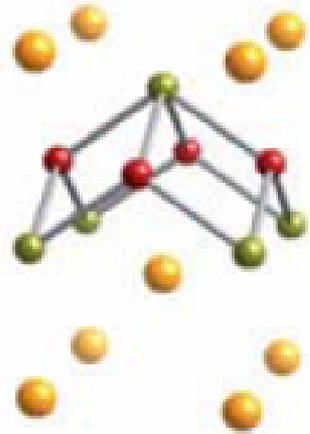


ARPESable

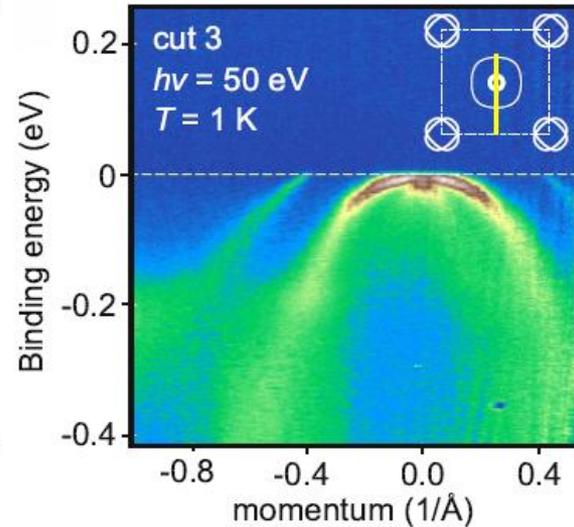
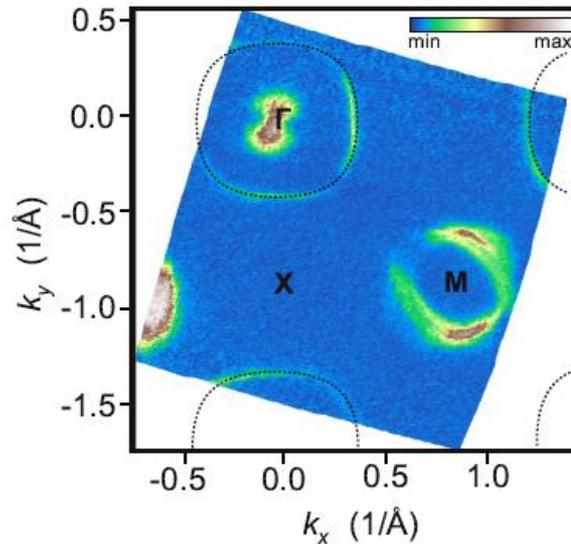
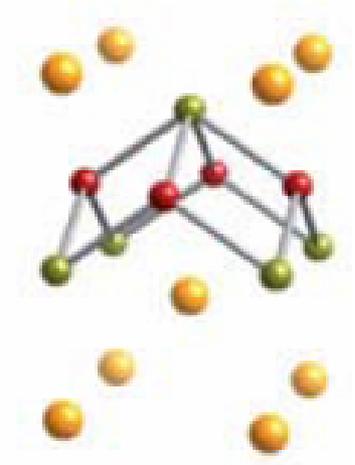
111

LiFeAs ($T_c = 18$ K, non-magnetic)

NaFeAs ($T_c = 9-26$ K, $T_{AF} = 40$ K)

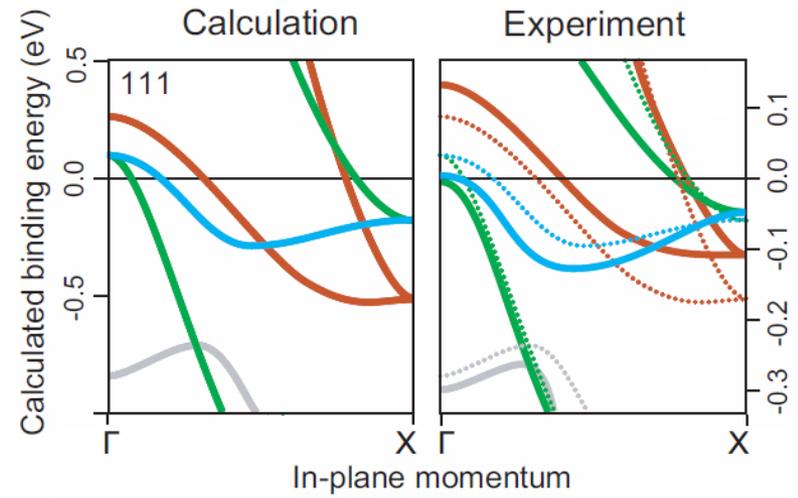
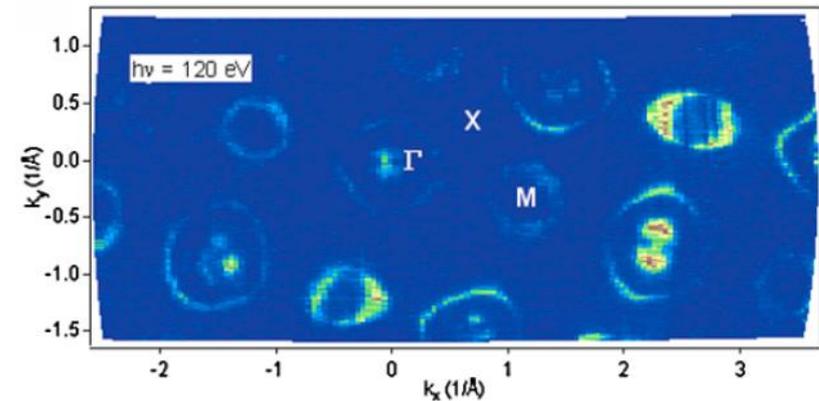
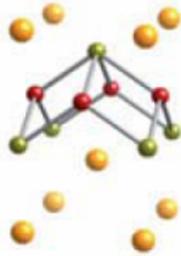
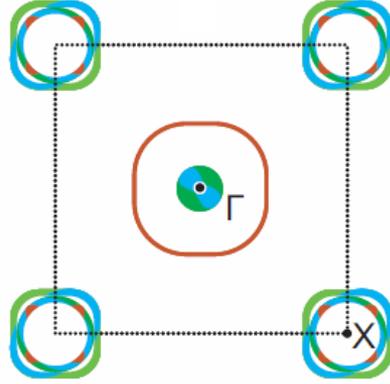
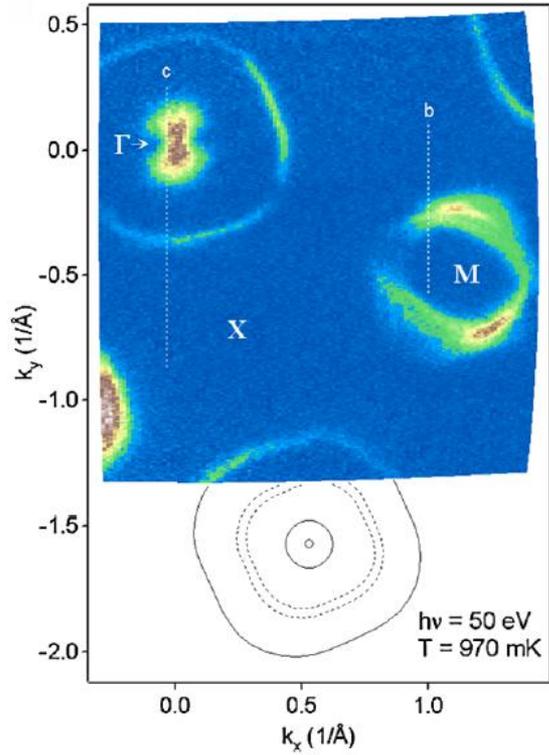


Perfectly ARPESable LiFeAs



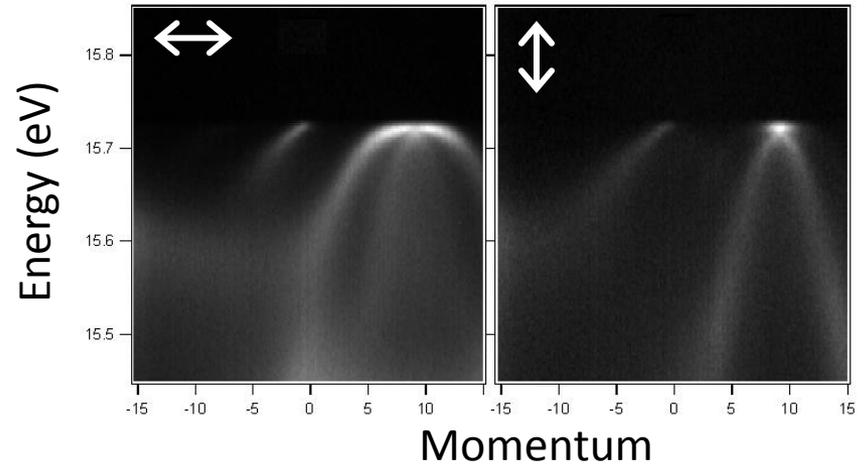
1. Superconducting with $T_c = 18$ K but non-magnetic...
2. Stoichiometric = impurity clean.
3. Perfectly two-dimensional Fe-3d_{xy} band well separated from other bands: easy to analyse its fine structure.
4. Cleaves between the two Li layers => non-polar surface.

Fermi surface of LiFeAs



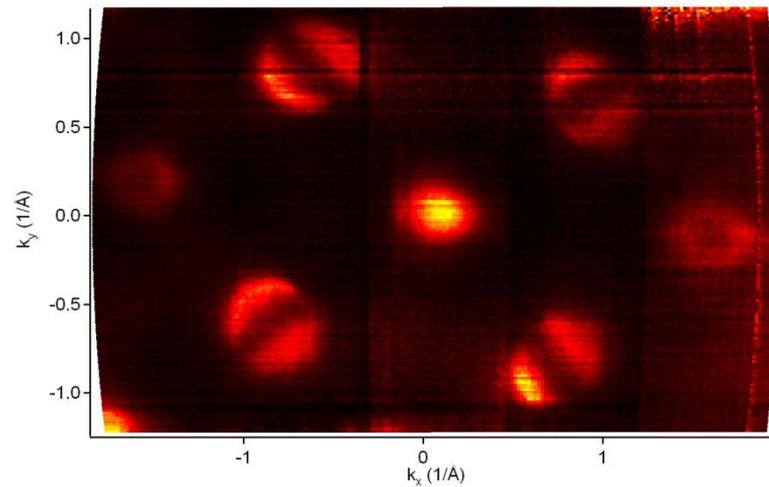
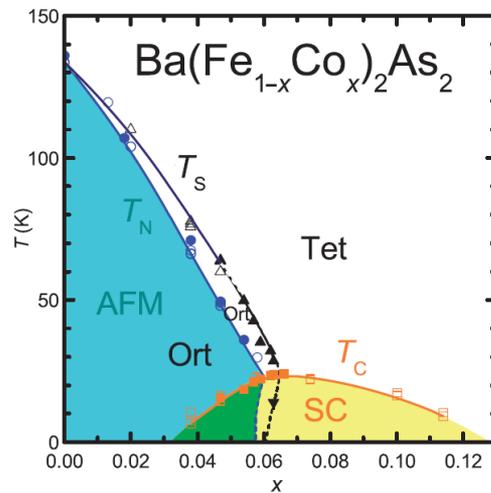
Kordyuk, *J. Supercond. Nov. Magn.* 2012

polarization



122

electron doped

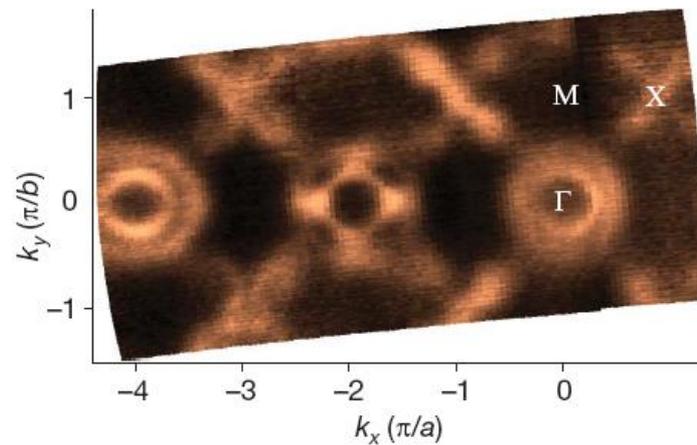
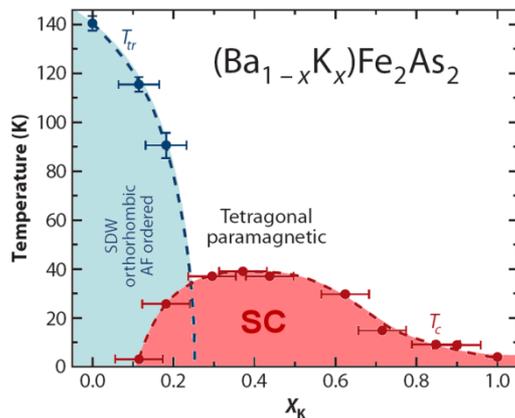


122

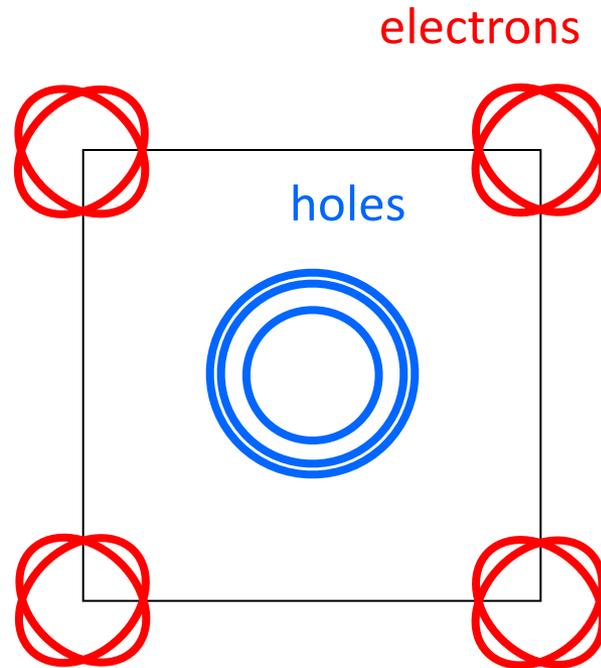
hole doped

BaFe_2As_2 (BFA) ▪ $\text{Ba}_{1-x}\text{K}_x\text{Fe}_2\text{As}_2$ (BKFA) ▪ KFA

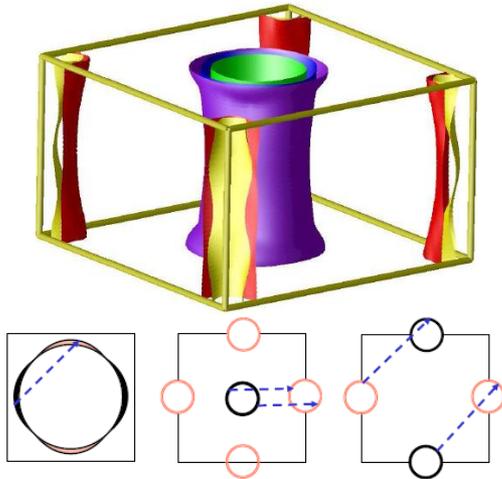
$\text{Ba}_{1-x}\text{Na}_x\text{Fe}_2\text{As}_2$ (BNFA)



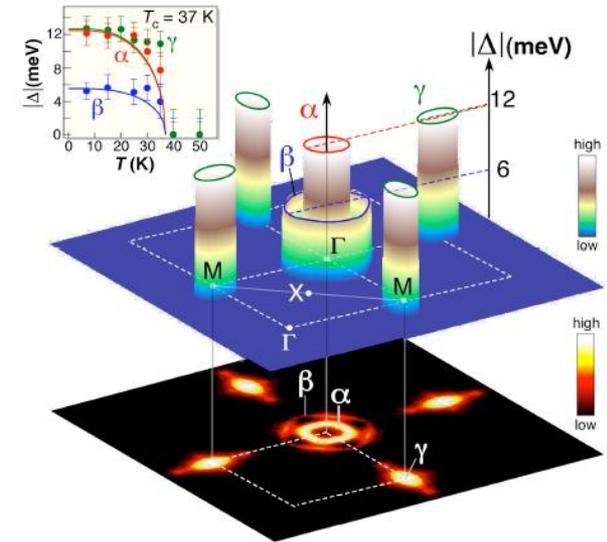
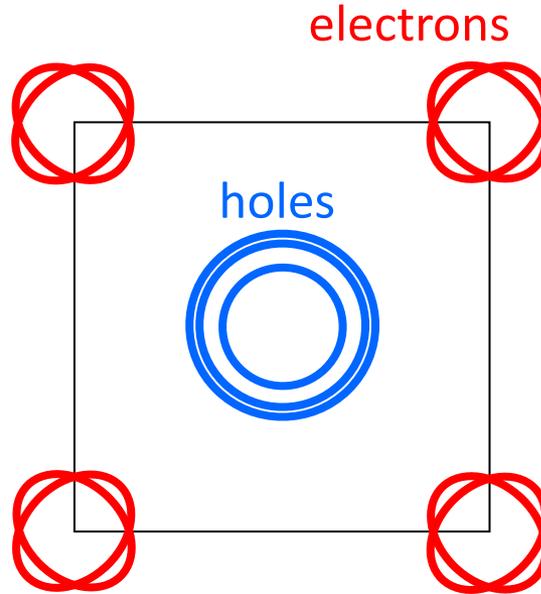
Fermi surface of BKFA



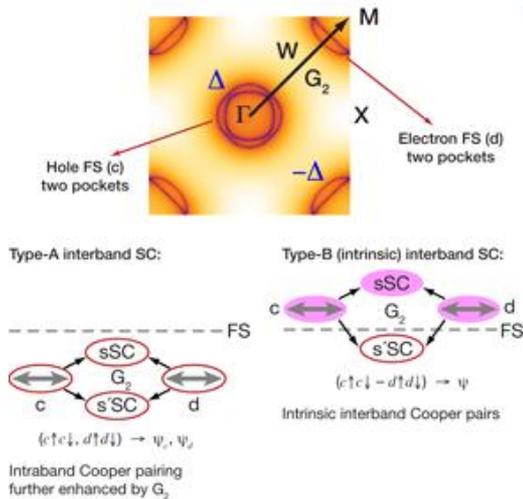
Fermi surface of BKFA



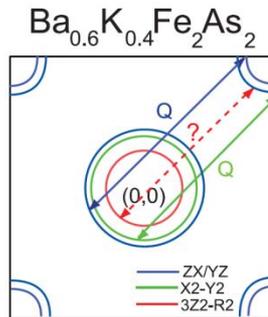
Mazin & Schmalian 2009



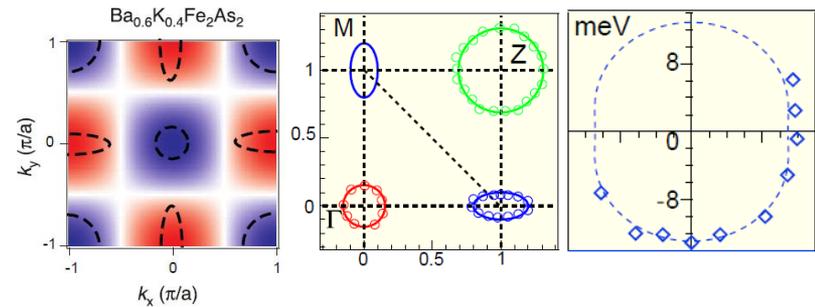
Ding *EPL* 2008



Tesanovic *Physics* 2009

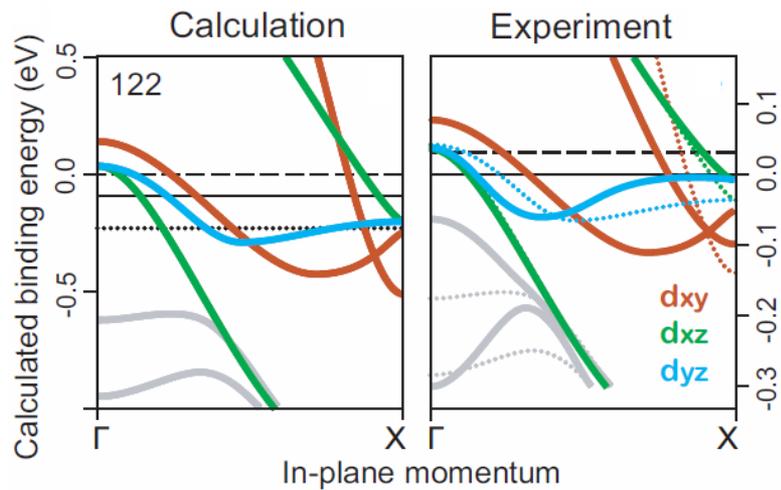
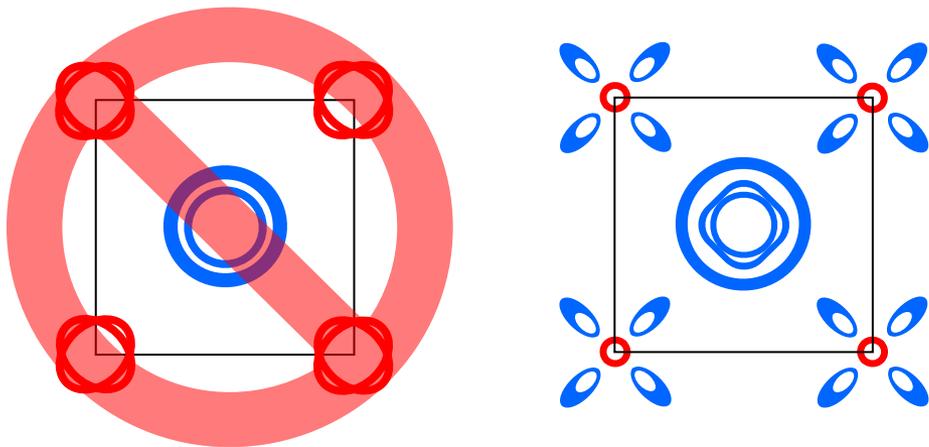


Shimozima *Science* 2011

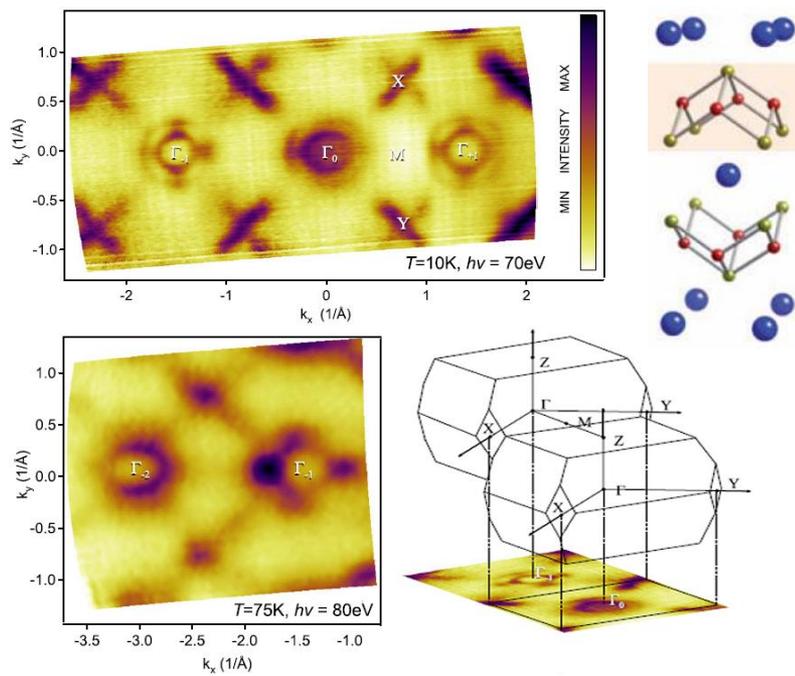
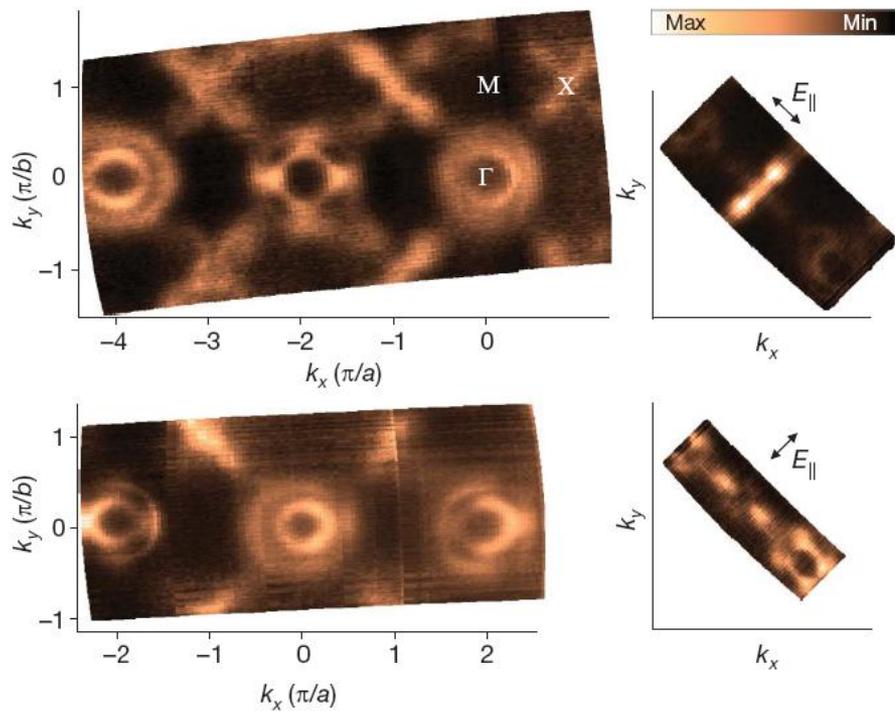


Hu & Ding arXiv:1107.1334

Fermi surface of BKFA

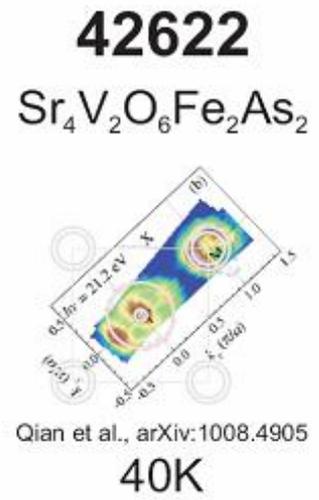
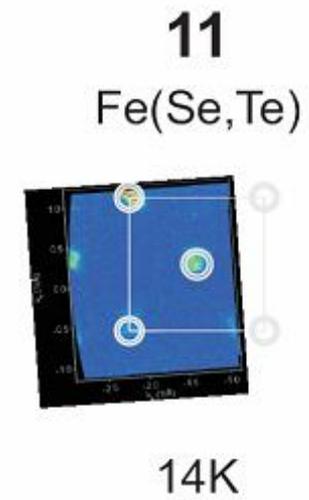
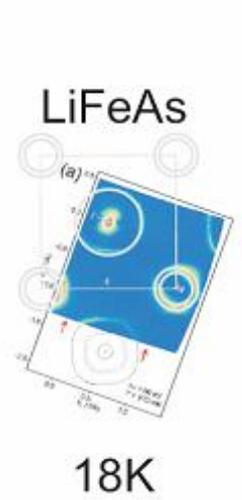
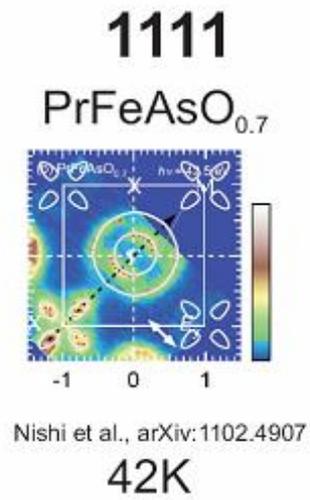
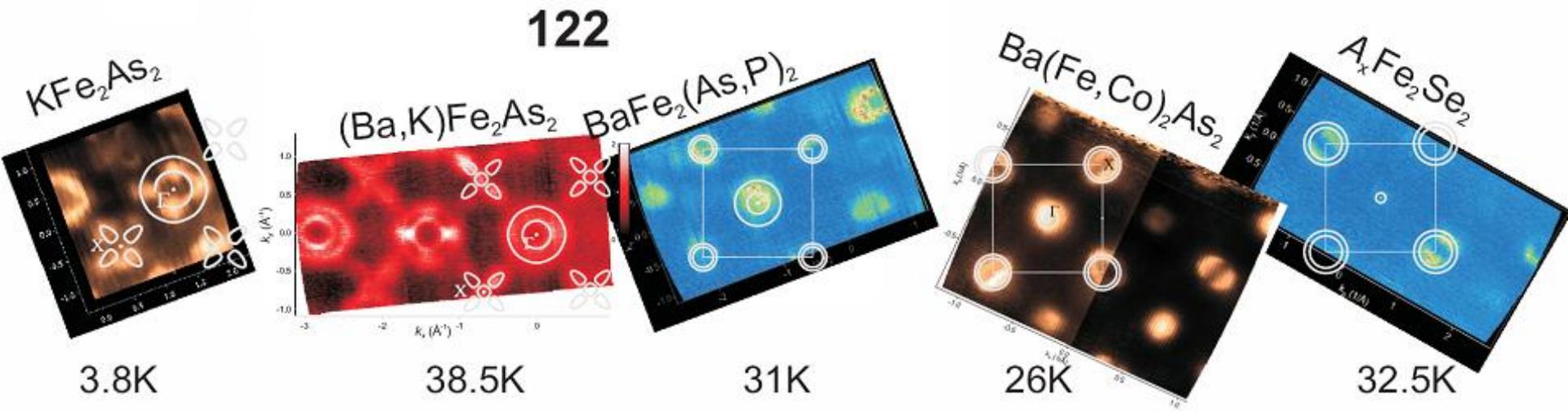


A. A. Kordyuk, *J. Supercond. Nov. Magn.* 2012



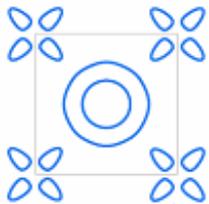
V. Zabolotnyy *Nature* 2009

FS's of iron-based superconductors

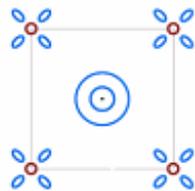


FS's of iron-based superconductors

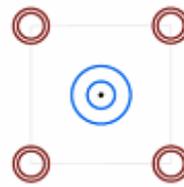
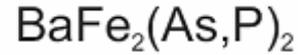
122



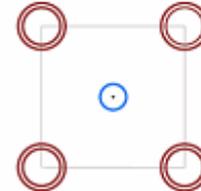
3.8K



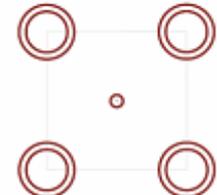
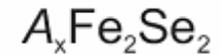
38K



31K

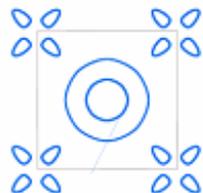


26K



31K

1111



42K

111

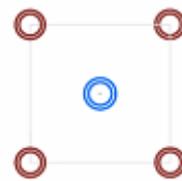


18K



18K

11



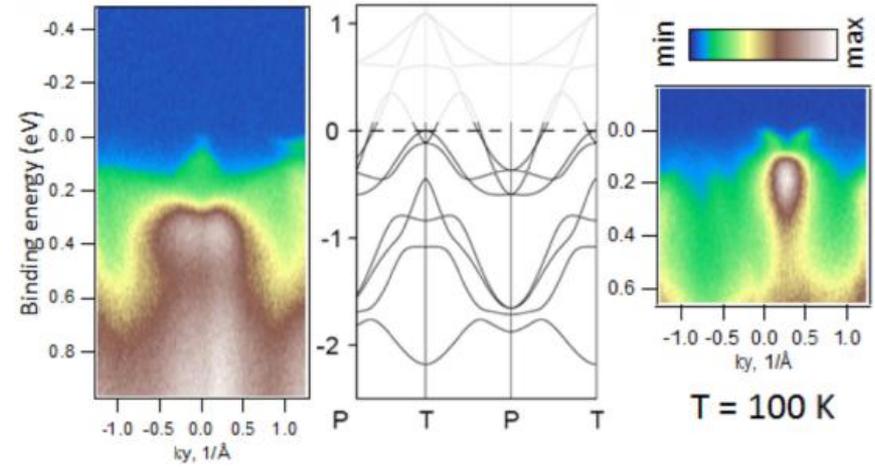
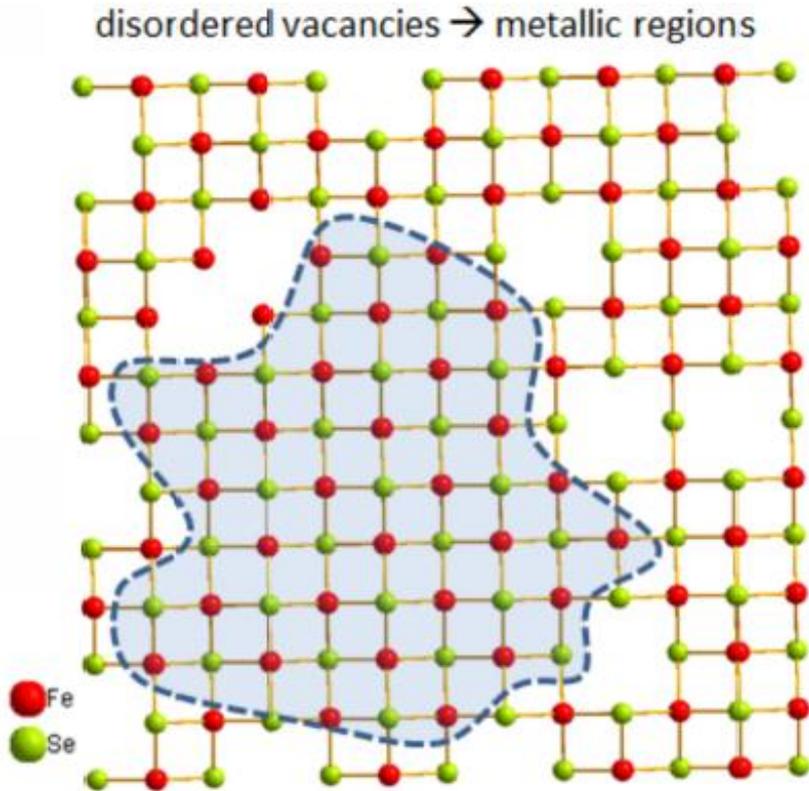
14K

42622

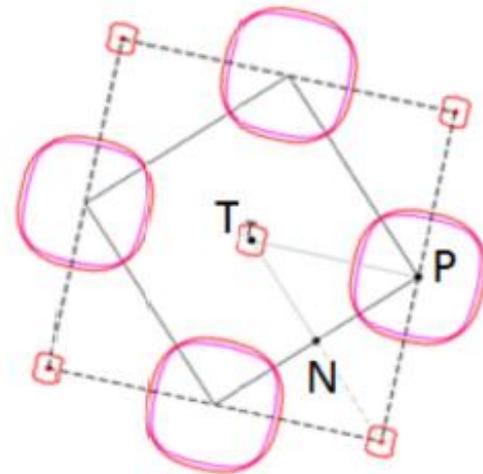


40K

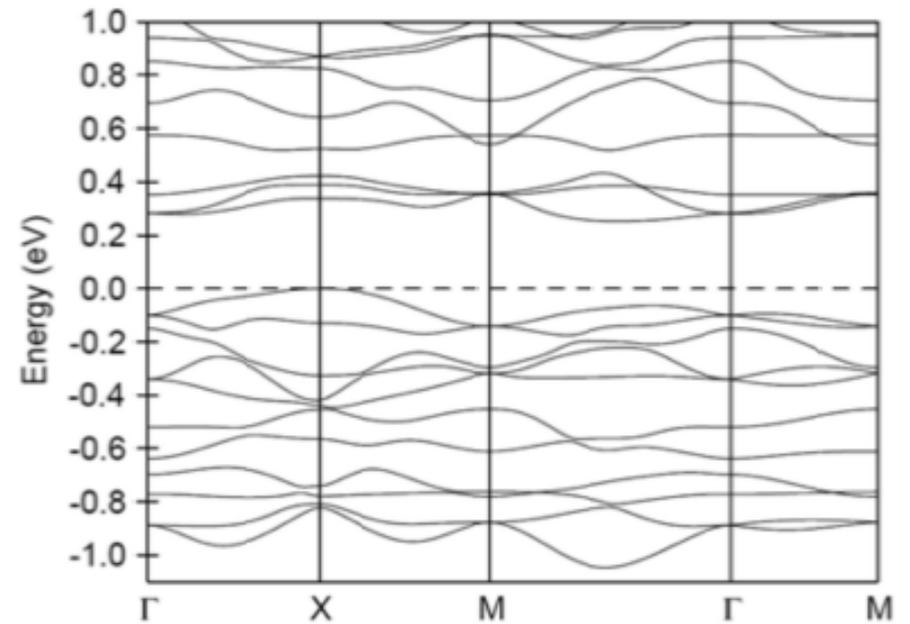
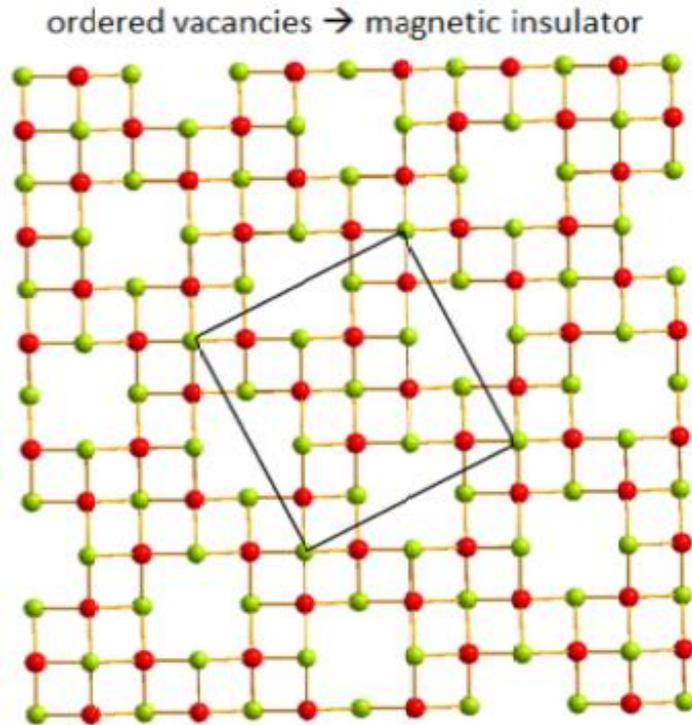
Rb-FeSe



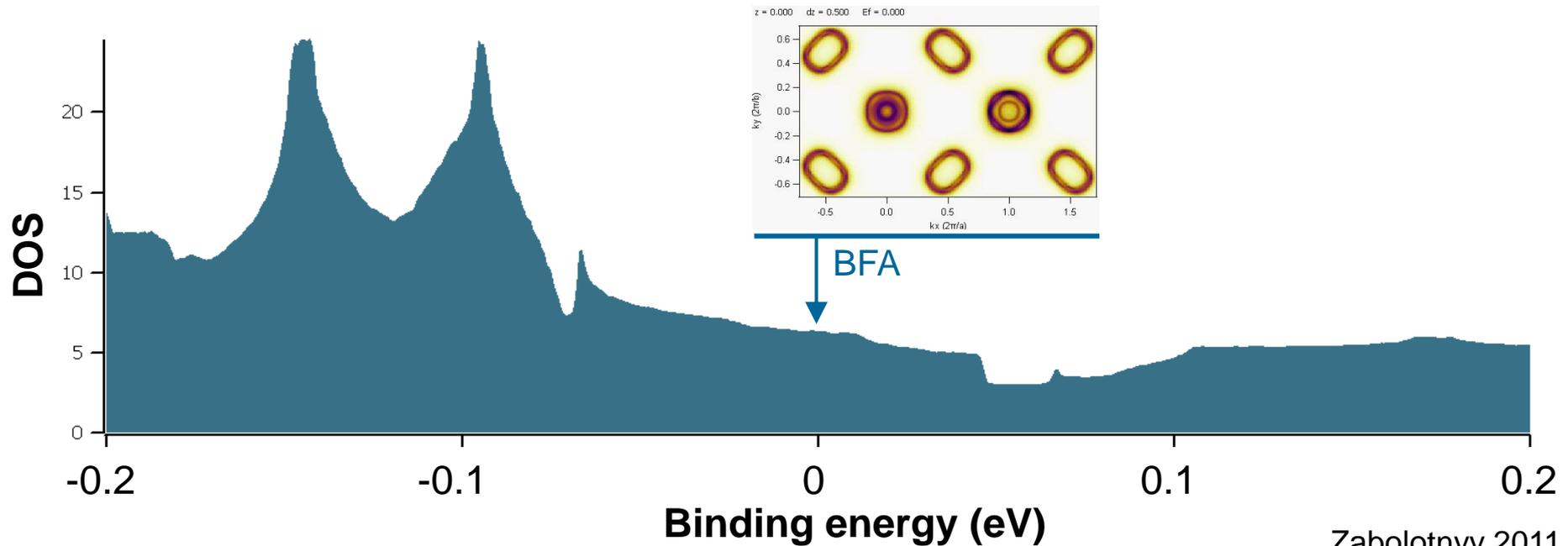
12% RbFe₂Se₂



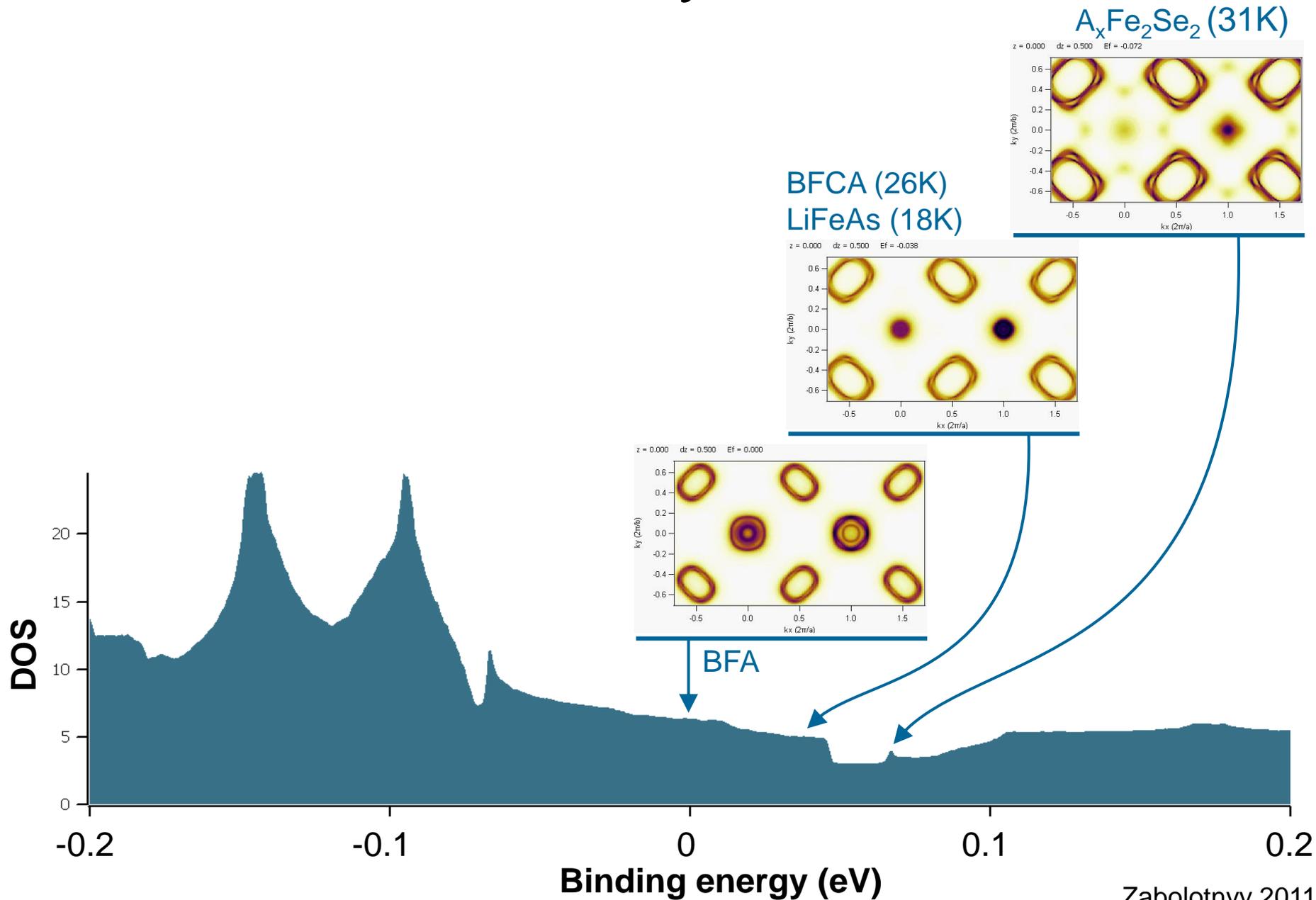
Rb-FeSe



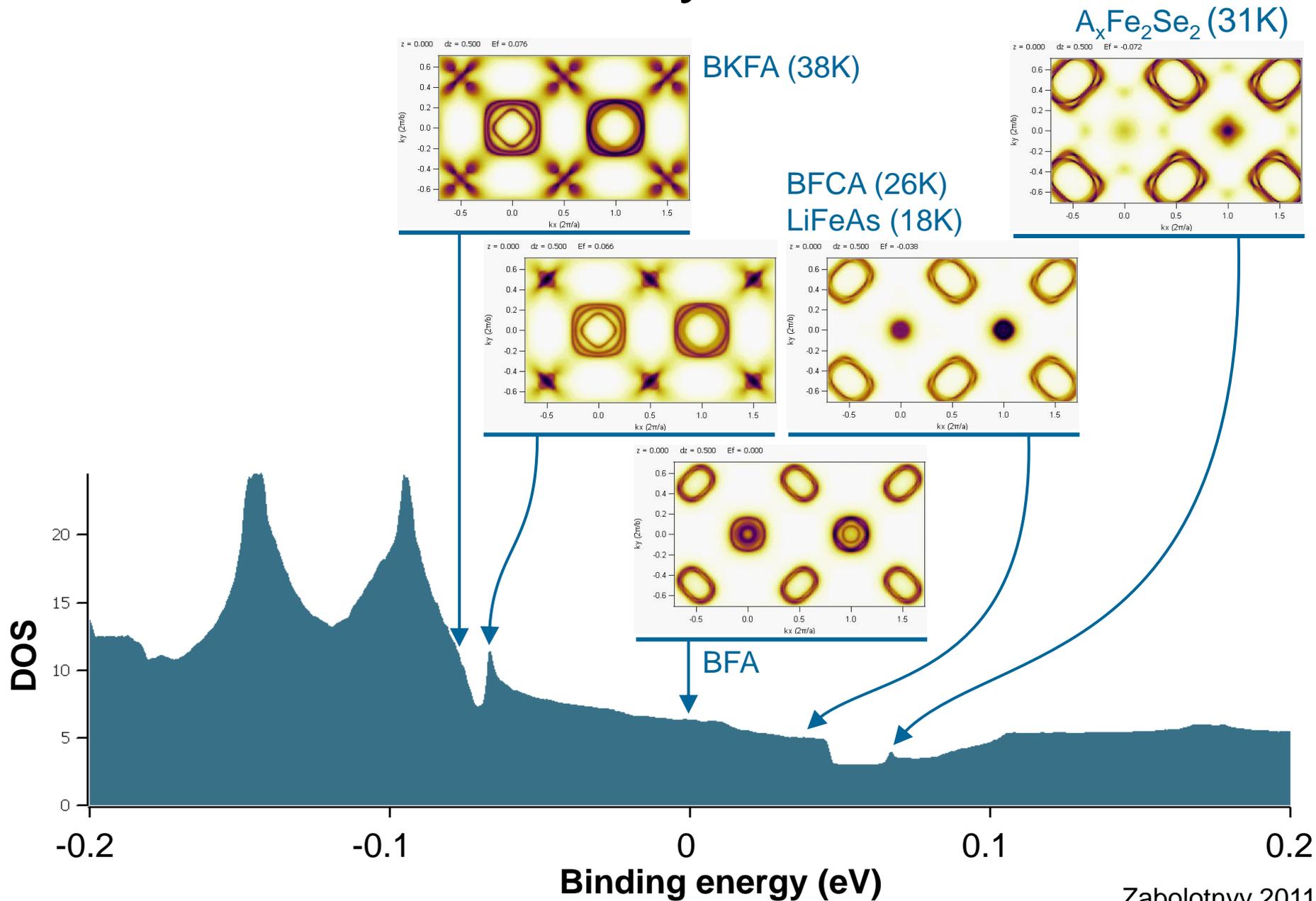
BFA: density of states



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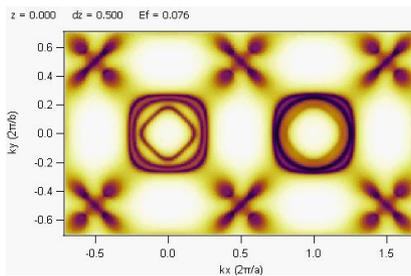
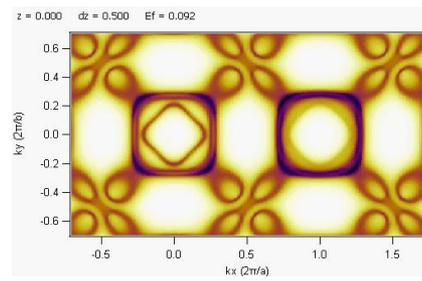


BFA: density of states

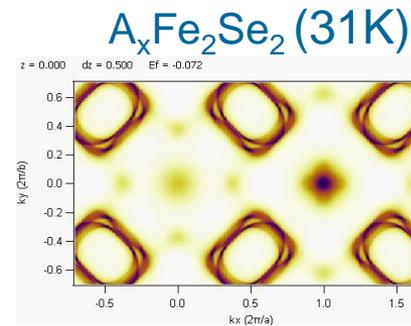


BFA: density of states

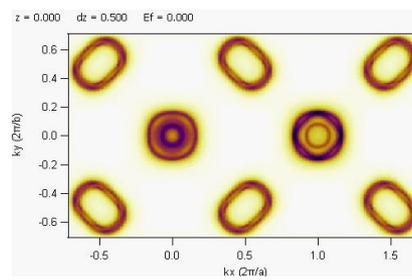
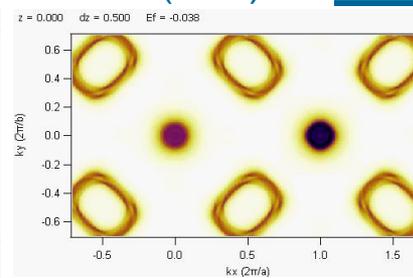
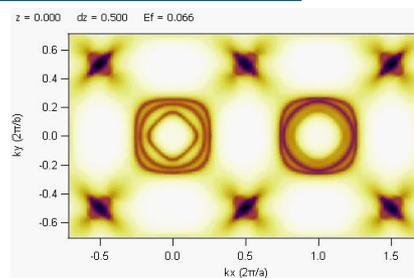
Hole doped KFA



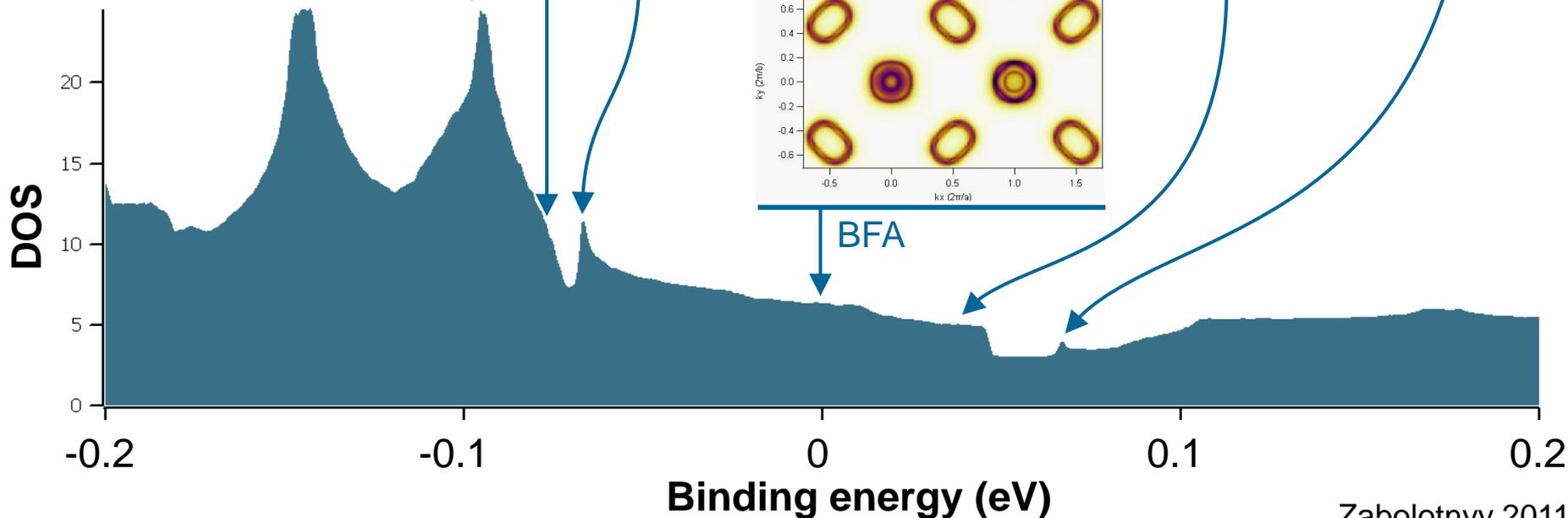
BKFA (38K)



BFCA (26K)
LiFeAs (18K)

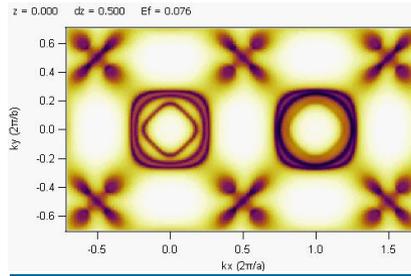
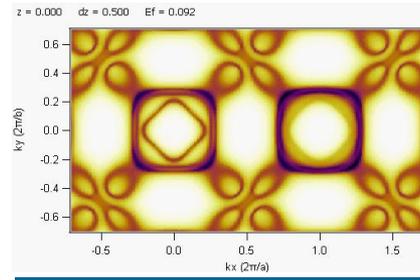


BFA

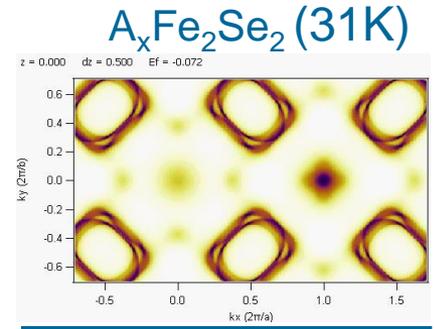


BFA: density of states

Hole doped KFA

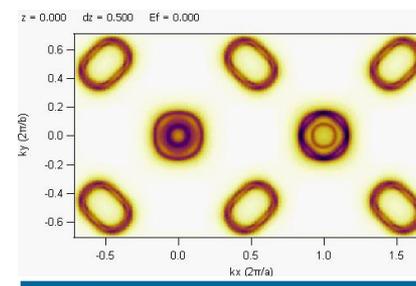
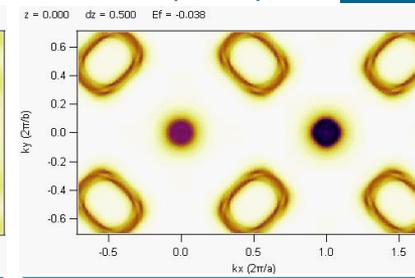
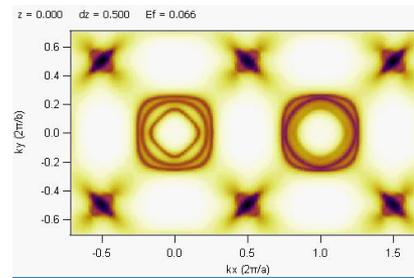


BKFA (38K)

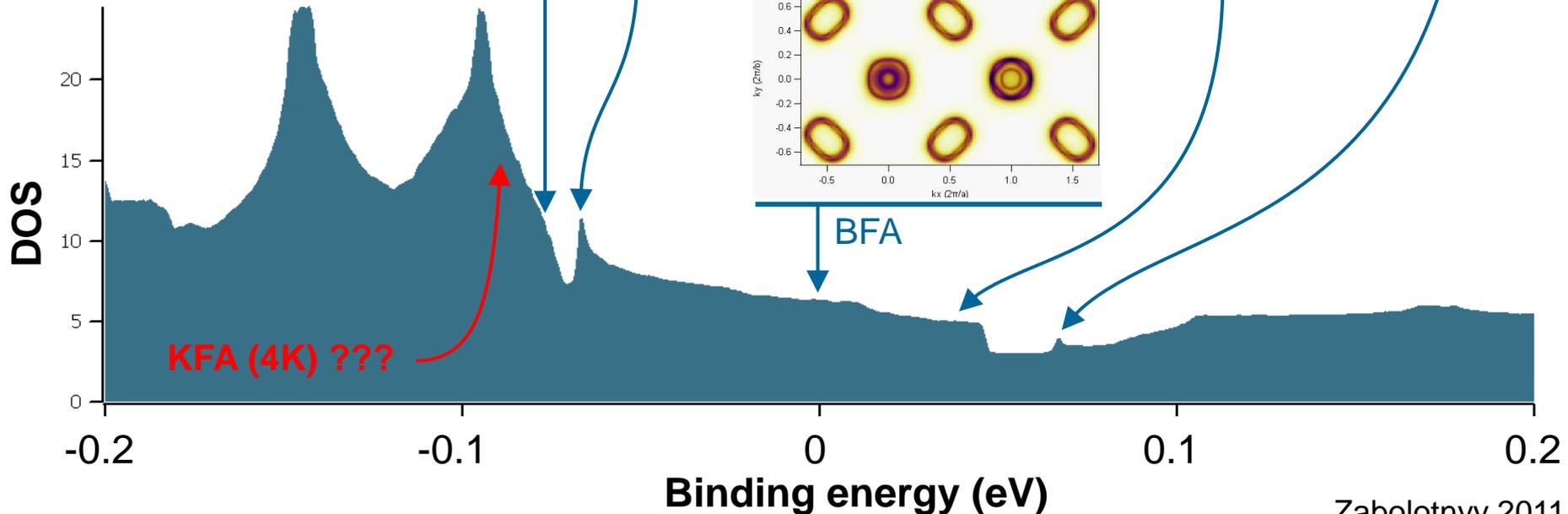


$A_xFe_2Se_2$ (31K)

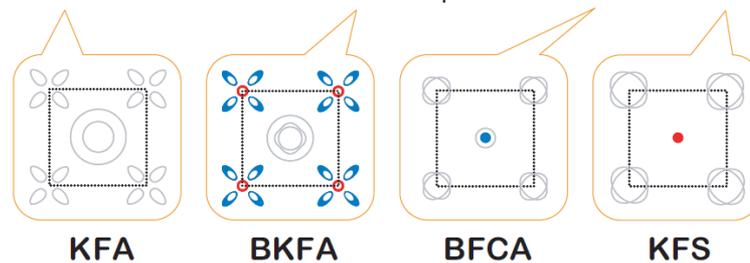
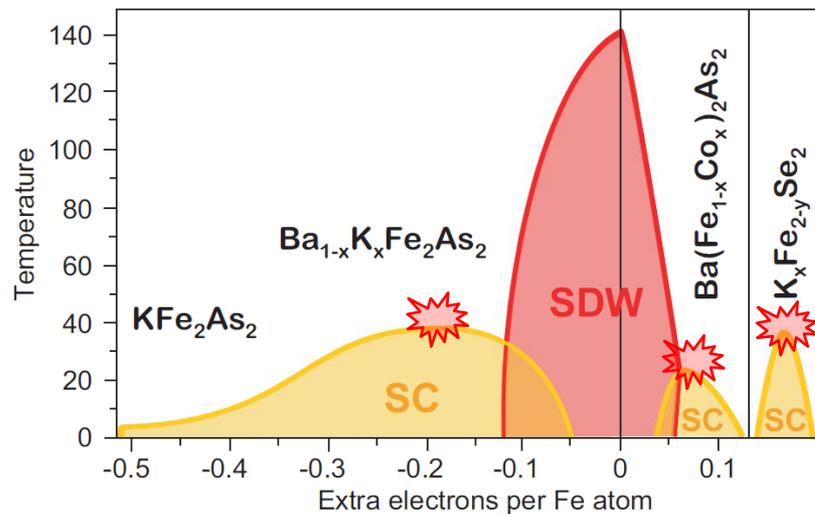
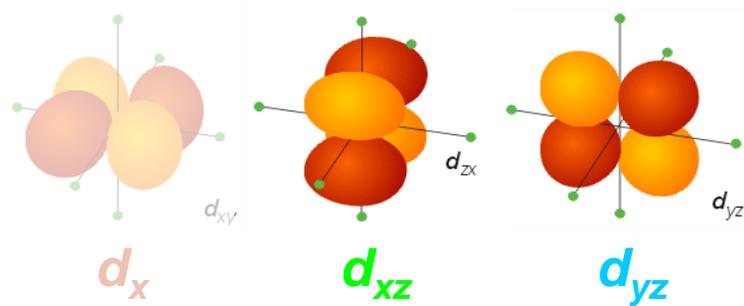
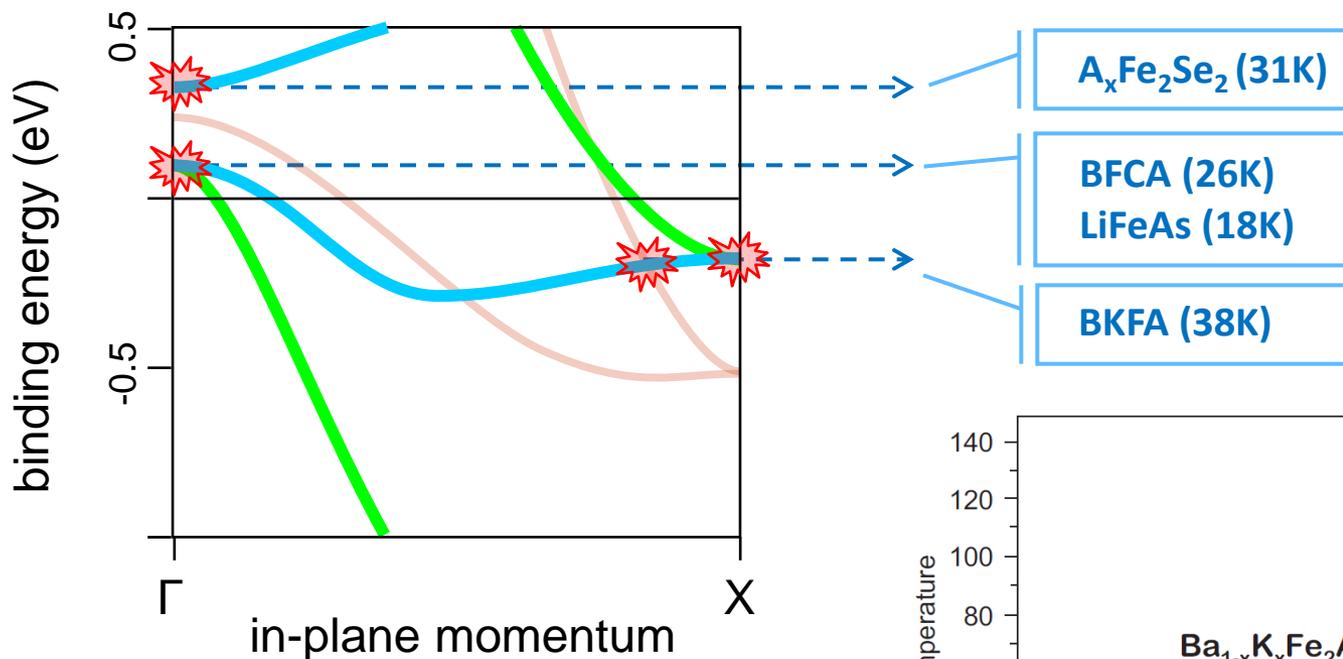
BFCA (26K)
LiFeAs (18K)



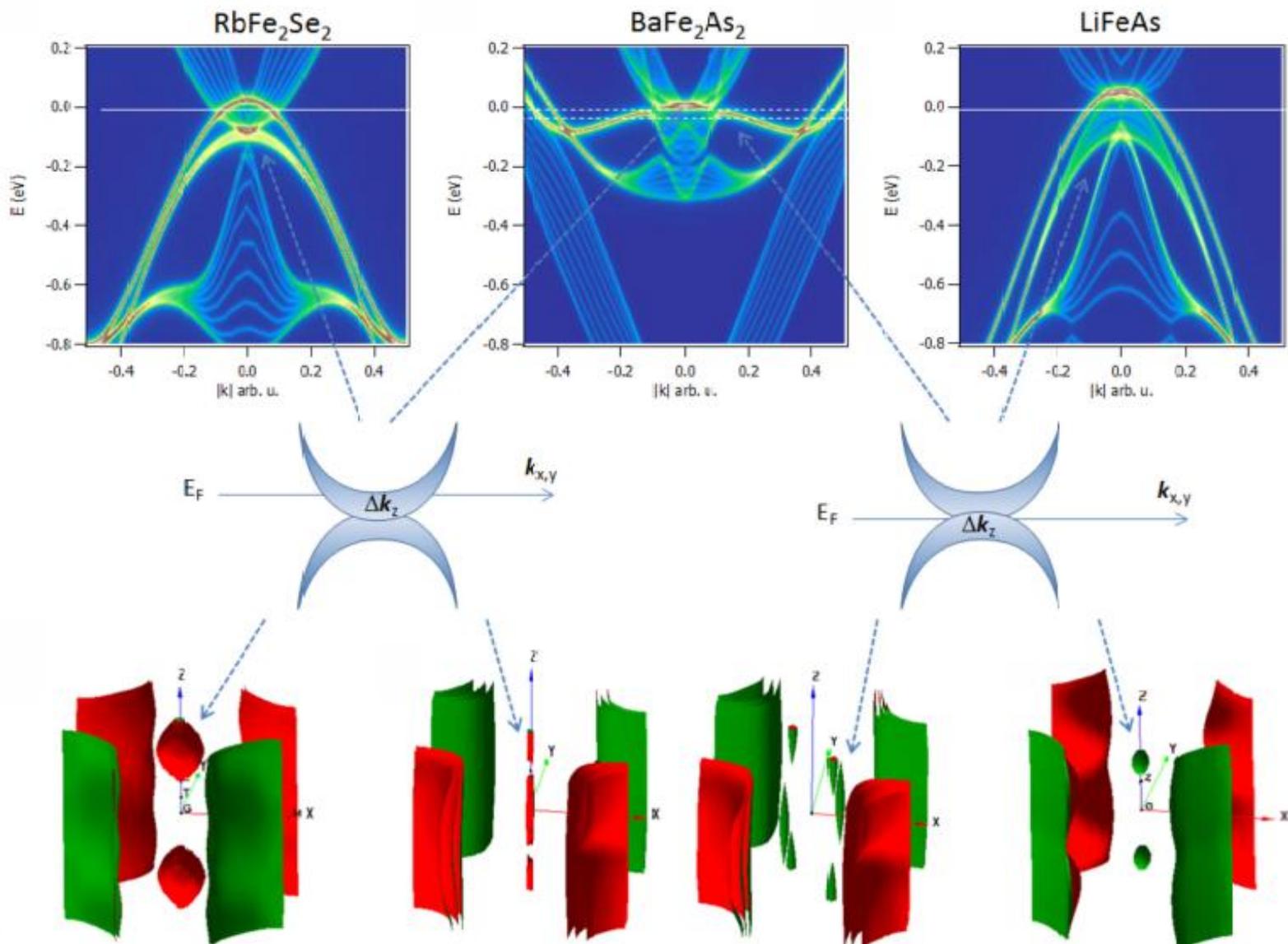
BFA



FeSC: электронная структура и сверхпроводимость



FeSC: электронная структура и сверхпроводимость



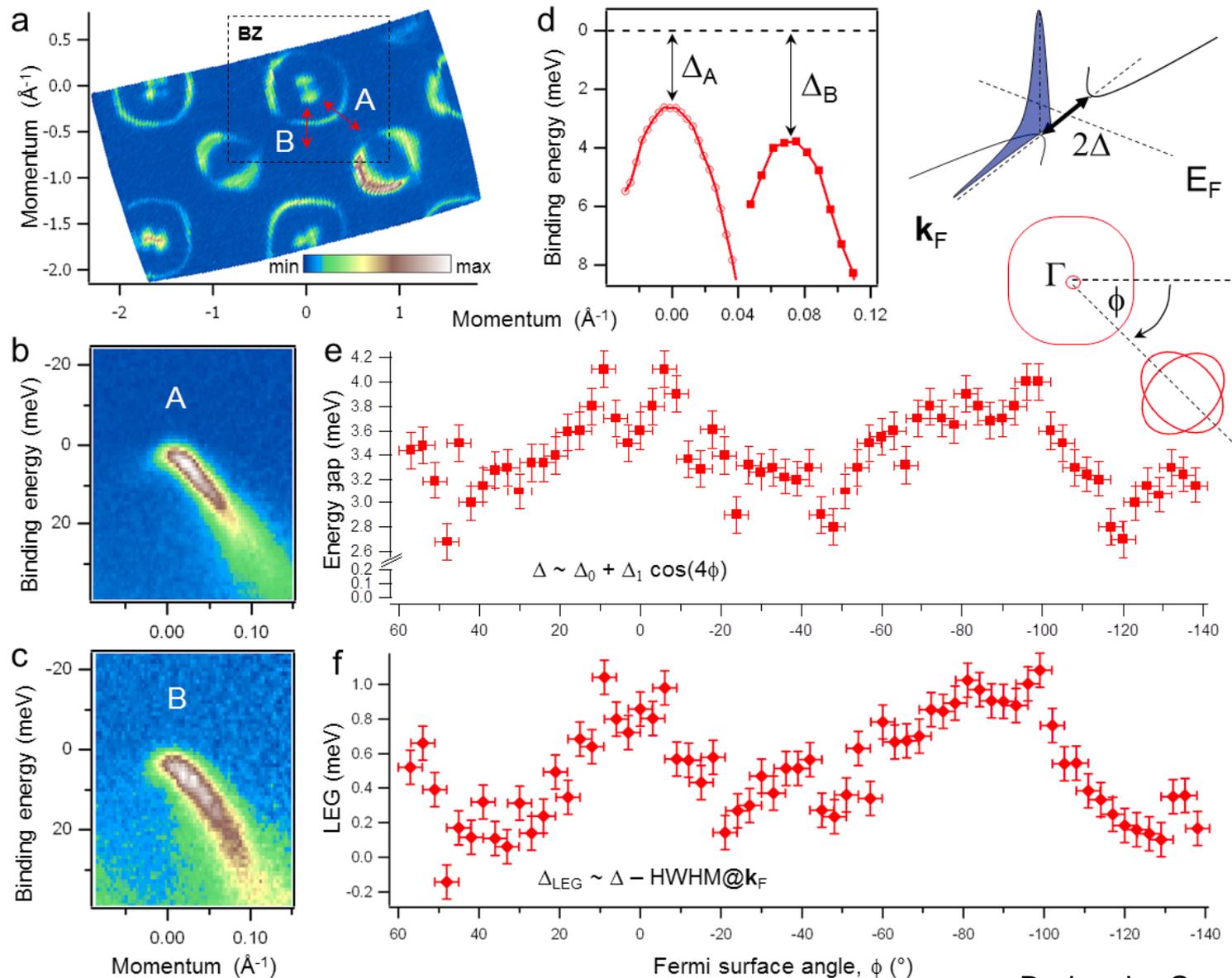
Выводы

- Механизм сверхпроводящего спаривания в FeSC остается пока невыясненным, но можно сказать, что электронная структура здесь является определяющей: максимальную склонность к сверхпроводимости демонстрируют исключительно системы с предельно малыми (близкими к топологическому переходу) поверхностями Ферми определенной симметрии (Fe $3d_{yz/zx}$).
- Именно сложность электронной структуры этих материалов позволила обнаружить указанную корреляцию и указать путь к увеличению T_c (дырочное допирование BKFA или LiFeAs).

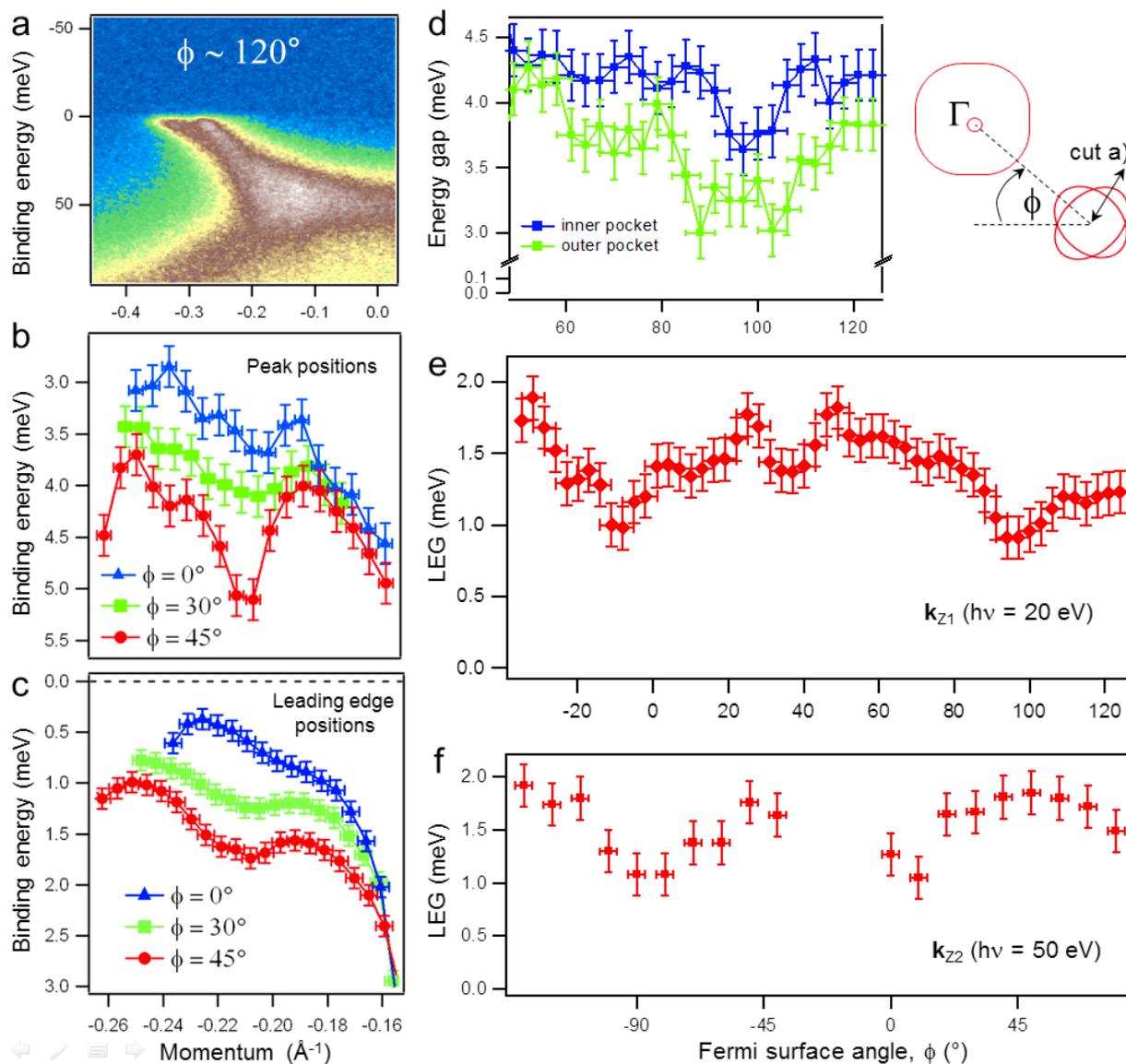
Сверхпроводящая щель

Сверхпроводящая щель в LiFeAs

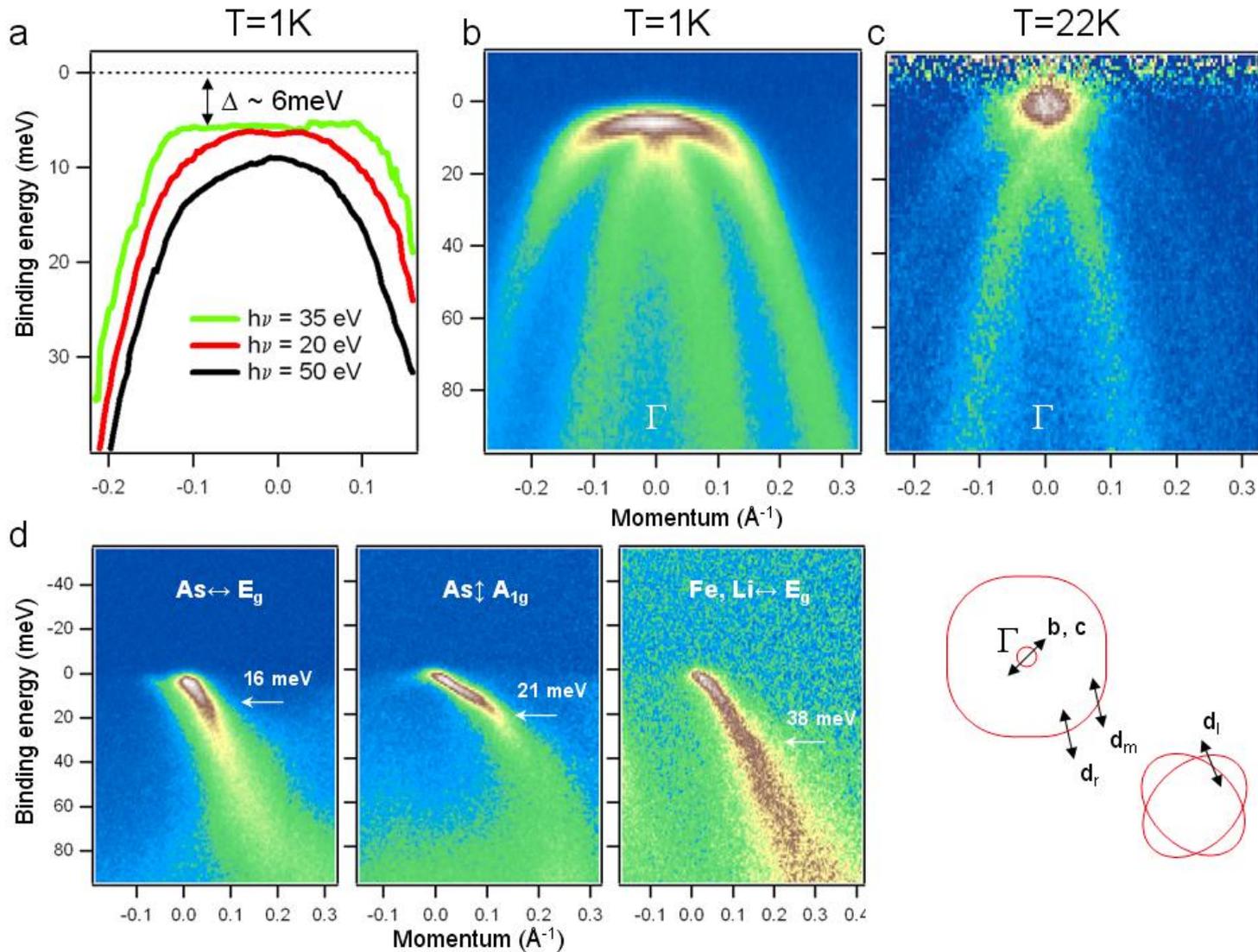
symmetry



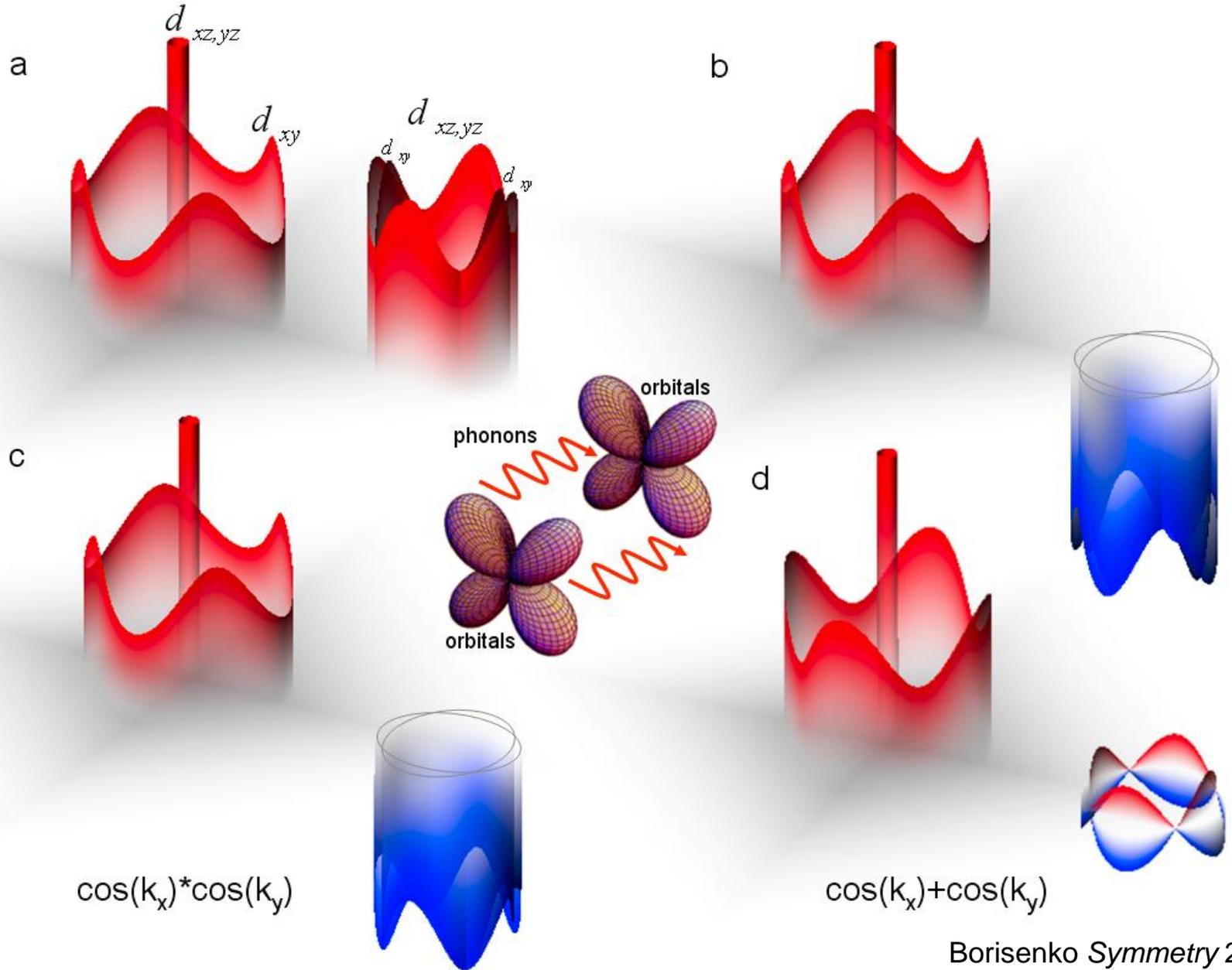
Сверхпроводящая щель в LiFeAs



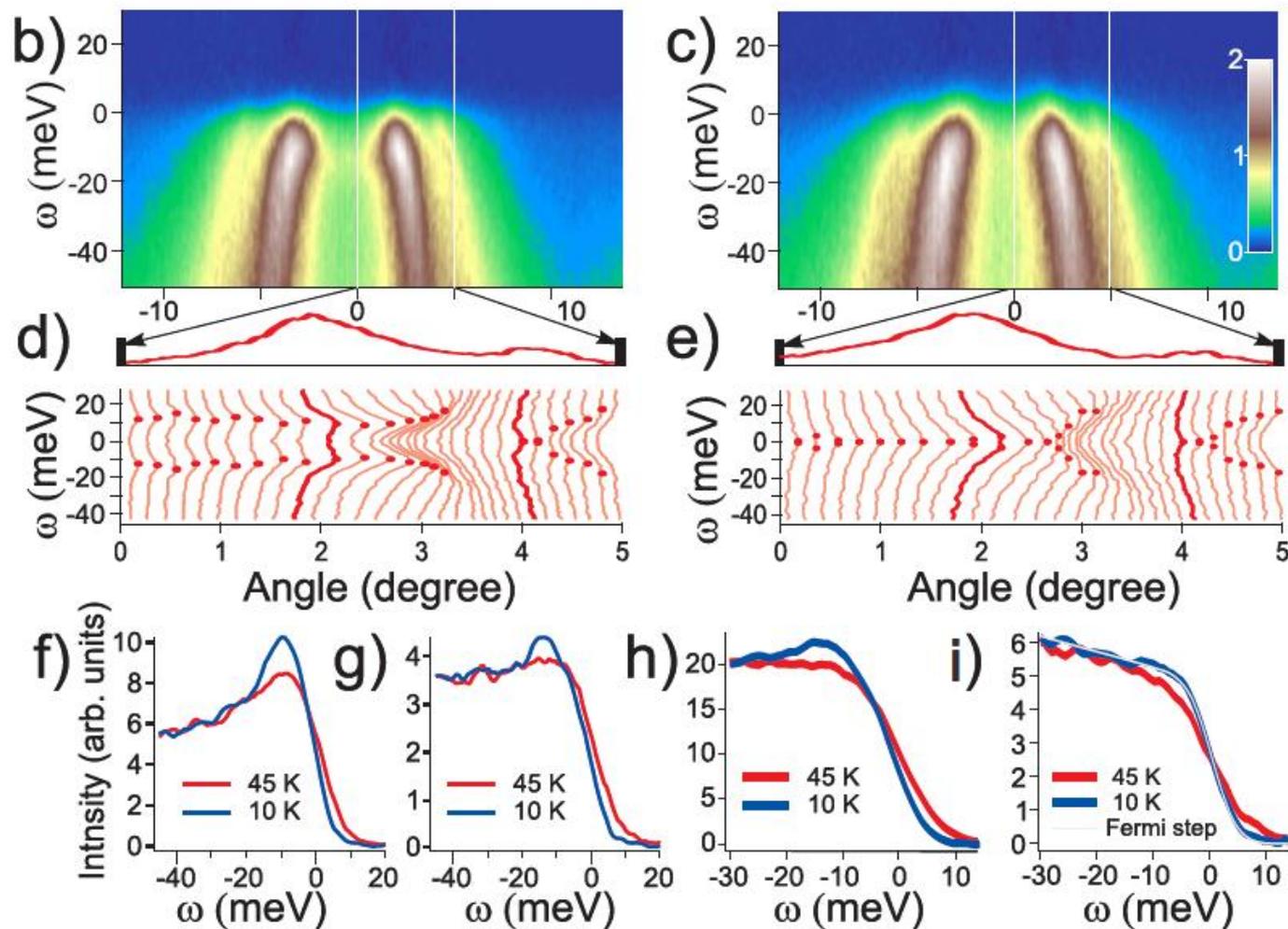
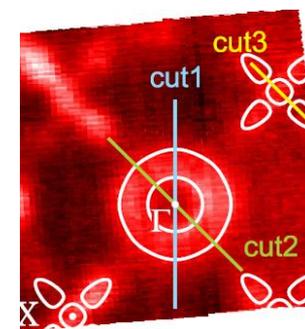
Сверхпроводящая щель в LiFeAs



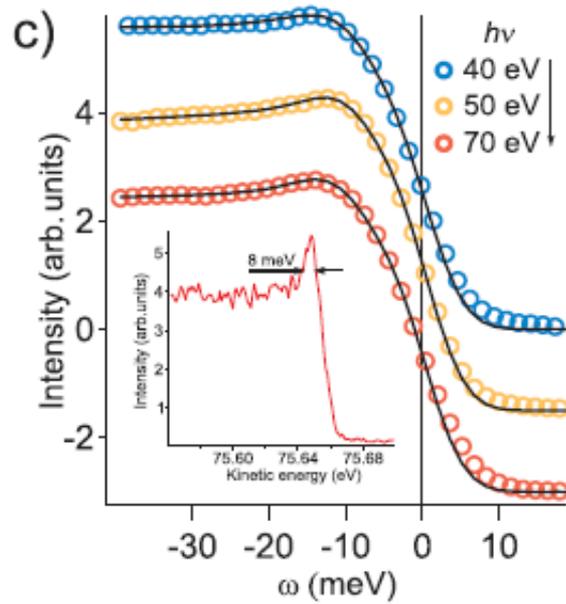
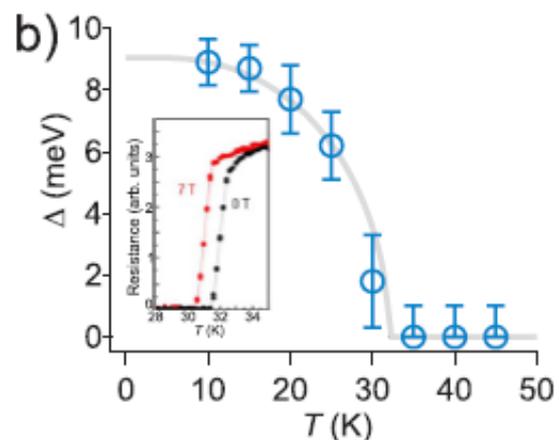
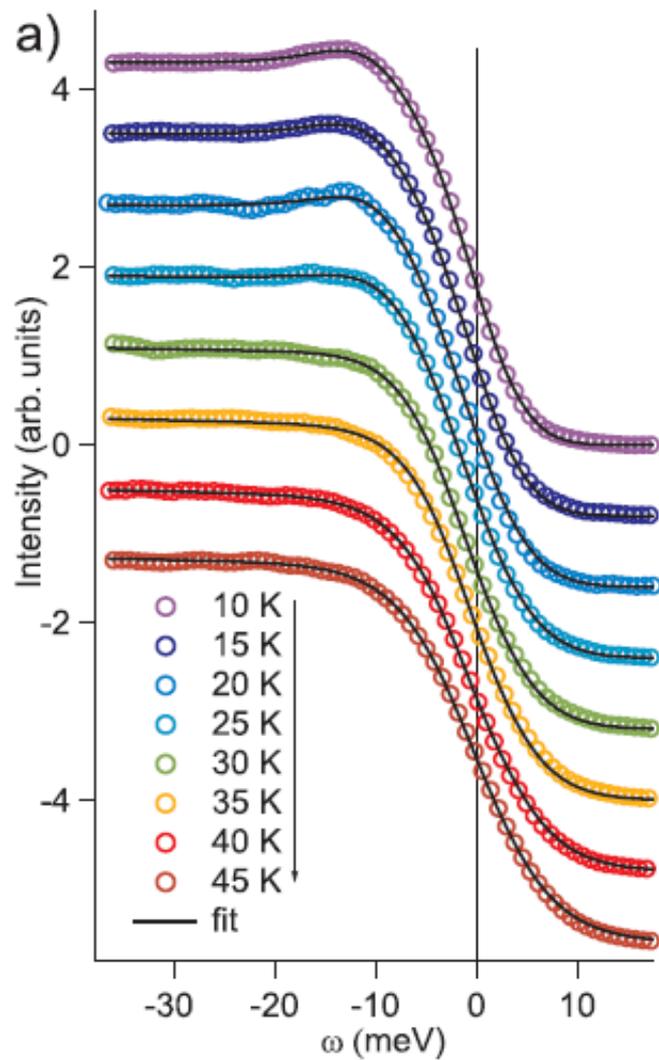
Сверхпроводящая щель в LiFeAs



Сверхпроводящая щель в ВКФА

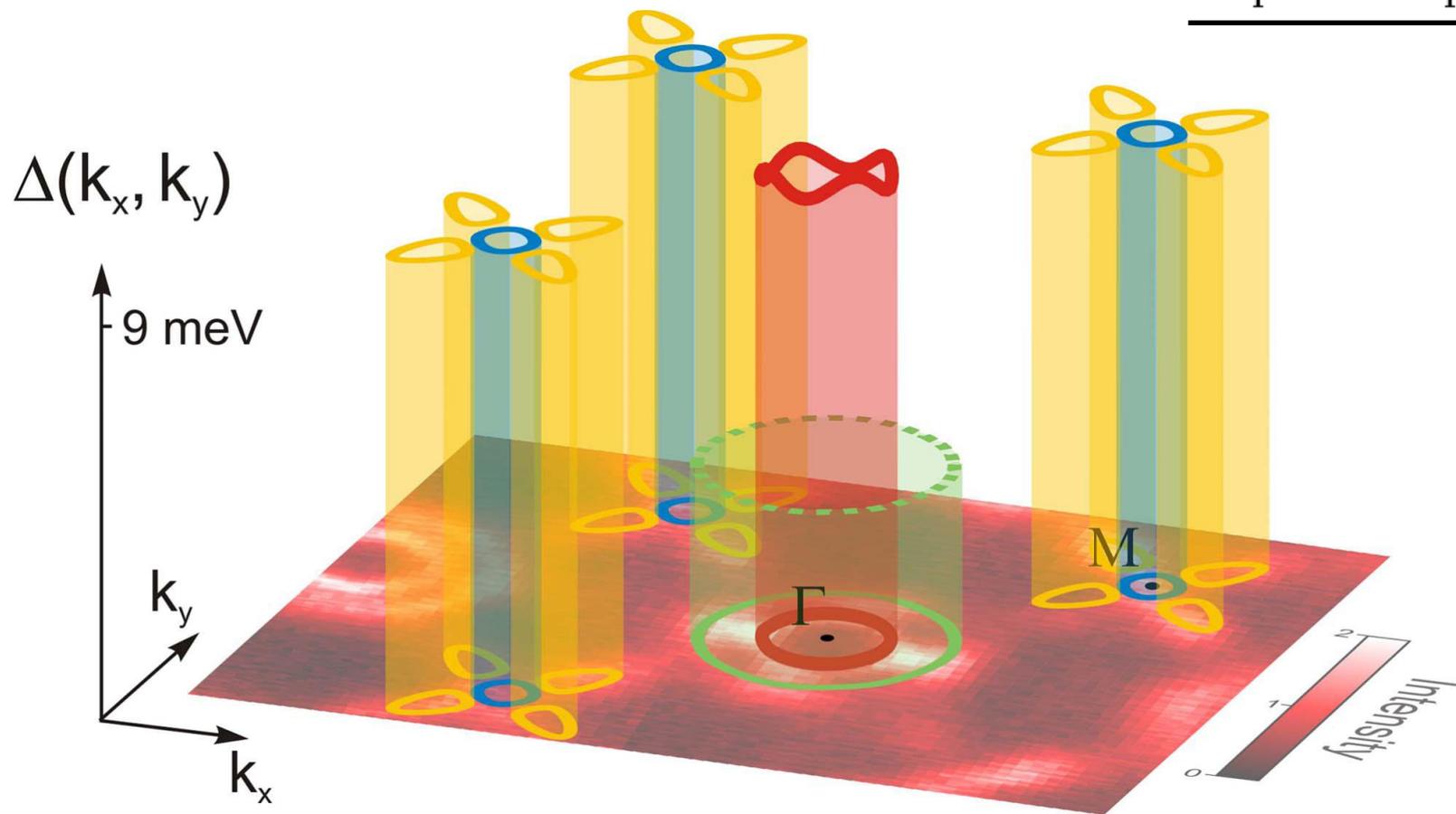


Сверхпроводящая щель в ВКФА

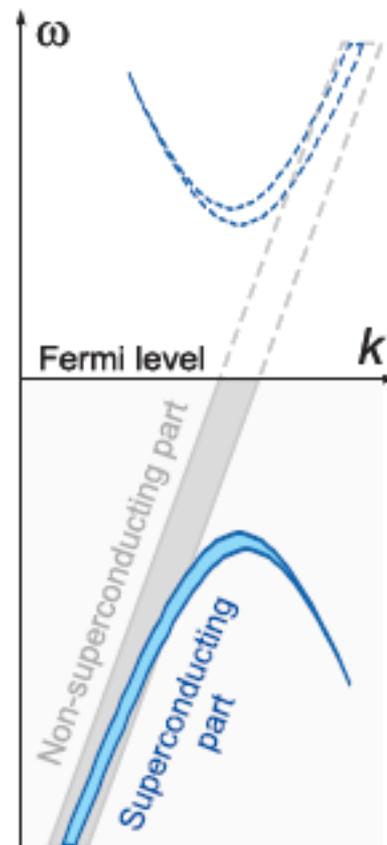
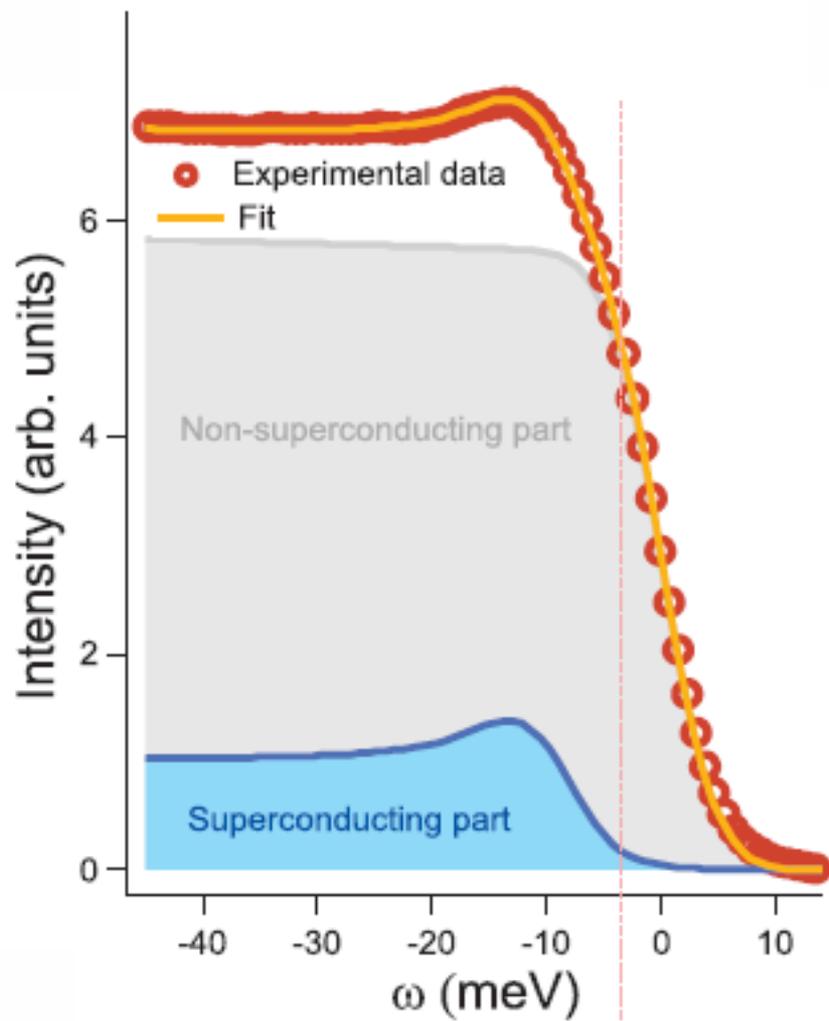


Сверхпроводящая щель в ВКФА

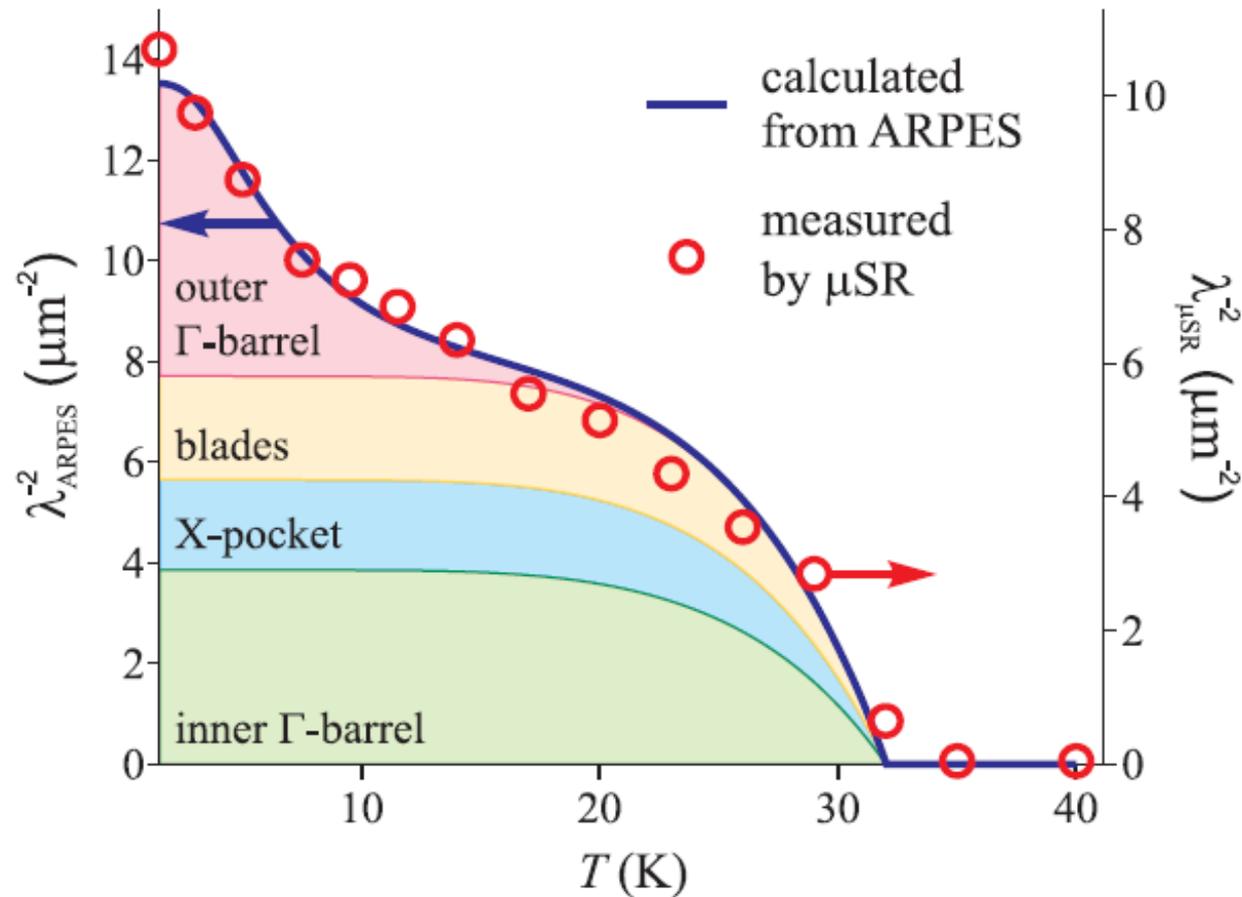
Inner Γ -barrel	9 ± 1
Outer Γ -barrel	< 4
X-pocket	9 ± 2
Blades	~ 9
Gap anisotropy	< 1.5



Сверхпроводящая щель в ВКФА

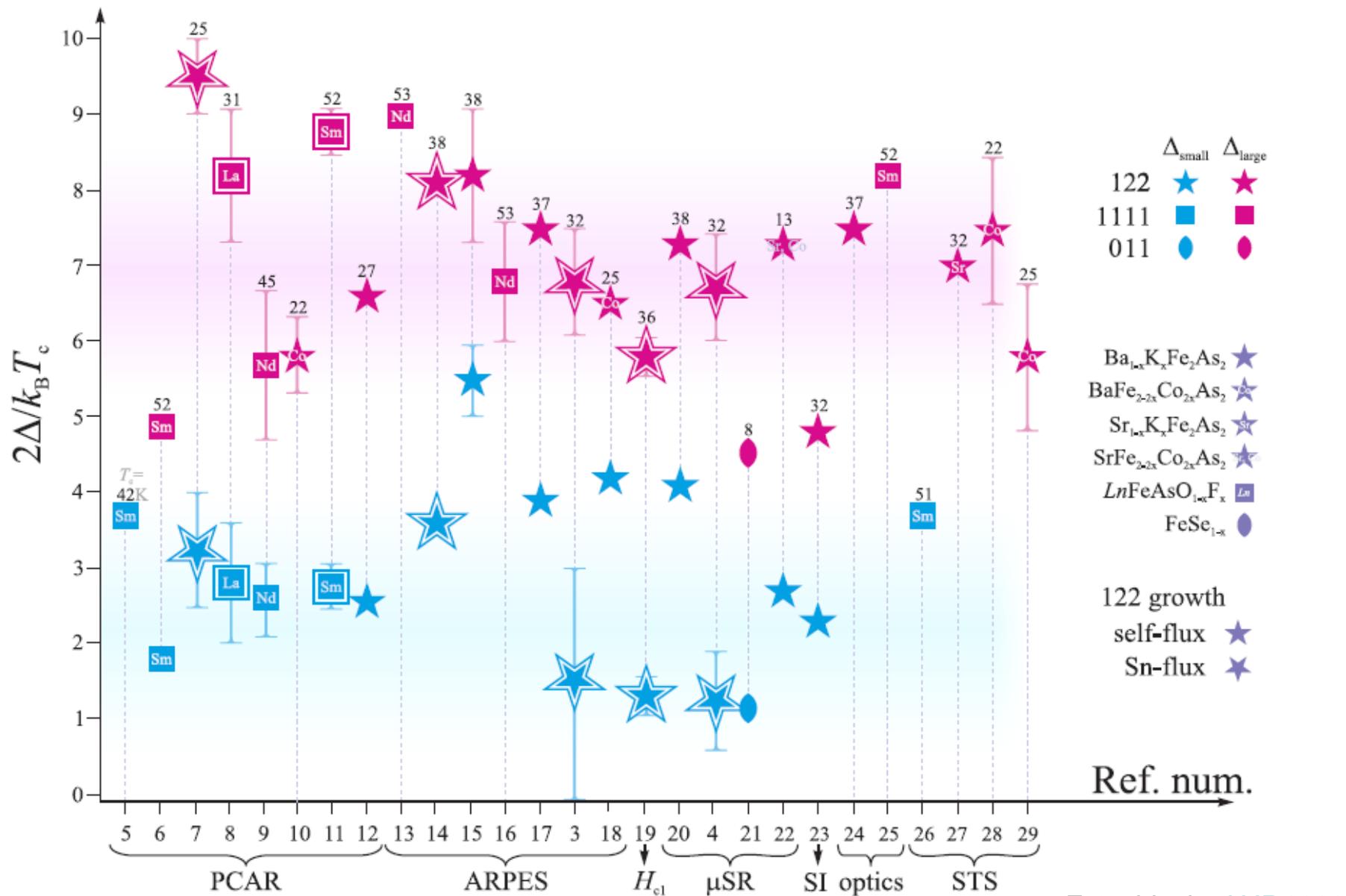


Сверхпроводящая щель в ВКФА

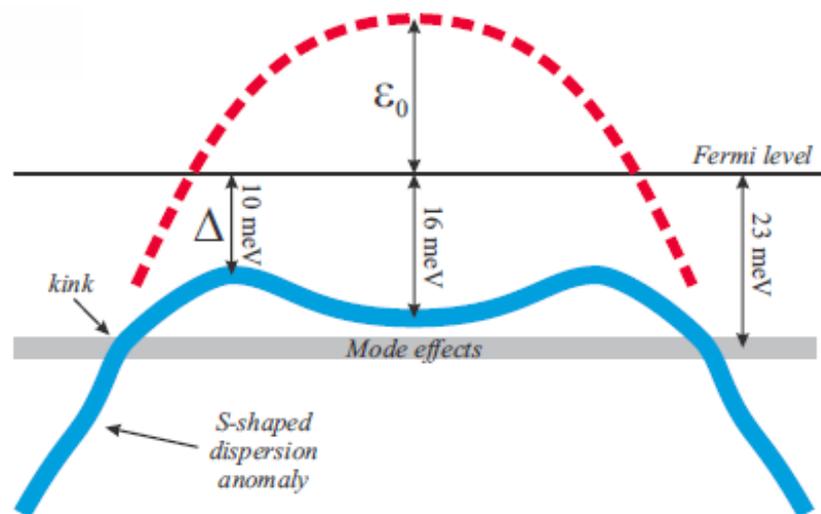
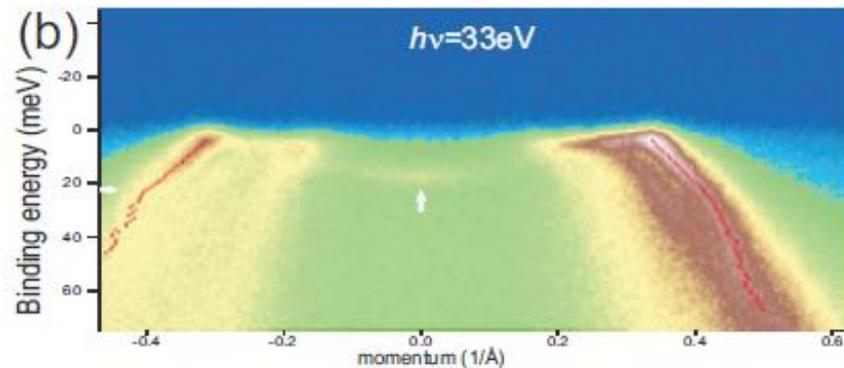
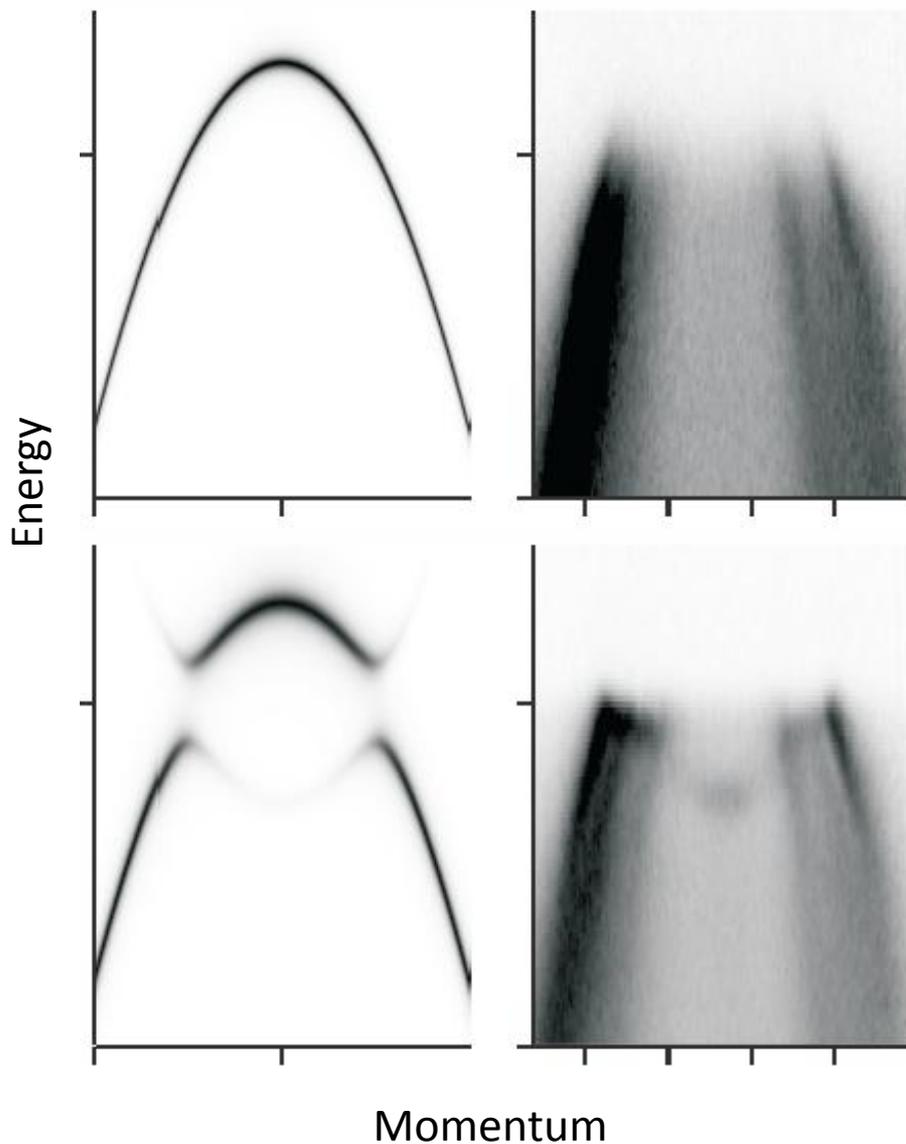


$$\frac{1}{\lambda^2(T)} = \frac{e^2}{2\pi\epsilon_0 c^2 h L_c} \cdot \int_{\text{FS}} v_F(\mathbf{k}) \left[1 - \int_{-\infty}^{+\infty} \left(-\frac{\partial f_T(\omega)}{\partial \omega} \right) \left| \text{Re} \frac{\omega + i\Sigma''}{\sqrt{(\omega + i\Sigma'')^2 - \Delta_{\mathbf{k}}^2(T)}} \right| d\omega \right] dk$$

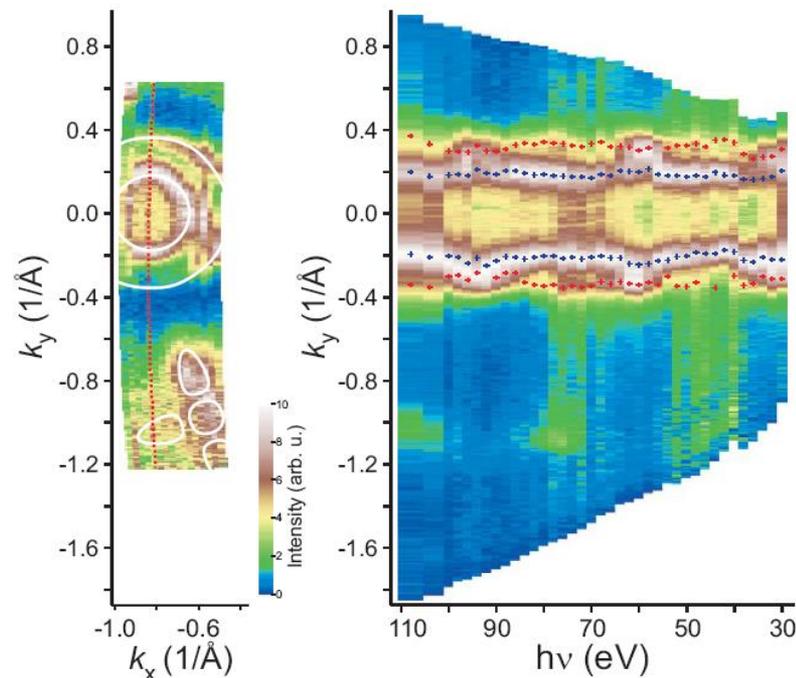
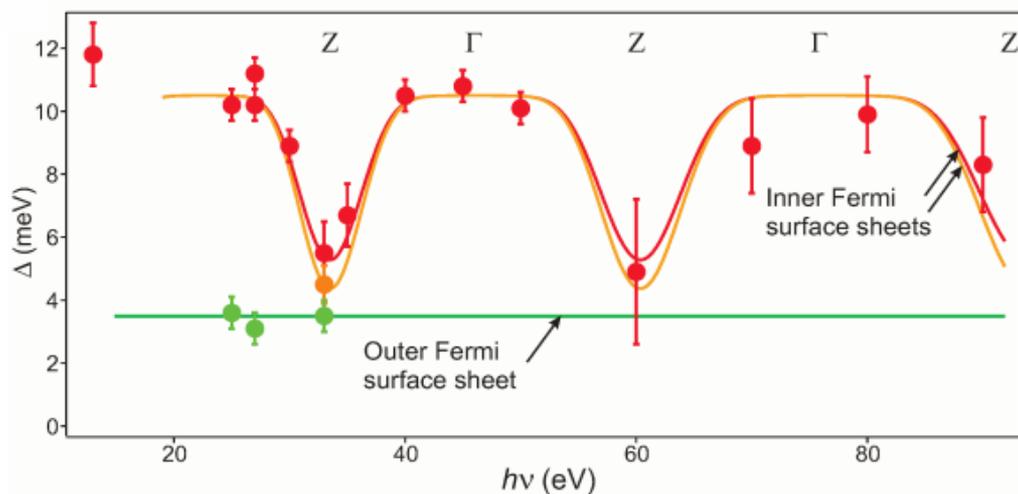
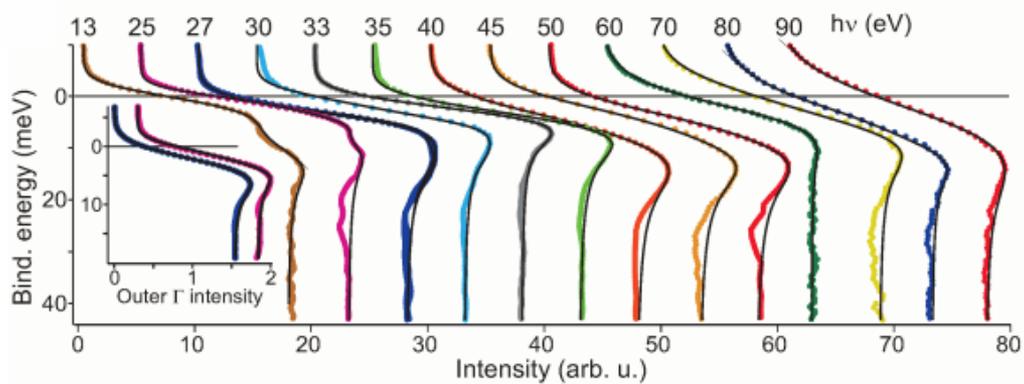
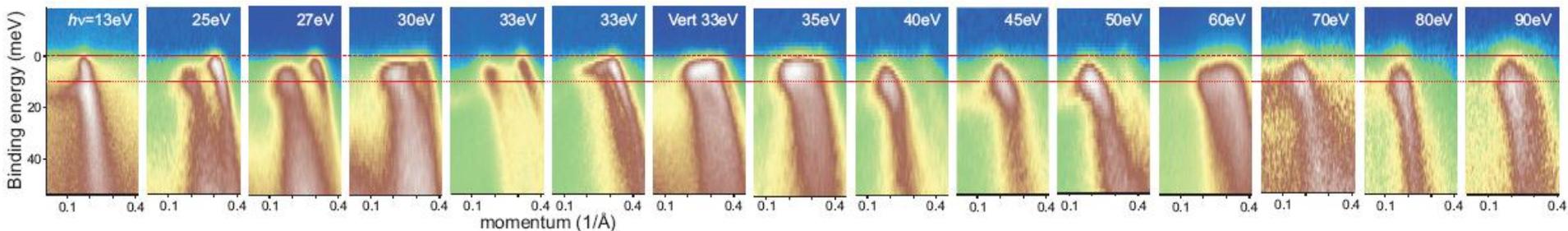
Сверхпроводящая щель в ВКФА



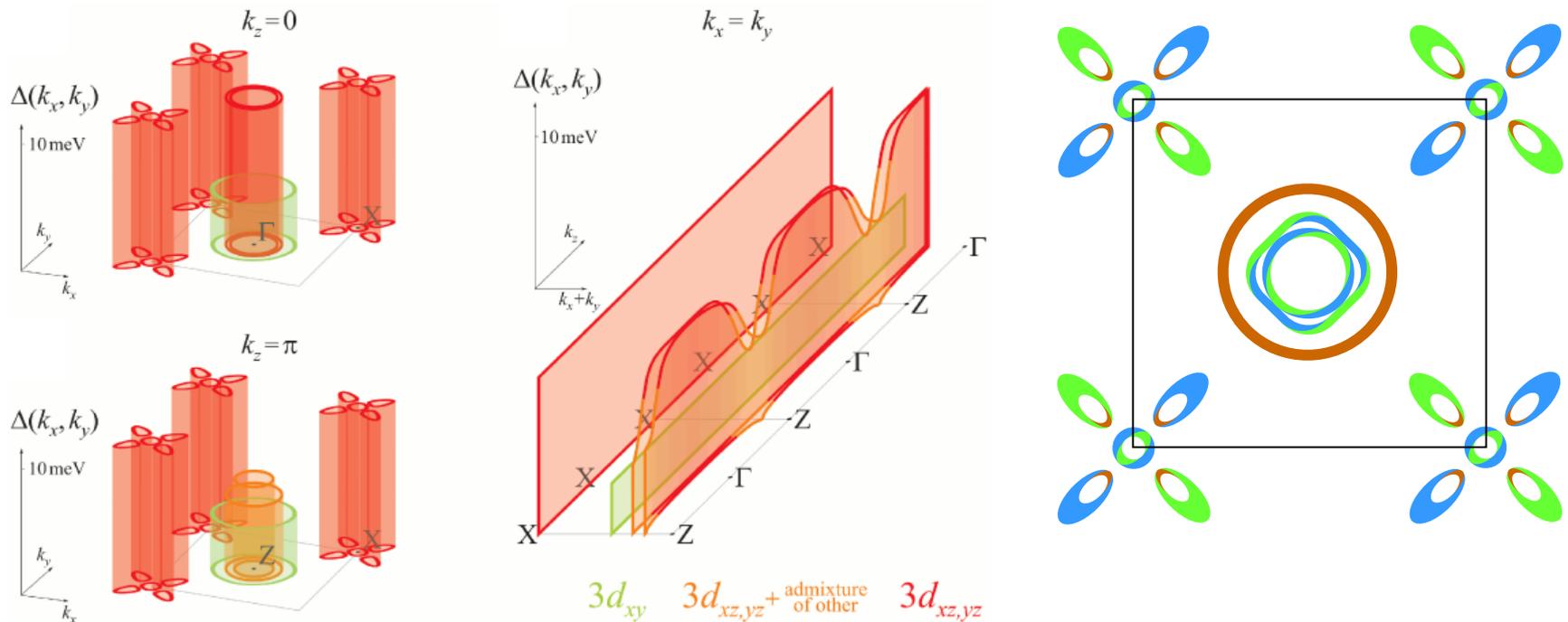
Сверхпроводящая щель в ВКФА



Сверхпроводящая щель в ВКФА



Сверхпроводящая щель в ВКФА



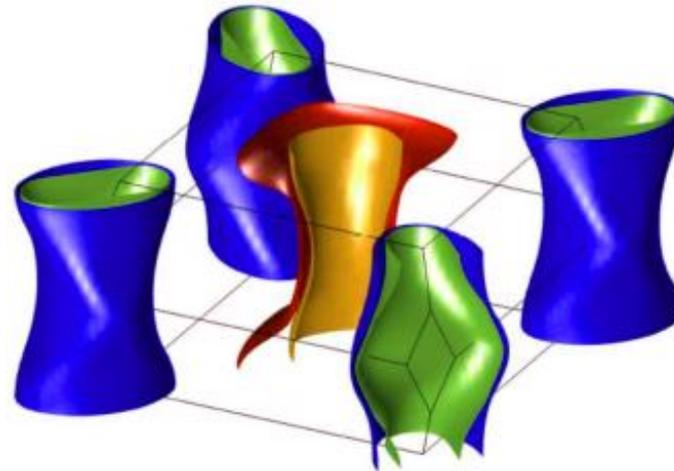
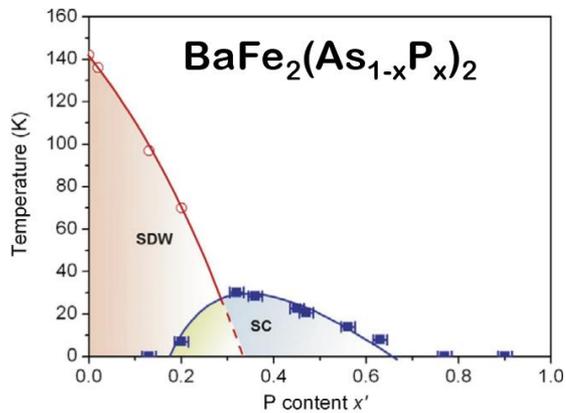
Δ correlates with the orbital composition:

$\Delta = 3\text{--}4$ meV for $3d_{xy}$ and $3d_{z^2}$

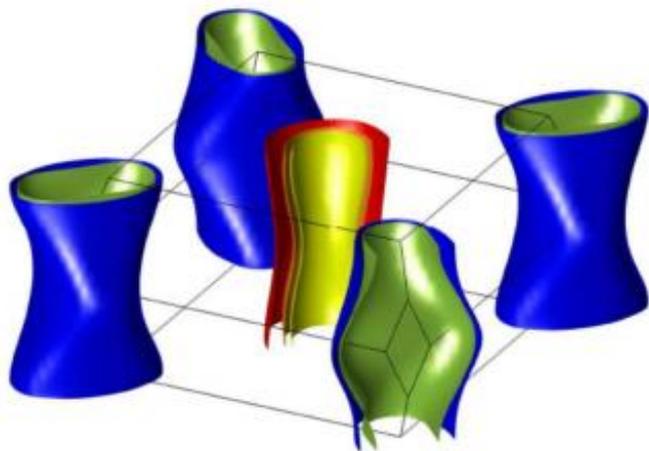
$\Delta = 10.5$ meV for $3d_{xz/yz}$.

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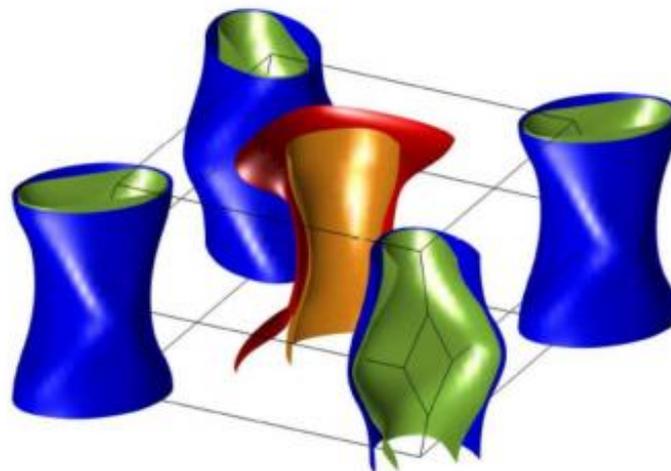
isovalent doping



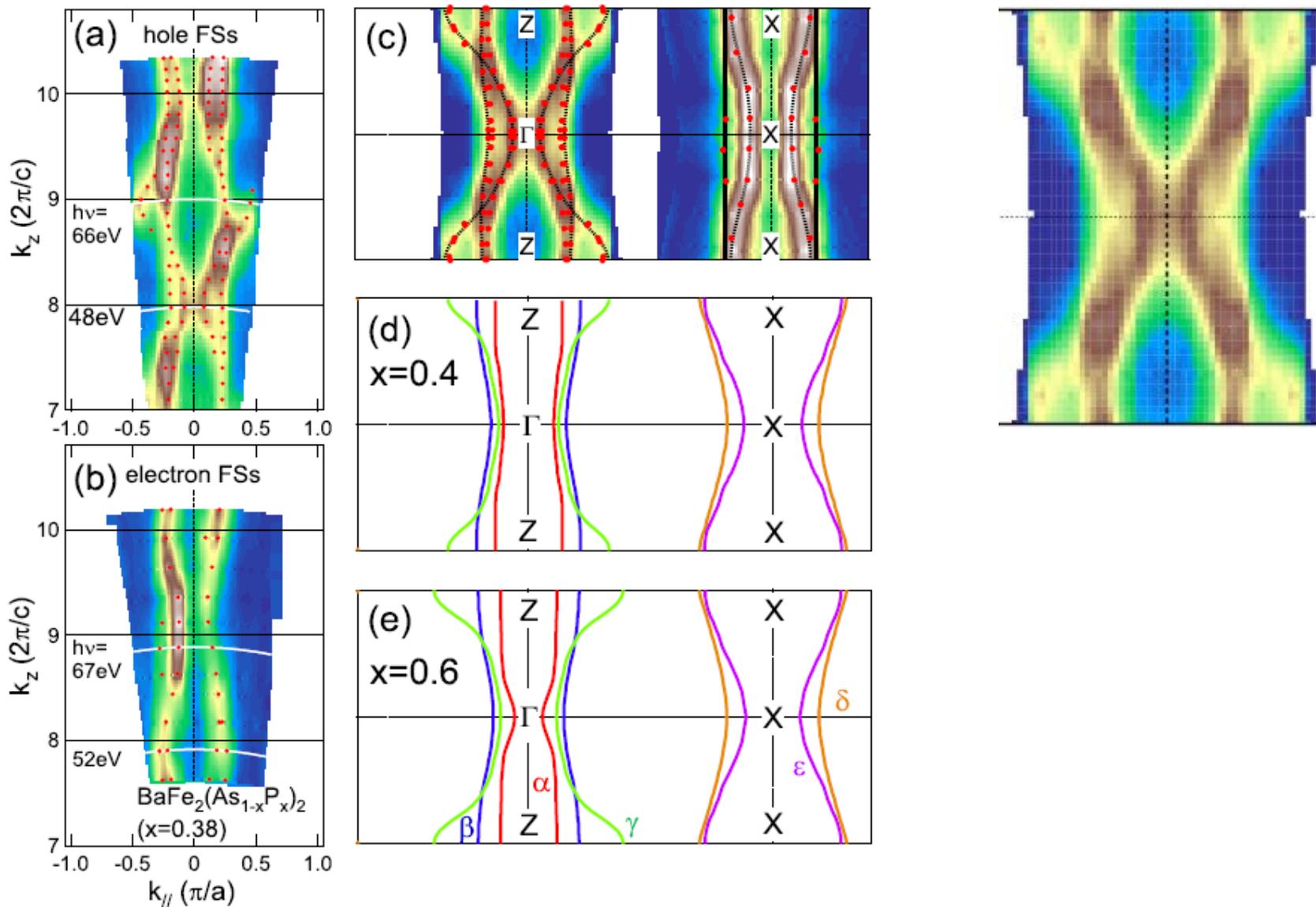
BaFe_2As_2



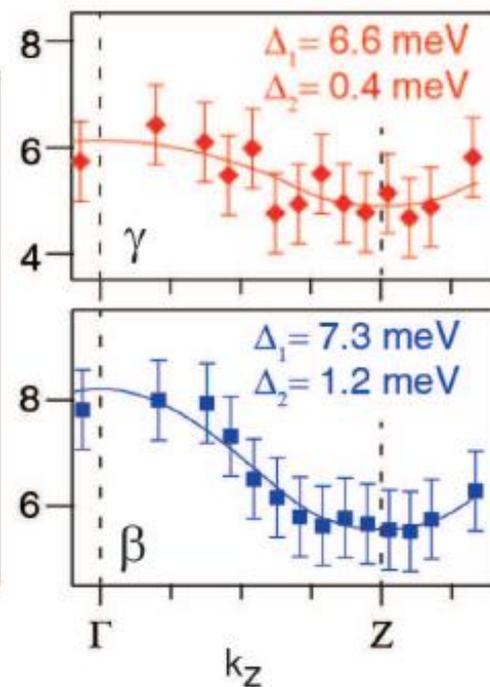
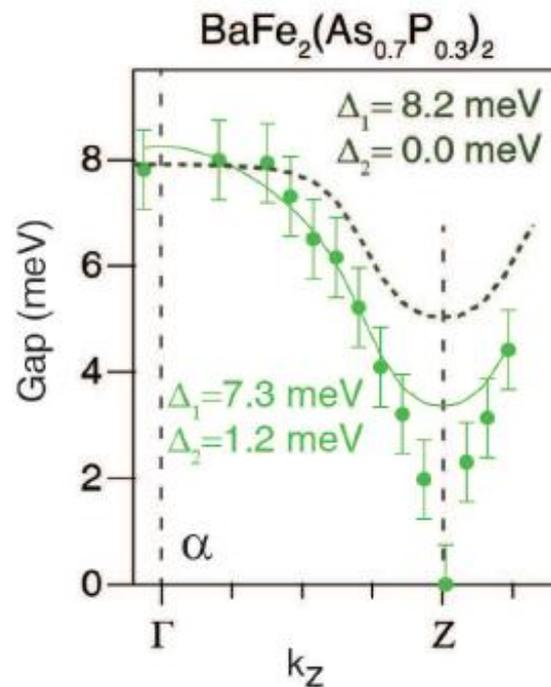
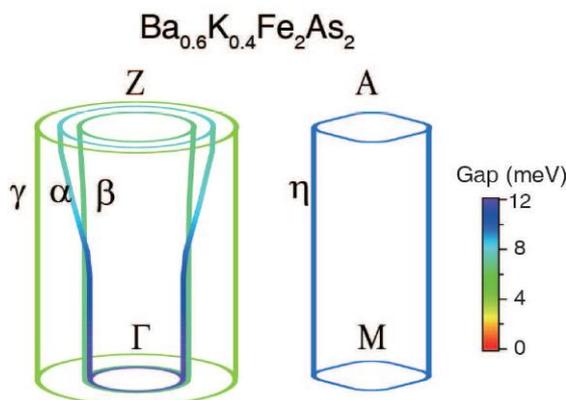
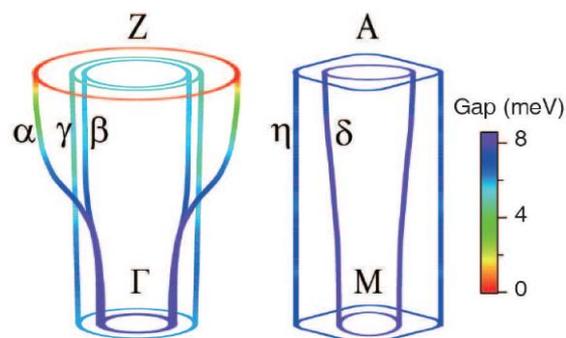
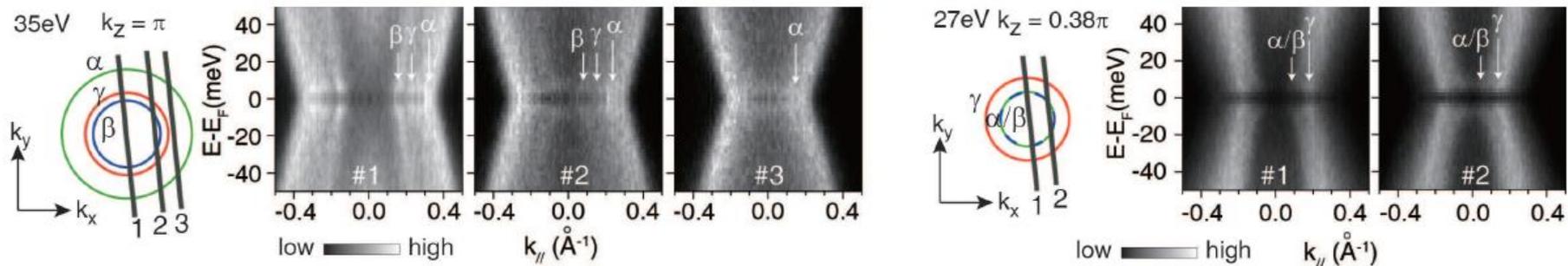
BaFe_2P_2



Сверхпроводящая щель в VFPA

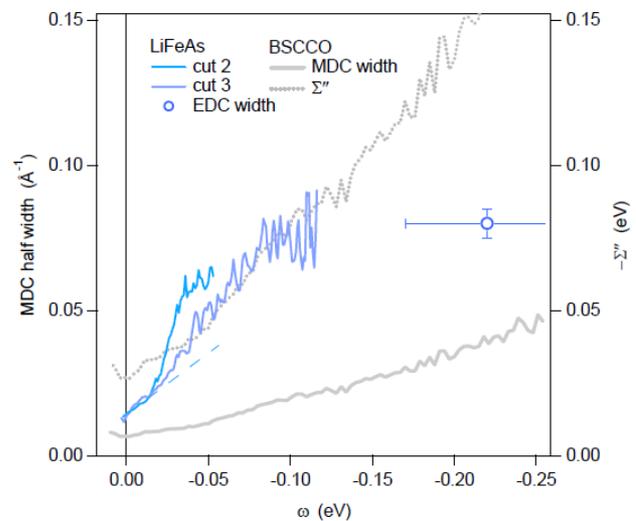
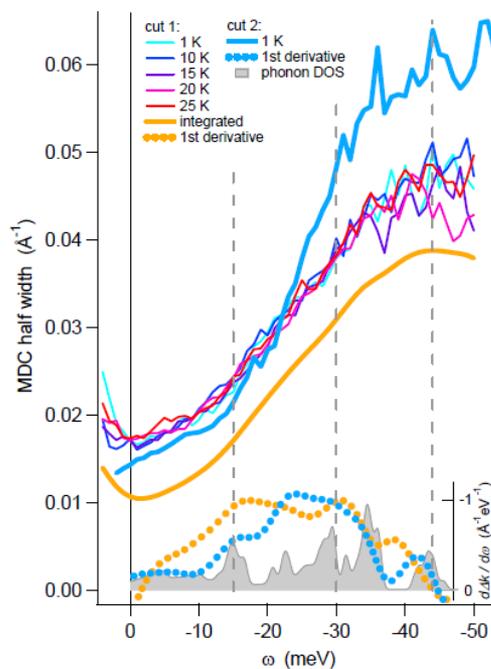
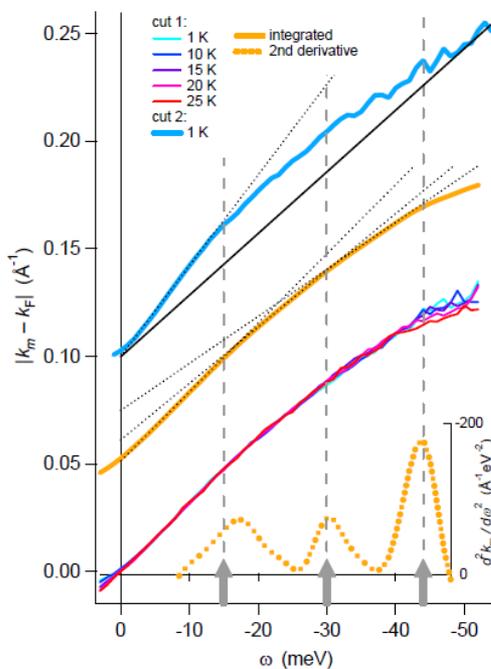
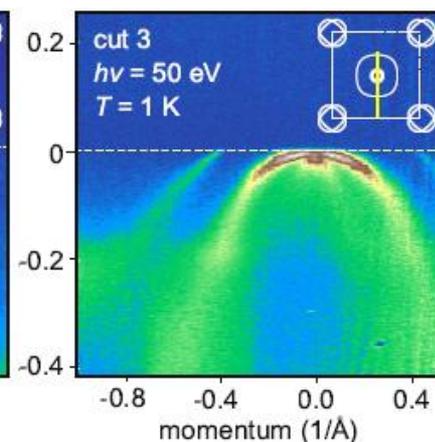
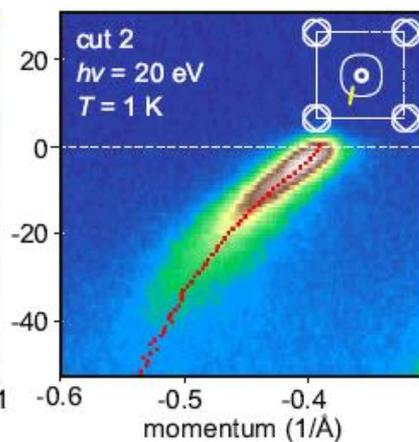
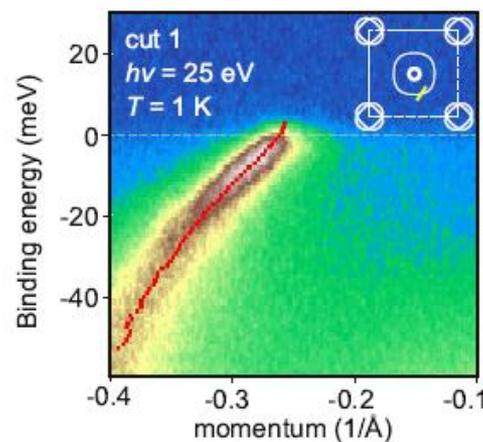
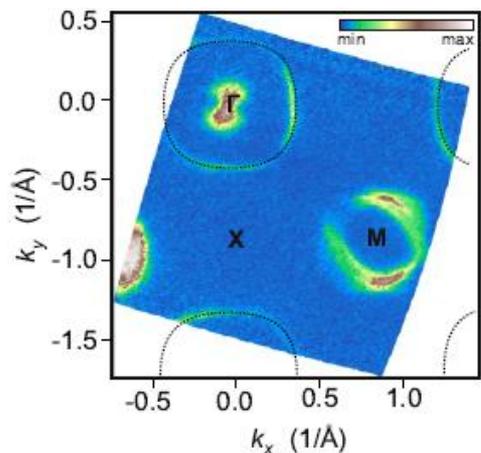


Сверхпроводящая щель в VFRA



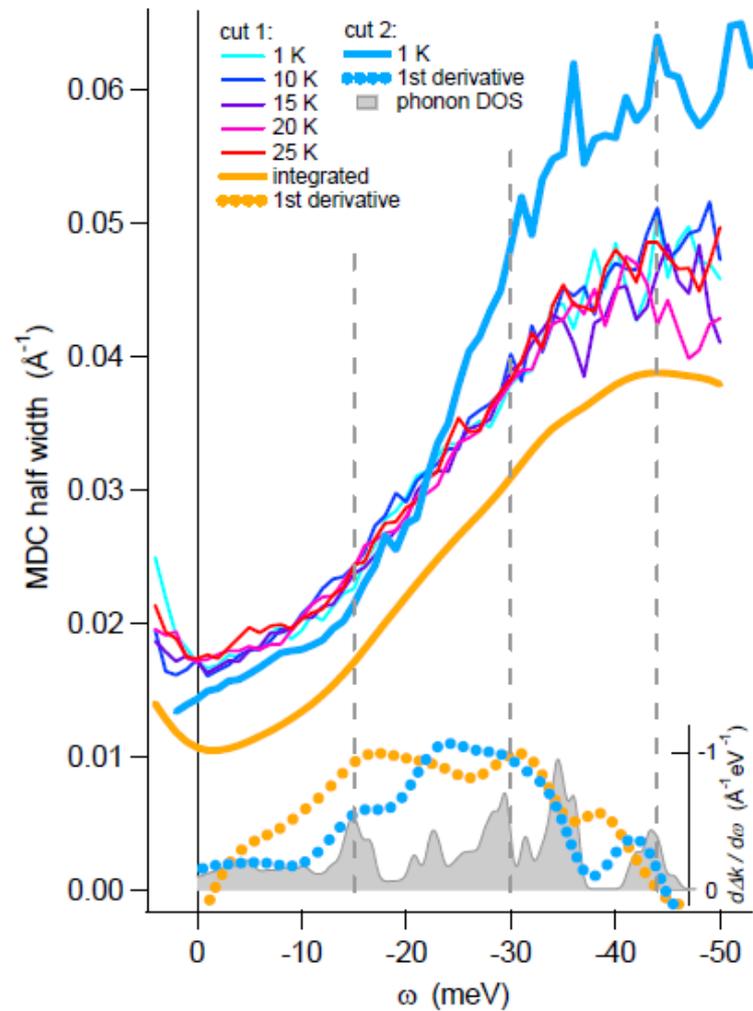
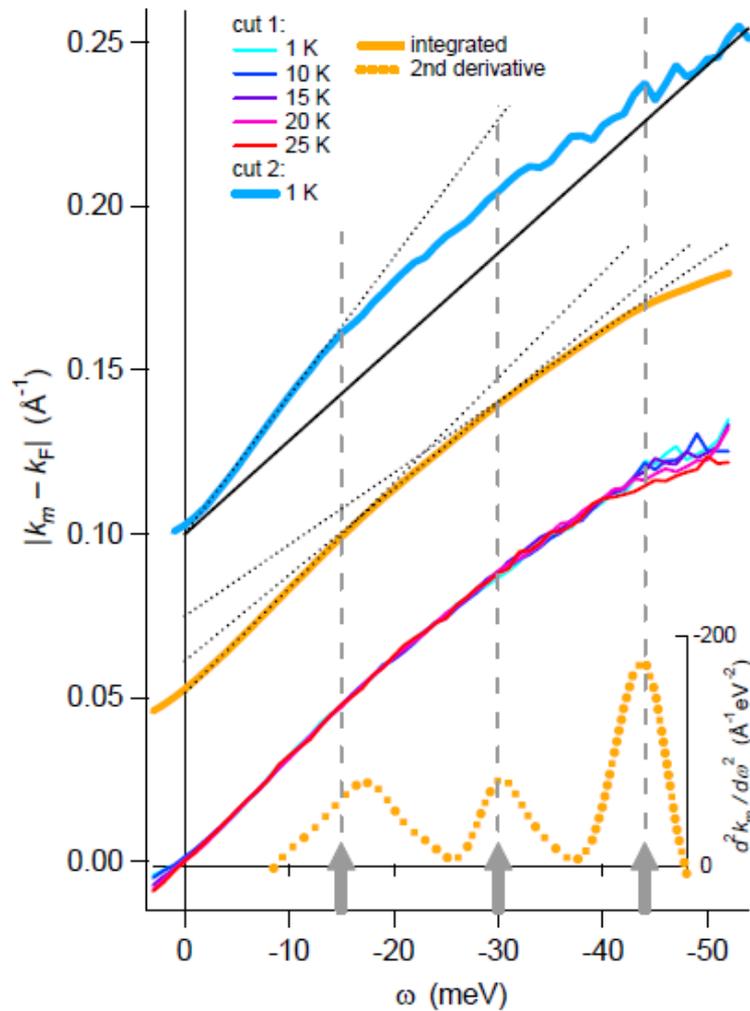
Собственная энергия

LiFeAs: renormalization



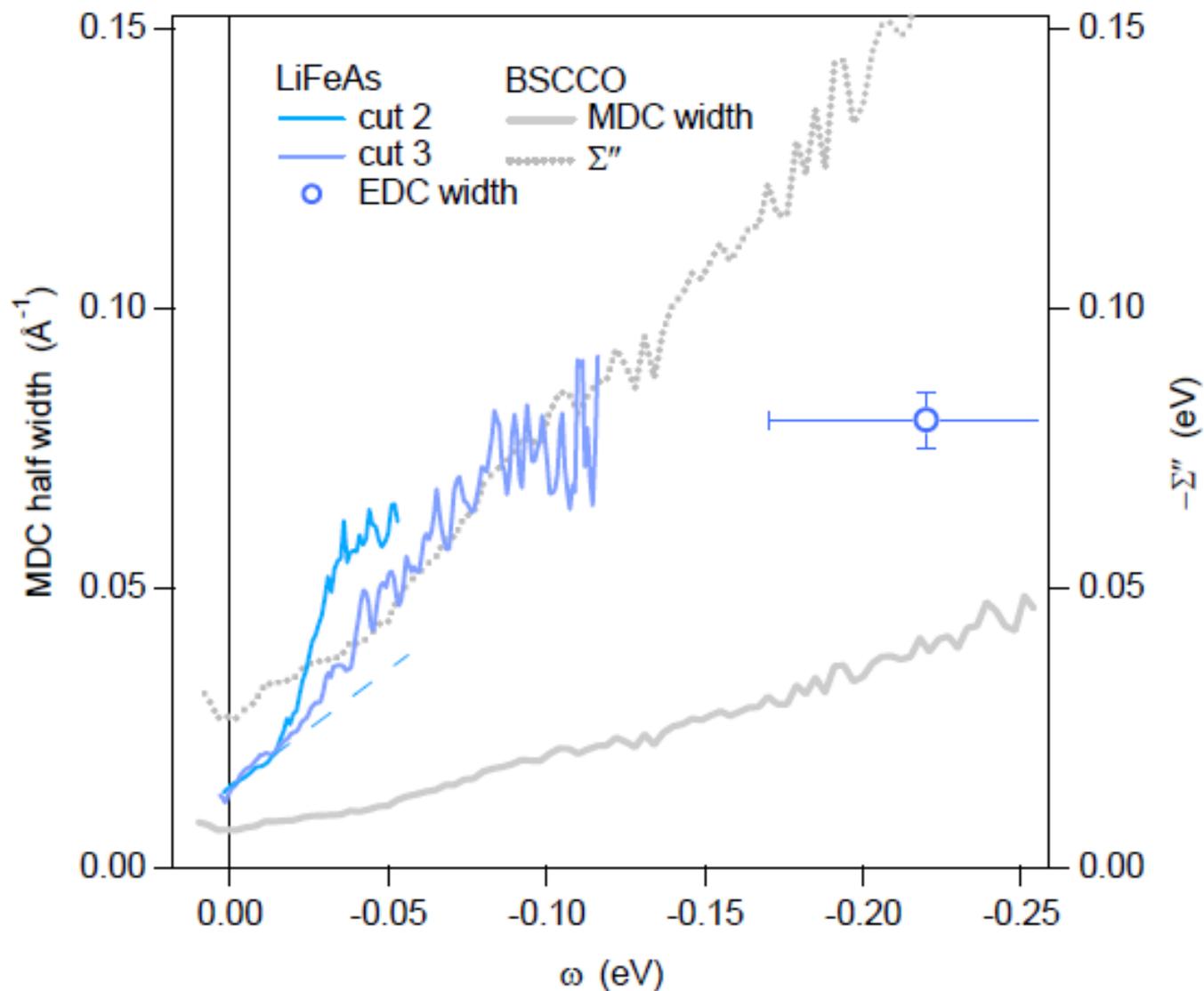
$$\lambda = \lambda_{el} + \lambda_{ph} = 2 + 1.38$$

LiFeAs: renormalization

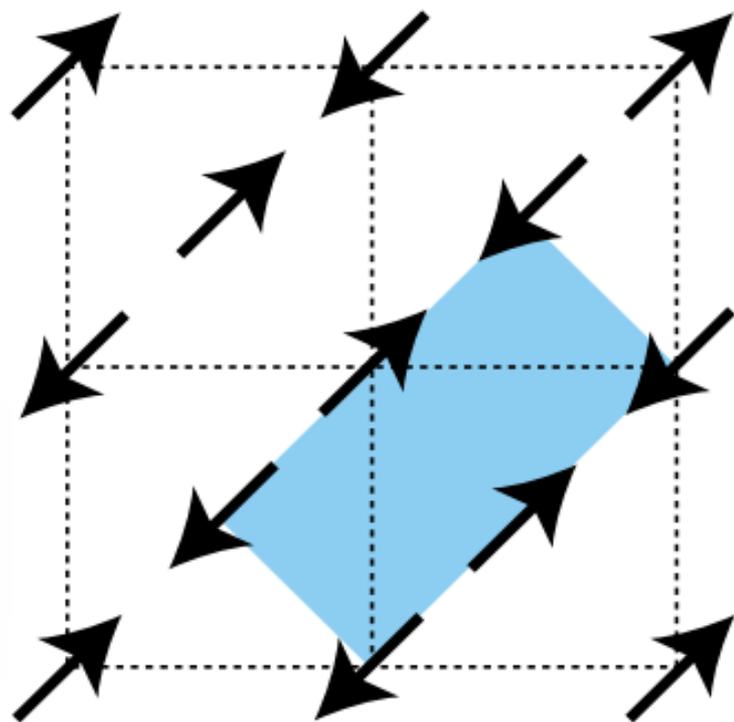


$$\lambda = \lambda_{el} + \lambda_{ph} = 2 + 1.38$$

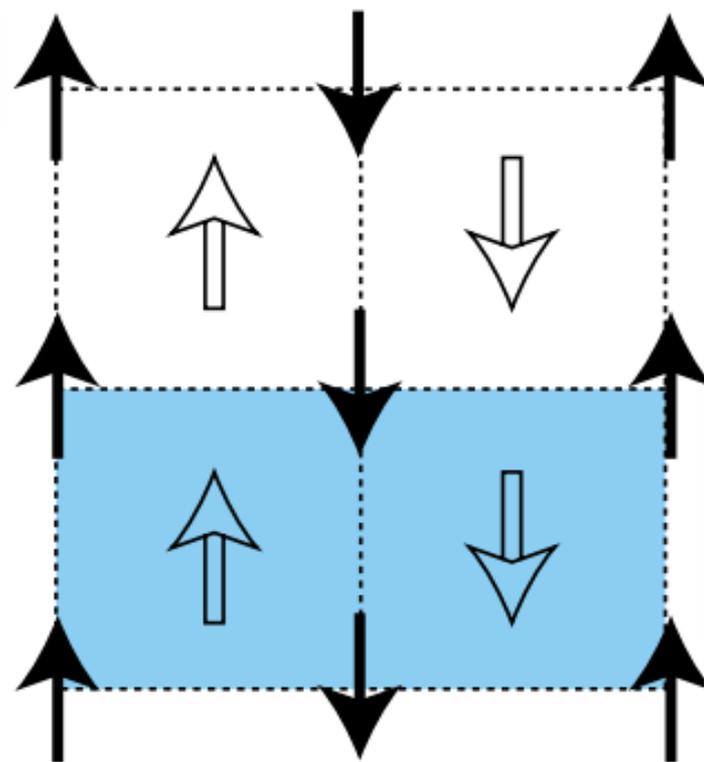
LiFeAs: renormalization



Магнетизм

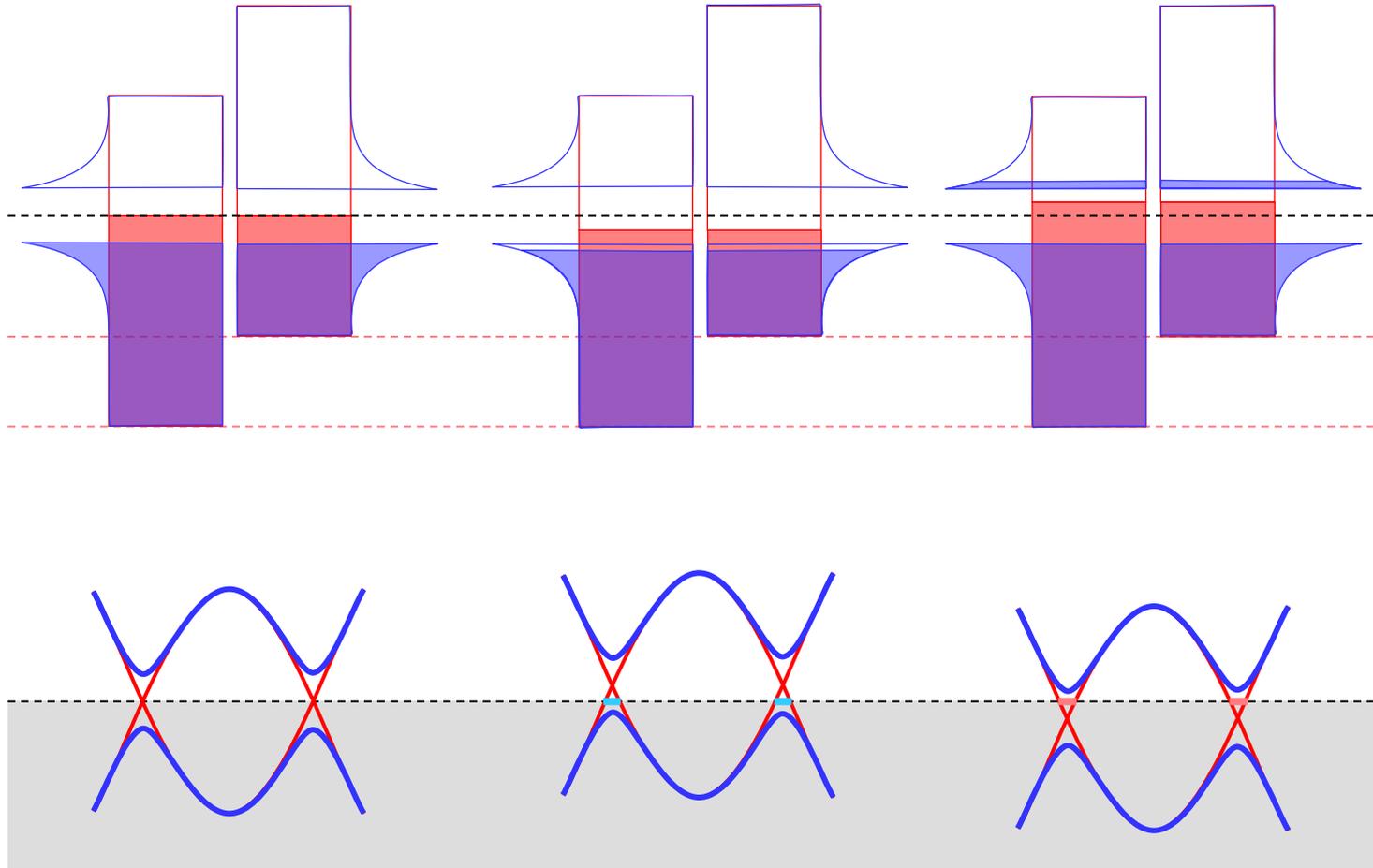


SrFe_2As_2

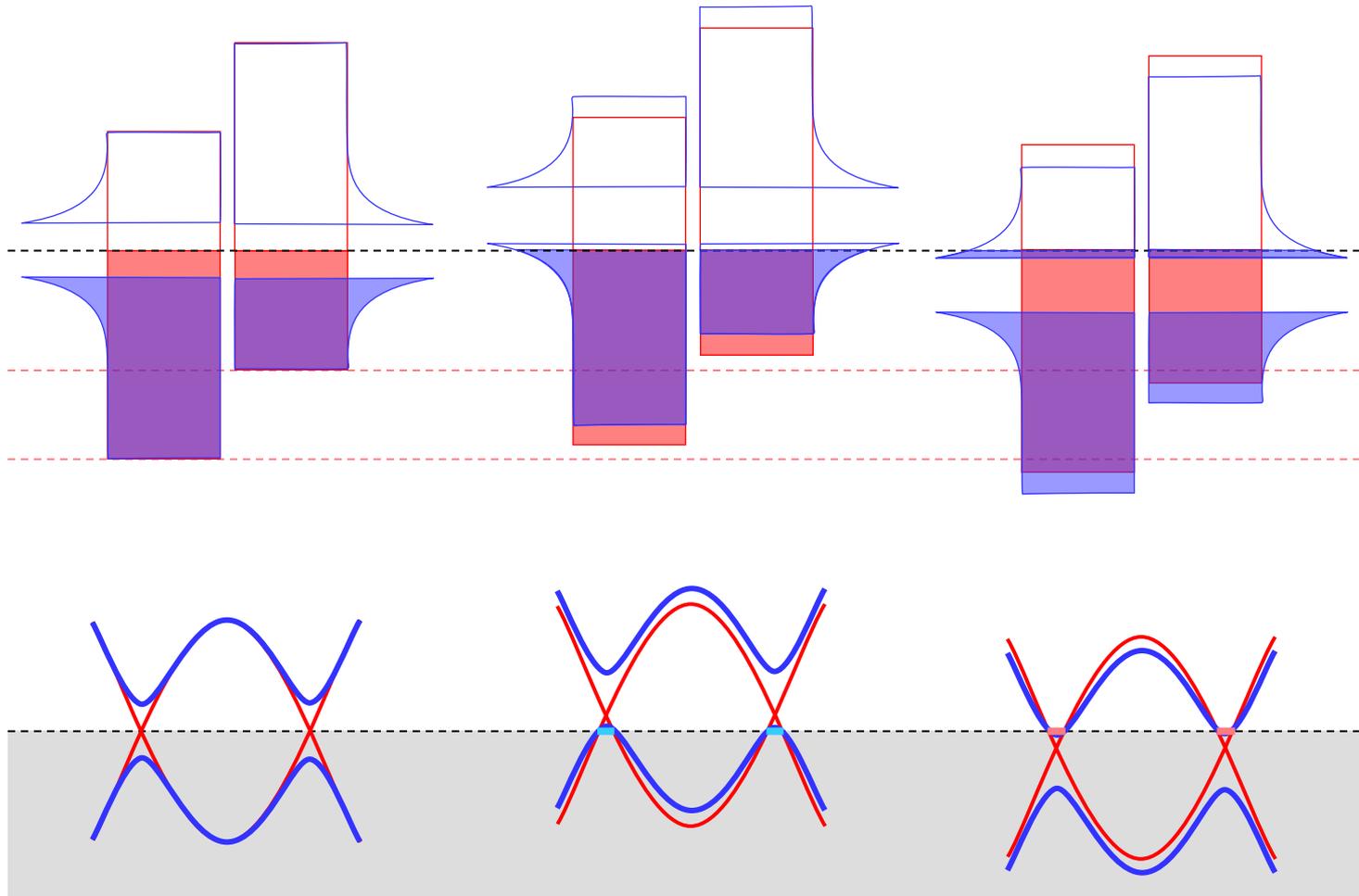


FeTe

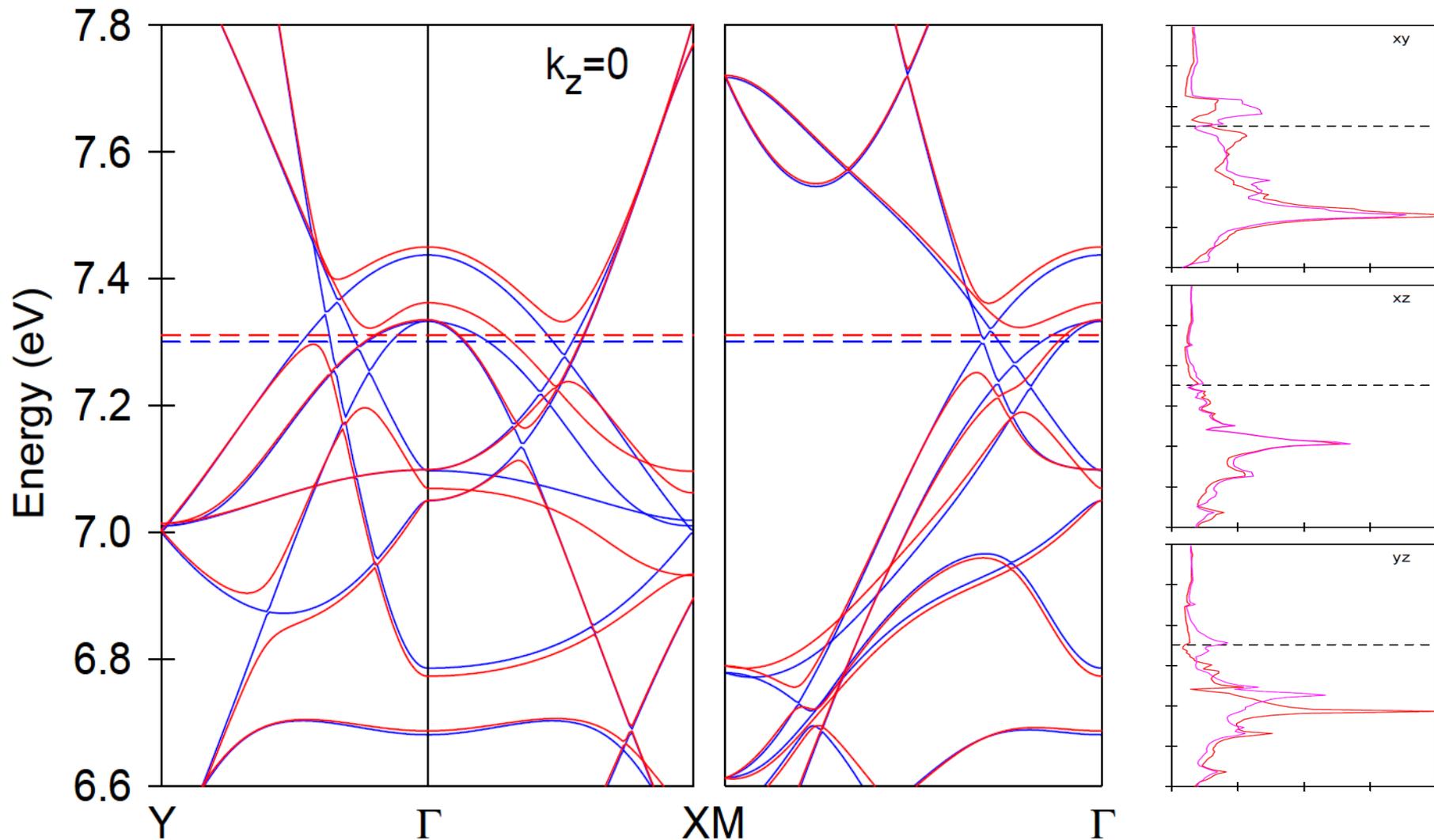
SC & SDW



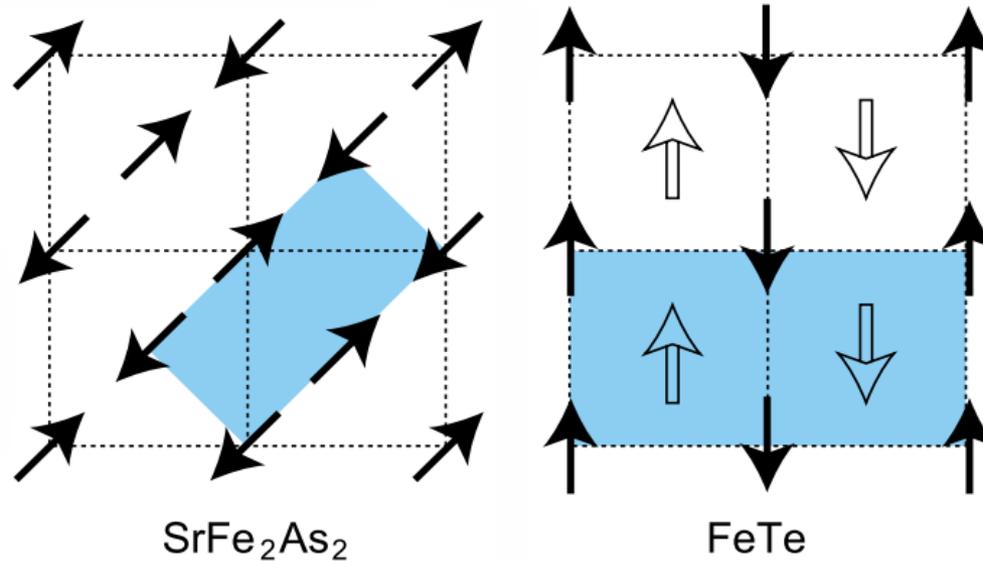
SC & SDW



SC & SDW



Magnetic ordering and FS nesting



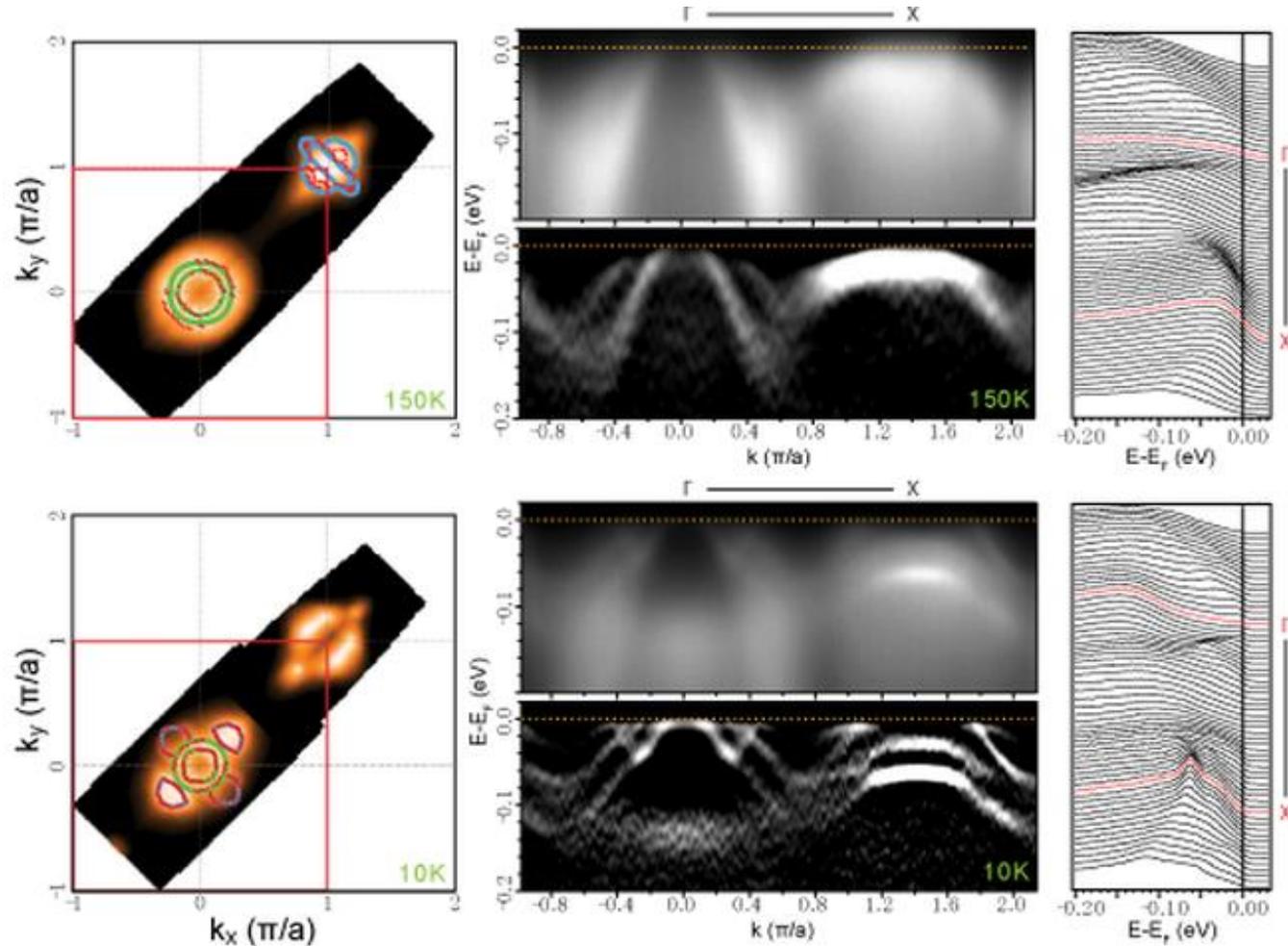
Pro:

any time when the FS nesting is good (BFA and other parent compounds of 122 family, NaFeAs), the SDW is present, and when nesting is poor or absent (superconducting BKFA, BFCA, BFAP, and stoichiometric LiFeAs), there is no magnetic ordering.

Con:

Fe_{1+y}Te shows different spin order, despite having very similar FS topology

Magnetic ordering and FS nesting



Collaboration



IMP

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Alexander Plyushchay
Roman Voznichenko

ARPES, IFW Dresden

Sergey Borisenko
Volodymyr Zabolotny

Timur Kim

Dmytro Inosov

Andreas Koitzsch

Roland Hübel

Jörg Fink

ARPES Worldwide

Mark Golden (UvA)

Toni Valla (BNL)

...

Neutron Scattering

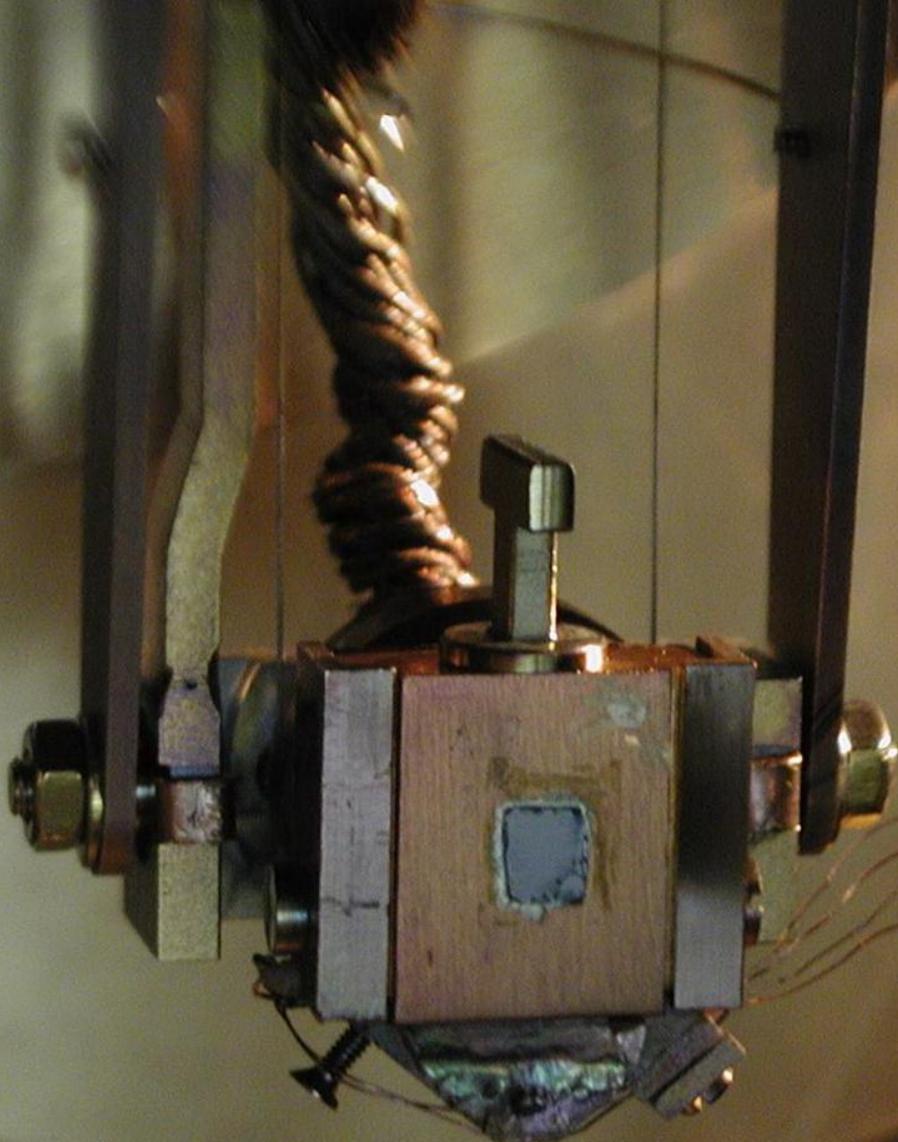
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Alexey Pan
Vladimir Karbovskii

Theory

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Eugene Krasovskii
Thomas Dahm
Doug Scalapino
Andrey Chubukov
Ilya Eremin



Single Crystals

Cuprates

Helmut Berger (EPFL Lausanne)

Chengtian Lin (MPI Stuttgart)

S. Ono, Yoichi Ando (CRIEPI Tokyo)

Iron based superconductors

Igor Morozov (MSU)

Chengtian Lin

S. Aswartham (IFW)

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