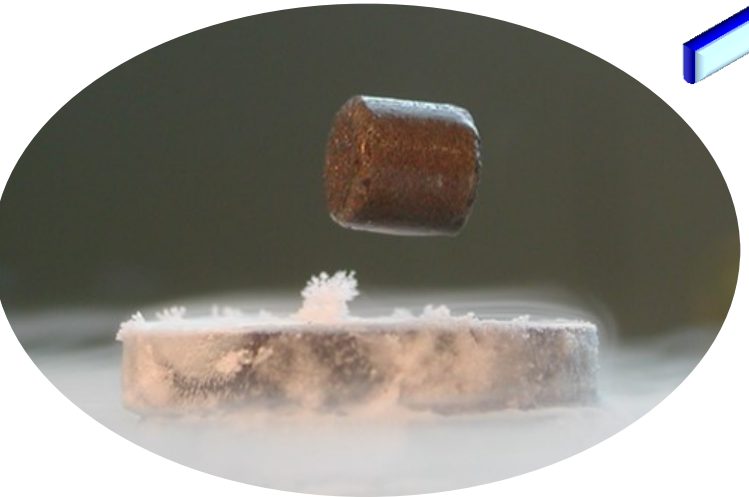
Effect of the electron-phonon coupling on phonons in iron based superconductors

Ilya Sergeev, PETRA III, Hamburg, Germany



Outline

- Fe superconductors: overview

- Study of lattice dynamics in *Ln*FeAsO
- Study of lattice dynamics in $EuFe_2As_2$

Fe-superconductors. Overview

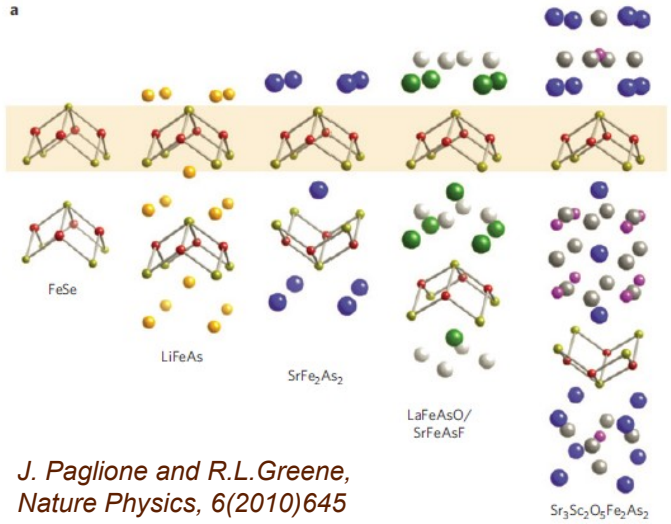
J|A|C|S COMMUNICATIONS

Published on Web 02/23/2008

Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs ($x = 0.05-0.12$) with $T_c = 26$ K

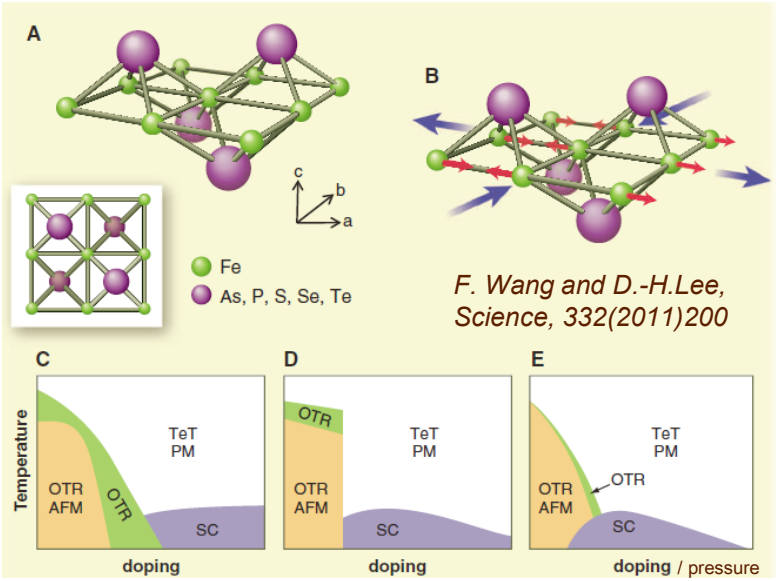
Yoichi Kamihara,*,† Takumi Watanabe,‡ Masahiro Hirano,†,§ and Hideo Hosono†,‡,§

Crystallographic structures of Fe-superconductors



J. Paglione and R.L.Greene, Nature Physics, 6(2010)645

Phase diagrams of Fe-superconductors



F. Wang and D.-H.Lee, Science, 332(2011)200

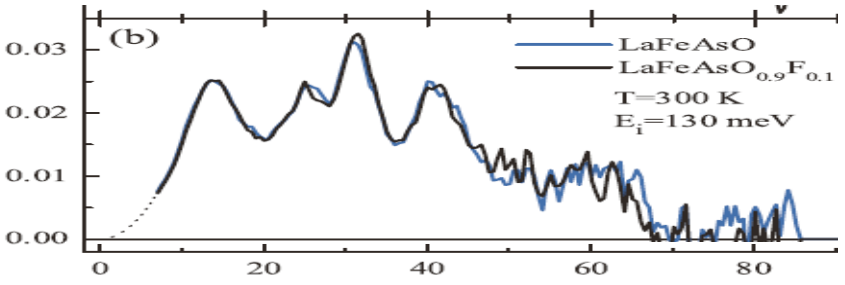
- superconductivity originates within Fe layer
- suppression of magnetism by doping or by pressure leads to SC
- unconventional superconductors: magnetic(?) excitations are the “glue” of the Cooper pair

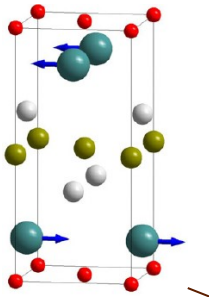
DESY

Measurements of phonons in FeSCs

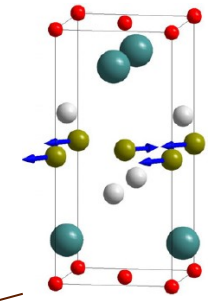
inelastic neutron scattering

Christianson et al., PRL 101 (2008) 157004





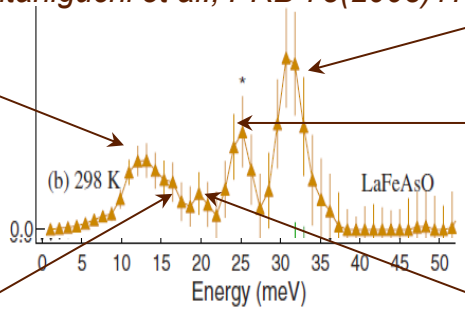
E_g, R

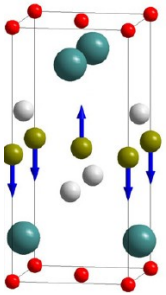


E_g, Fe

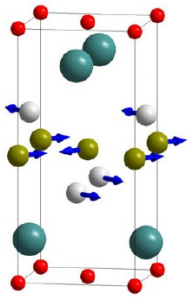
nuclear inelastic scattering

Higashitaniguchi et al., PRB 78(2008)174507

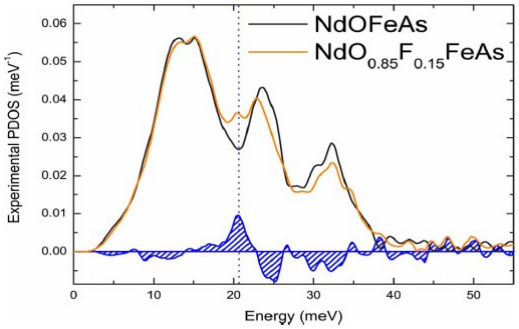


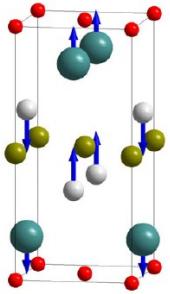


B_{1g}, As



E_g, FeAs





A_{1g}, As

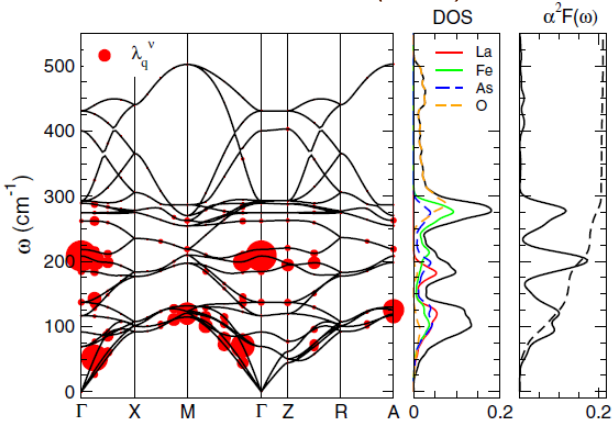
inelastic X-ray scattering

Le Tacon et al., PRB 78 (2008) 140505(R)

Theoretical phonon calculations

Electron-phonon properties of LaFeAsO

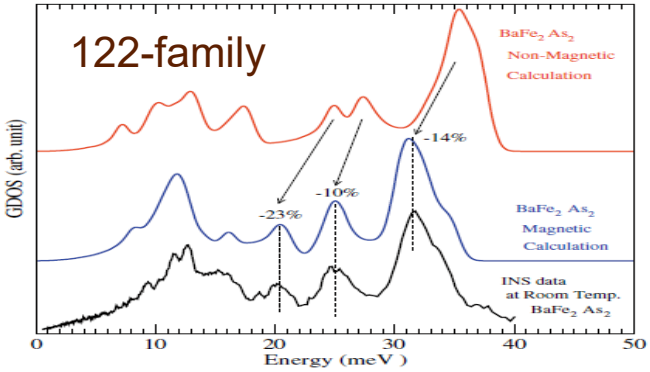
Boeri et al., PRL, 101(2008)026403



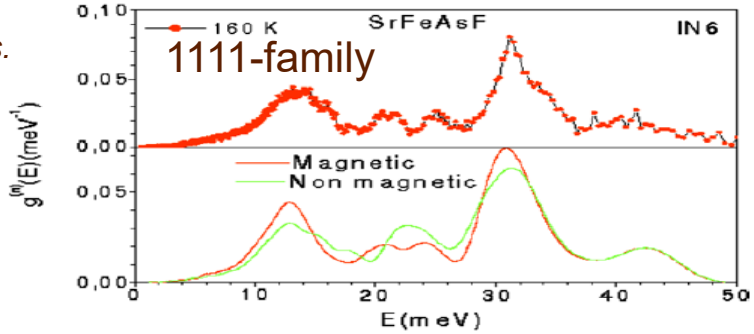
The theory predicts T_c=0.8K due to the phonon mediated Cooper pairing. Much smaller than exp. T_c = 25K

Dependence of phonons on magnetism

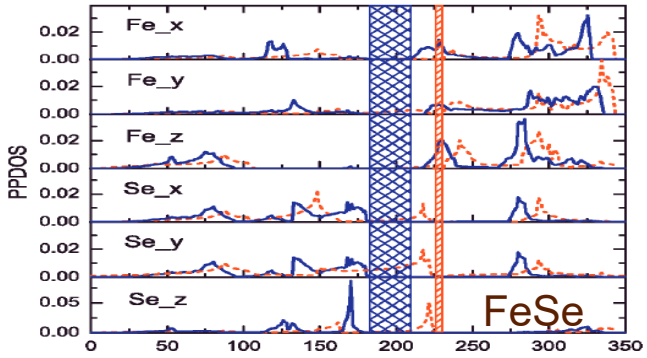
T. Yildirim, Physica C 469(2009) 425



Zbiri et al.,J.Phys. Cond.Matt 22(2010)315701



Theory predicts significant effect of the local magnetic moment on the phonon structure. It suggest to use phonons to reveal presence of the Fe magnetic moment.



11-family

Wang et al.,Physica C 472(2012)29

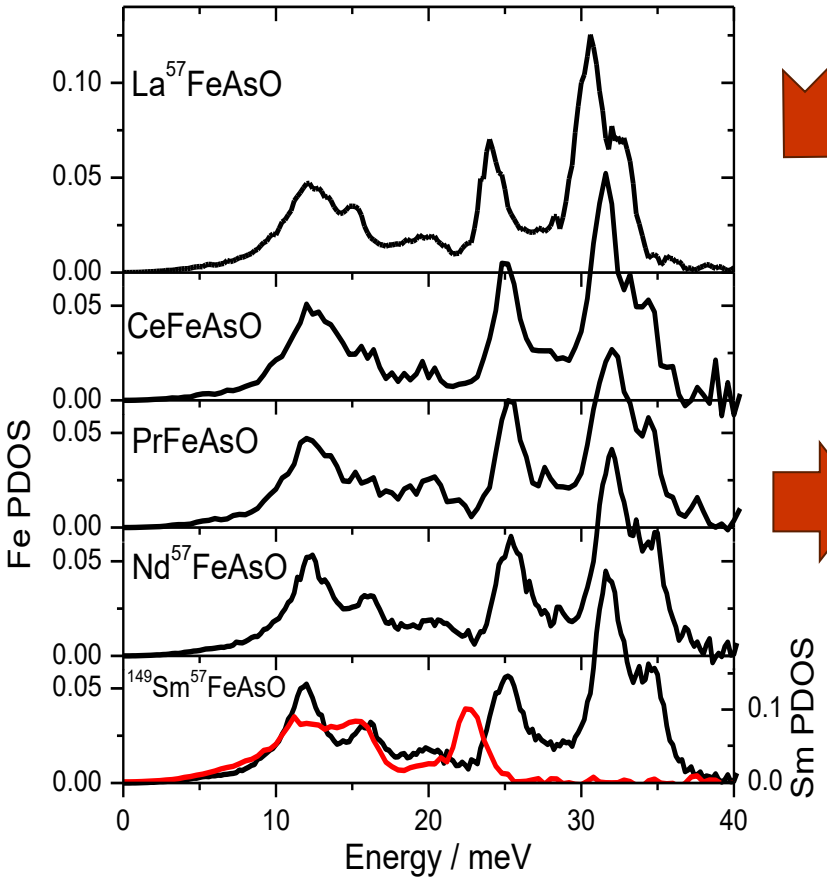
DESY

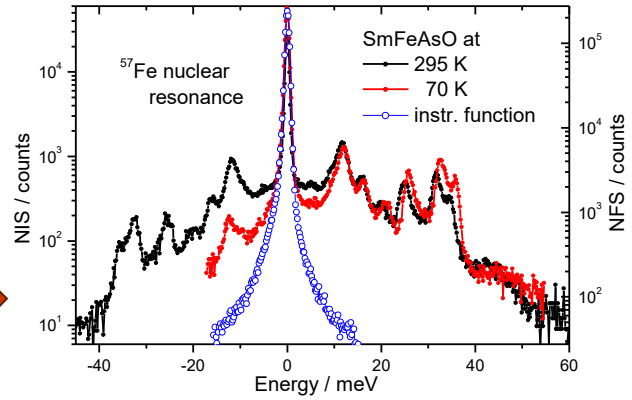
Fe PDOS for parent 1111 compounds

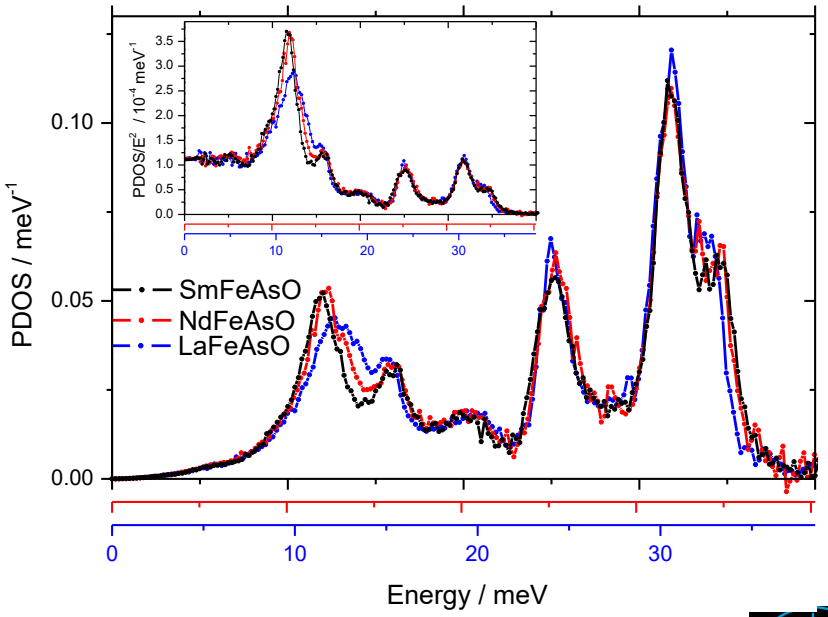
Sergueev et al., PRB 87 (2013) 064302

Measurements at ID18. ΔE = 0.7 meV

Fe PDOS for different compounds
at room temperature

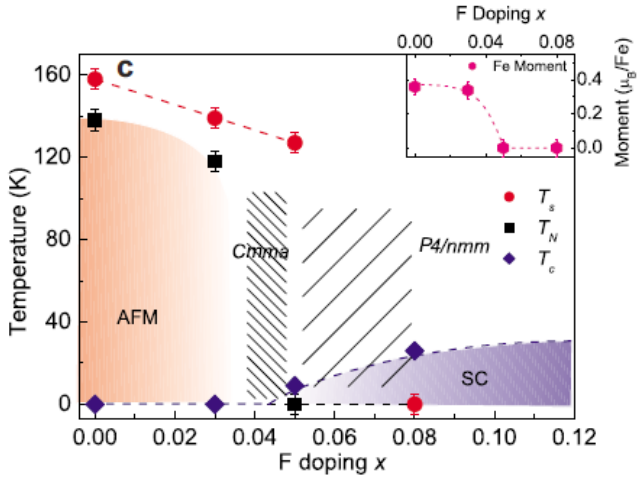






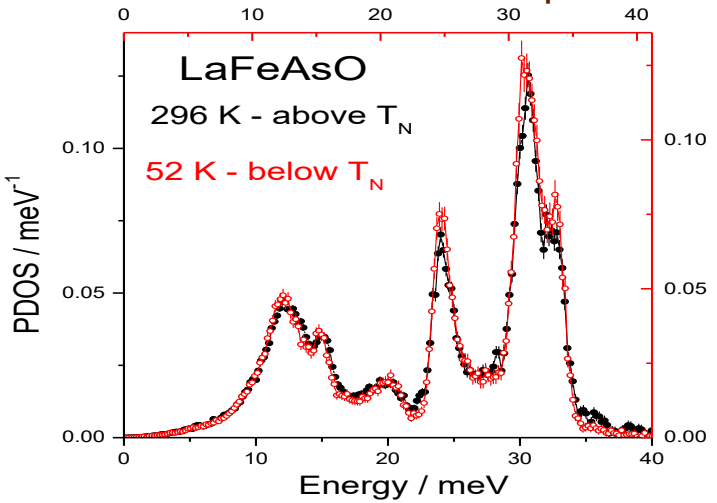
Fe PDOS for $LaFeAsO_{1-x}F_x$ at 0 and 296 K

Phase-diagram for $LaFeAsO_{1-x}F_x$

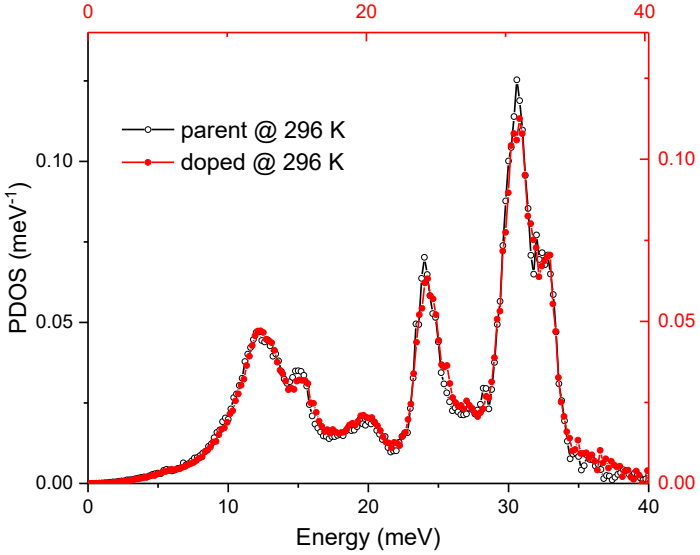


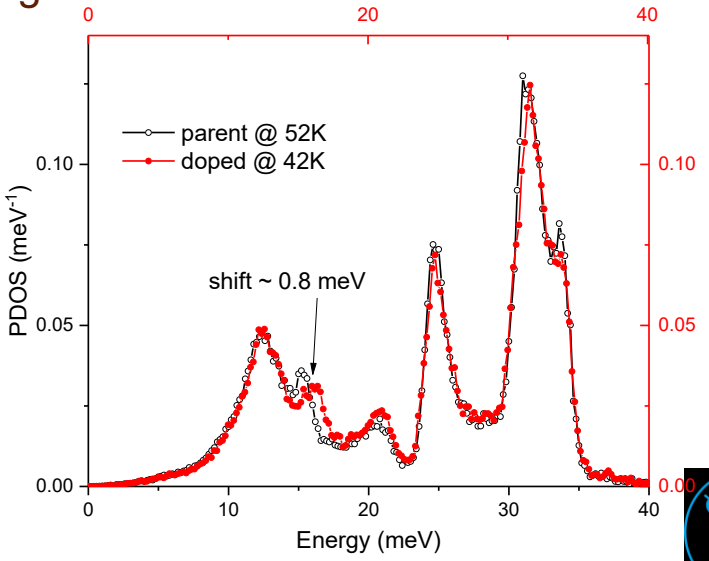
*Q. Huang et al. PRB **78** (2008) 054529*

Above and below Neel temperature

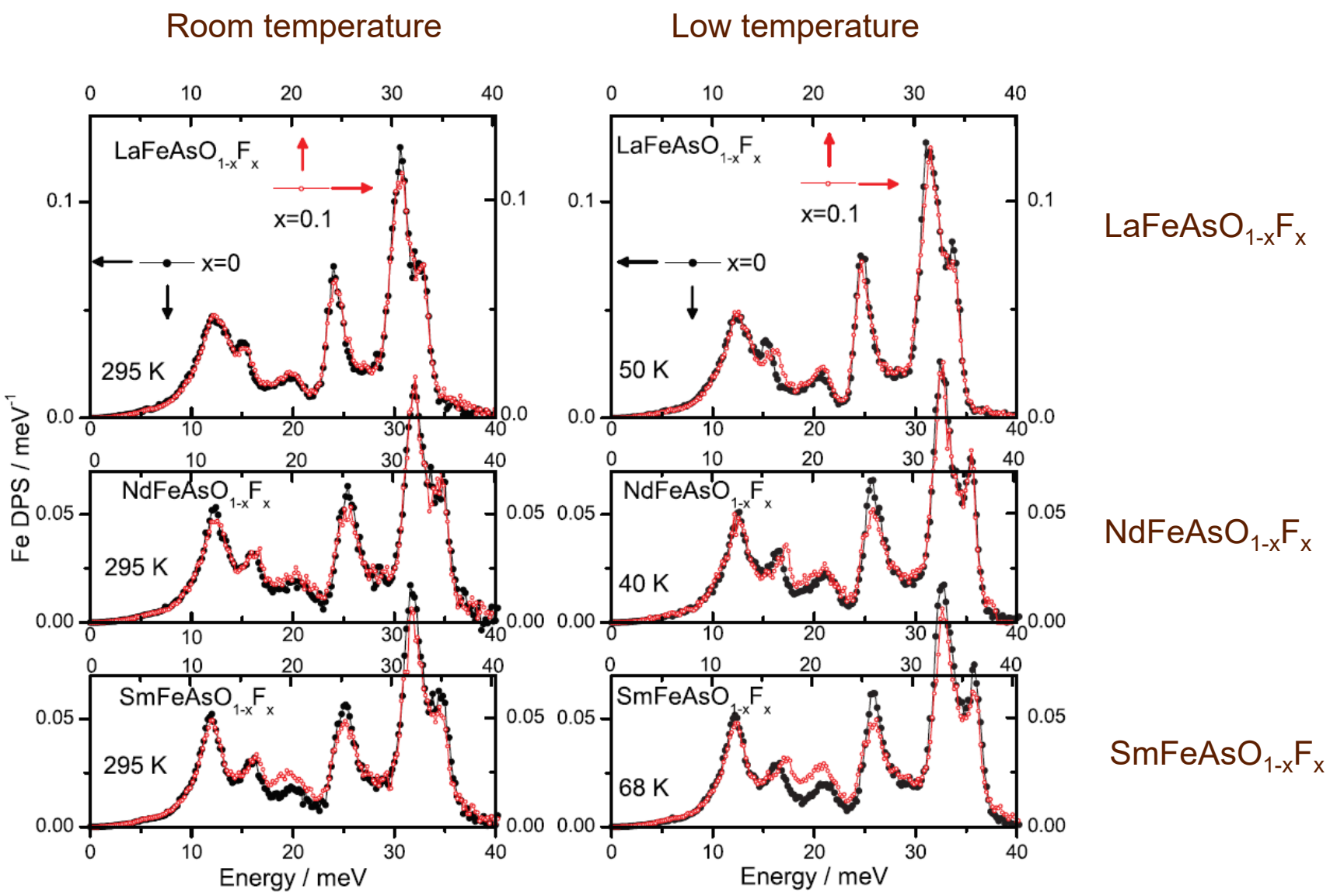


With doping





Fe PDOS for parent / doped 1111 compounds



$LaFeAsO_{1-x}F_x$

$NdFeAsO_{1-x}F_x$

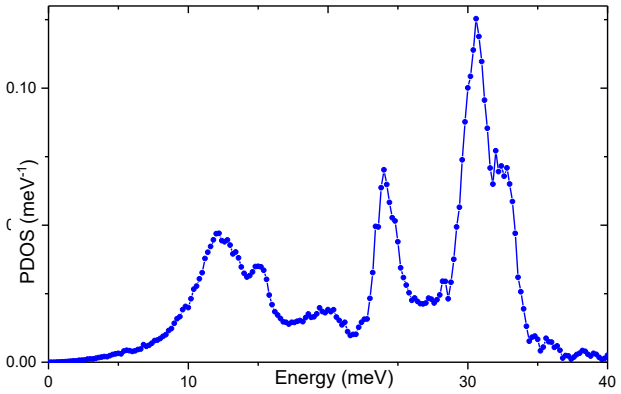
$SmFeAsO_{1-x}F_x$

How to find “peak” energy

Options to find peaks:

- Fit by peak function ←?→ peak shape unknown
- Use COM position ←?→ depends on chosen E-range

- Our solution: search or relative shift compared to reference spectrum by least square fit. Obtain value with statistical error.



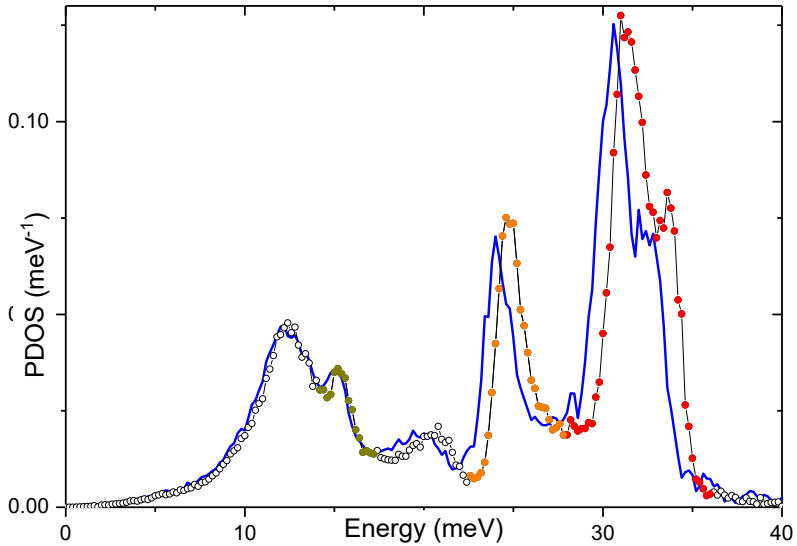
Interpolation: D(E)

Theoretical function for LSF:

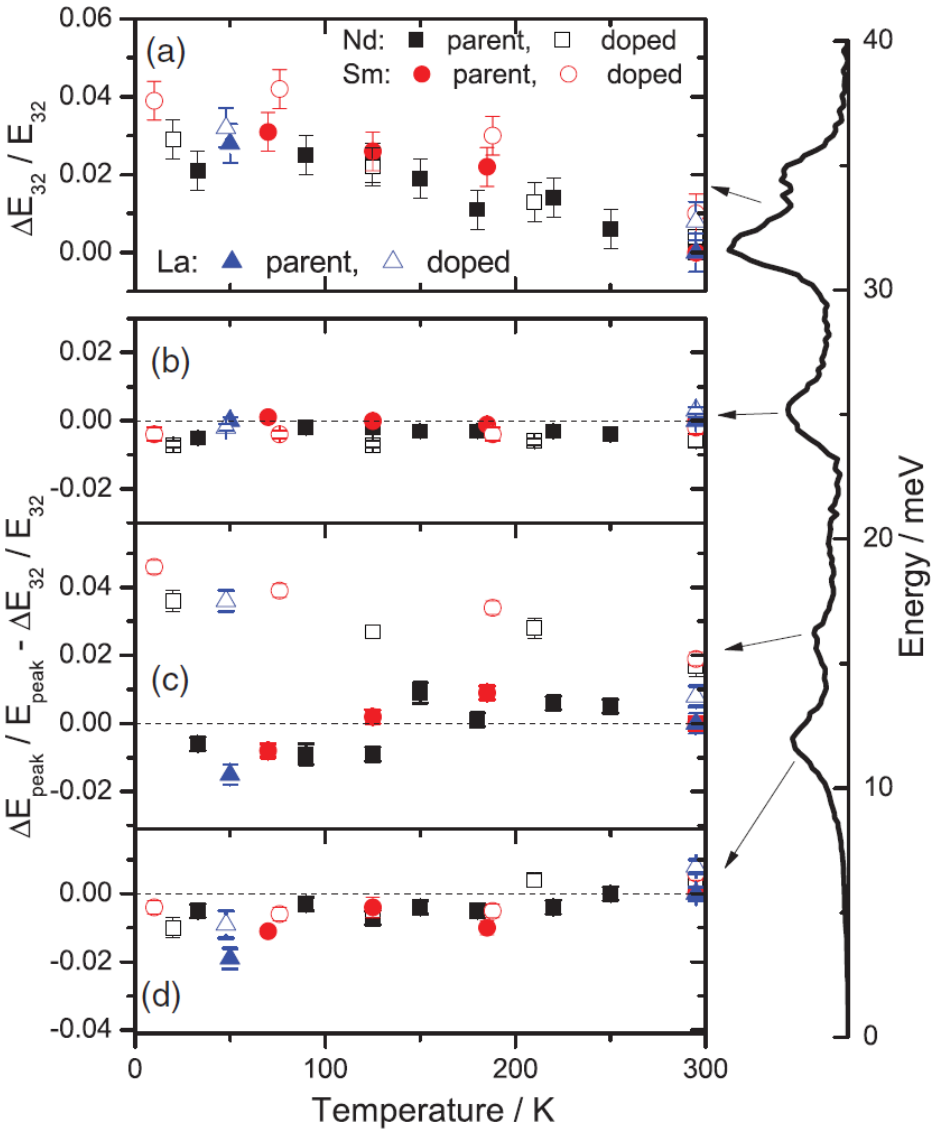
$$F(E) = \beta \cdot D(E \cdot (1+\alpha))$$

α = ΔE / E – relative “peak” shift

β (1/ α) – scaling factor



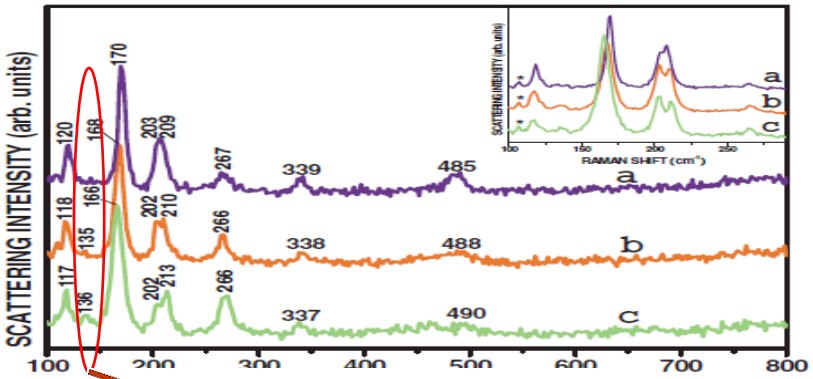
Peaks positions vs T for parent and doped conpounds



Raman scattering data with 1111 compounds

Raman scattering of $NdFeAsO_{1-x}F_x$

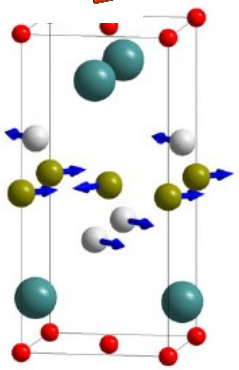
Zhang et al., PRB 79 (2009) 052507



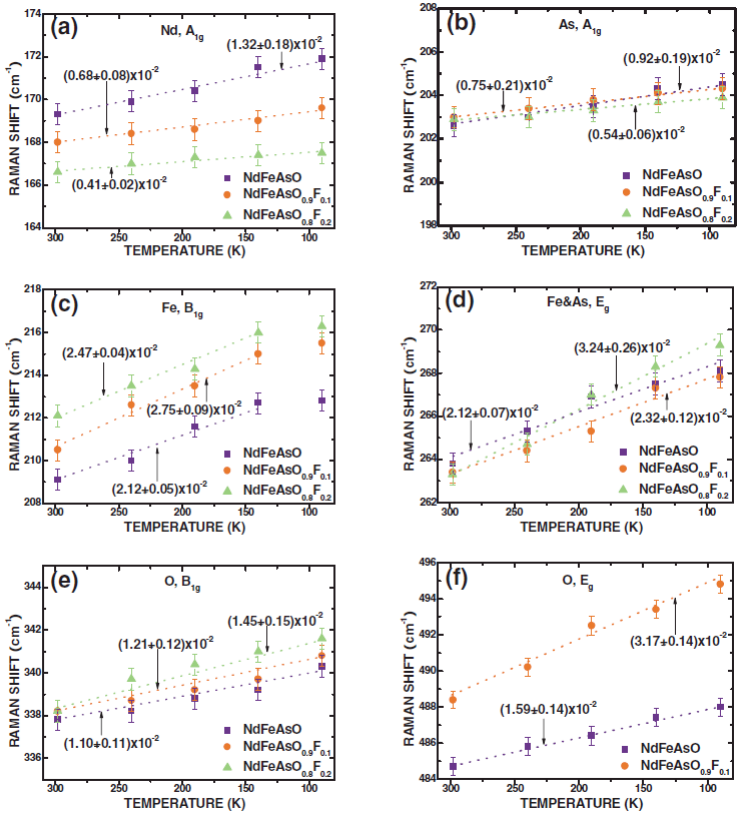
E_g of As and Fe

at ~ 16 meV (130 cm^{-1})

weak or invisible for 1111 family



T-dependence of other modes

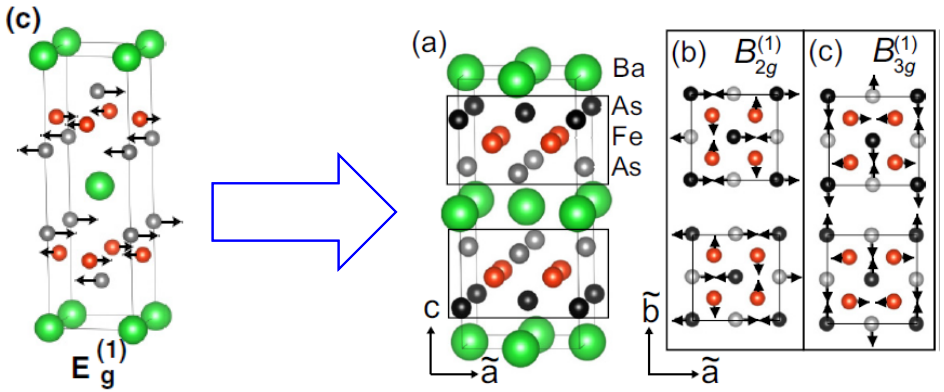


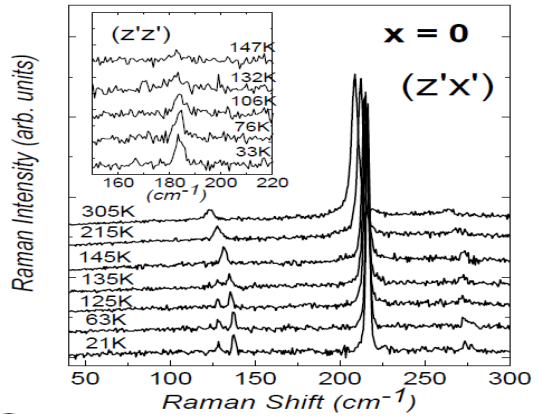
Raman scattering data with 122 compounds

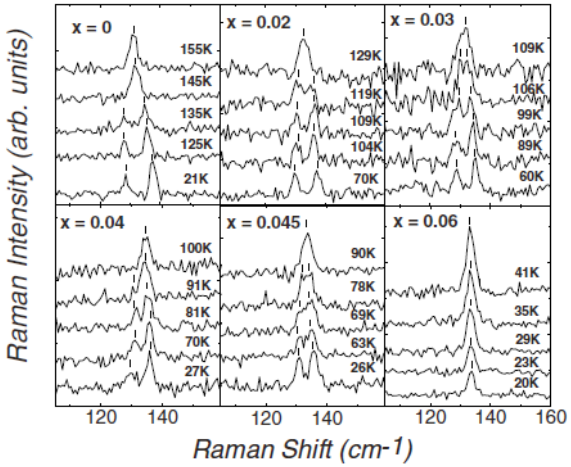
Raman scattering on $BaFe_2As_2$

Chauviere et al. PRB 80 (2009) 094504

Baum et al., PRB 98(2018) 075113







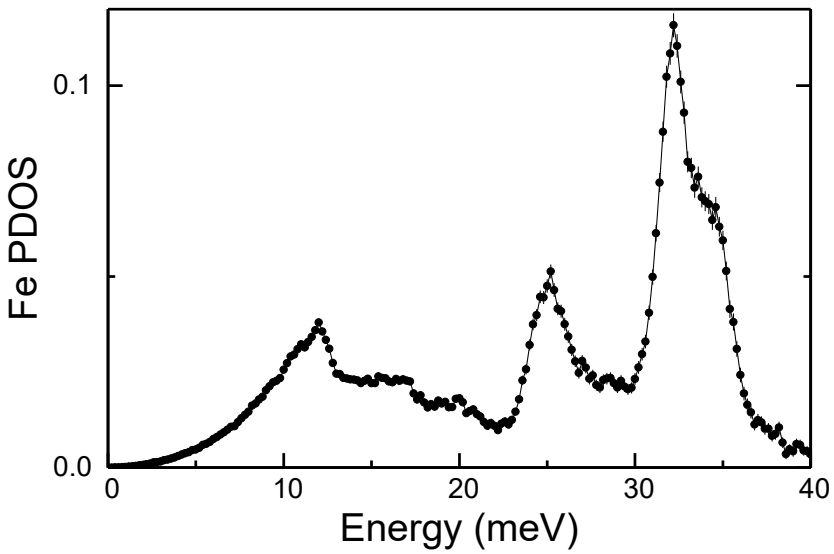
Gap between $B_{2g}^{(1)}$ and $B_{3g}^{(1)}$:

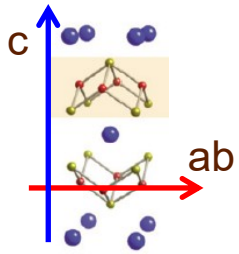
theory : 2.8 meV

exp : 1.2 meV

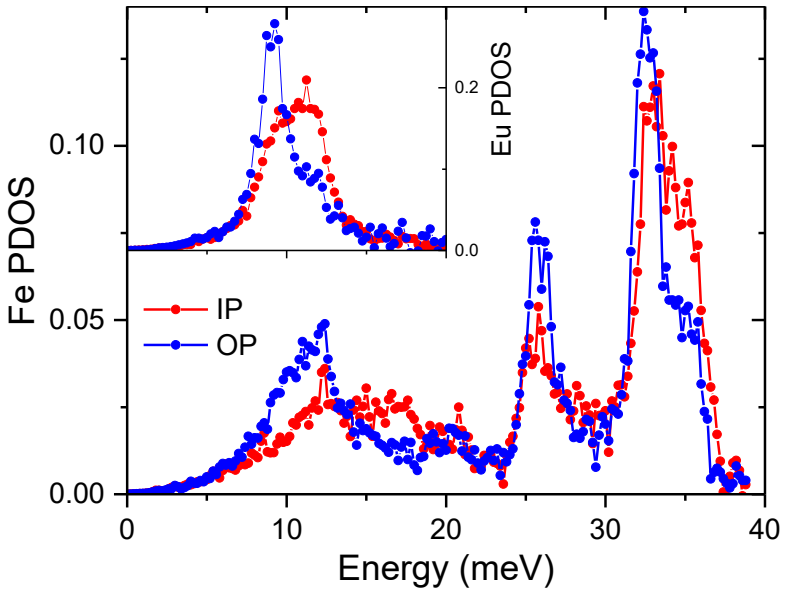
$EuFe_2As_2$. NIS measurements at room T

$EuFe_2As_2$
NIS on powder



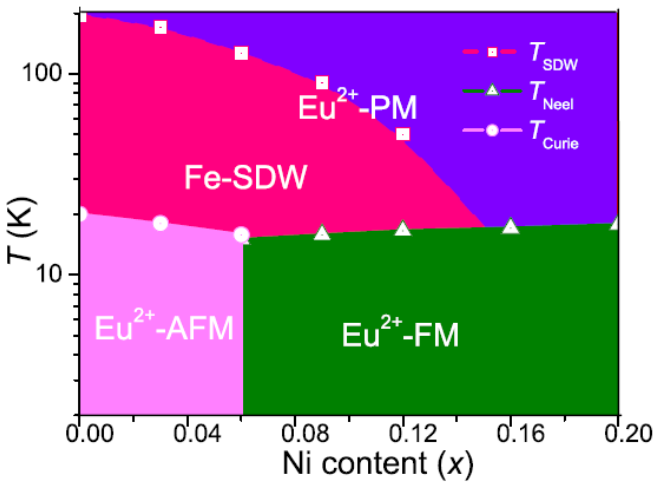


$EuFe_2As_2$
NIS on single crystal



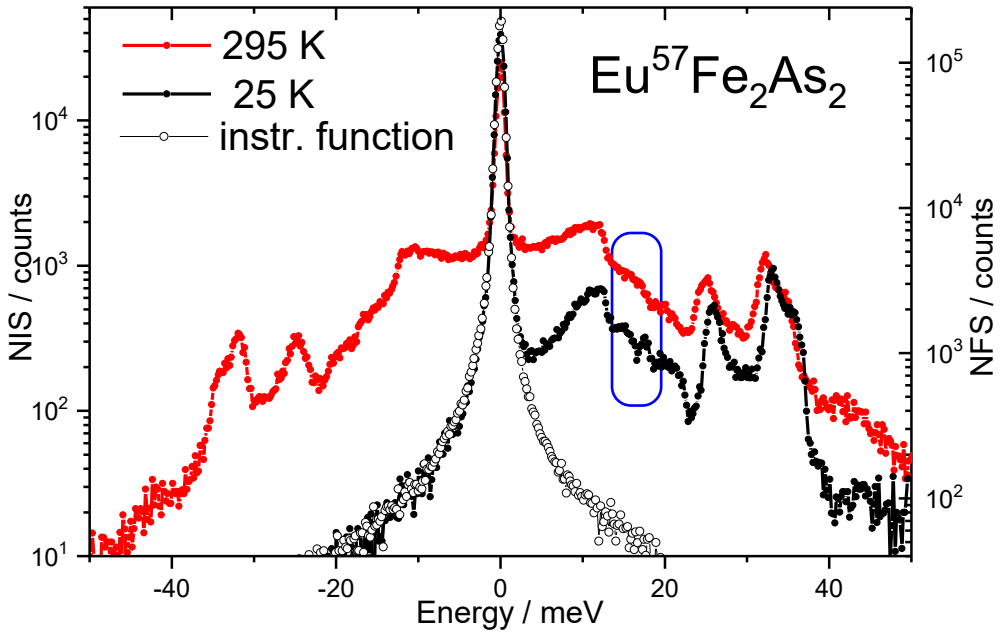
Phase diagram of $EuFe_2As_2$

Phase diagram of $EuFe_{2-x}Ni_xAs_2$

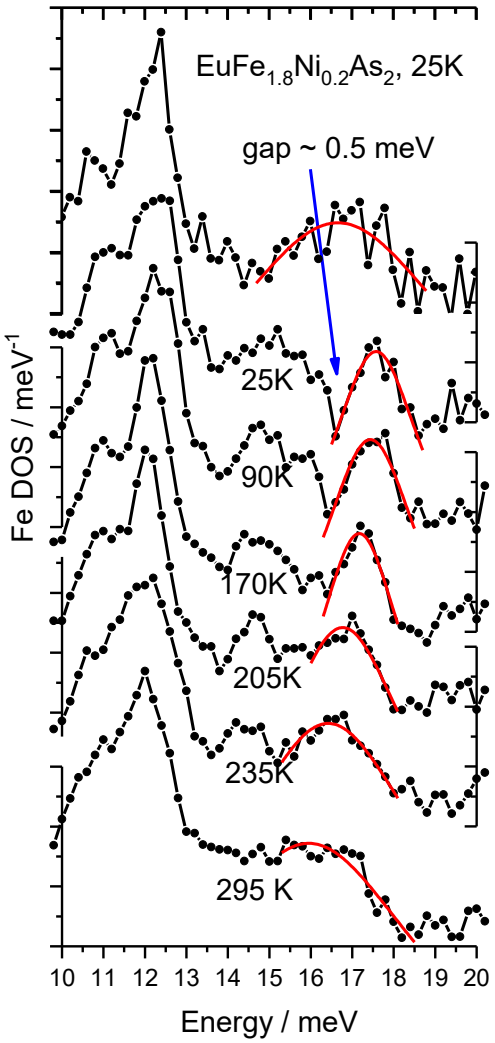


Ren et al., PRB 79 (2009) 094426

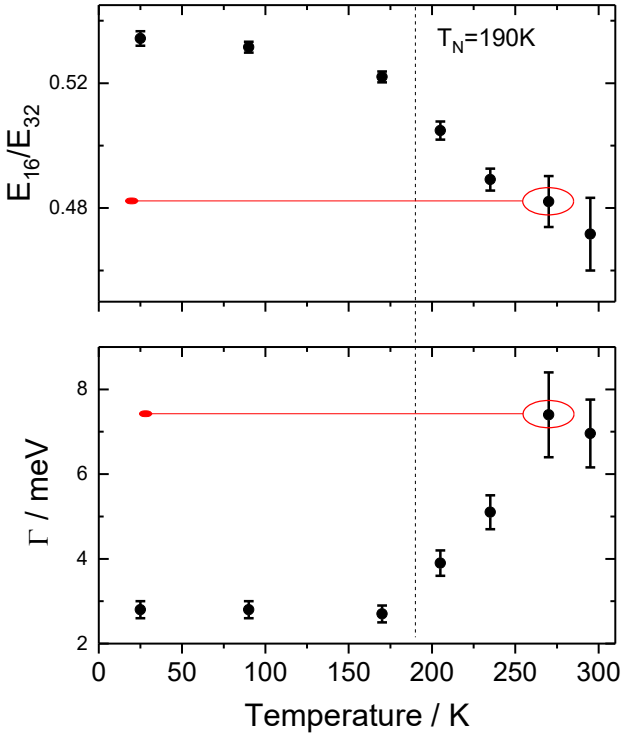
NIS on $EuFe_2As_2$ at low and room T



T – dependence of phonons in $EuFe_2As_2$



T – dependence of the phonon line position and width obtained by Lorentz fit

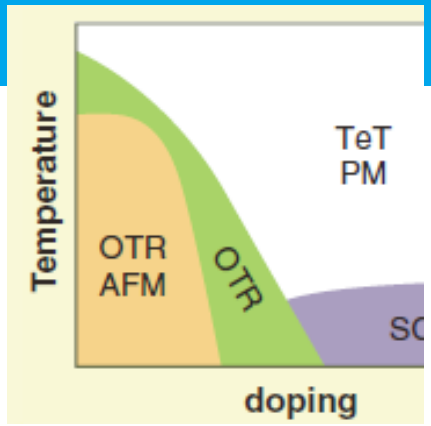


Theory proposition for spin-dynamics

A key role for unusual spin dynamics in ferropnictides

Nature Physics 5 (2009) 141

I. I. Mazin and M. D. Johannes*

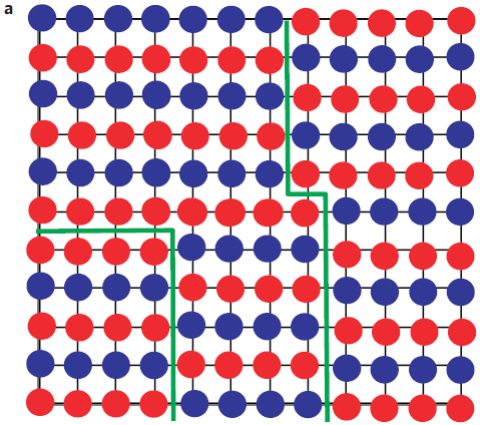


- AF magnetic
- orthorhombic

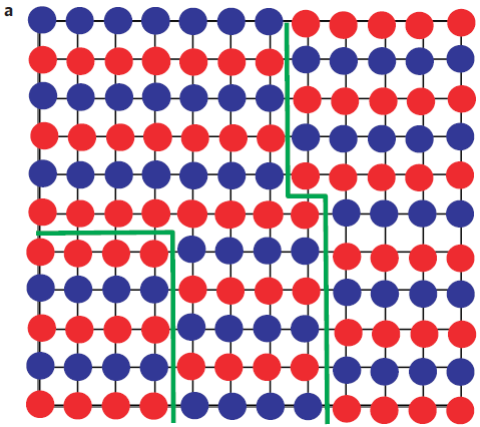
- paramagnetic
- orthorhombic

- paramagnetic
- tetragonal

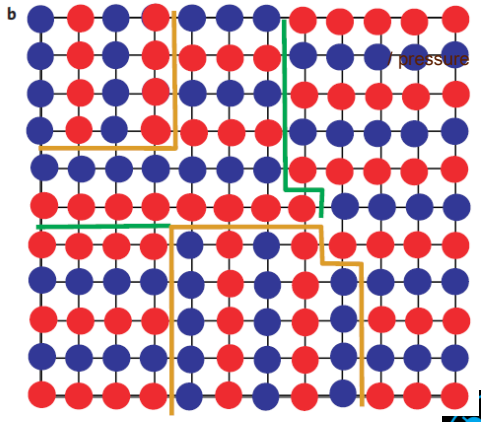
* domain walls fixed
* all domains with same direction (x/y symmetry broken)



* dynamic domain walls
* all domains with same direction (x/y symmetry broken)

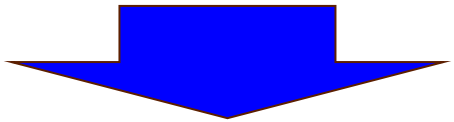


* dynamic domain and twin walls
* twins at different directions (x/y symmetry conserve)



Conclusion

- There are anomalies in the T – dependence of the phonon structure for FeSc of 1111 and 122 families.
- They can be related to the structural transition, spin-lattice coupling, e-ph coupling, …???
- Characteristic E scale of anomalies is 0.1 – 1 meV. E –resolution of current HRM is 0.7 – 1 meV



Investigation of the T evolution of the phonon anomalies requires monochromator with 0.1 meV E resolution (spectrograph).

Other useful capability of the spectrograph is simultaneous measurements of different samples (doped / parent FeSc)

Acknowledgment

ESRF
The European Synchrotron

JÜLICH
Forschungszentrum

OAK RIDGE NATIONAL LABORATORY

U. Pelzer
R. Rüffer,
A. Chumakov
J.-P. Celse

R. P. Hermann
D. Bessas
M. Angst
W. Schweika
A. Möchel

M. A. McGuire
A.S. Sefat
B.C. Sales
D.Mandrus

DESY

Thank you for your attention