Walther Meissner Institut

The Janus face of electrons in superconductors with high transition temperature

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Walther-Meissner-Institut, D-85748 Garching,
Bayerische Akademie der Wissenschaften

Objectives:

⇒ Electronic Raman scattering

⇒ Conventional superconductors with strong coupling

⇒ Cuprates

⇒ $Ba(Fe_{1-x}Co_x)_2As_2$

Funded by the DFG via Research Unit FOR538 and Priority Program SPP1458

http://for538.wmi.badw.de/

Collaborators

Walther Meissner Institut

Experiments:

- B. Muschler
- W. Prestel
- H. Eiter
- N. Munnikes
- T. Buttler
- F. Venturini
- L. Tassini
- M. Opel

Theory:

- T.P. Devereaux (Stanford)
- C. Di Castro, M. Grilli, S. Caprara (Roma)
- I Tüttö
- A. Zawadowski (Budapest)

Samples:

- H. Berger, L. Forró (Lausanne)
- A. Erb, M. Lambacher (WMI)
- B. Revaz (Genève)
- Yoichi Ando (Osaka)
- Shimpei Ono (Tokyo)
- A. Damascelli (Vancouver)
- M. Greven (Stanford)
- H. Eisaki (Tsukuba)
- I. R. Fisher, Jim Analytis, Jin-Haw Chu (Stanford)

Conventional and unconventional superconductors

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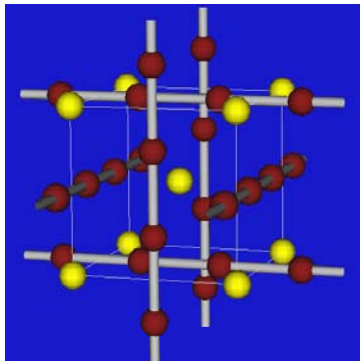
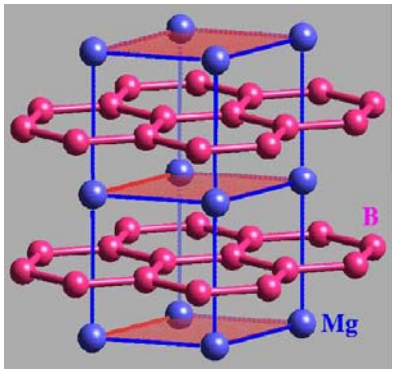
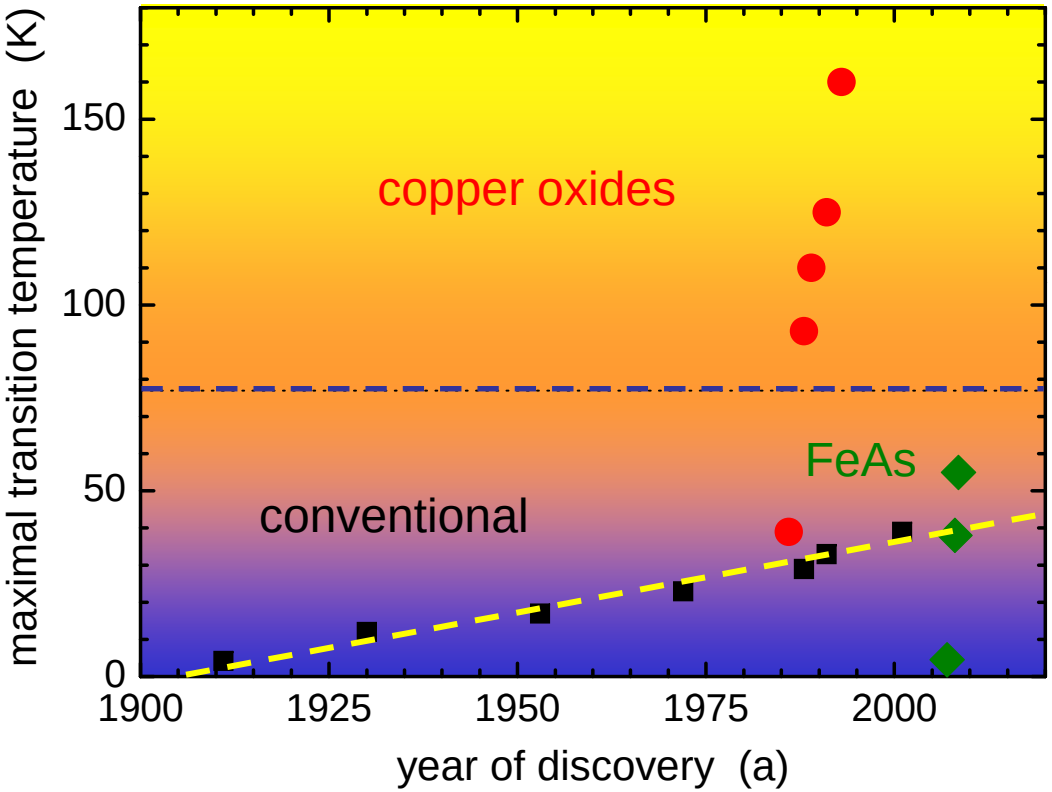
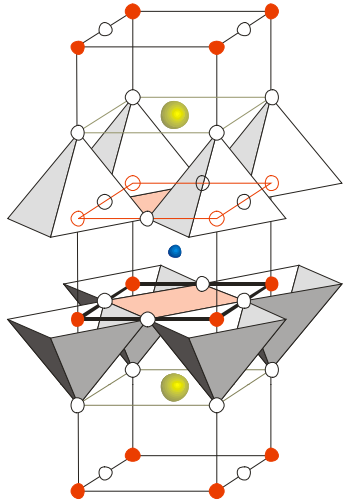


Nb_3Sn

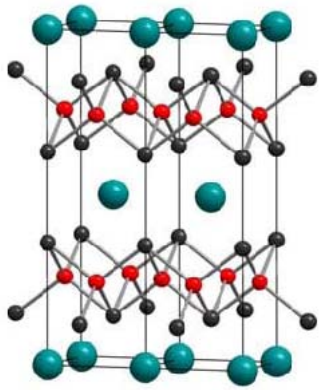


MgB_2





$YBa_2Cu_3O_{6+x}$



$Ba(FeAs)_2$

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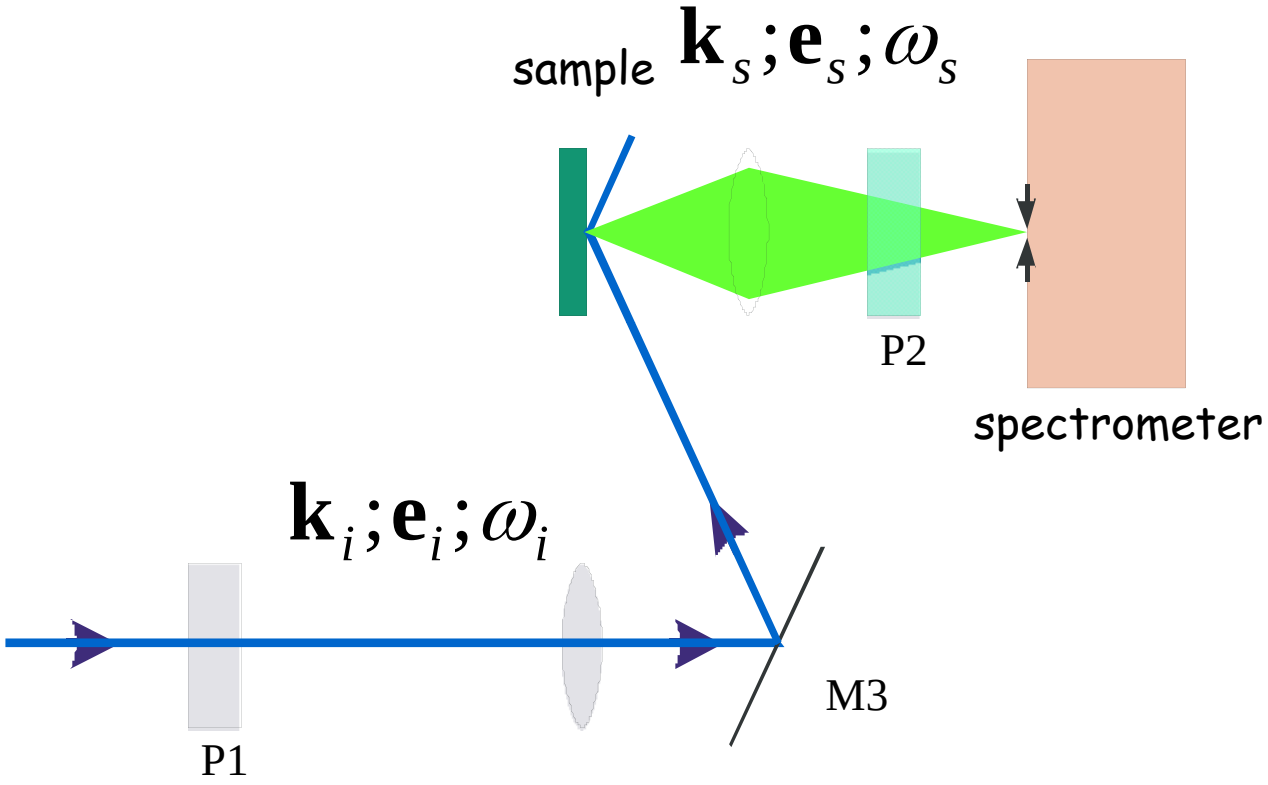
Electronic Raman scattering

strongly coupled conventional SC cuprates

$Ba(Fe_{1-x}Co_x)_2As_2$

Raman Experiment



$$\Omega = \omega_i - \omega_s$$

Electronic Raman scattering – a primer

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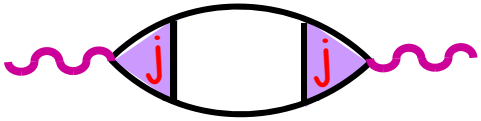
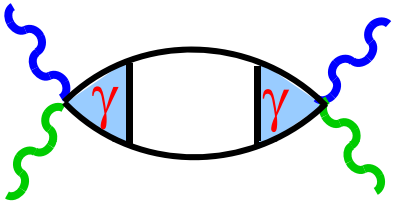
optical conductivity

$\sigma =$ 

current – current correlation

vertex v_F

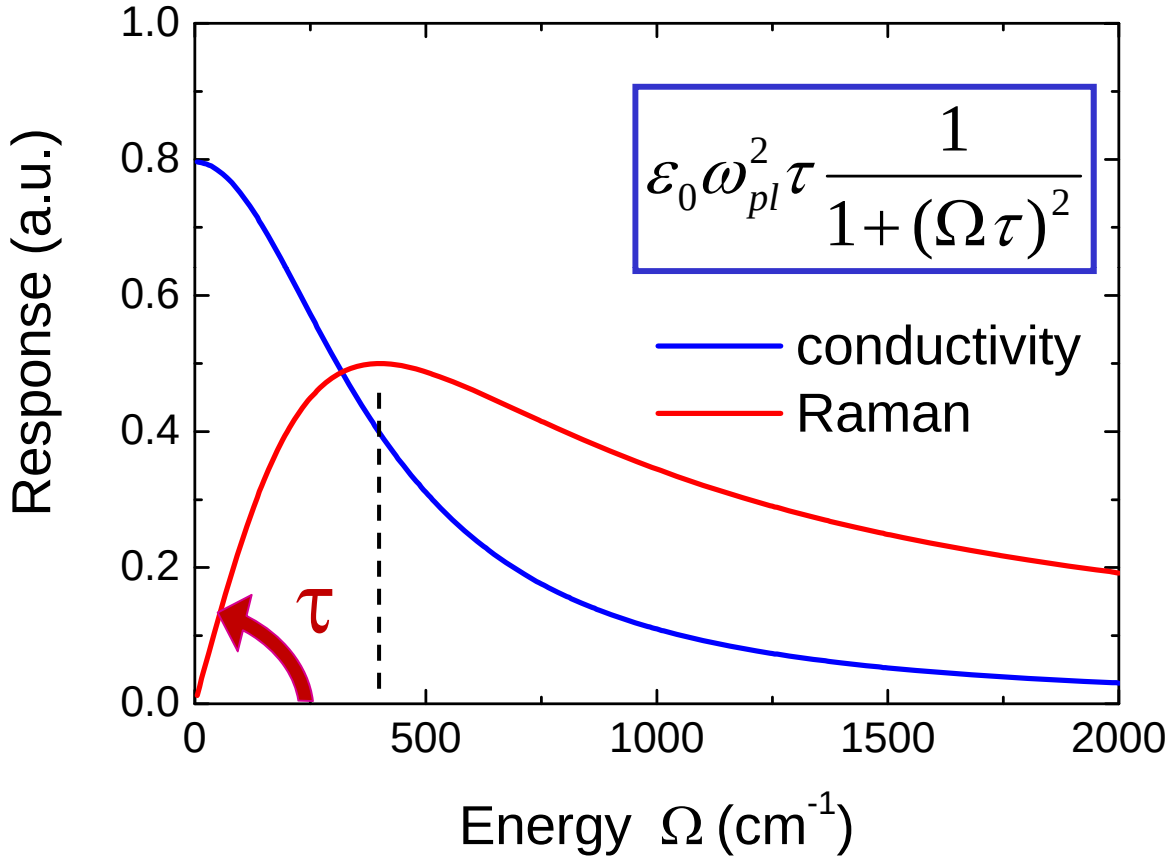
Raman scattering

$\chi =$ 

"density"- "density" correlation

vertex $\left[m(\mathbf{k})\right]^{-1}$

Conductivity vs. Raman (normal state)



$$\mathrm{Im}\,\chi(\Omega)\propto\Omega\,\mathrm{Re}\,\sigma(\Omega)$$

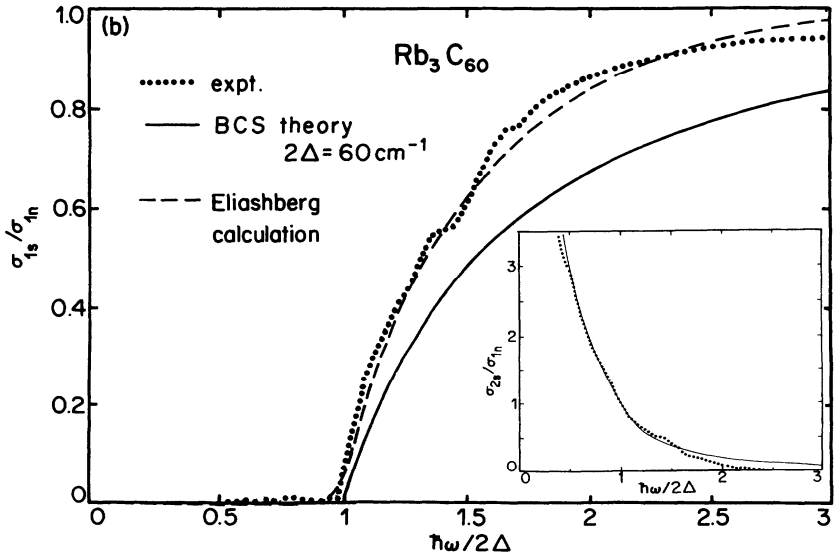
Shastry and Shraiman
PRL **65**, 1068 (1990)

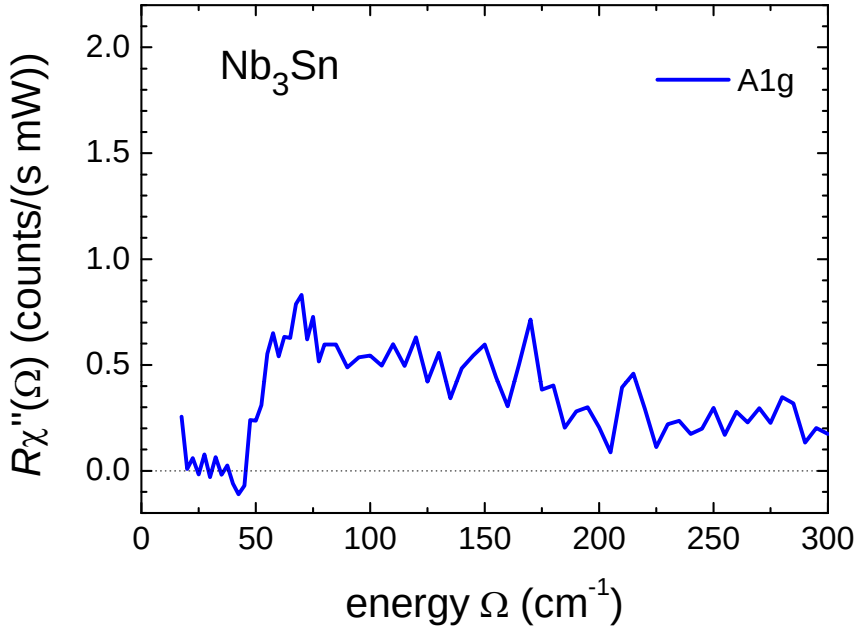
$$\chi_\mu(\Omega)=\frac{M_\mu(\Omega)}{\Omega+M_\mu(\Omega)}$$

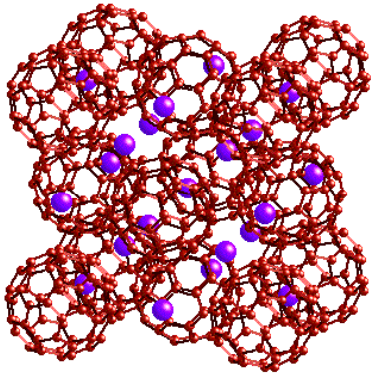
$$M(\Omega)=\Omega\lambda(\Omega)+\frac{i}{\tau(\Omega)}$$

Opel,…, Tüttö et al.
PRB **61**, 9752 (2000)

Conductivity vs. Raman (superconducting state)

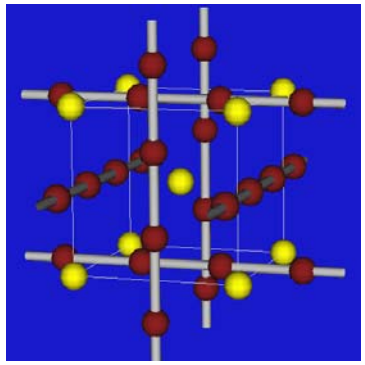






Degiorgi et al.
PRB **49**,
7012 (1994)

Dierker, Klein
Webb, Fisk
PRL **50**, 853 (1983);
R.H. et al. JPC **16**,
1729 (1983)



Rb_3C_{60}

Nb_3Sn

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Sum rules

f sum rule
conservation of carriers

no sum rule

$$[\hat{H}, \hat{\rho}_{Raman}] \neq 0$$

Selection rules

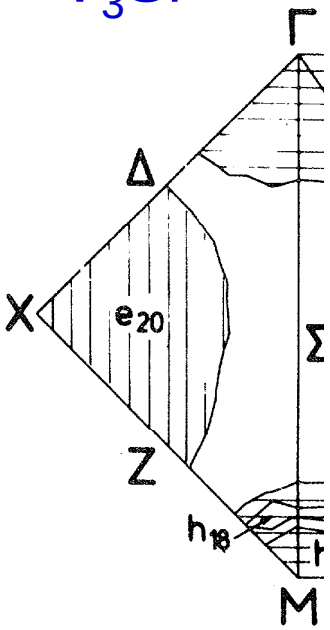
entire Fermi surface

polarization dependent projections of the Fermi surface

Coulomb $\left\langle [m(\mathbf{k})]^{-2} \right\rangle_{FS} - \left\langle [m(\mathbf{k})]^{-1} \right\rangle_{FS}^{2}$

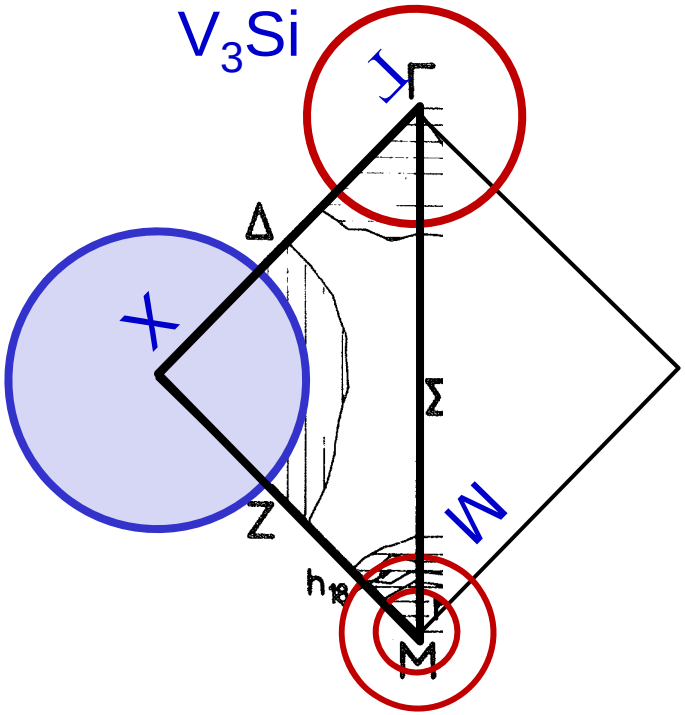
Selection rules

V_3Si

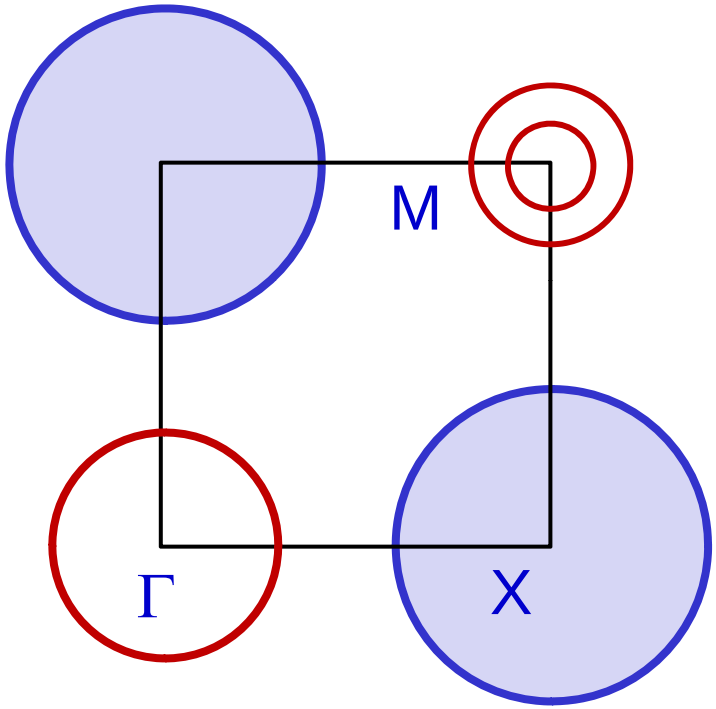


Mattheiss and Weber,
PRB **25**, 2248 (1982)

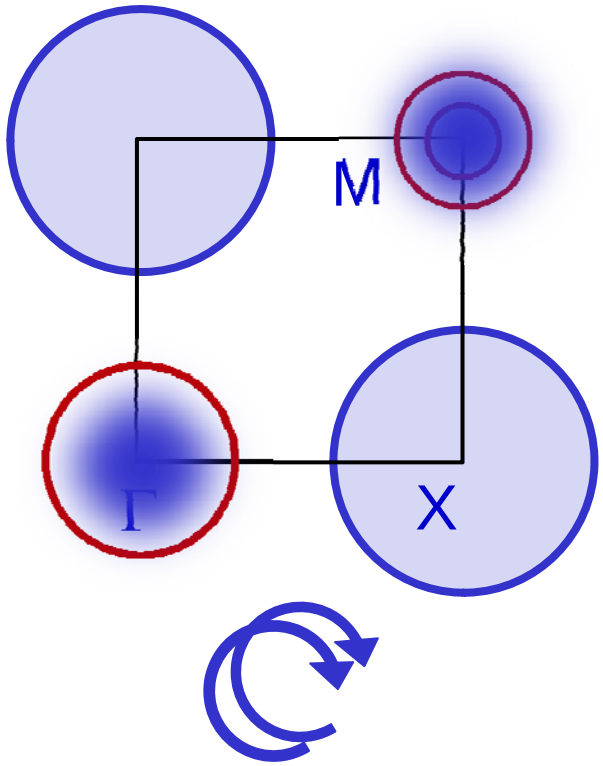
Selection rules

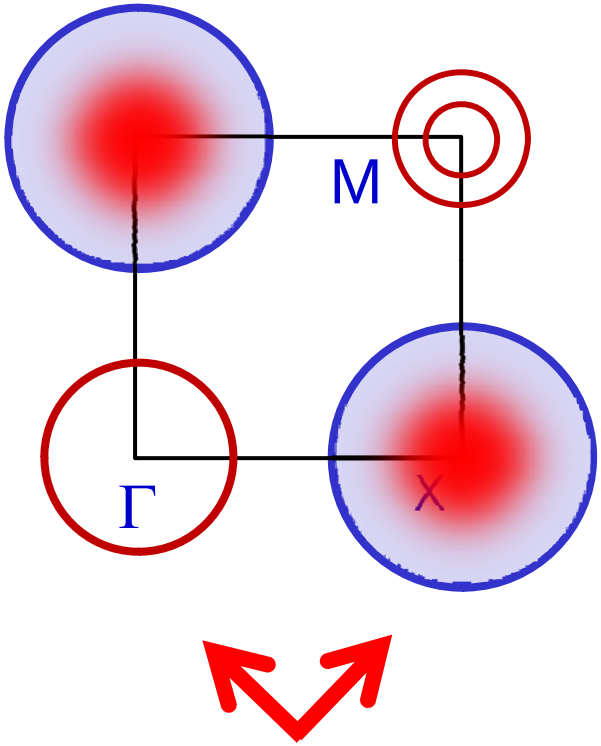


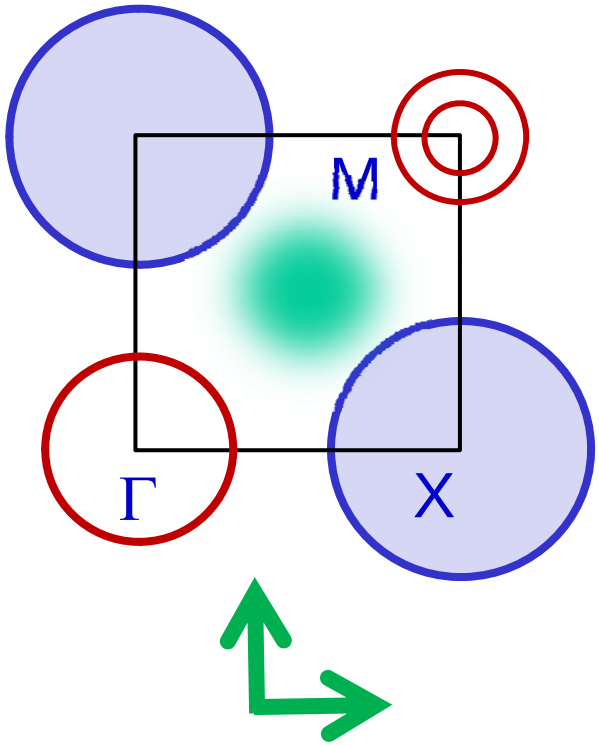
Mattheiss and Weber,
PRB **25**, 2248 (1982)



Selection rules







const + cos(k_x) + cos(k_y)

cos(k_x) - cos(k_y)

sin(k_x)sin(k_y)

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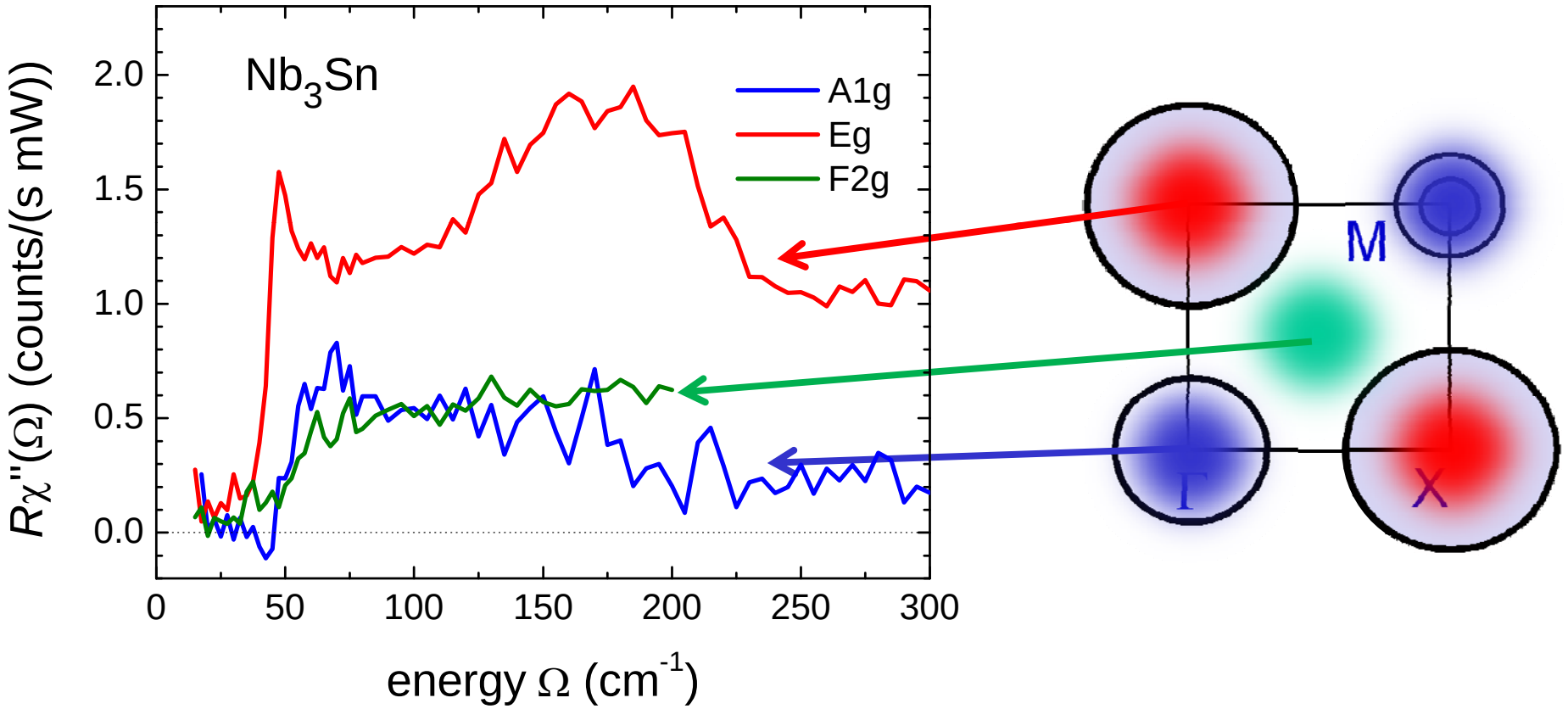
Electronic Raman scattering

strongly coupled conventional SC

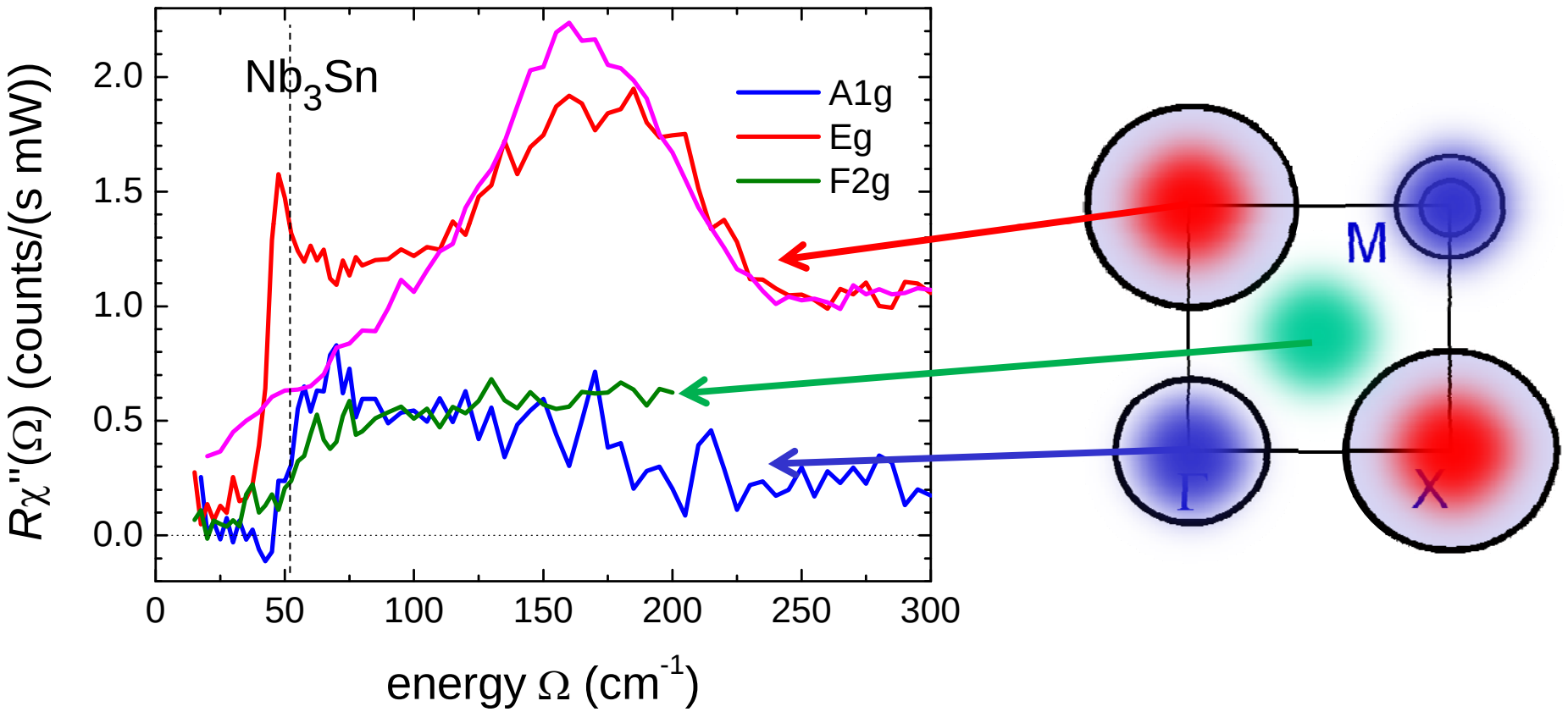
cuprates

$Ba(Fe_{1-x}Co_x)_2As_2$

Nb_3Sn (superconducting state)



Nb_3Sn (superconducting state)



sharp gap inspite of a multi sheeted FS

More selection rules for ERS

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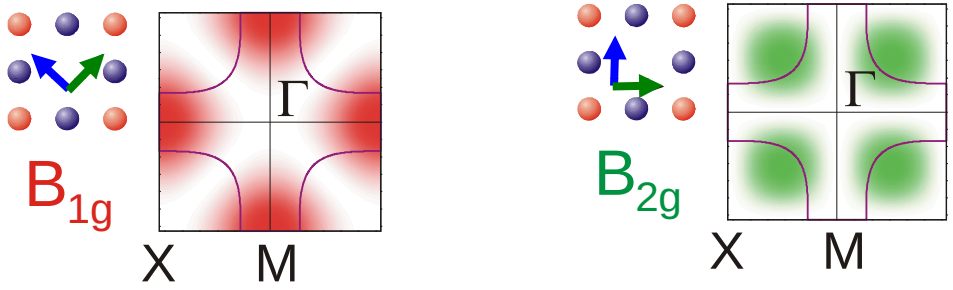
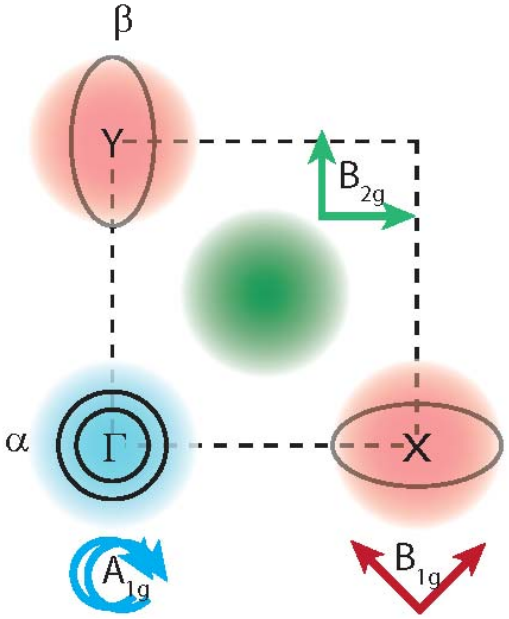
cuprates



different parts of the Fermi surface

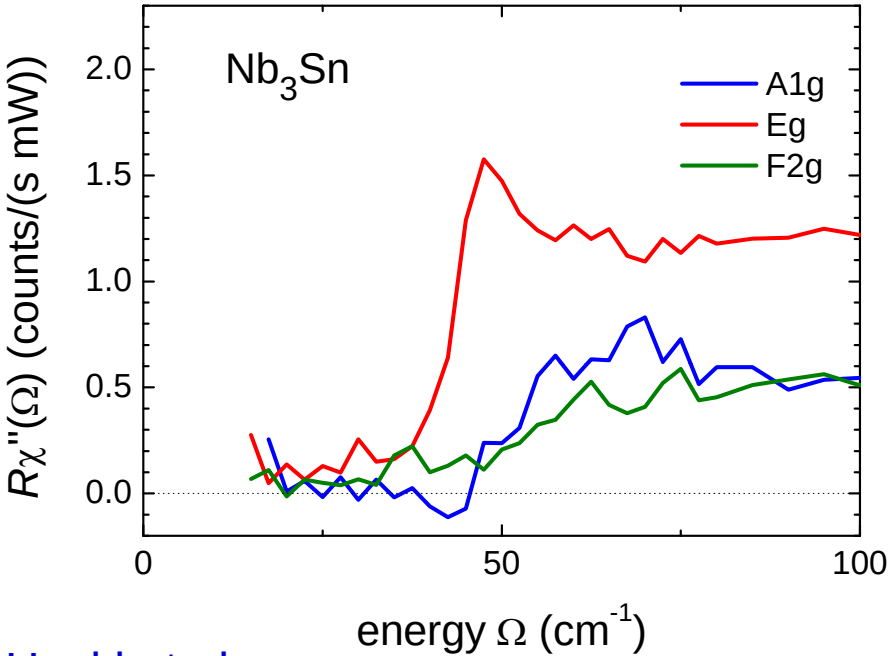
FeAs



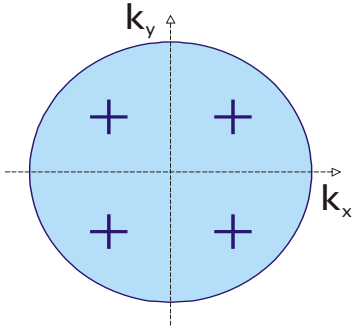
different Fermi surface sheets

T.P. Devereaux and R.H.,
Rev. Mod. Phys. **79**, 175 (2007)

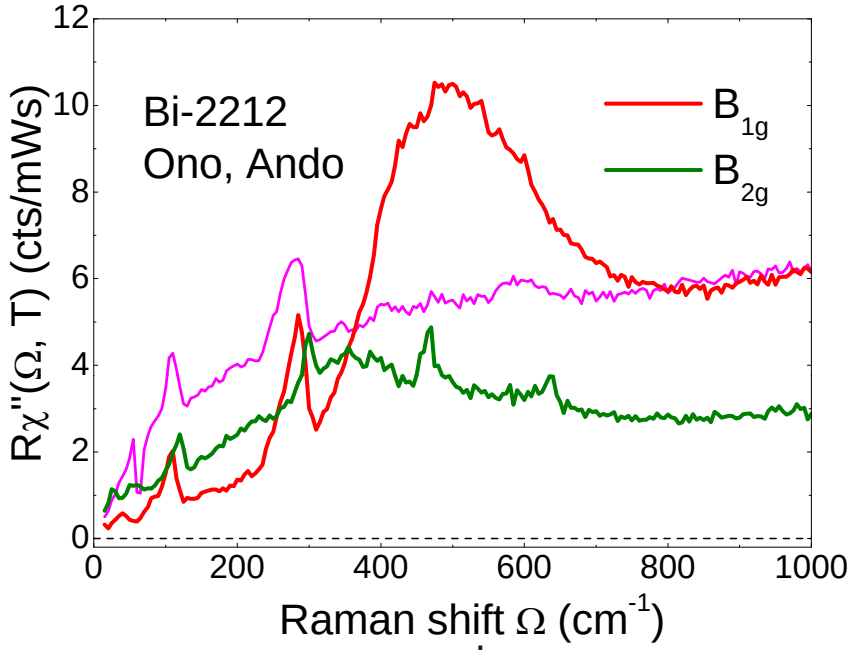
Electronic RS in the superconducting state



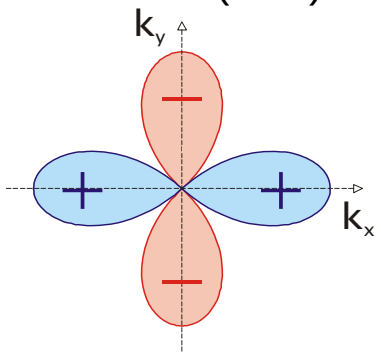
Hackl et al. Physica C **162-165**, 431 (1989)



s-wave



Devereaux et al. PRL **71**, 3291 (1994)



$d_{x^2-y^2}$-wave

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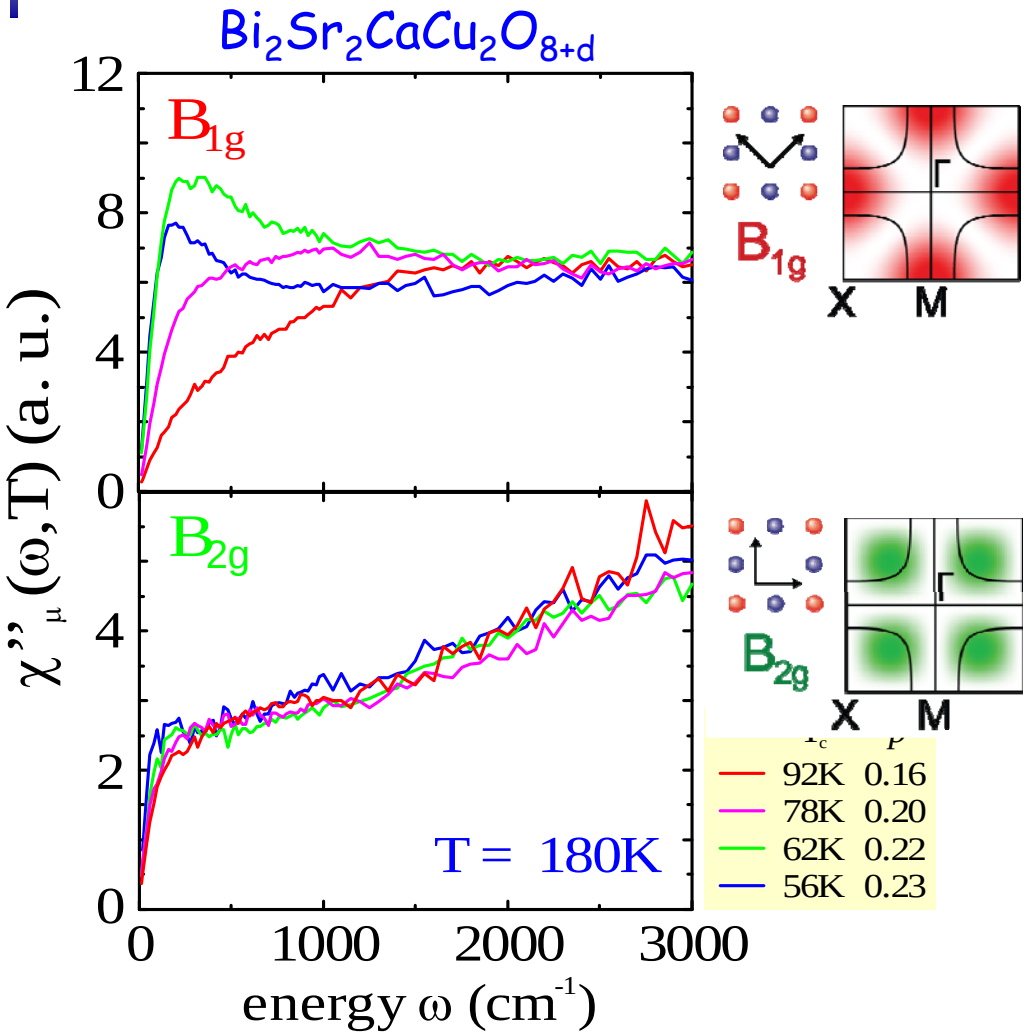
Electronic Raman scattering

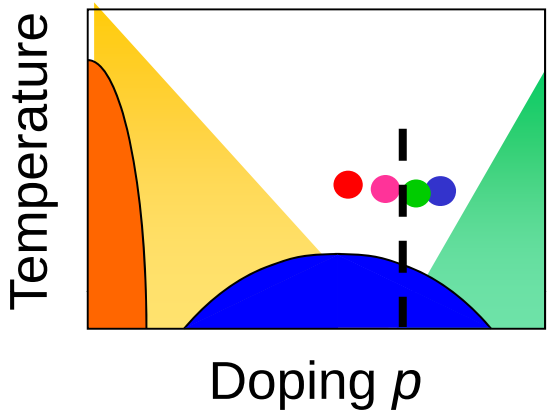
strongly coupled conventional SC

cuprates

$Ba(Fe_{1-x}Co_x)_2As_2$

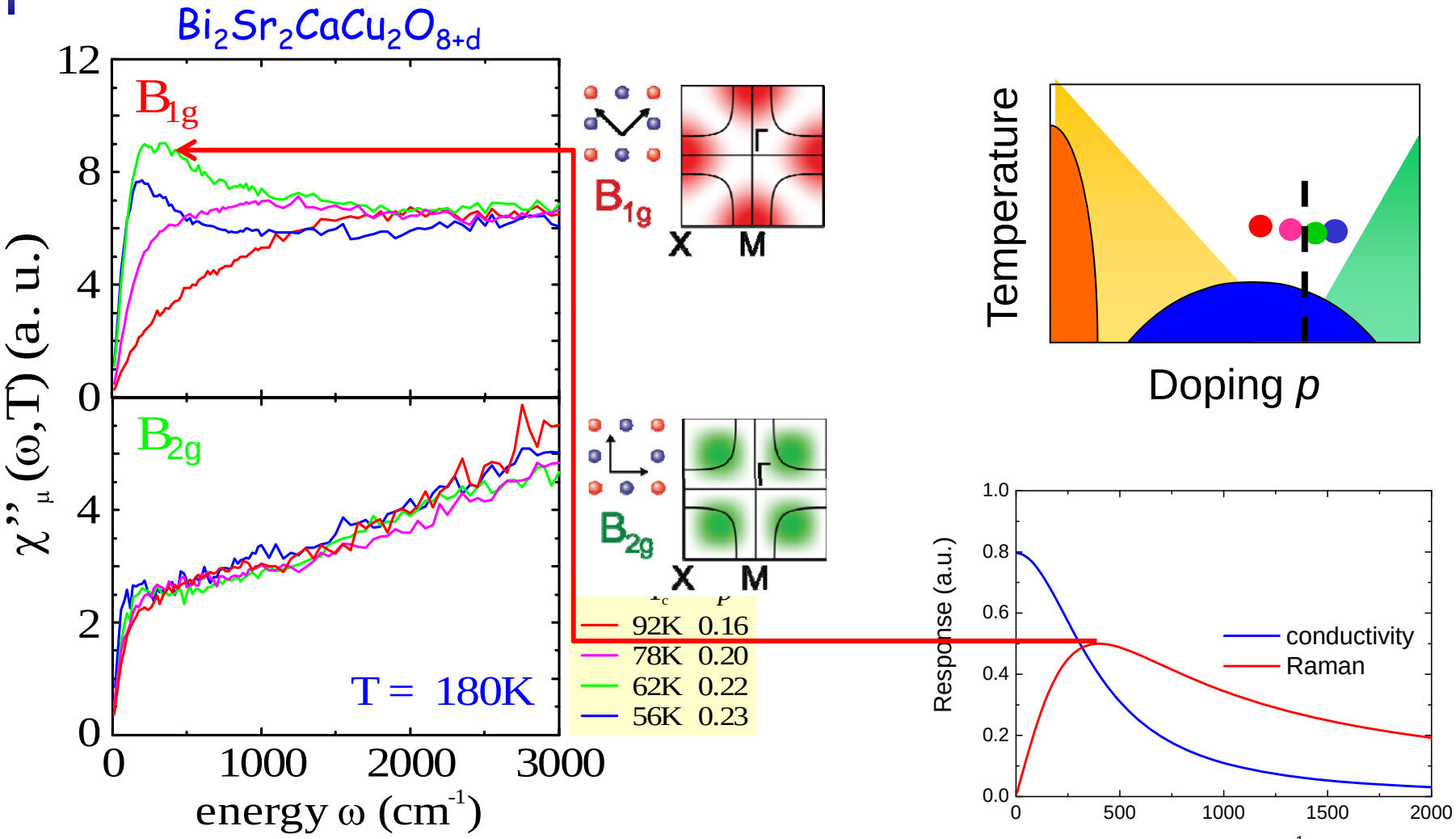
Doping dependence in Bi2212





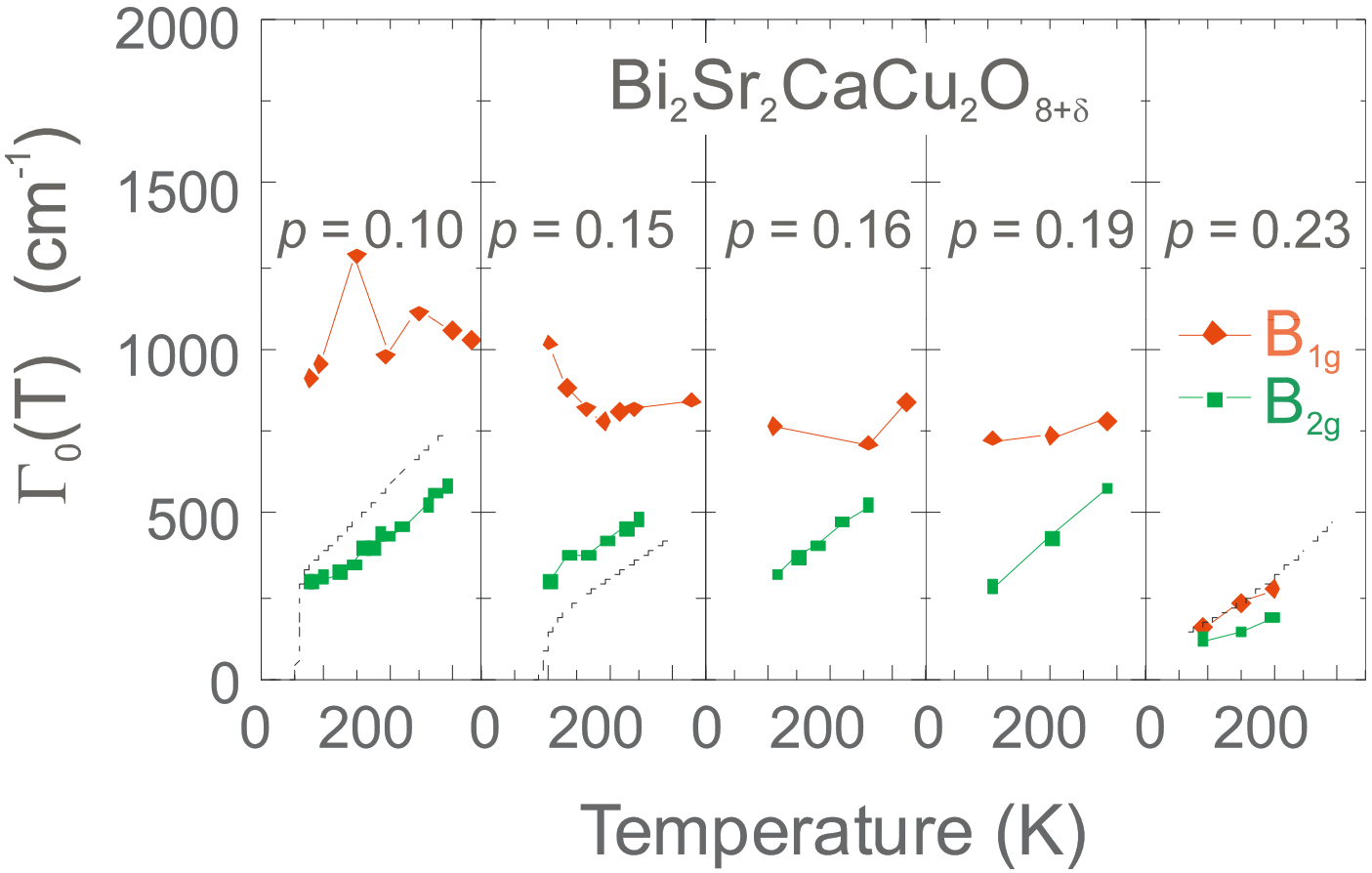
Venturini *et al.*, PRL **89**, 107003 (2002)

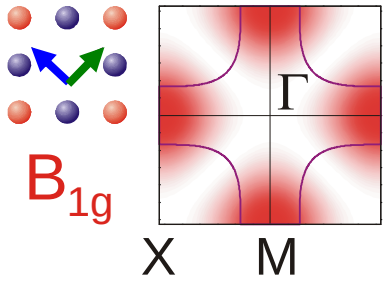
Doping dependence in Bi2212

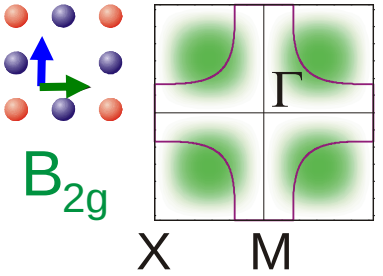


Venturini *et al.*, PRL **89**, 107003 (2002)

Ba122:Co – Bi2212







Opel et al. PRB **61**, 9752 (2000)

Walther Meissner Institut

Electronic Raman scattering strongly coupled conventional SC cuprates

$Ba(Fe_{1-x}Co_x)_2As_2$

In collaboration with

Walther Meissner Institut

Bernhard Muschler

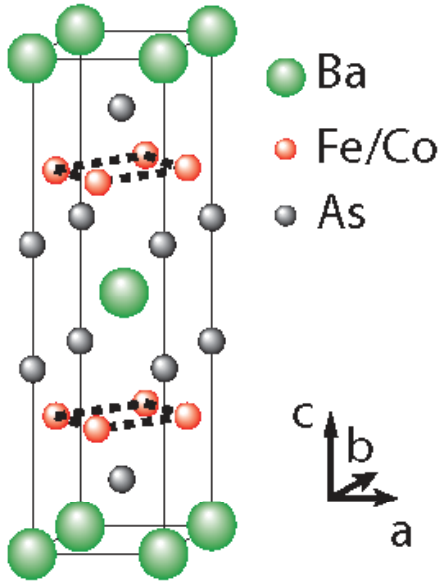
Wolfgang Prestel

Hans Eiter

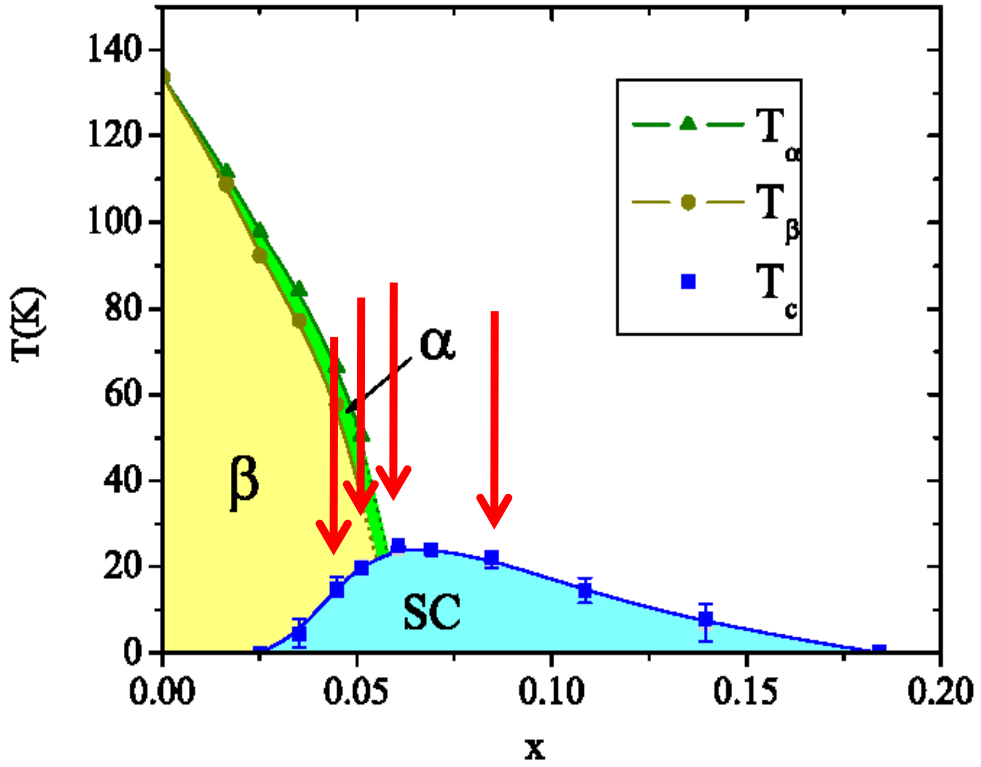
Tom Devereaux

Jim Analytis
Jiun-Haw Chu
Ian Fisher

$BaFe_2As_2$



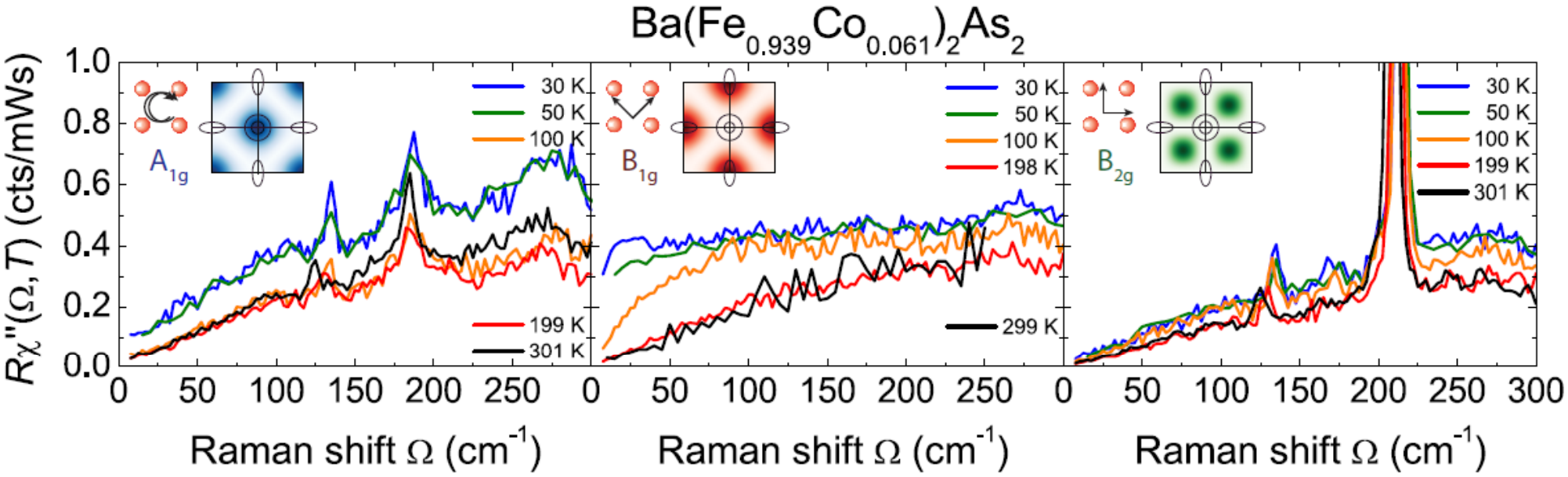
Kamihara et al.
J.Am.Chem.Soc.
130, 3296 (2008)
Rotter et al. PRL
Sefat et al. PRL



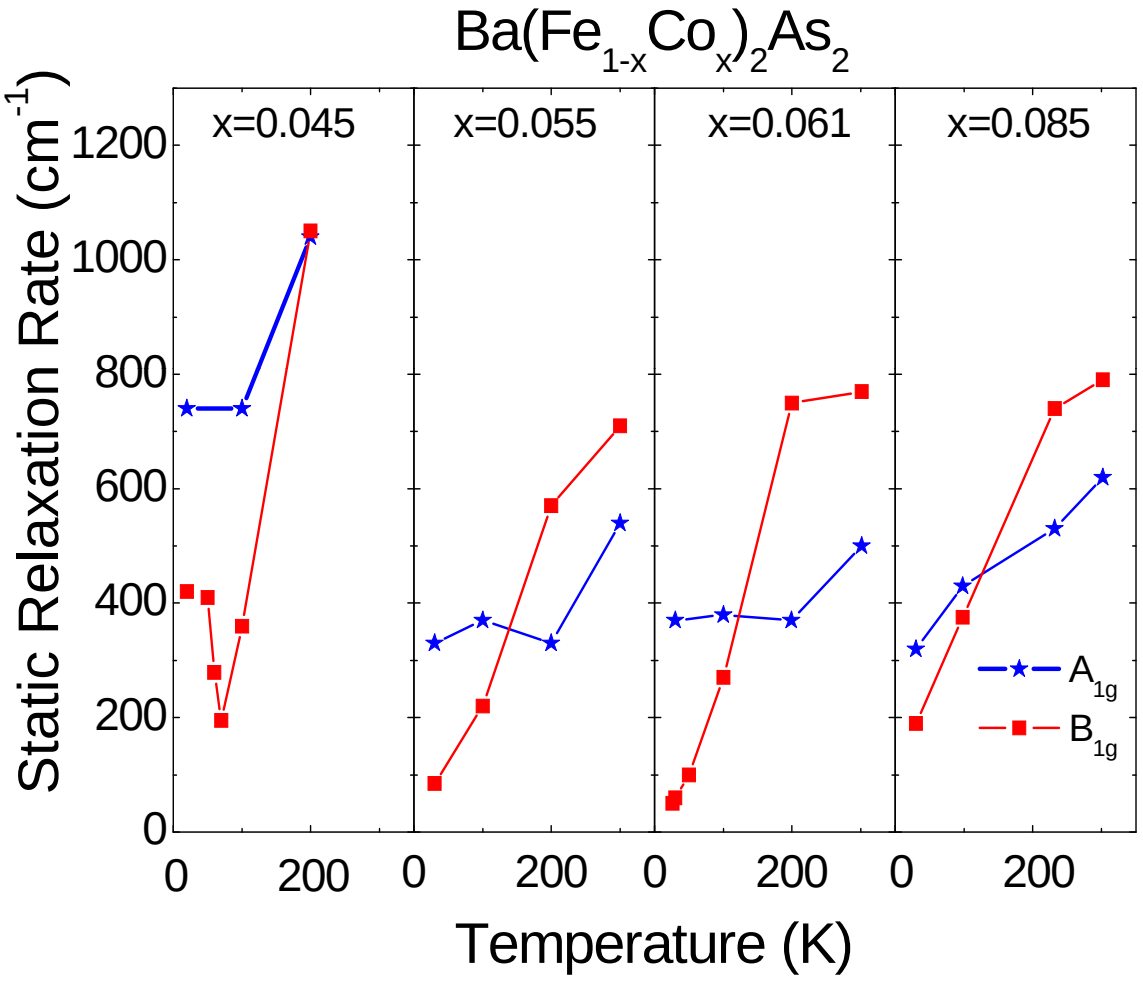
Chu et al. PRB **79**, 014506 (2009)

Mandrus, Canfield, Büchner, Klauss, Dai,….

Ba122 normal state



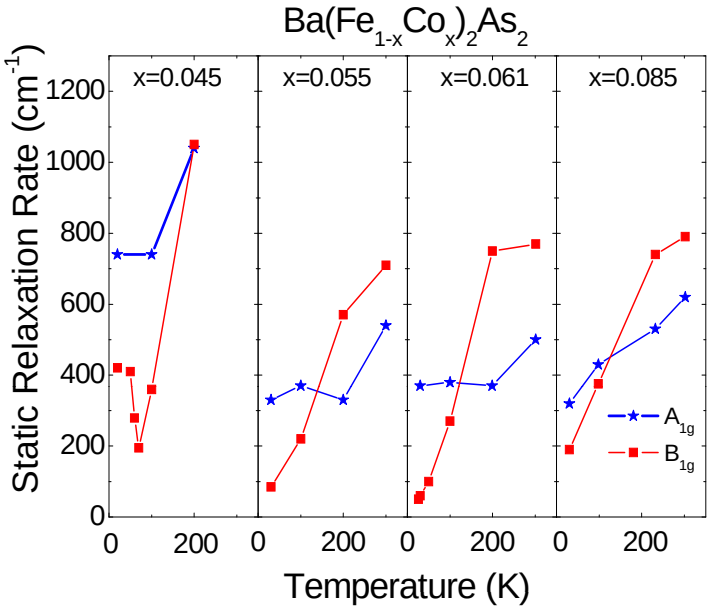
Raman resistivities

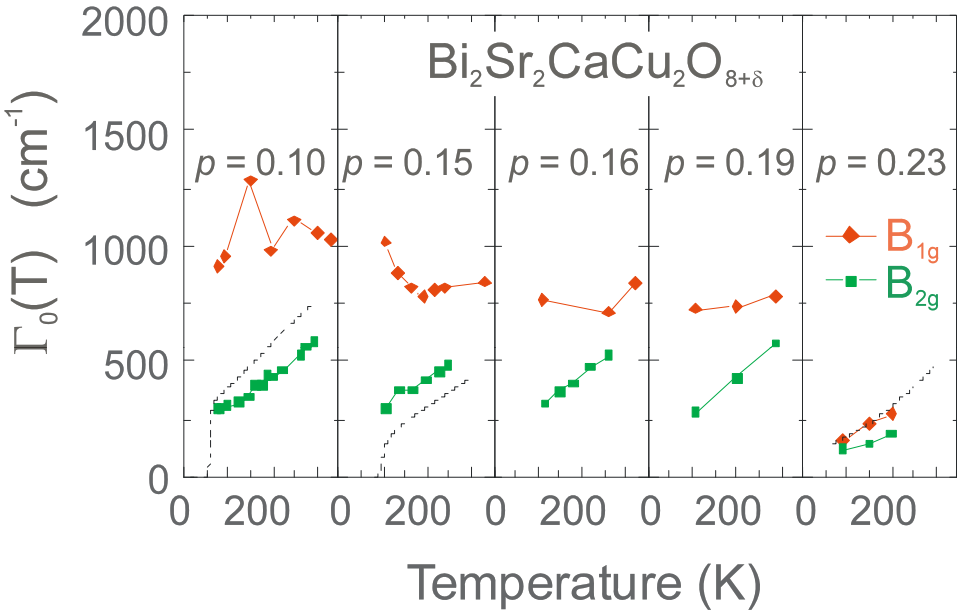


electron bands

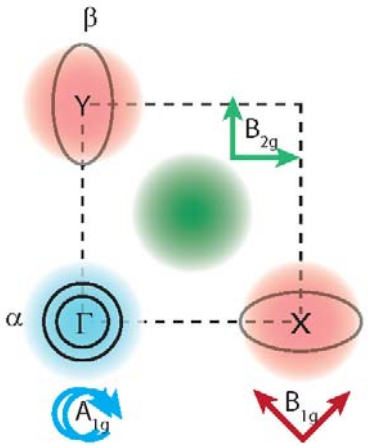
hole bands

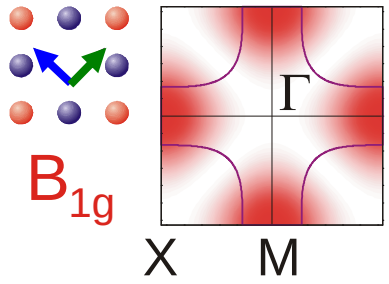
Ba122:Co – Bi2212

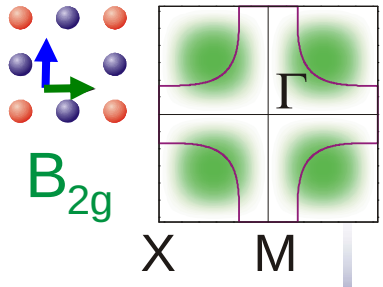




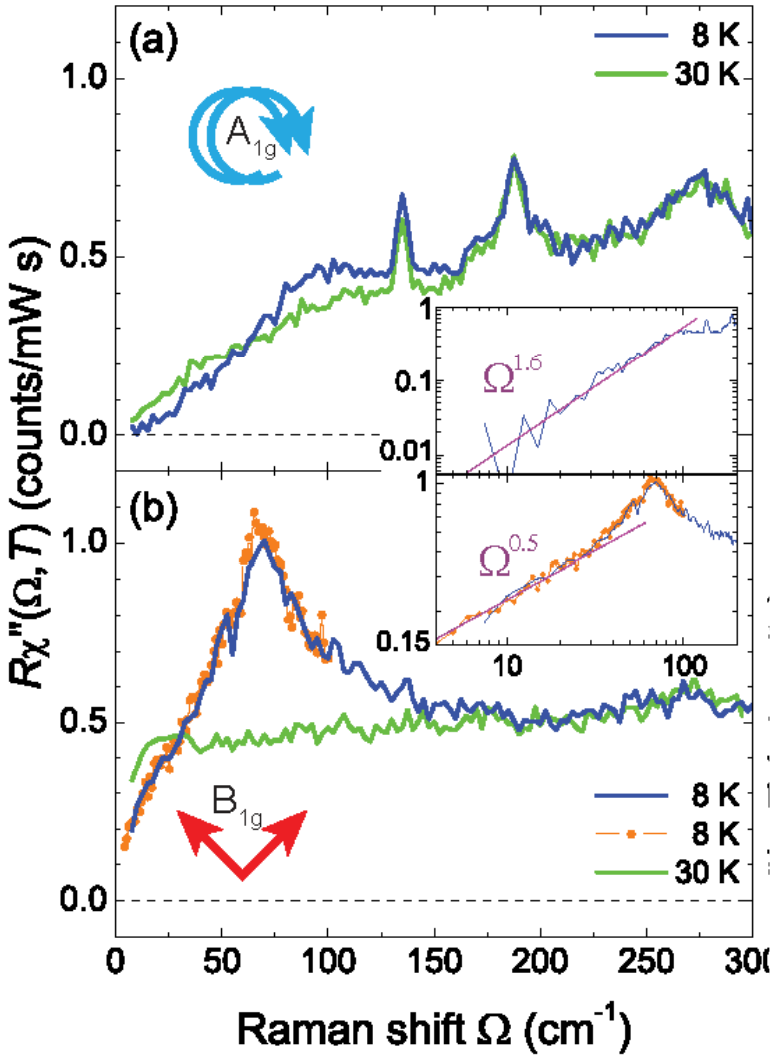
Opel et al. PRB **61**, 9752 (2000)



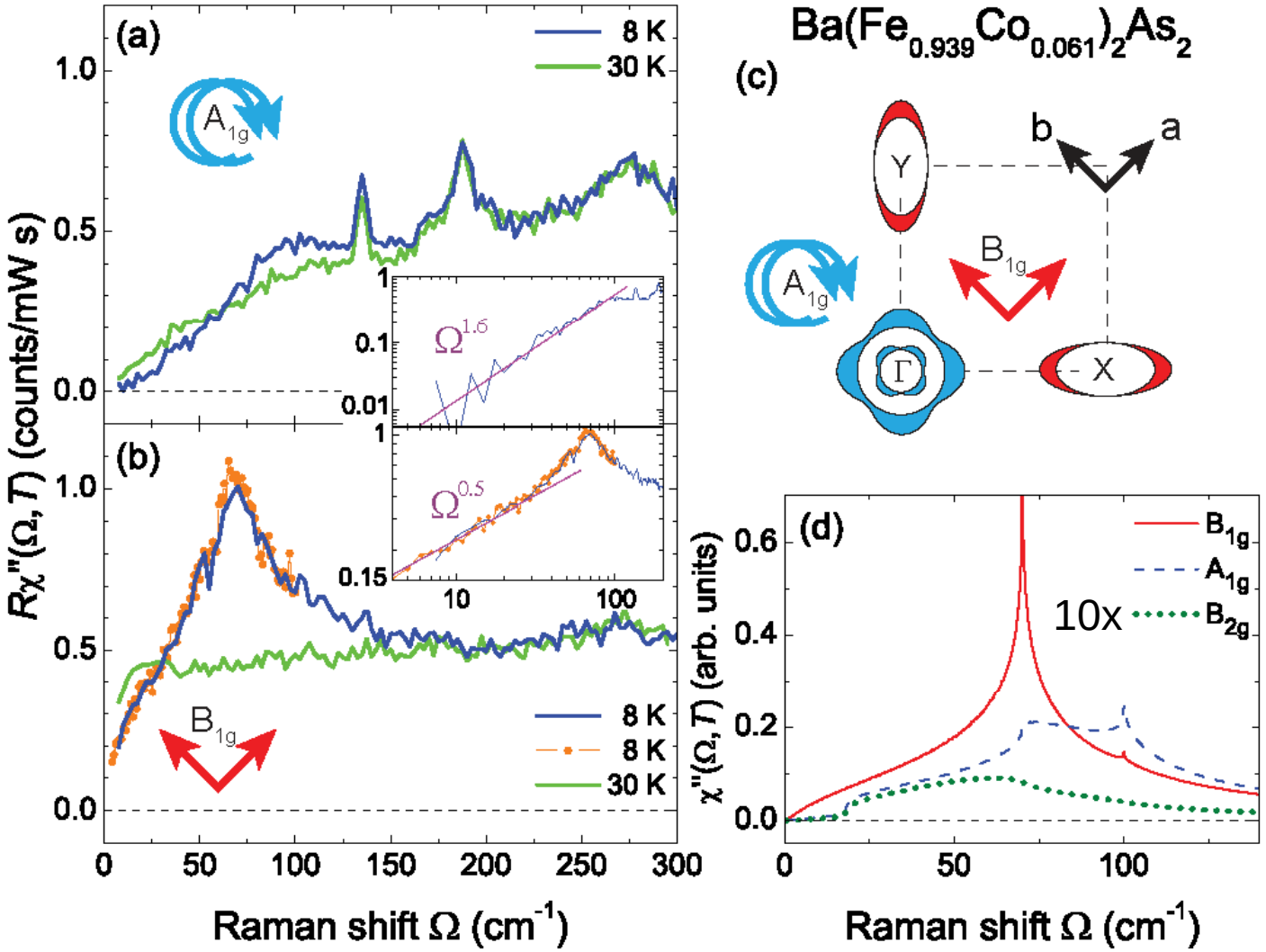




Ba122:Co - superconductivity

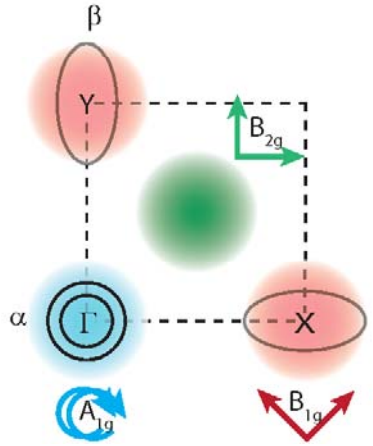


Ba122:Co - superconductivity



Summary

- Electronic Raman scattering **projects different parts of the BZ**



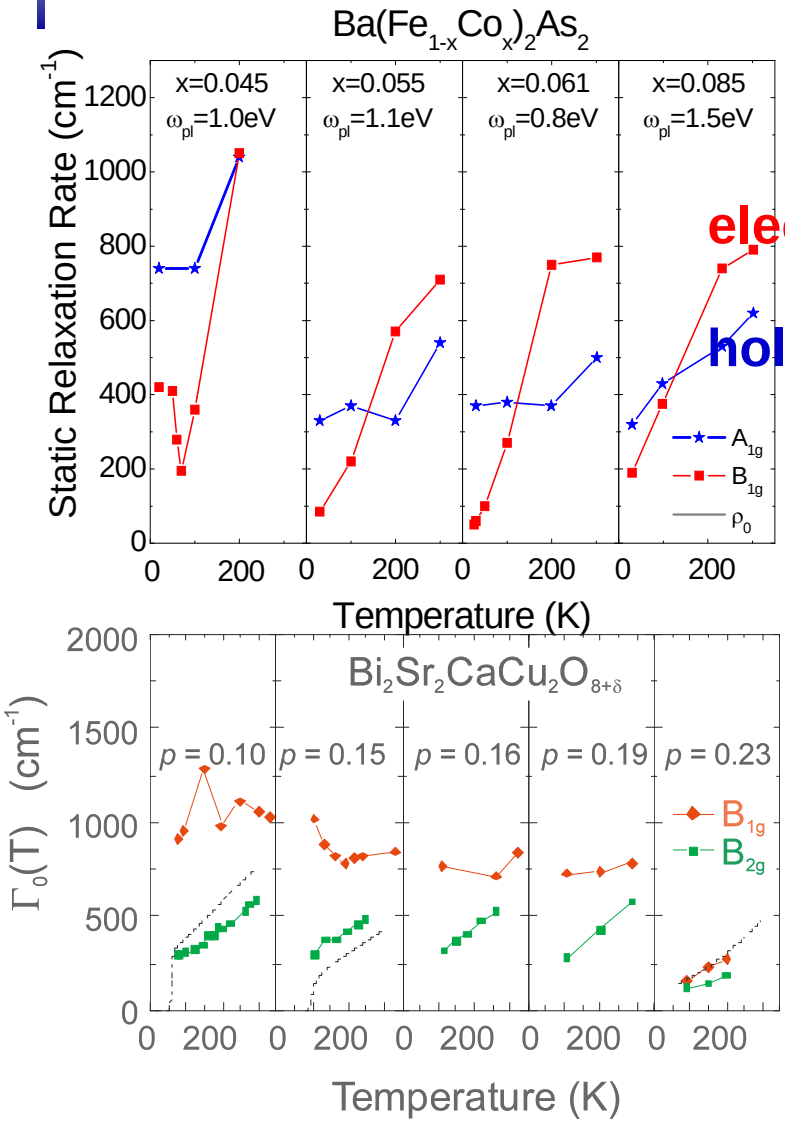
- Nearly **isotropic gap in multi-band A15**

- Strong **k** anisotropy of the carrier properties in single-band CuO_2 and multi-band FeAs

- **Unconventional gap in CuO_2**

- **Conventional** but strongly **k**-dependent **gap** in $Ba(Fe_{0.931}Co_{0.069})_2As_2$

The Janus face of electrons in HTSC



electron bands

hole bands

anti-node

node

God Janus (Musei Vaticani)