Pseudo-Gap and its Collapse in hole doped Cuprates

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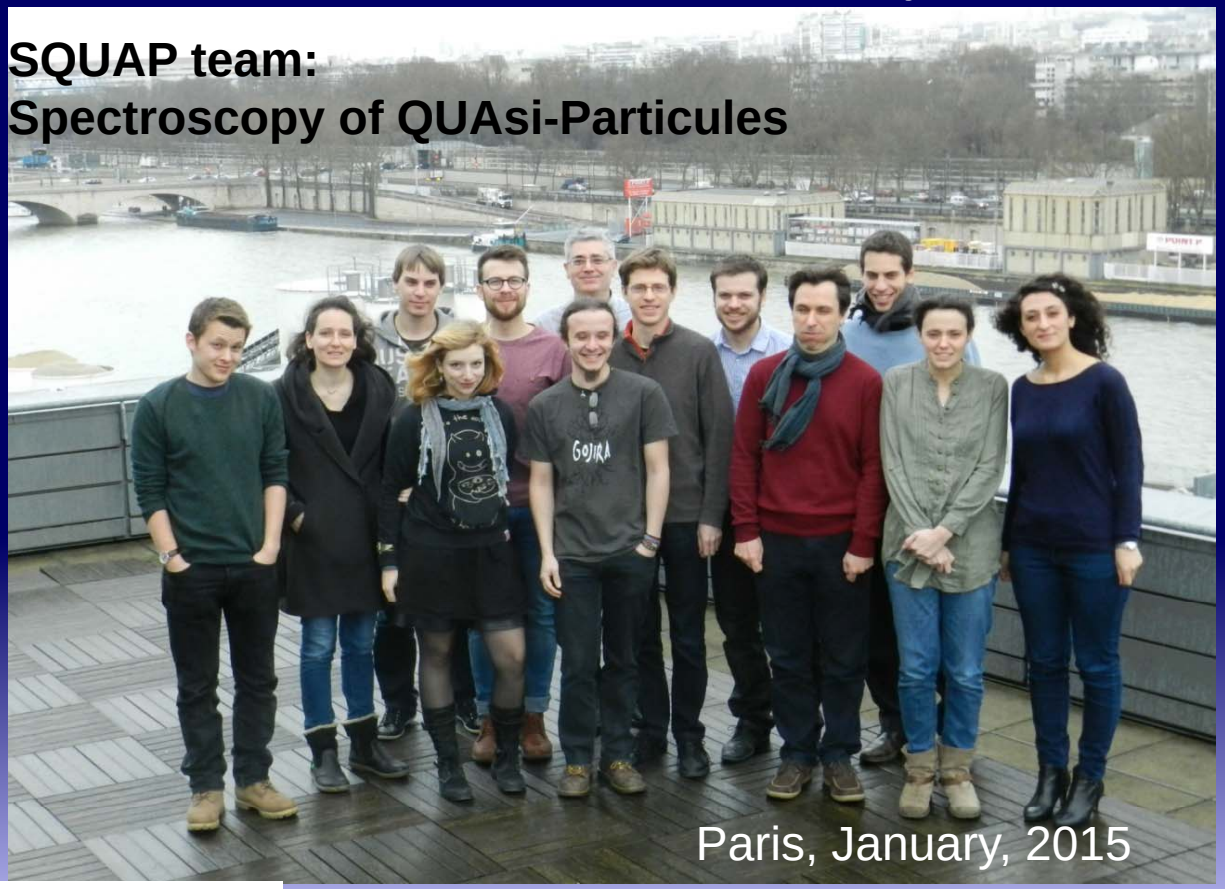
SQUAP team:
Spectroscopy of QUAsi-Particules



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RÉSEAU FRANCILIEN SUR LES OXYDES FONCTIONNELS

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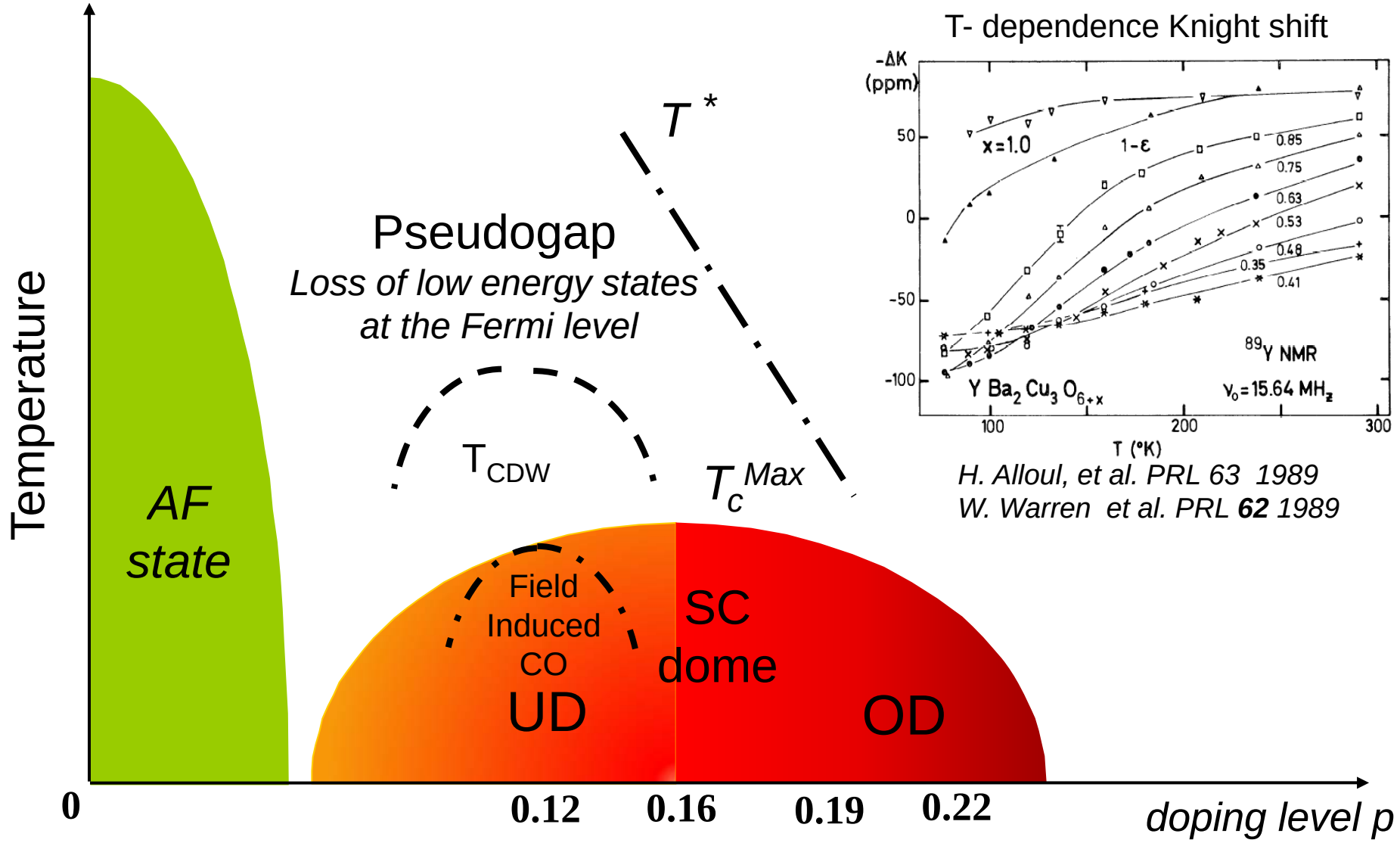
Hole-doped cuprate phase diagram



T- dependence Knight shift

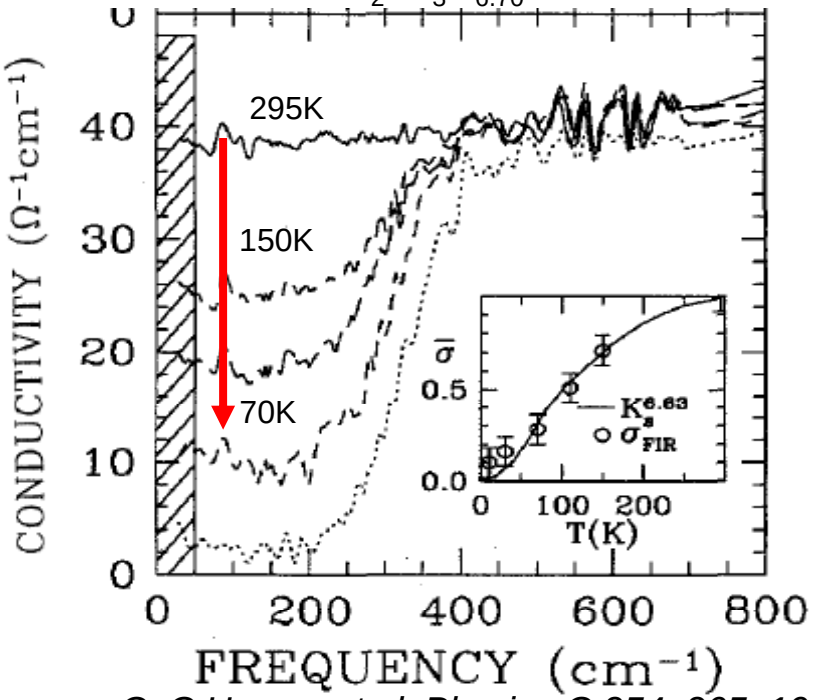
H. Alloul, et al. PRL 63 1989
*W. Warren et al. PRL **62** 1989*

2 signatures of the pseudogap In optical conductivity

along the c axis

Loss of QSP spectral weight

UD- $YBa_2Cu_3O_{6.70}$ Tc=63K

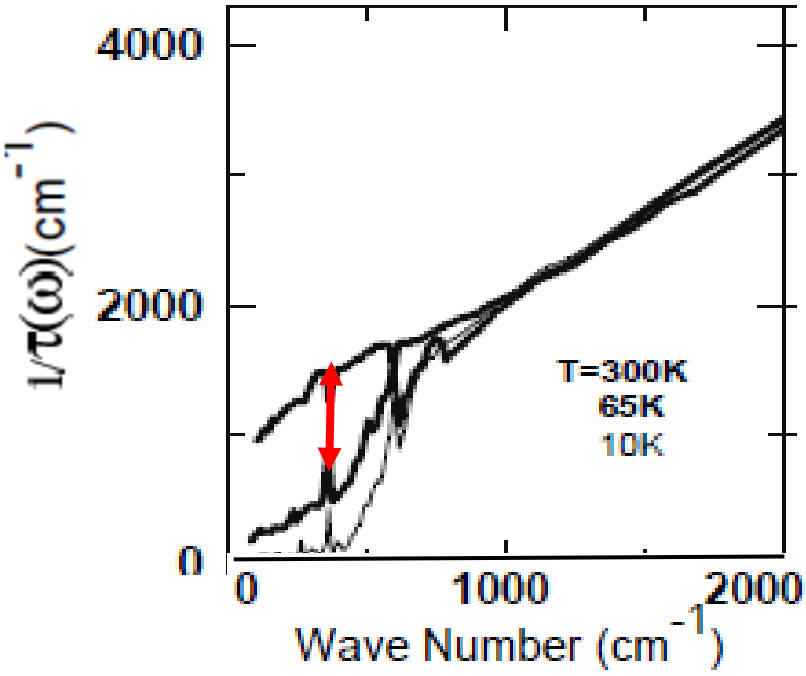


C. C.Homes et al. Physica C 254, 265, 1995

in the ab-plane

Loss of scattering rate

UD-$YBa_2Cu_3O_{6.60}$ Tc=58K



A.V. Pushkov et al. J.Phys: Cond Matter 8, 10049, 1996

See also: RMP 77, 2005, **Basov, Timusk**; RMP 83, 2011 **Basov, Averiit, Van der Marel**, **Dressel** and the Review of **R. Lobo**, The optical conductivity of HTS, Chap. 3, p. 103, Ed. X. G. Qiu, Woodhead Publishing, Oxford 2011.

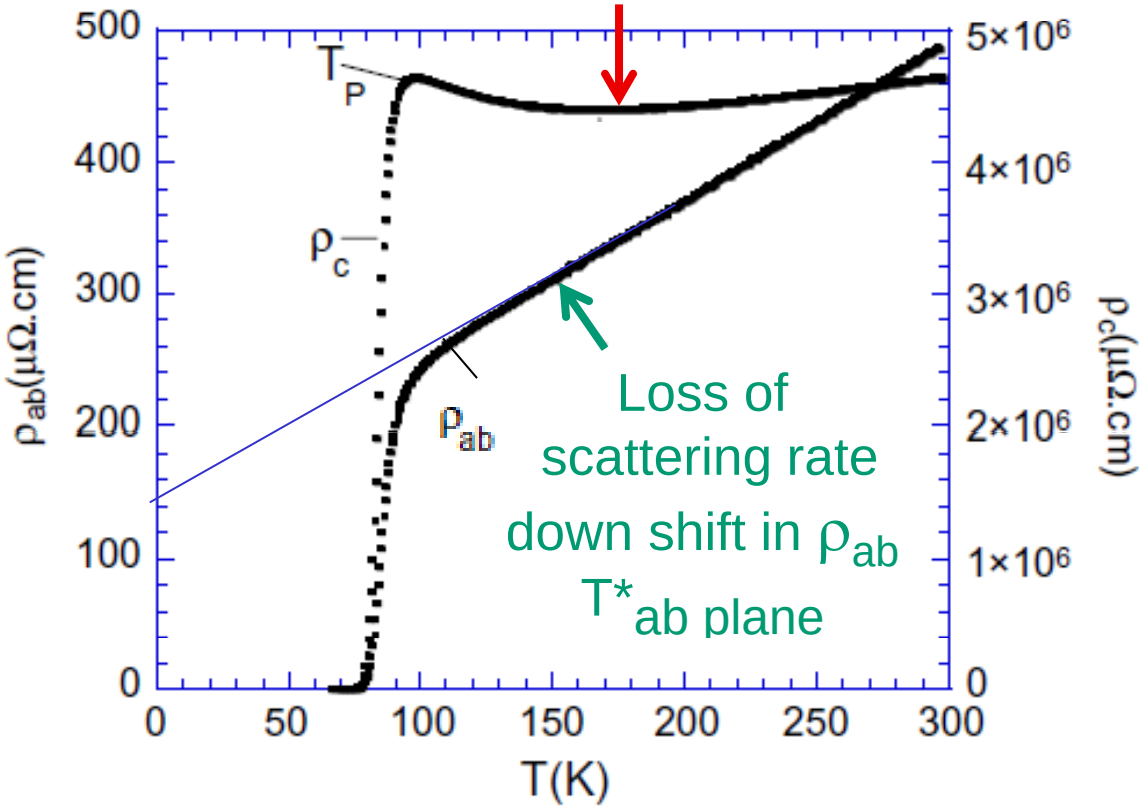
2 distincts signatures of the PG in Resistivity

Loss of low energy spectral weight

upturn in ρ_c

$T^*_{c\text{-axis}}$

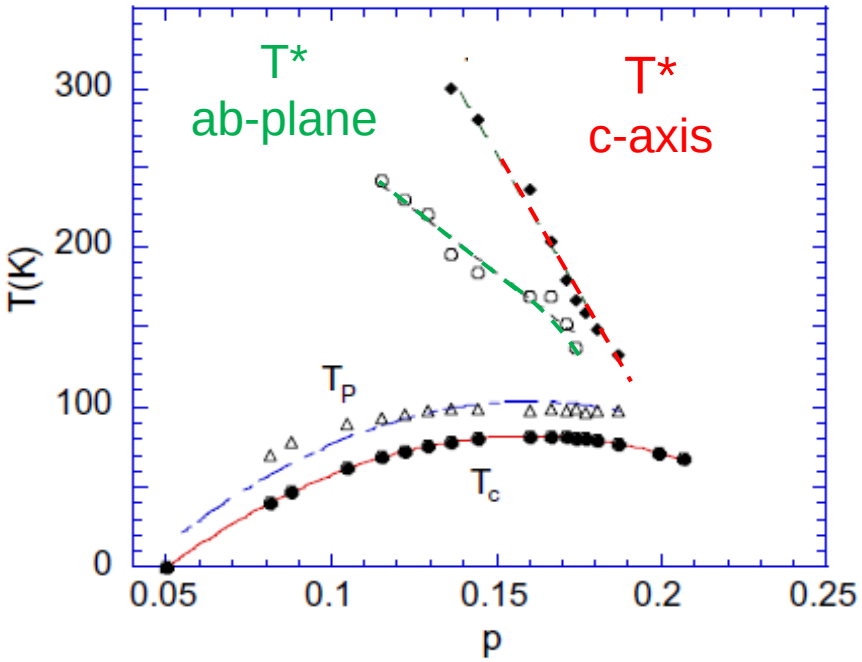
Bi-2212 optimal doping



H. Raffy et al. Physica C 460-62 8512007

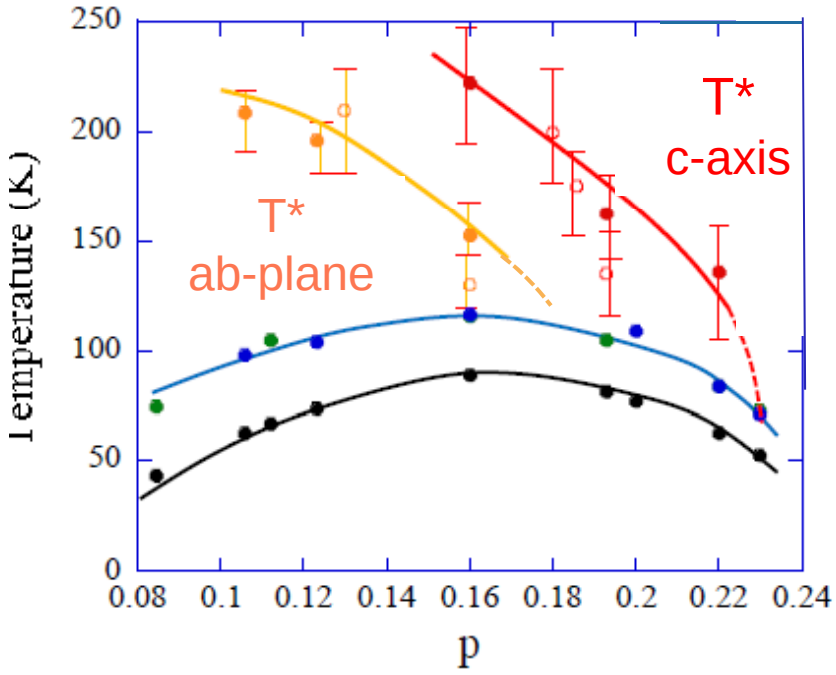
2 distinct doping evolutions of T* along the c-axis and the ab-plane

Bi-2212



H. Raffy et al. Physica C 460-62 8512007

Bi-2212



T. Usui et al. arXiv:1404.4736v1
See also: T. Shibauchi et al. PRL 86, 5764, 2001

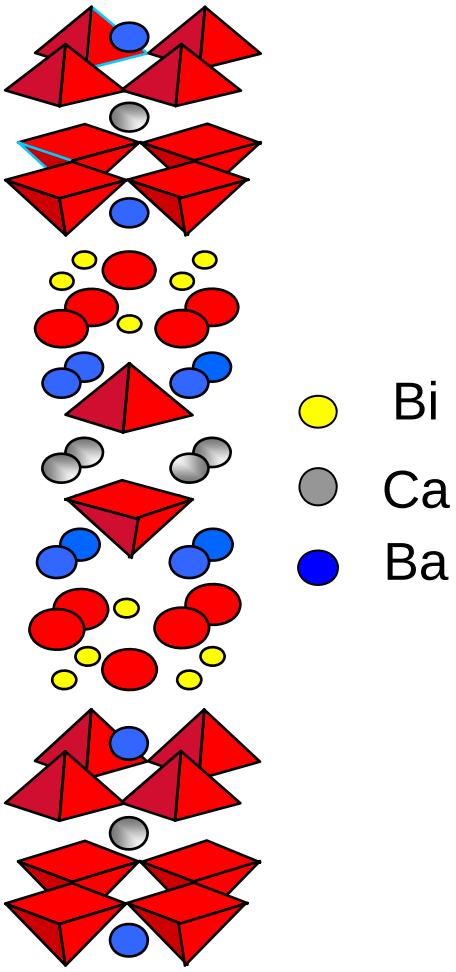
Does these 2 distinct T* merge or correspond to 2 distinct transitions at low temperature?

ab-plane properties deduced from transport, optics, tunnelling ...
Suggest a QCP, p≈0.19 in Bi-2212

What can we learn from **c-axis** properties in Bi-2212?

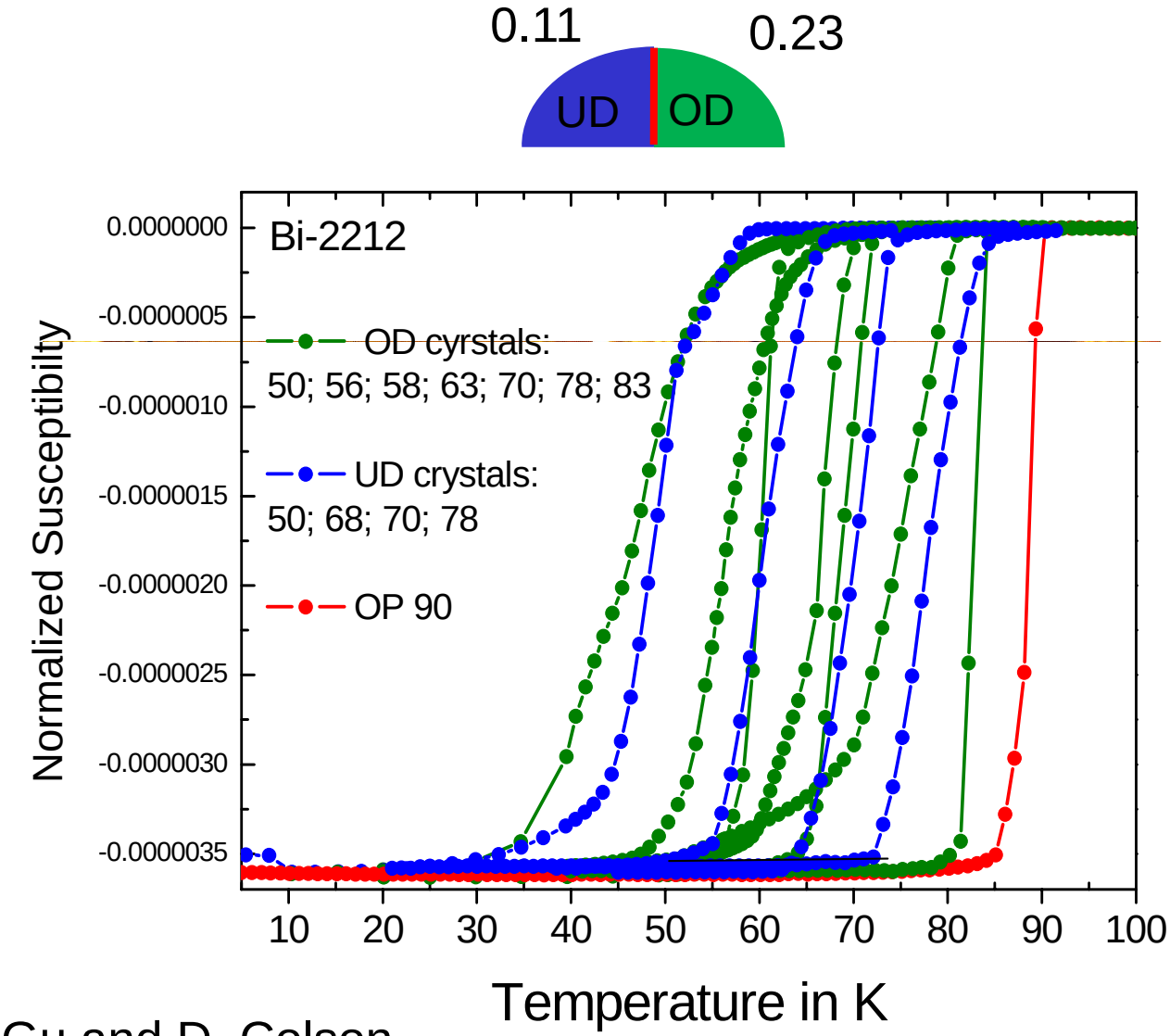
Electronic Raman scattering on Bi-2212 single crystals

Bi-2212 Single Crystals



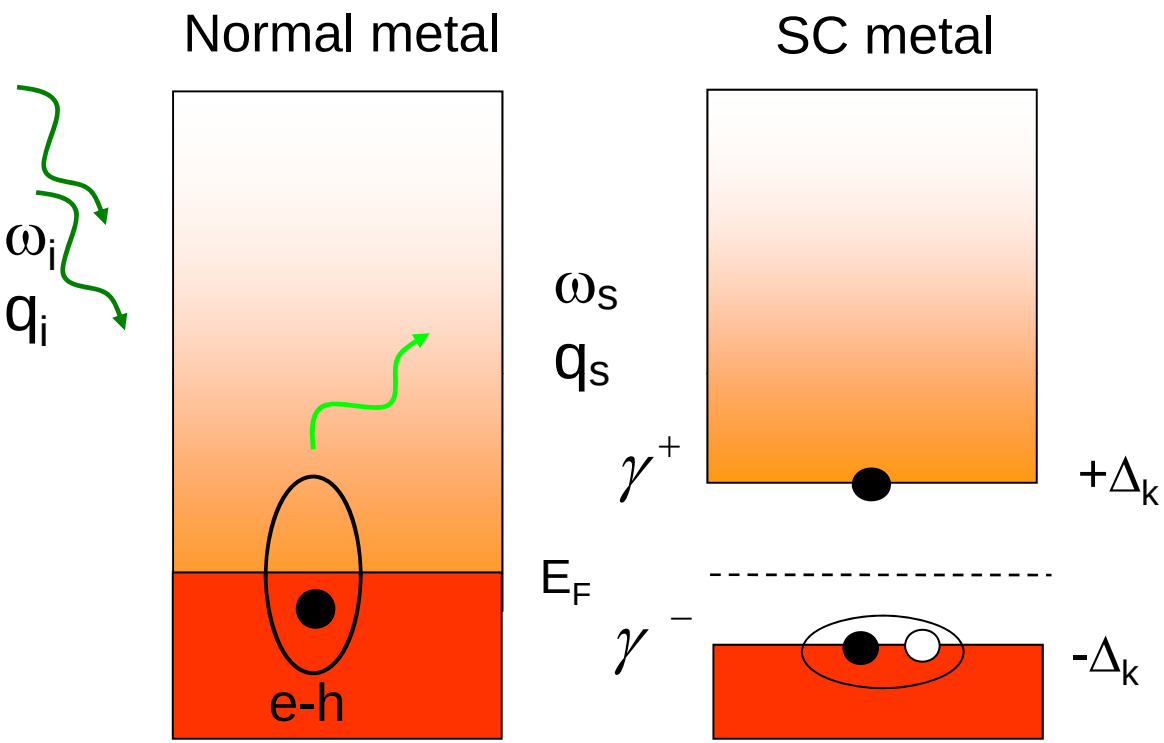
Bi-2212

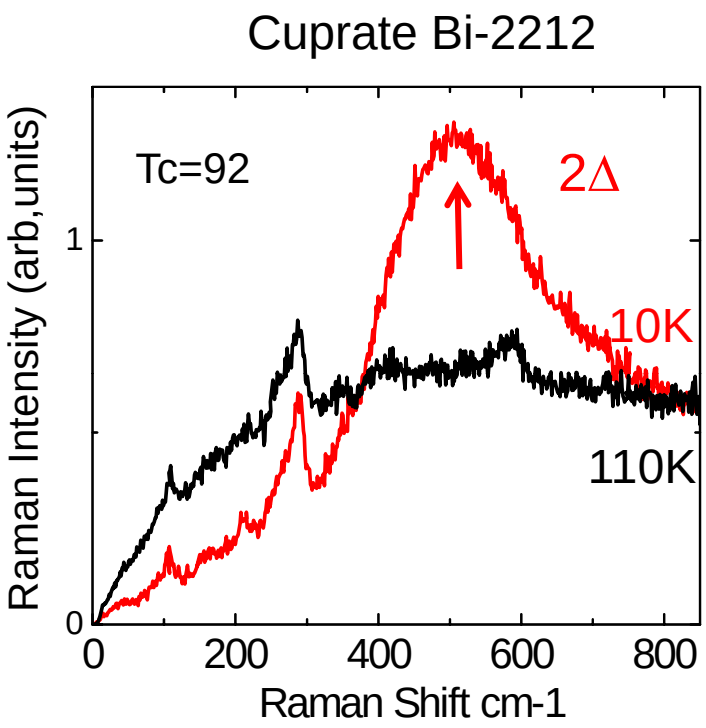
T^{max}_c=90 K



Single crystals from G. Gu and D. Colson

Electronic Raman Scattering in the Normal/SC states



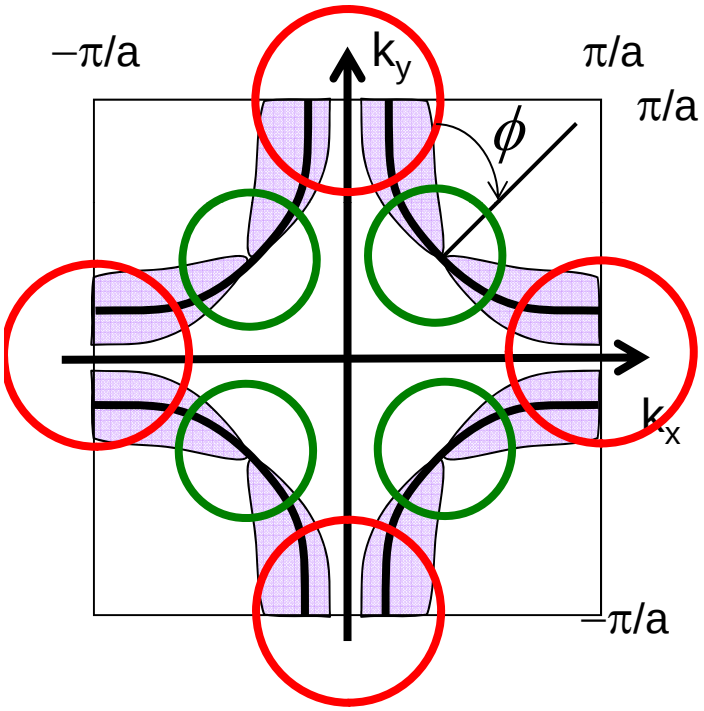


Raman shift :

$\omega_R = \omega_i - \omega_s$

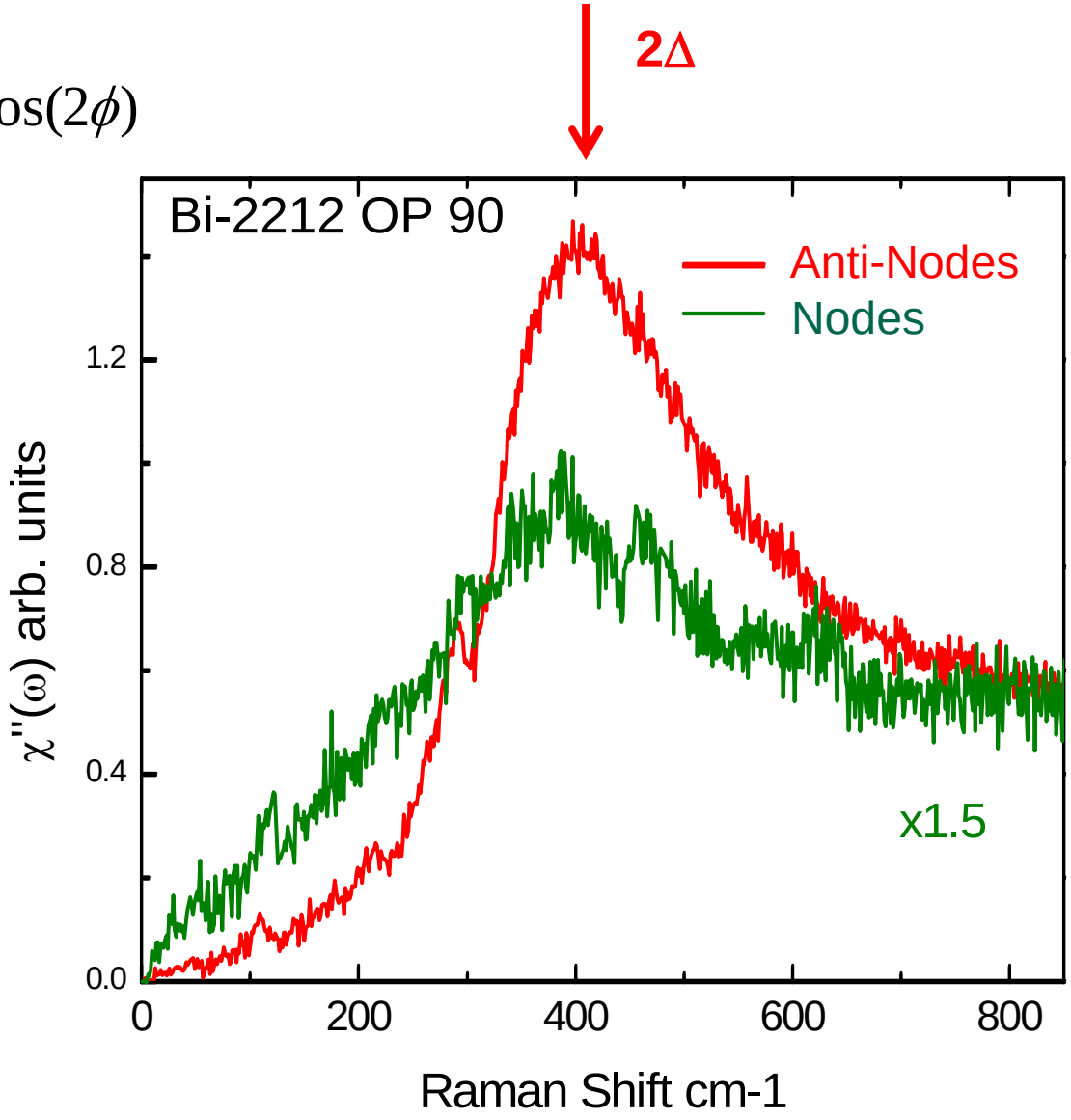
Raman response for a « d-wave » gap in cuprates

$$\Delta(\phi) \propto \cos(kx) - \cos(ky) \equiv \cos(2\phi)$$



Anti-Nodal Region

Nodal Region



Raman vertices: γ_{AN} or γ_{N}

See RMP 79, 175, Hackl, Devereaux and Blanc et al. PRB 82, 144516, 2009

Focus on the Anti-Nodal Raman response

Raman vertex
at the Anti-Nodes

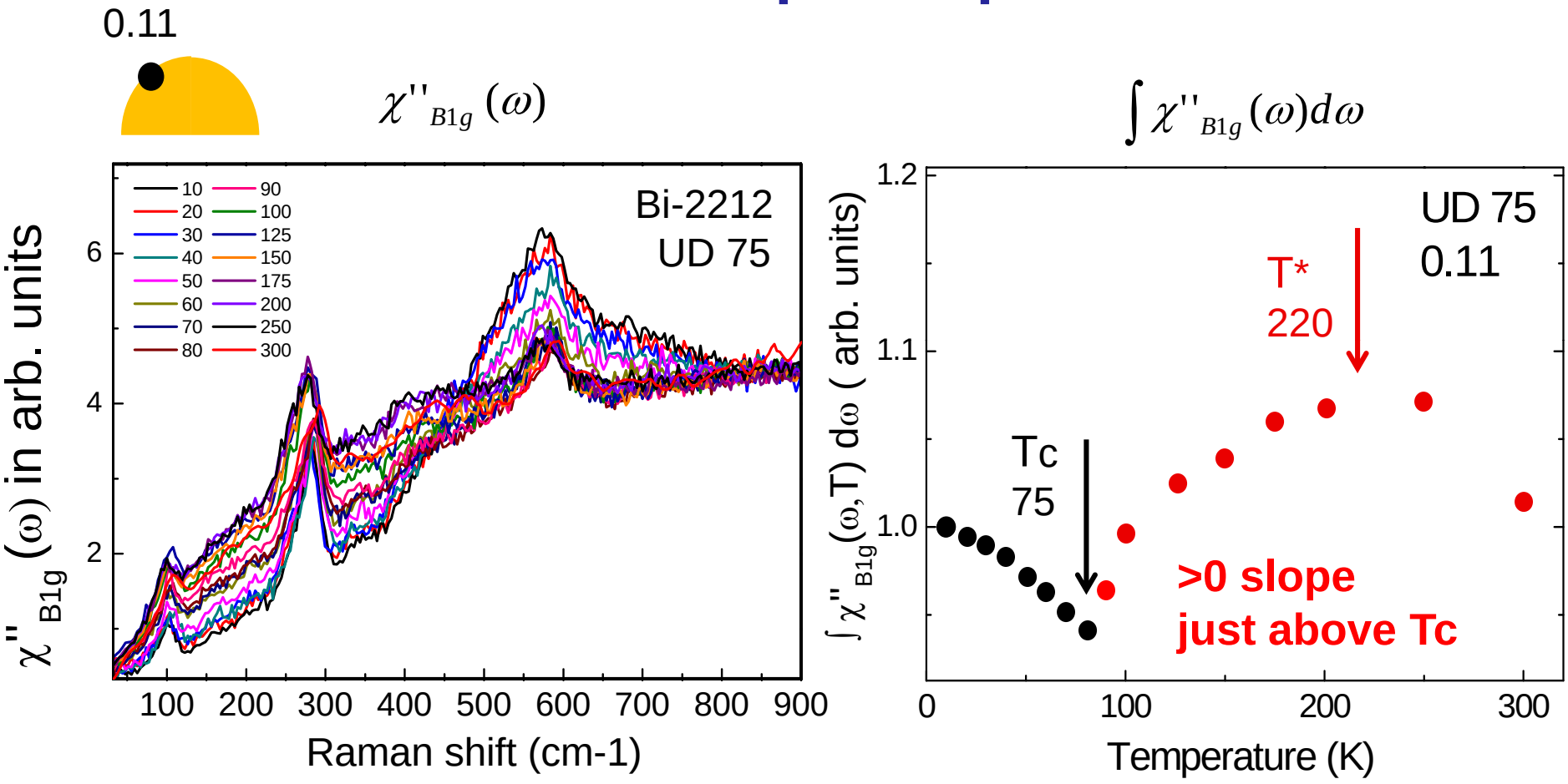
c-axis hopping

$$\left|\gamma_{AN}\right|^2 \propto \left(\cos(kx)-\cos(ky)\right)^2 \approx t_{\perp}(k)$$

Probing the QSP dynamic at the Anti-Nodes
Corresponds to
probing the QSP dynamic along the c-axis

the Anti-Nodal Raman response should exhibit
a loss of spectral weight
as in c-axis optical conductivity

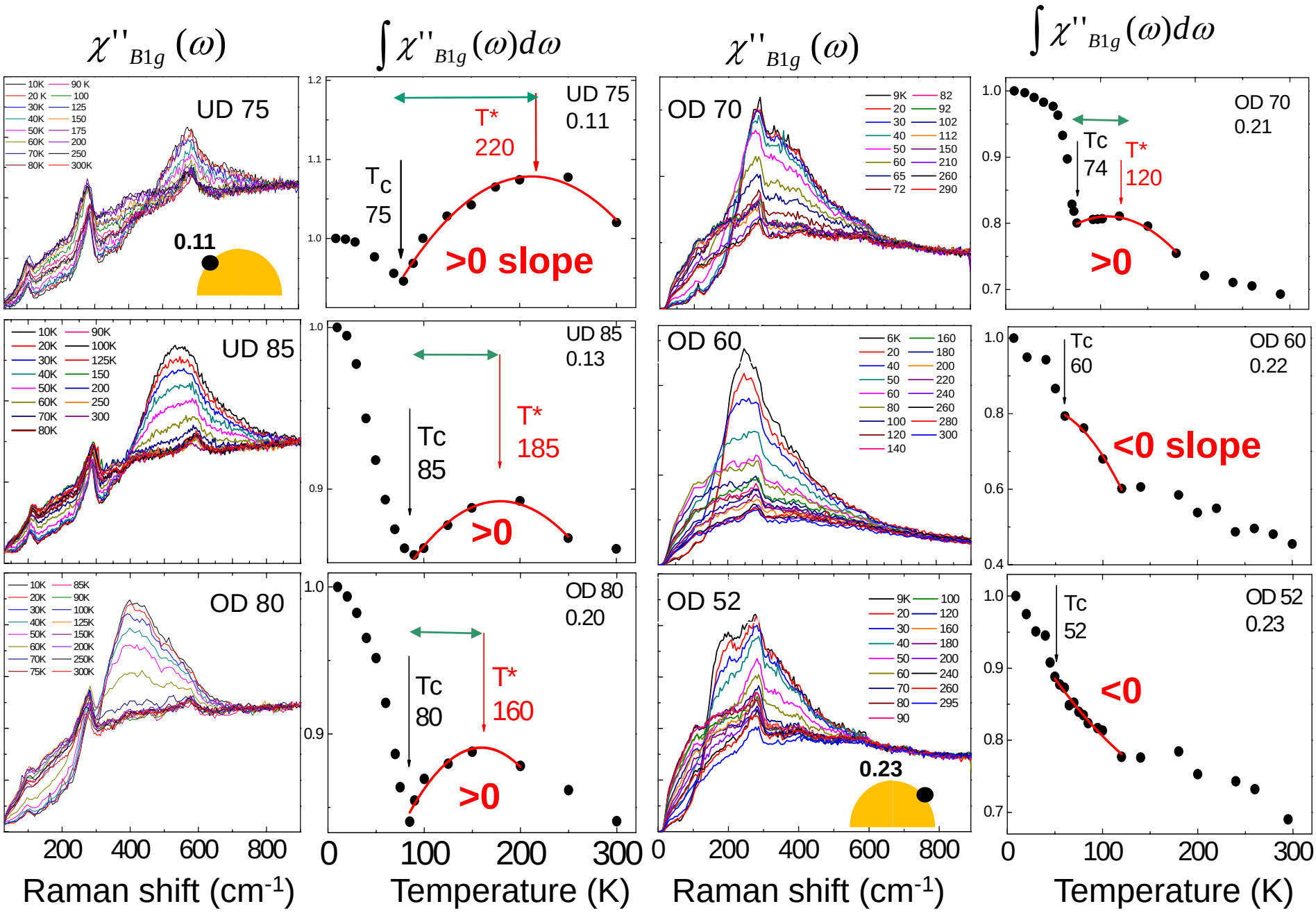
Electronic Raman response at the Anti-Nodes In underdoped cuprate



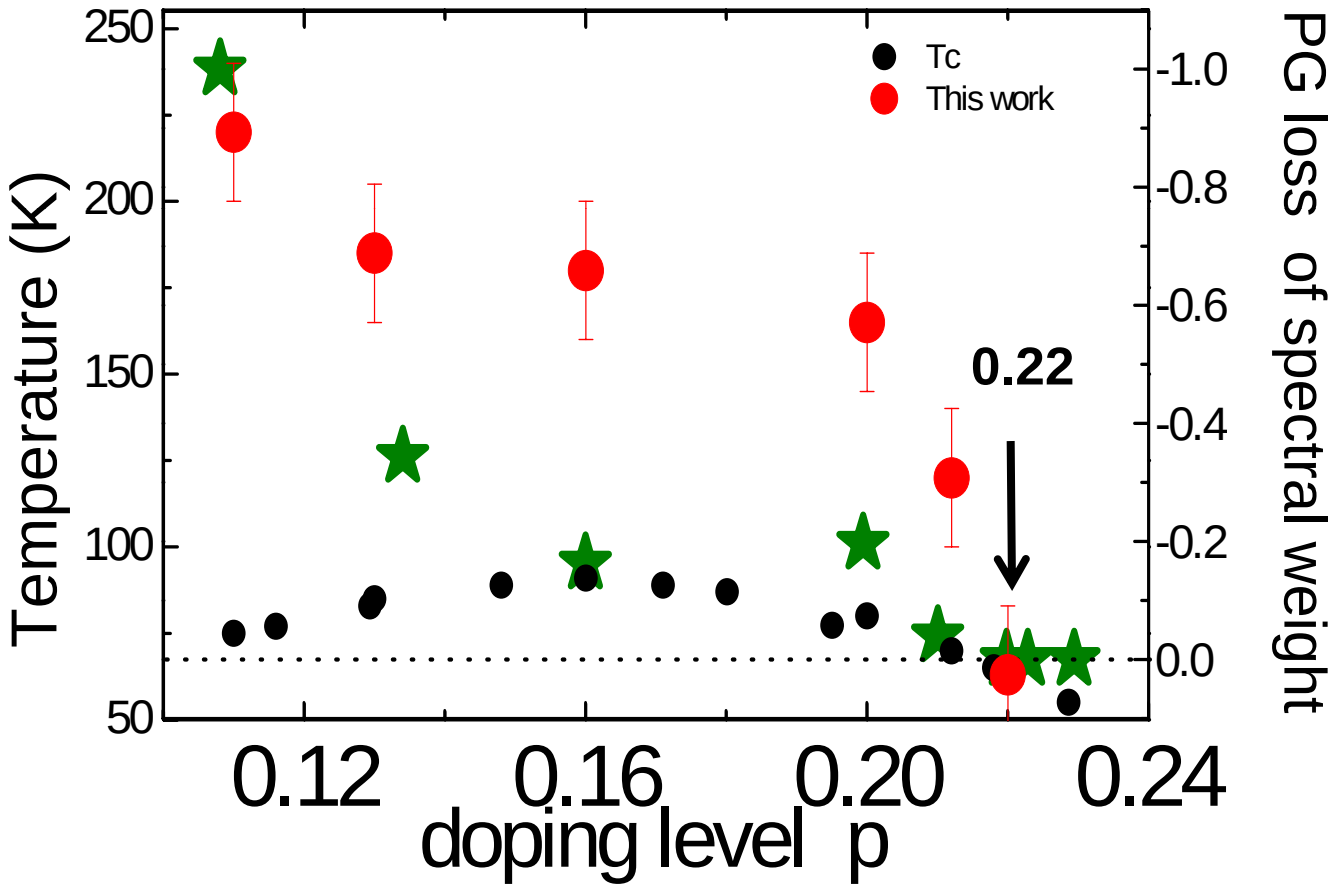
S. Benhabib, A.S, M.Civelli, I. Paul et al. arXiv:1403.7620, accepted in PRL 2015

ROP 76, 022502, 2013 . A.S. Y. Gallais, M. Cazayous, M. Méasson, D.Colosn et al.

Detection of the normal state Pseudogap

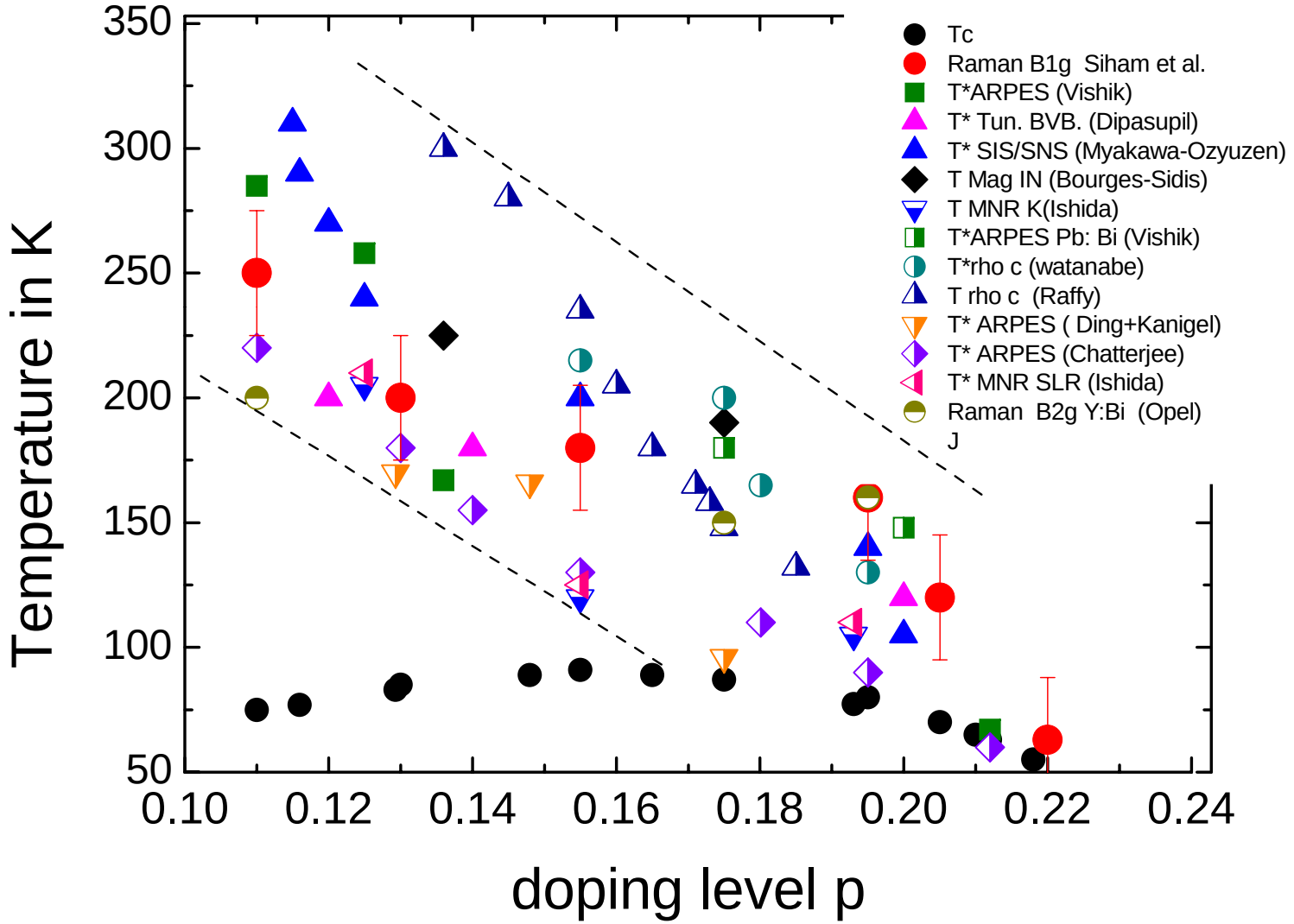


Ending Point of the normal state PG in Bi-2212 from the Anti-Nodes

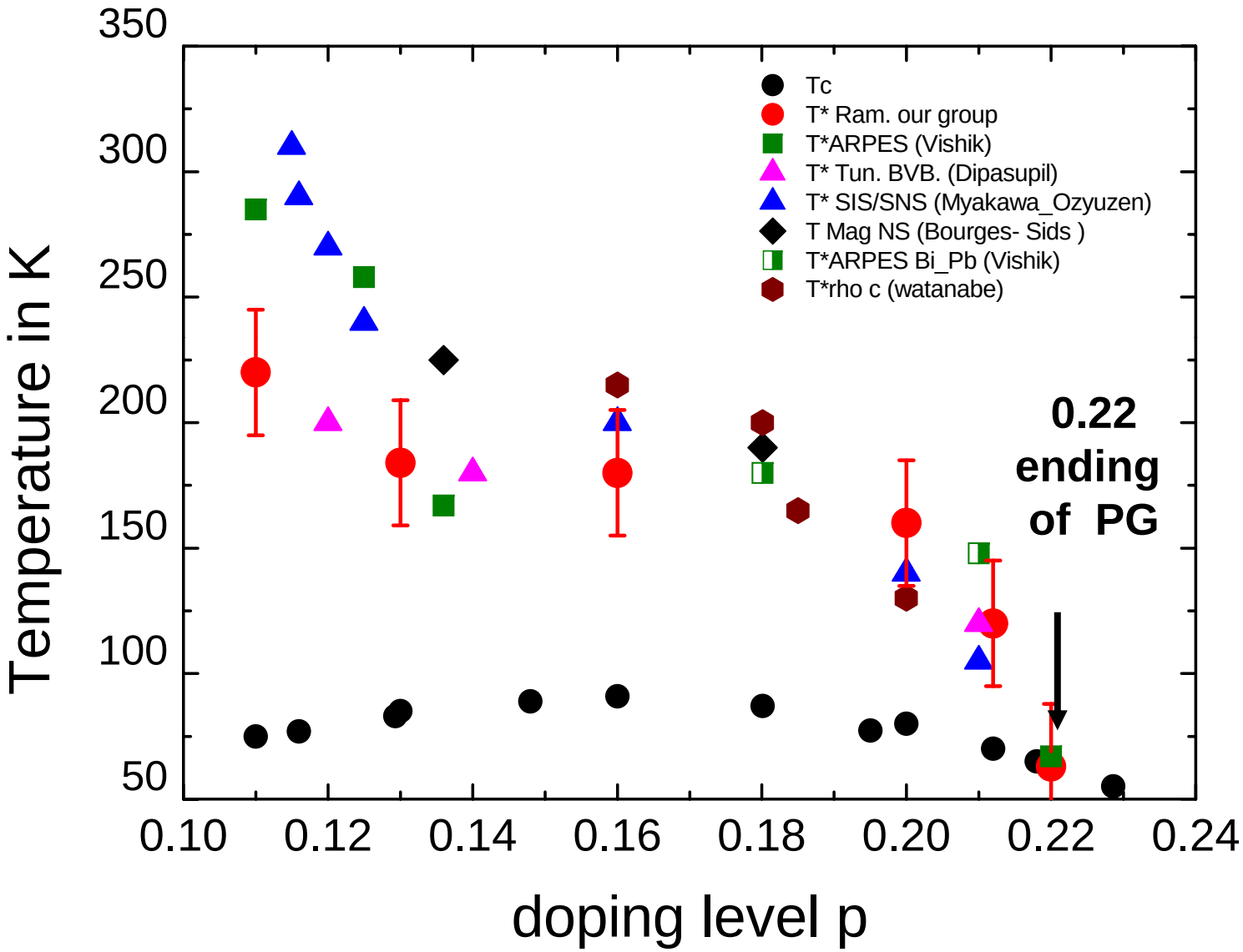


S. Benhabib, A.S. M.Civelli, I. Paul et al. arXiv:1403.7620, accepted in PRL 2015

Nebula of T* values from spectroscopy and transport on Bi-2212 only

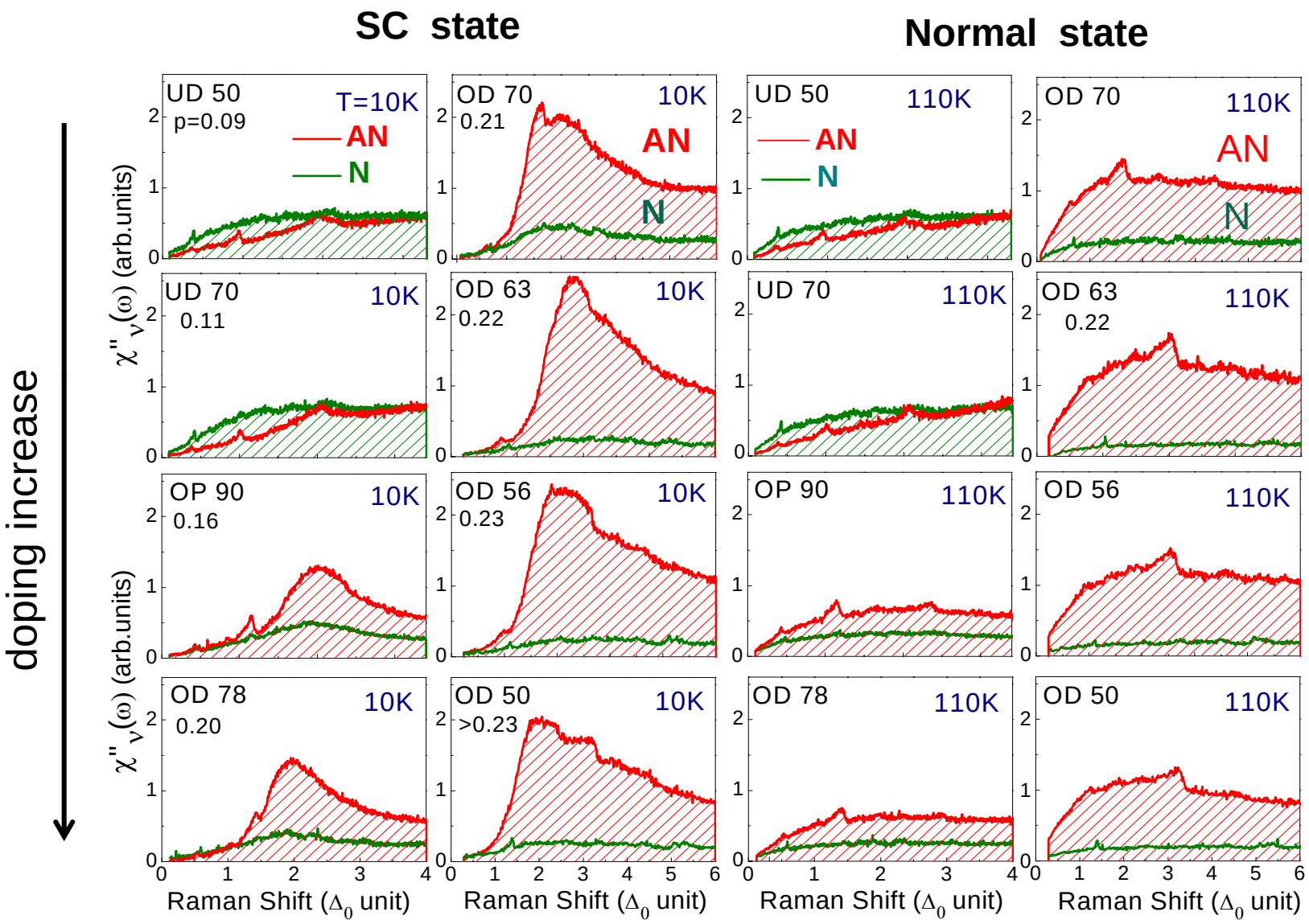


Selection of T* from Anti-Nodes and C-axis



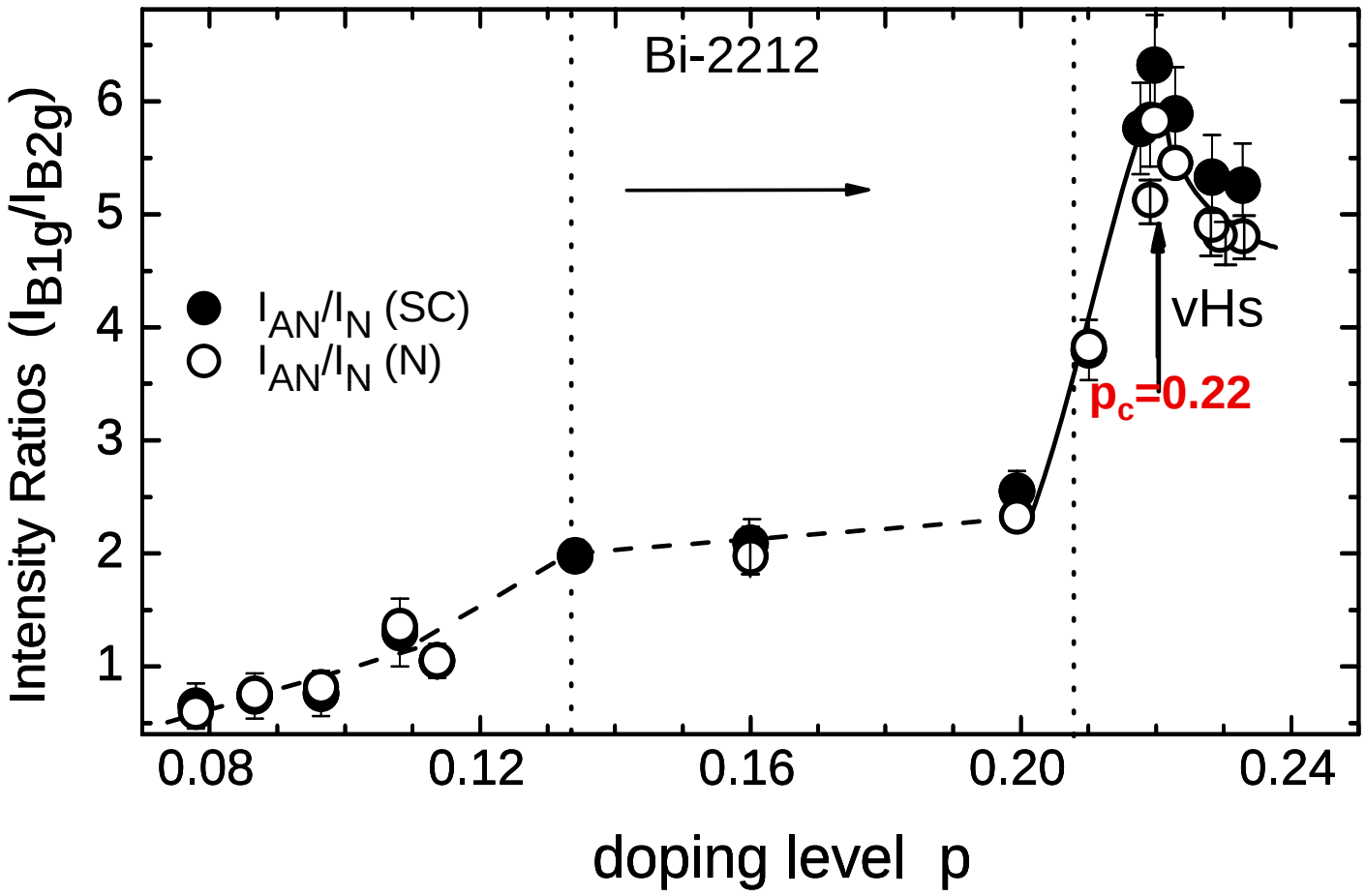
What is happening at p=0.22 ?

Doping evolution of the A-Nodal/Nodal Raman responses



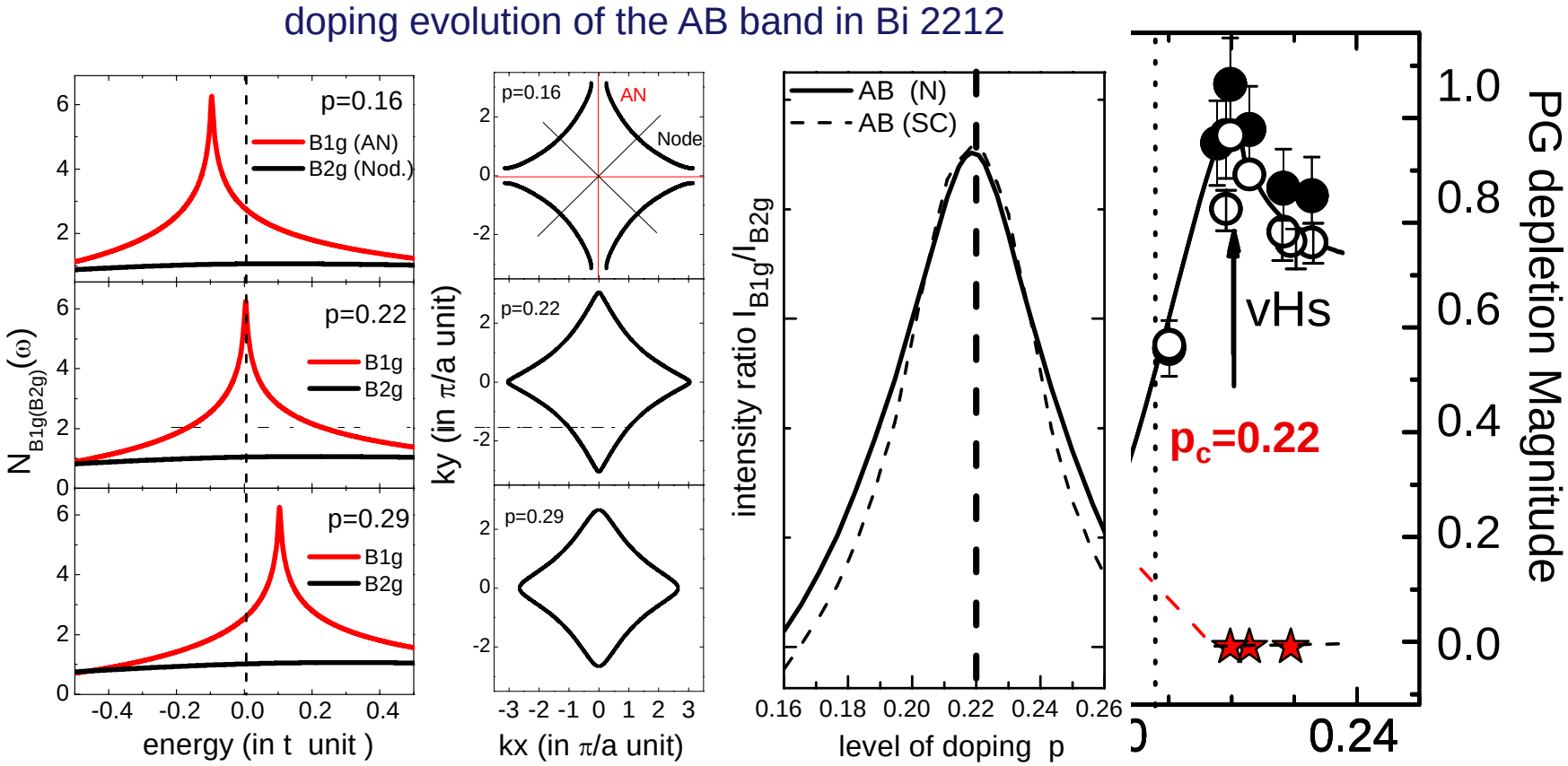
S. Benhabib, A.S. M.Civelli, I. Paul et al. arXiv:1403.7620, accepted in PRL 2015

Doping evolution of the A-N /N integrated intensity ratio



S. Benhabib et al. arXiv:1403.7620 accepted in PRL 2015

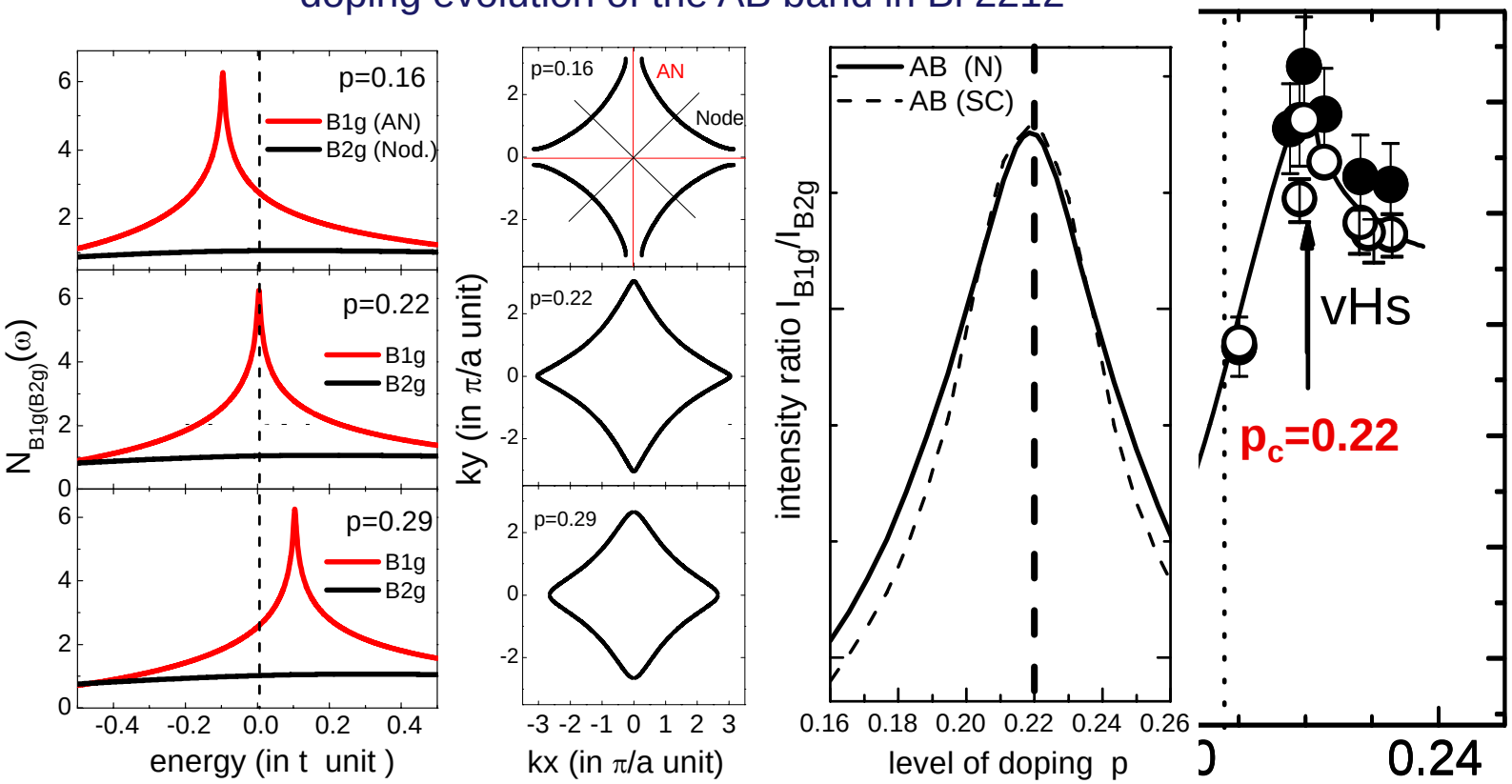
Doping evolution of the A-N /N integrated intensity ratio

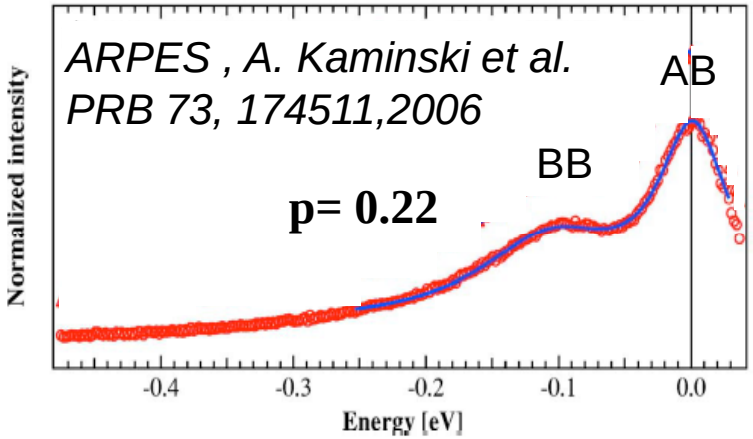


S. Benhabib et al. arXiv:1403.7620 accepted in PRL 2015

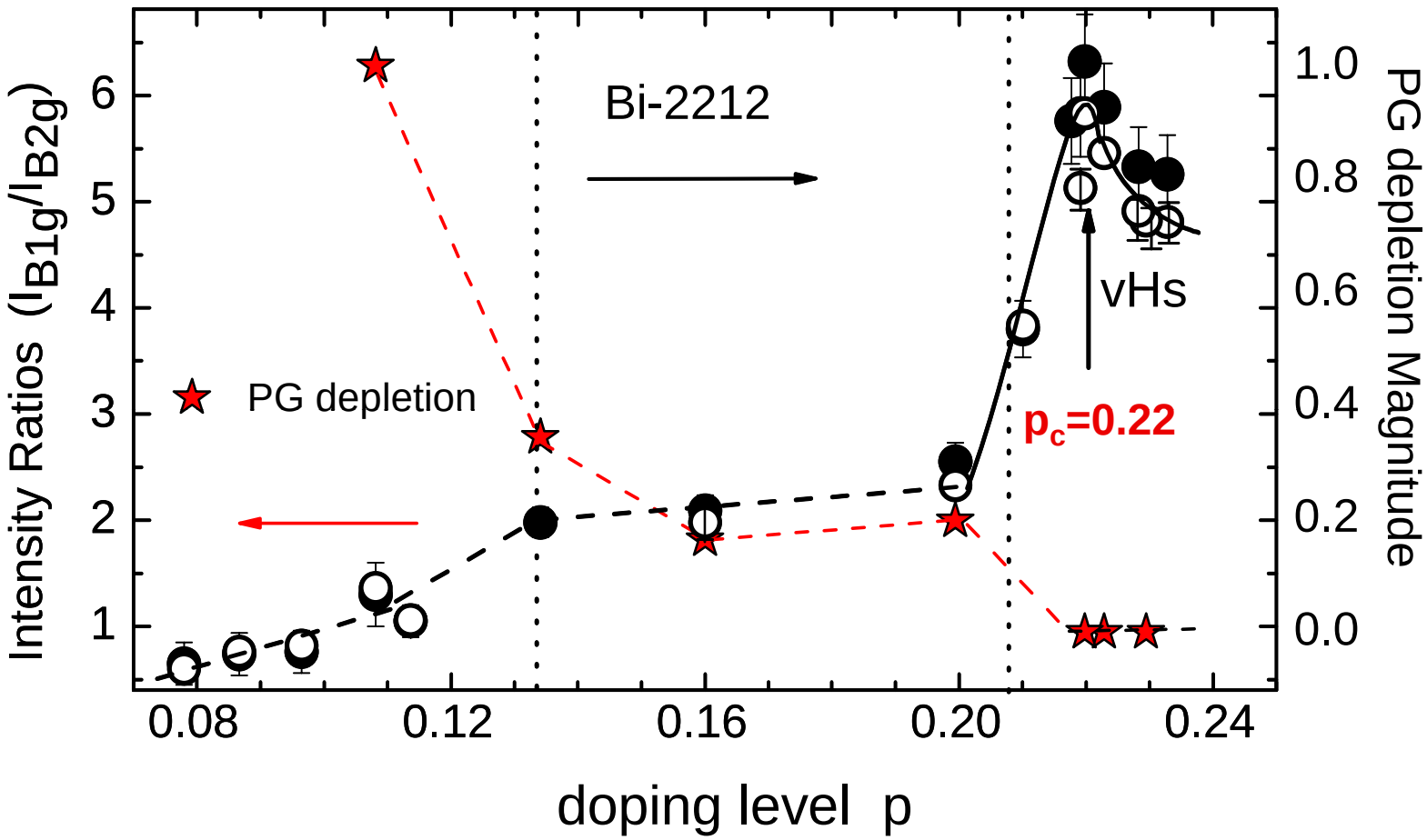
Doping evolution of the A-N /N integrated intensity ratio

doping evolution of the AB band in Bi 2212





Doping evolution of the A-N /N integrated intensity ratio



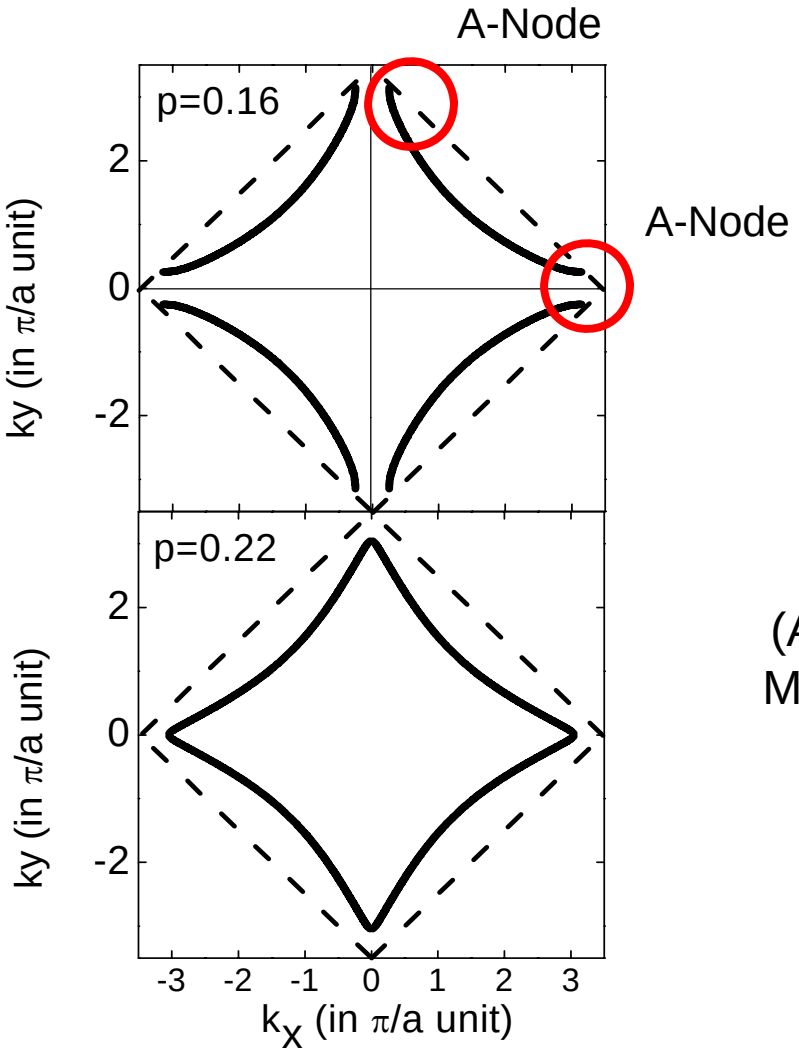
The normal state pseudo gap disapears at the Lifshitz transition

S. Benhabib et al. arXiv:1403.7620 accepted in PRL 2015

How can we explain this coincidence?

hole like
Fermi surface

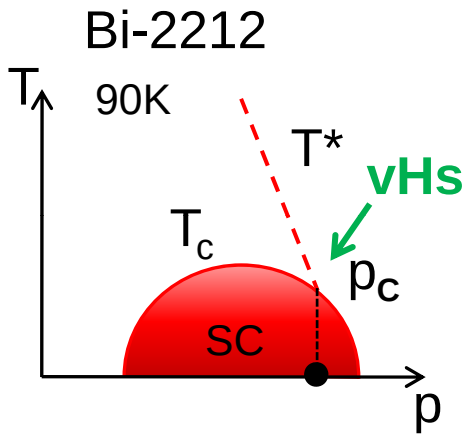
electron like
Fermi surface



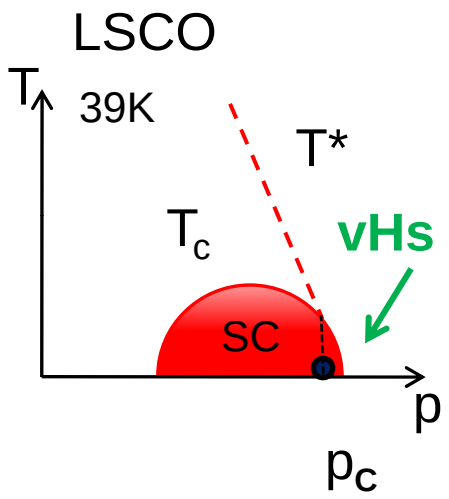
We remove
Quasi-particles
from hot Regions
associated to
strong scattering
(AF fluctuations, CDW
Mott-related Physics)

So, we loose
the PG

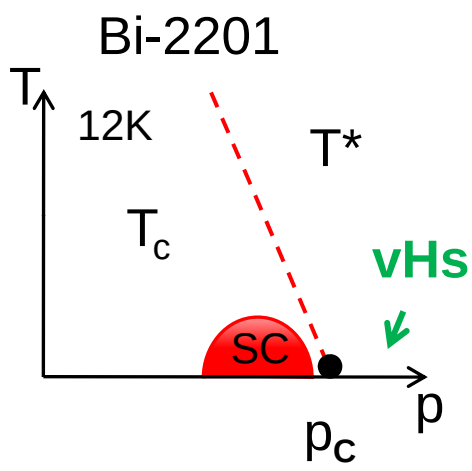
Does this Coincidence of the pseudogap closing with a Lifshitz transition is universal ?



Our study Raman
arXiv:1403.7620



A. Ino et al. ARPES
PRB 65, 094504



A. Piriou et al. Tunnelling
Nat. Comm. 1229

The location of the PG collapse appears to be material dependent

S. Benhabib, A.S, M.Civelli, I. Paul et al. arXiv:1403.7620

Conclusions

Probing the QSP at the Anti-Nodes in Bi-2212 by Electronic Raman Scattering allows us to detect the loss of spectral weight due to the PG seen in c-axis data (optics, resistivity,SIS) and reveal its collapse at p_c=0.22 ($\neq$ 0.19 detected from ab plane data)

This collapse occurs at a Lifshitz transition

This demonstrates that the mecanism that gives rise to the normal state pseudogap at the Anti-Nodes is sensitive to the FS topology

Thank you!