Superconductivity in electron doped cuprates

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Bell Labs, Lucent Technologies

WORKSHOP ON "EMERGENT MATERIALS AND HIGHLY CORRELATED ELECTRONS”

5th August 2002

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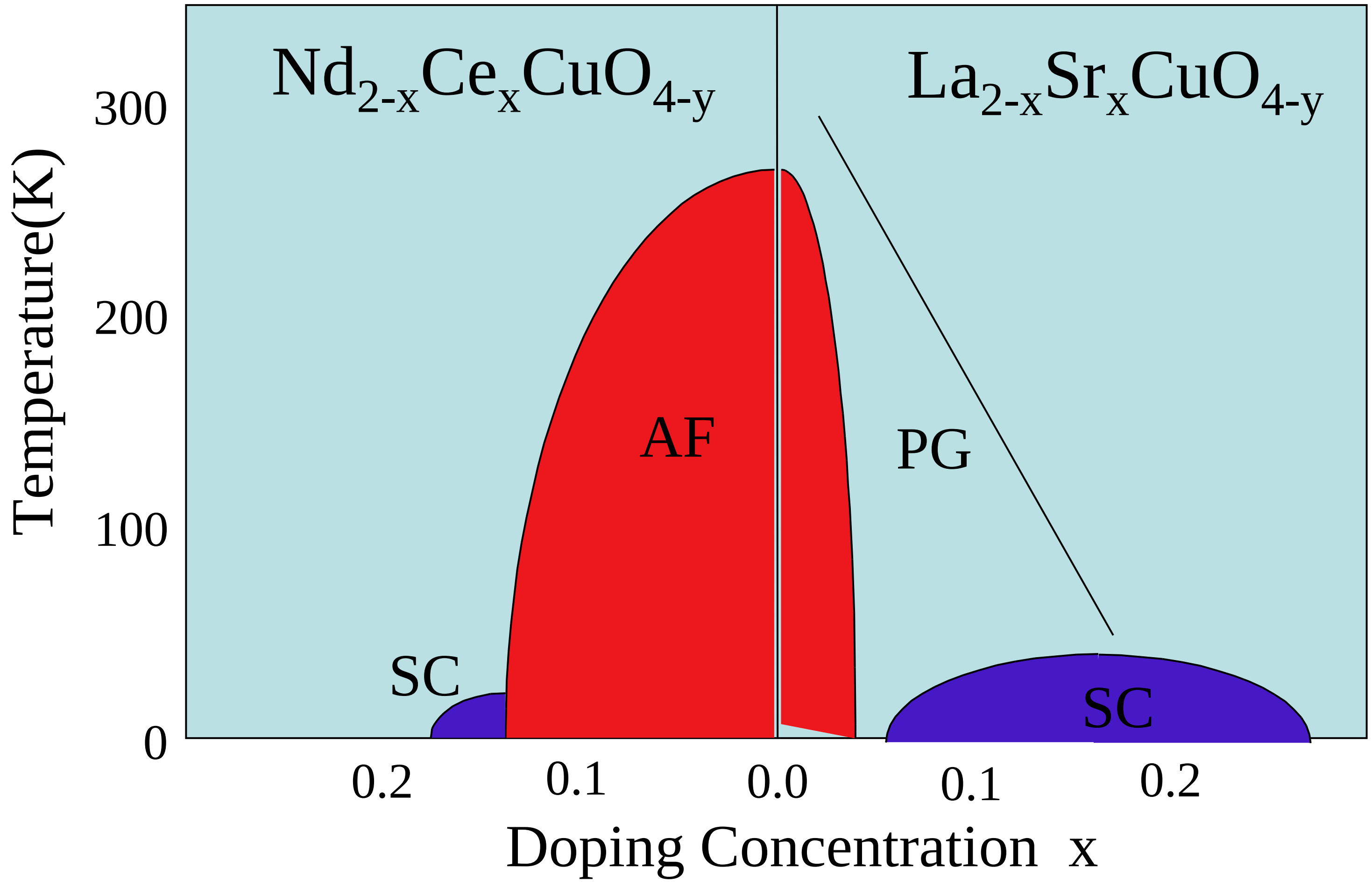
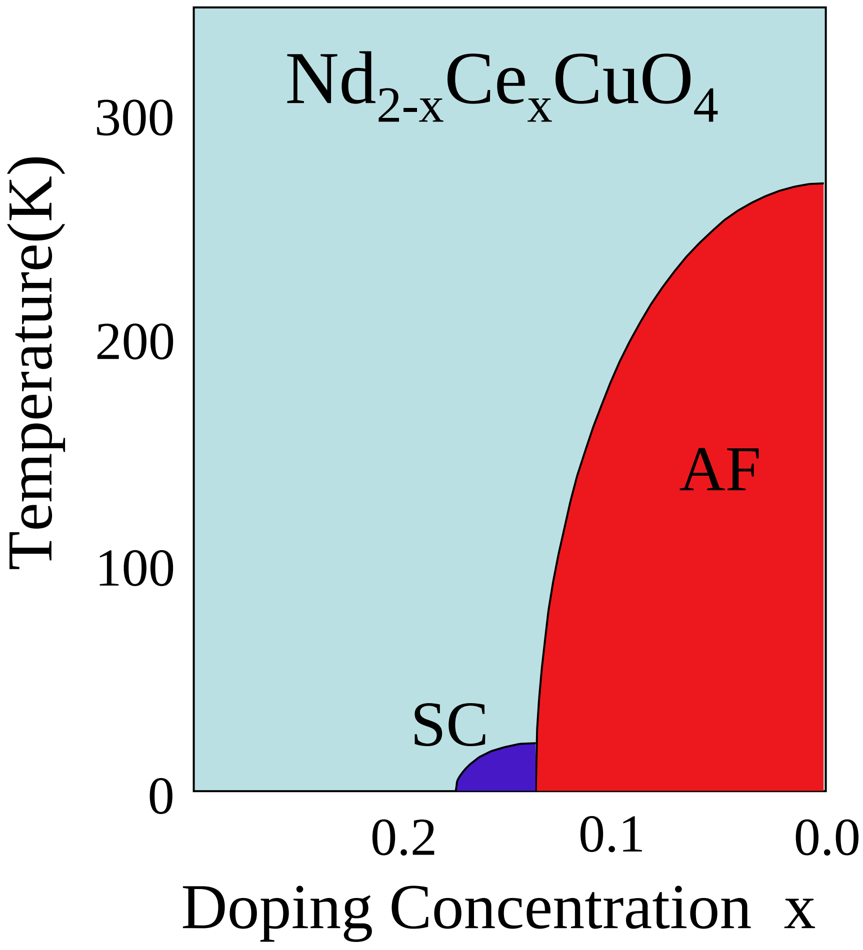
E.J. Singley & T. Takahashi

Phase diagram



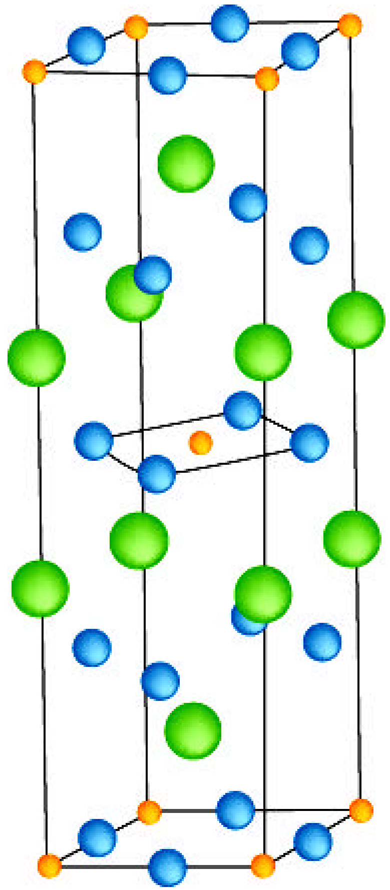
Outline

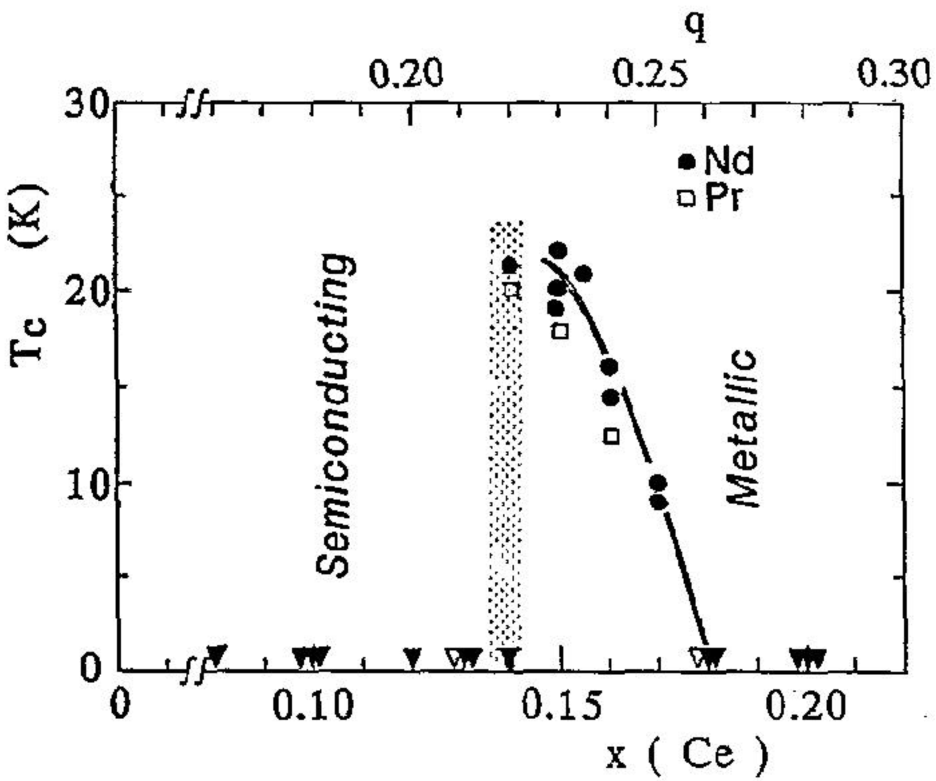
- SC Order Parameter
- The H-field effect
- PseudoGap



$Nd_{2-x}Ce_xCuO_4$

Y. Tokura *et. al. Nature* ***337*** *345(89);*
PRL ***62*** *1197 (1989).*





Introduction

ARPES

Nd_2CuO_4

N.P. Armitage *et al.*
*PRL **88** 257001 (2002).*

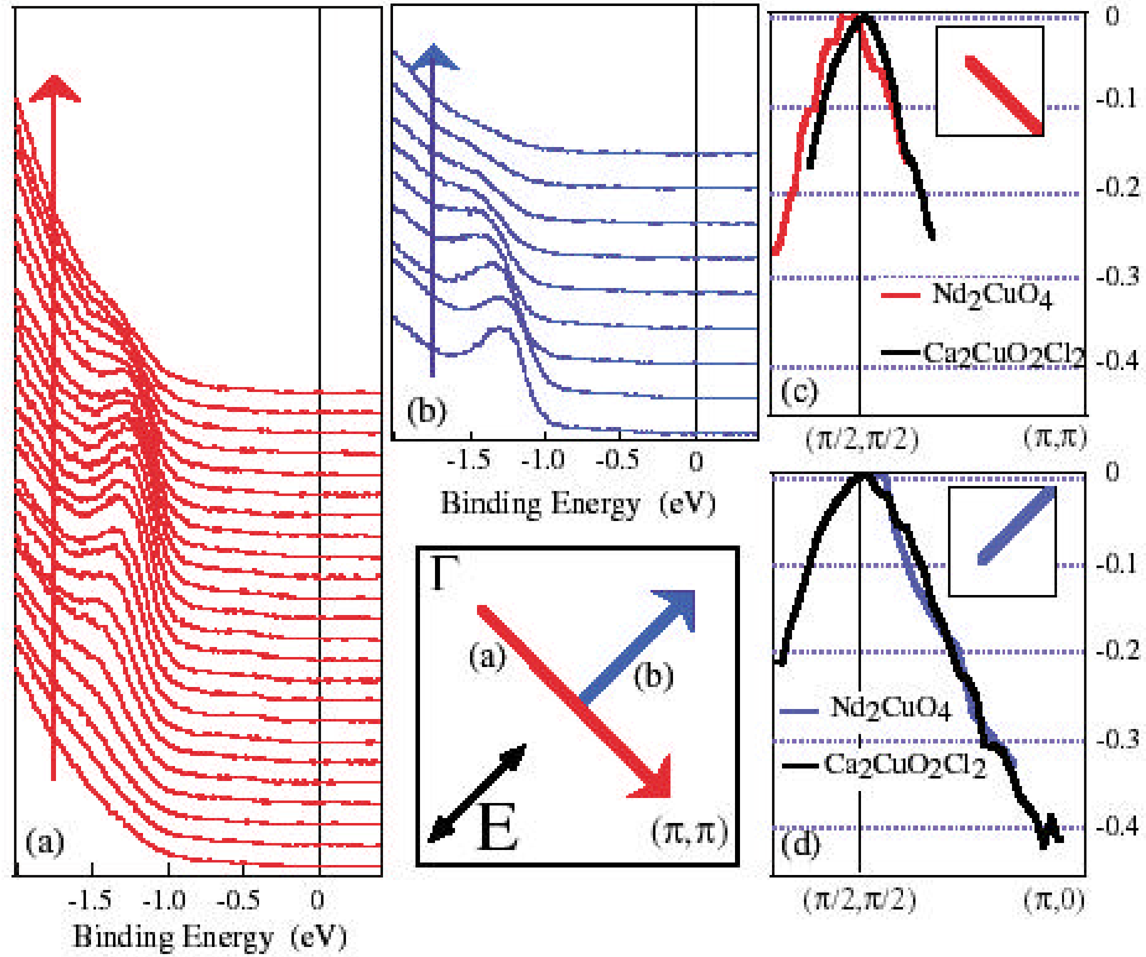
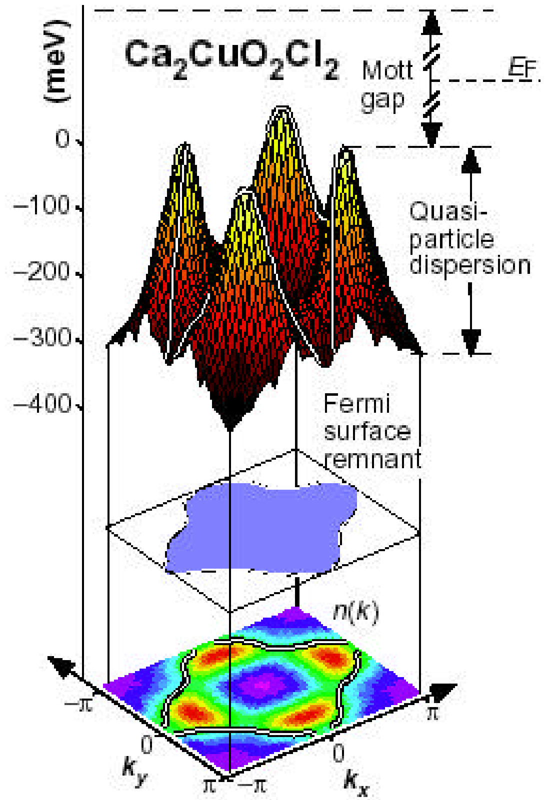
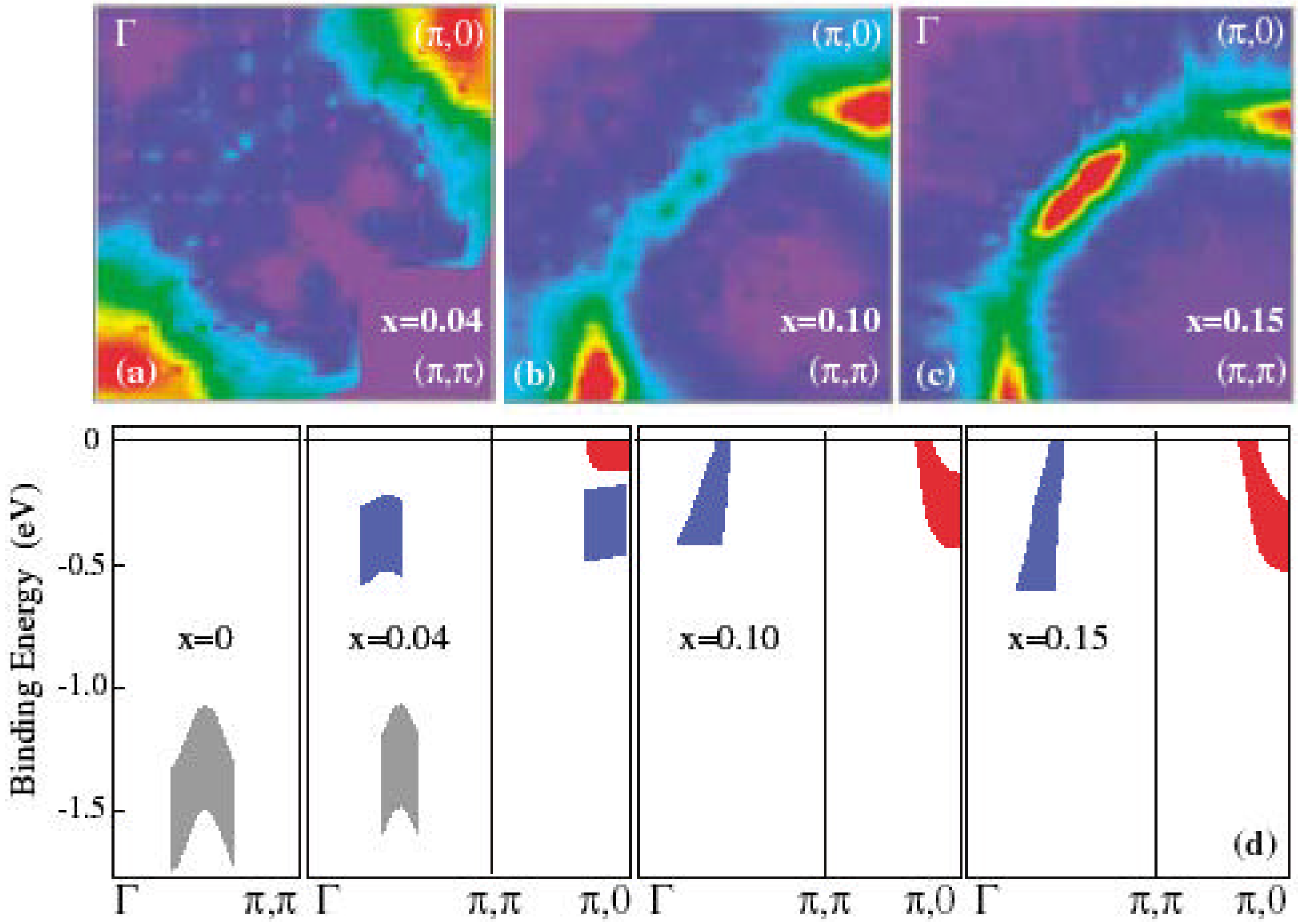


FIG. 1 (color). (a) Dispersion of the charge transfer band in Nd_2CuO_4 along zone diagonal from 25% to 75% of Γ to (π, π) distance. (b) Dispersion of the CTB from $(\pi/2, \pi/2)$ to 50% of the $(\pi/2, \pi/2)$ to $(\pi, 0)$ distance (c) and (d). Comparison of the CTB dispersion in NCO (red and blue) and CCOC (black).



ARPES $Nd_{2-x}Ce_xCuO_4$

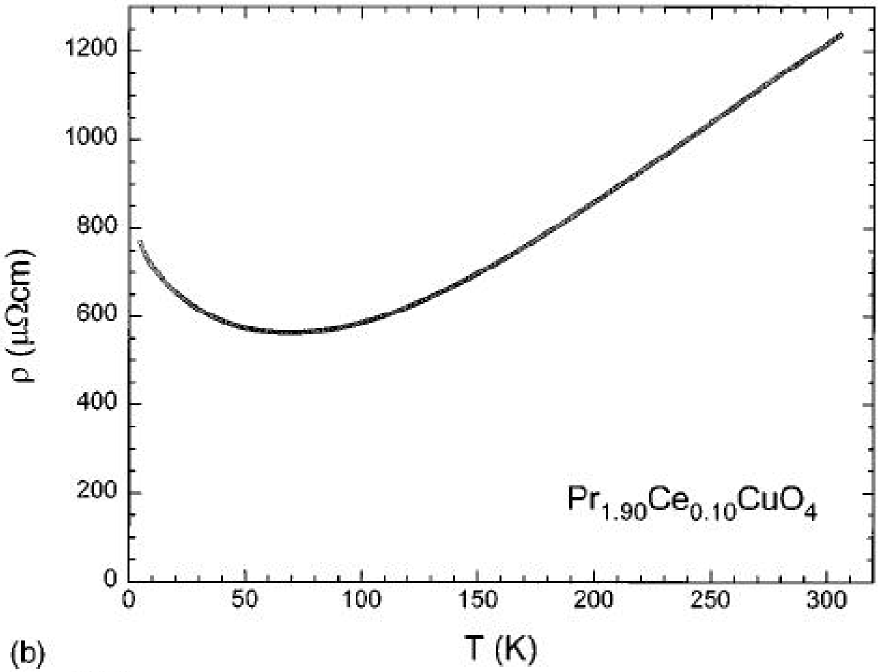
N.P. Armitage *et al.*
*PRL **88** 257001 (2002).*



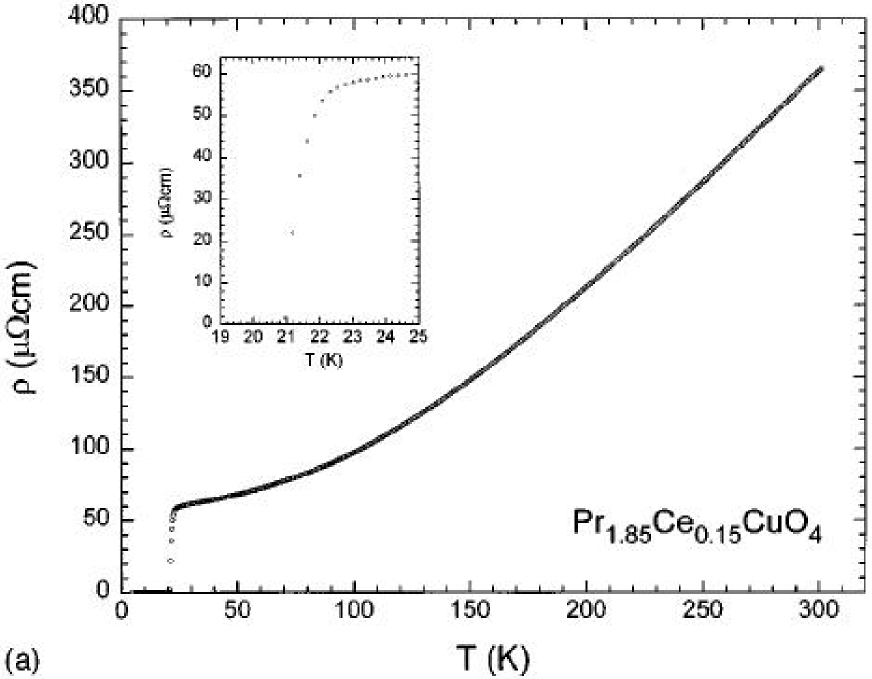
Resistivity

J.L. Peng *et al*.
*PRB **55** 6145 (1997).*

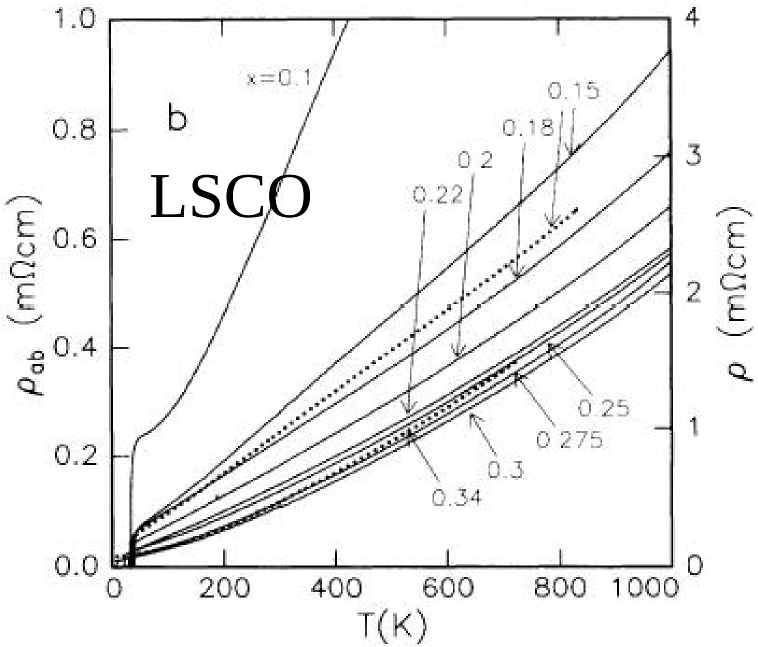
H. Takagi *et al*.
*PRL **69** 2975 (1992).*



(b)

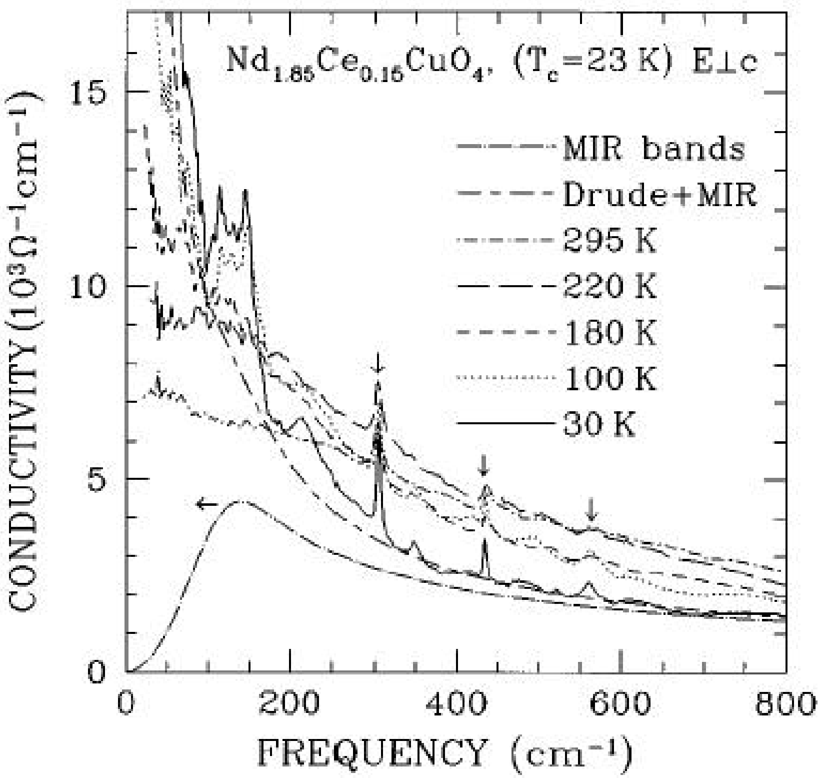


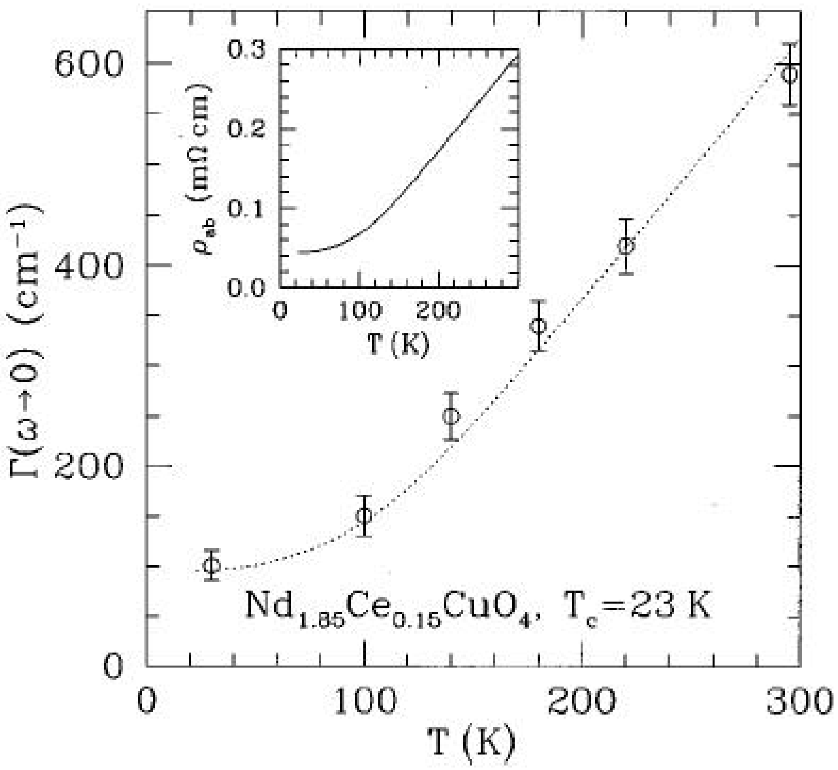
(a)



Optical conductivity

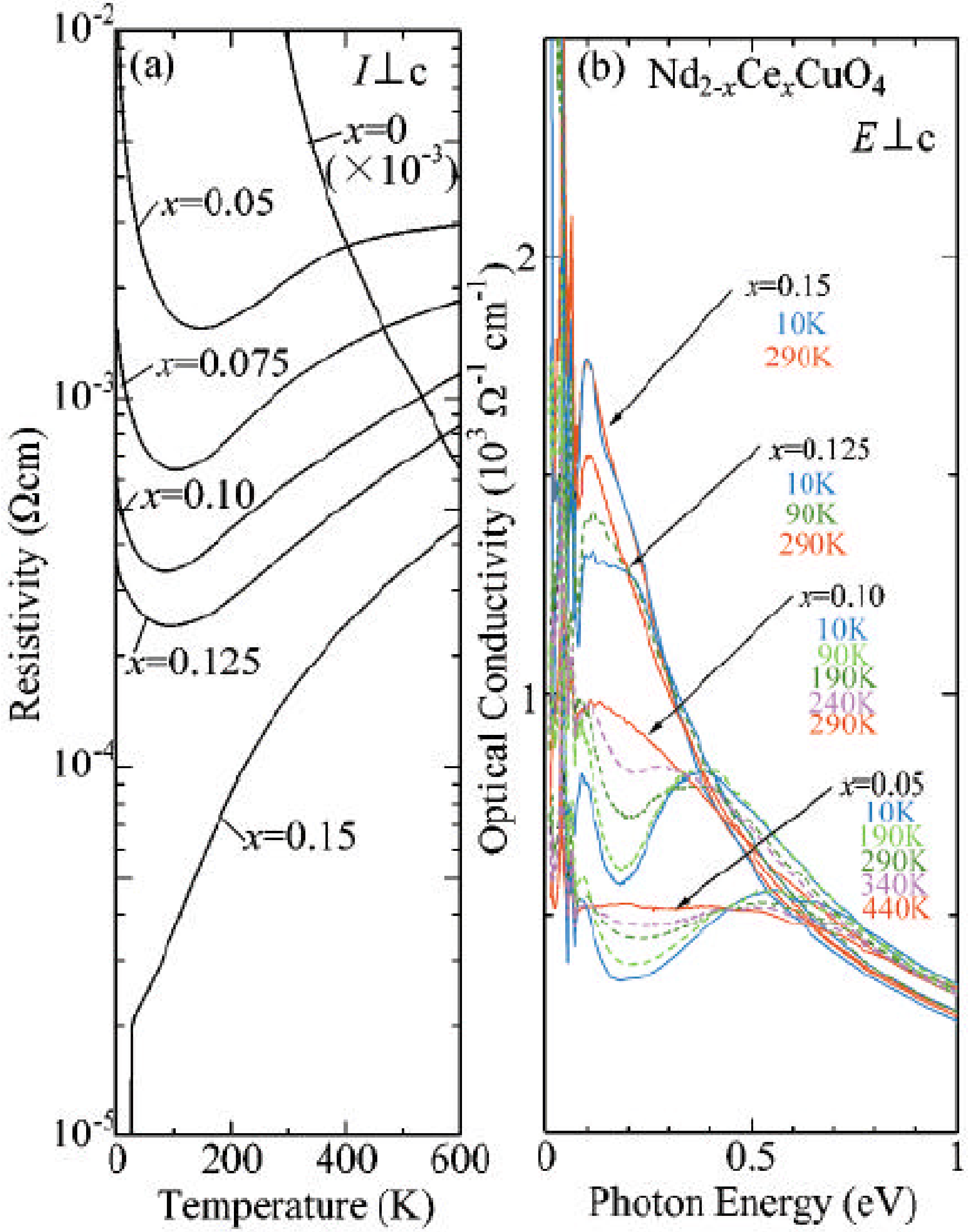
C.C. Homes *et al*.
PRB ***56*** *5525 (1997).*

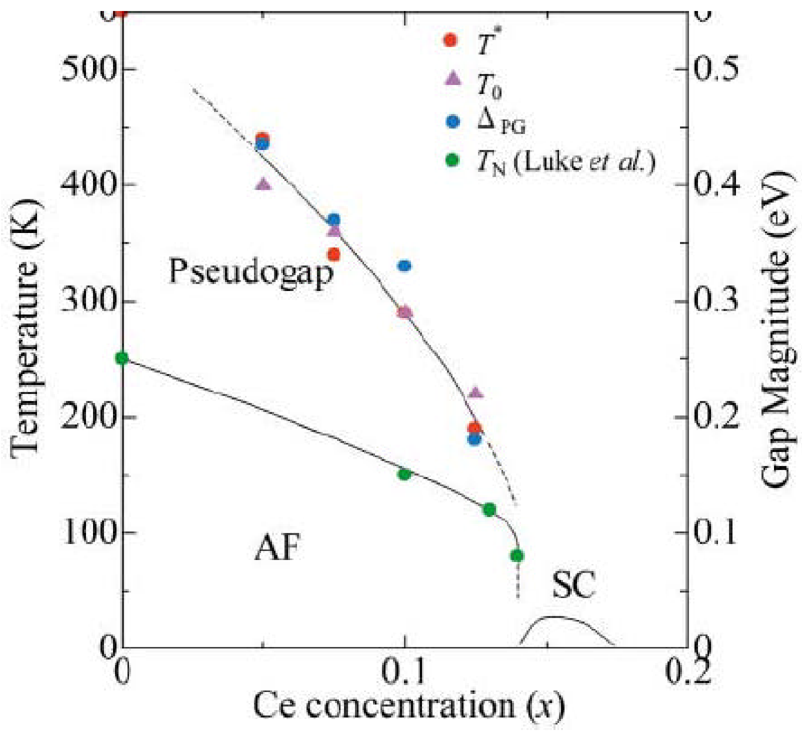




Conductivity

Y. Onose *et al.*
*PRL **87** 217001 (2001).*





Violation of Wiedemann-Franz law

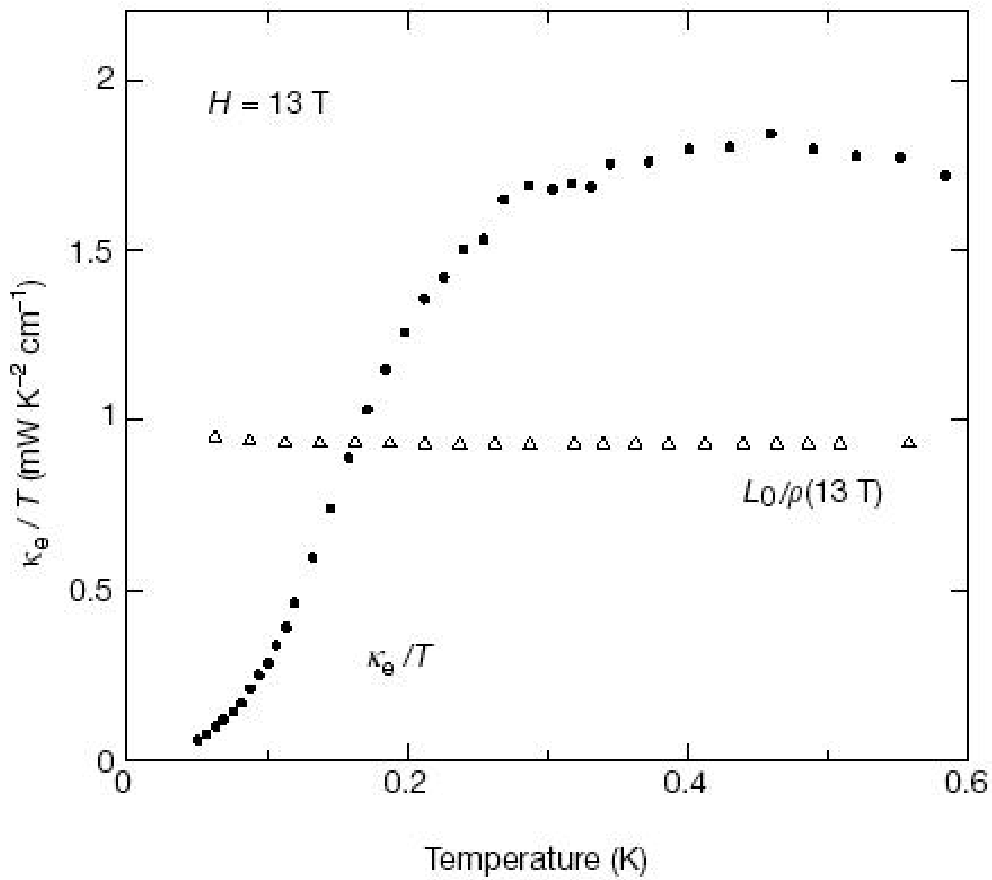


Figure 3 Comparison of charge conductivity $\sigma(T) = 1/\rho(T)$, plotted as $L_0/\rho(T)$ (triangles), and electronic heat conductivity κ_e, plotted as κ_e/T (circles), as a function of temperature in the normal state at $H = 13$ T. The electronic contribution to the heat conduction is the difference between the measured κ(13 T) and the phonon contribution κ_{ph}(13 T), estimated in the text. In a Fermi liquid, the curve of κ_e/T would lie precisely on the data for L_0/ρ_0. Below $T = 0.15$ K, $\kappa_e \approx T^{3.6}$.

R.W. Hill *et al.*
*NATURE **414** 711 (2001).*

$$\frac{\kappa}{\sigma T} = \frac{\pi^2}{3}\left(\frac{k_B}{e}\right)^2 =$$

$$2.45 \times 10^{-8}\ W\Omega K^{-2}$$

Is NCCO a high-temperature SC?

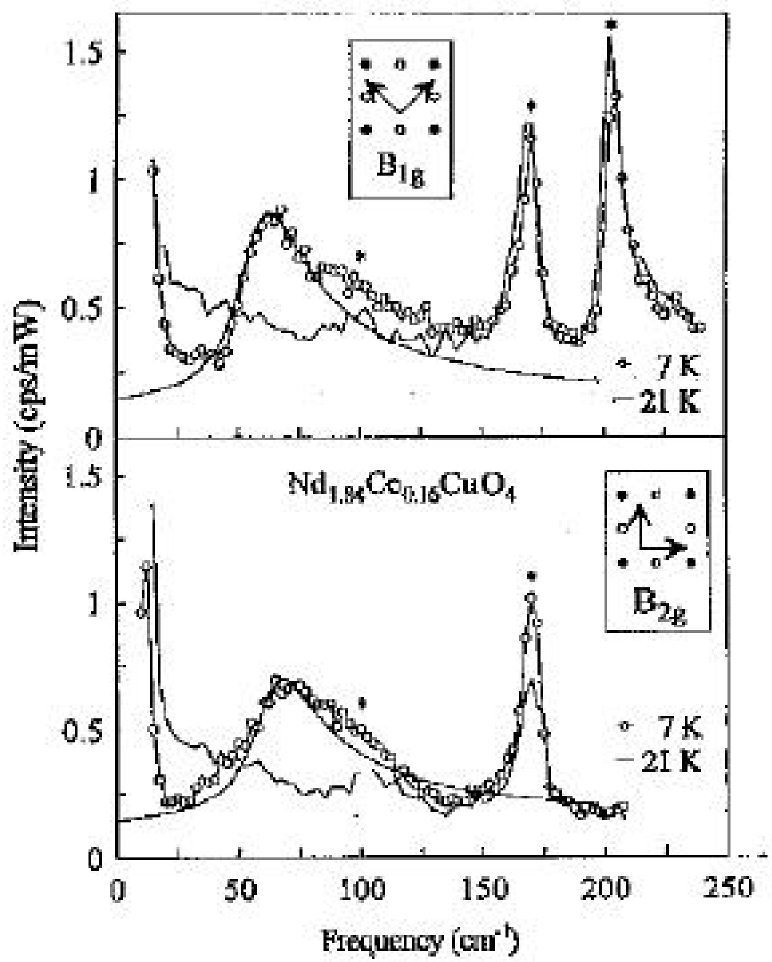
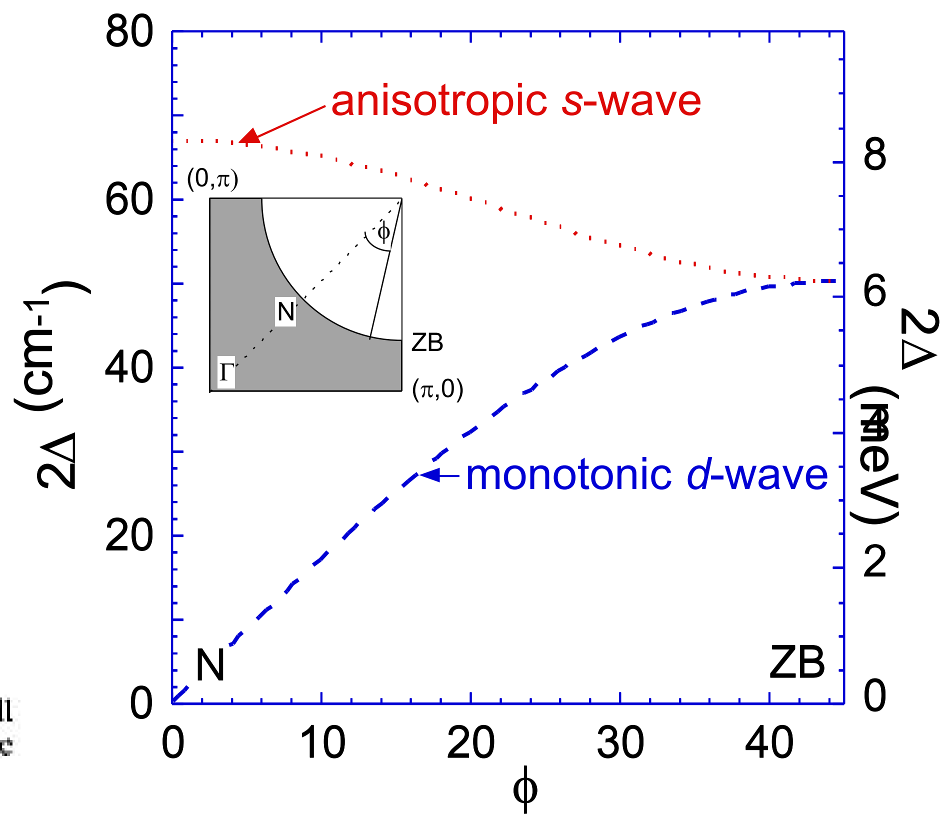


FIG. 2. Raman spectra of $Nd_{1.84}Ce_{0.16}CuO_4$ just above and well below T_c. The smooth lines are fits using a slightly anisotropic *s*-wave gap. Again, the CF excitations are asterisked.

B. Stadlober *et. al.*
*PRL **74** 4911 (1995).*



Scanning SQUID: *d*-wave for NCCO

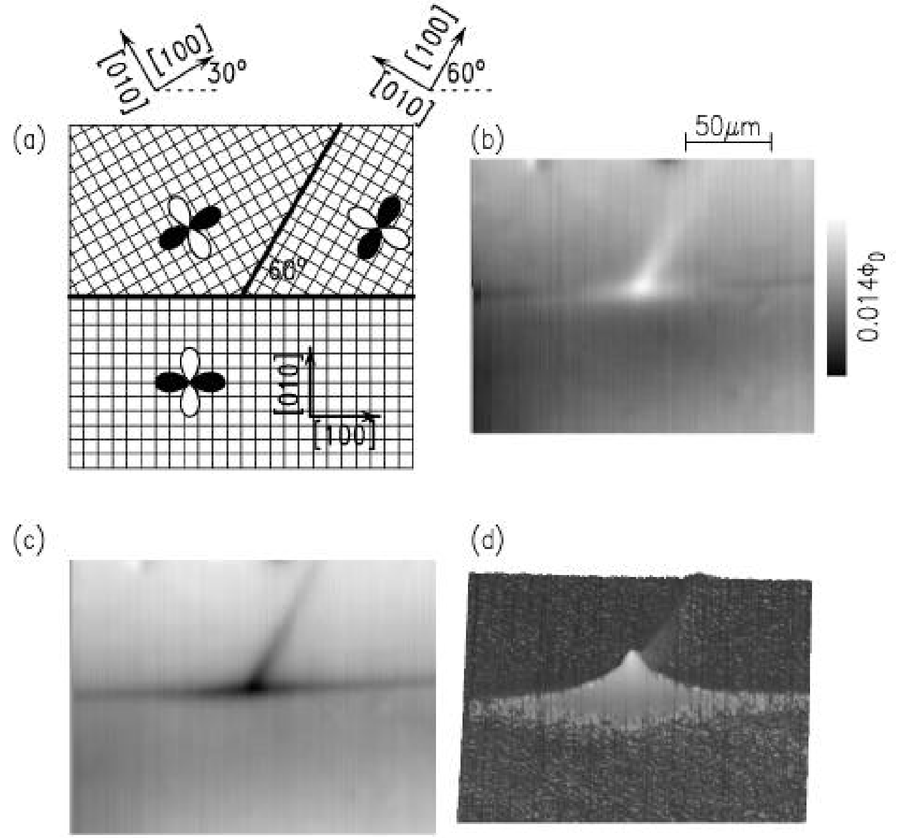


FIG. 1. (a) Geometry of the frustrated tricrystal geometry, with polar plots of the pairing orbital wave functions (white and black indicating opposite signs) for a $d_{x^2-y^2}$ superconductor. (b), (c) SSM images of a NCCO thin film epitaxially grown on the STO substrate (a), cooled in nominal zero field and imaged at 4.2 K with a square pickup loop 7.5 μm in diameter, with fields of $+0.2$ mG (b) and -0.2 mG (c) applied. (d) A three-dimensional rendering of the image $[(b) - (c)]/2$.

C.C. Tsuei & J.R. Kirtley
*PRL **85** 182 (2000).*

Zero-bias conduction peak

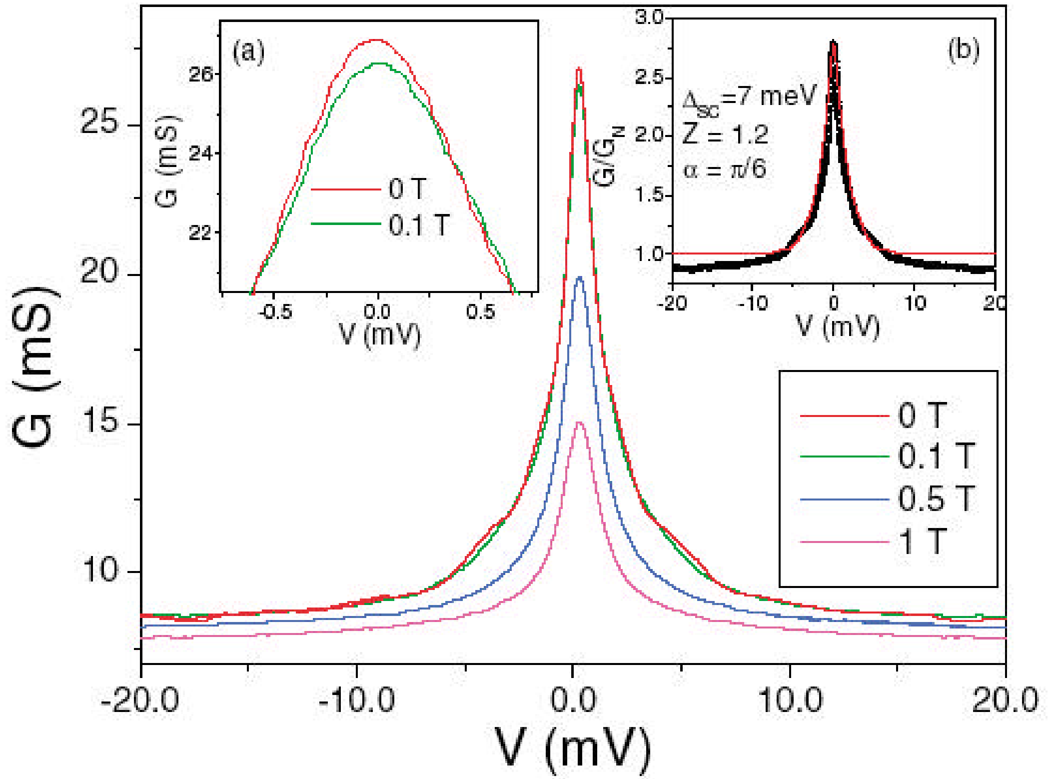
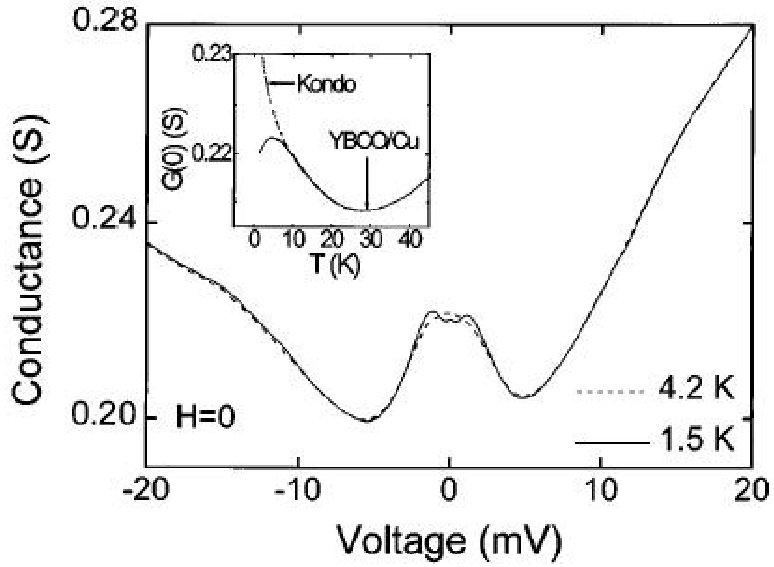


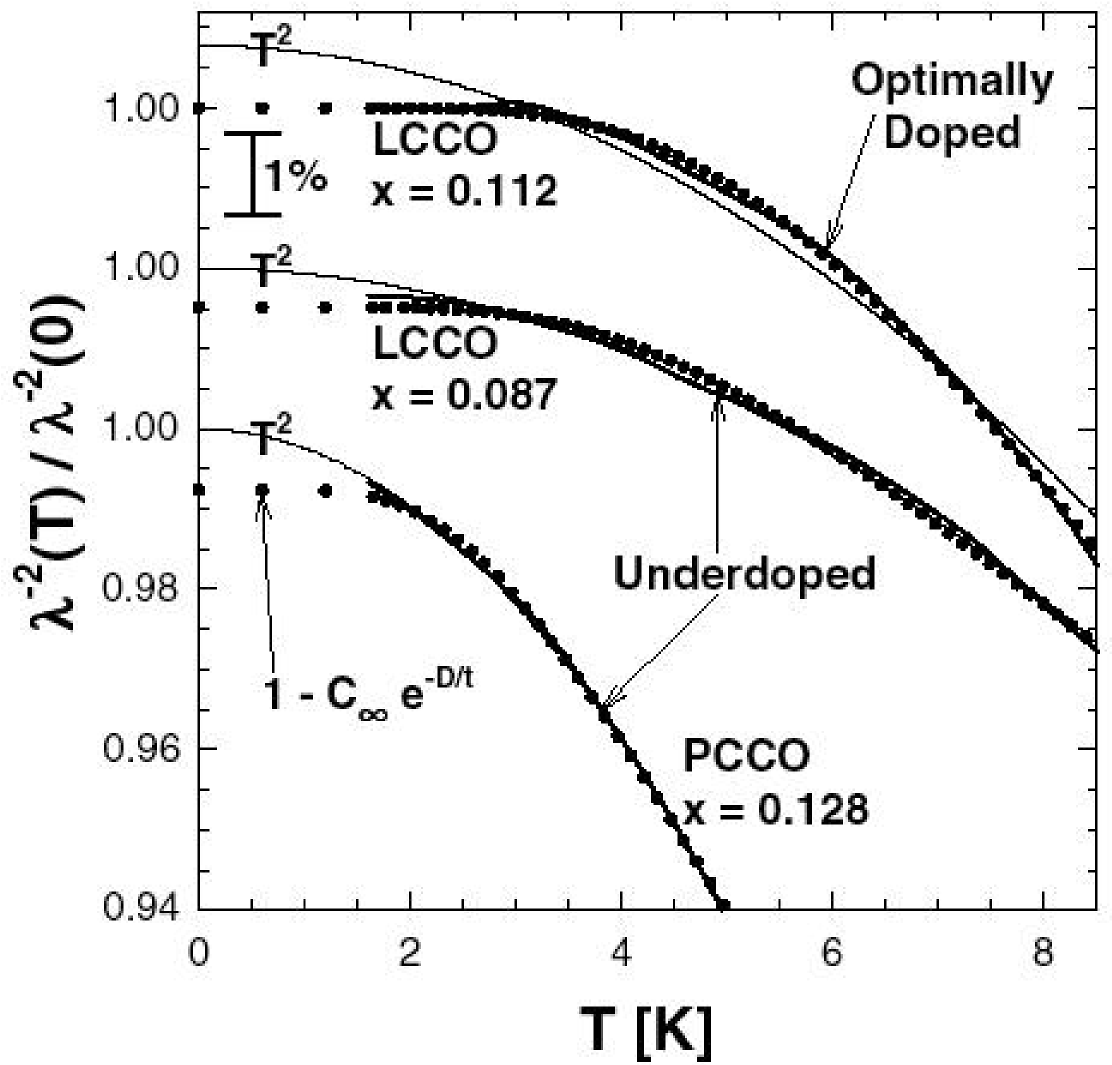
FIG. 2 (color). G-V characteristics for a low Z, a-b plane point contact junction between a thin film of PCCO ($x = 0.13$) and gold at $T = 1.6$ K. The G_0/G_N ratio is ~ 3.0. For a magnetic field of 1000 G there is a very small suppression of the peak [inset (a)]. Larger fields reduce the width and the height of the peak. A comparison with a calculated curve for a d-wave pairing symmetry (red line) is shown in inset (b).

A. Biswas *et al.*
PRL ***88*** *207004 (2002).*

M. Covington *et al.*
PRL ***79*** *277 (1997).*



d- to s-wave transition: $\lambda^{-2}(T)$

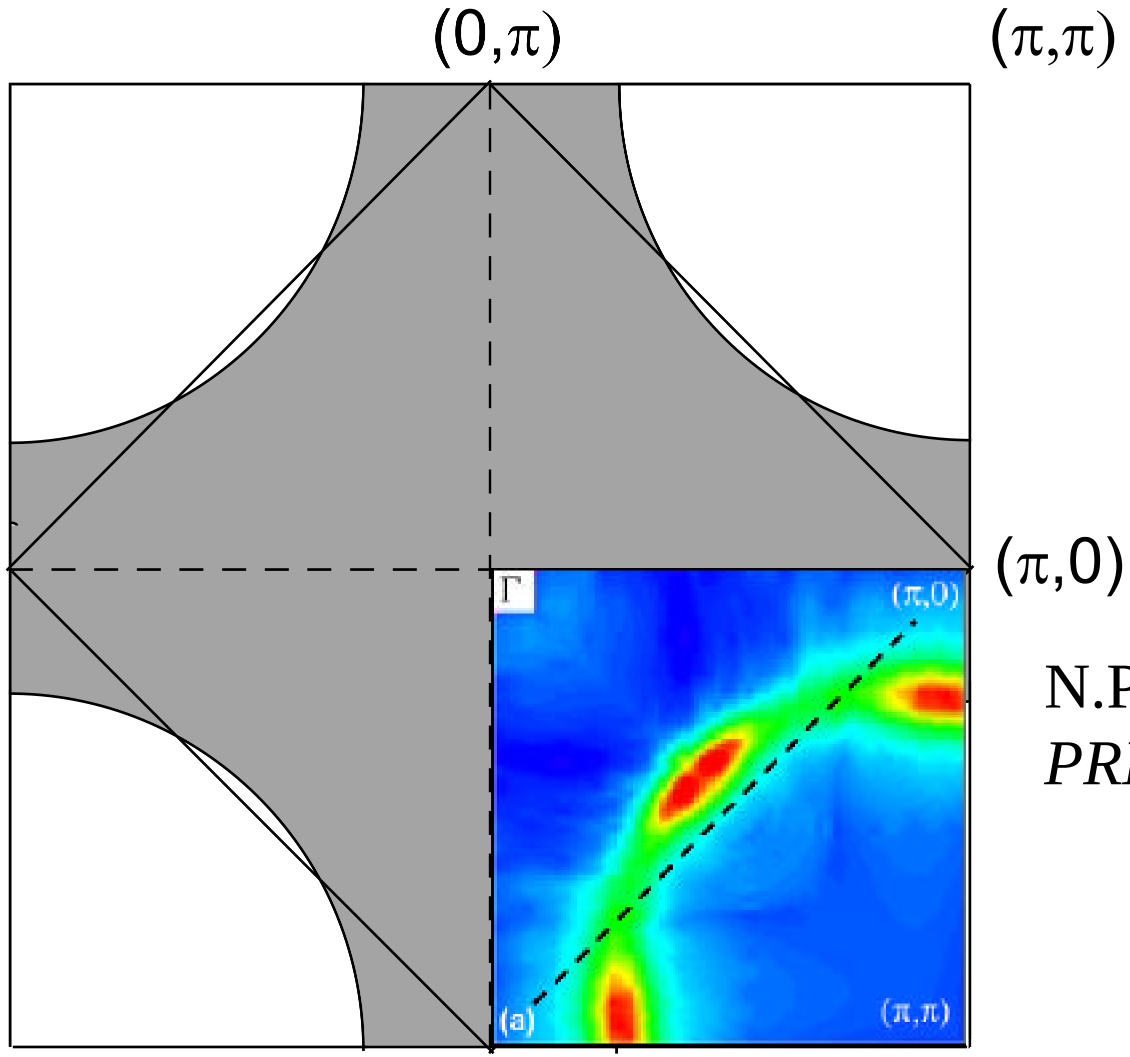


J.A. Skinta *et al*.
PRL ***88*** *207003 (2002);*
PRL ***88*** *207005 (2002).*

$\lambda^{-2}(T)$: T^2 -> $Exp(-\Delta/T)$

The anisotropy of the SC gap

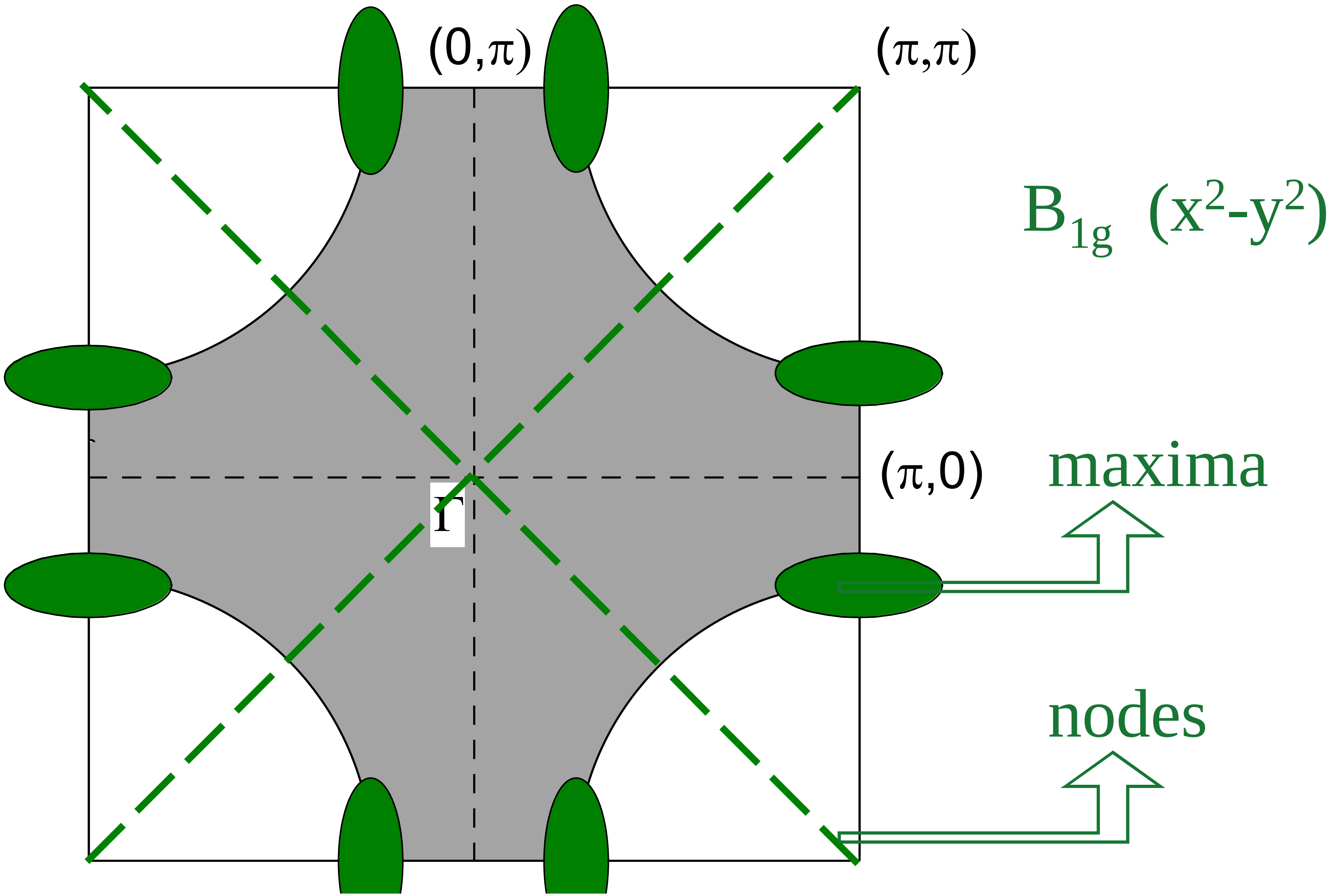
Fermi surface



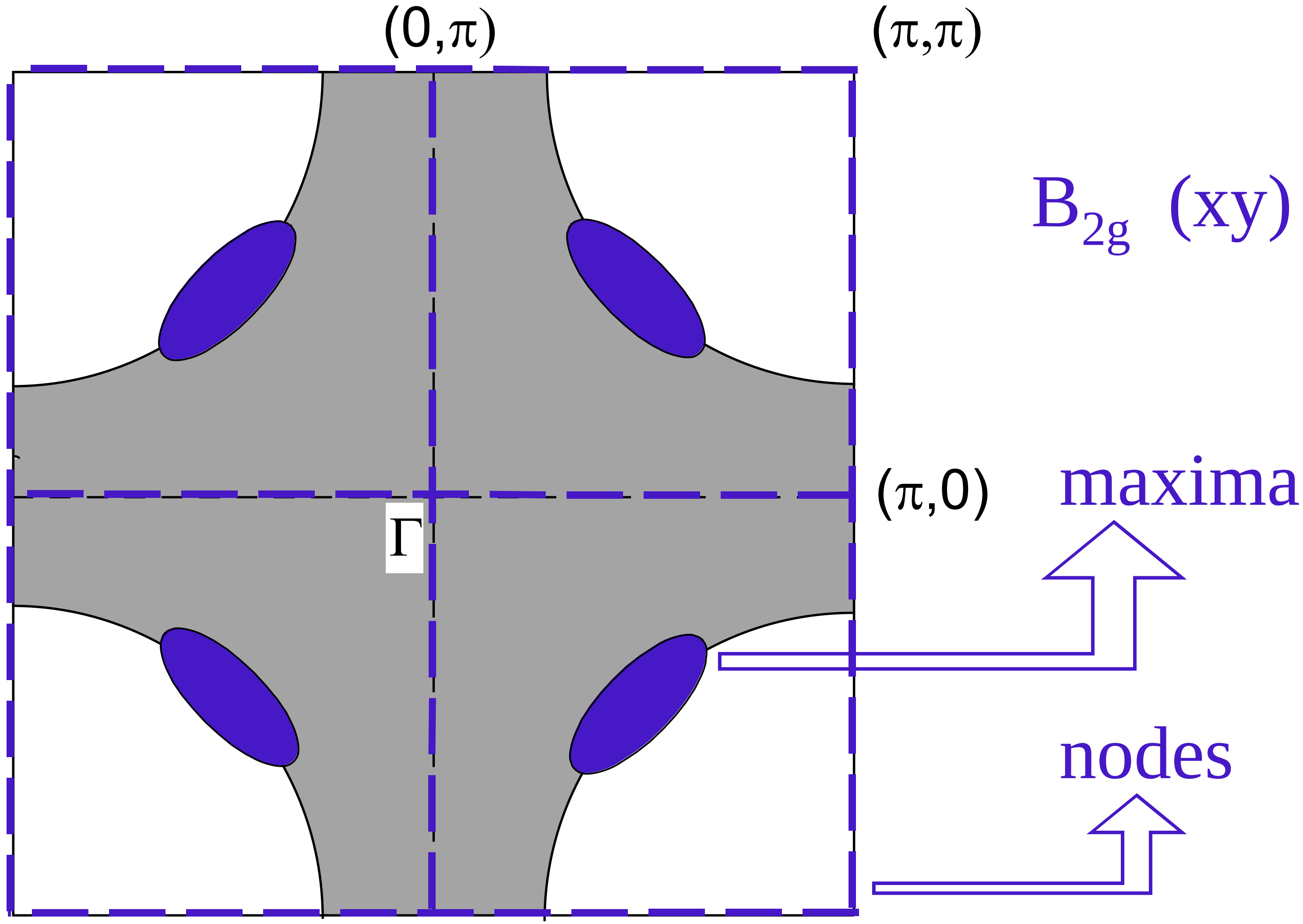
N.P. Armitage *et. al.*
*PRL **86** 1126 (2001).*

A short Raman tutorial

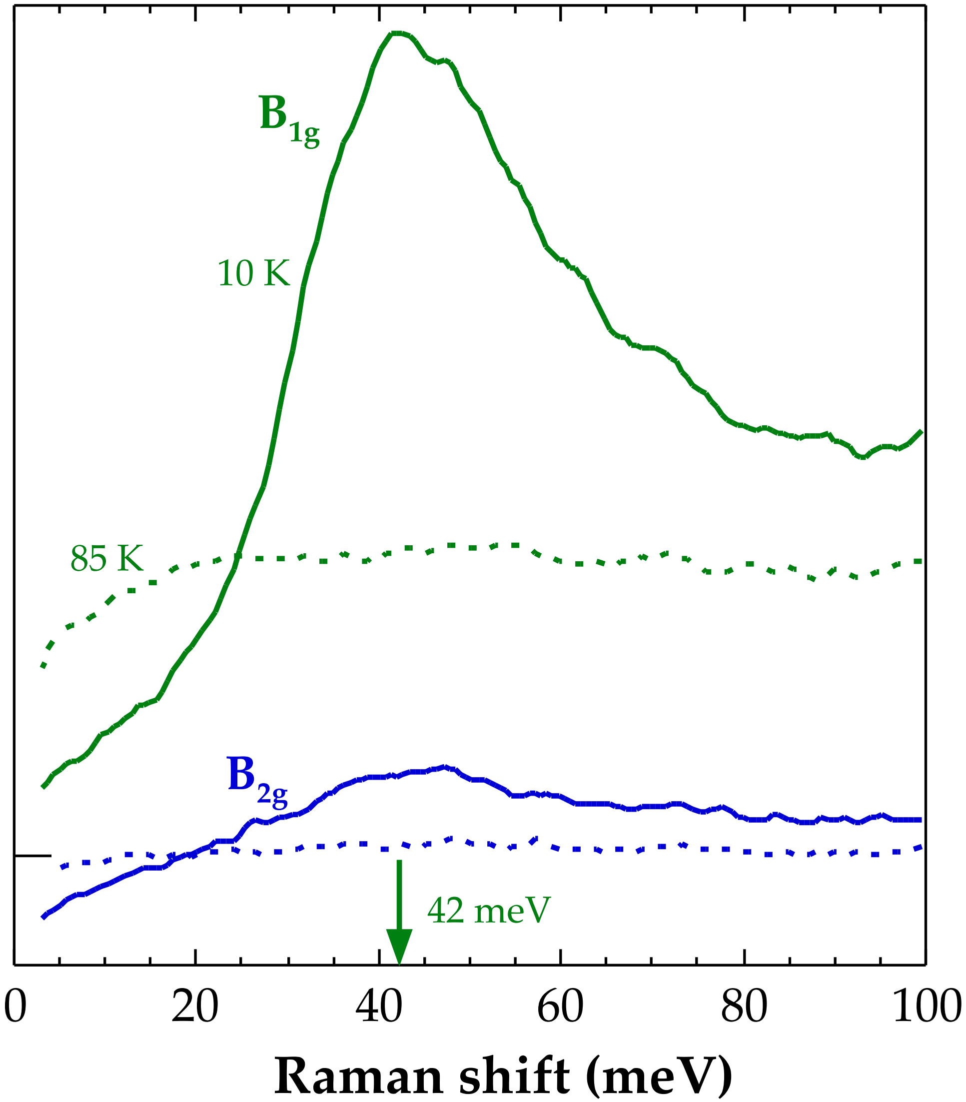
Raman form-factor

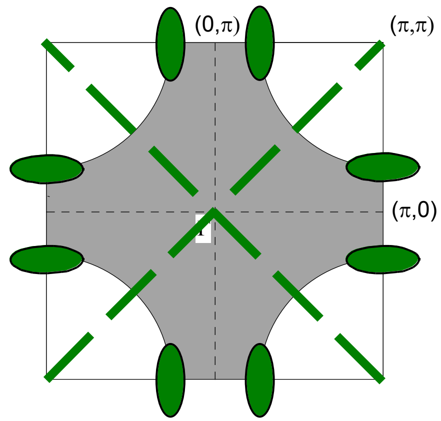


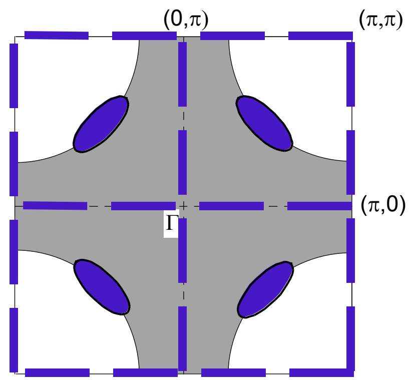
Raman form-factor



2Δ excitation in BSCCO (T_c=78 K)



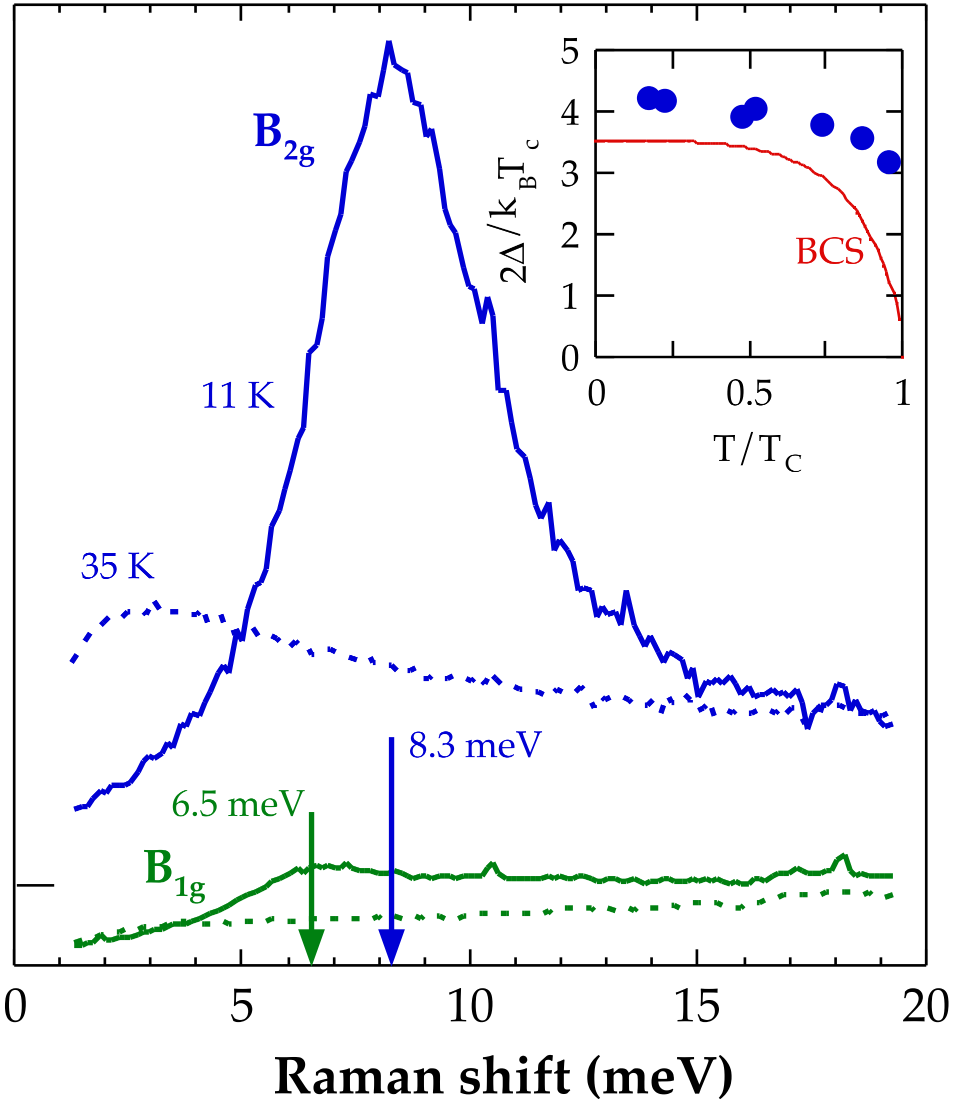


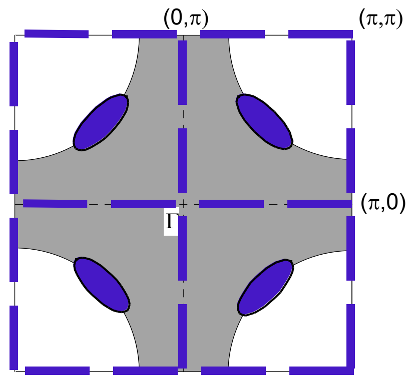


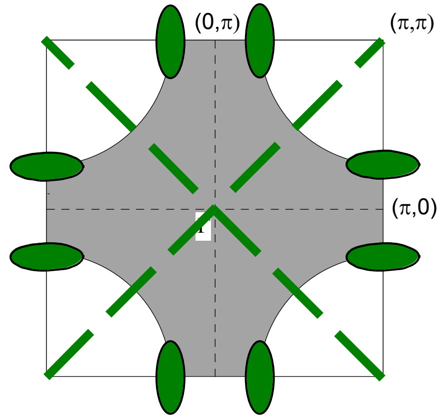
Nonmonotonic *d*-wave OP

GB et. al.
PRL ***88*** *107002 (2002).*

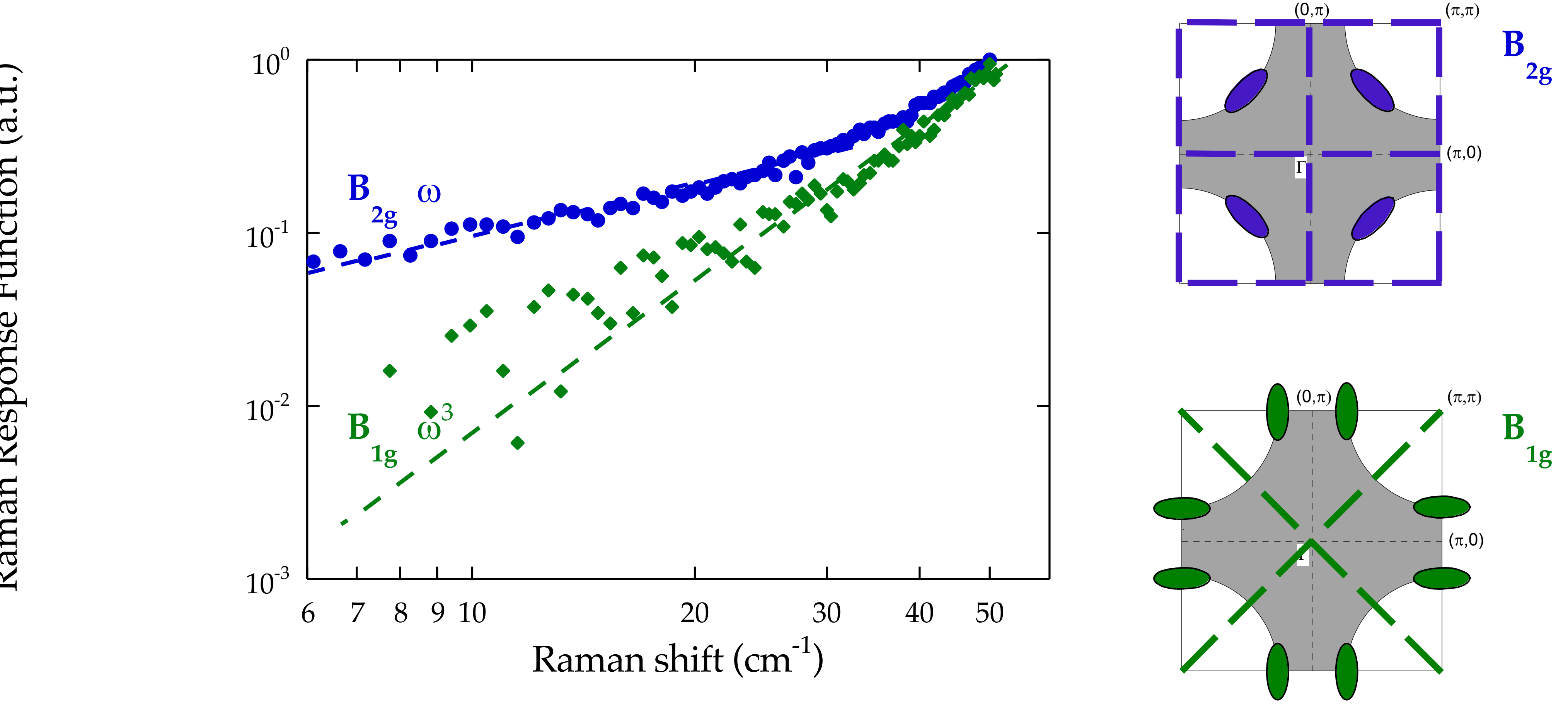
2Δ excitation in NCCO (T_c=22 K)







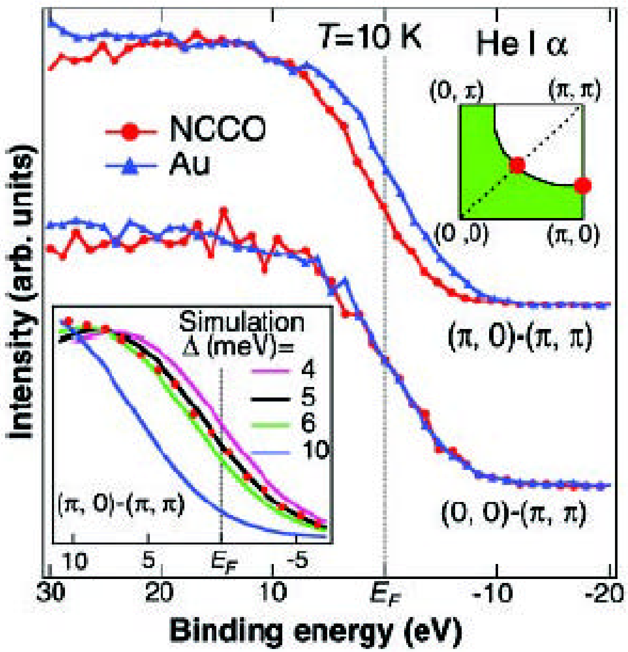
Low-frequency power laws: *d*-wave

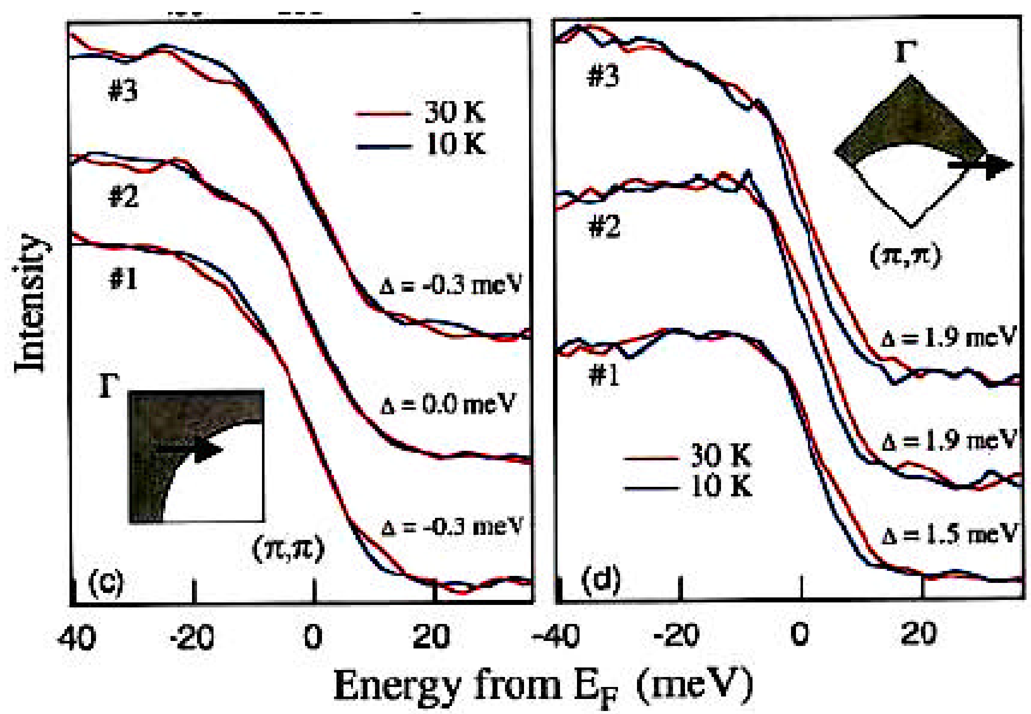


Gap Anisotropy by ARPES

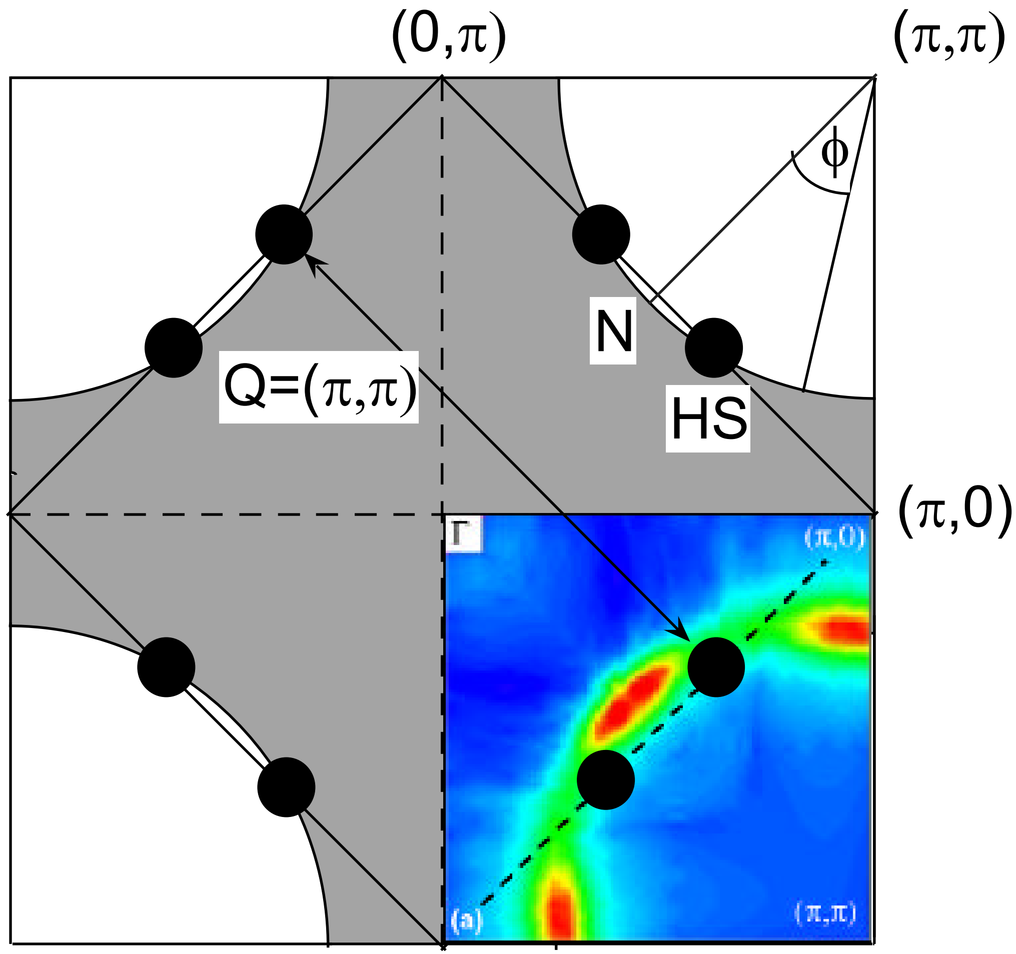
T. Sato *et. al.*
Science ***291*** *1517 (2001).*

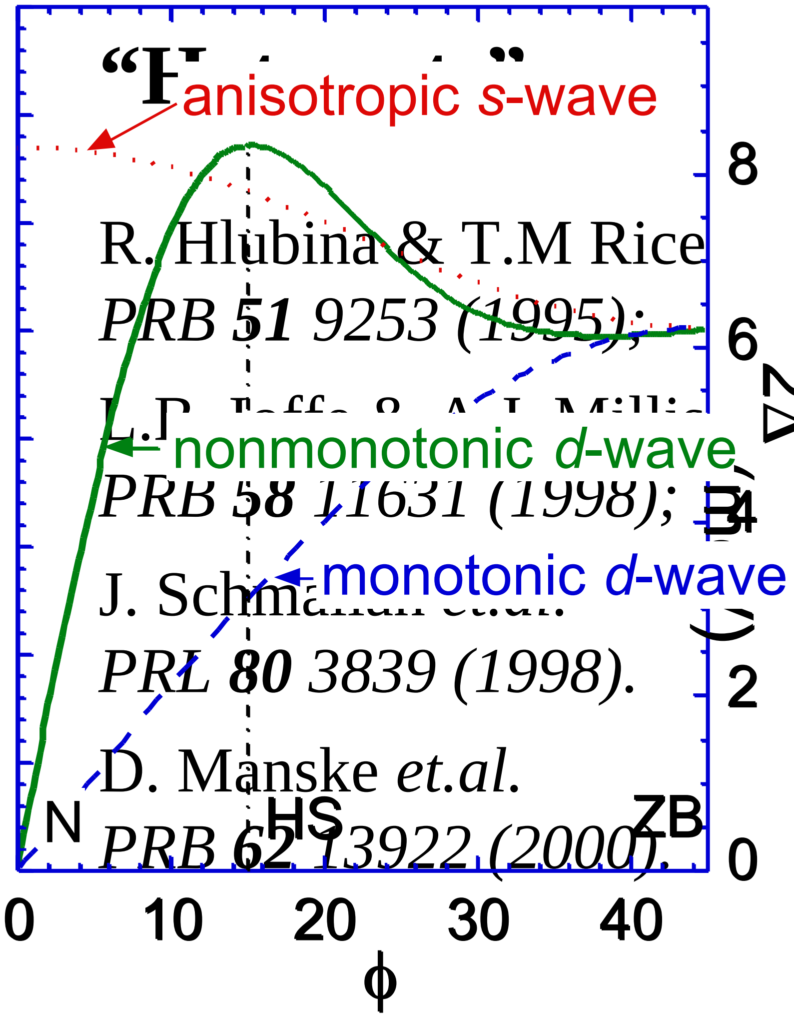
N.P. Armitage *et. al.*
PRL ***86*** *1126 (2001).*



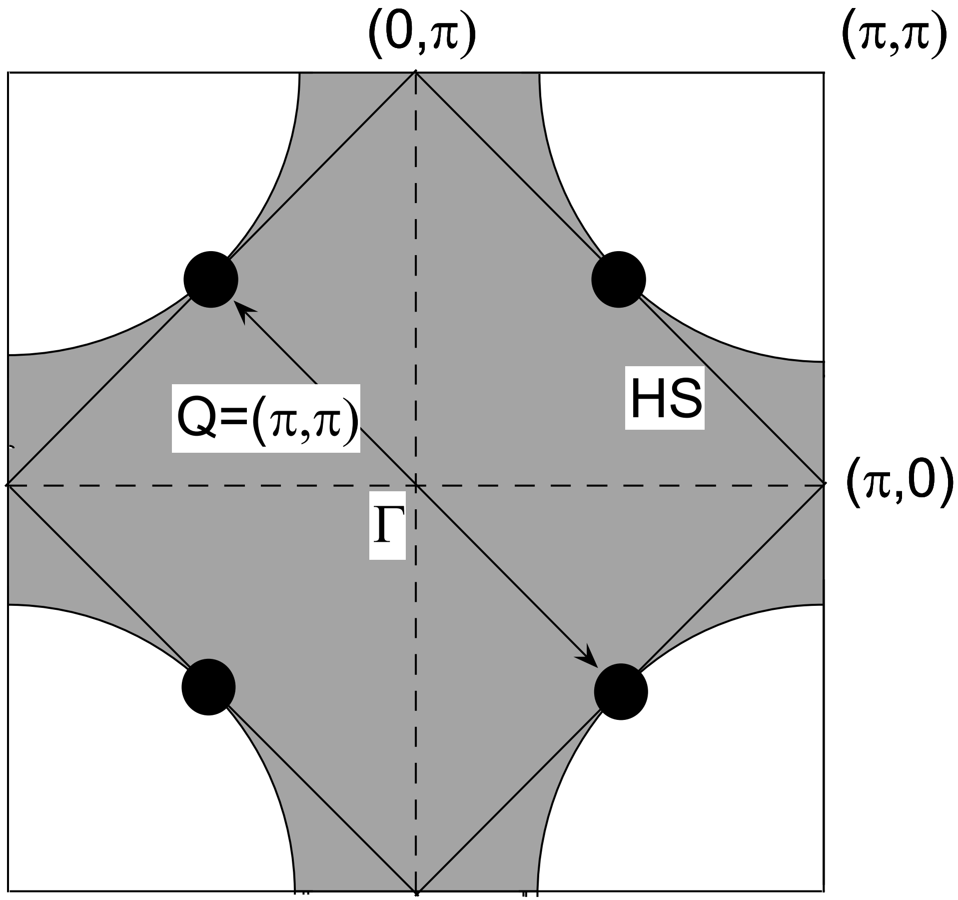


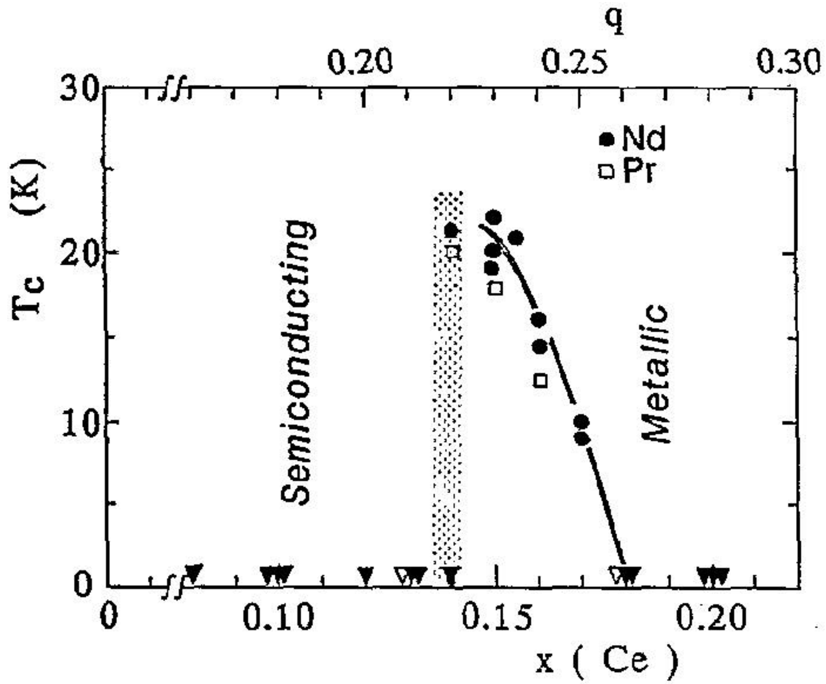
Nonmonotonic *d*-wave OP





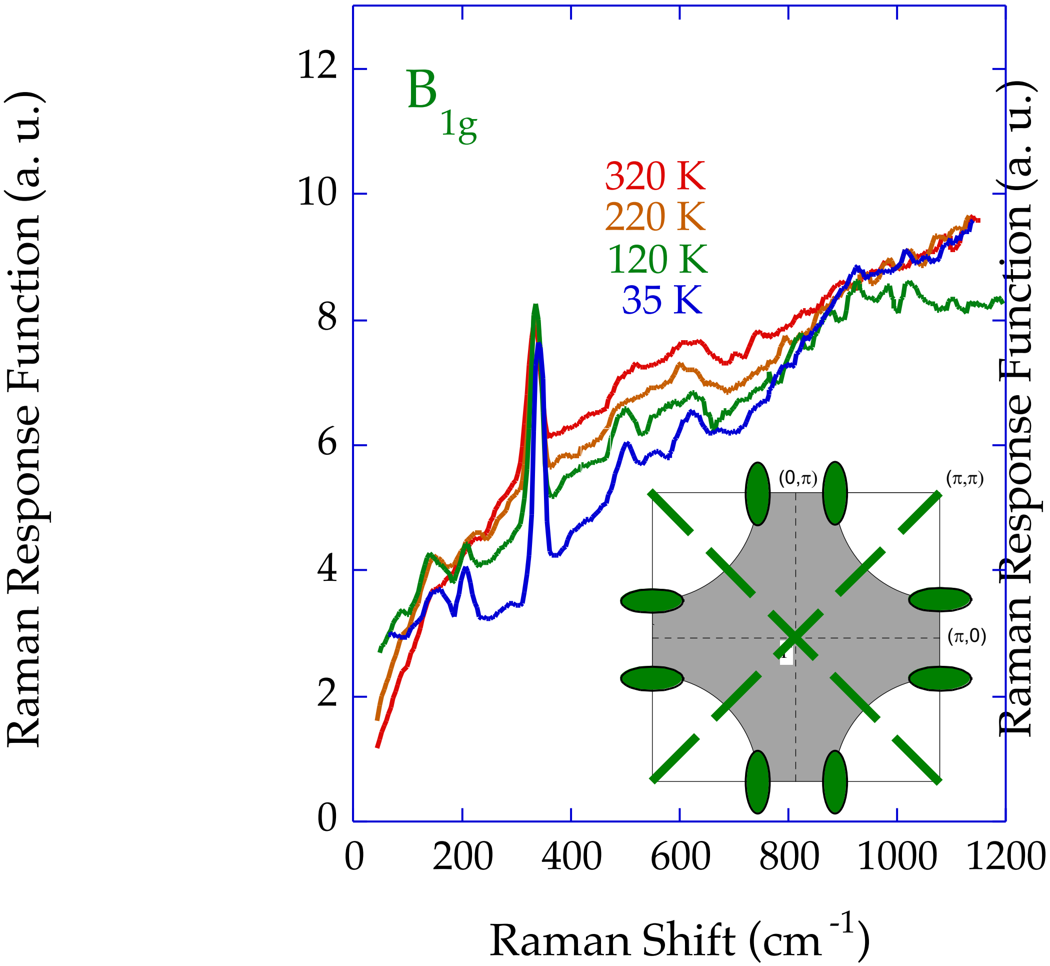
Doping dependence

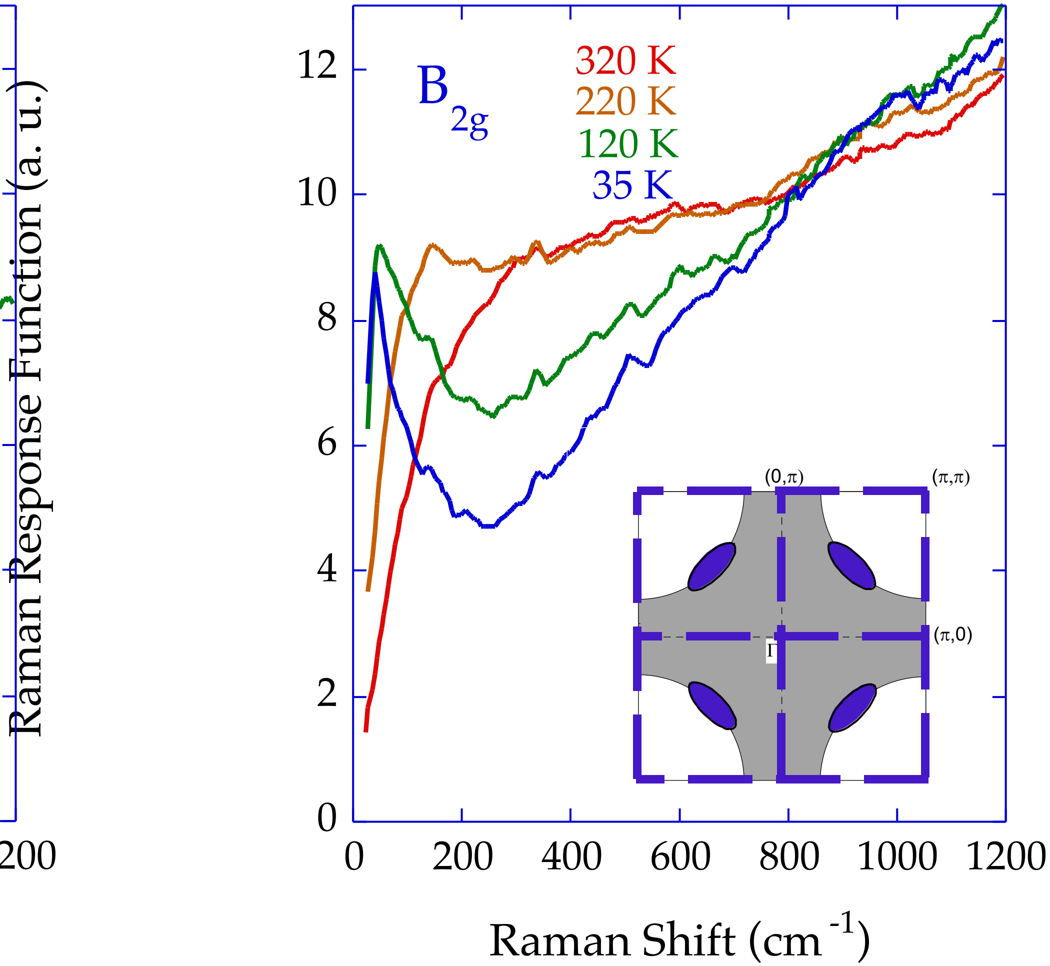




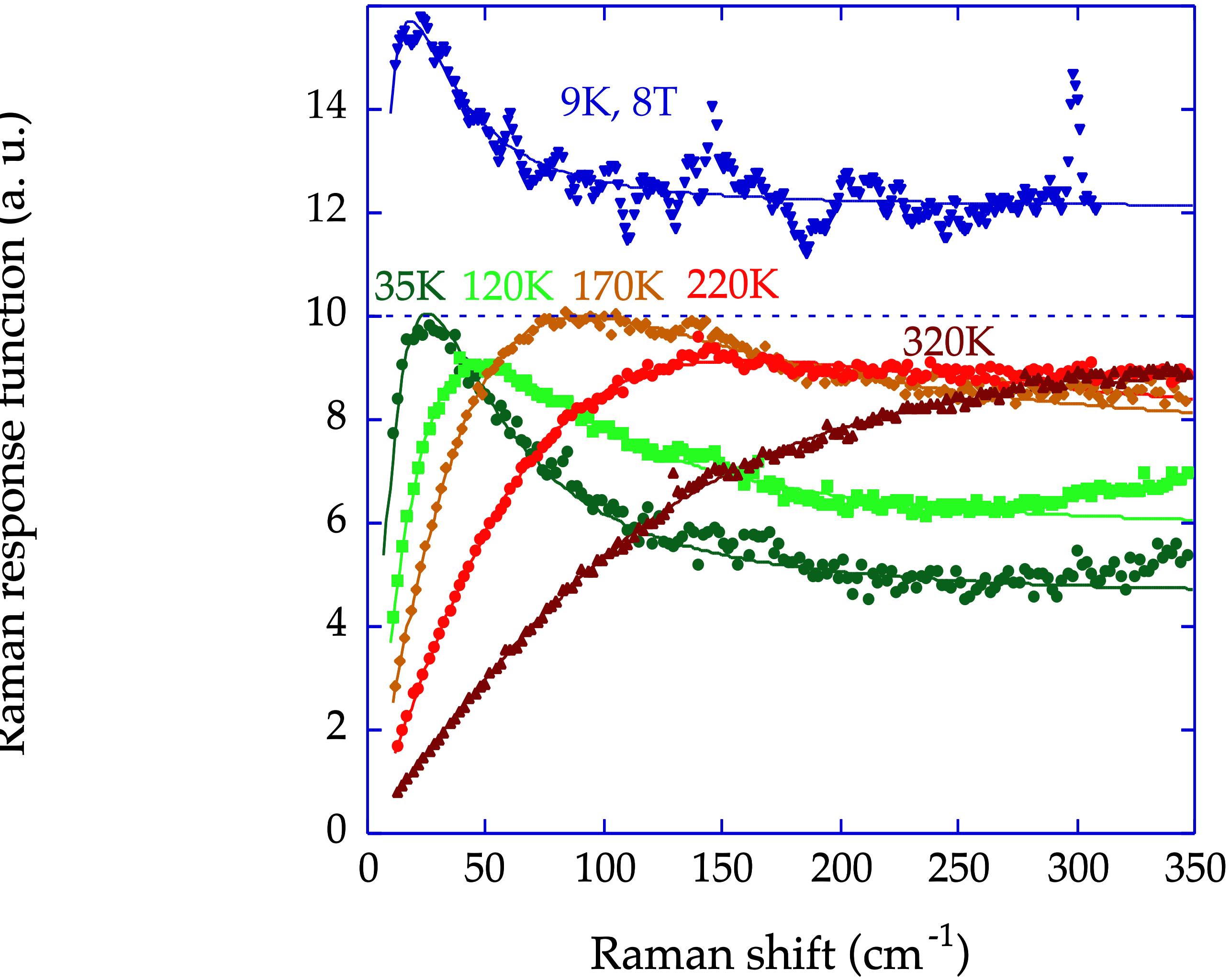
The pseudogap

Pseudogap anisotropy





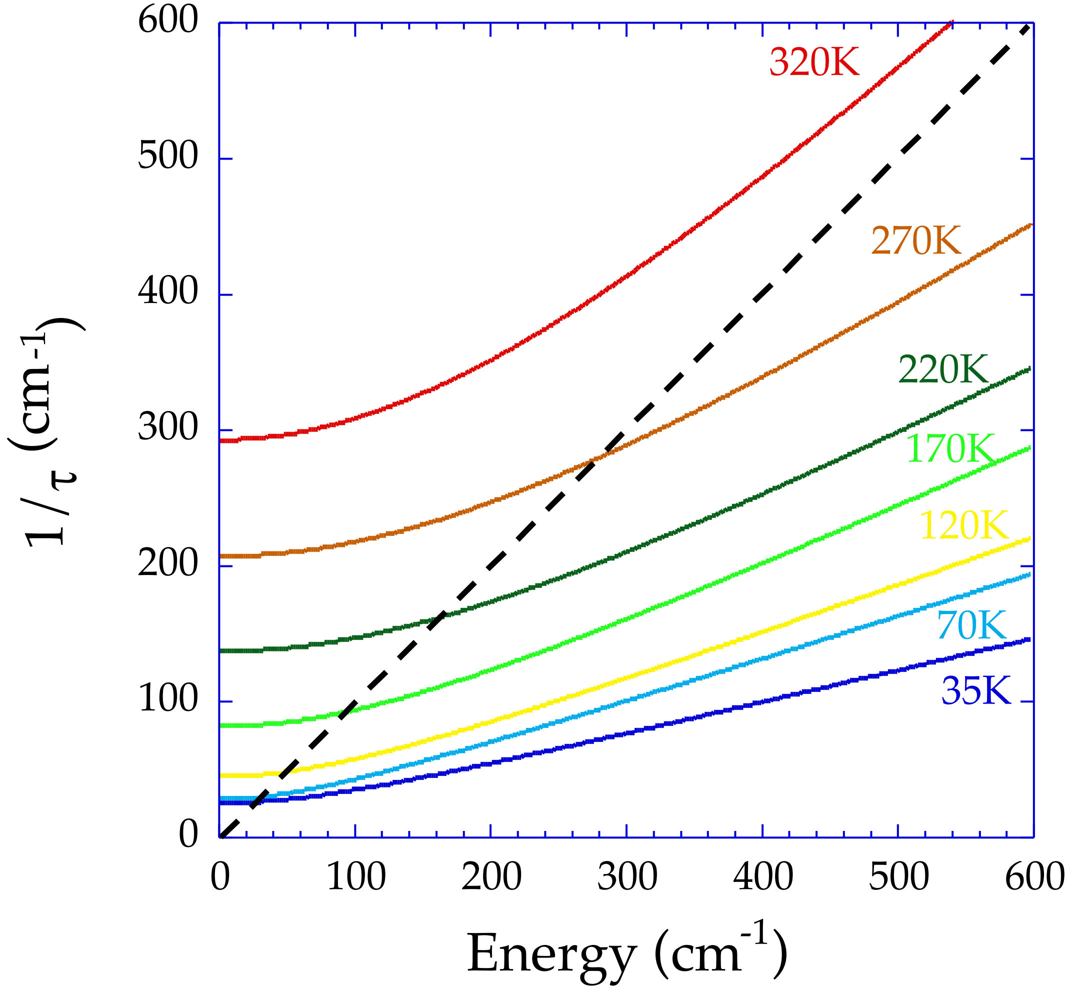
Quasi-elastic scattering

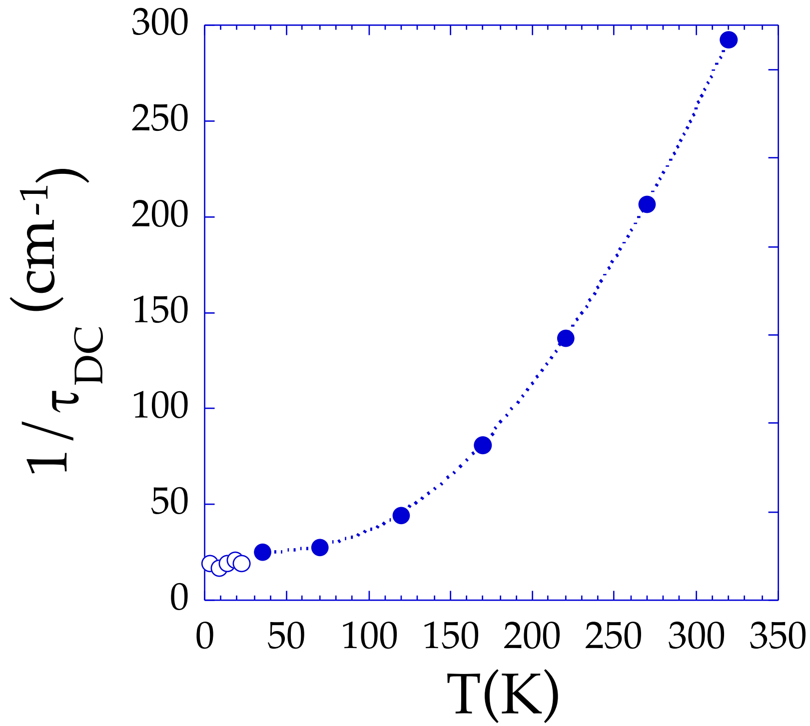


$$X'' \propto \frac{\omega\tau(\omega, T)}{1+[\omega\tau(\omega, T)]^2}$$

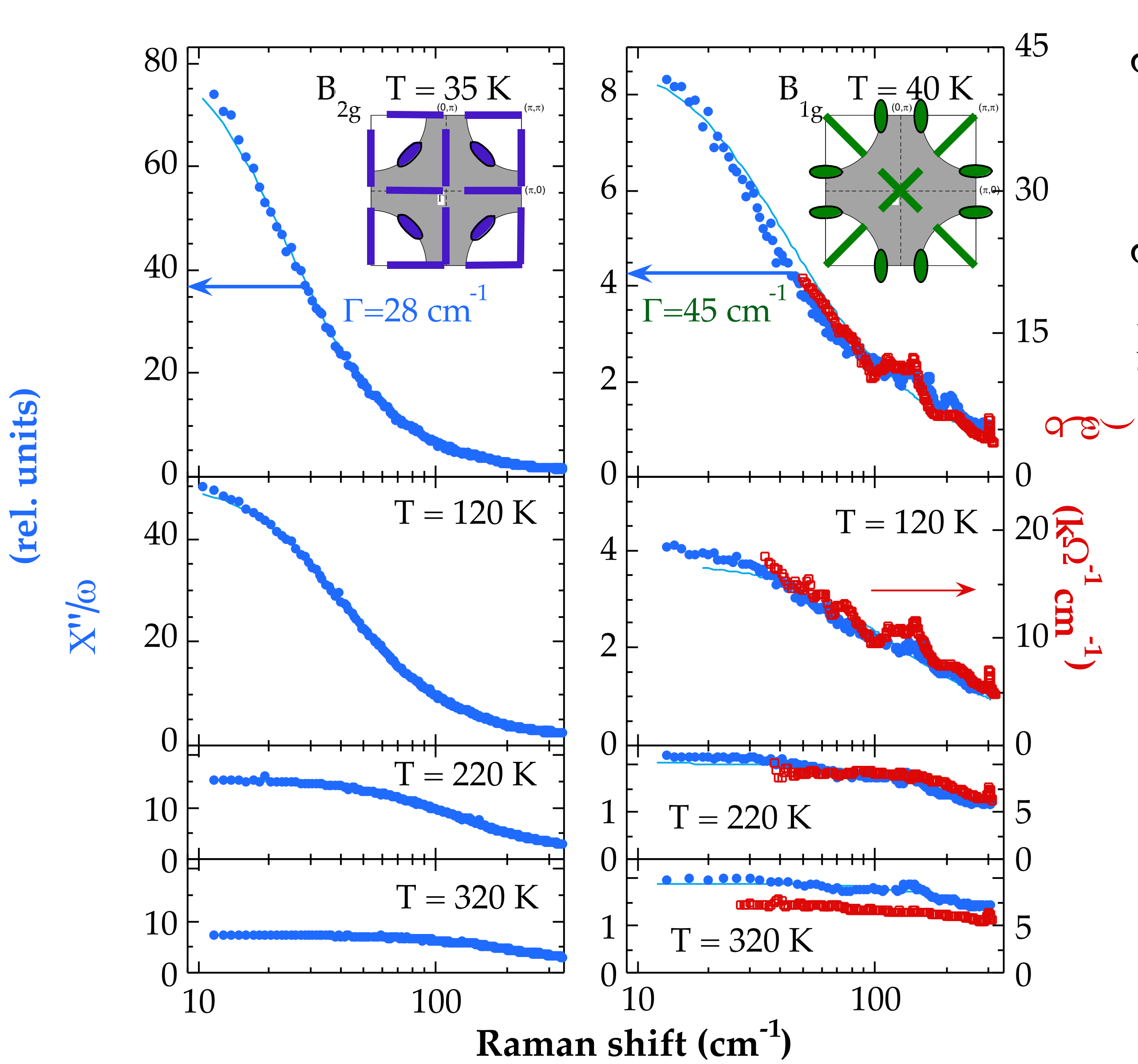
The scattering rate

$$1/\tau(\omega, T) = \sqrt{[a(T)]^2 + [b(T)\bullet\omega]^2}$$





Nodal excitations



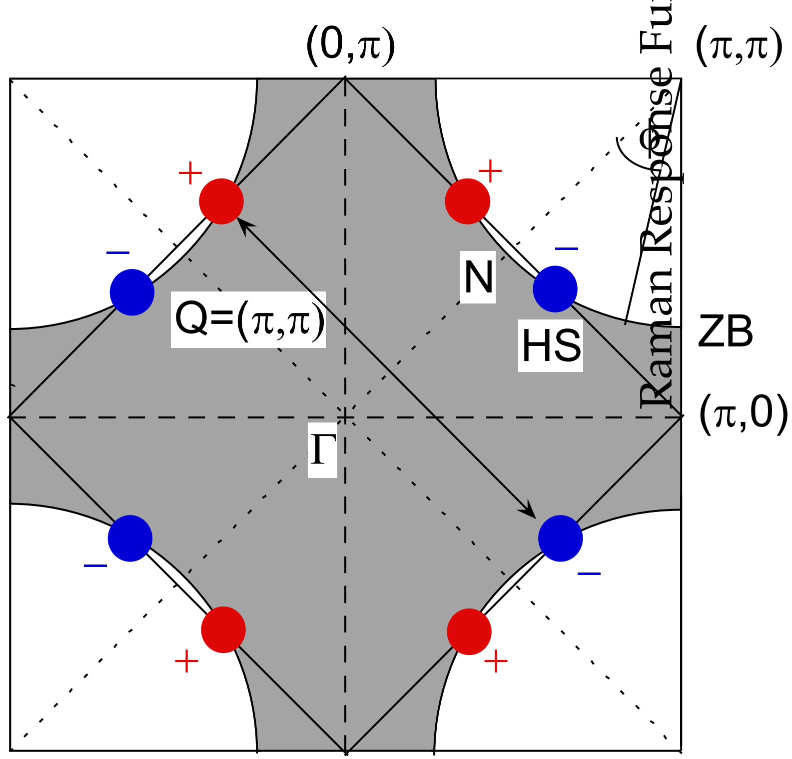
$$\sigma(\omega) = \frac{\omega_p^2}{4\pi} \frac{[\tau_\sigma(\omega)]^{-1}}{[\omega \frac{m_\sigma}{m_0}]^2 + [\tau_\sigma(\omega)]^{-2}}$$

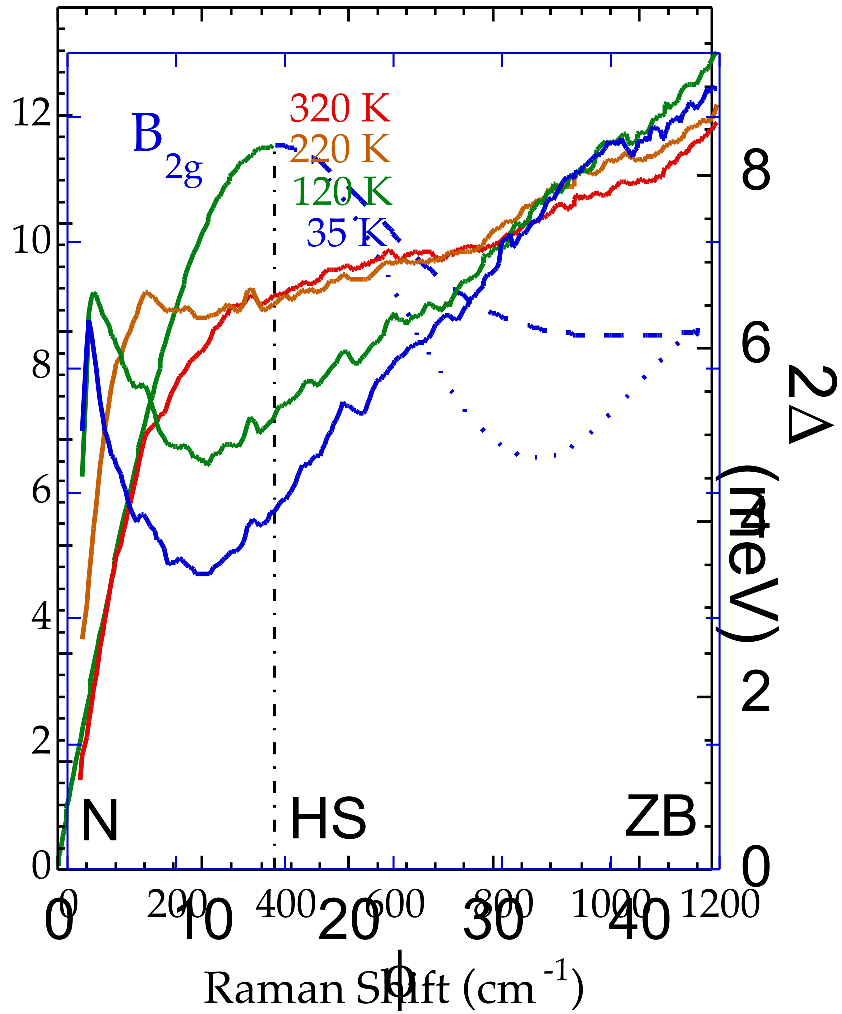
$$\sigma(\omega \to 0) = \frac{\omega_p^2 \tau_\sigma}{4\pi}$$

$$\frac{X''^R(\omega)}{\omega} = |\gamma^R|^2 \frac{[\tau_R(\omega)]^{-1}}{[\omega \frac{m_R}{m_0}]^2 + [\tau_R(\omega)]^{-2}}$$

The end

- Small FS -> nonmonotonic *d*-wave
- Δ(H)
- Pseudogap





Is NCCO a high-temperature SC?

Yes!

Thank You!