A pressure-tuned electronic transition in lightly doped Bi2212

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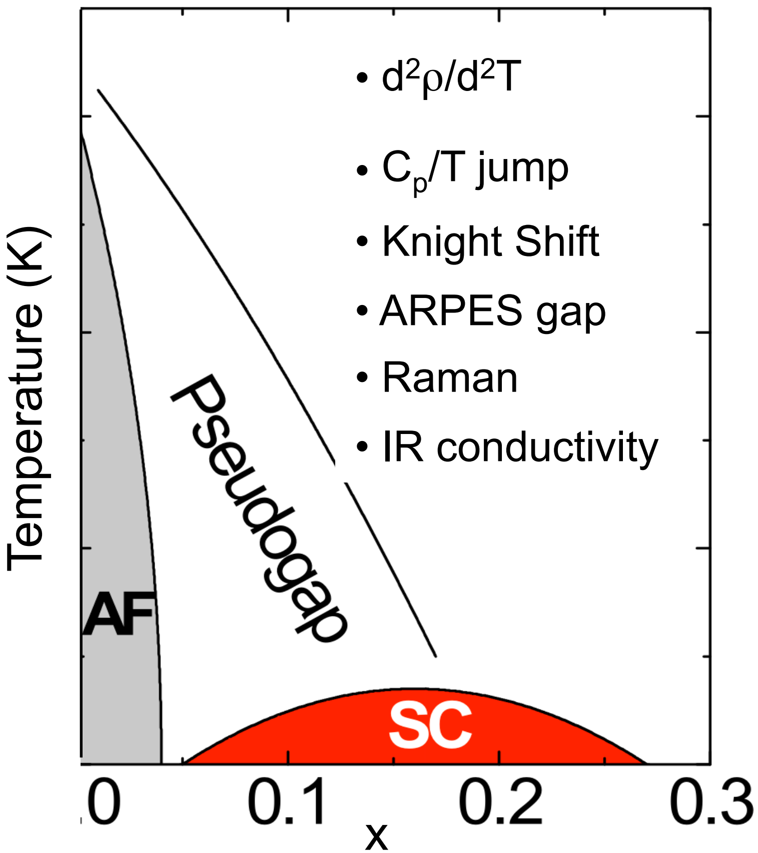
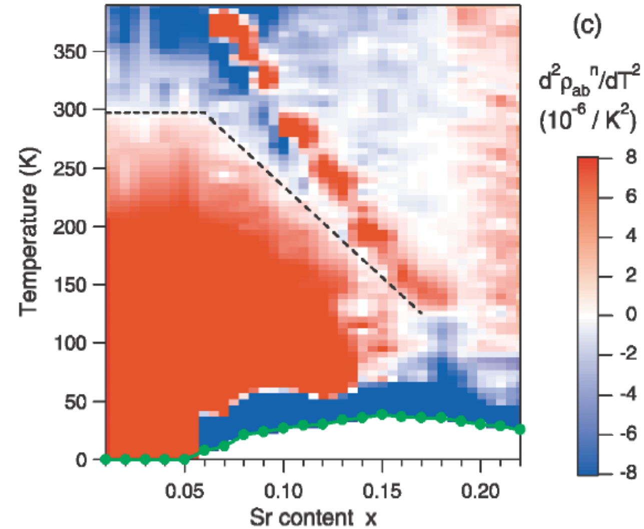
Outline

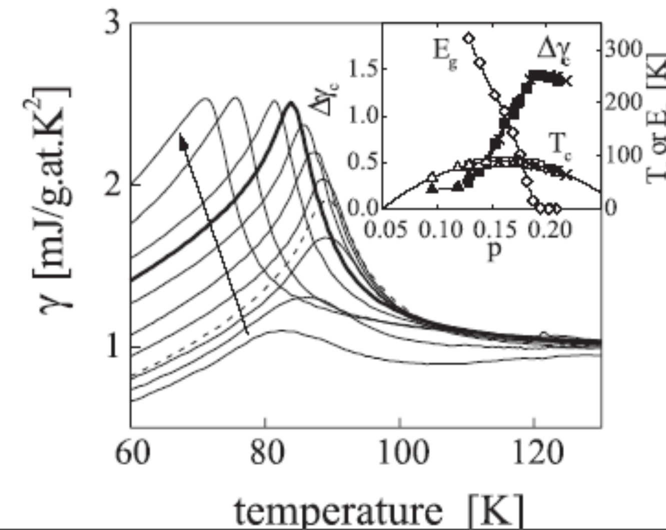
- Quantum Critical Point in cuprates and why we need a pressure axis
- Sample and experimental technique (Diamond Anvil Cell)
- Results from Raman Spectroscopy and X-Ray Diffraction (Cuk et al. Phys. Rev. Lett. **100**, 217003 (2008))
- Results from transport measurements
- Conclusions and Future Directions

High T_c Phase Diagram and Quantum Critical Point?





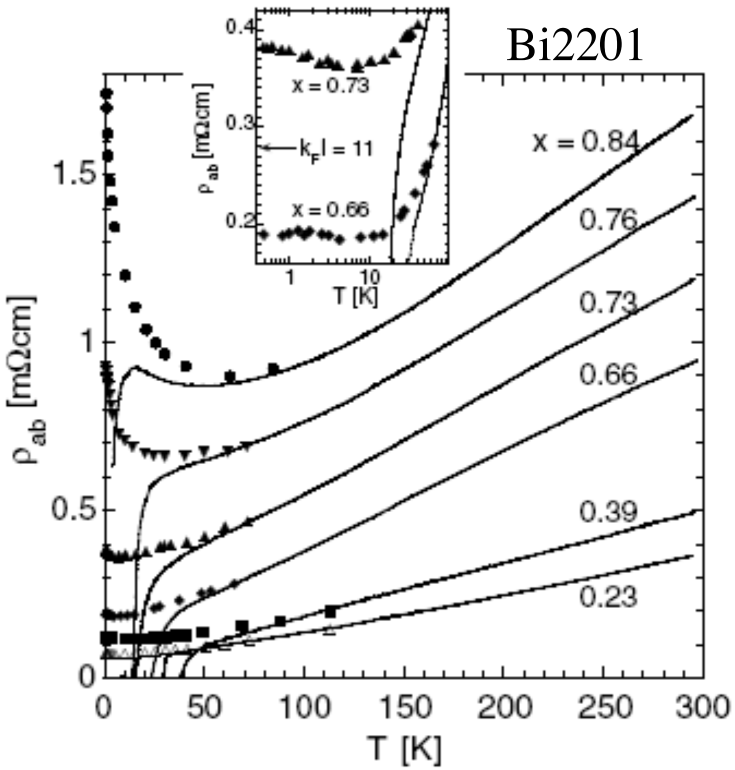
Ando et al. (2004)



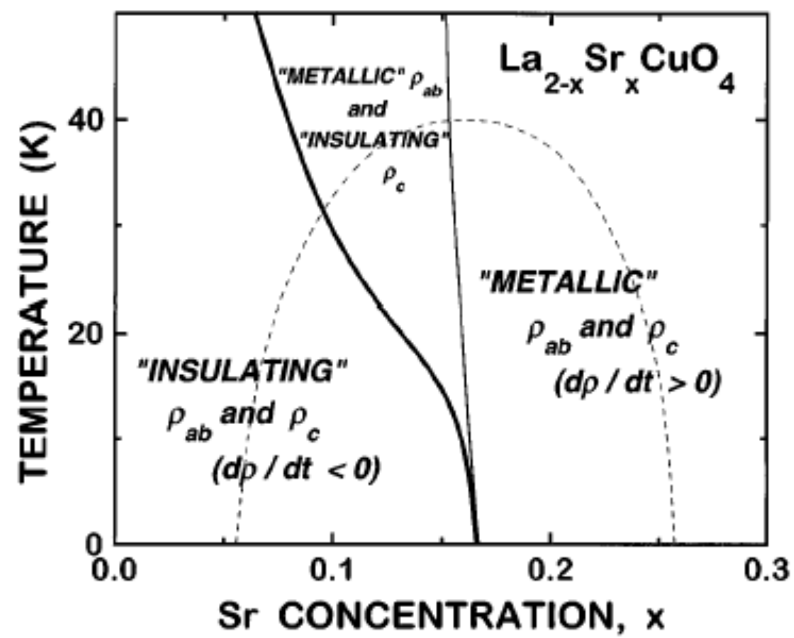
Loram et al. (2000)

Applying 60T to destroy the superconductivity…

Insulator to Metal Phase Transition at T ~ 0



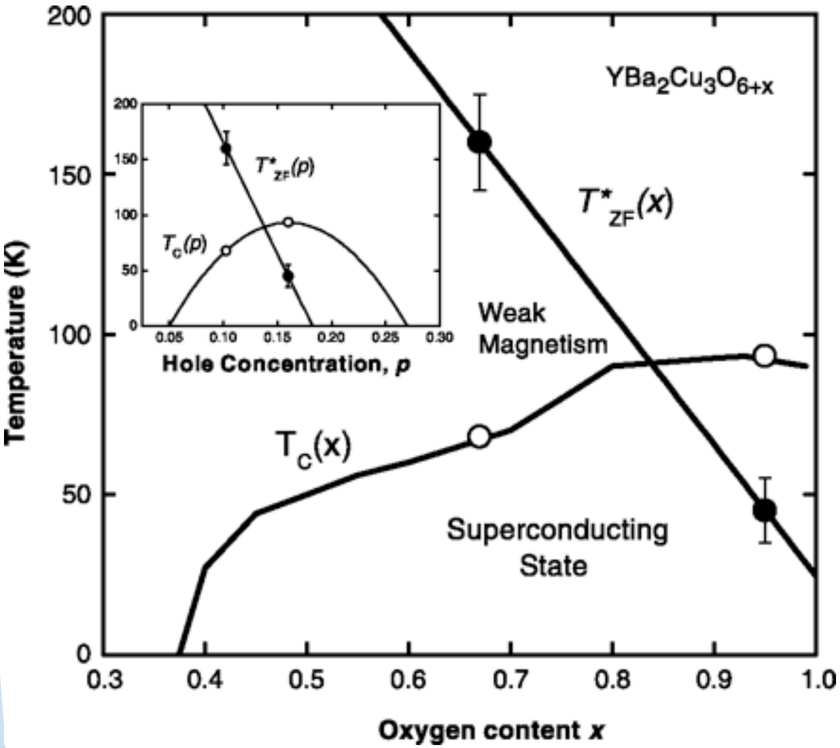
Ono et. al., Phys. Rev. Lett. ***85****, 638 (2000)*



G.S. Boebinger, Y. Ando et. al.
Phys. Rev. Lett. **77**, 5417 (1996)

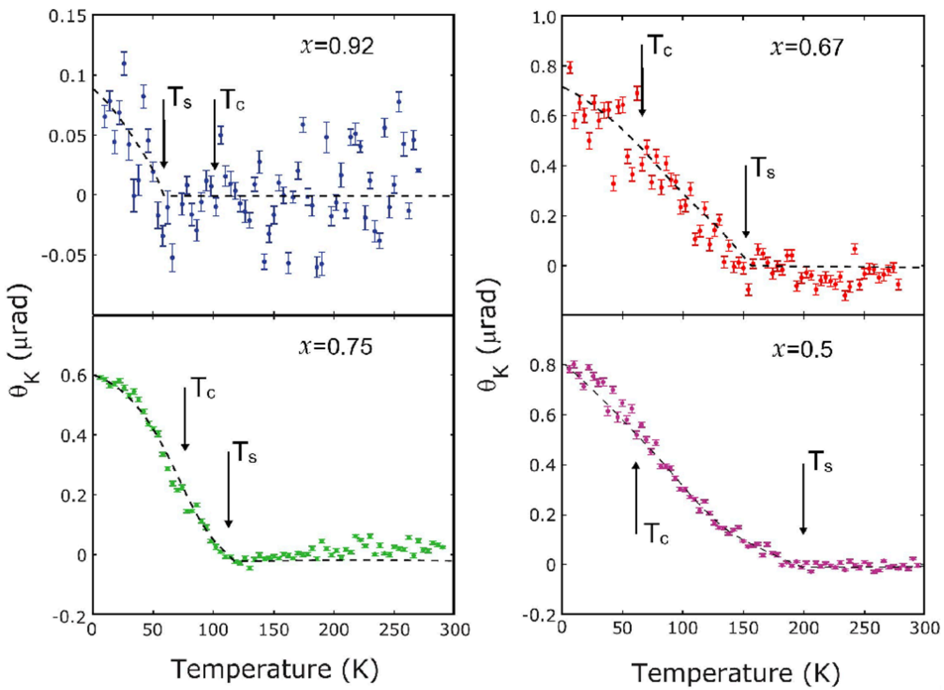
Weak Magnetic changes across putative QCP

μ-Spin Resonance



J.E. Sonier Science 292, 1692 (2001)

Optical Kerr Effect



Xia, Kapitulnik PRL 100, 127002 (2008)

Advantages of studying transition with pressure

- Tune through QCP without applying a magnetic field
- Continuous axis, finer than doping
- Laboratory control: Same sample, same experimental setting; avoids disorder

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Helping theory get closer to experiment:

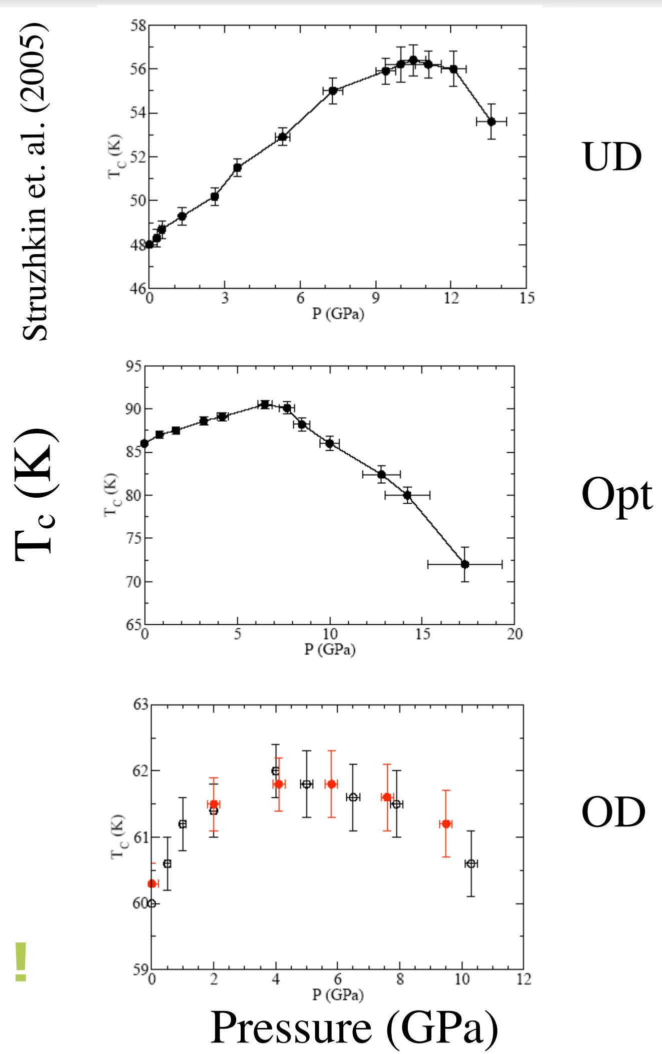
- Investigates free energy landscape
- Controlled metric (lattice compression)

Previous Pressure Effects in Cuprates

Tuning T_c and Metallicity on Superconducting Samples …

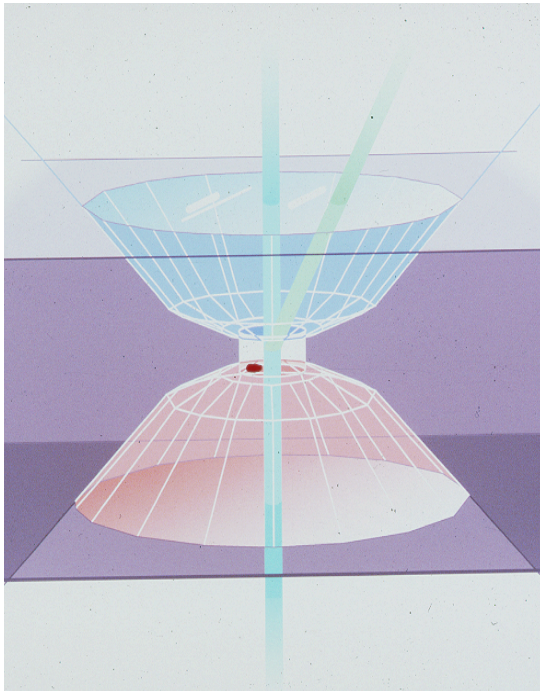
- increased hopping t_{pd} between Cu_d and O_p bands
- increased interlayer tunneling matrix element (t)
- doping by bringing the chemically substituted block layers closer to the Cu-O planes
- variation of electron-electron and electron-phonon interactions

Highest T_c of 164K in Hg1223 at 40 GPa !



Experimental Technique

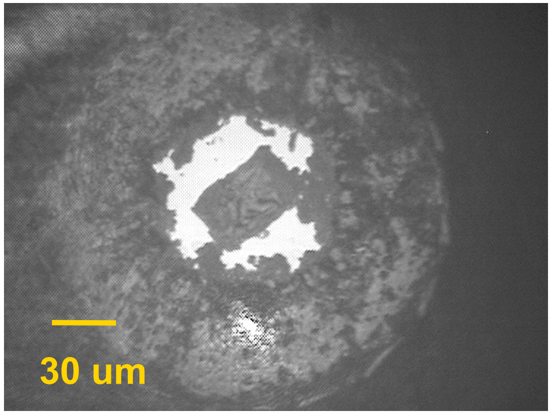
Raman Spectroscopy
X-Ray Diffraction



Diamond Anvil Cell
Ruby chip as Pressure manometer

1 GPa = 10 kbar = 10,200 atm

Loaded sample



Resistance measurements:
Requires leads into sample
Chamber

Raman Spectroscopy

$\chi'' \sim \Omega\ \sigma(\Omega)$

Raman Conductivity

λ

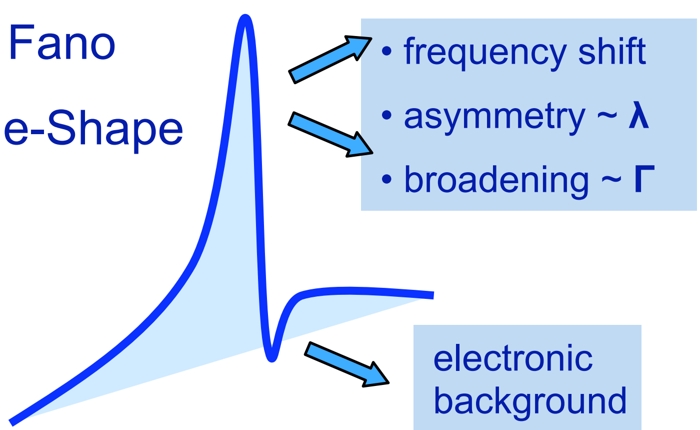
Electron-Phonon Coupling

γ_{gr} ~ *Gruneissen Parameters*

Compressibility of Magnons, Phonons

Fano

Line-Shape



X-Ray Diffraction

Equation of State:

Structural Transitions; Compressibility

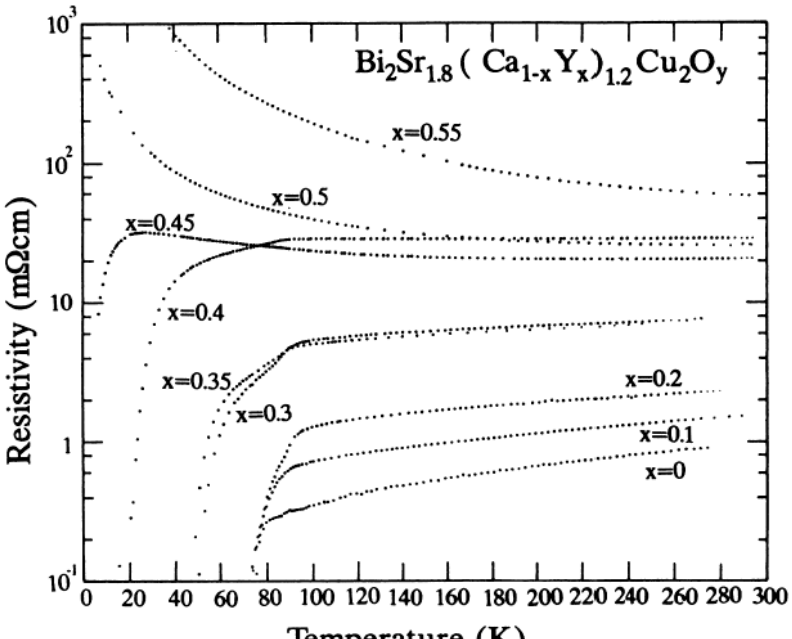
Magnitude compression of Bi2212:

- *a, b-axis ~ 5 % compression by 30 GPa*
- *c-axis ~ 10 % compression by 30 GPa, complimentary metric to P*

Samples: insulating Bi2212

$Bi_{1.98}Sr_{2.06}Y_{0.68}Cu_2O_8$

$Y^{+3} \rightarrow Ca^{+2}$ $\delta \sim 0.02$



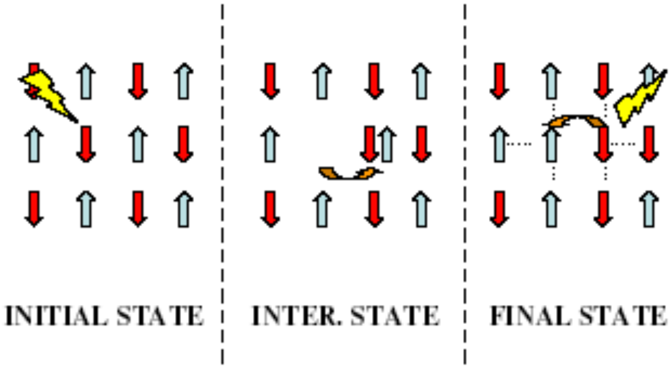
Maeda, *et. al.* (1990)

Why Bi2212 ?

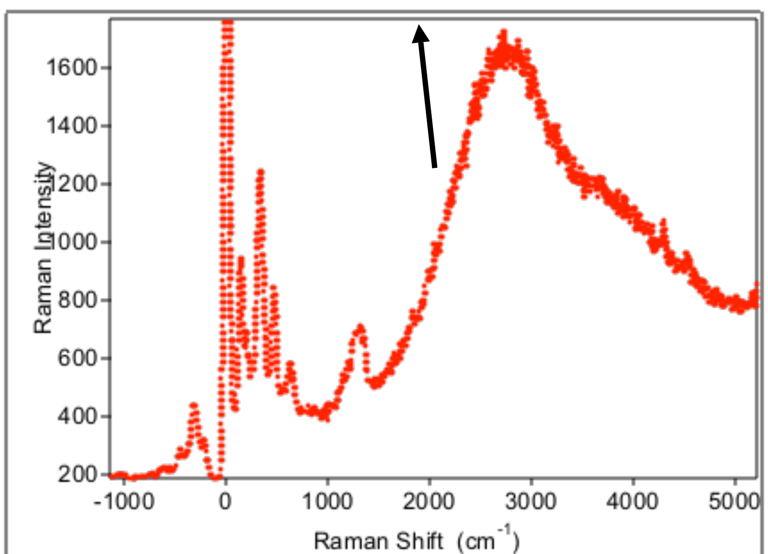
- YBCO chain ordering with pressure
- LSCO stripe phase, not as compressible, lower T_c
- Generic, high T_c cuprate exhibiting main features of phase diagram

Raman Spectra of Insulating Bi2212 Sample

Two Magnon Scattering

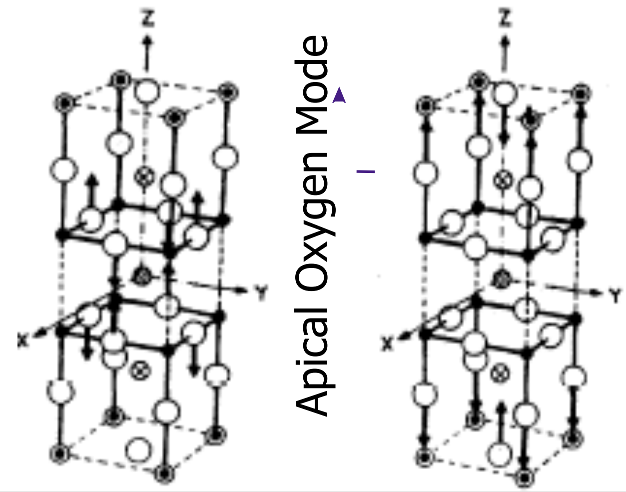


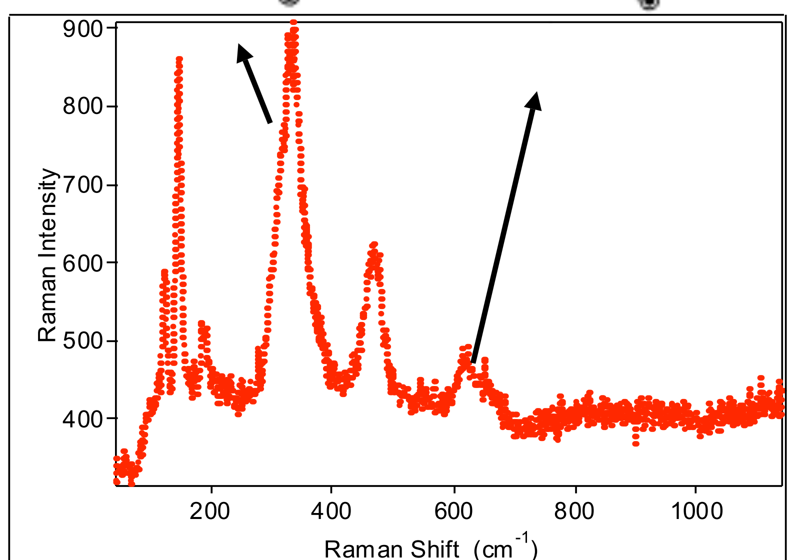
Peak 3J ~ 6 broken bonds of J/2



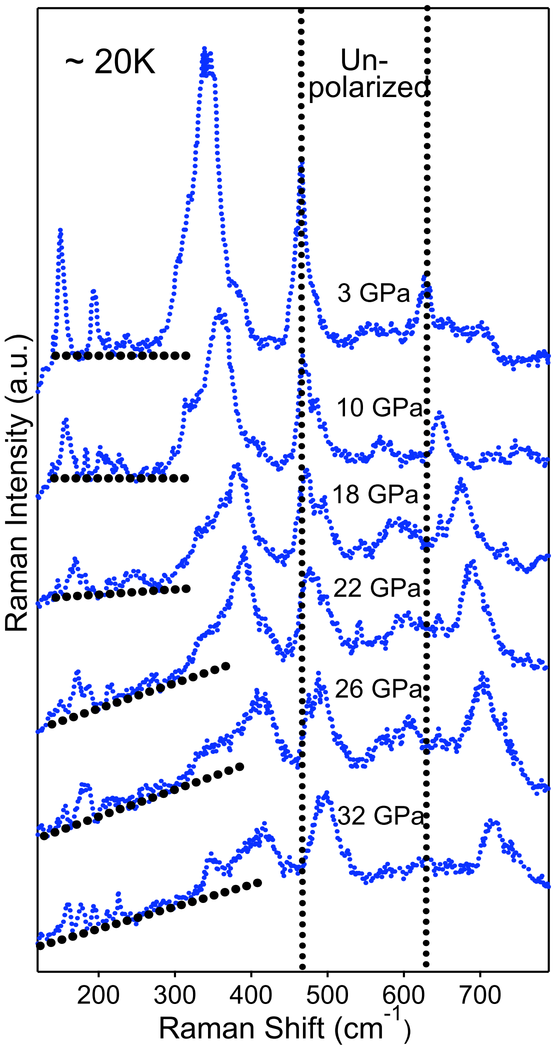
B_{1g} Bond Buckling Mode

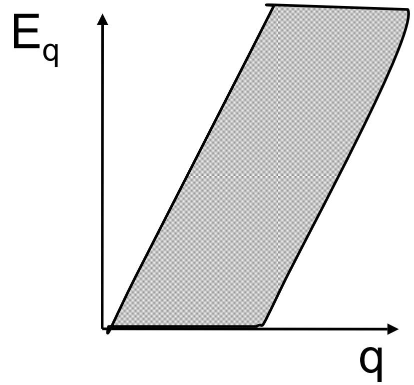
Apical Oxygen Mode

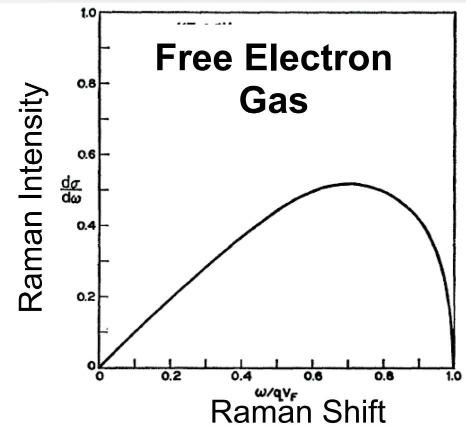


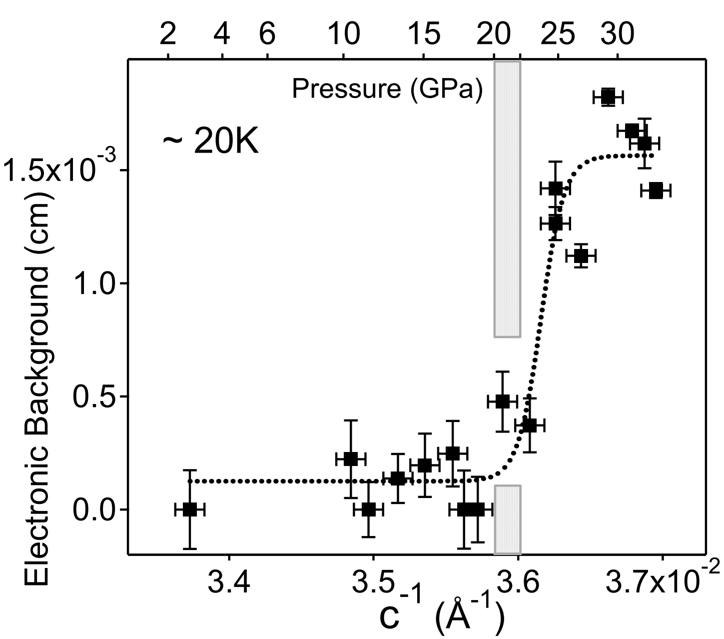


$\chi'' \sim \Omega\, \sigma(\Omega)$: Raman Conductivity

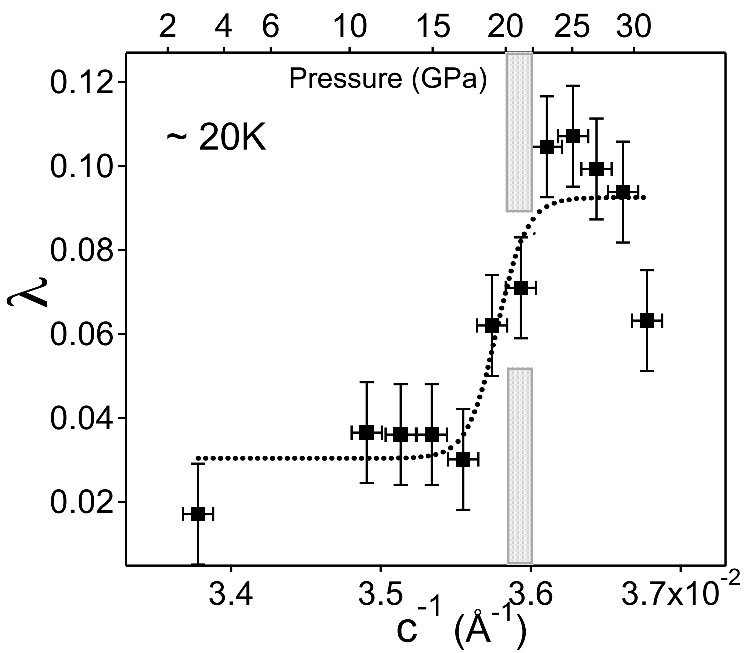




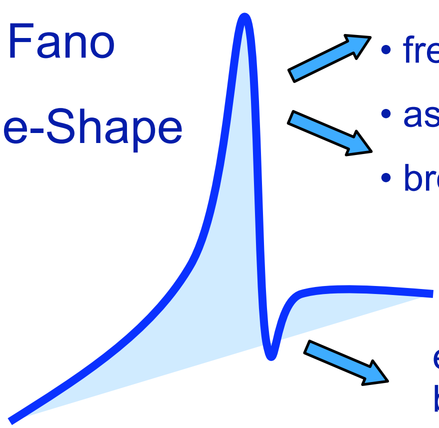




Electron–Phonon Coupling



B_{1g} Bond-Buckling Mode



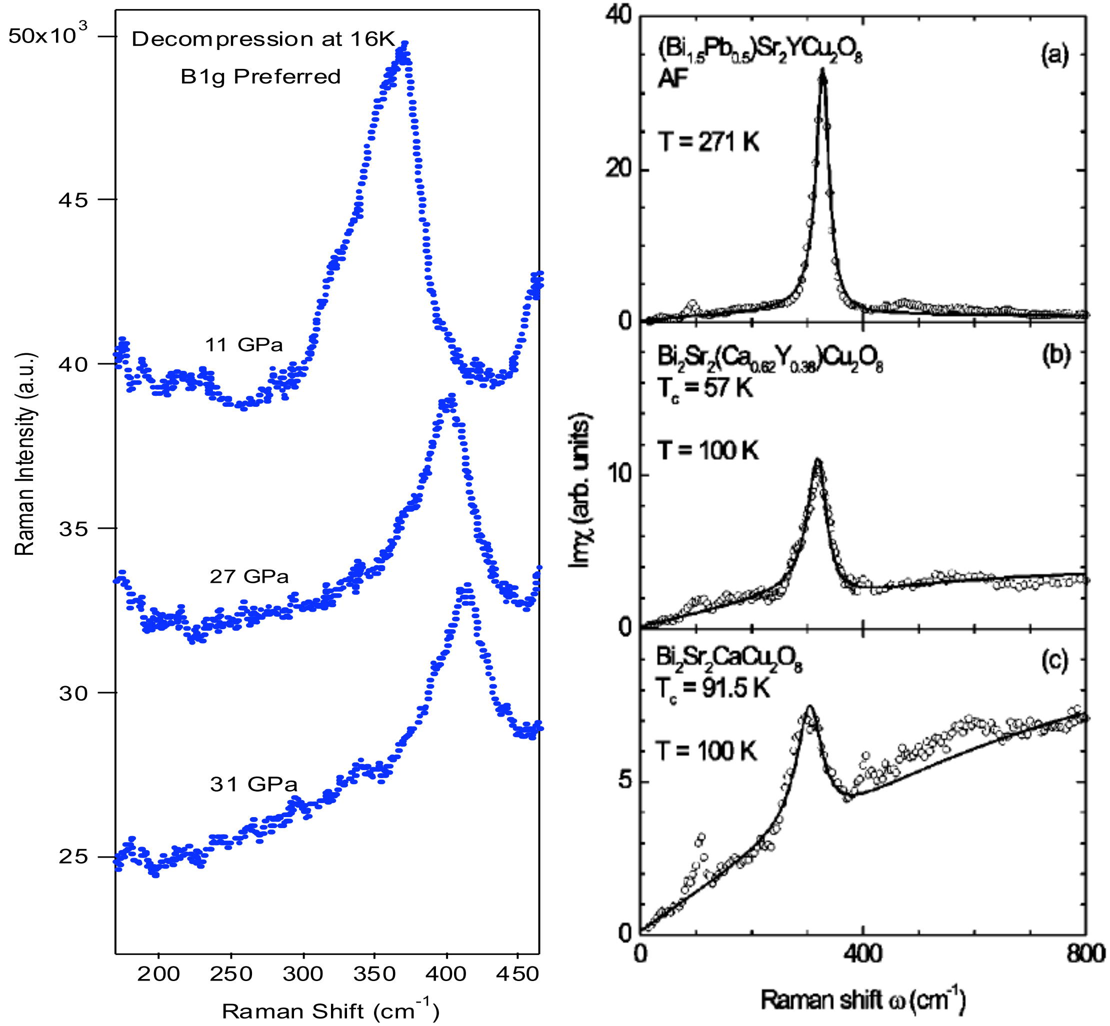
Comparison to Doping Axis

Opel, M *et. al.* (1999)

11 GPa

27 GPa

31 GPa



AF

Under-doped

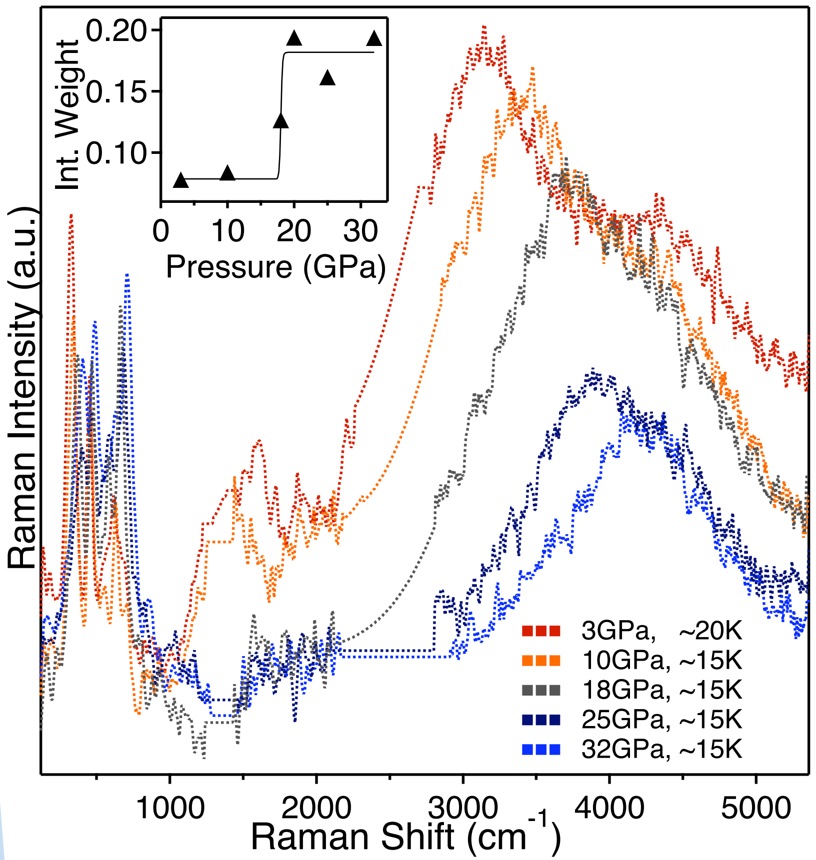
Over-doped

How 20GPa compares to x~0.2

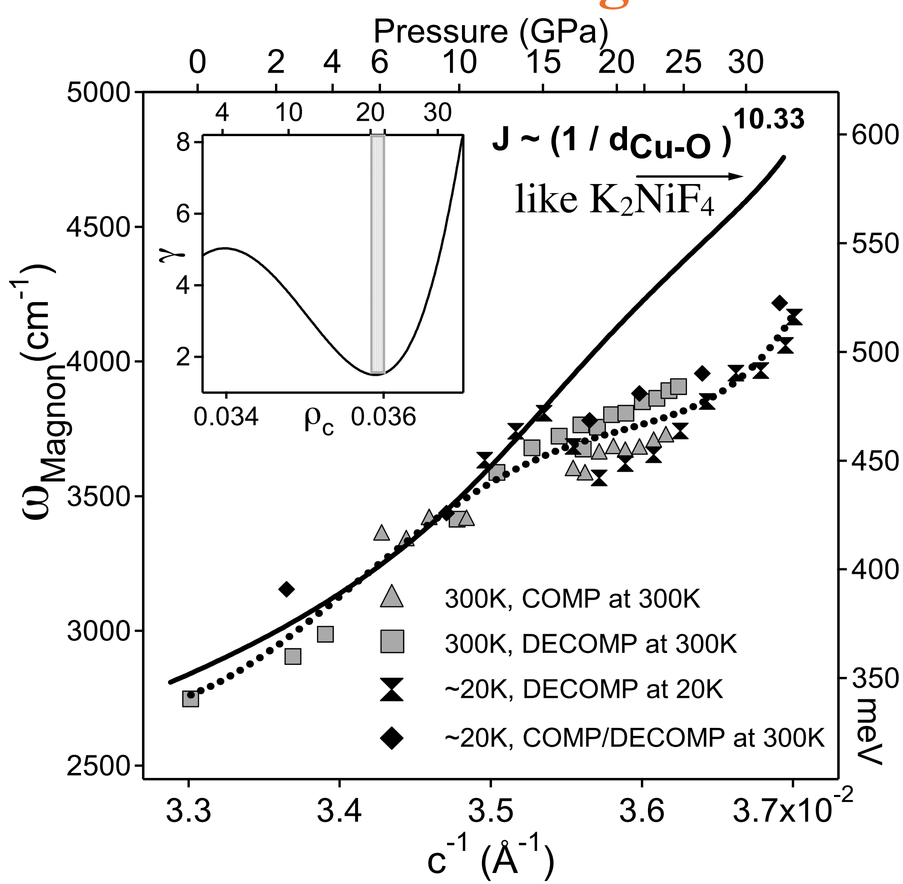
- Linearity in Raman background begins around 0.2 holes/Cu *(Venturini (2002))*
- λ fits become appreciable around optimal doping *(Opel (1999), Devereaux (1995))*
- LDA count ~0.01 holes/Cu/GPa means ~0.2 holes/Cu at 20GPa *(J.D. Jorgensen (1990))*

Two-Magnon Peak

Spectral Weight Transfer

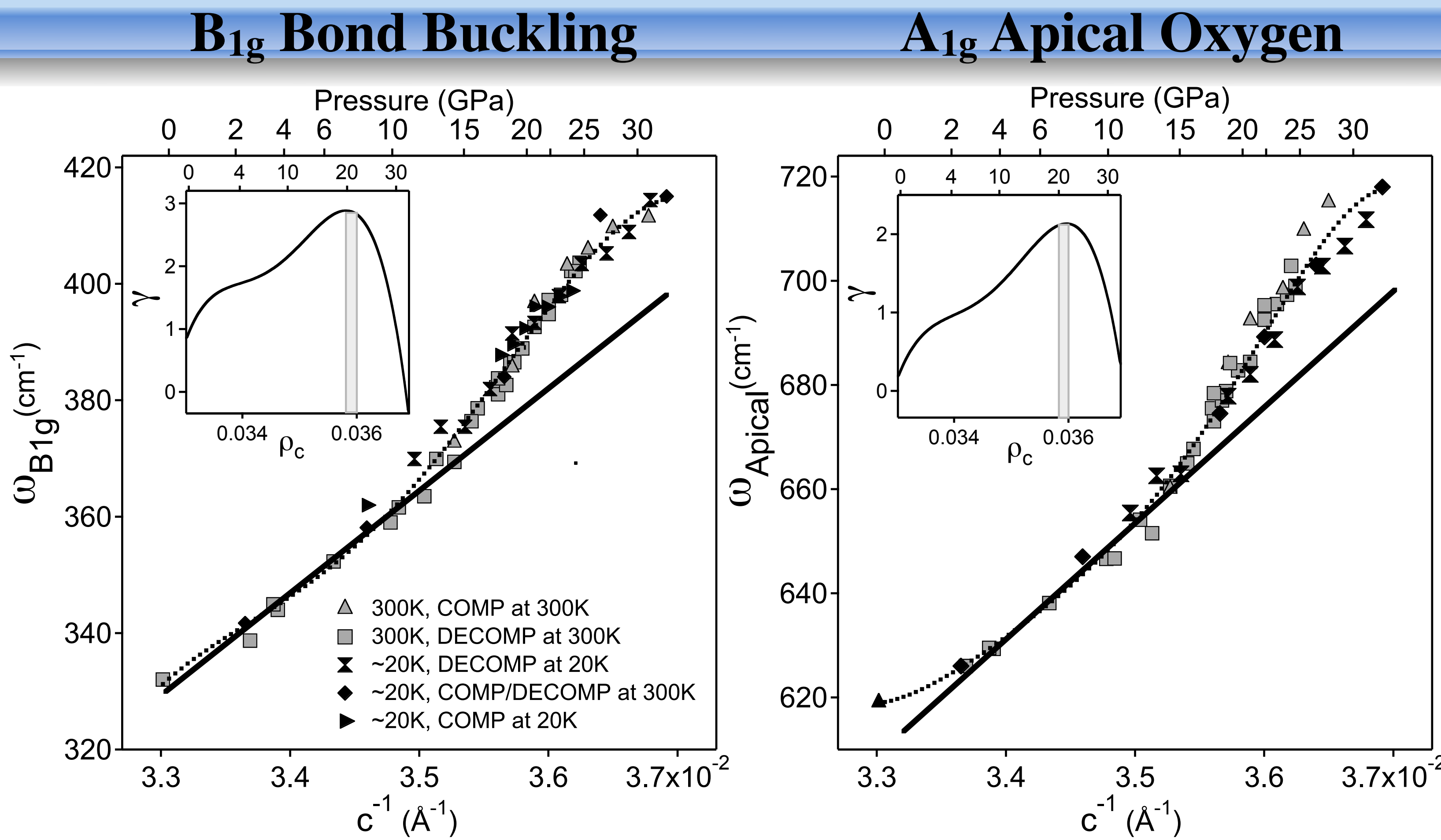


Softening



also softens by ~150meV from AF to optimally doped (Sugai, 2003)

Phonon Compressibility

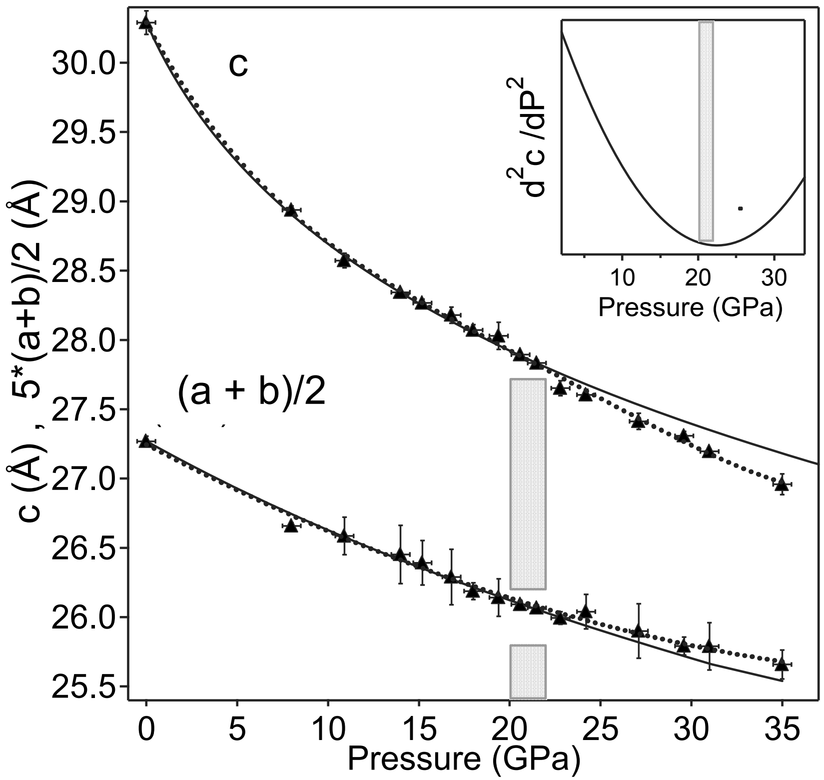


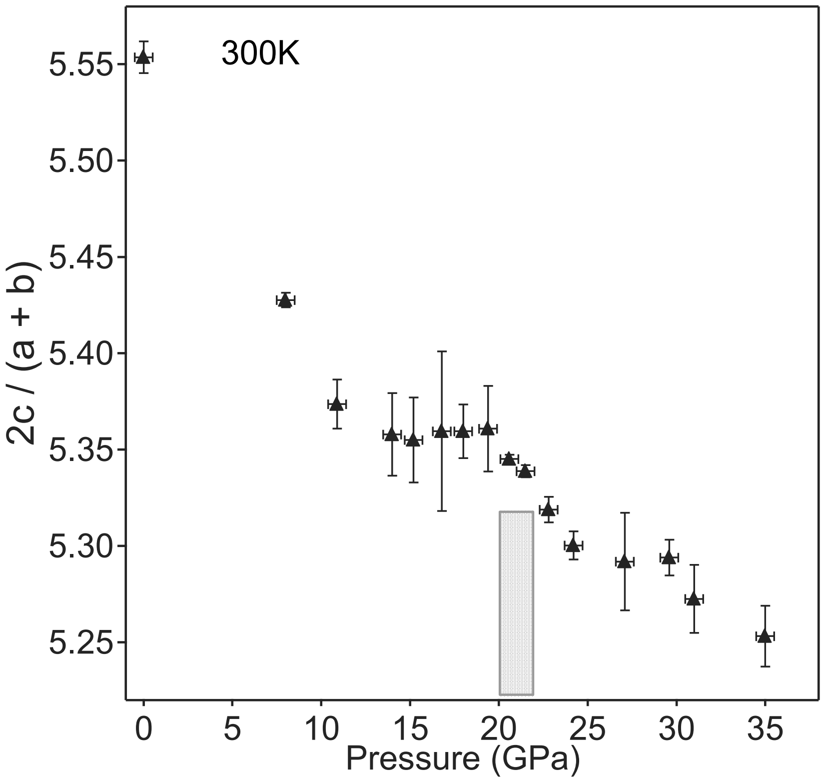
$\gamma = (\delta \ln \omega / \delta \ln \rho_c)$ **Gruneissen Parameter**

Continuity of Transition: Independent of P,T Pathway

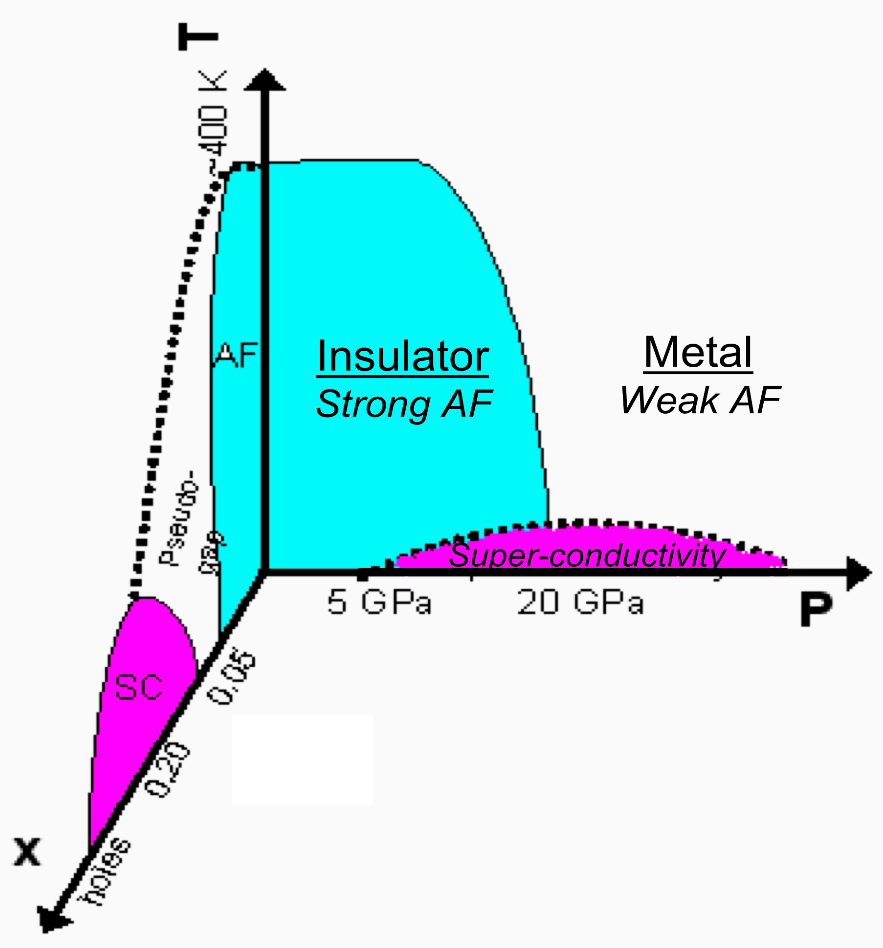
Lattice Compressibility

Change in Compressibility of c-axis at 21 GPa
Also consistent with 2nd order transition





20 GPa Transition



- Electronic Transition in Raman background and λ
- Spectral weight transfer to low energy from two-Magnon peak; softening of two-Magnon peak
- Maximum in the Gruneissen parameter of B_{1g} and apical oxygen phonons
- Compressibility discontinuity in the c-axis lattice constant

Interpretation of Transition

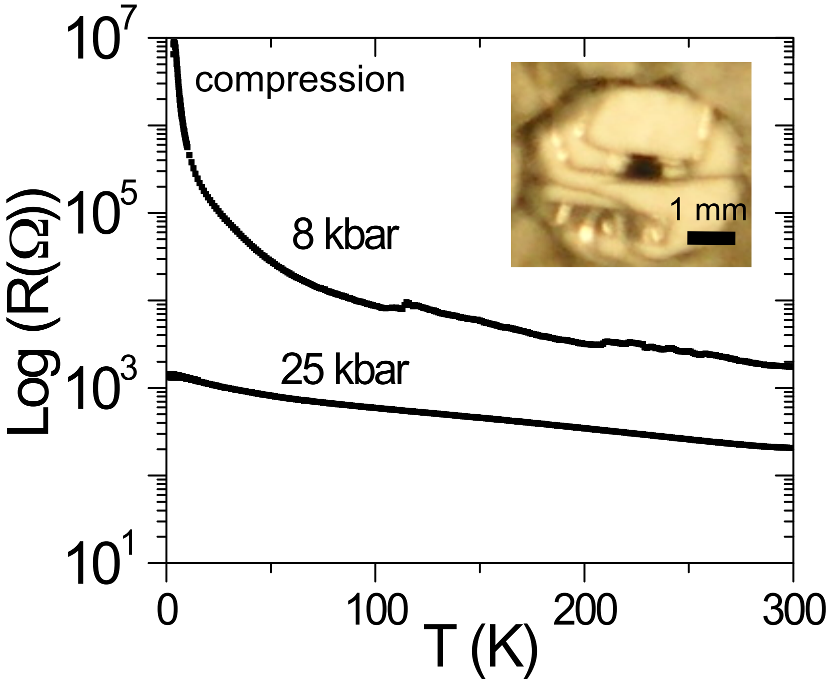
- Lifshitz topological Transition
  - unifying low energy feature, like Fermi surface, changes
  - 2^{nd} order like, continuous transition
  - evidence from ARPES (arcs) and Hall jump at x ~ 0.2

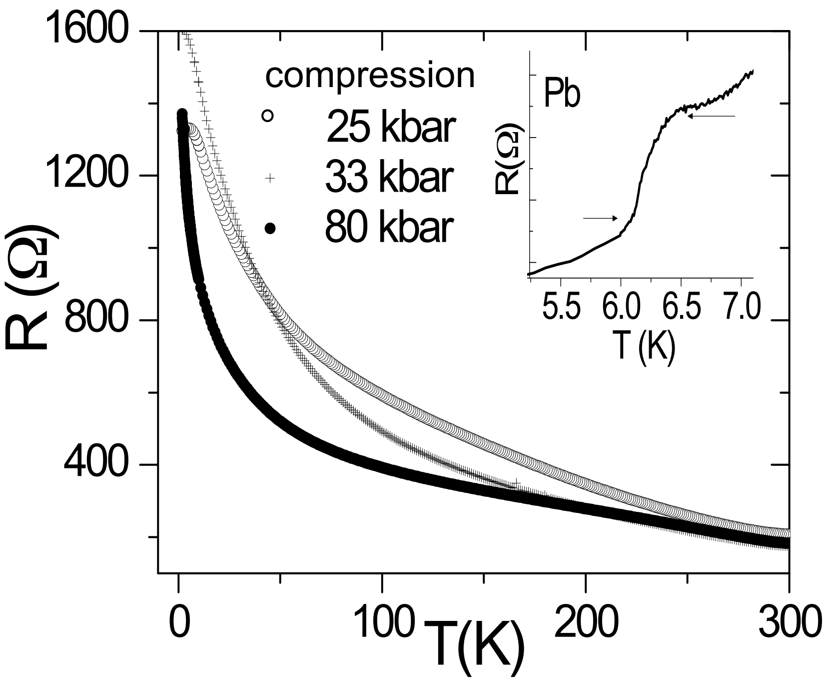
- Competing order

Transport Measurements

- Resistance measurements require leads brought into cell
- Low–T R changes by four orders of magnitude at ~3–5GPa
- Resistance downturn, and magnetoresistance suggest superconducting patches
- Consistency: Three groups, Bridgman and Diamond Anvil Cells

Bridgman Anvil Cell



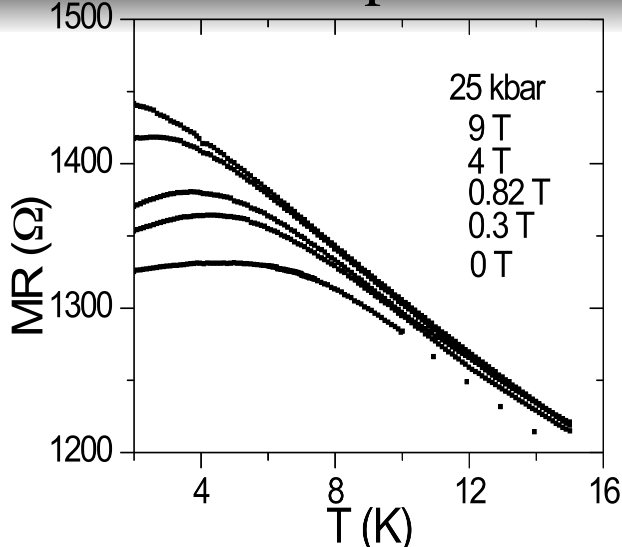


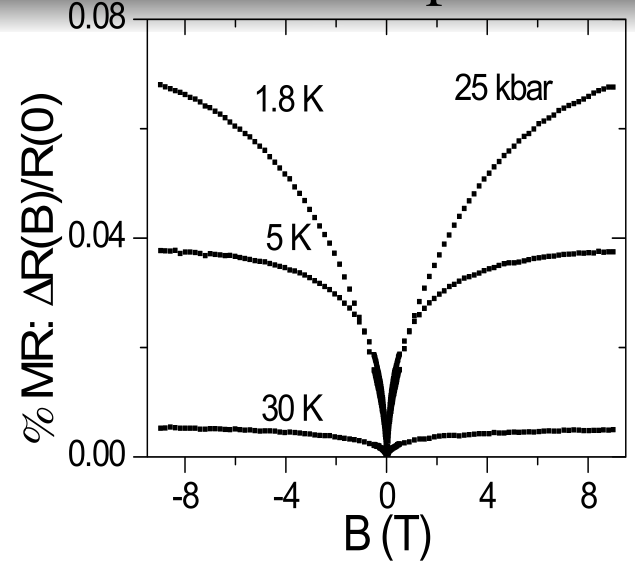
Magnetoresistance

Sweep T

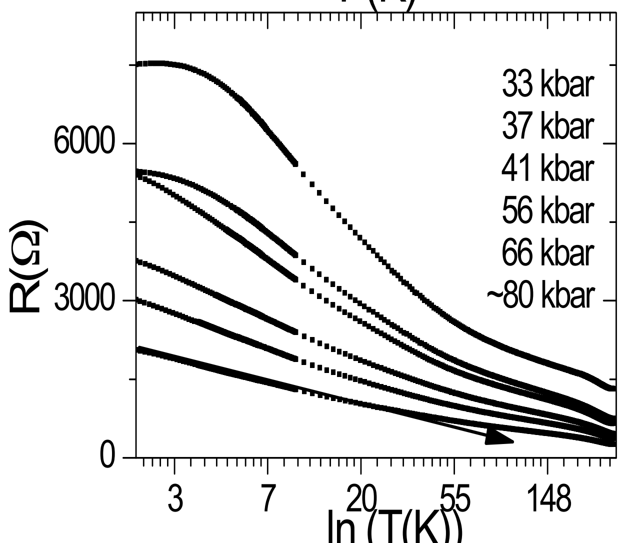
Sweep B

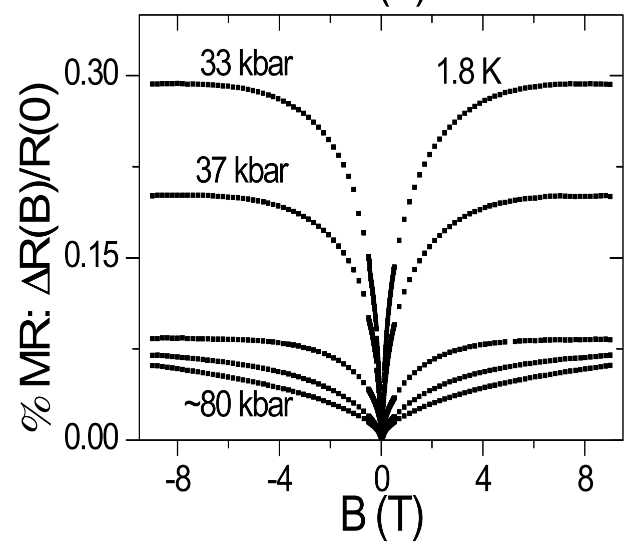
Compression





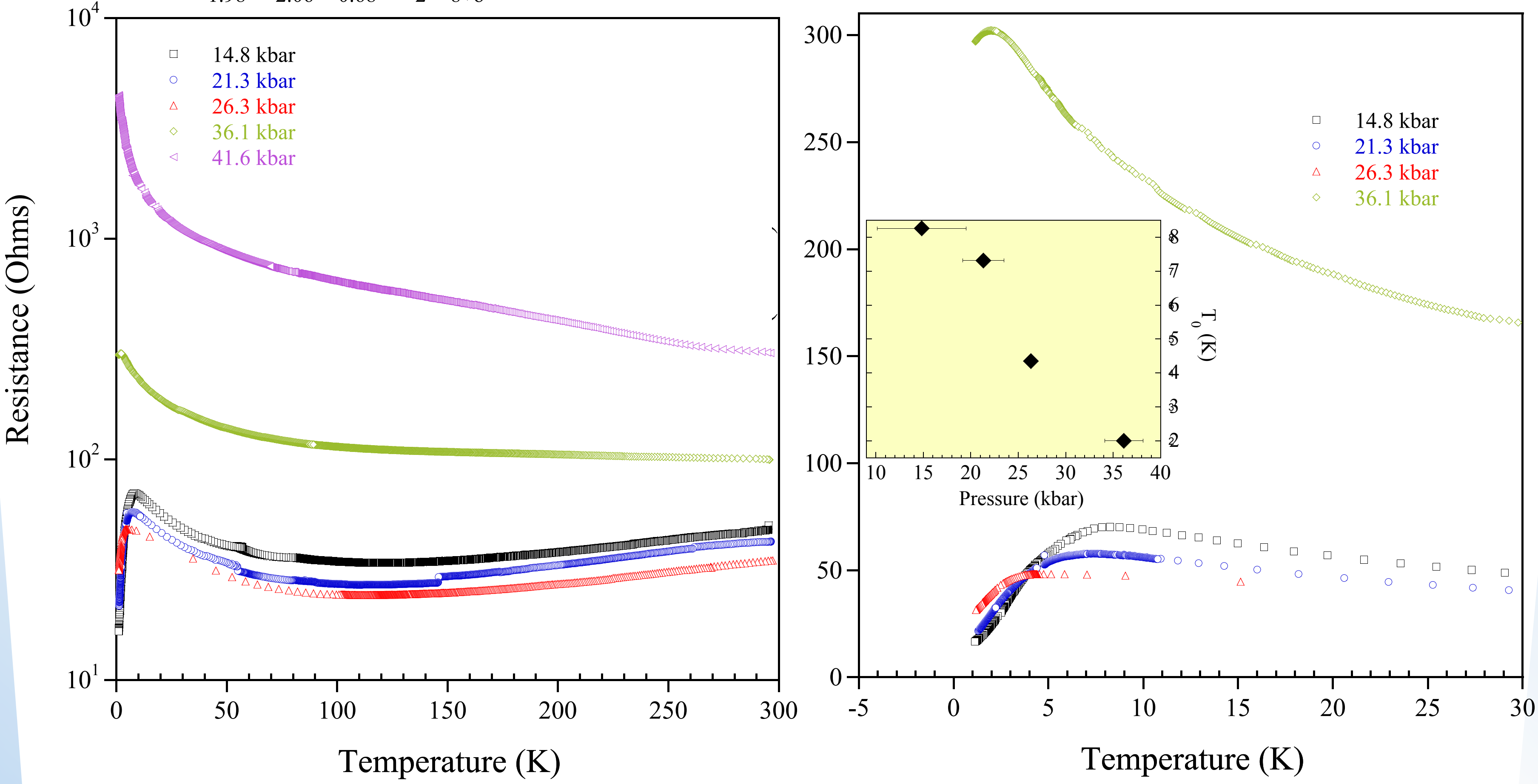
Decompression





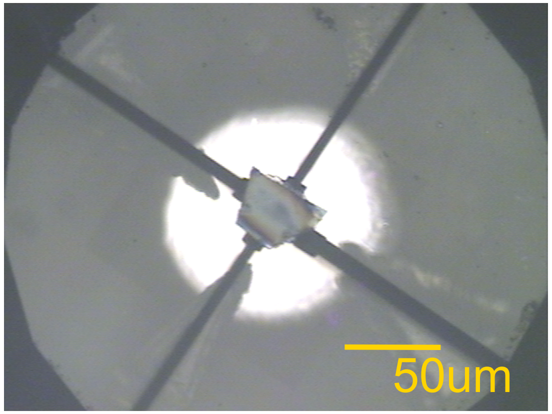
Bridgman Cell: Maple Group

$Bi_{1.98}Sr_{2.06}Y_{0.68}Cu_2O_{8+\delta}$ - Bridgman cell measurements by Diego Zocco in Brian Maple Group, UCSD



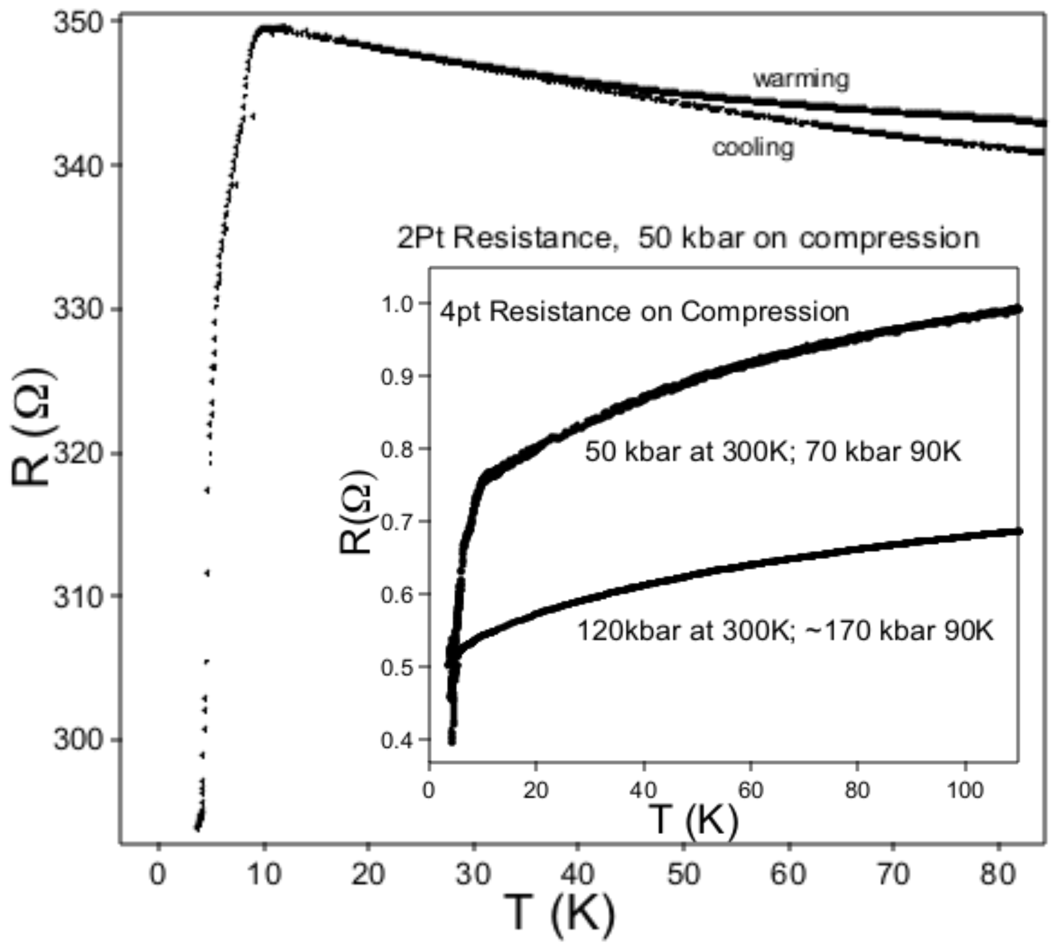
Diamond Anvil Cell

DIAMOND ANVIL CELL



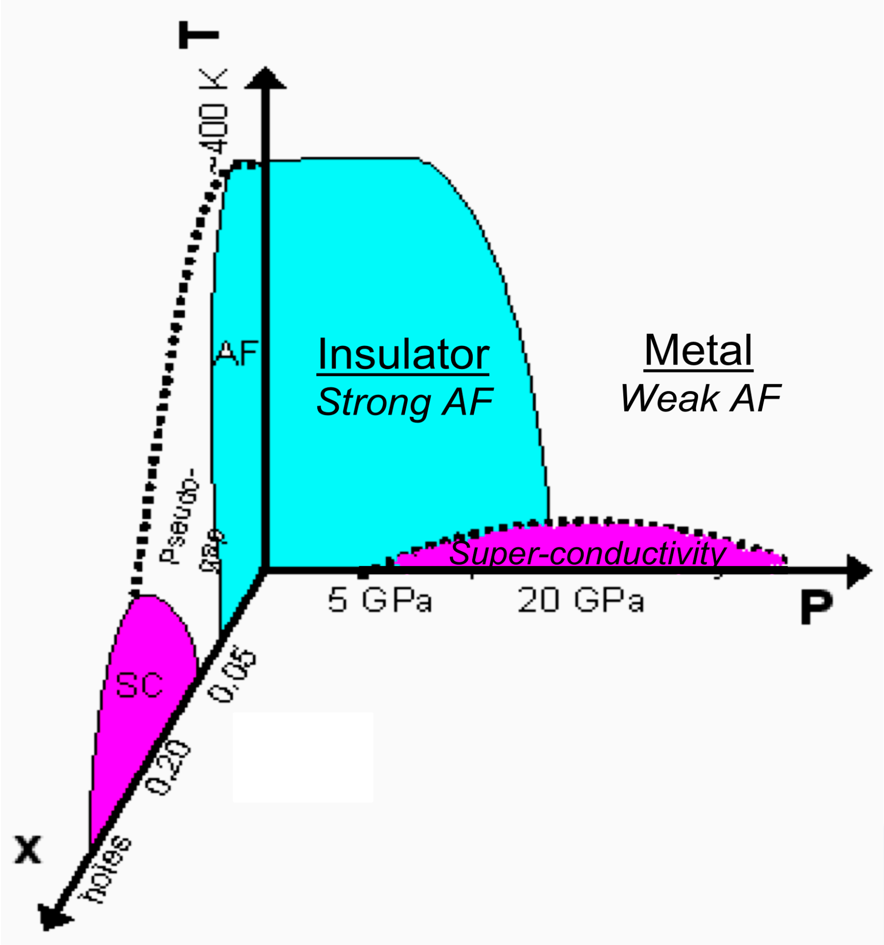
High Pressure Cell
~ 50 GPa Range

Requires FIB contacts

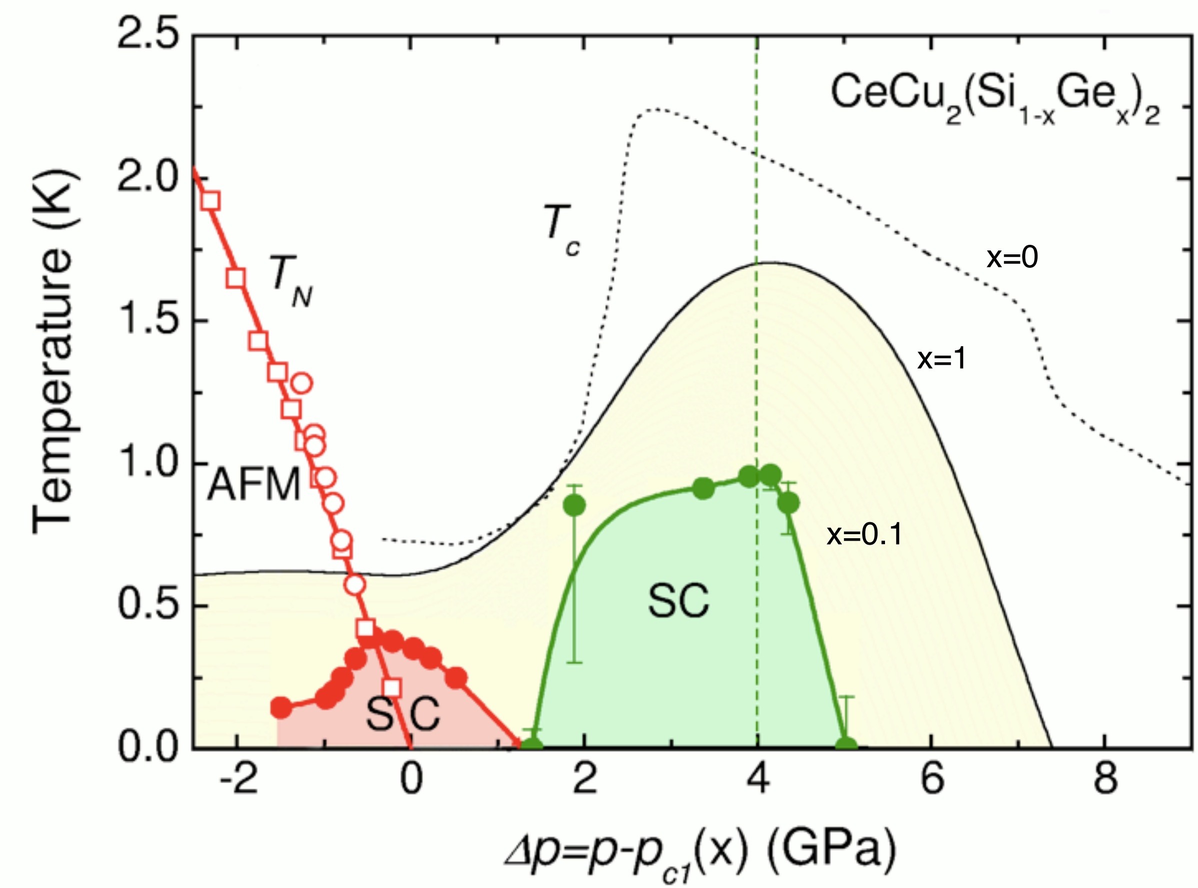


~3 GPa Transition

- Four orders of magnitude change in resistance at low temperatures
- Signatures of superconductivity in Magnetoresistance
- Seen by three different groups with Bridgman and Diamond Anvil Cells
- Inhomogeneity of pressure distribution leads to differing results at higher pressures



Comparison to Heavy Fermions



H.Q. Yuan M. Grosche Science 302, 2104 (2003)

Future Experiments

- Resistivity measurements with c-axis uniaxial pressure
- Optical Reflectivity
- Extended X-Ray Absorption Spectroscopy

Conclusions

- Two transitions at ~3 GPa and 20 GPa which resemble the insulator–superconductor transition and the putative quantum critical point at optimal doping
- At 20GPa, lattice, magnetic, and electronic dynamics change together
- Future experiments using the pressure axis will characterize the transitions better, and possibly help identify relevant terms in the Hamiltonian