Effect of out-of-plane disorder on Tc in high-Tc copper oxide superconductors

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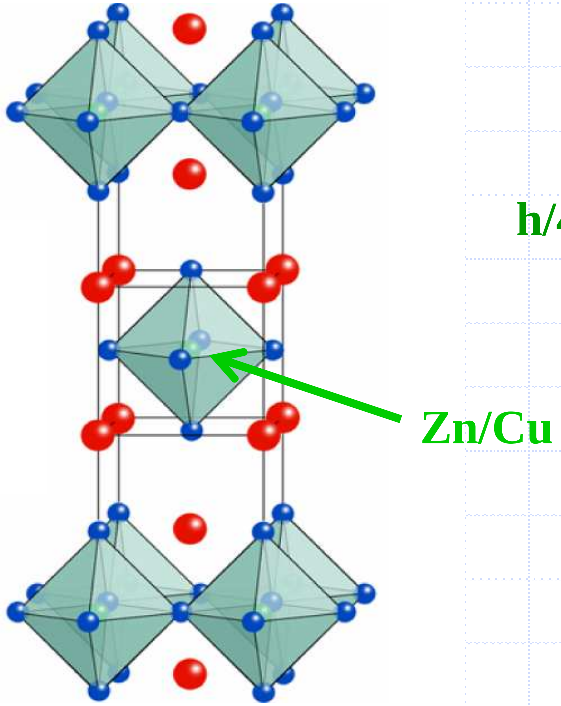
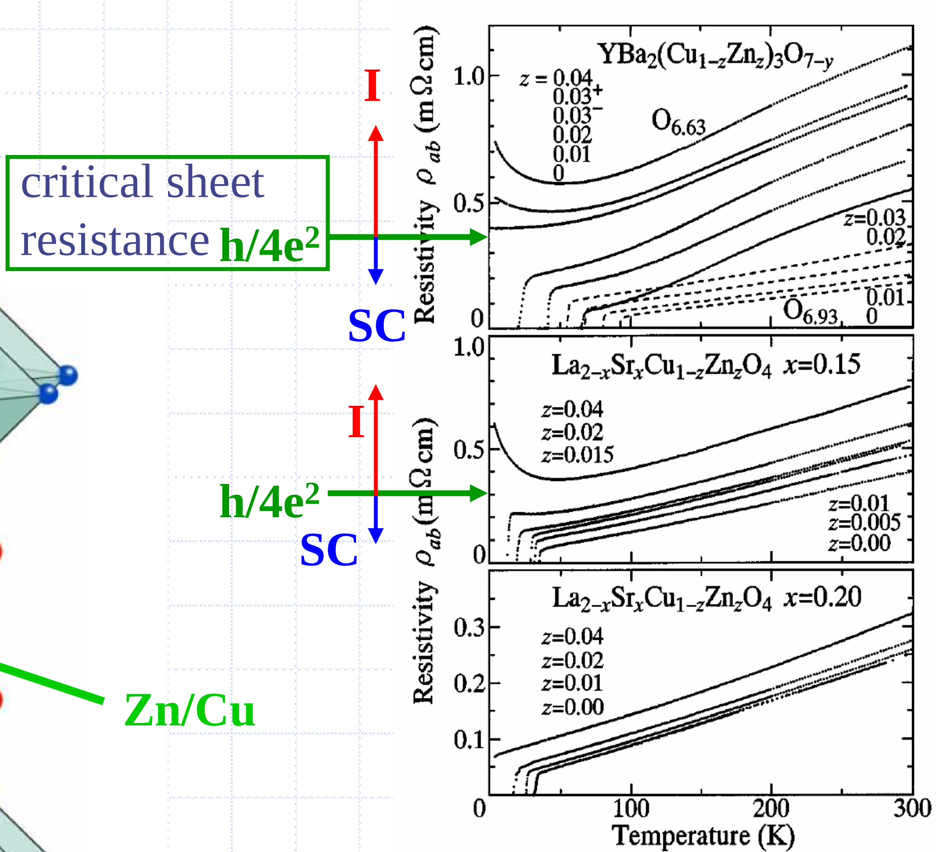
AIST	Akira Sugimoto Satoshi Kashiwaya

Chemical inhomogeneity : In-plane vs. Out-of plane

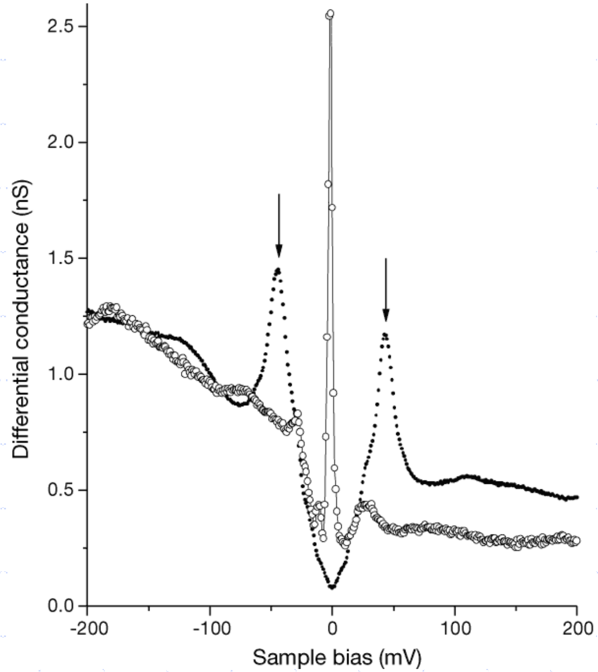
In-plane disorder : strong (unitarity limit) scattering





•Y. Fukuzumi et al.,
Phys. Rev. Lett. **76**, 684-687 (1996)

on Zn



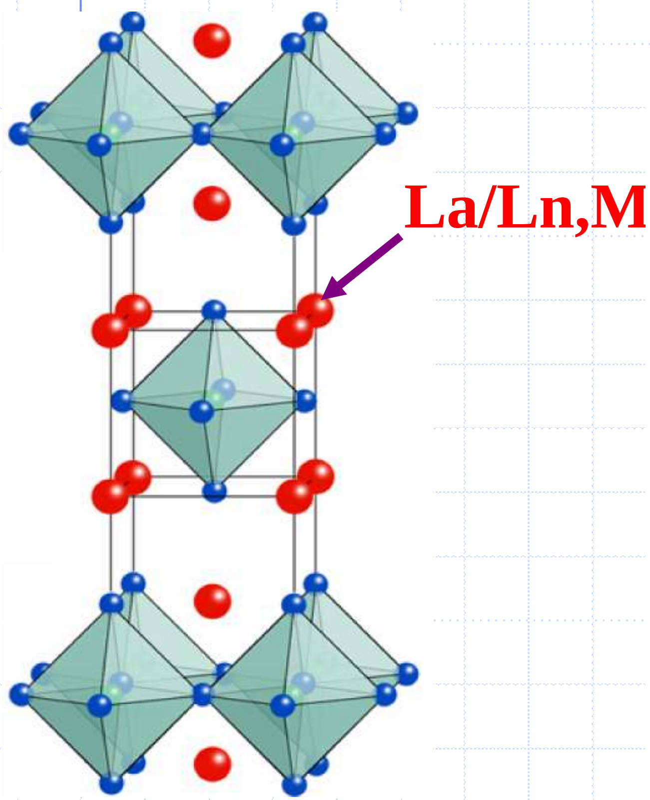
•S. H. Pan et al.,
Nature **403**, 746 (2000)

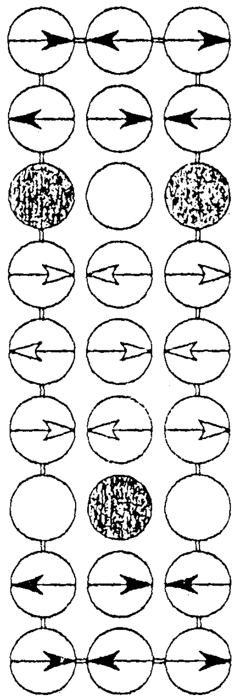
Out-of-plane disorder : also affect Tc

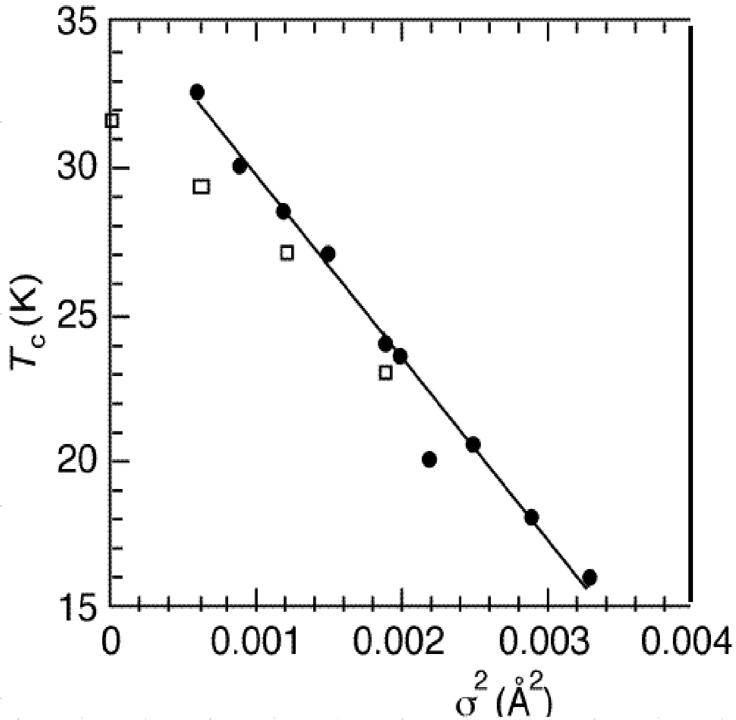
$La_{2-x-y}Ln_yM_xCuO_4$

La (1.14A) | Nd (1.04A) | Ca (0.99A) / Sr (1.12A) / Ba (1.34A)

$$\sigma^2 = \langle r_A^2 \rangle - \langle r_A \rangle^2$$





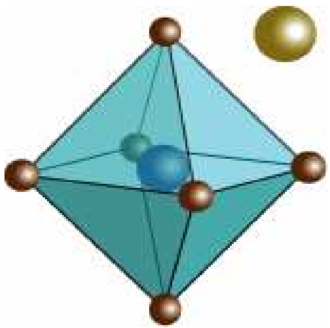


J. P. Attfield et al., Nature **394**, 157 (1998)

Location of disorder in single-layer cuprates

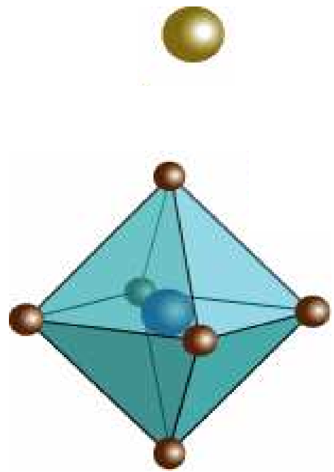
Next to apical oxygen/halogen

A-site disorder



$La_{2-x}Sr_xCuO_4$	39K
$Bi_2Sr_{2-x}La_xCuO_{6+\delta}$ (Bi2201)	38K
$TlBa_{1+x}La_{1-x}CuO_5$ (Tl1201)	45K
$PbSr_{2-x}La_xCu_2O_z$	33K
$Ca_{2-x}Na_xCuO_2Cl_2$	26K

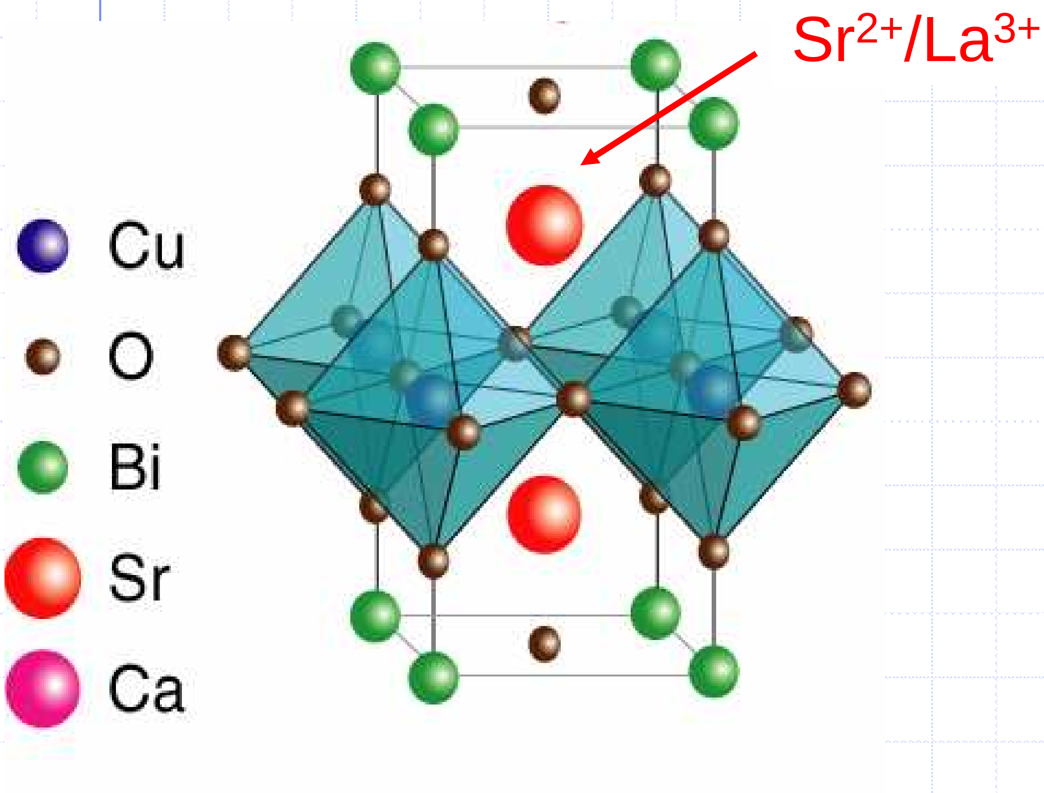
Away from CuO_2 plane

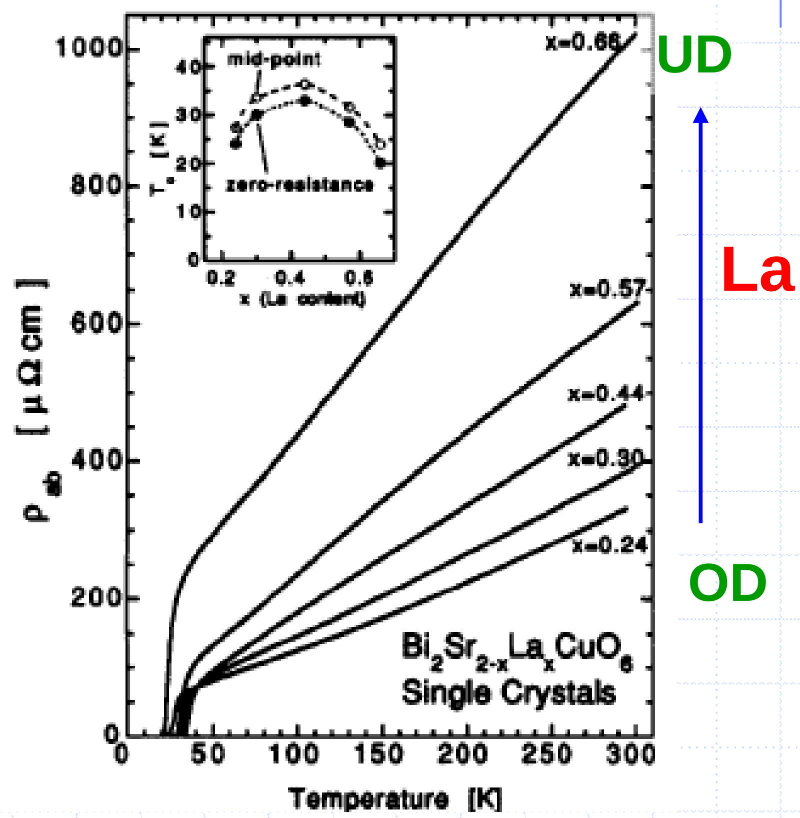


$La_2CuO_{4.055}$	45K
$Tl_2Ba_2CuO_{6+\delta}$ (Tl2201)	93K
$Hg_2Ba_2CuO_{4+\delta}$ (Hg1201)	94K
$Sr_2CuO_2F_{2+x}$	46K

Case study -- Bi2201

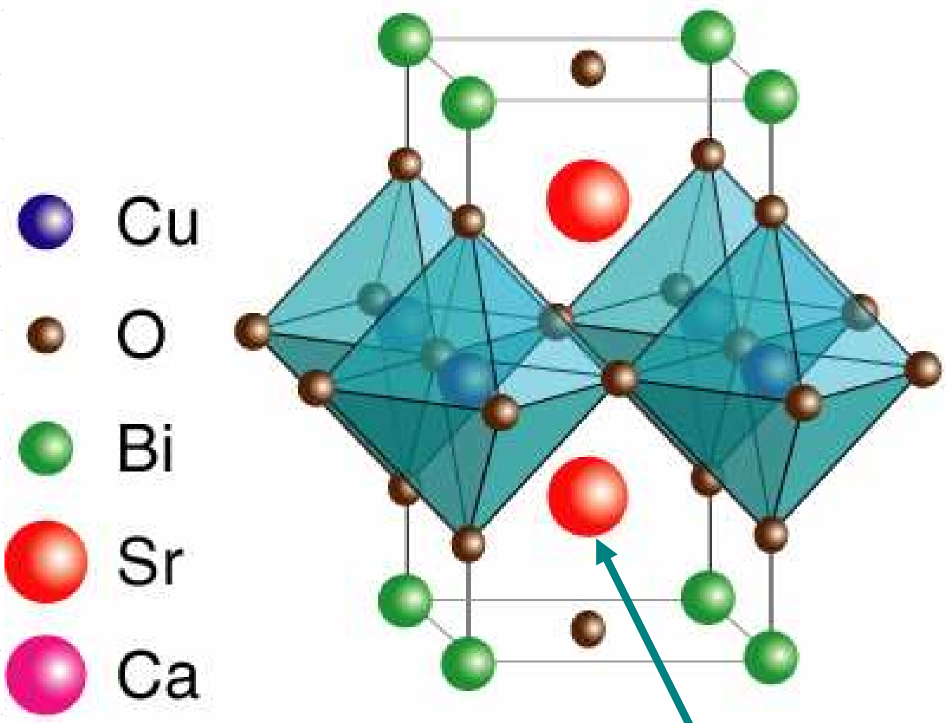
Hole doping -- $Bi_2Sr^{2+}_{2-x}La^{3+}_xCuO_{6+\delta}$





Y. Ando et al., PRB60, R6901 (1999)

"Active" control of chemical disorder



$Sr_{1.6}Ln_{0.4}$

$Bi_2Sr_{1.6}Ln_{0.4}CuO_{6+\delta}$

Sr (1.12A)

La (1.14A)

Pr (1.06A)

Nd (1.04A)

Eu (0.98A)

Gd (0.97A)

- cf. $La_{2-x-y}Ln_yM_xCuO_4$

La (1.14A)

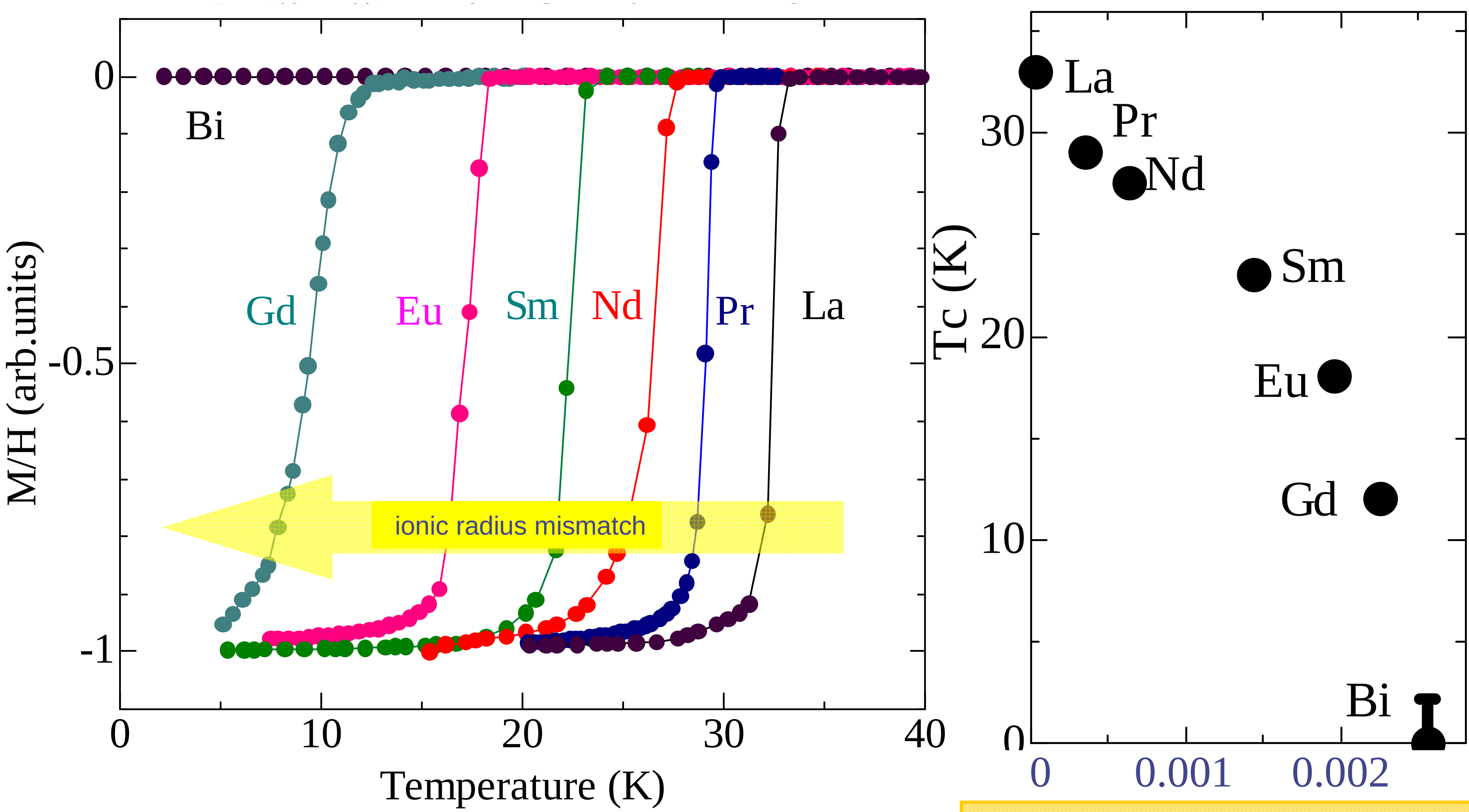
Nd (1.04A)

Ca (0.99A)

Sr (1.12A)

Ba

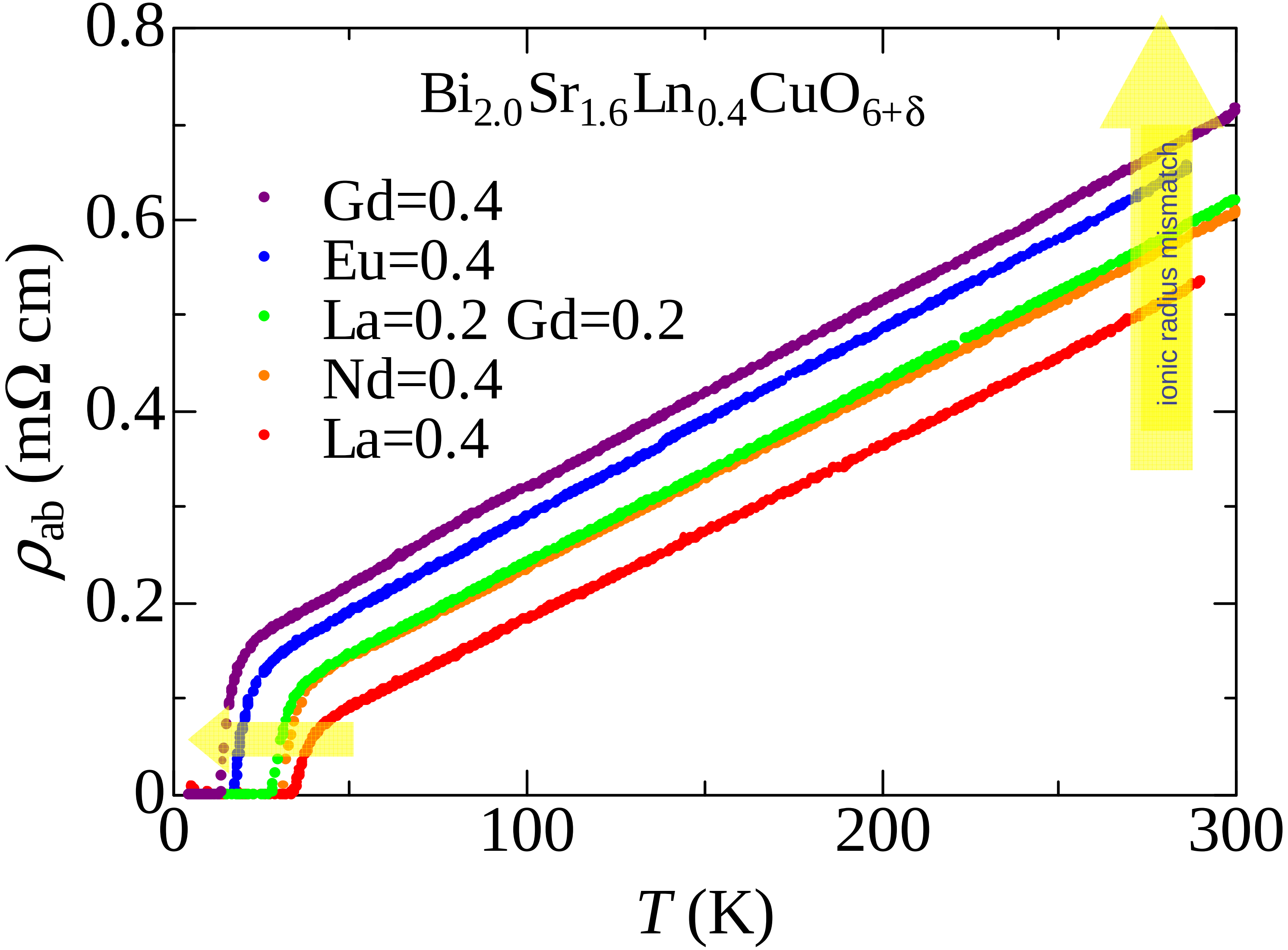
Bi2201 : T_c scaled to the magnitude of disorder



$\sigma^2 = \langle r_{Sr/Ln}^2 \rangle - \langle r_{Sr/Ln} \rangle^2$

H. Eisaki, N. Kaneko, D.L. Feng, A. Damascelli, P. K. Mang, K. M. Shen, Z.-X. Shen, M. Greven, PRB69, 064512 (2004)

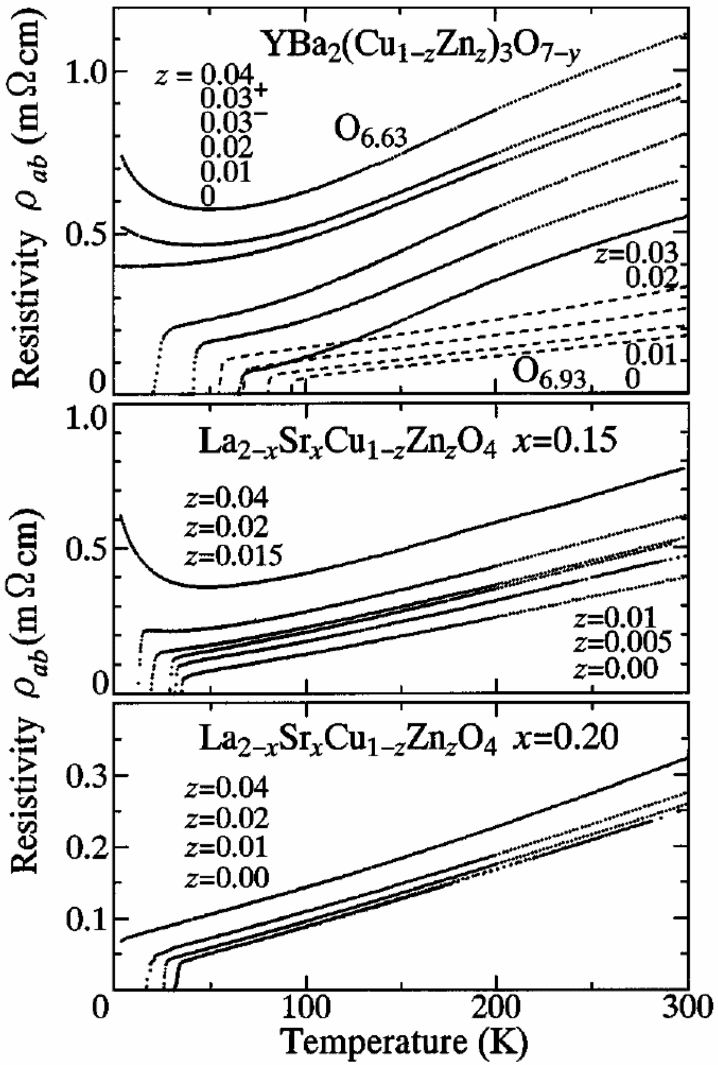
In-plane Resistivity measurement



K. Fujita, S. Uchida, H. Eisaki

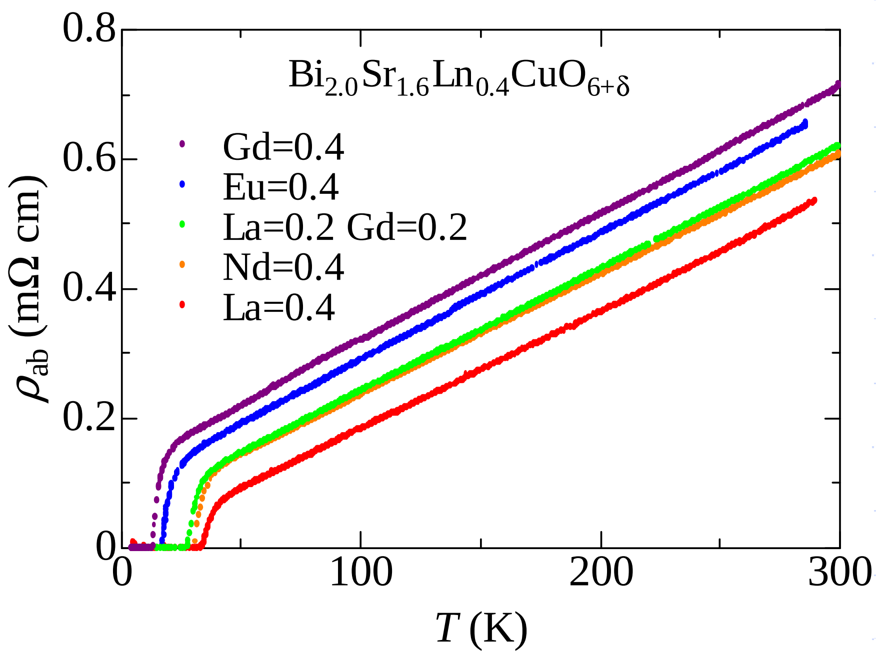
In-plane vs. Out-of plane :Similar look

In-plane



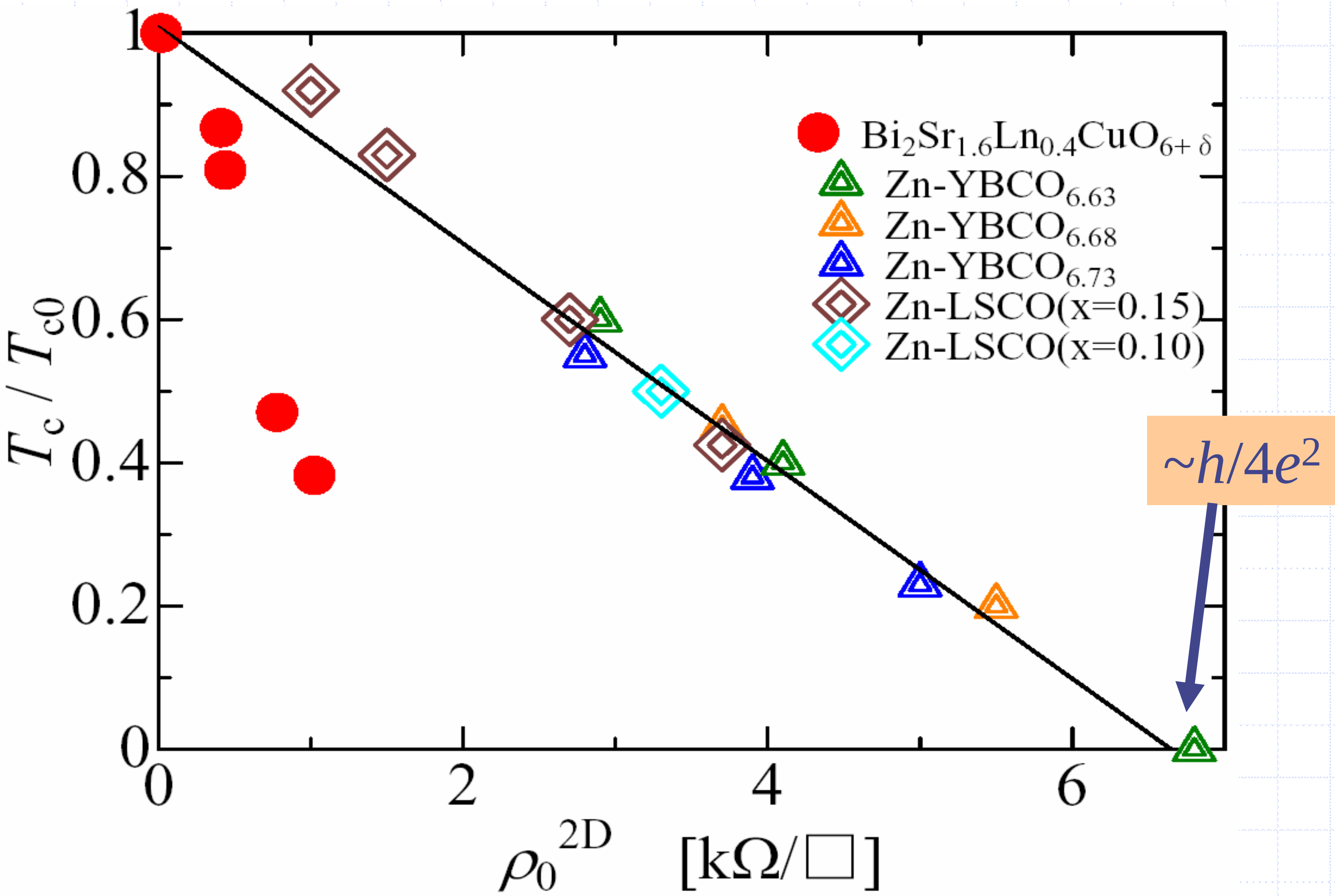
Fukuzumi *et al.*, PRL **76**, 684 (1996)

Out-of-plane



With decreasing T_c, residual resistivity increase. Apparently, similar results.

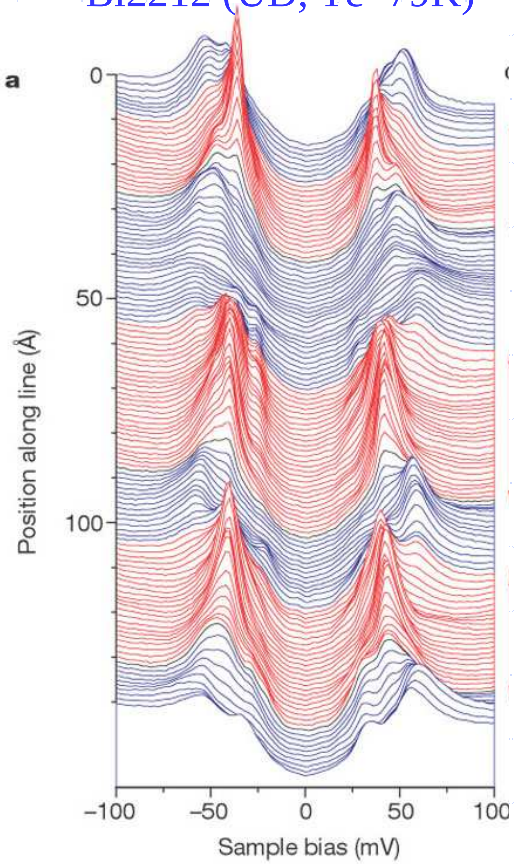
(Presumably) different mechanism

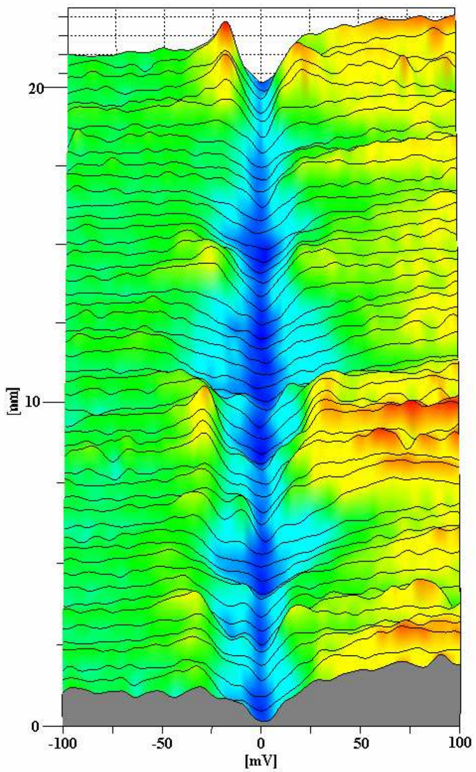


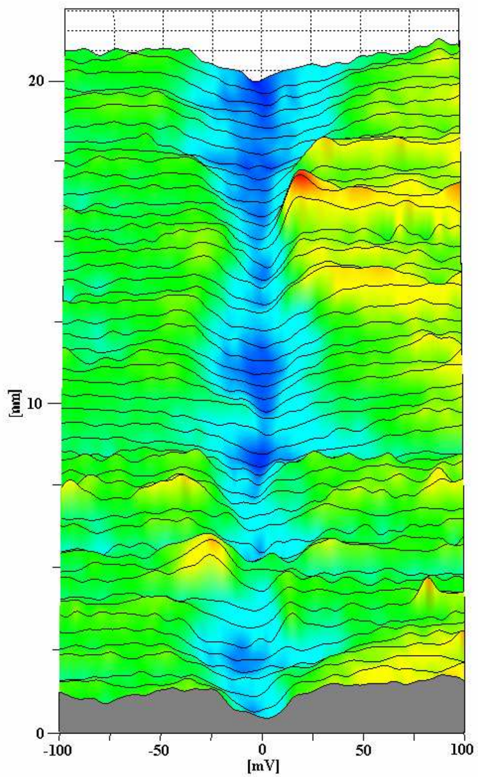
ρ_0^{2D} are much smaller than universal sheet resistance ~$h/4e^2$, while T_c is largely suppressed.

STS observation

Bi2212 (UD, Tc=79K) $Bi_2Sr_{1.6}La_{0.4}CuO_6$ (OP,Tc=34K) $Bi_2Sr_{1.6}Gd_{0.4}CuO_6$ (OP,Tc=14K)

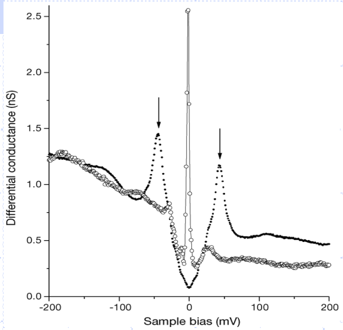






K. M. Lang et al.,
Nature **415**, 412 (2002)

Small → **Disorder** → **Large**

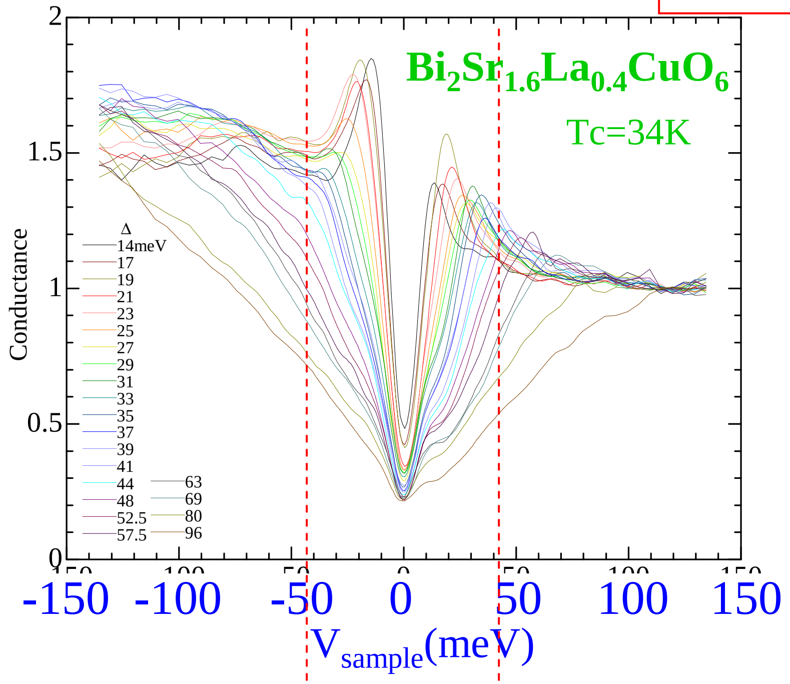


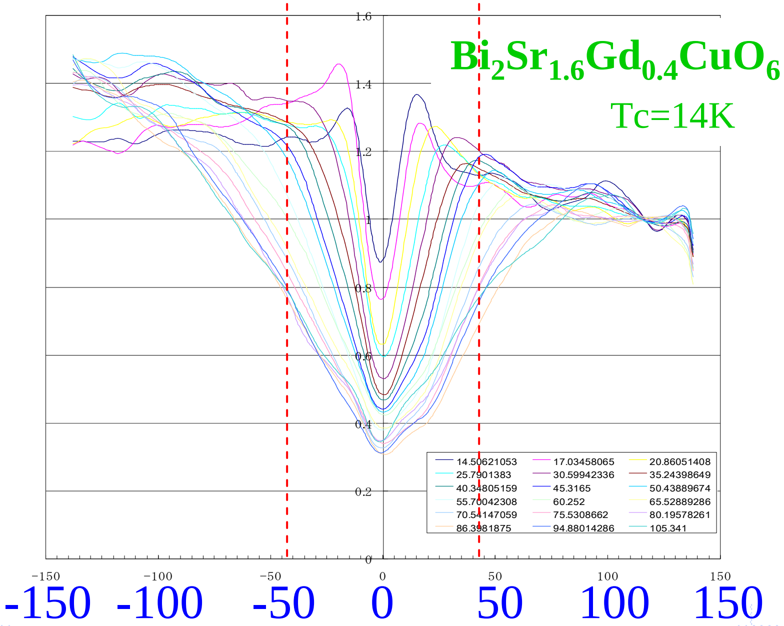
Out-of-plane disorder affects SC gap

Different from in-plane disorder (Zn, Ni)

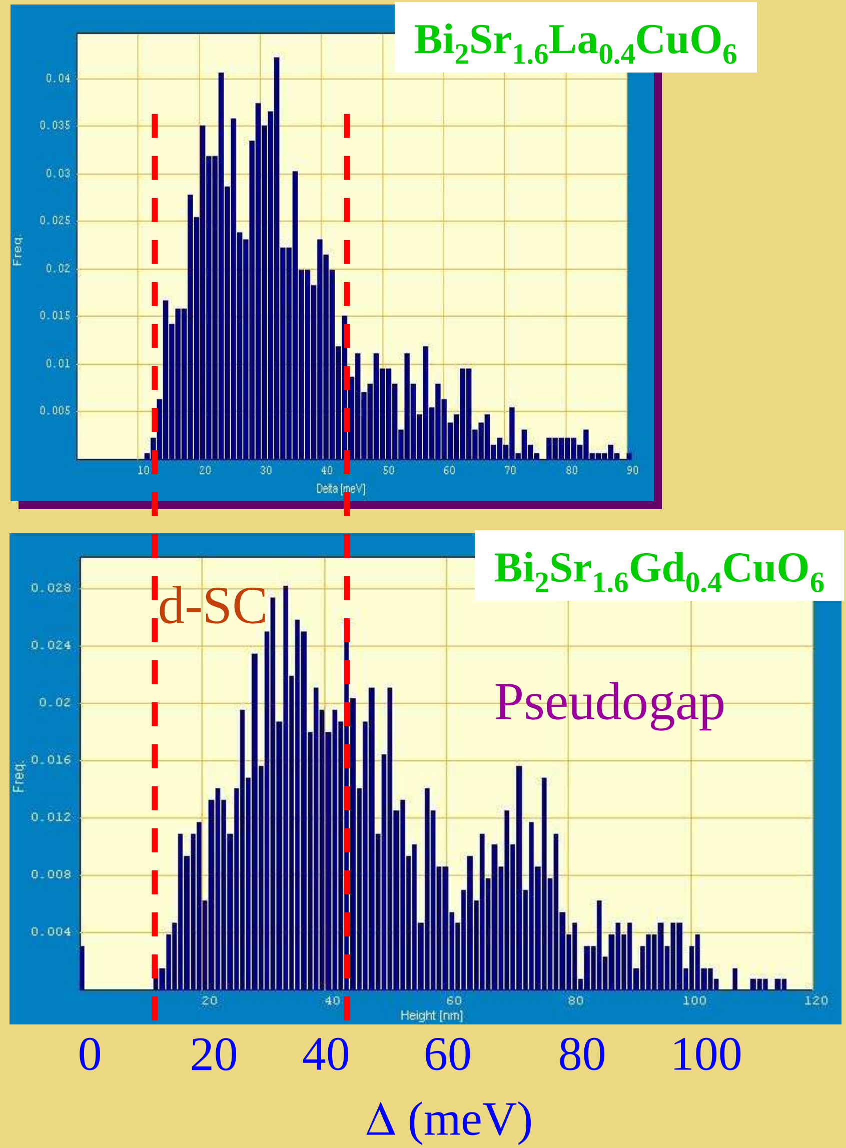
No scaling between Δ and Tc

Closer look

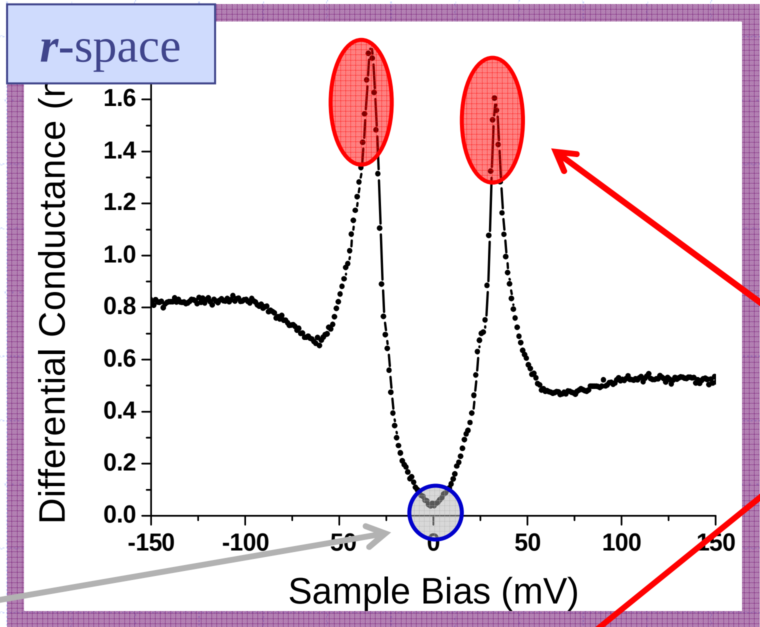


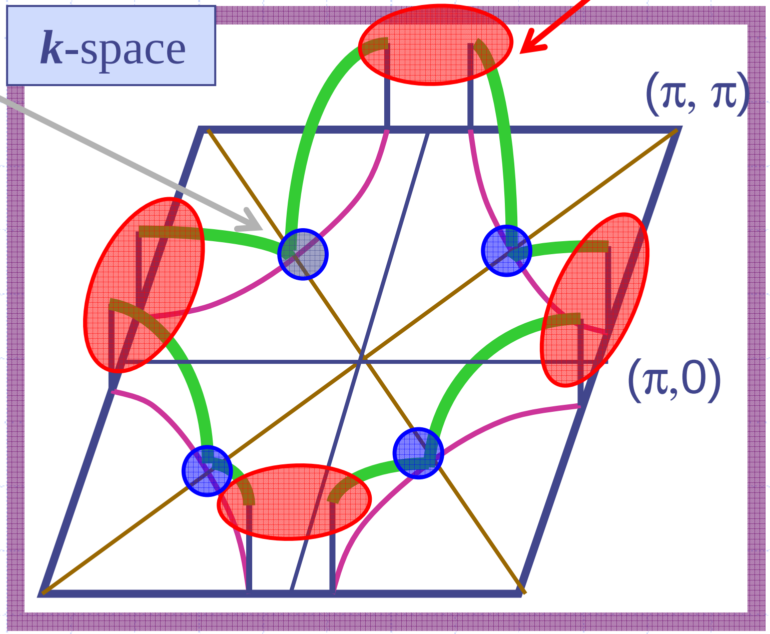


☆Gap(Δ) histogram



r-space vs. k-space





Nodes

(π/2, π/2)

Cold spot

normal state

charge dynamics

Anti-nodes

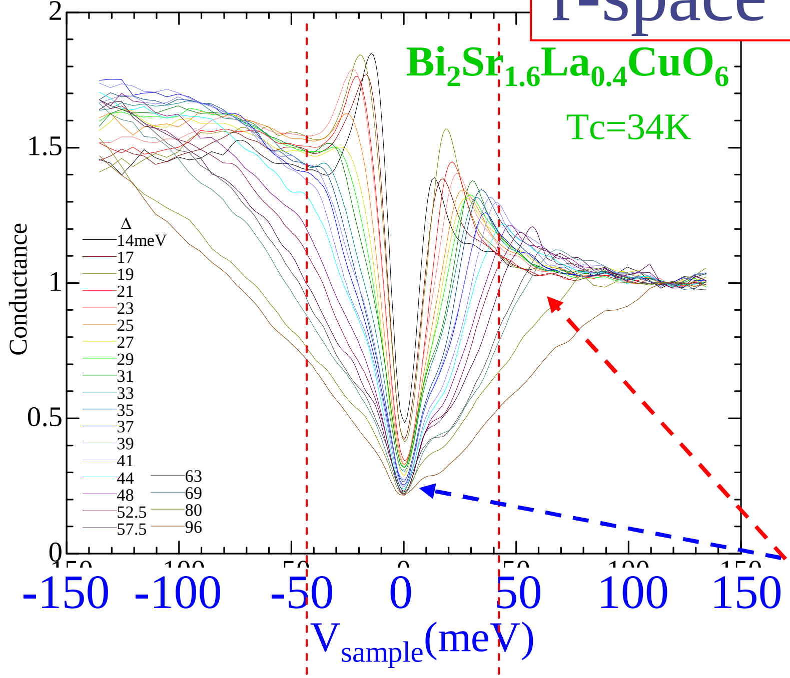
(π,0)

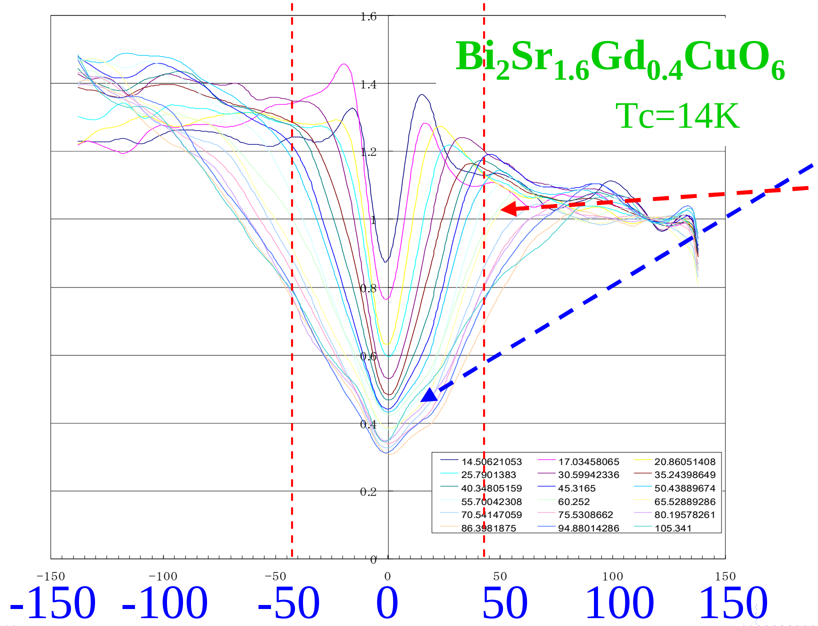
Hot spot

d-wave

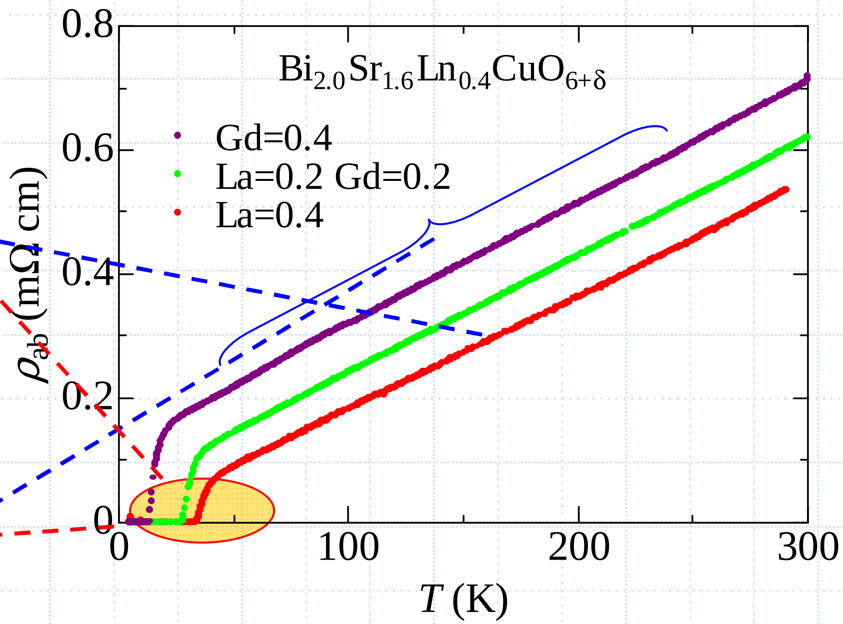
superconductivity

r-space vs. k-space





Node normal state
charge dynamics



Anti-node

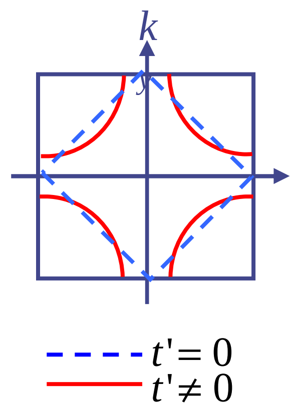
d-wave SC
Pseudogap

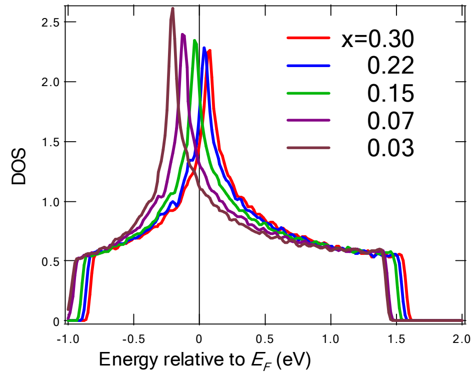
cf. μSR

Possible scenarios

local lattice distortion

T. Tohyama, Phys. Rev. B70, 174513 (2004)

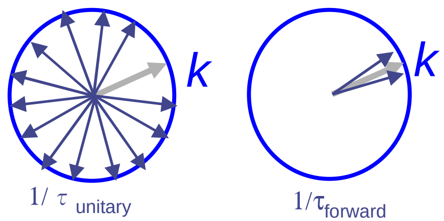




inhomogeneous hole distribution

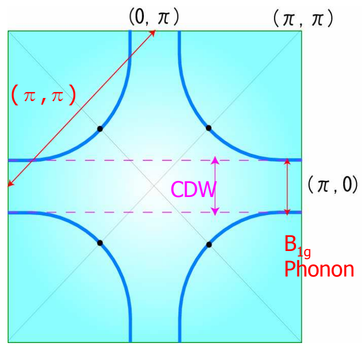
P. M. Singer, A.H. Hunt, T. Imai, cond-mat/0302078

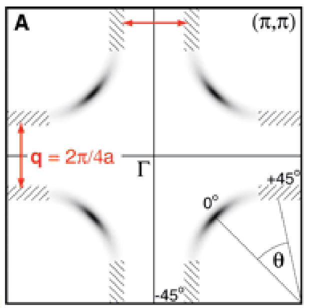
k-dependent scattering



L. Zhu, P. J. Hircshfeld, D. J. Scalapino, PRB70, 214503 (2004)

coupling to Bosonic modes





T.Cuk et al., PRL 93, 117003 (2004).

T. P. Devereaux et al.,PRL **93**, 117004 (2004).

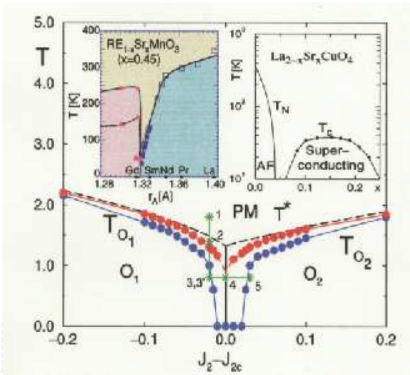
Z. –X. Shen, J. R. Schrieffer, PRL **78**, 1771 (1997)

competing order

Kyle M. Shen et al., Science 307, 901 (2005)

T. Hanaguri et al., Nature 430, 1001 (2004)

J. Burgy et al., Phys. Rev. Lett. 87, 277202 (2001)



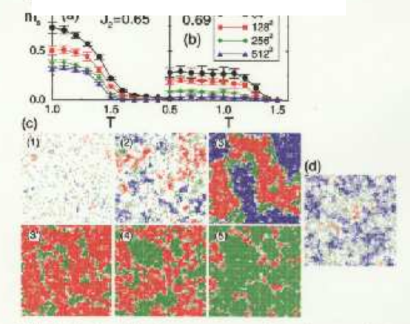


FIG. 2 (color). AF order parameter vs T for the toy model at fixed W = 1.5, using several lattice sizes with periodic boundary