Robert J. Birgeneau

University of California, Berkeley

"High Temperature Superconductivity and Magnetism:

Friends or Foes?"

NIST

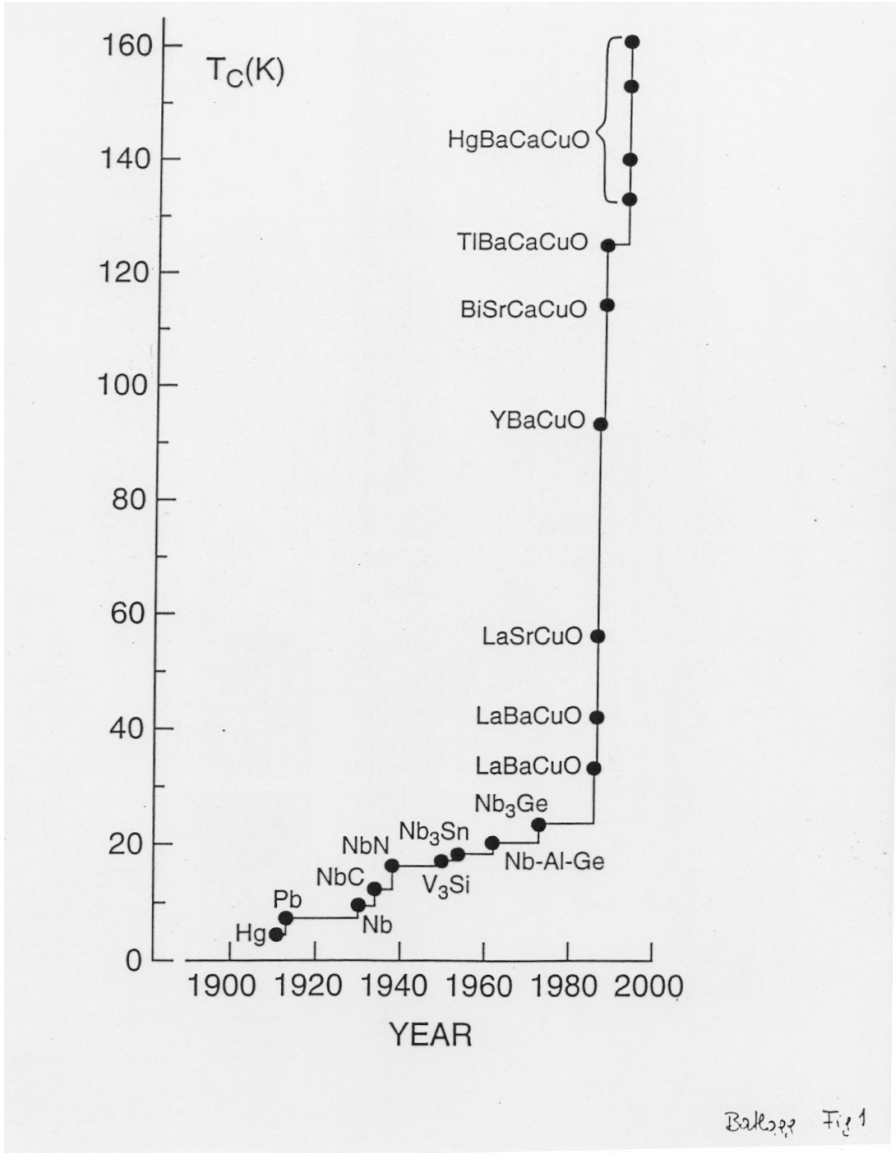
Neutron Research at NIST

NCNR

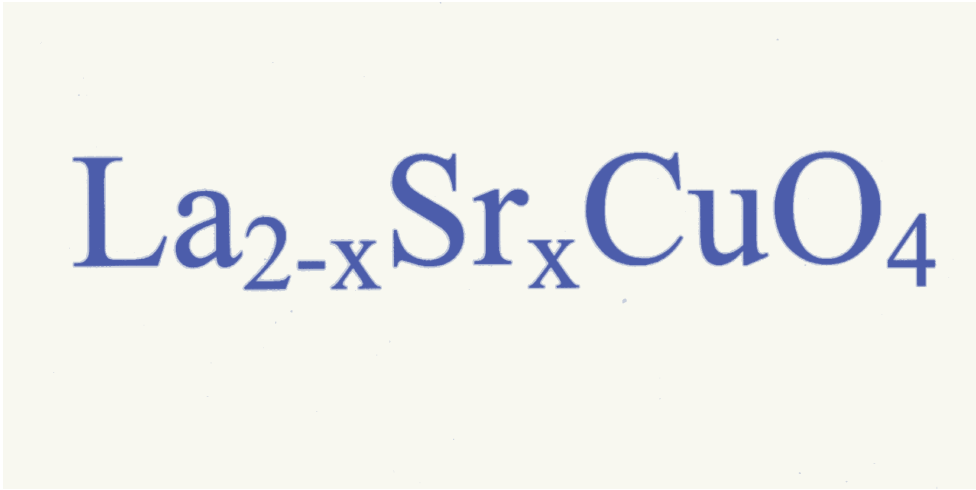
A Symposium Honoring Mike Rowe and Jack Rush

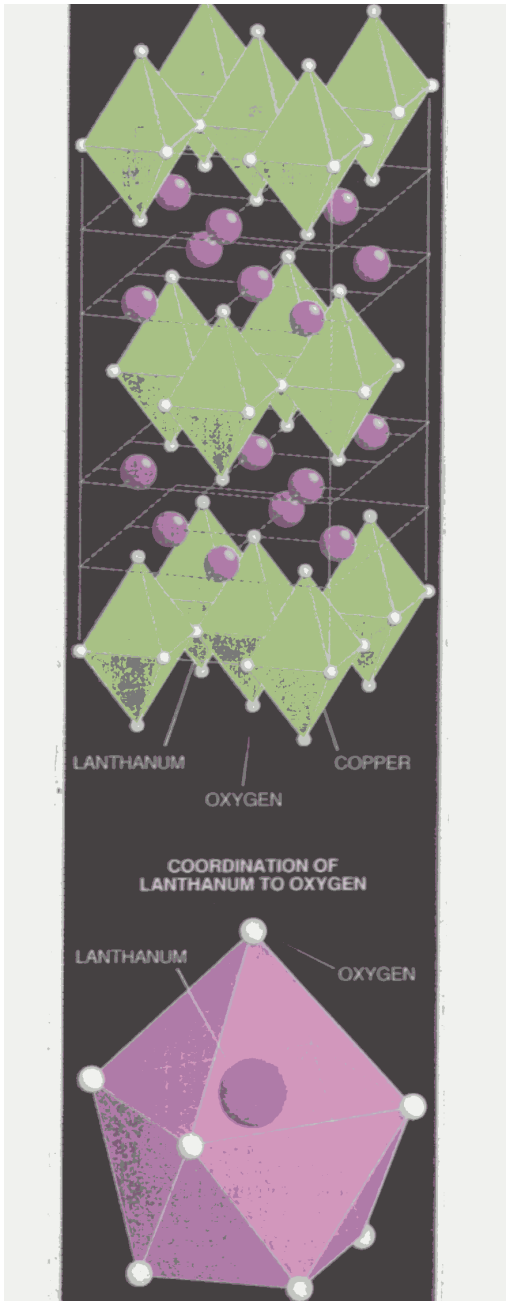
September 9, 2005 - Rockville, Maryland

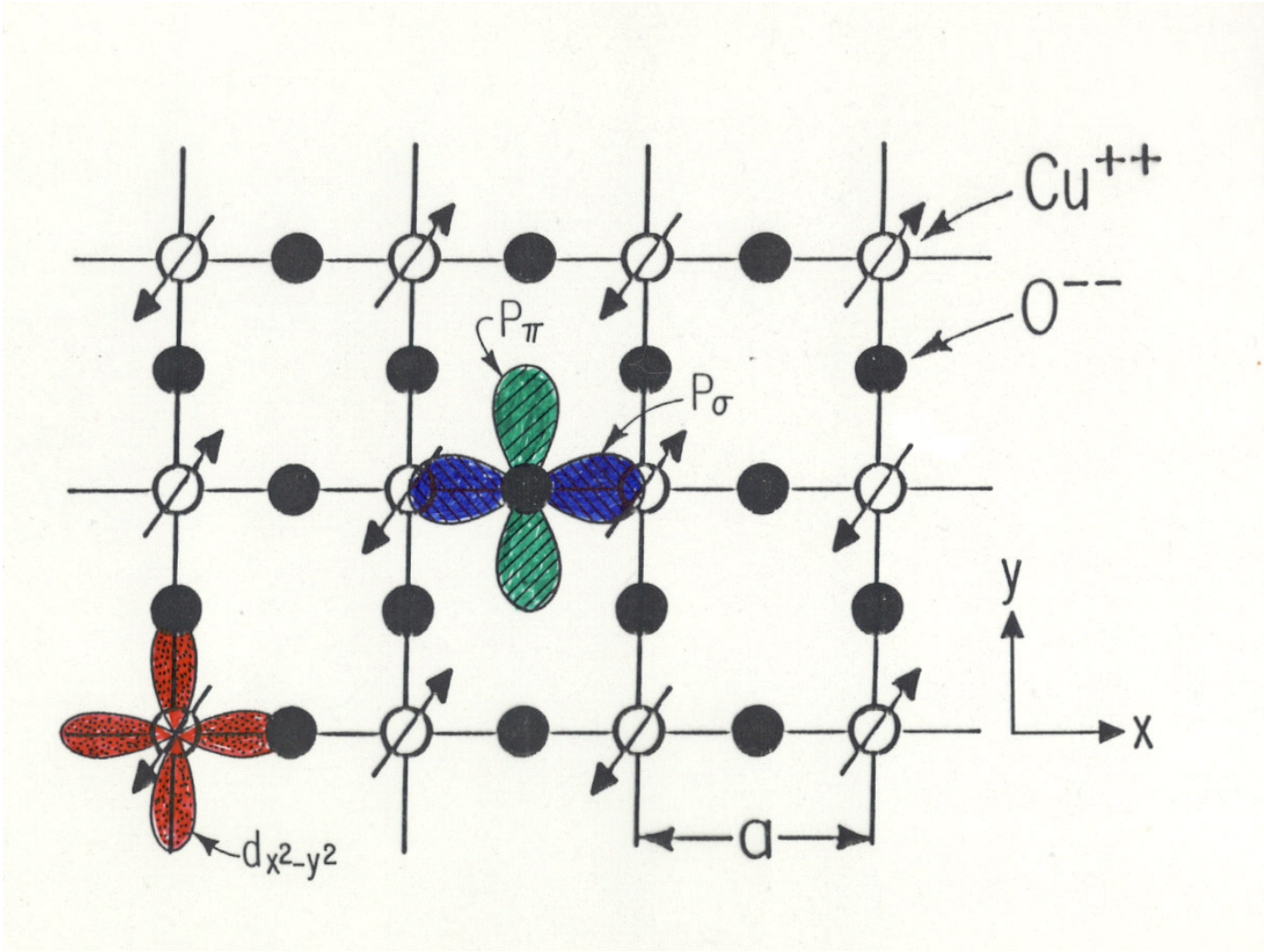

N1
BERKELEY LAB
"CALIFORNIA RESEARCH


160
140
120
100
80
60
40
20
0
T_C(K)
HgBaCaCuO
TlBaCaCuO
BiSrCaCuO
YBaCuO
LaSrCuO
LaBaCuO
LaBaCuO
Nb_3Ge
Nb_3Sn
NbN
Nb-Al-Ge
NbC
V_3Si
Pb
Nb
Hg
1900 1920 1940 1960 1980 2000
YEAR

Bakker Fig 1


La2-xSrxCuO4


LANTHANUM
OXYGEN
COPPER
COORDINATION OF
LANTHANUM TO OXYGEN
LANTHANUM
OXYGEN


Cu++
O--
Pπ
Pσ
y
x
a
dx2-y2

$YBa_2Cu_3O_{6.5}$

Ortho - II

Crystal Structure of $YBCO_{6+x}$:

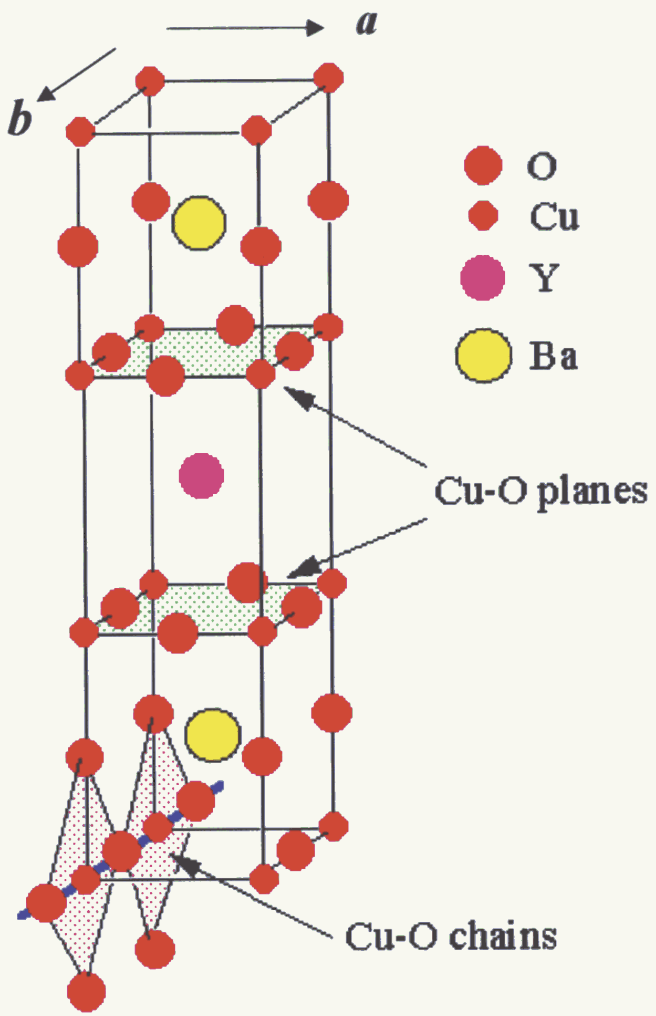
C. Stock, W. J. L. Buyers *et al.*

***x*=0.5**
a=3.84 Å
b=3.88 Å
c=11.78 Å

Orthorhombic for *x*>0.3:
1-a/b = 0.01
for *x*=0.5

J. D. Jorgensen *et al.* Phys. Rev. B. **41**, 1863 (1990).

H. Casalta *et al.* Physica C **258**, 321 (1996).

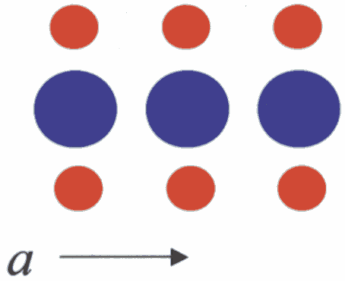


Chain Oxygen Staging and Superstructures ($YBCO_{6+x}$):

C. Stock, W. J. L. Buyers *et al.*

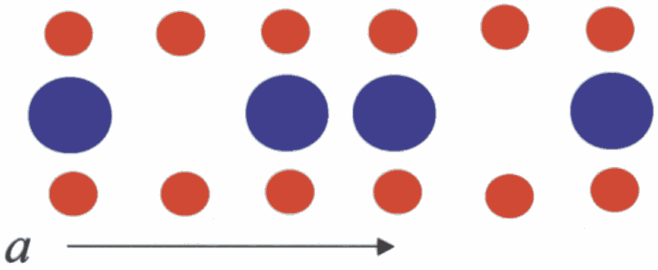
Ortho–I Phase:

x=1.0



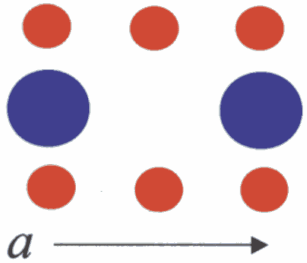
Ortho–III Phase:

x=0.67



Ortho–II Phase:

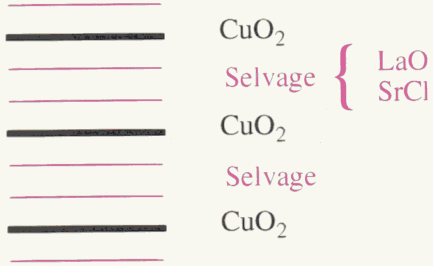
x=0.5



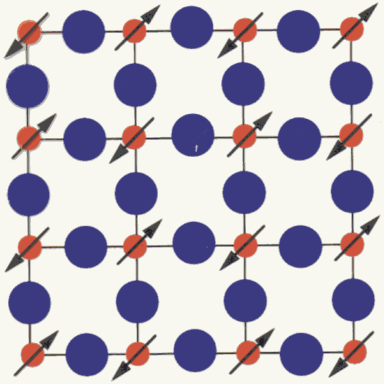
N. H. Andersen *et al.*
Physica C. **317-318**
(1999).

The Copper Oxides

Schematic Structure



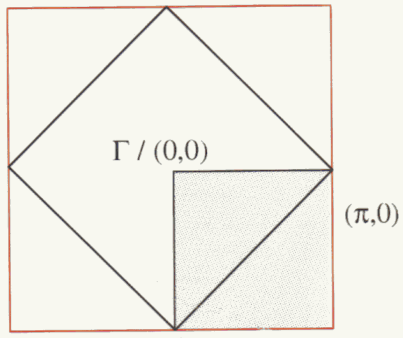
The Copper Oxygen Plane



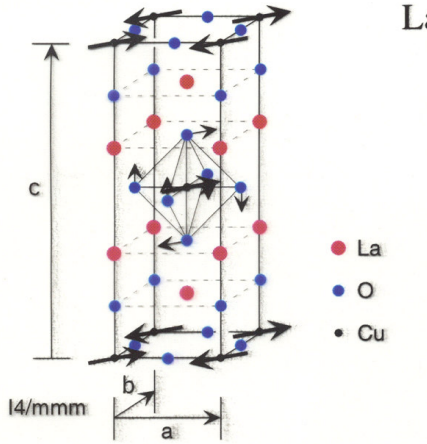
Oxygen

Copper

The 2D Brillouin Zone



$La_{2-x}Sr_xCuO_4$



La_2CuO_4

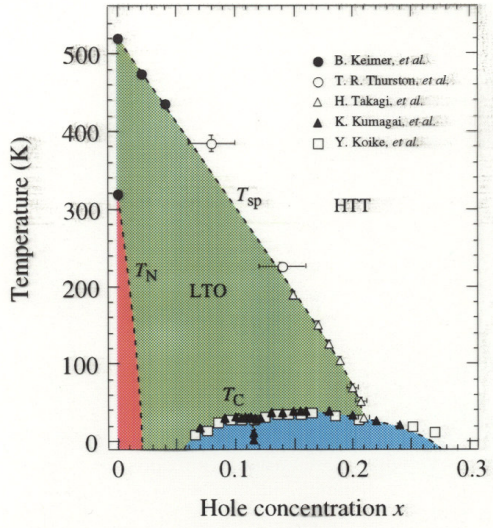
- Antiferromagnet Insulator

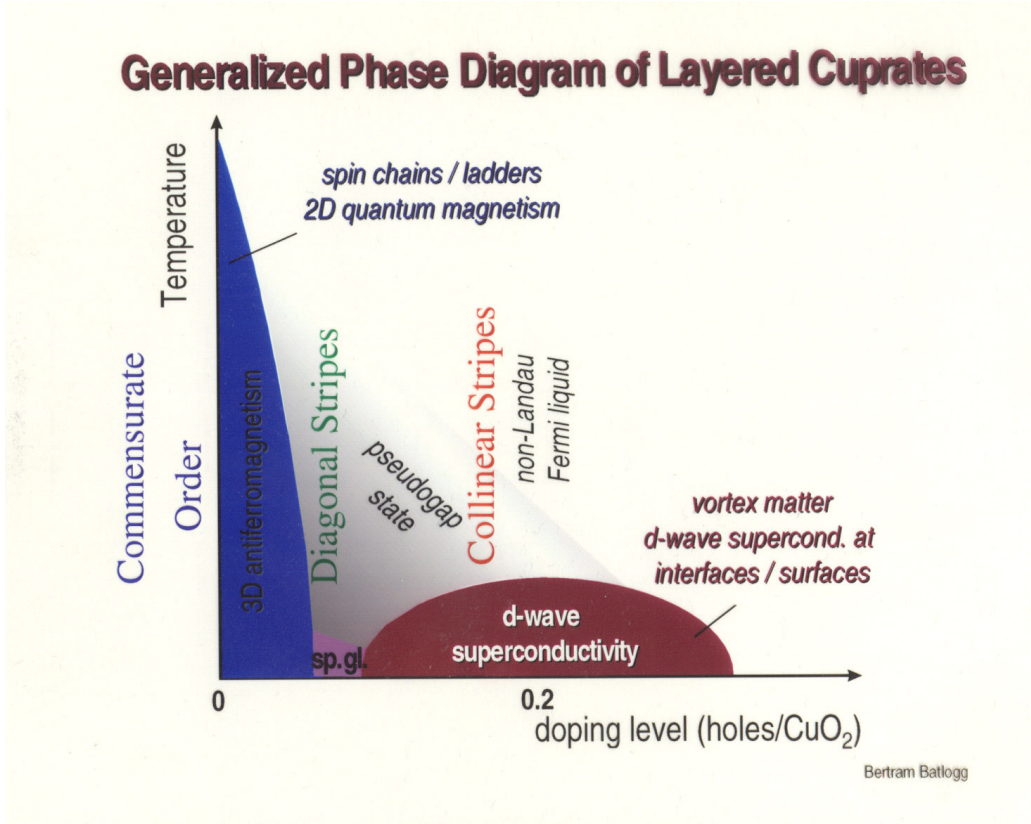
  T_N=320K

- Tetragonal(I4/mmm)

  ↓ T_{sp}=520K

  Orthorhombic(Bmab)




Generalized Phase Diagram of Layered Cuprates
Temperature
spin chains / ladders
2D quantum magnetism
Commensurate
Order
3D antiferromagnetism
Diagonal Stripes
pseudogap
state
Collinear Stripes
non-Landau
Fermi liquid
vortex matter
d-wave supercond. at
interfaces / surfaces
d-wave
superconductivity
sp.gl.
0
0.2
doping level (holes/CuO2)
Bertram Batlogg

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	Ross Erwin	NIST
	Masaki Fujita	Kyoto Univ.
	Peter Gehring	NIST
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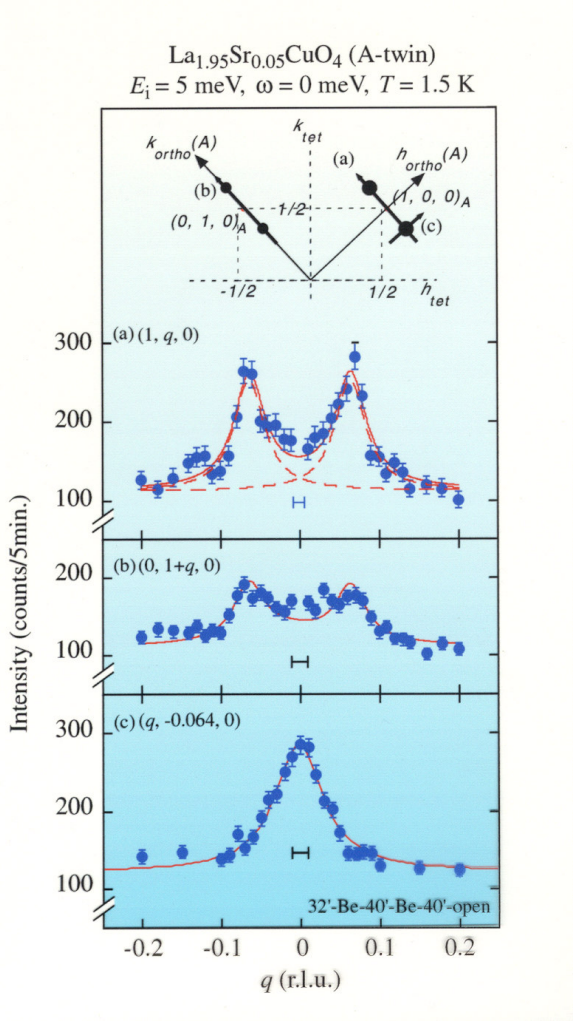
	Seung-Hun Lee	NIST
✸	Young S. Lee	MIT
	Masa Matsuda	RIKEN
✸	Shuichi Wakimoto	MIT/Tohoku


$La_{1.95}Sr_{0.05}CuO_4$ (A-twin)
E_i = 5 meV, ω = 0 meV, T = 1.5 K
k_{tet}
k_{ortho}(A)
h_{ortho}(A)
(a)
(b)
(c)
(0, 1, 0)$_A$
(1, 0, 0)$_A$
1/2
-1/2
1/2
h_{tet}
(a) (1, q, 0)
(b) (0, 1+q, 0)
(c) (q, -0.064, 0)
300
200
100
200
100
300
200
100
Intensity (counts/5min.)
32'-Be-40'-Be-40'-open
-0.2
-0.1
0
0.1
0.2
q (r.l.u.)

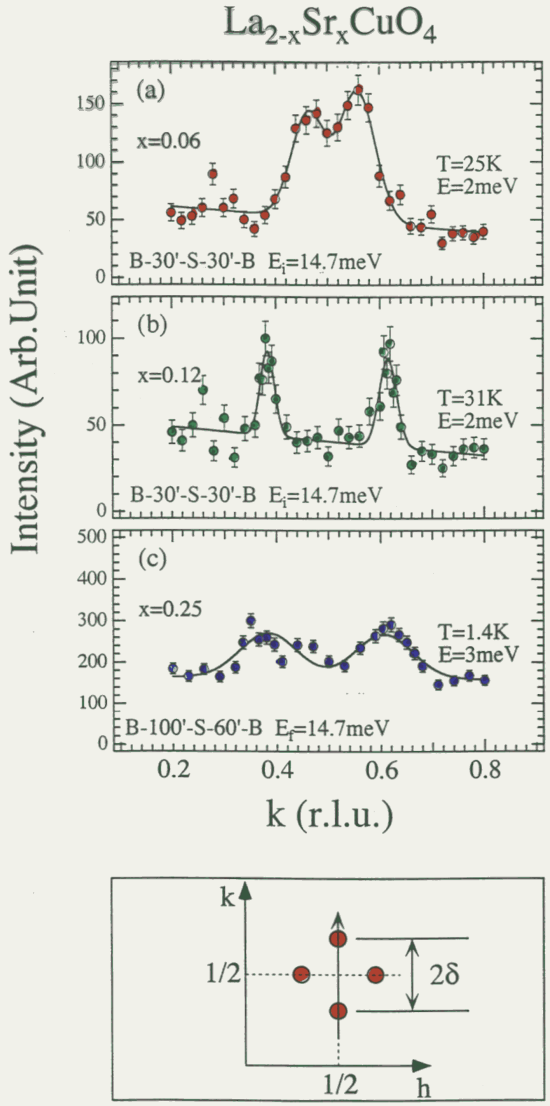
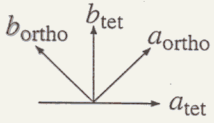


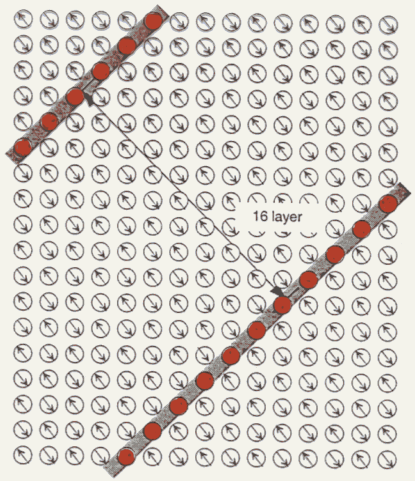
Fig.4: K.Yamada et al

$La_{1.95}Sr_{0.05}CuO_4$

Insulator

絶縁体

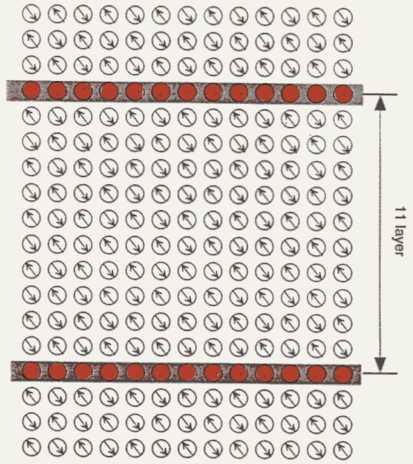




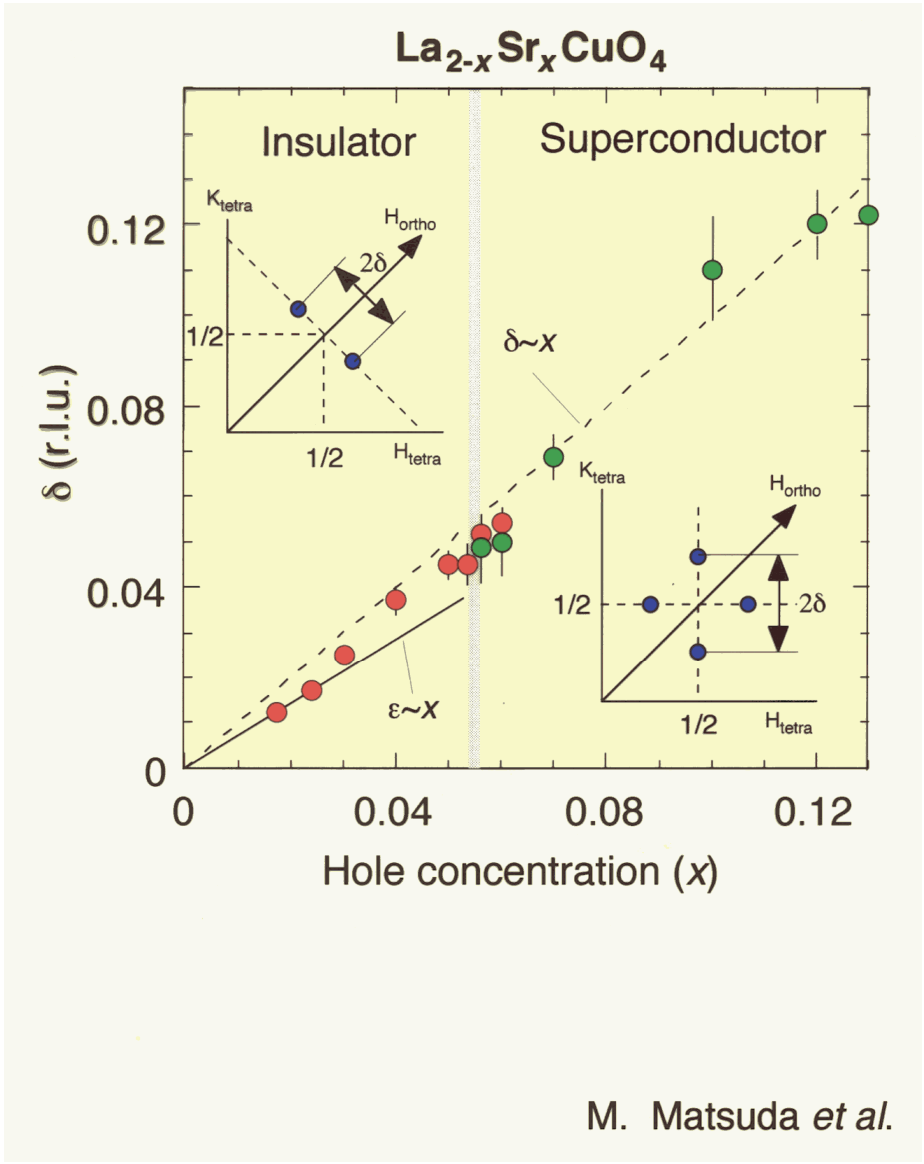
$La_{1.94}Sr_{0.06}CuO_4$

Superconductor

超伝導体



Hole concentration in a charge stripe
ストライプ上のホール濃度 ~0.7 holes/Cu



M. Matsuda *et al.*

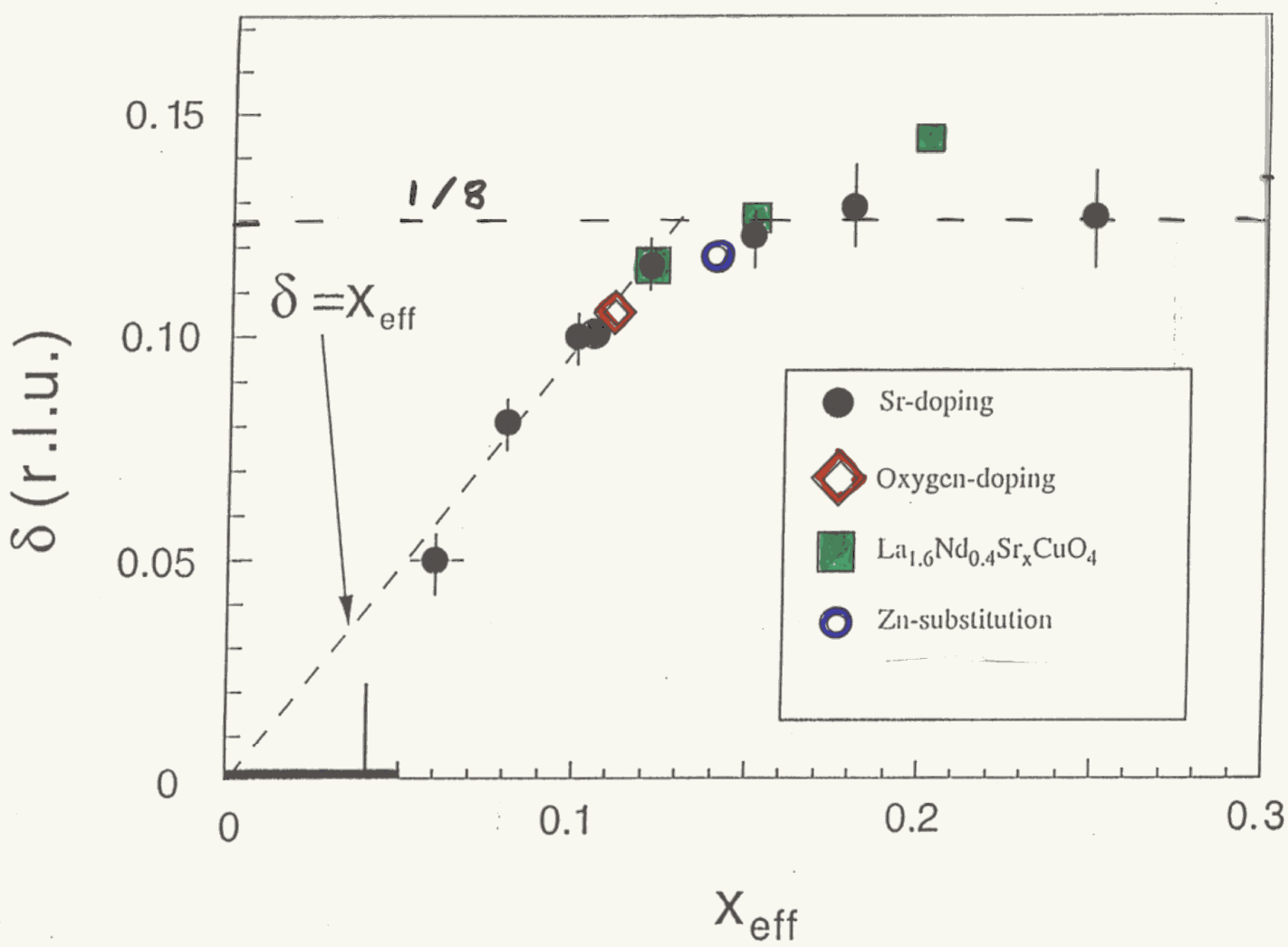
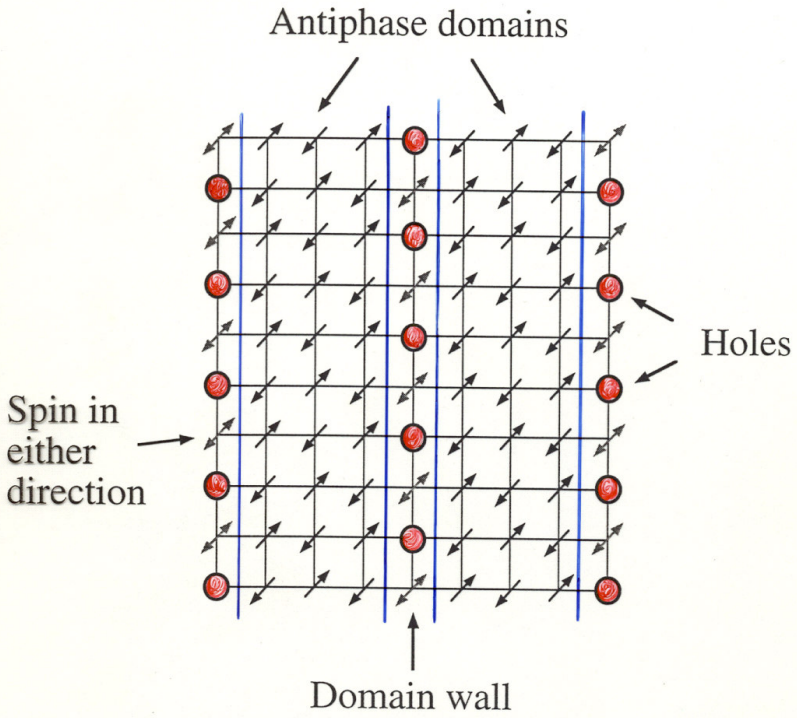


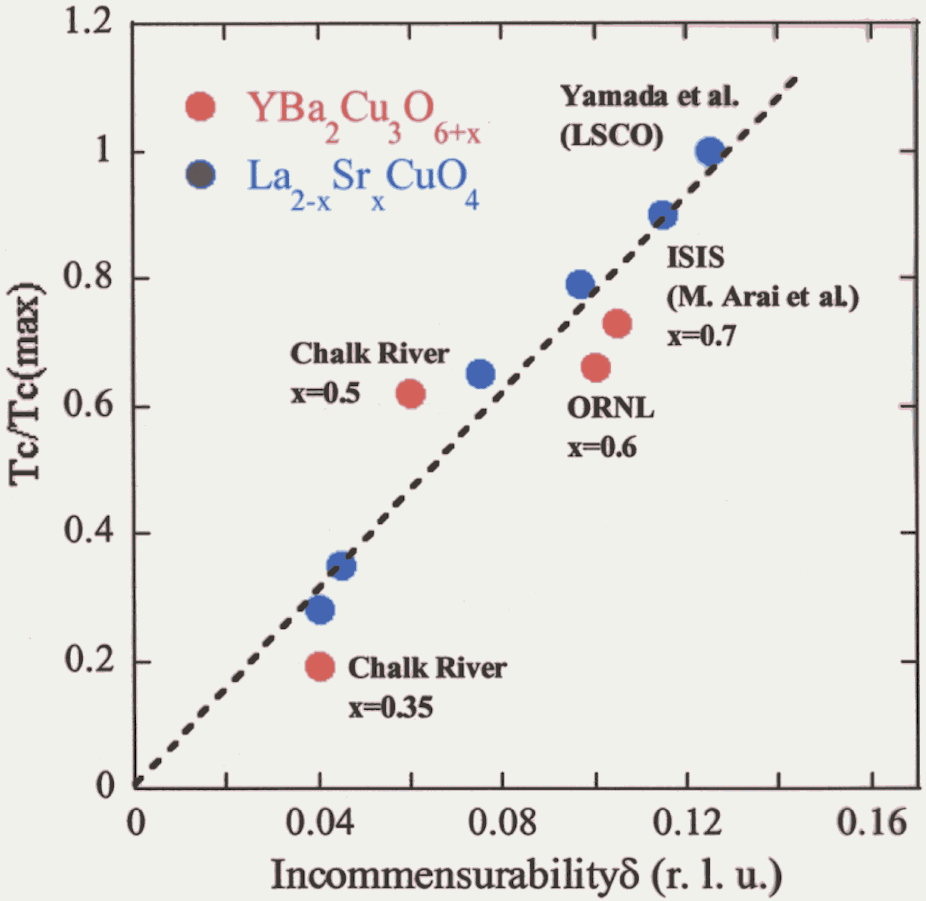
Fig. 7: K.Yamada et al.

Model of Stripes of Spin and Charge



Yamada Plot: T_c ~ Incommensurability

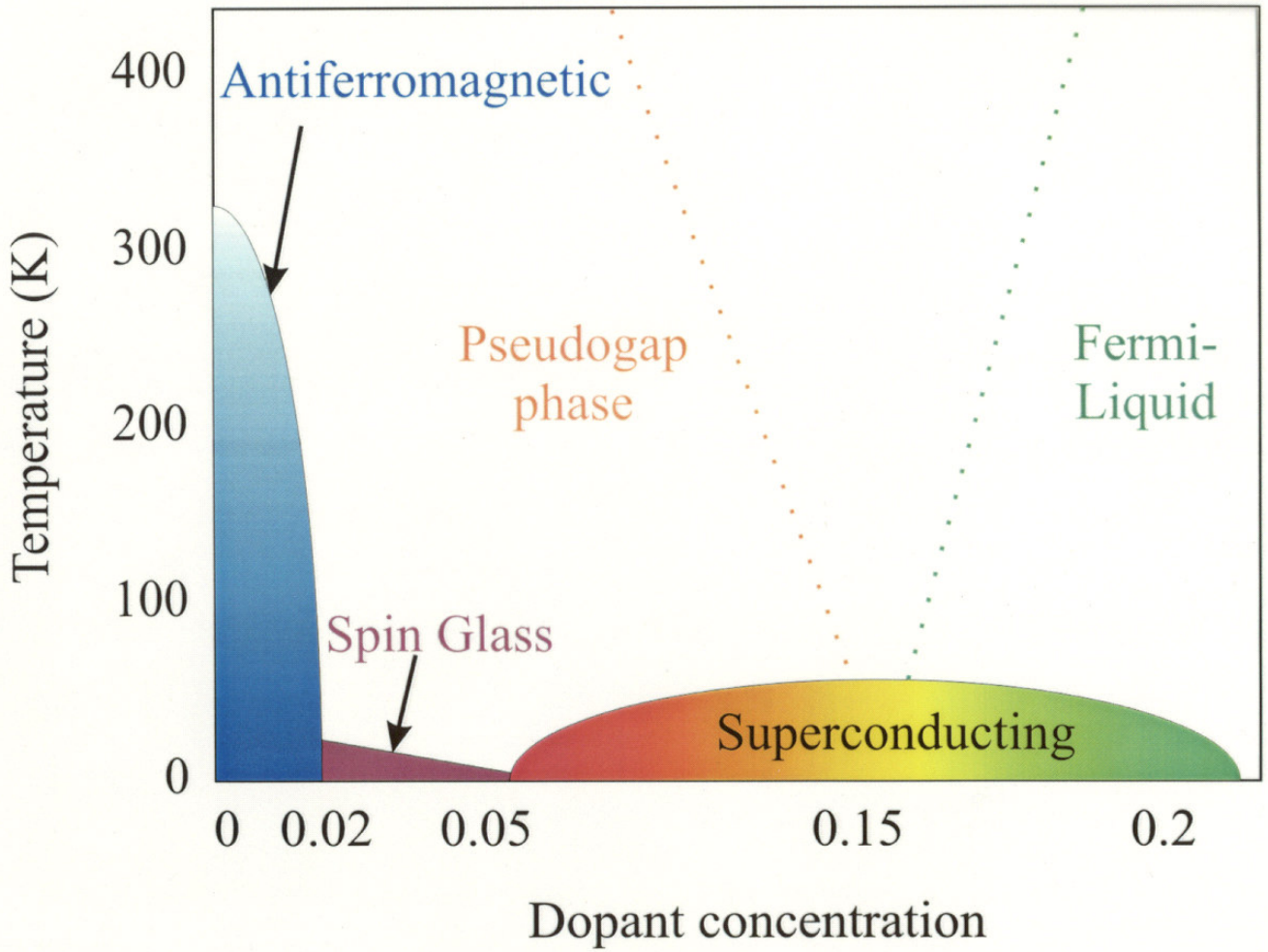
- $T_c \sim \delta$ (Yamada et al.)
- A universal relation for YBCO and possibly all cuprates?
- Not for $\delta < \delta_c$ $p<p_c$

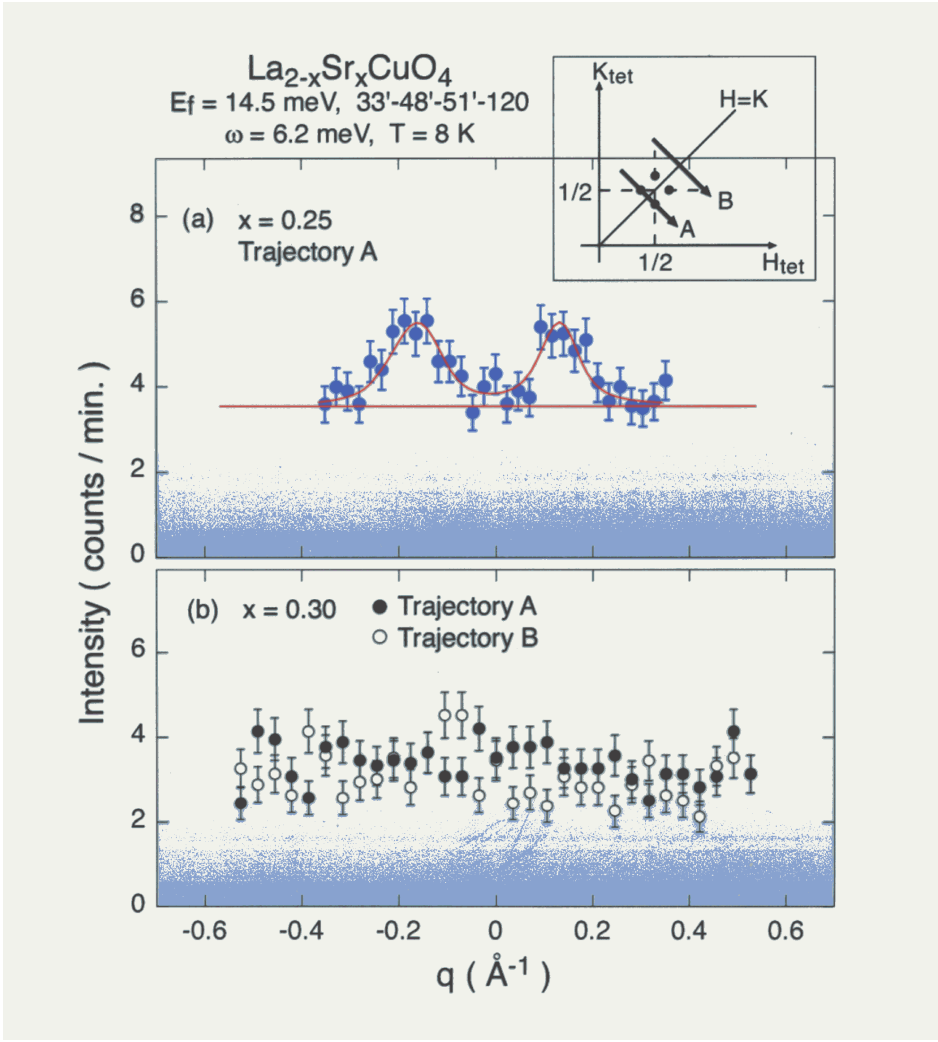


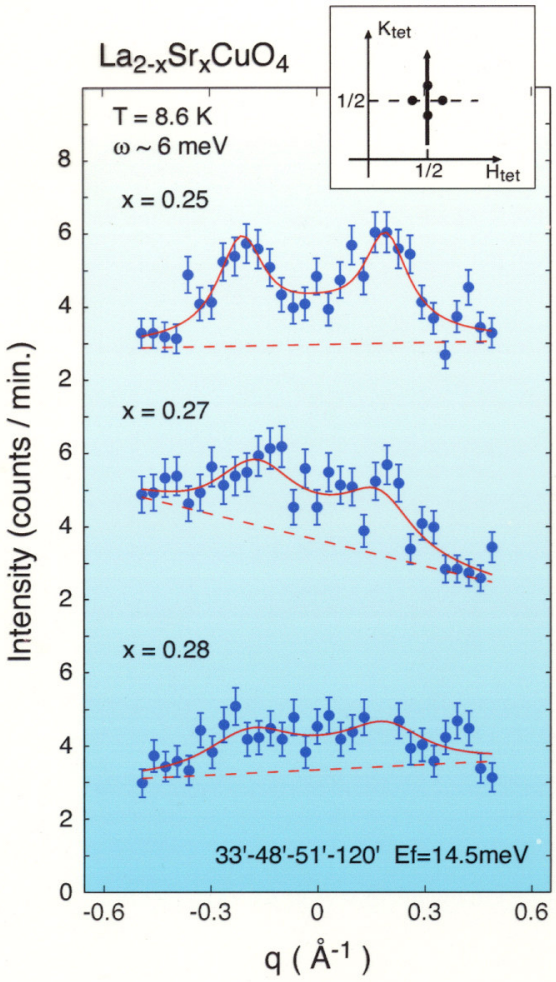
Overdoped $La_{2-x}Sr_xCuO_4$

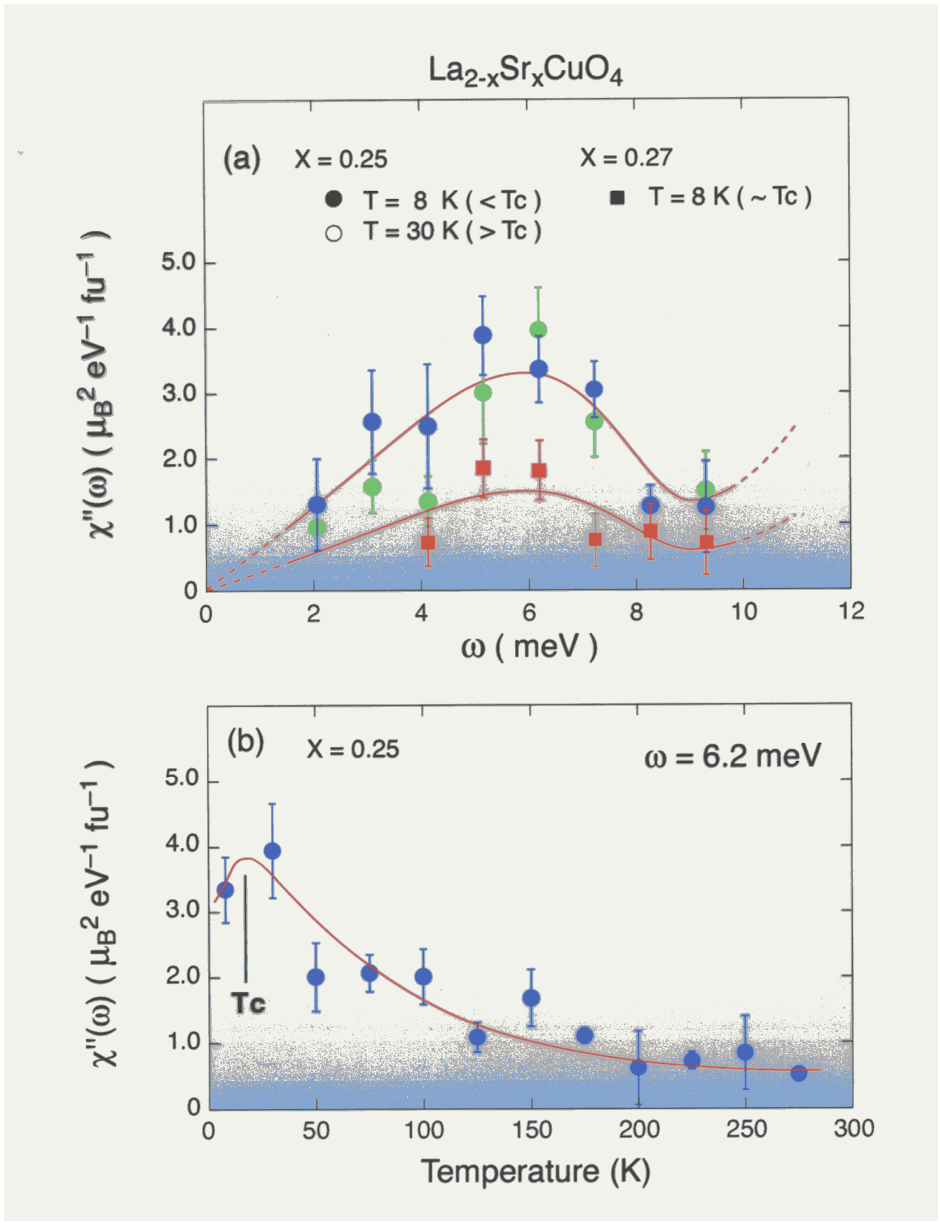
Shuichi Wakimoto
Kazu Yamada
Hyunkyang Kim
Ian Swainson

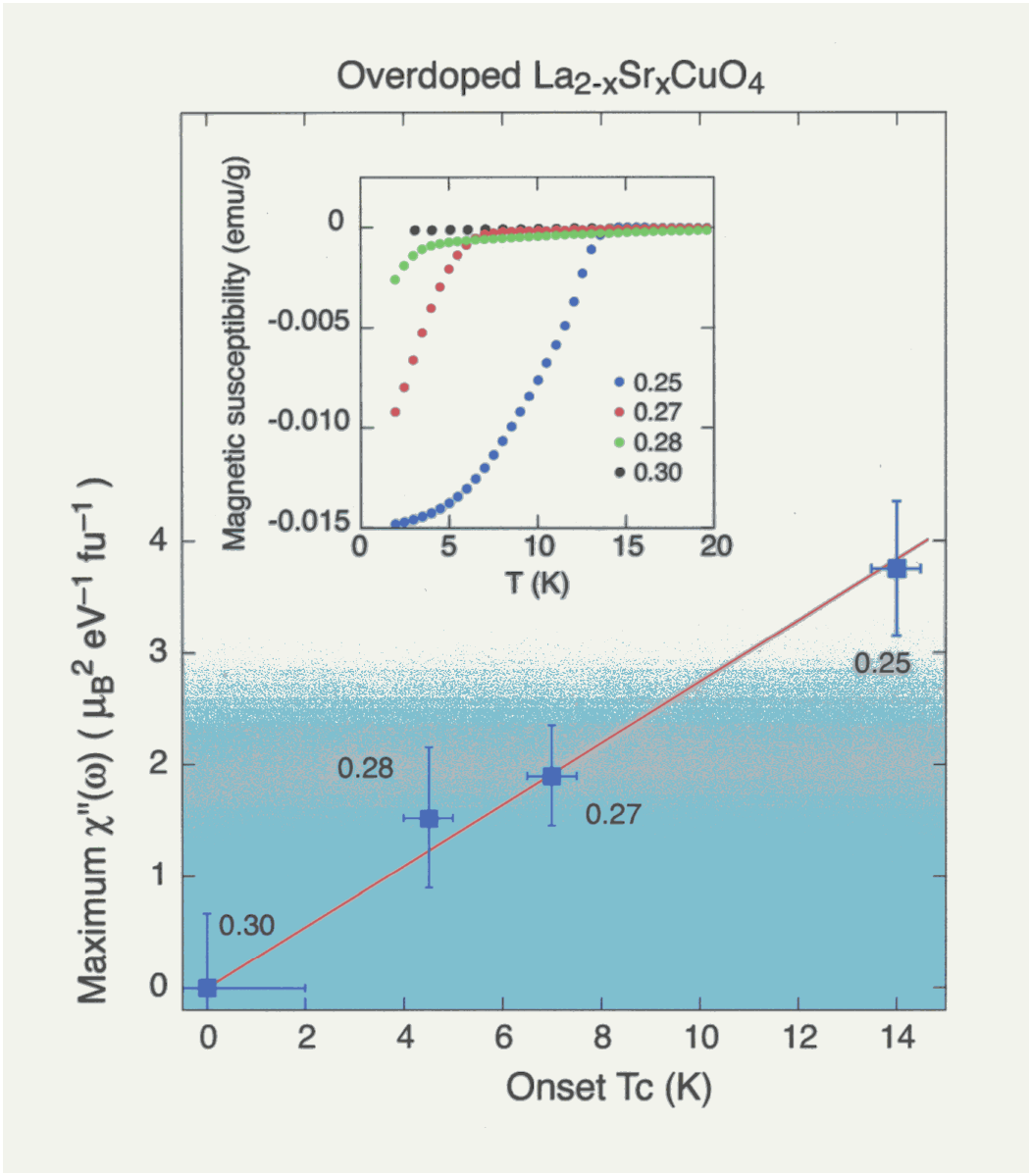
Phase diagram: $La_{2-x}Sr_xCuO_4$




La2-xSrxCuO4
Ef = 14.5 meV, 33'-48'-51'-120
ω = 6.2 meV, T = 8 K
Ktet
H=K
1/2
B
A
1/2
Htet
(a) x = 0.25
Trajectory A
(b) x = 0.30
Trajectory A
Trajectory B
Intensity (counts / min.)
0
2
4
6
8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
q (Å-1)


La2-xSrxCuO4
T = 8.6 K
ω ~ 6 meV
x = 0.25
x = 0.27
x = 0.28
33'-48'-51'-120' Ef=14.5meV
Intensity (counts / min.)
q (Å-1)
Ktet
Htet
1/2
1/2
0
2
4
6
8
-0.6
-0.3
0
0.3
0.6


La2-xSrxCuO4
(a)
X = 0.25
X = 0.27
T = 8 K (< Tc)
T = 30 K (> Tc)
T = 8 K (~ Tc)
χ''(ω) (μB2 eV−1 fu−1)
ω (meV)
(b)
X = 0.25
ω = 6.2 meV
Tc
Temperature (K)


Overdoped La2-xSrxCuO4
Magnetic susceptibility (emu/g)
0
-0.005
-0.010
-0.015
0
5
10
15
20
T (K)
0.25
0.27
0.28
0.30
Maximum χ''(ω) (μB2 eV−1 fu−1)
0
1
2
3
4
0.30
0.28
0.27
0.25
0
2
4
6
8
10
12
14
Onset Tc (K)

Magnetic Order and

Superconductivity Compete

but

No Magnetic Fluctuations,

No Superconductivity!!!

Conclusions

1. In the Quasi-2D Copper Oxides Magnetism and Superconductivity are intimately related
2. Static Magnetic Order and Superconductivity Compete
3. Dynamic Magnetic Fluctuations Pervade the Superconductivity Phase Diagram
4. We still do not know what is cause and what is effect
5. Perhaps all of these are just the properties of a strong-coupling Hamiltonian
6. We need an original idea!!!