Outline

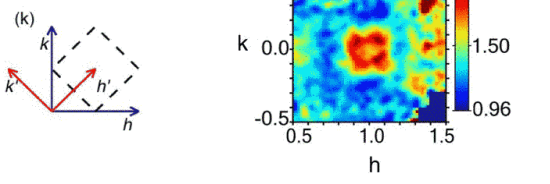
- Universal magnetic excitation spectrum
  - Consistent with excitations of a stripe-ordered state
  - T_c scales with spin gap
- T-dependence of spin excitations in LBCO, x = 1/8
  - Modest changes up to 300 K
- Spin-waves in $La_{2-x}Sr_xNiO_4$ with diagonal stripe order
  - Superexchange is robust in doped 2D antiferromagnets
- Over-doped LSCO
  - Spin excitations become very weak
- Phonon anomaly and anisotropic charge gap in LBCO, x=1/8
  - CDW within ordered charge stripes?

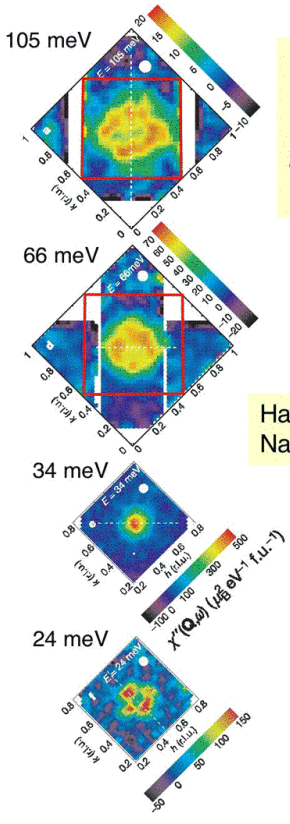
$La_{2-x}Ba_xCuO_4$

x = 1/8

Normal state with Stripe order

Nature **429**, 534 (2004)



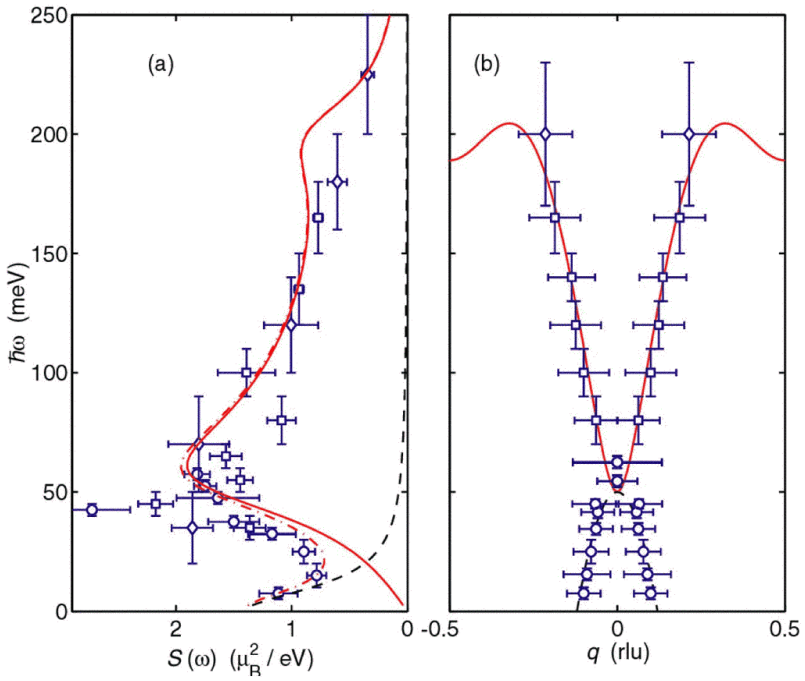


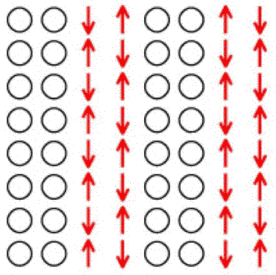
$YBa_2Cu_3O_{6.6}$

Superconducting state

Hayden et al., Nature **429**, 531 (2004)

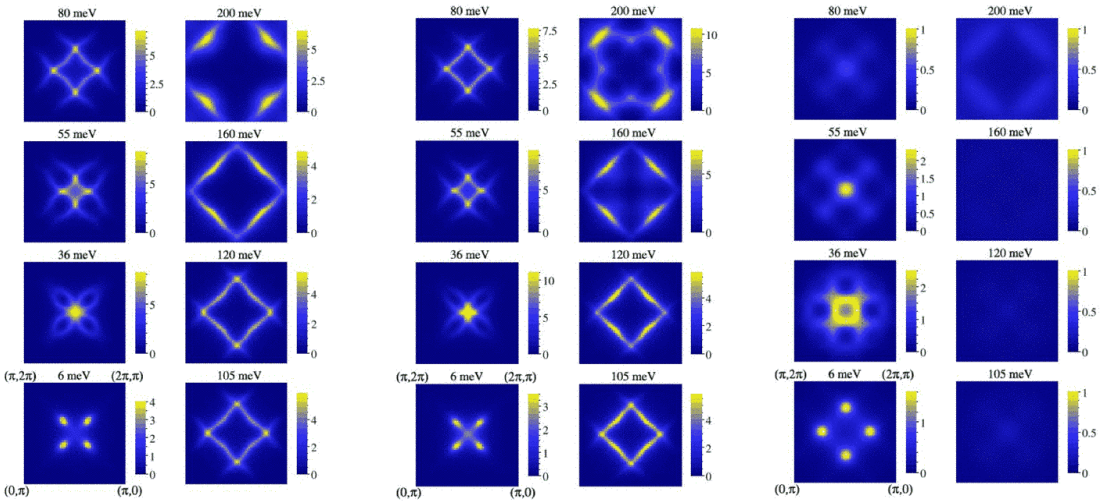
LBCO spectrum, with pseudo spin gap





J = 100 meV

Stripes: yes; Checkerboard: no



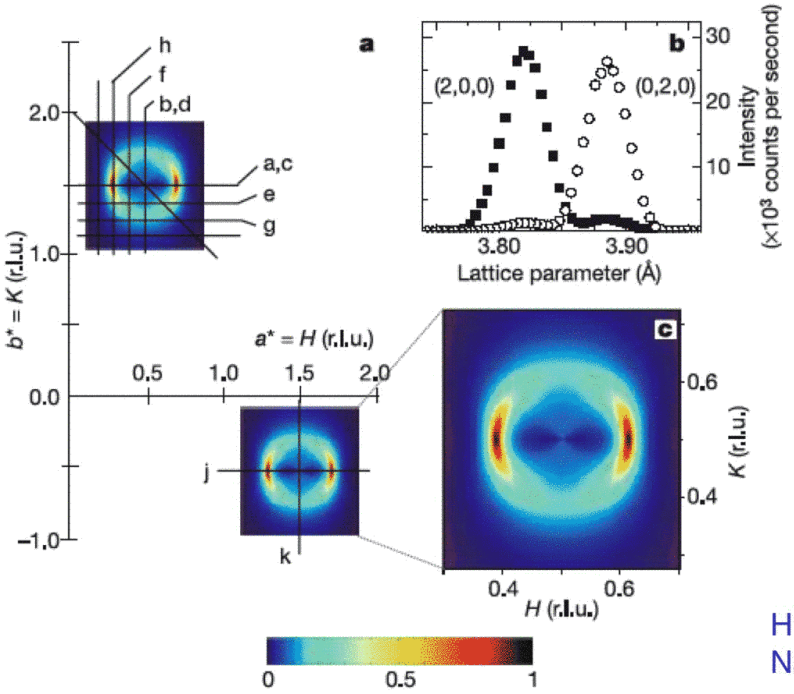
Bond-centered stripes

Site-centered stripes

Checkerboard
--- bond-centered

Vojta and Sachdev, cond-mat/0408461

Detwinned $YBa_2Cu_3O_{6.85}$

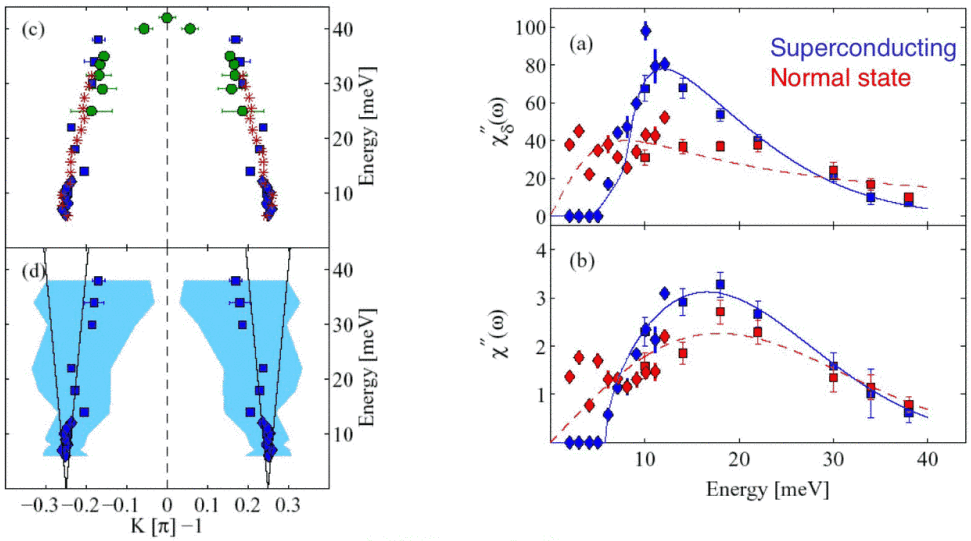


E = 35 meV

(E_r = 41 meV)

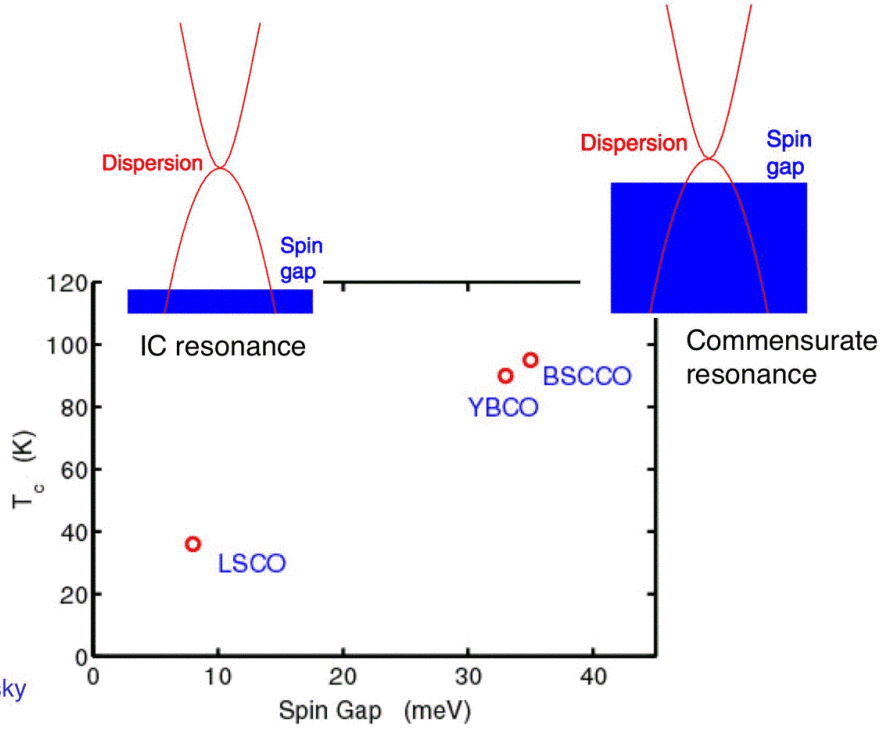
Hinkov *et al.*,
Nature **430**, 650 (2004)

Spin gap in $La_{2-x}Sr_xCuO_4$



LSCO x = 0.16
Christensen *et al.*
PRL **93**, 147002 (2004)

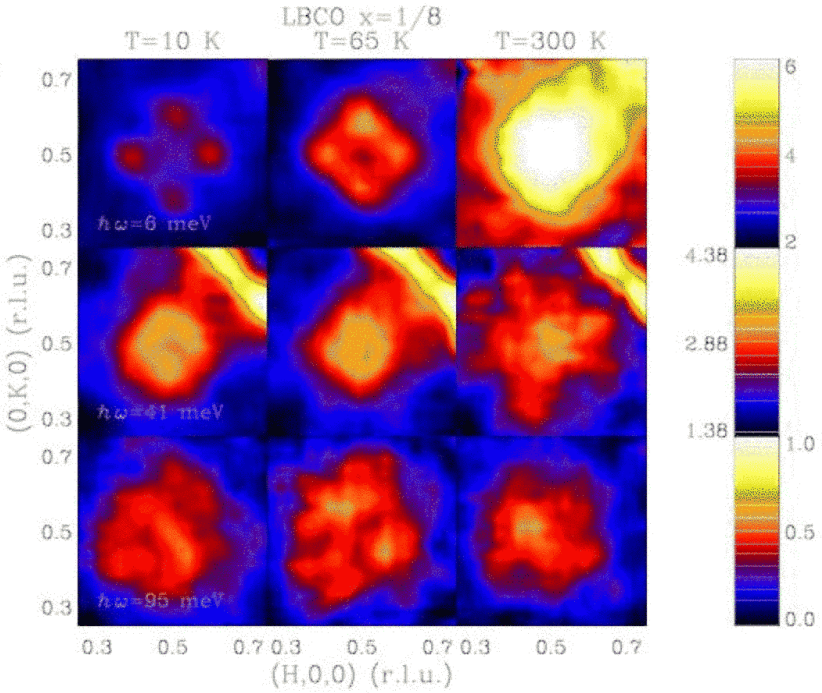
Optimally-doped cuprates



Batista, Ortiz, Balatsky
PRB (2001)

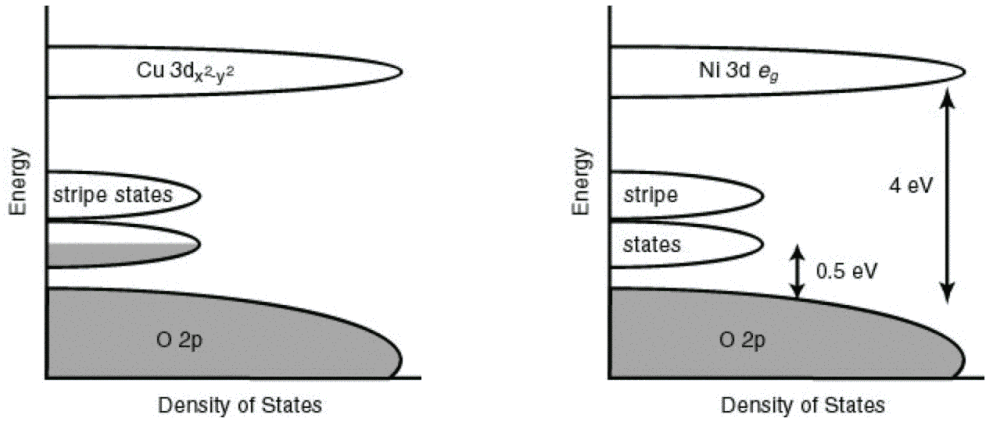
T-dependence of spin excitations in LBCO (x=1/8)

Guangyong Xu,
Toby Perring,
Genda Gu



Stripe order: yes no no

Superexchange vs. FS nesting



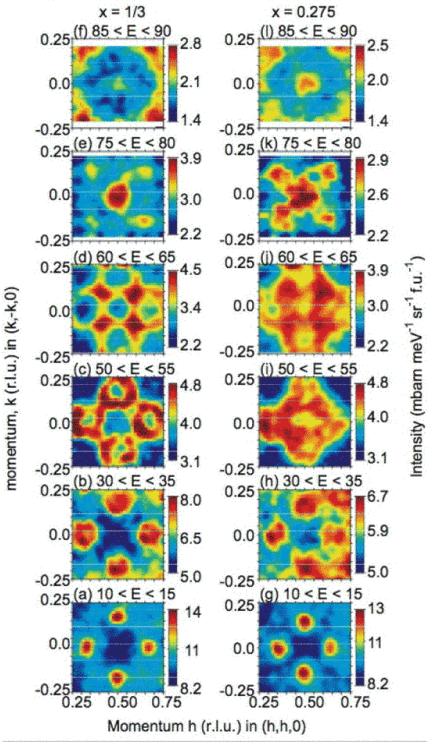
J determined by virtual excitations across charge transfer gap
Robustness of *J* seems to require (dynamic) inhomogeneity

How do local spin excitations interact with charge excitations?

What is the nature of the low-energy charge excitations in a stripey state?

Constant-E cuts through spin waves in LSNO

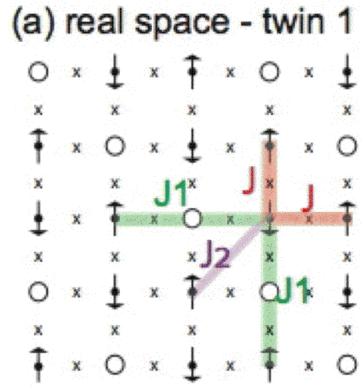
x = 1/3



x = 0.275

H. Woo, A. Boothroyd et al.
PRB (in press)

Results of fitting spin waves in $La_{1.67}Sr_{0.33}NiO_4$



J = 27.5(4) meV

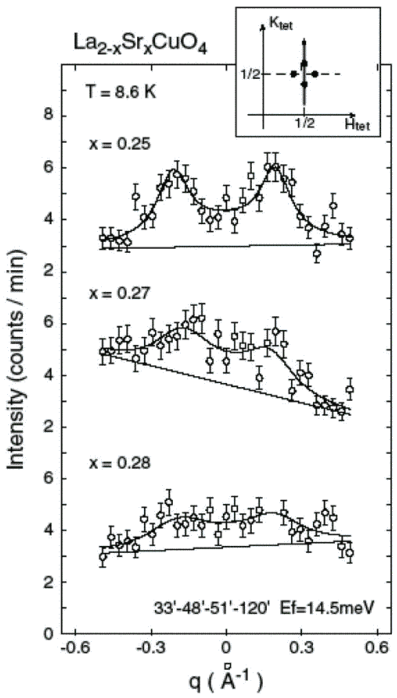
J_1 = 13.6(3) meV

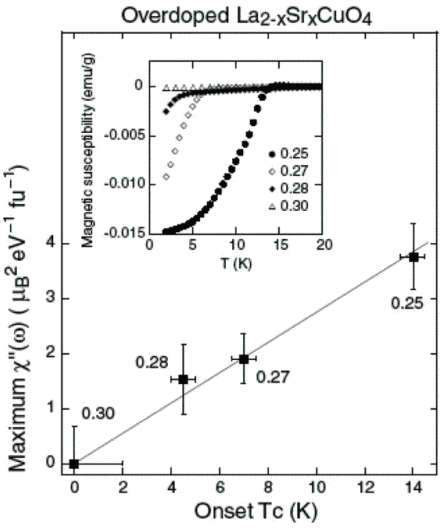
J_2 small

La_2NiO_4

J = 31 meV

Magnetic excitations disappear in over-doped LSCO



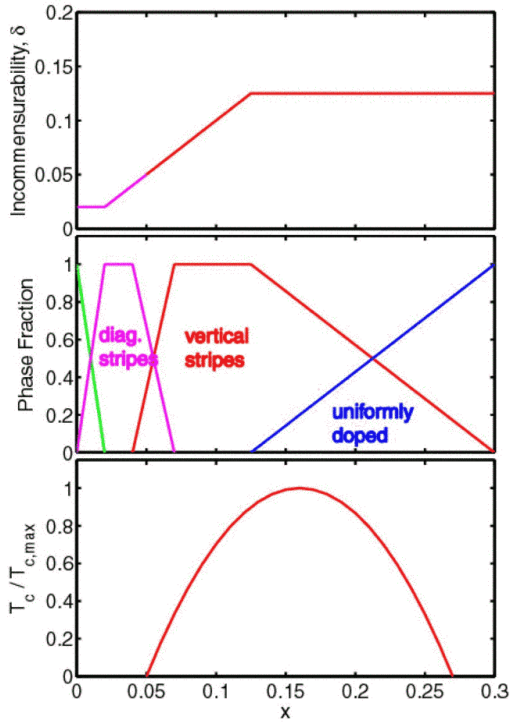


Wakimoto *et al.*, PRL **92**, 217004 (2004)

Over-doped LSCO

- Recent measurements on LSCO x=0.25 and 0.30
  - On MAPS at ISIS (same conditions as for LBCO)
- Spin excitations are difficult to see at any energy up to 100 meV
- What would Fermi-liquid approach predict for S(Q,ω) in over-doped LSCO?
  - ARPES has measured Fermi surface for x ≤ 0.22

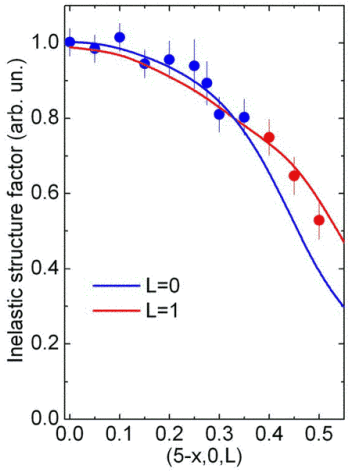
Stripe liquid and superconductivity in LSCO



Bond-stretching phonon anomaly in LBCO (x=1/8)

Reznik, Pintschovius, Sato, Yamada, Gu, …

Unpublished plot of measured dispersion of the bond-stretching phonon along (h,0,0)---redacted because I don't have permission from coauthors to put online



Doping dependence of anomaly

Plot of phonon lineshapes at Q=(4.75,0,0) for LSCO at various dopings---redacted

- Anomaly at (0.25,0,0) in LSCO x=0.15
- No anomaly for x=0 or x=0.30
- Related anomaly seen in YBCO
- Question:
  - Is anomaly parallel or perpendicular to stripes?
  - Results for YBCO (Hinkov et al. plus phonons) suggest anomaly is *parallel* to stripes

Optical conductivity of $La_{1.875}Ba_{0.125}CuO_4$

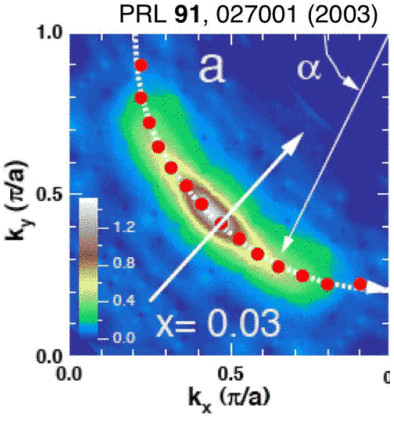
Dordevic, Homes, Q. Li

Unpublished plot of optical conductivity vs. frequency at various temperatures (looks very much like behavior in LSCO)---redacted

Antinodal charge gap in stripe-ordered phase

Unpublished plot of frequency-integrated conductivity for two different cutoffs, 50 cm-1 and 300 cm-1, with the first increasing monotonically to low temperature and the second showing a drop below 50 K. Redacted.

Yoshida *et al.*,
PRL **91**, 027001 (2003)



Dordevic and Homes

CDW within ordered stripes?

- Magnetic (Hinkov et al.) and phonon (Pintschovius et al.) measurements on YBCO indicate phonon anomaly is parallel to charge stripes
- Phonon anomaly consistent with electron-phonon coupling at $2k_F$ along charge stripes
- CDW gap occurs among states that already have a pseudogap
- Can a calculation be done for the effect of a $2k_F$ instability on a bond-stretching phonon in a correlated 1D system?

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