

Experimental Evidence for Striped Superconductivity in $\text{La}_{2-x}\text{Ba}_x\text{CuO}_4$

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Higher Temperature Superconductors
KITP
June 24, 2009

Outline

- Momentum space dichotomy
 - ▶ Evidence for 2 gaps in stripe-ordered LBCO $x=1/8$
 - ▶ Interpretation: PDW-SC + d-wave SC
- Are stripes relevant?
 - ▶ Evidence for fluctuating stripes + diamagnetism
- New signatures of stripes
 - ▶ RIXS: dispersion of peak in $\text{Im } \epsilon^{-1}(q)$
- $2k_F$, $4k_F$ effects
 - ▶ Anomaly in Cu LO phonon at $4k_F$

Collaborators

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Qiang Li

Chris Homes

Alexei Tselik

HASYLAB

M. von Zimmermann

Stanford

Steve Kivelson

Erez Berg

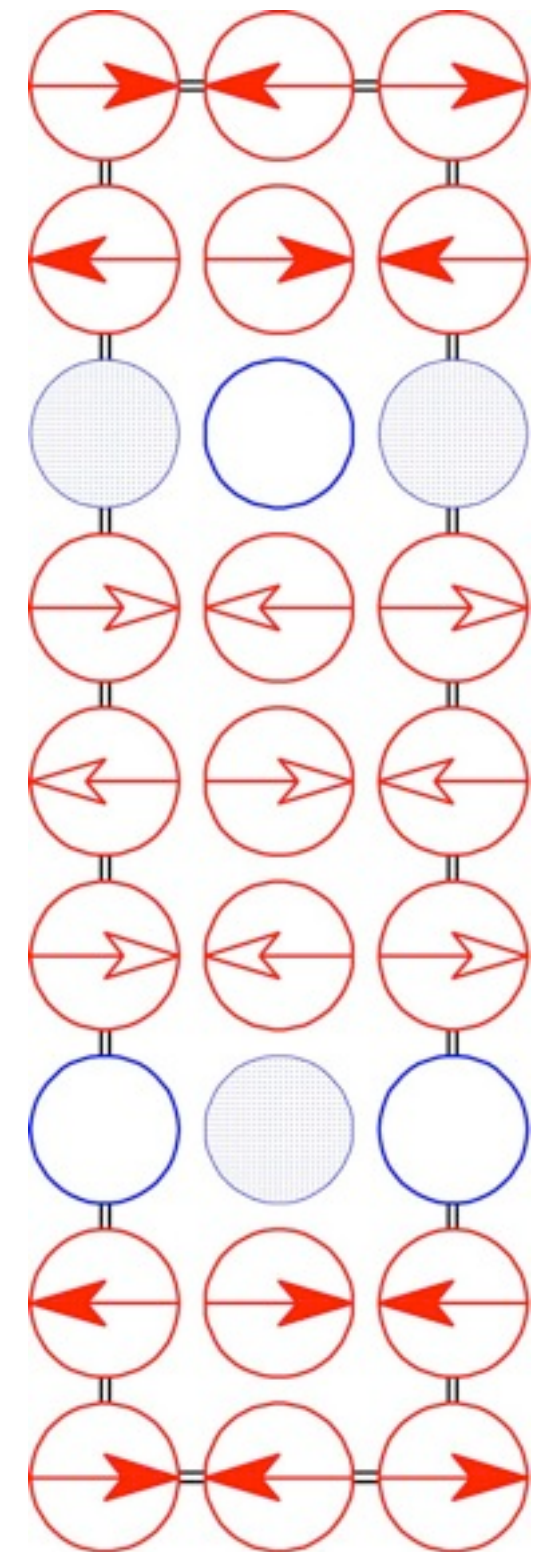
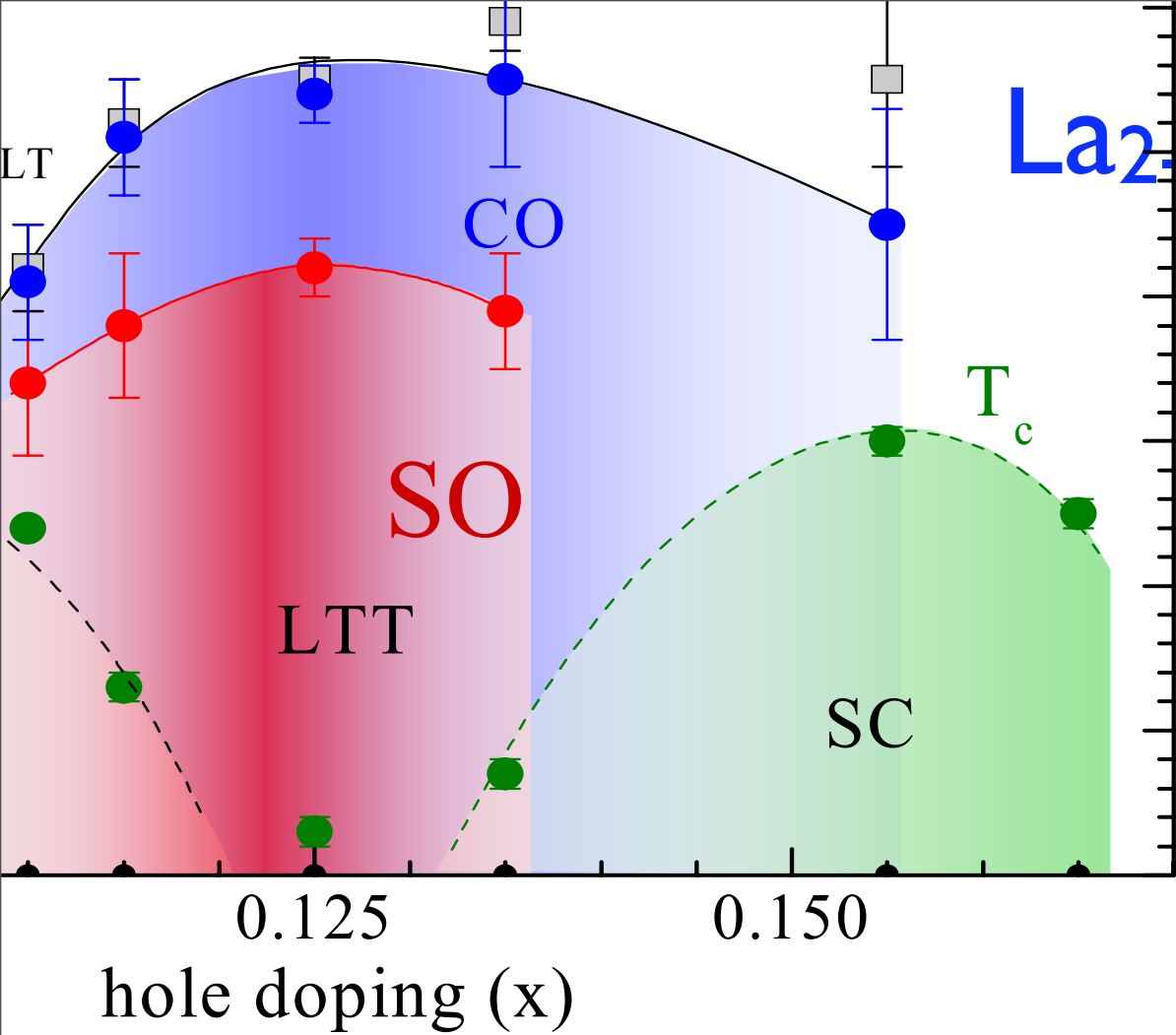
U. Illinois

Eduardo Fradkin

IMR, Tohoku U.

Masaki Fujita

Kazu Yamada



M. Hücker, G.D. Gu

Stripe order competes with bulk SC

Gap Summary

T

53 K

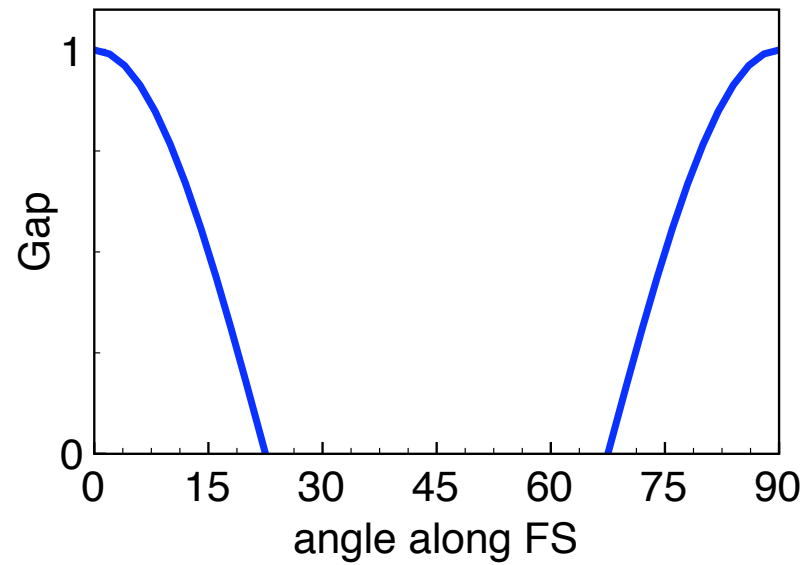
gap
evidence

S_{ab} , ρ_c ,
in-plane
reflectivity

ARPES
(Shen's group)

interpretation

charge
stripe
order

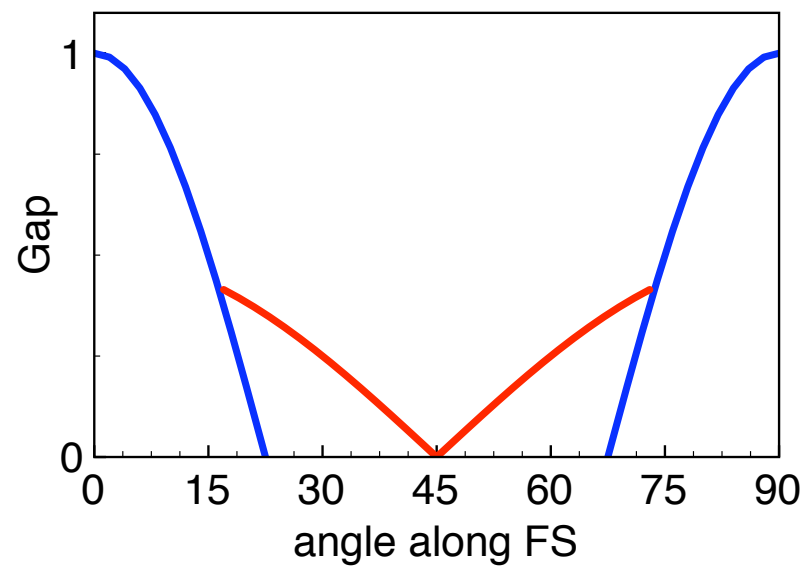


PDW (sro)

40 K

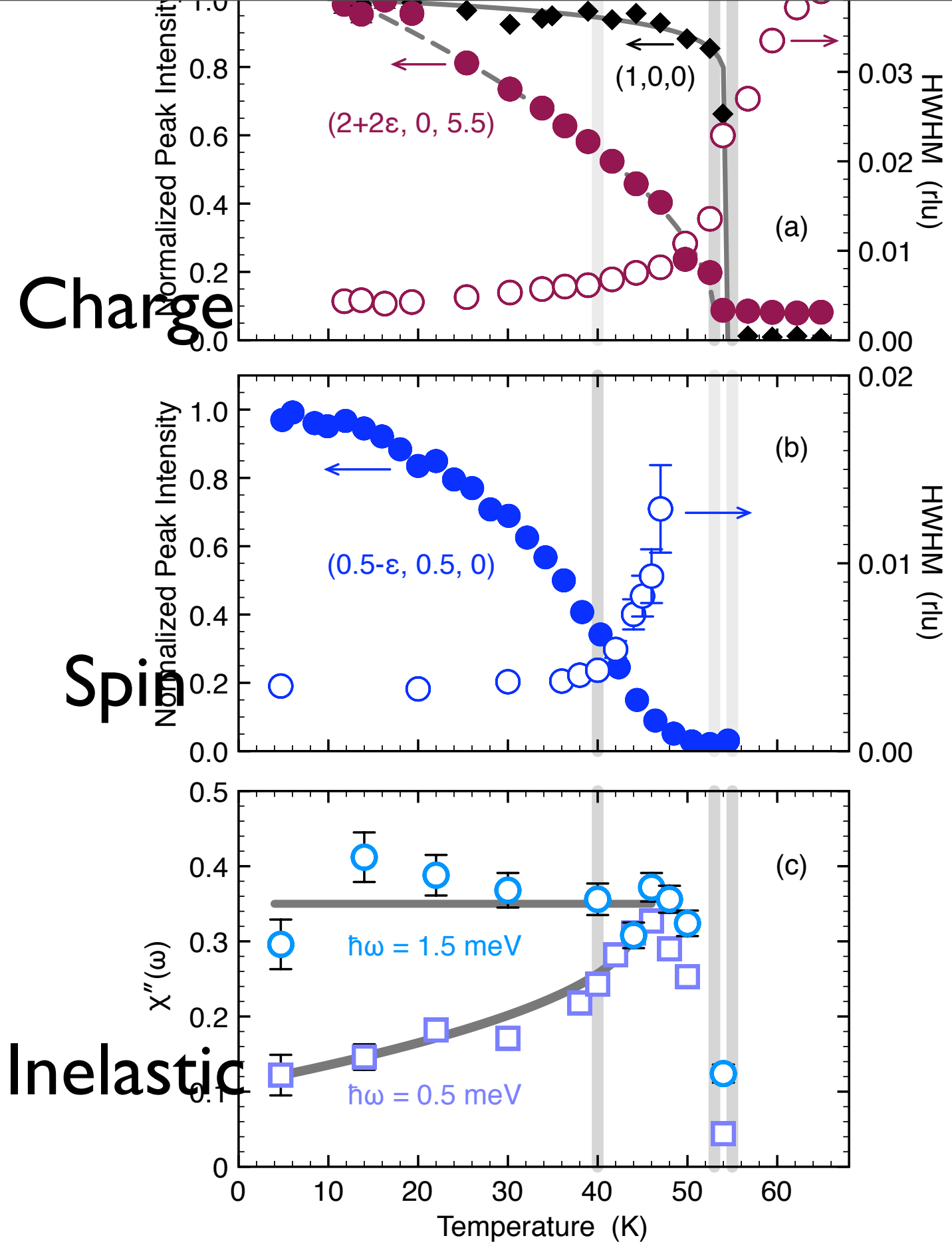
spin
stripe
order

ρ_{ab} , χ_{\perp}



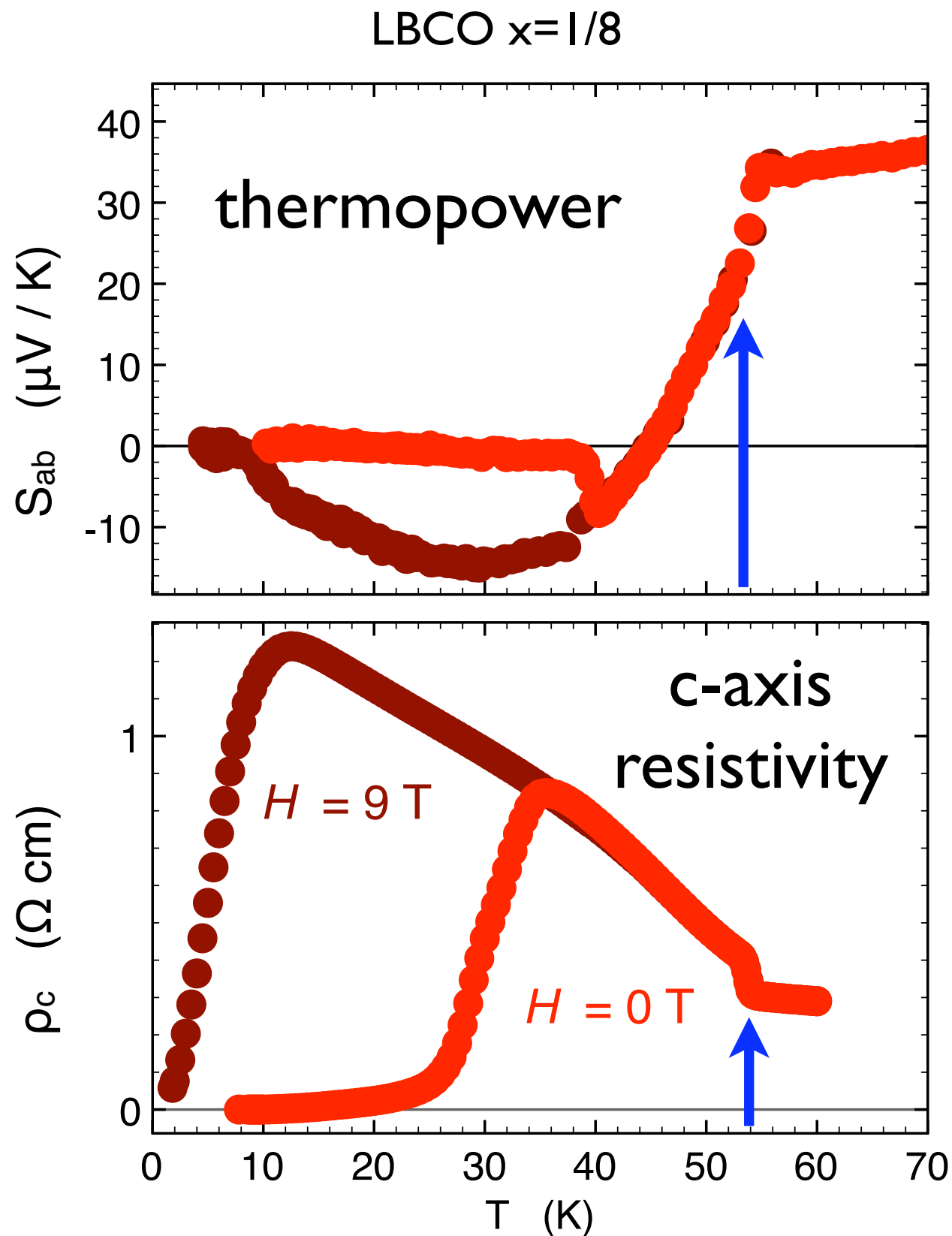
PDW (sro)
+
uniform d-wave

Stripe ordering in LBCO $x=1/8$



PRB **78**, 174529 (2008)

Gapping at $T = 53$ K

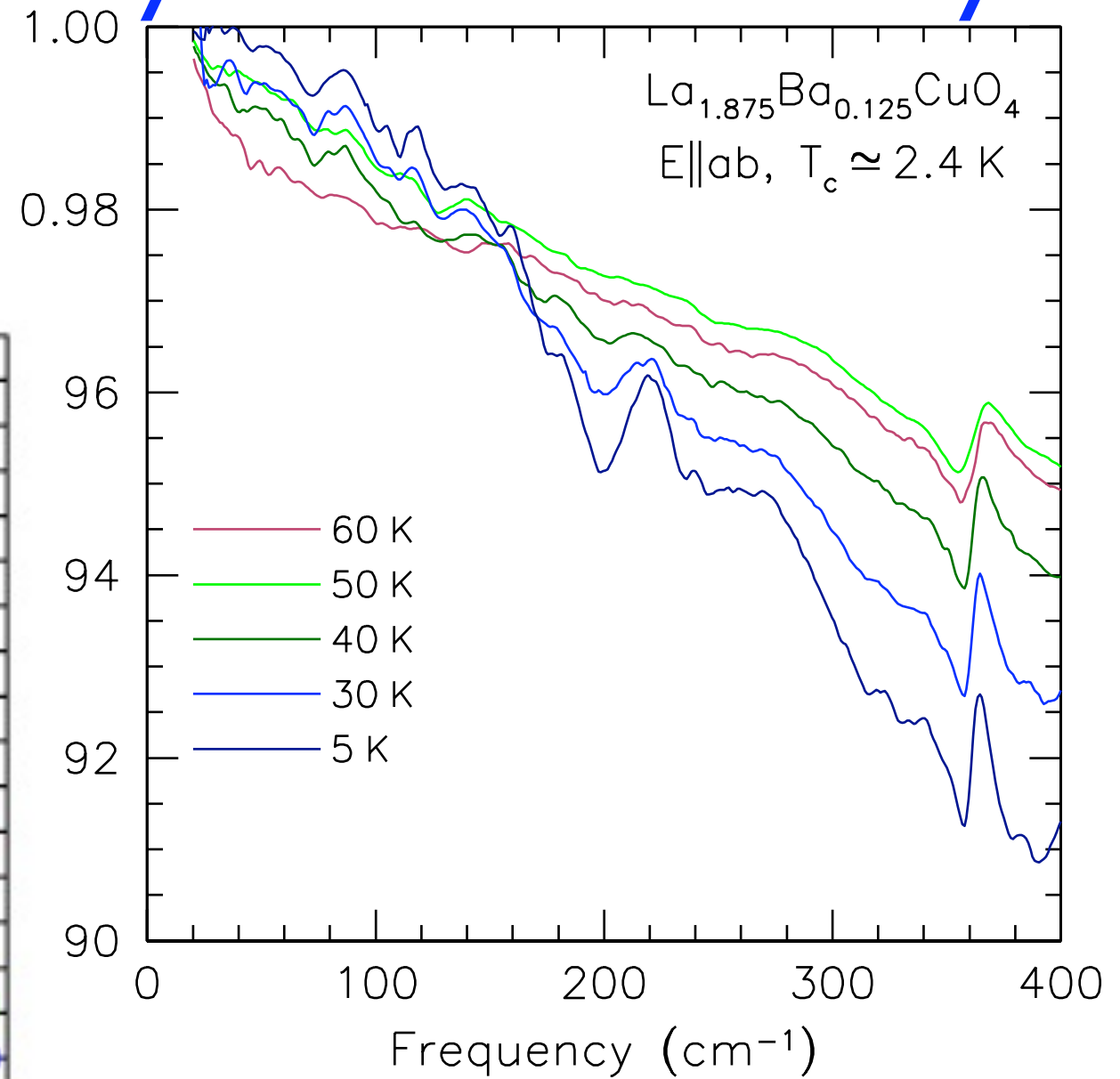
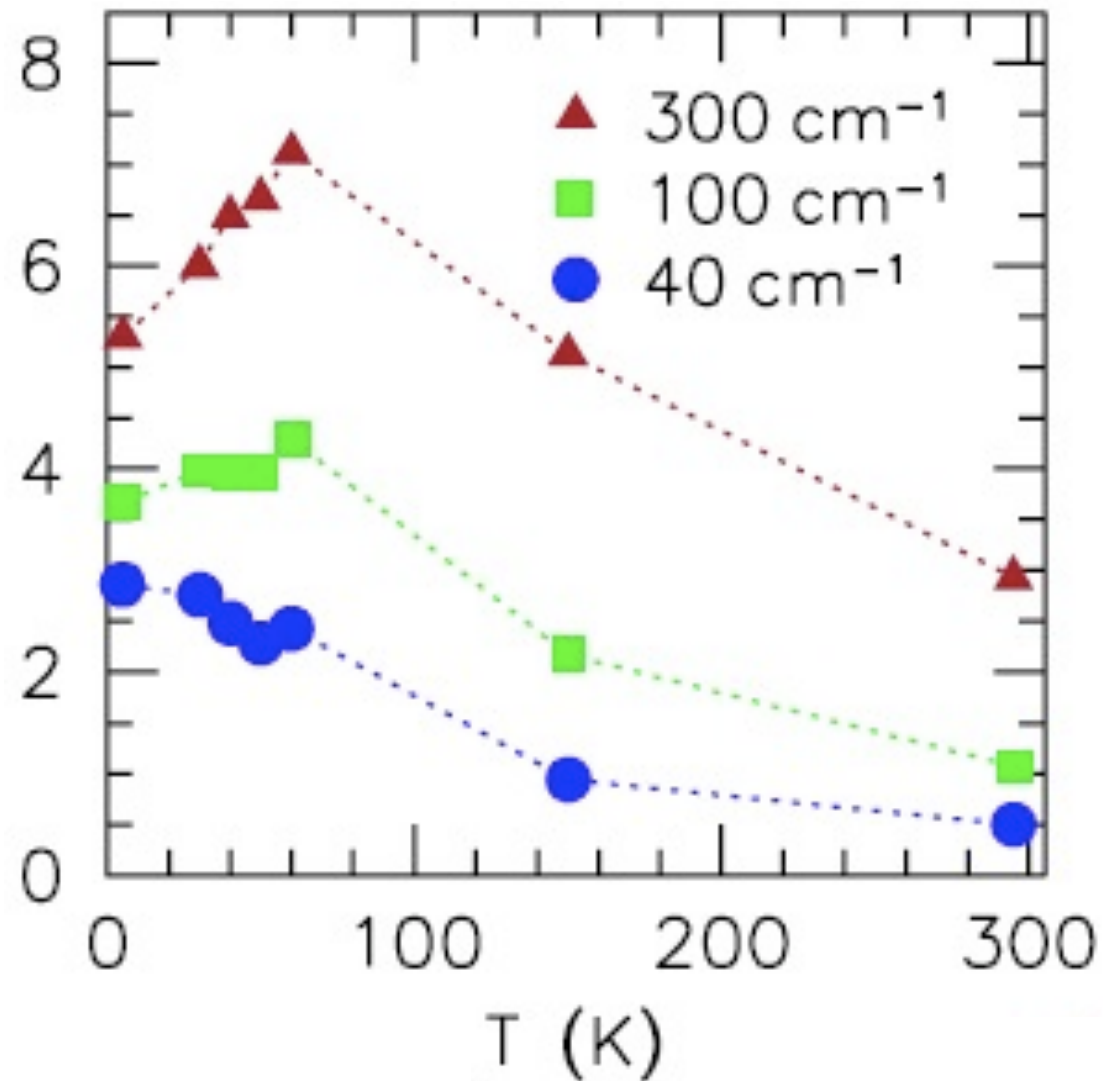


Not seen in ρ_{ab}

Suggests:
Antinodal gap

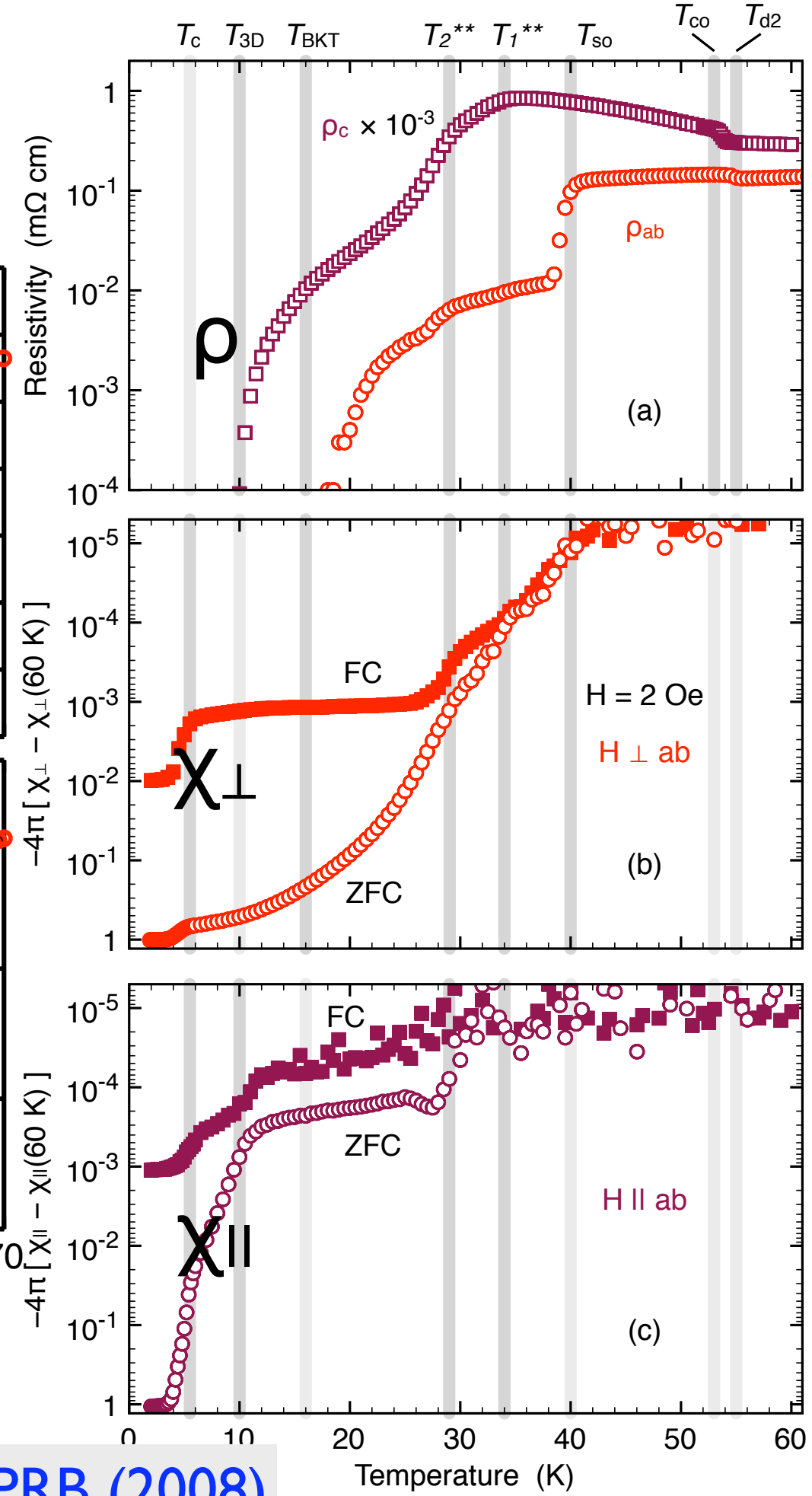
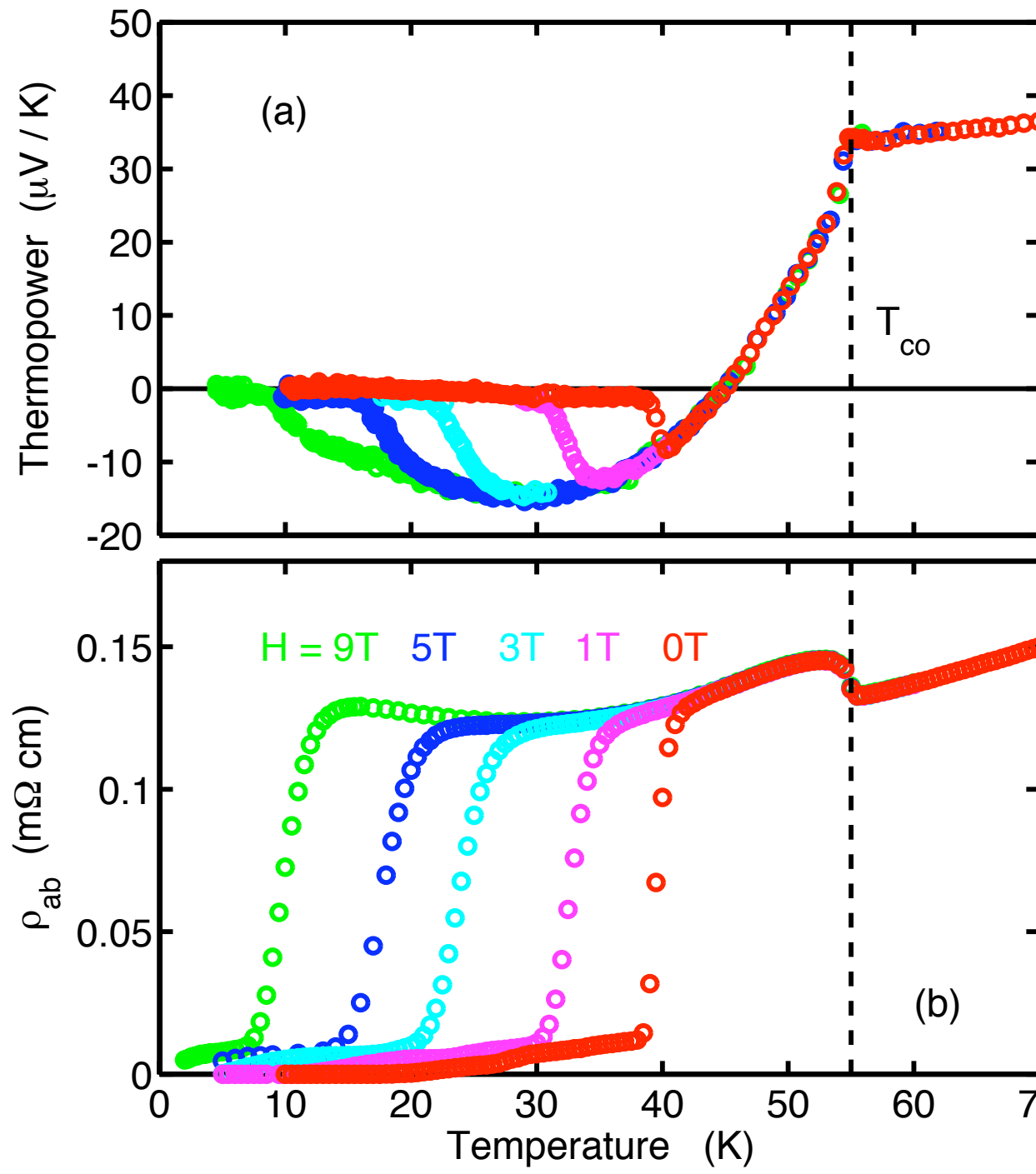
Infrared Reflectivity and Conductivity

$$N(\omega_c, T) = \int_{0^+}^{\omega_c} \sigma_1(\omega, T) d\omega$$



C. Homes *et al.*, PRL (2006)

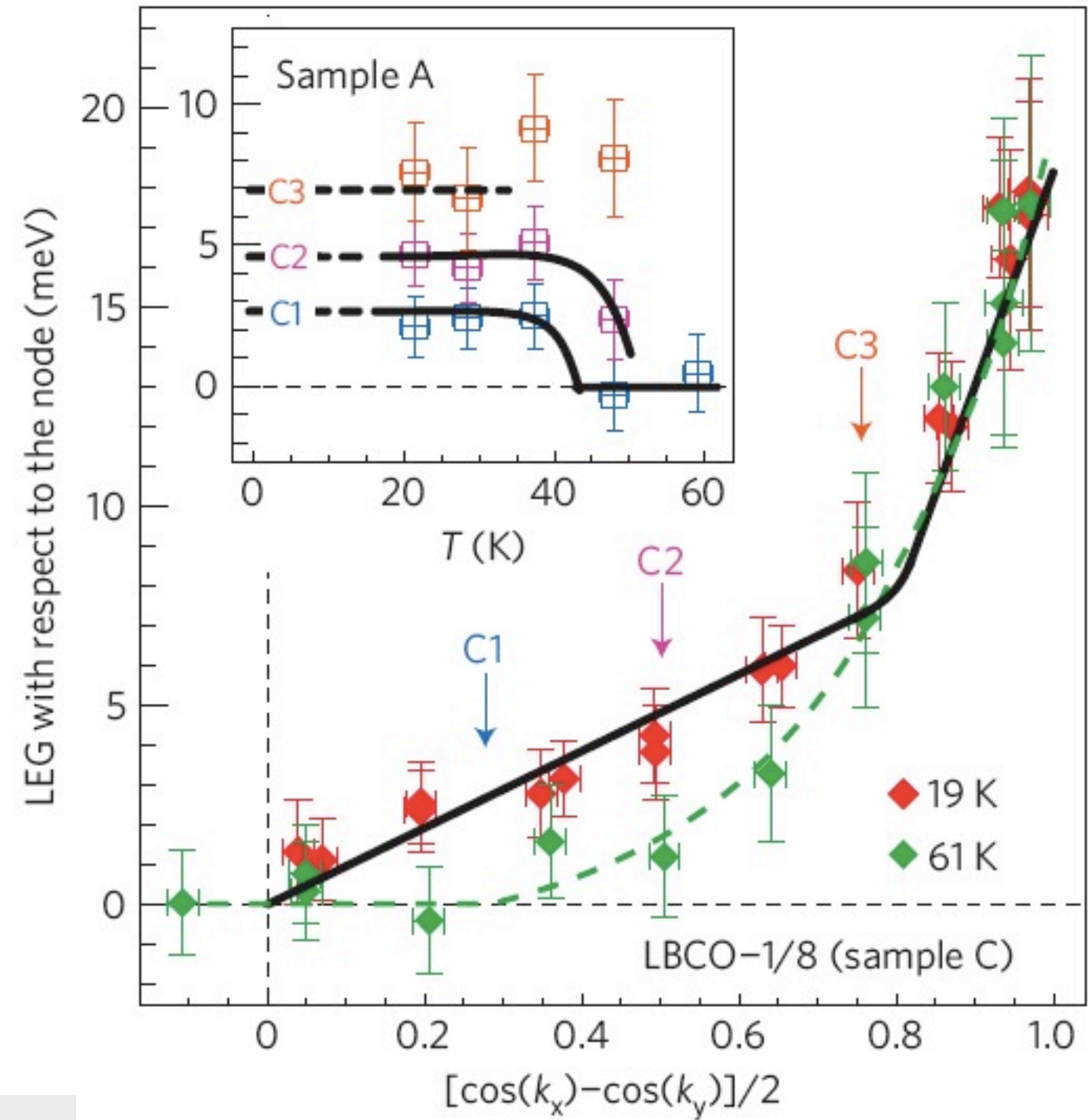
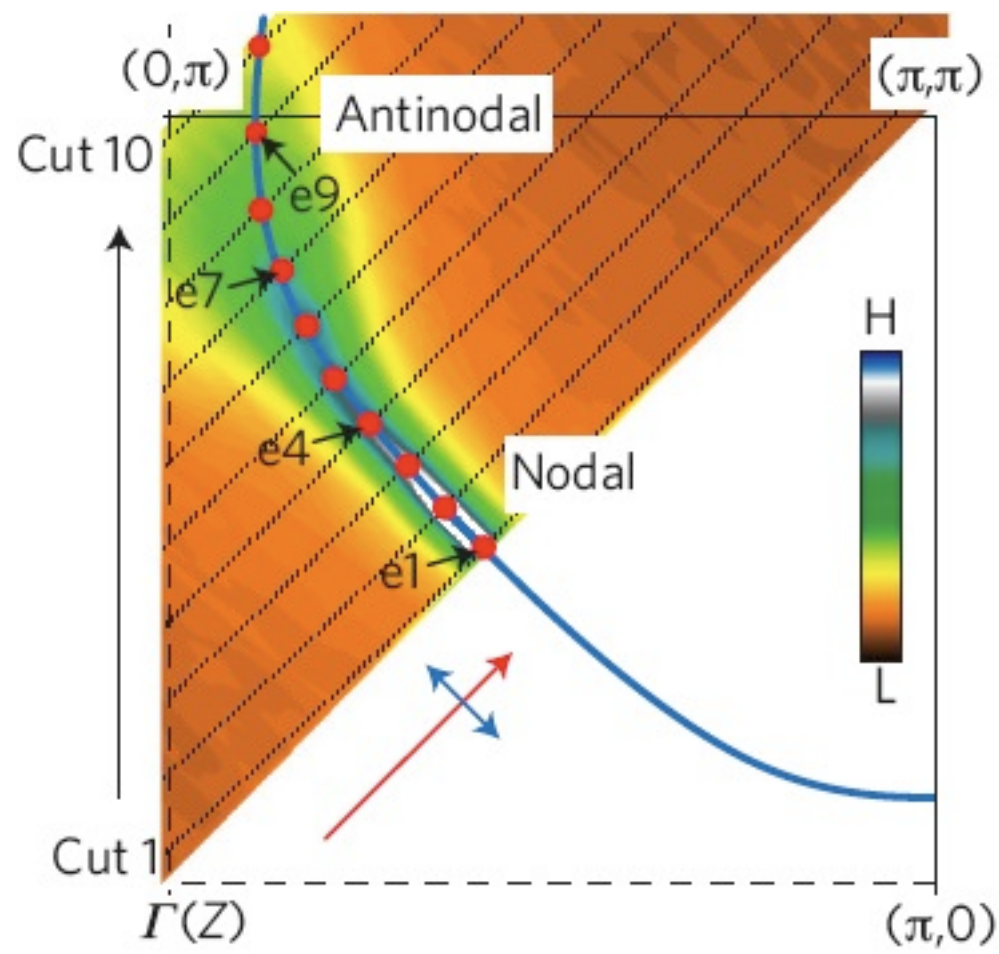
2D SC correlations at $T < 40$



Q. Li *et al.*, PRL (2007)

JMT *et al.*, PRB (2008)

T-dependent gaps from ARPES

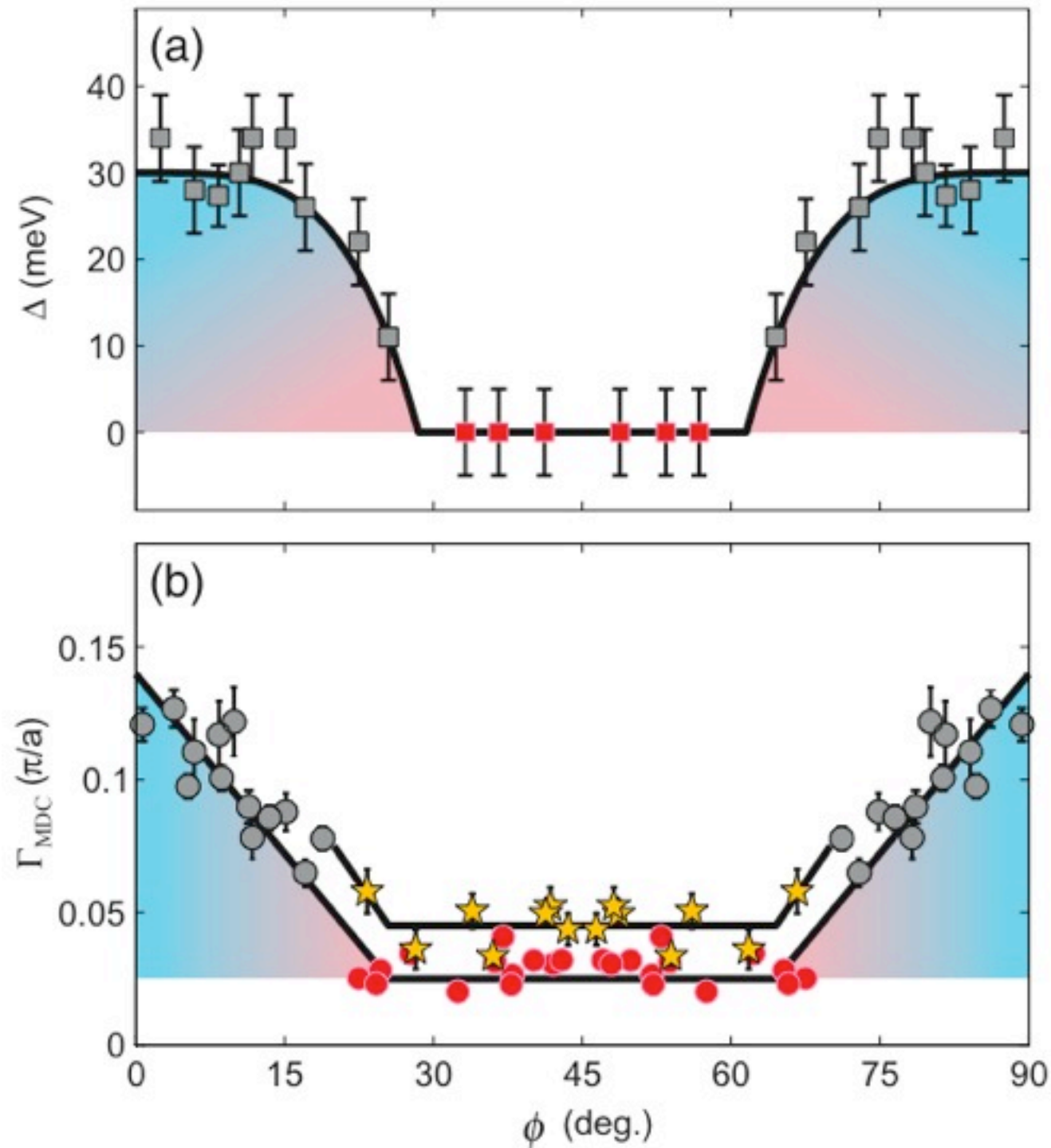


R. He *et al.*, Nat. Phys. (2009)

ARPES pseudogap in $\text{La}_{1.48}\text{Nd}_{0.4}\text{Sr}_{0.12}\text{CuO}_4$

$T = 15 \text{ K}$

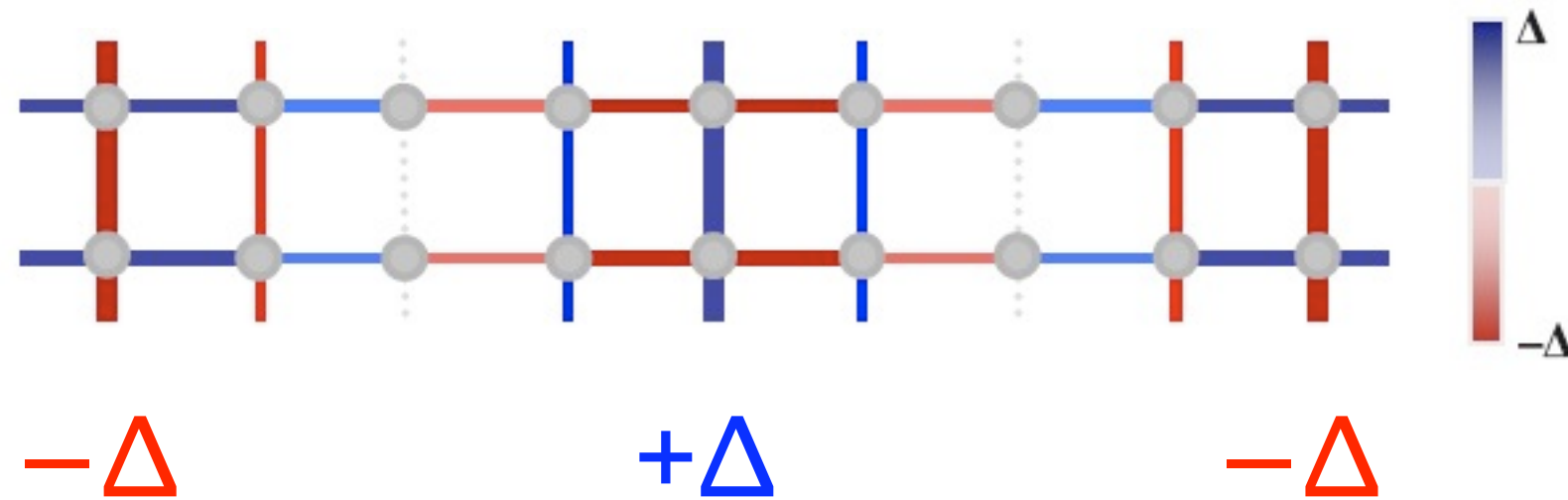
$T_c < 7 \text{ K}$



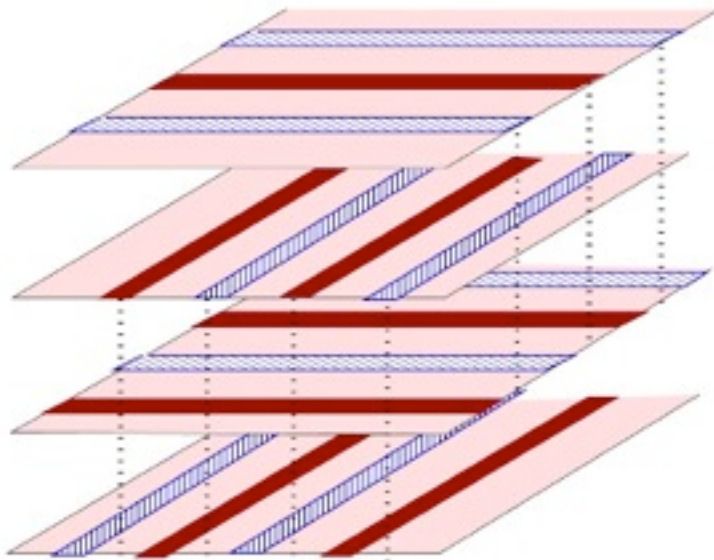
J. Chang *et al.*, NJP (2008)

Pair Density Wave (PDW) State

Spatially-modulated superconducting order parameter
analogous to FFLO



Frustration of interlayer coupling:
Himeda *et al.*, PRL (2002)
Berg *et al.*, PRL (2007)



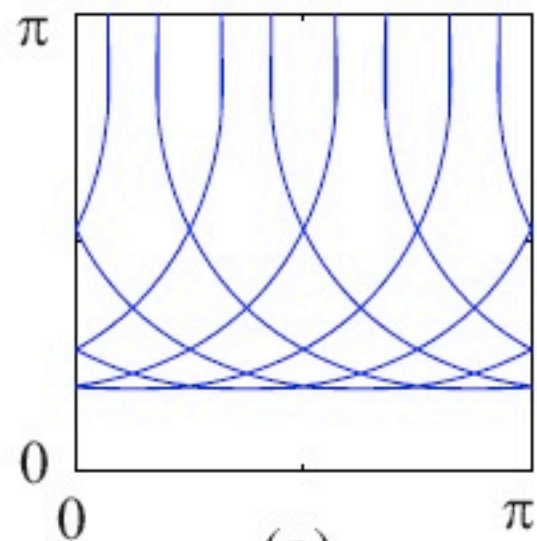
Energetics and stability:
Rackowski *et al.*, PRB (2007)
Berg *et al.*, PRB (2009)
K.Y. Yang *et al.*, arXiv:0807.3789
White+Scalapino, PRB (2009)

PDW Gap

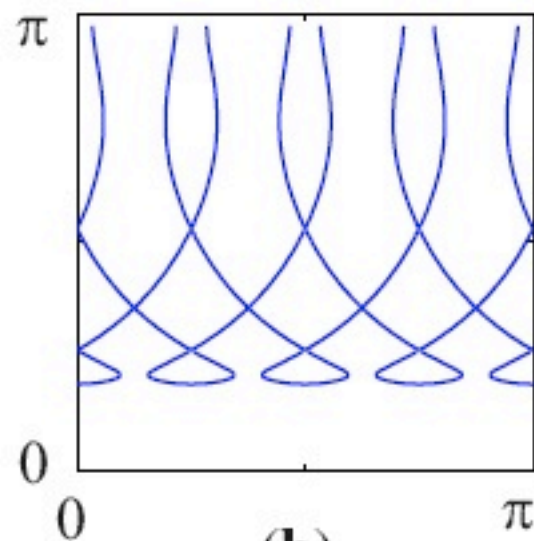
$$\Delta = 0$$

$$\Delta = 0.075t$$

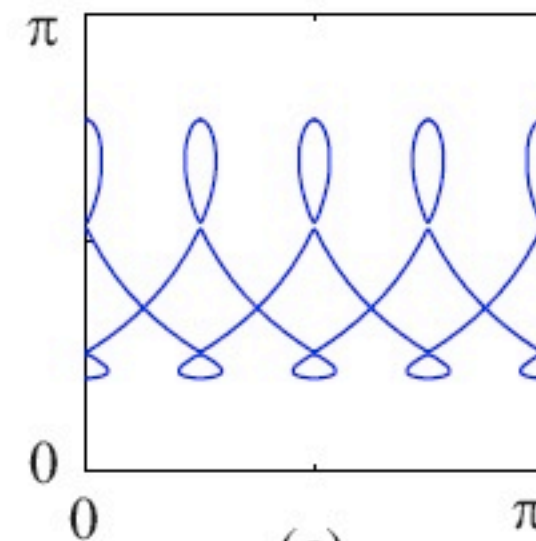
$$\Delta = 0.15t$$



(a)

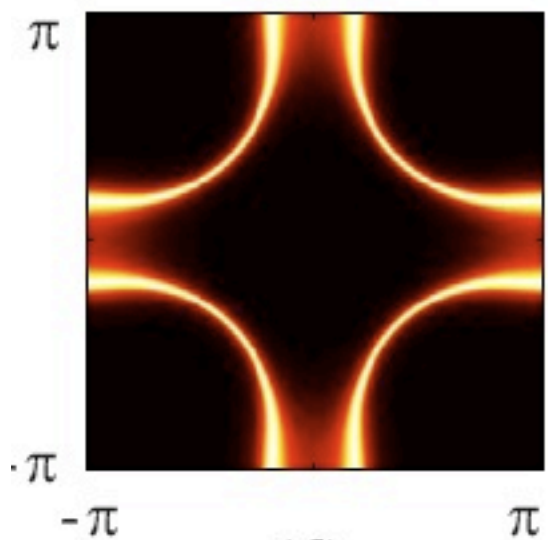


(b)

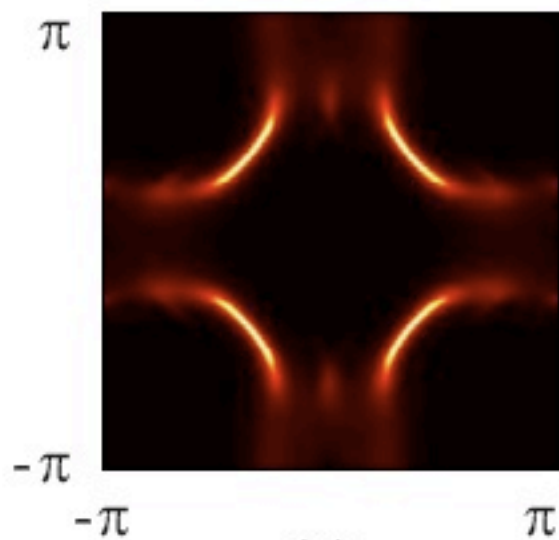


(c)

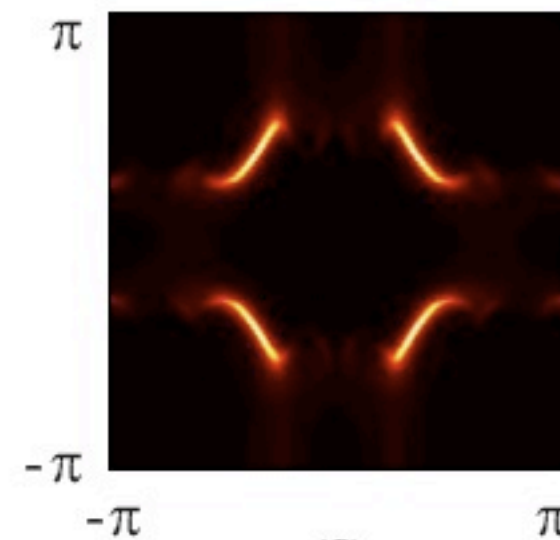
$$|t| = 0.6 \text{ eV}$$



(d)



(e)



(f)

Baruch + Orgad, PRB (2008)

Uniform d-wave gap can form on the gapless nodal arc (Berg *et al.*)

Gap Summary

T

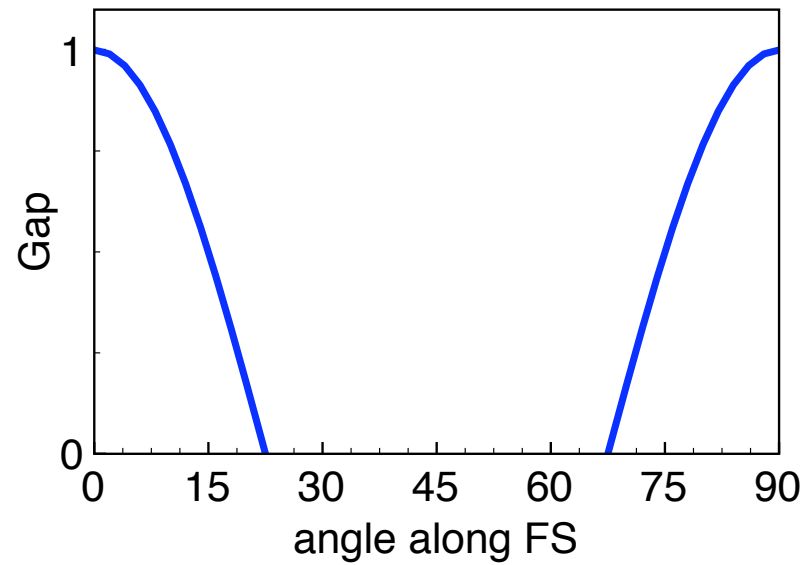
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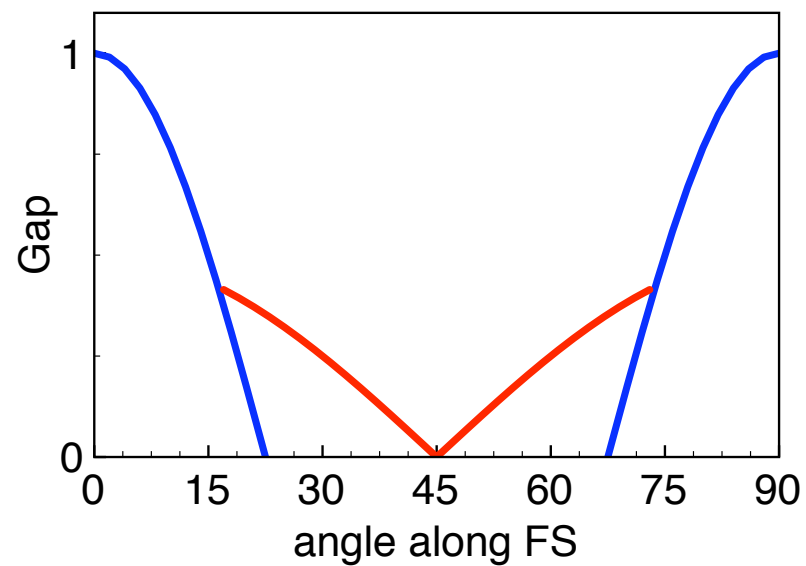
PDW (sro)

charge
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spin
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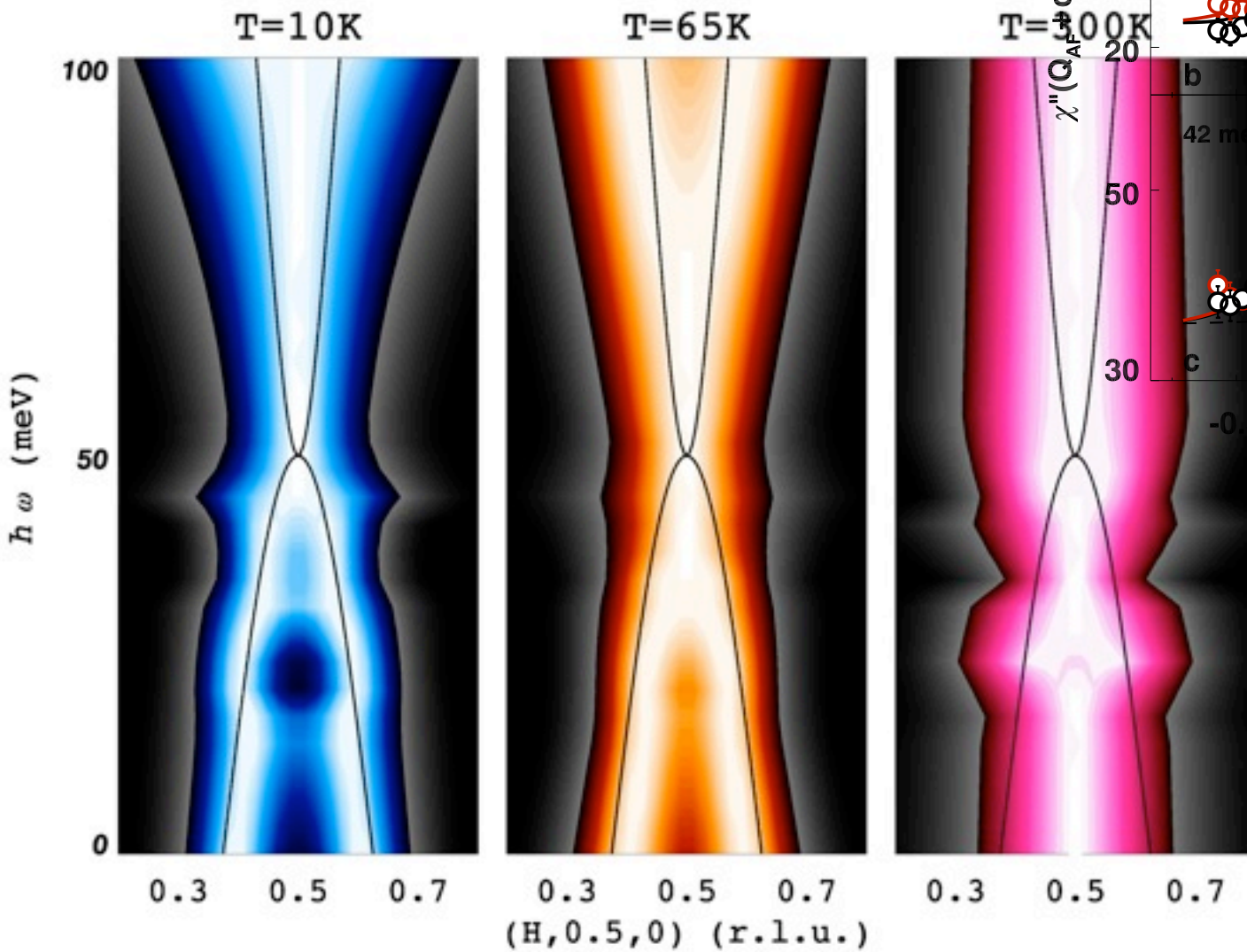
ρ_{ab} , χ_{\perp}



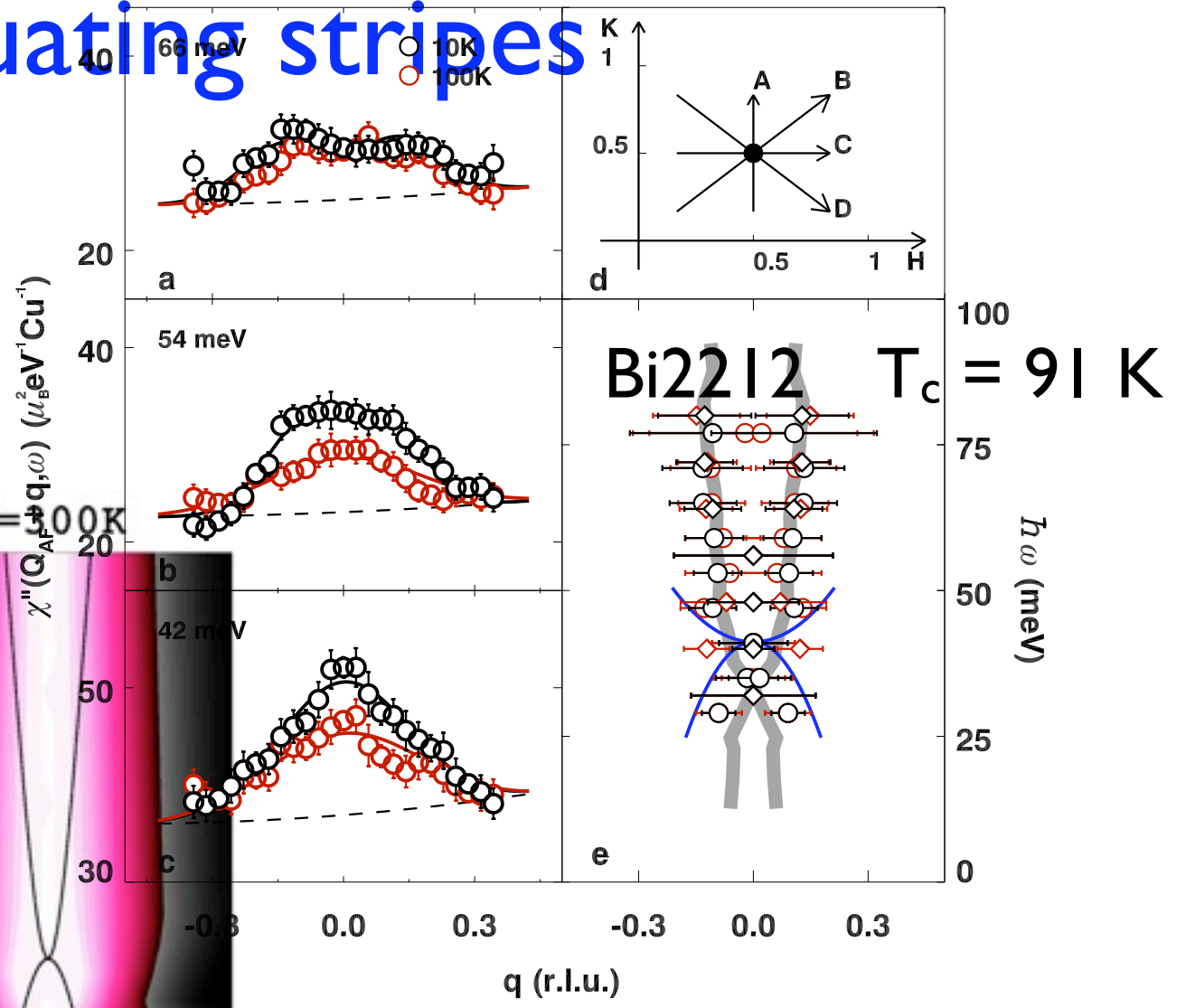
PDW (sro)
+
uniform d-wave

Fluctuating stripes

LBCO $x=1/8$

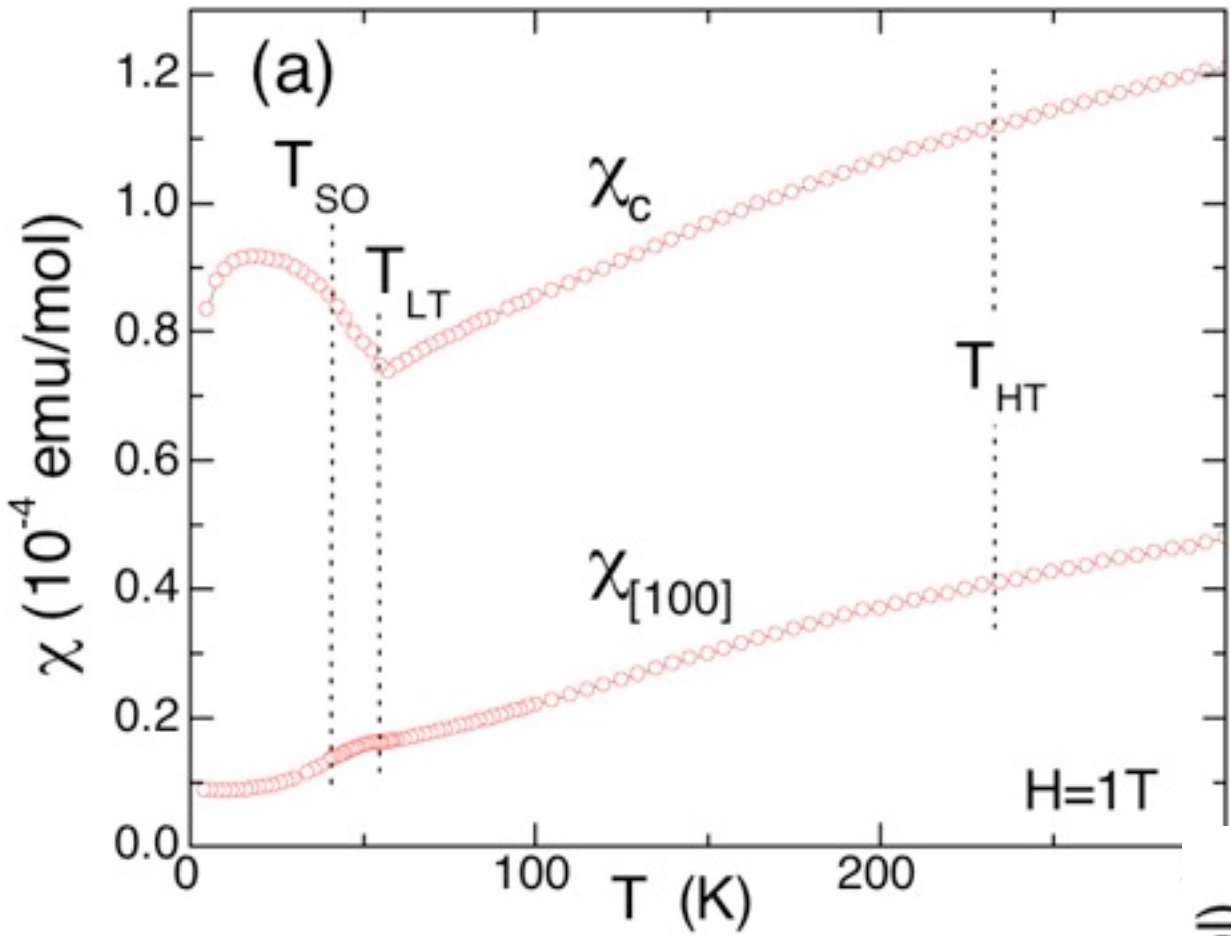


Xu et al., PRB (2007)



Xu et al., arXiv:0902.2802

Magnetic susceptibility of LBCO $x=1/8$



T -dependent anisotropy requires local moments

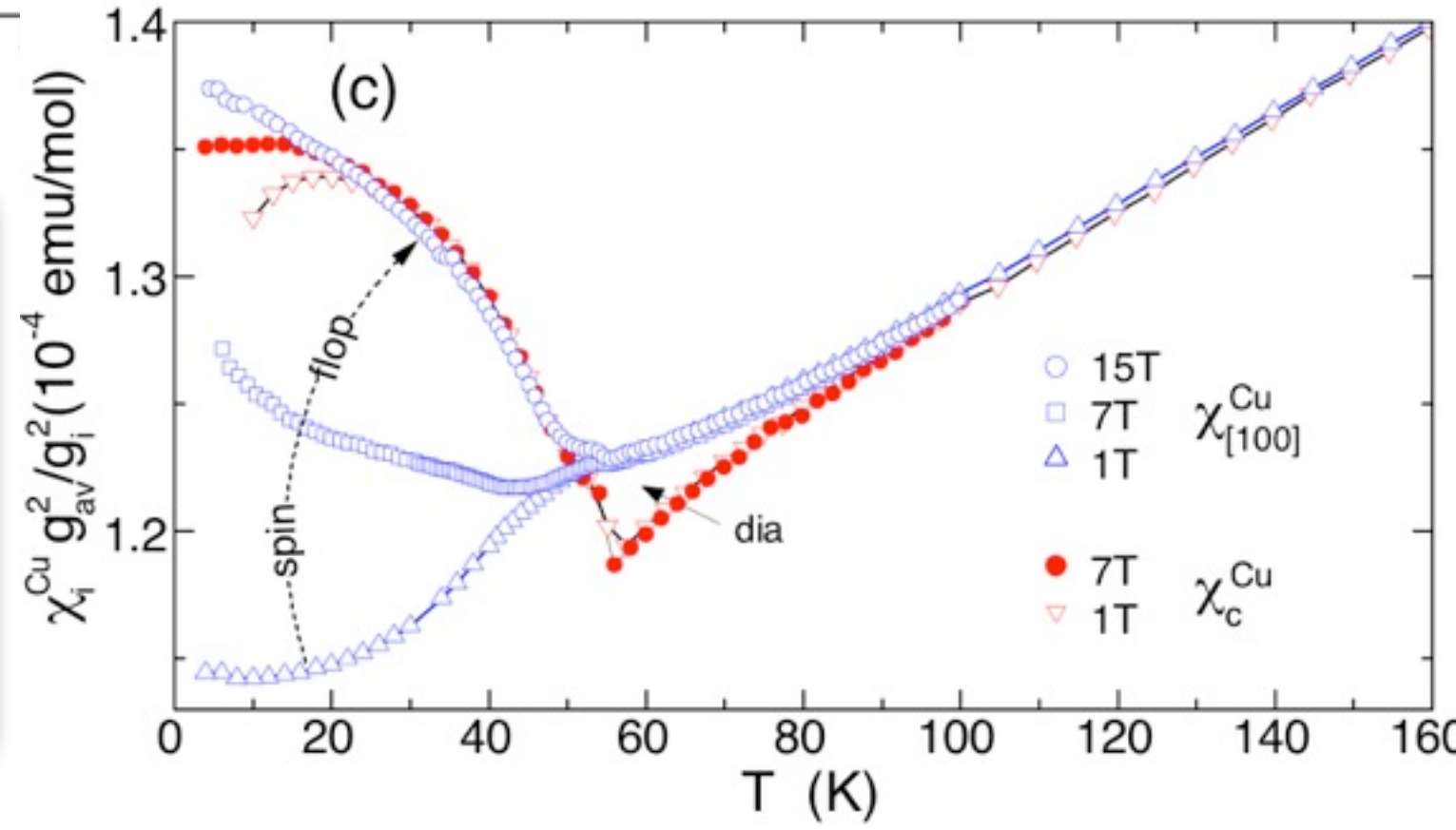
$g_{ab} = 2.15$

$g_c = 2.58$

No sign of Pauli susceptibility

Ordered state:
anisotropic χ as in AF
spin flop at $H = 6 T$

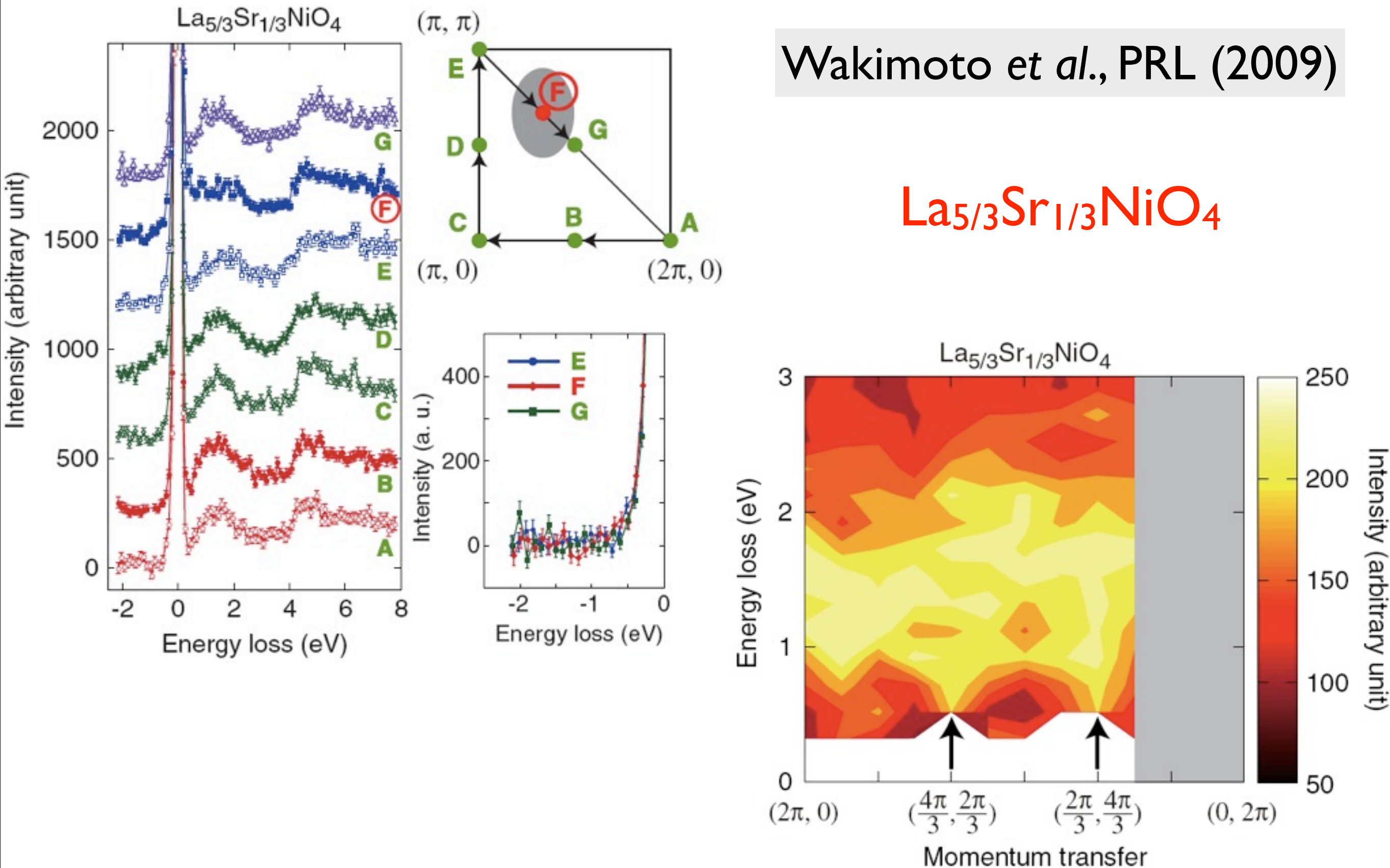
Hücker *et al.*, PRB (2008)



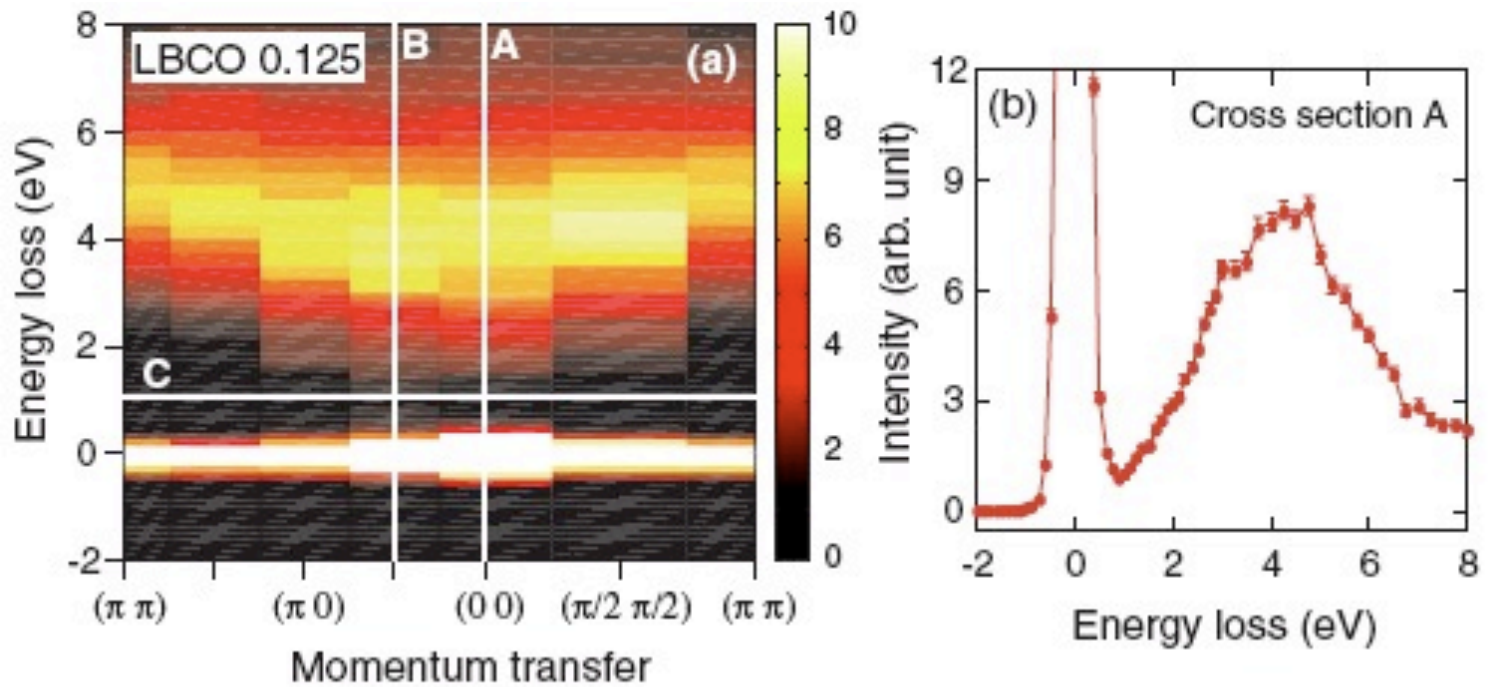
Inelastic x-ray scattering study of stripe order

Wakimoto *et al.*, PRL (2009)

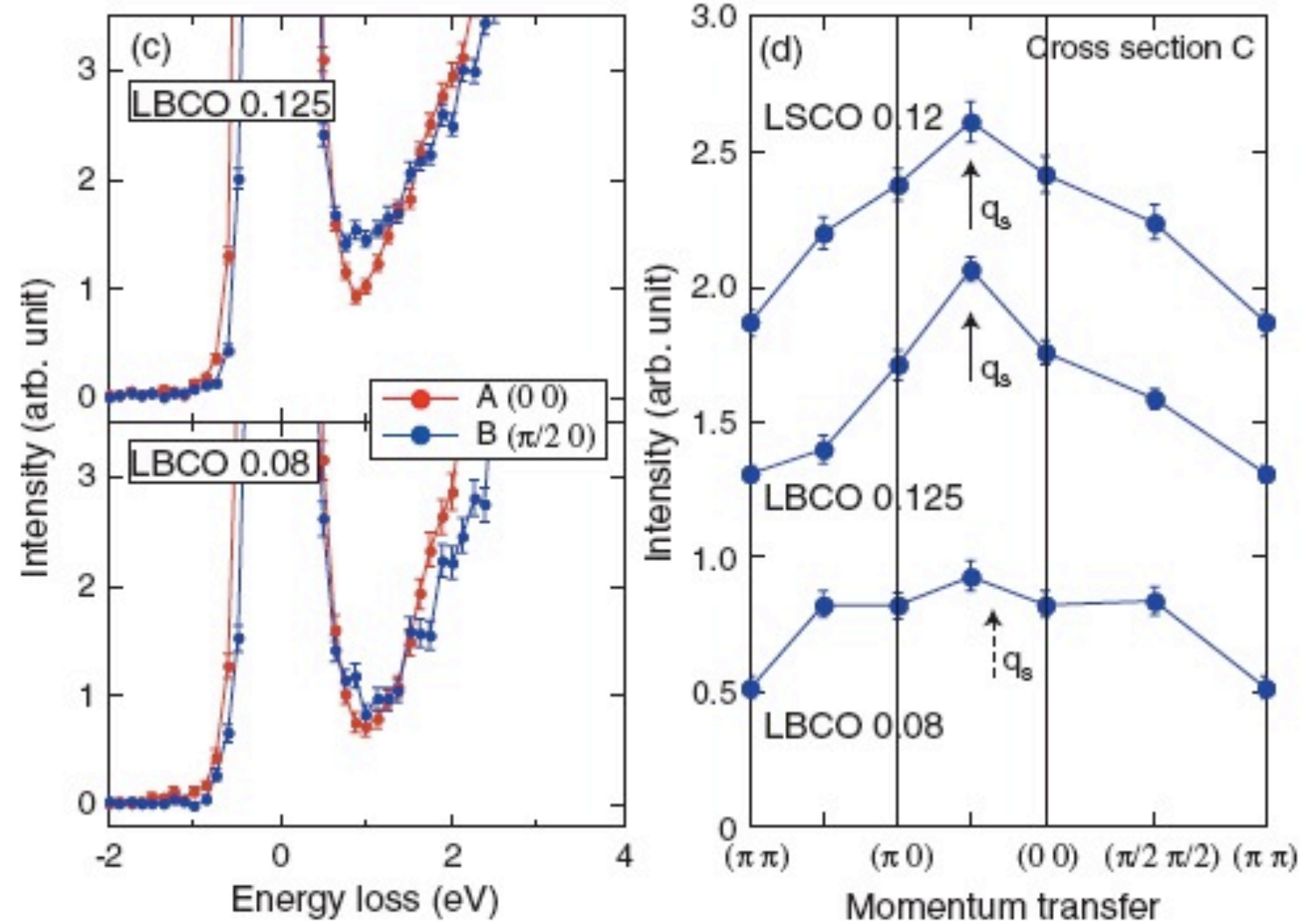
$\text{La}_{5/3}\text{Sr}_{1/3}\text{NiO}_4$



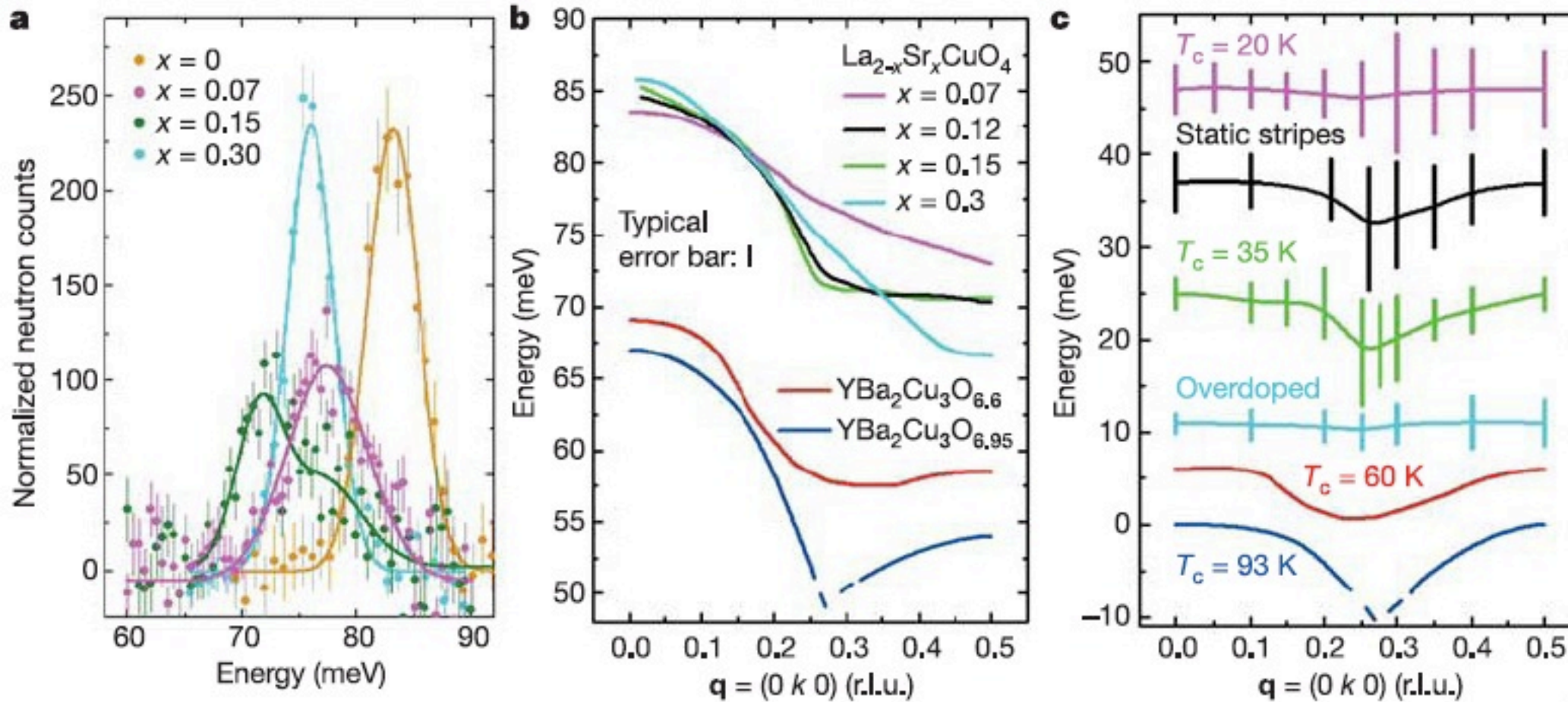
Dispersion in LBCO



Wakimoto *et al.*, PRL (2009)



Phonon anomaly at $4k_F$

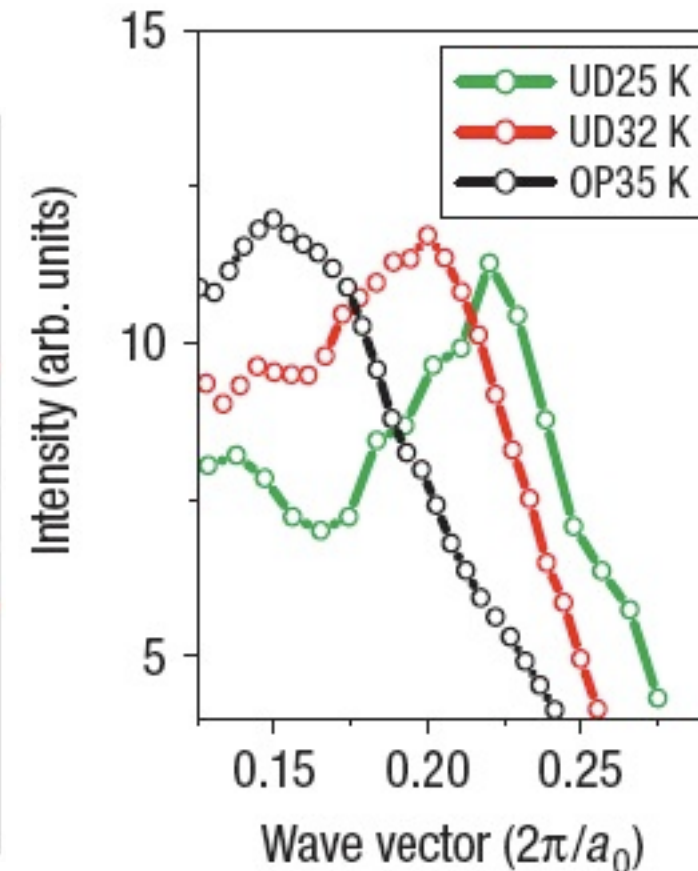
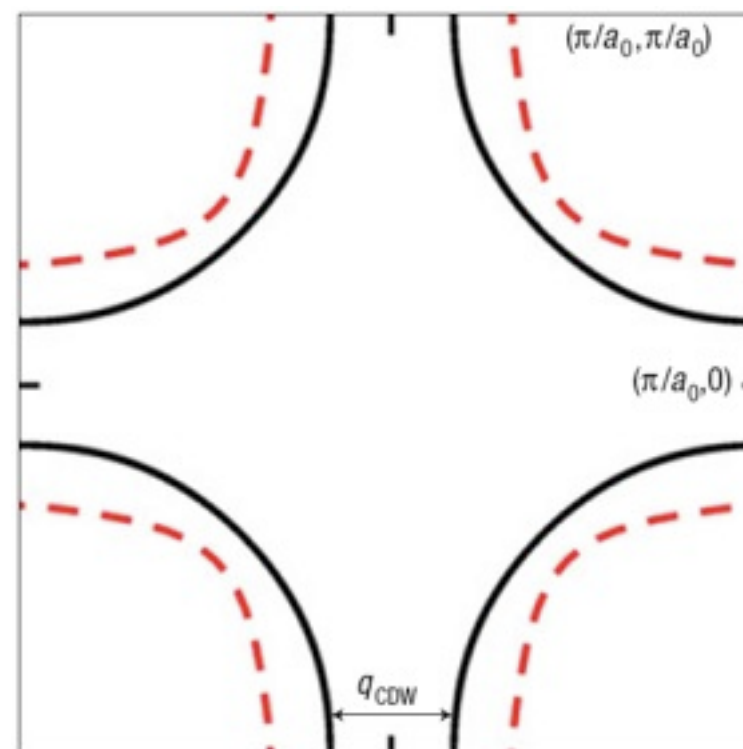


AN nesting is expected *within* stripes

Reznik *et al.*, Nature (2006)

DOS modulations in Bi2201

Wise *et al.*, Nat. Phys. (2006)



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