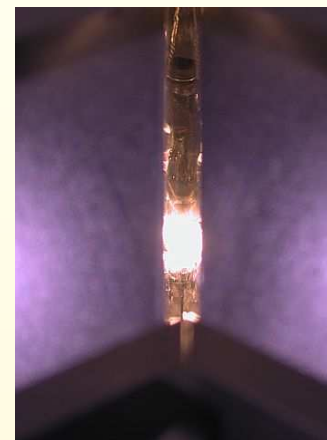
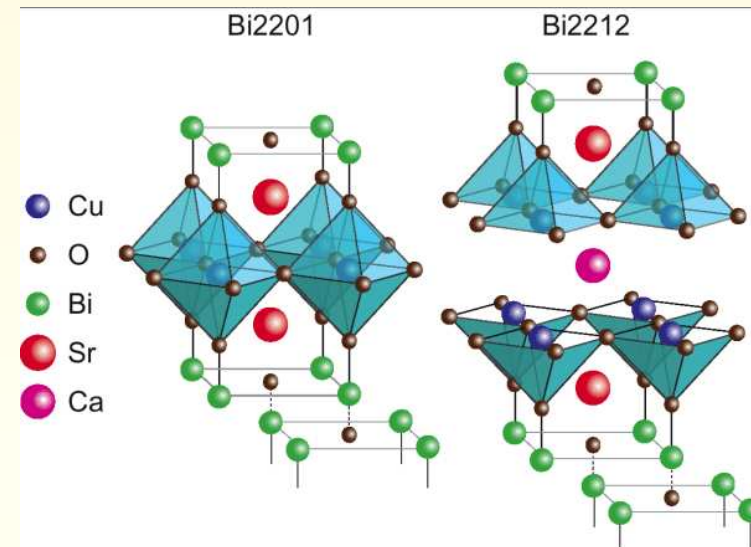


Magnetizam i fotoefekt u visokotemperaturnim supravodičima

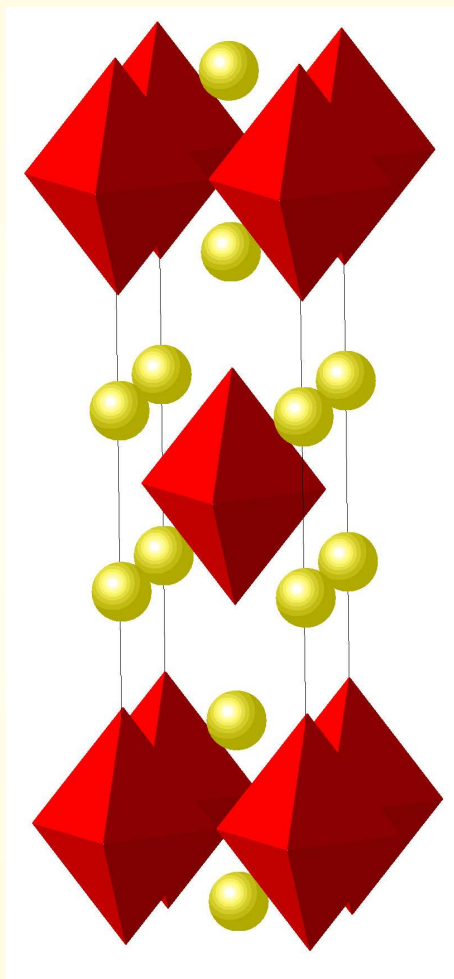
Osnovni podaci:

- ▣ Kompleksni metalni oksidi — **keramike**;
- ▣ **Perovskiti** — kisikove piramide ili oktaedri.
- ▣ Karakteristične **ravnine** bakrenog oksida;
- ▣ Izolatori — treba ih **dopirati!**

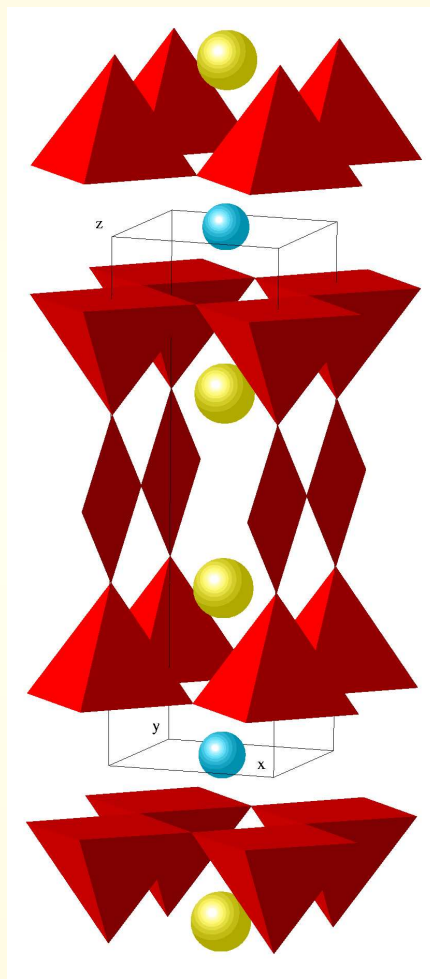


Fotoefekt u BSCCO: D.K. Sunko i S. Barišić, Eur. Phys. J. B 43 (2005) 269-279.

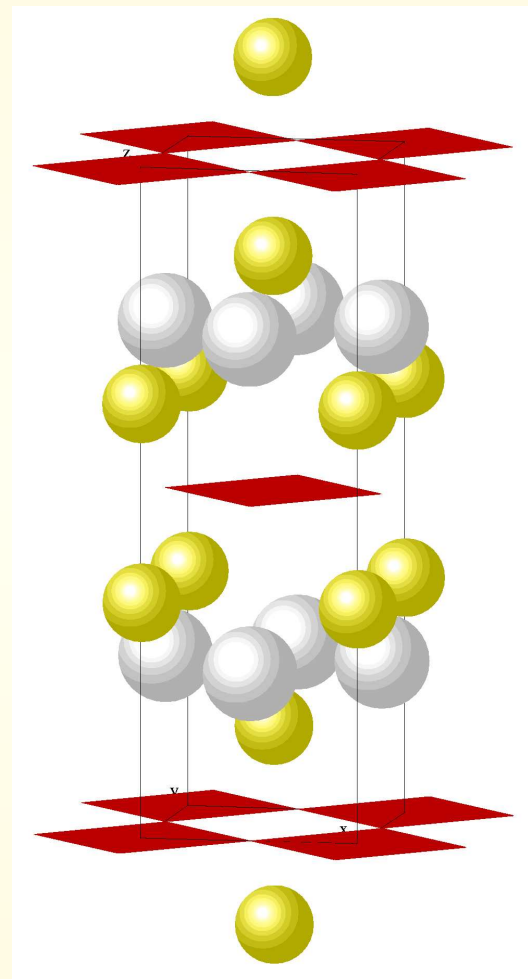
Kristalna struktura



La_2CuO_4

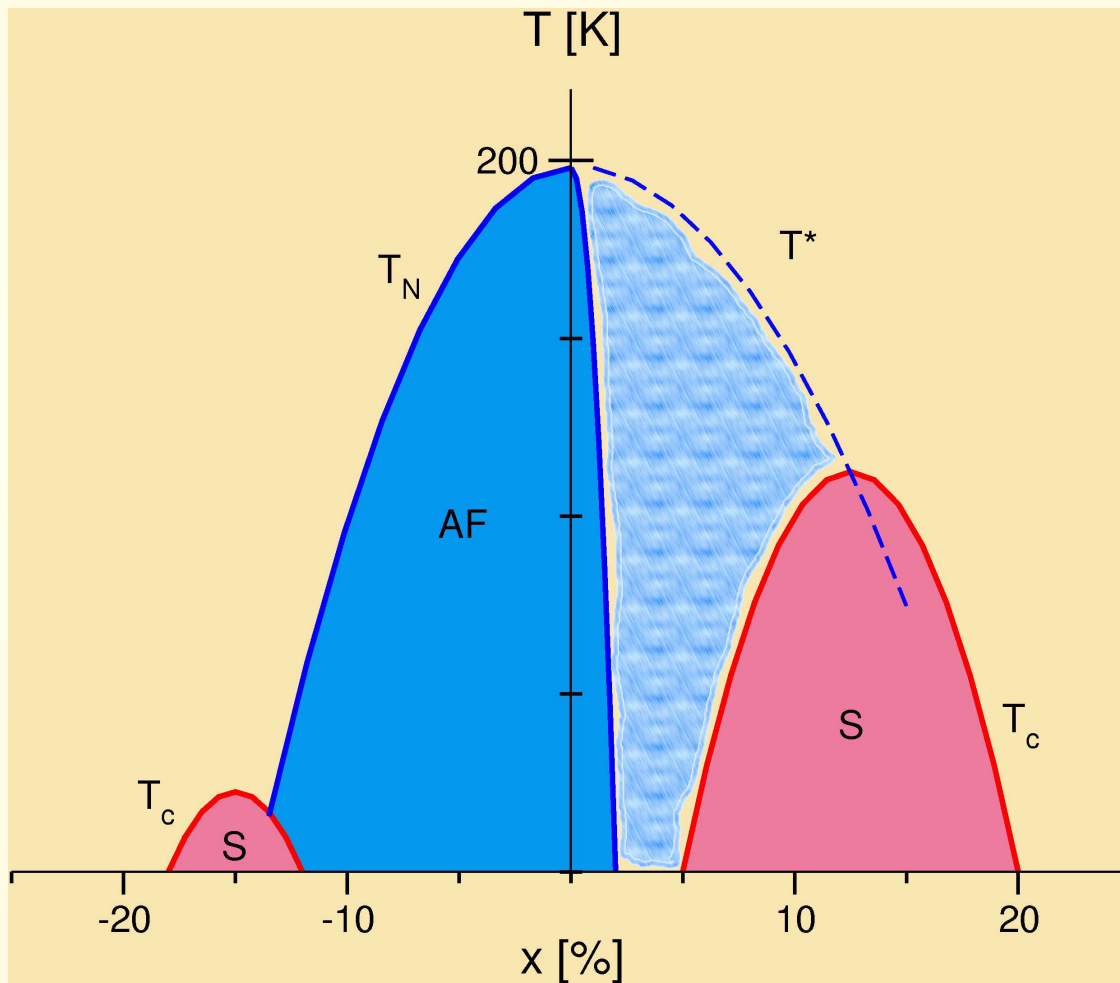


$\text{YBa}_2\text{Cu}_3\text{O}_7$

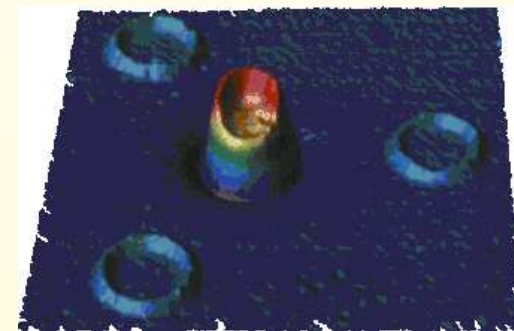
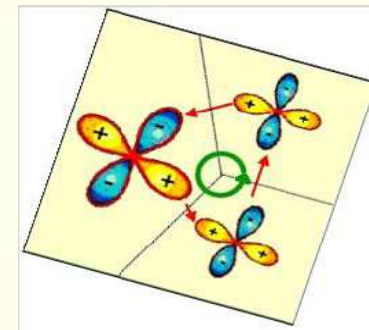


NdCu_2O_4

Fazni dijagram

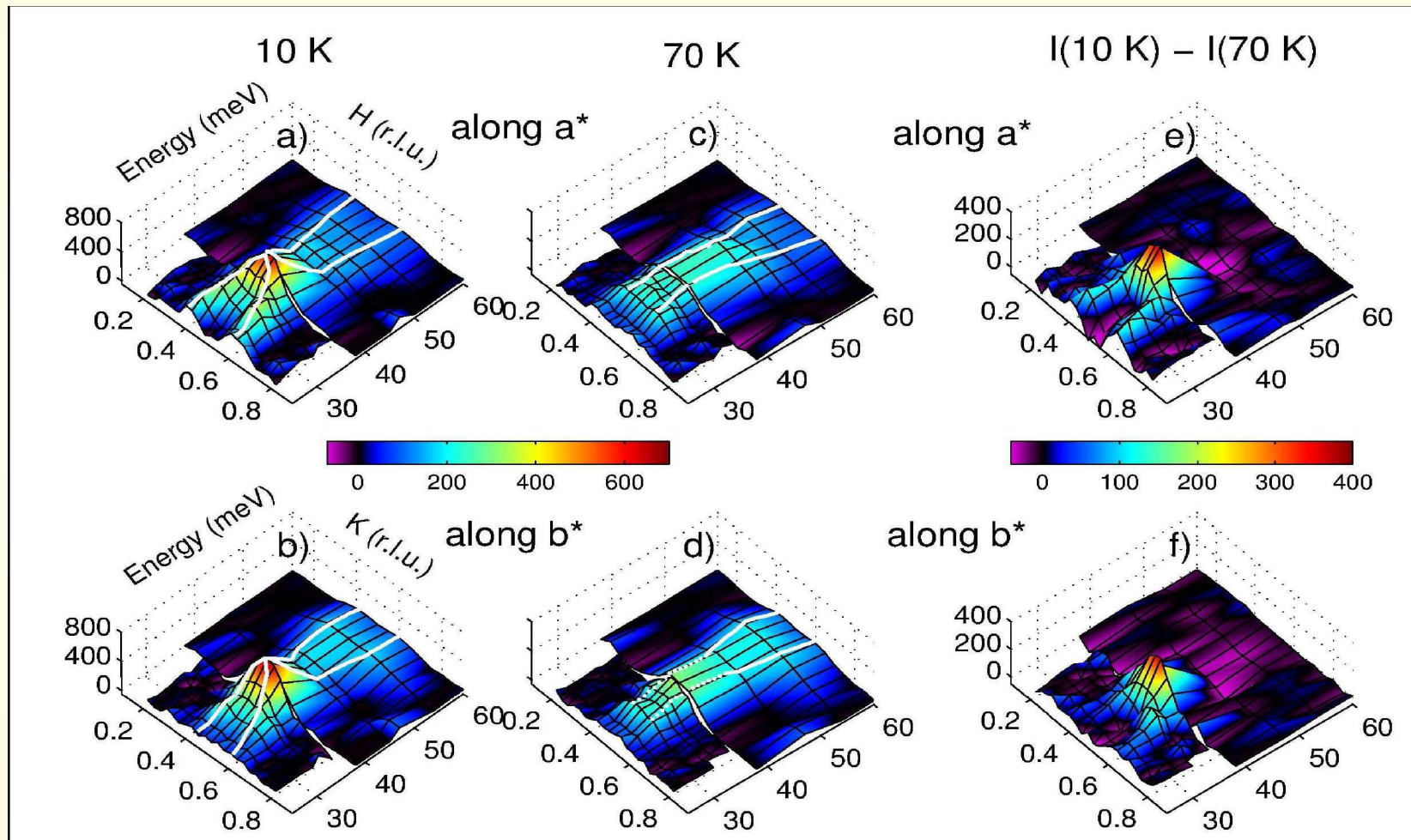


- ▣ Asimetrija T_N ;
- ▣ Neobični metal ispod T^* ;
- ▣ d -valna supravodljivost:



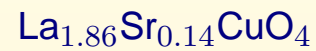
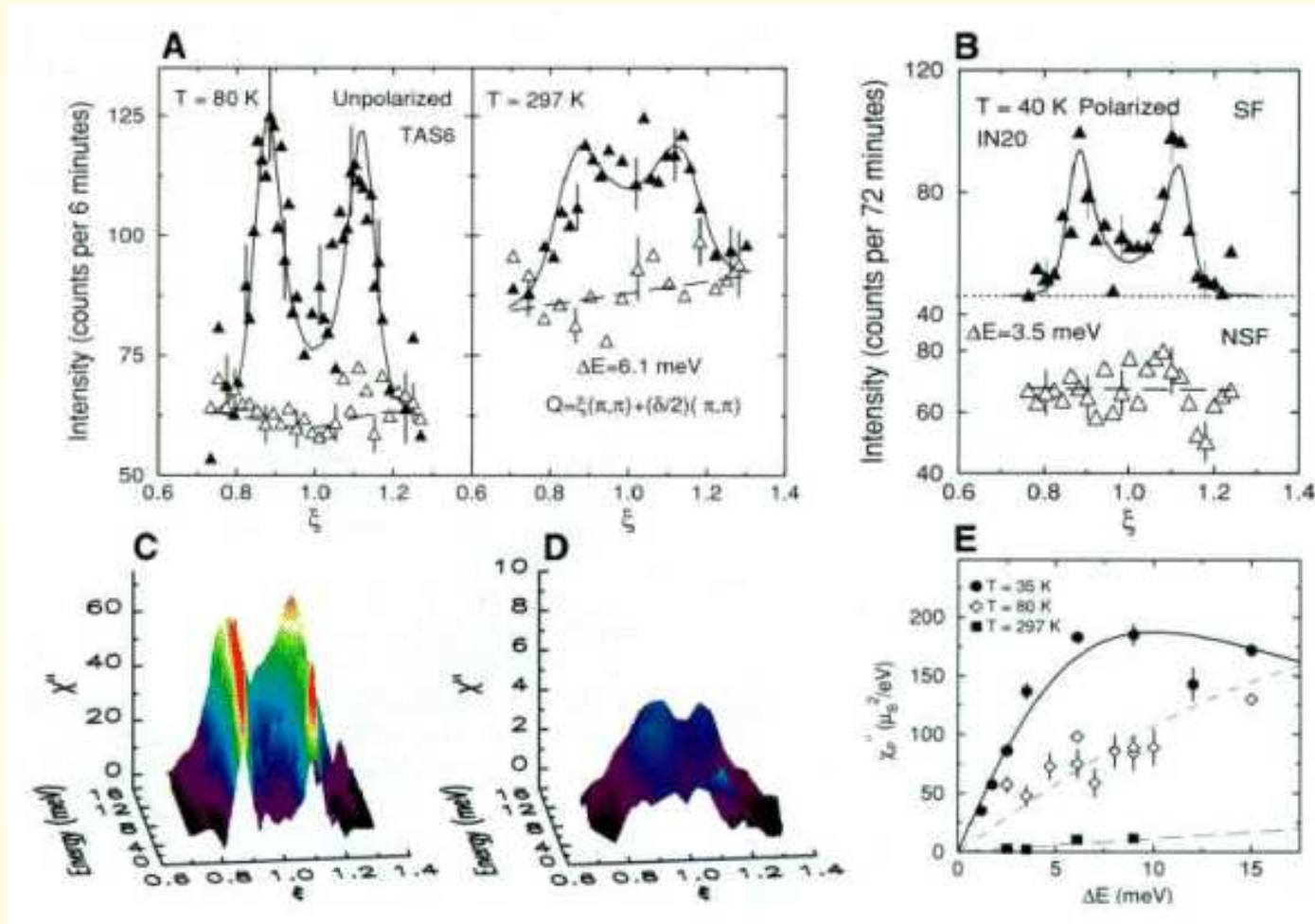
Mjerenje: C. C. Tsuei et al., PRL 73, 593 (1994)

Magnetizam YBCO



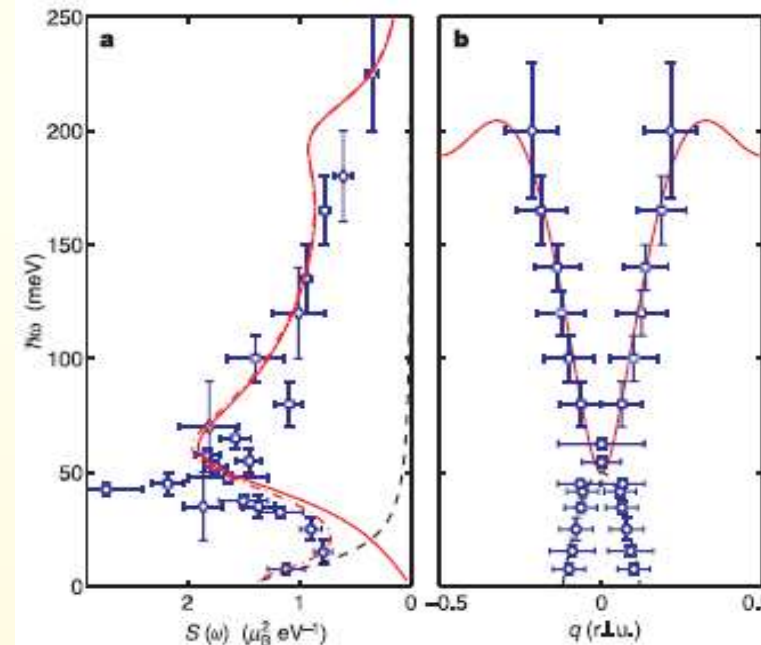
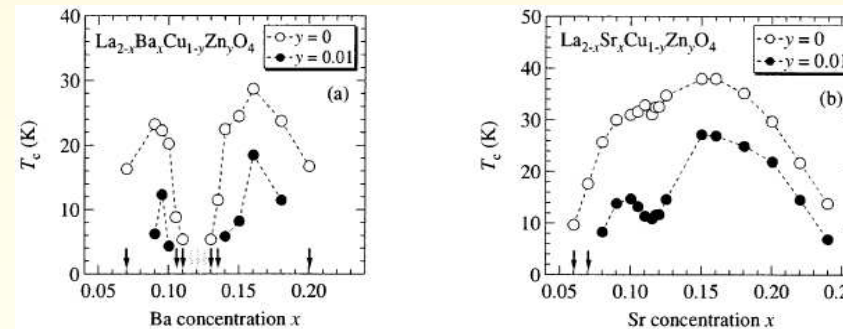
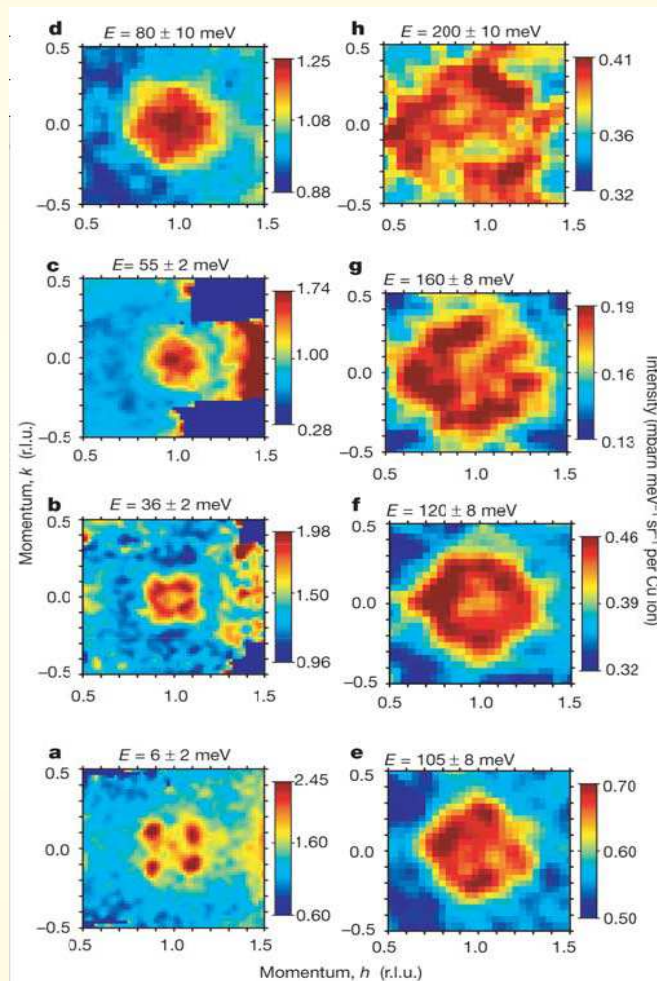
Mjerenje: V. Hinkov et al., cond-mat/0601048

Magnetizam LSCO



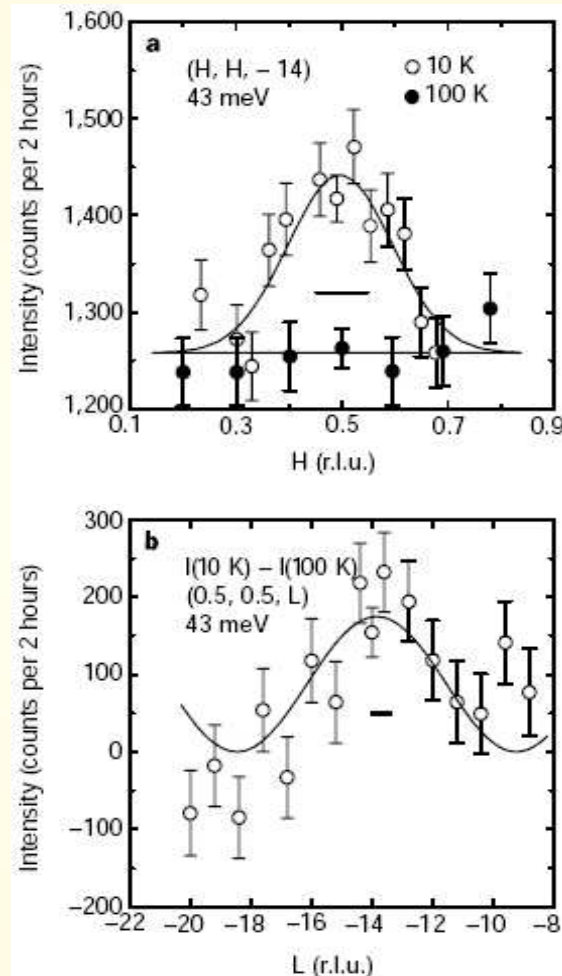
Mjerenje: G. Aeppli et al., Science **278**, 1432 (1997).

Magnetizam LBCO



Mjerenja: J. M. Tranquada et al., *Nature* **429**, 534 (2004); J. Arai et al., *J. Low Temp. Phys.*, **131**, (2003).

Magnetizam BSCCO i NCCO



BSCCO, neutroni: H. F. Fong et al.,
Nature **398**, 588 (1999).

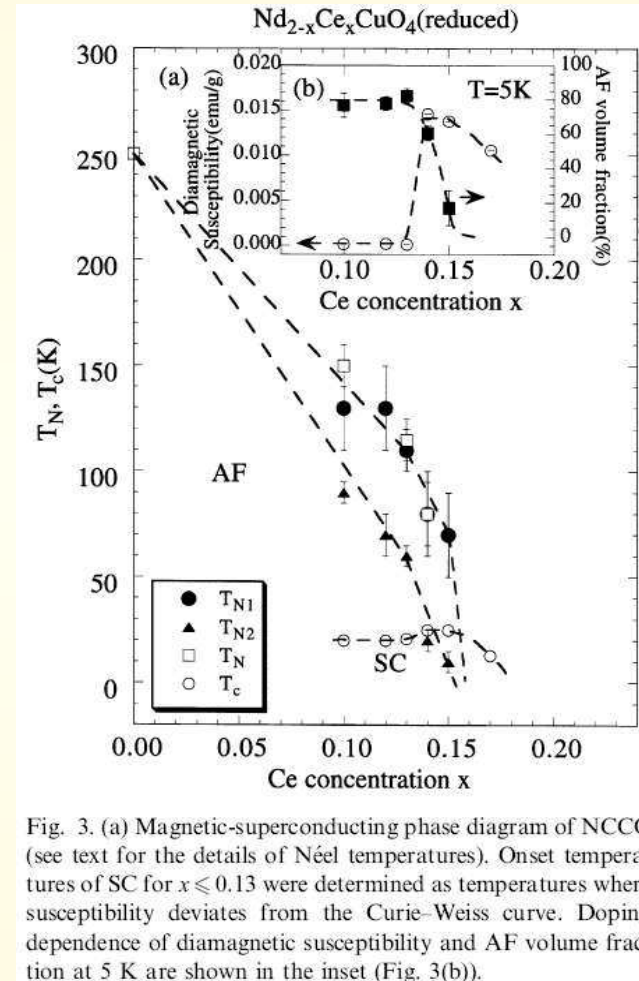


Fig. 3. (a) Magnetic-superconducting phase diagram of NCCO (see text for the details of Néel temperatures). Onset temperatures of SC for $x \leq 0.13$ were determined as temperatures where susceptibility deviates from the Curie-Weiss curve. Doping dependence of diamagnetic susceptibility and AF volume fraction at 5 K are shown in the inset (Fig. 3(b)).

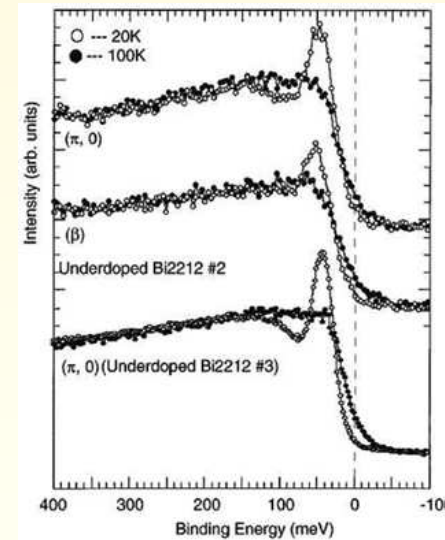
NCCO, mioni: T. Uefuji et al.,
Physica C **357-360**, 208 (2001).

Sažetak magnetskih mjerenja

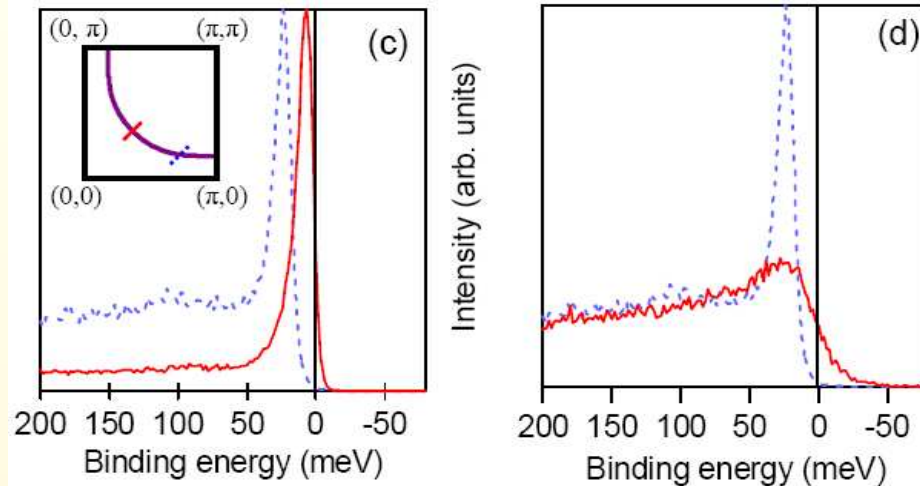
- Statički magnetizam je **antikoreliran** sa supravodljivošću.
- Dinamički magnetski odgovor se drastično **mijenja** na T_c .
- Za šupljinsko dopiranje magnetske korelacije imaju **procjep** $> T_c$.
- Za elektronsko dopiranje **procjep je** $< T_c$.



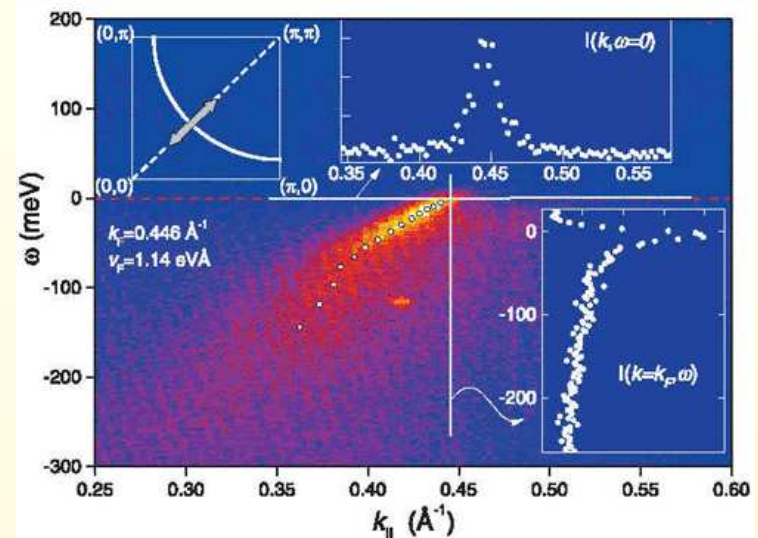
Fotoefekt



J. M. Harris et al., PRL **78**, 1771 (1997).



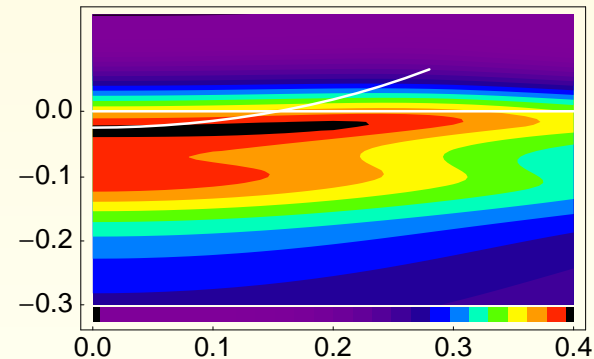
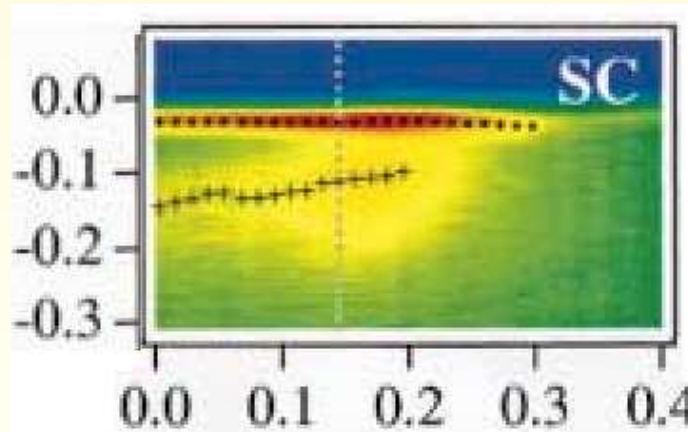
J. D. Koralek et al. cond-mat/0508404 (2006).



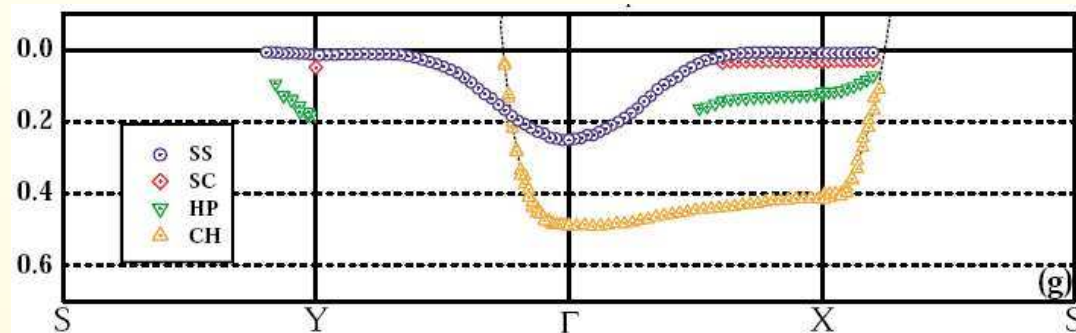
T. Valla et al., Science **285**, 2110 (1999).

Rez u energiji duž $(\pi, 0) - (\pi, \pi)$

BSCCO:



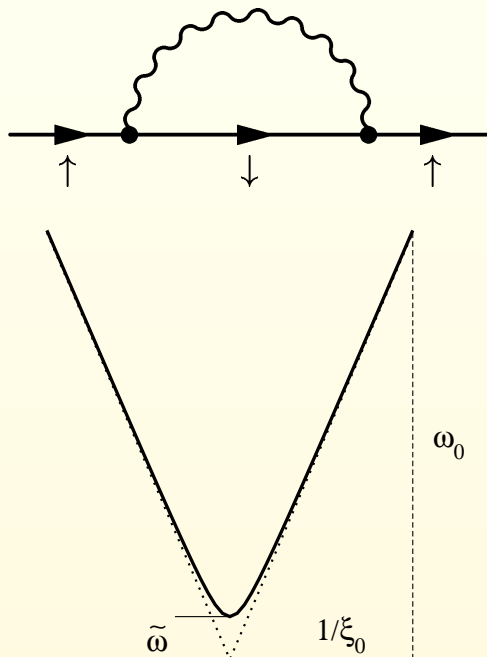
YBCO pokazuje slično ponašanje:



Mjerenje: A. V. Fedorov et al., PRL **82**, 2179 (1999); D. H. Lu et al., PRL **86**, 4370 (2001).

Utjecaj AF fluktuacija na gibanje elektrona

$$\Sigma_R(\mathbf{k}, \omega) \sim \int g_{\mathbf{k}, \mathbf{q}}^2 d^2 q \int_{-\infty}^{\infty} d\omega' \times \left[\chi_R(\mathbf{Q} + \mathbf{q}, \omega - \omega') (1 - f(\omega')) \text{Im} G_R^{(0)}(\mathbf{k} - \mathbf{q} - \mathbf{Q}, \omega') + G_R^{(0)}(\mathbf{k} - \mathbf{q} - \mathbf{Q}, \omega - \omega') n(\omega') \text{Im} \chi_R(\mathbf{Q} + \mathbf{q}, \omega') \right]$$



⇒ Antiadijabatski elektroni tvore **podstav** sporiji od magnona.

⇒ Bozonski odgovor dominira u klasičnoj granici

$$n(\omega') \approx kT/\tilde{\omega} \rightarrow \infty,$$

no u kvantnoj granici $kT \ll \tilde{\omega}$ oba su jednako važna.

$$\chi_R(\mathbf{Q} + \mathbf{q}, \omega) = \frac{\omega_0^2}{(\omega + i\gamma)^2 - \omega_D(\mathbf{Q} + \mathbf{q})^2}$$

] odnos $\tilde{\omega}$ i kT je kritičan!

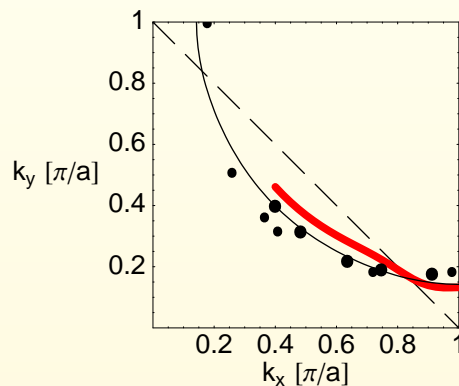
Jaka veza u naboju, slaba u spinu

Fizikalno razdvajanje skala:

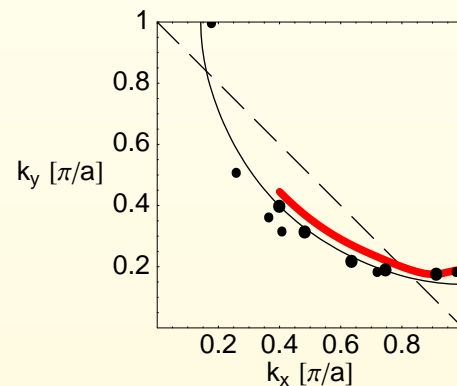
$$U \approx 10 \text{ eV} \gg W \approx 1 \text{ eV} \gg \Delta_{PS} \approx 0.1 \text{ eV}$$

- ▣ Velika odbojna sila na bakru daje **spore** fluktuacije naboja \rightarrow efektivne vrpce;
- ▣ Izravno skakanje sa kisika na kisik nije ometeno \rightarrow postaje **dominantno!**
- ▣ AF korelacije (paramagnoni) su onda **brze** i slabe smetnje:

$kT \gg \tilde{\omega}$:



$kT \ll \tilde{\omega}$:



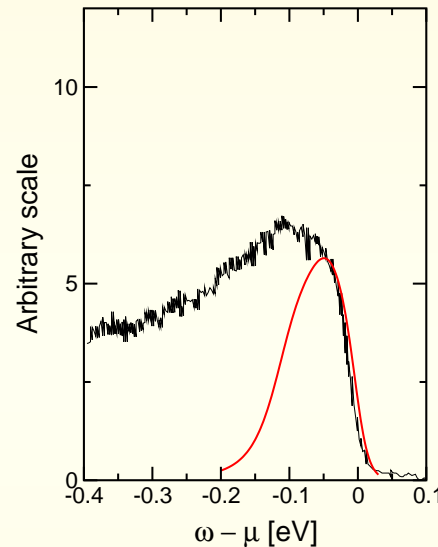
- ▣ Visokotemperaturni **poluklasični** režim daje "vruću točku".
- ▣ Niskotemperaturni **kvantni** režim savija Fermijevu plohu u **suprotnom** smjeru!

Mjerenja: T. Valla et al., PRL **85**, 828 (2000), M. R. Norman et al., PRB **52**, 615 (1995).

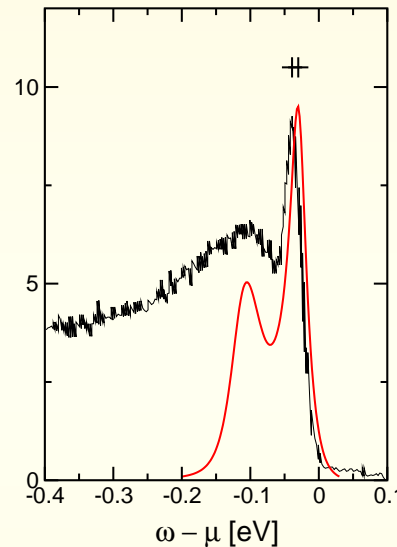
Parametri modela

Svi parametri se odrede na **jednom** mjerenju, na samoj **vH točki** $(\pi, 0)$ u BSCCO-u.

Natkritično
gušenje:
 $\gamma > \tilde{\omega}$
Exp. 104 K



Potkritično
gušenje:
 $\gamma < \tilde{\omega}$
Exp. 46 K

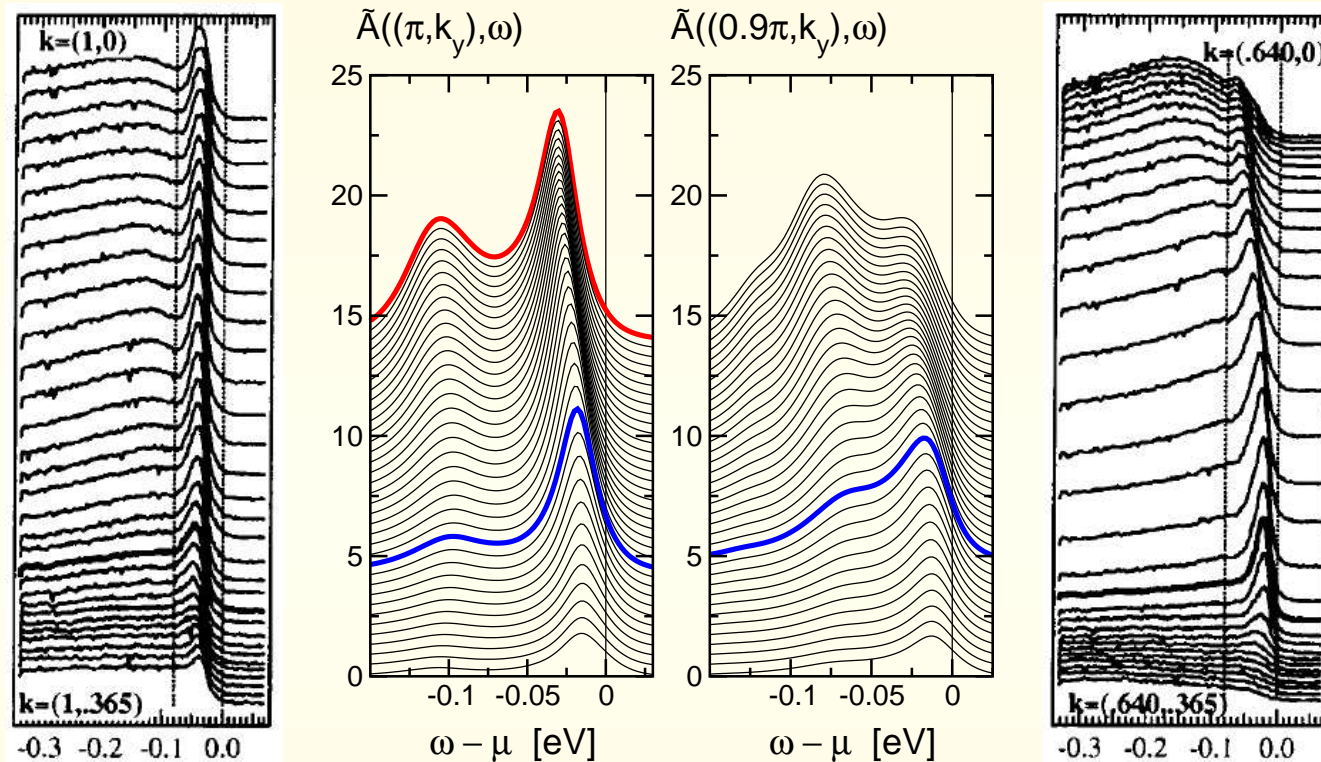


$$\Delta_{pf} = 3.6 \text{ eV} \gg t' = -1.0 \text{ eV} \gg t = 0.3 \text{ eV}, \mu = 0.025 \text{ eV} \quad (\text{vrpca})$$

$$\tilde{\omega} = 0.04 \text{ eV} \gg kT = 0.01 \text{ eV} \approx \gamma = 0.015 \text{ eV}; \xi = c/\tilde{\omega} \approx 3 \text{ k.r.} \quad (\text{paramagnoni})$$

Experiment: A. V. Fedorov et al., PRL **82**, 2179 (1999).

Predviđanja za popunjena stanja



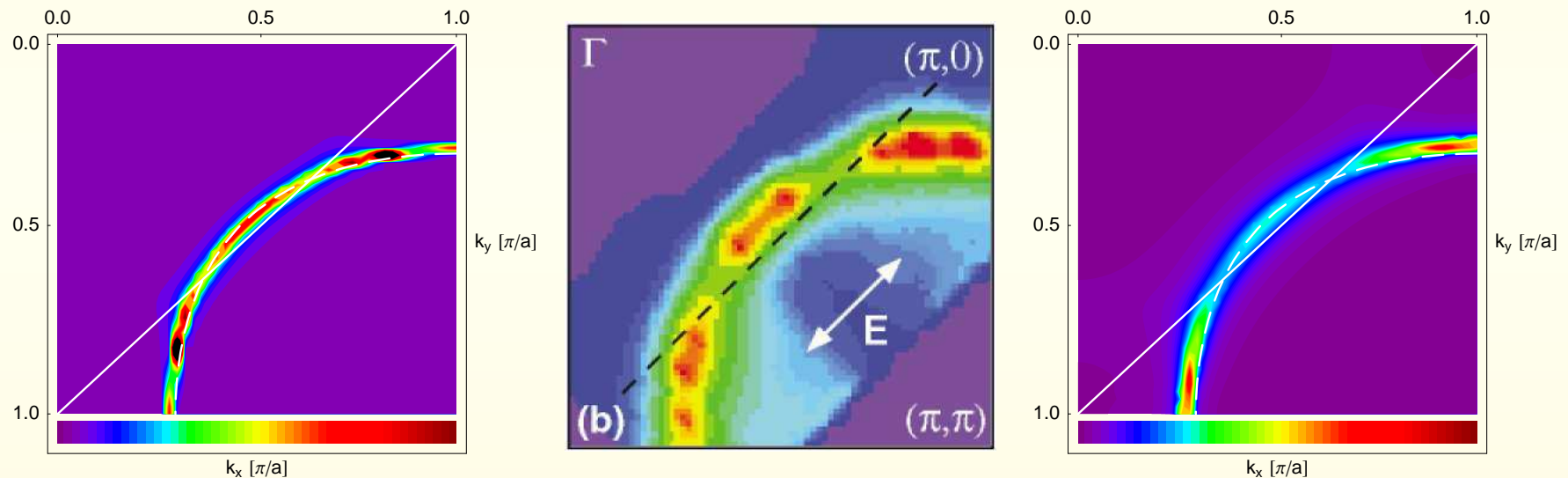
- Visokotemperaturno **poluklasično** predviđanje: središnji vrh prvi nestaje — **krivo**.
- Niskotemperaturno **kvantno** predviđanje: krilo sa strane nestaje prije — **tako je!**

*Experiment: A. Kaminski et al., PRL **86**, 1070 (2001).*

NCCO: 20 K je visoka temperatura!

Visoka temperatura: $\tilde{\omega} = 0.01 \text{ eV} < \gamma = 0.02 \text{ eV} \ll kT = 0.1 \text{ eV}$

Niska temperatura: $kT = 0.005 \text{ eV} < \tilde{\omega} = 0.01 \text{ eV} < \gamma = 0.02 \text{ eV}$



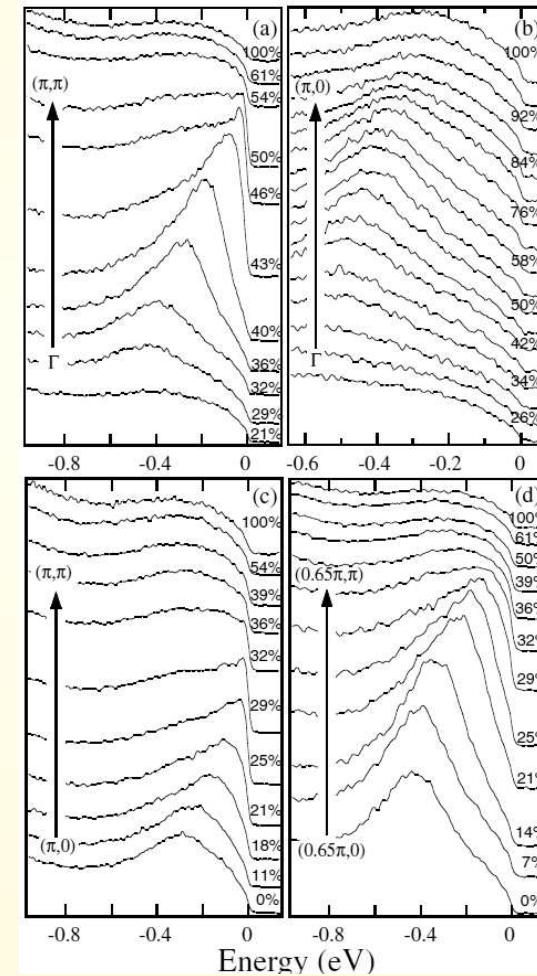
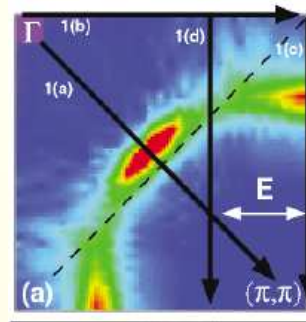
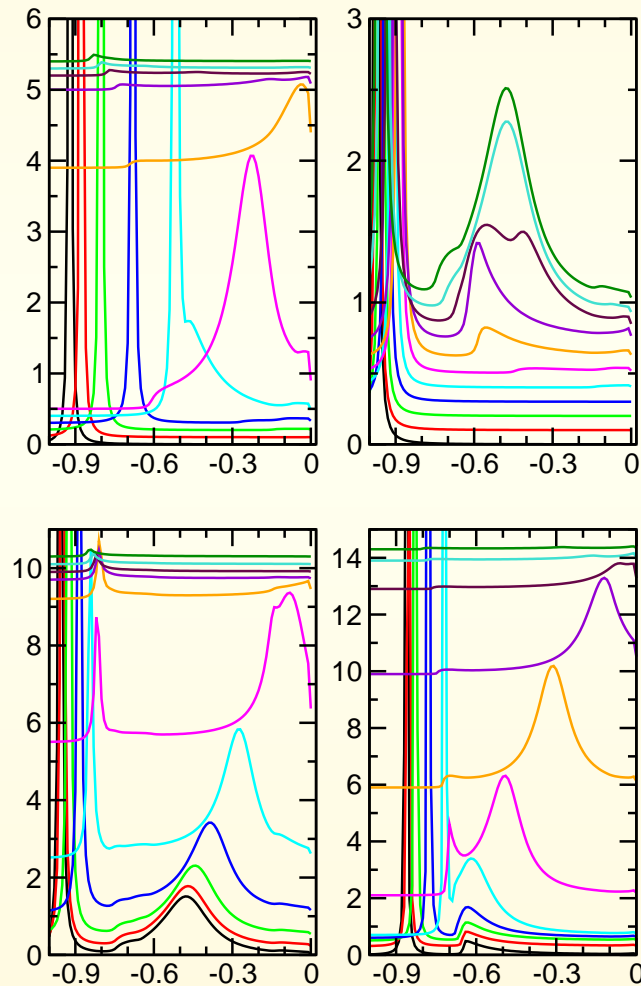
Parametri vrpce: U nije značajno, preklop kisik-kisik jest.

$$\Delta_{pf} = 1.6 \text{ eV}, t' = -1.2 \text{ eV}, t = 0.3 \text{ eV}, \mu = 0.75 \text{ eV}$$

Mjerenje: *N. P. Armitage et al., PRL* **87**, 147003-1/4 (2001).

Fotoefekt u NCCO-u

Visoka temperatura, natkritično gušenje: $\tilde{\omega} = 0.001 \text{ eV} < kT = 0.002 \text{ eV} \ll \gamma = 0.02 \text{ eV}$



Mjerenje: *N. P. Armitage et al., PRL* **87**, 147003-1/4 (2001).

Zaključci

- Optimalno dopirani BSCCO i NCCO su **oba** u režimu razvijenog pseudoprocjepa, koji je "**generički**" za kuprate.
- Uski antiadijabatski vrh na vH točki u BSCCO je **također** dio pseudoprocjepa, odgovarajuća energija veze nije dinamička nego **termodinamička** skala (μ).
- Magnoni se javljaju kao **kvantne fluktuacije** u BSCCO-u, a kao **poluklasični potencijal** u NCCO-u.
- Široke disperzivne strukture u NCCO-u **nisu** koherentne!
- Preskok sa kisika na kisik je **jednako** važan u elektronski i šupljinski dopiranim kupratima, dok je veliko U važno **samo** za šupljinske.
- Skala supravodljivosti je **odvojena** za gotovo red veličine!