Self-consistency of quasiparticle description in high-Tc cuprates

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Complexity of HTSC

Complex physics?

Complex structure?

Complexity in ARPES?

HTSC are simple!

⇩

LDA + Self-energy + ?

complex but
understandable

**self-consistency
as a tool**

Self-consistency as a tool

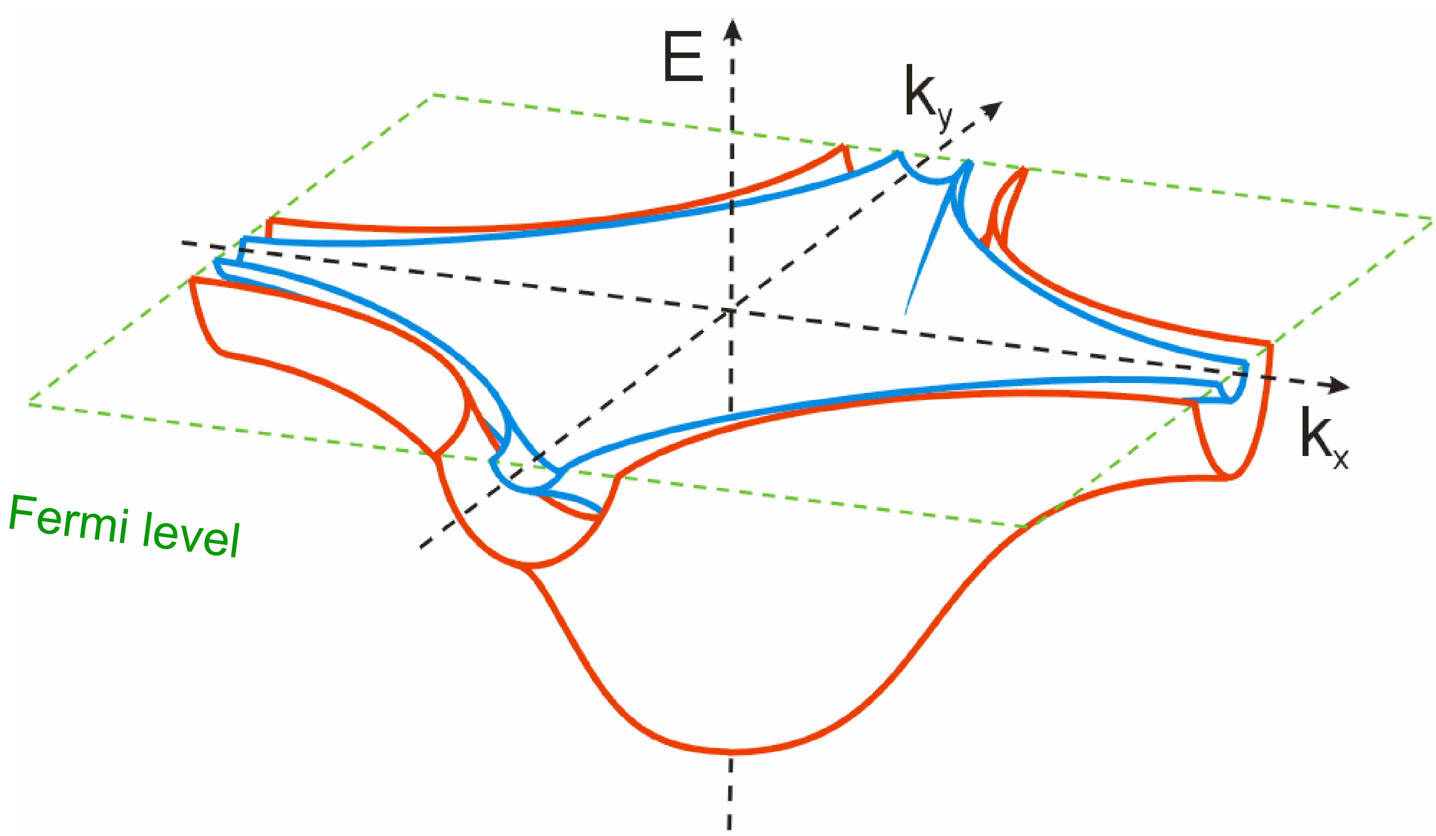
1. **How Kramers-Kronig (KK) consistency works**
   Why we believe it is applicable.
   Fine details of quasiparticle spectral function.
   Room for complexity in photoemission process.

2. **The waterfalls** (Where the consistency stops).

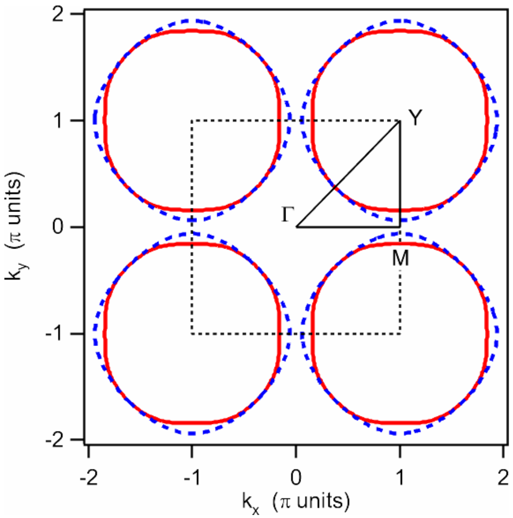
3. **Fingerprints of the bosonic spectrum**
   Quasiparticle spectrum in the whole Brillouin zone
   k-dependent self-energy
   ARPES – INS

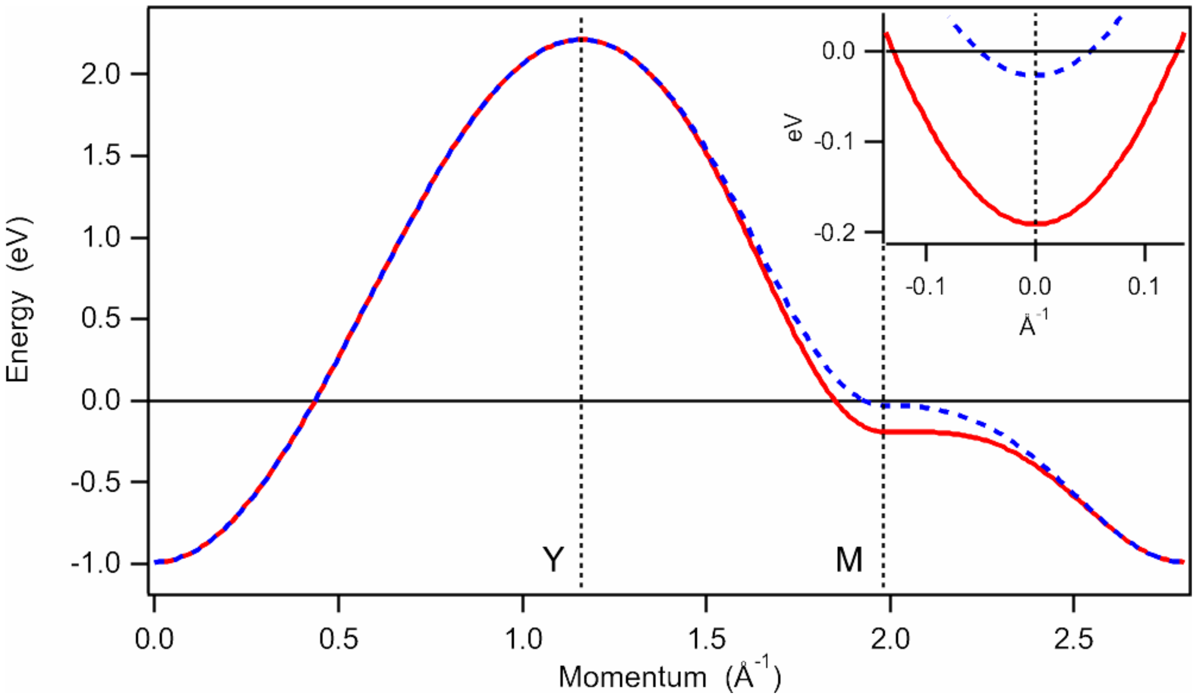
4. **Pseudo-gap problem…**

Complex electronic structure of CuO_2 bi-layer



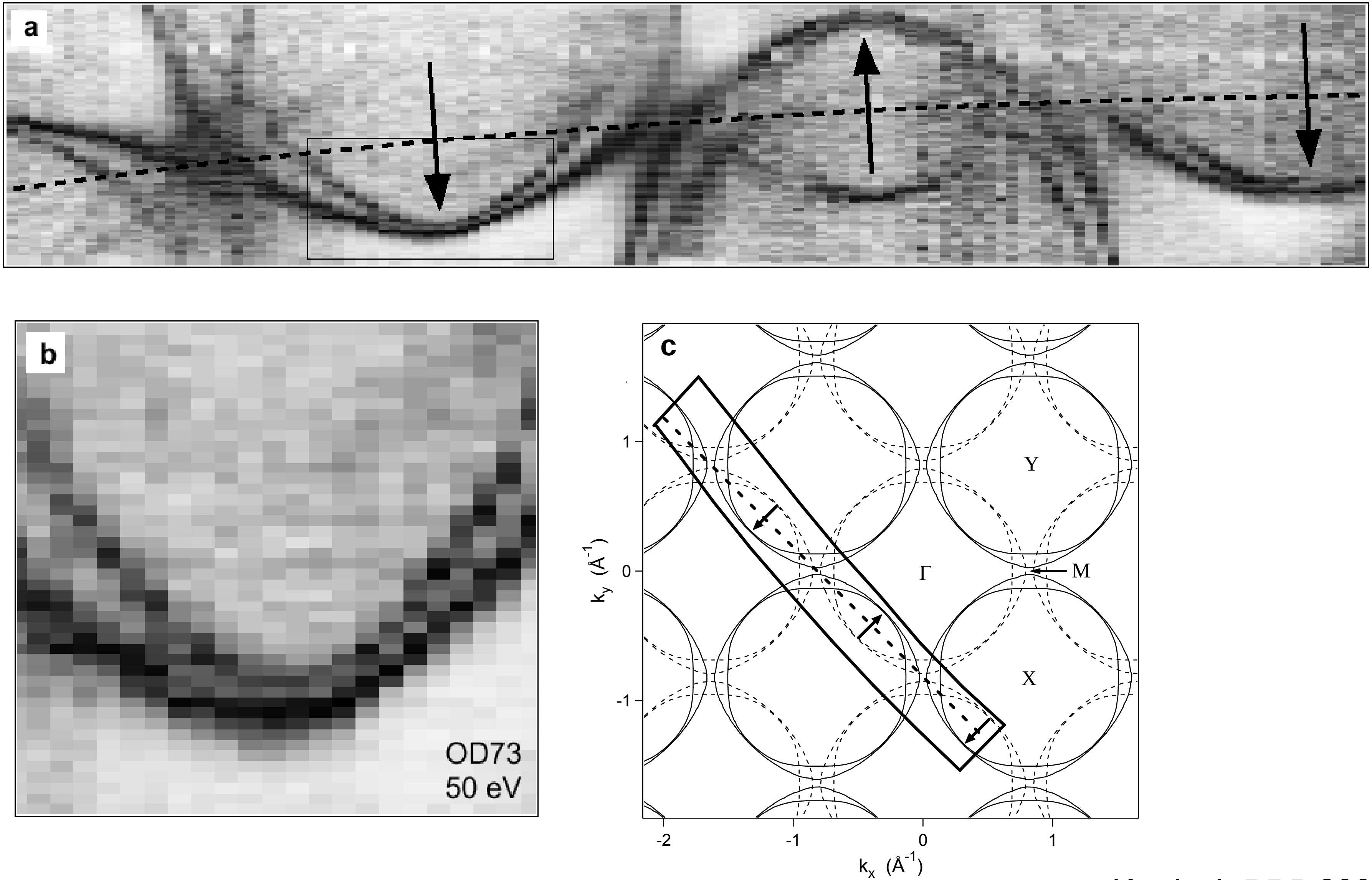
Complex electronic structure of CuO_2 bi-layer





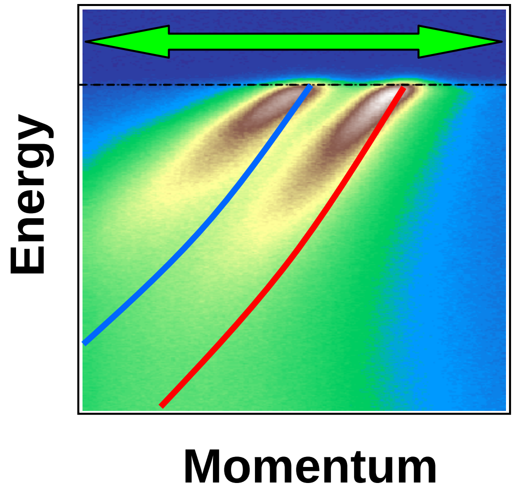
Kordyuk *PRB* 2003

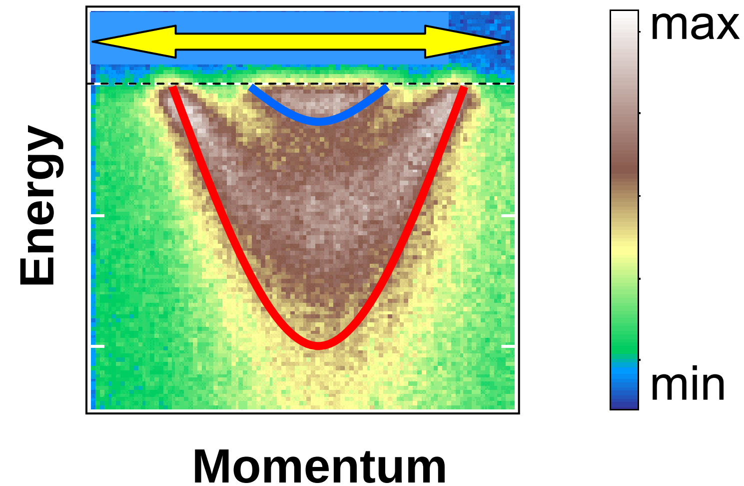
Bare band dispersion = LDA dispersion

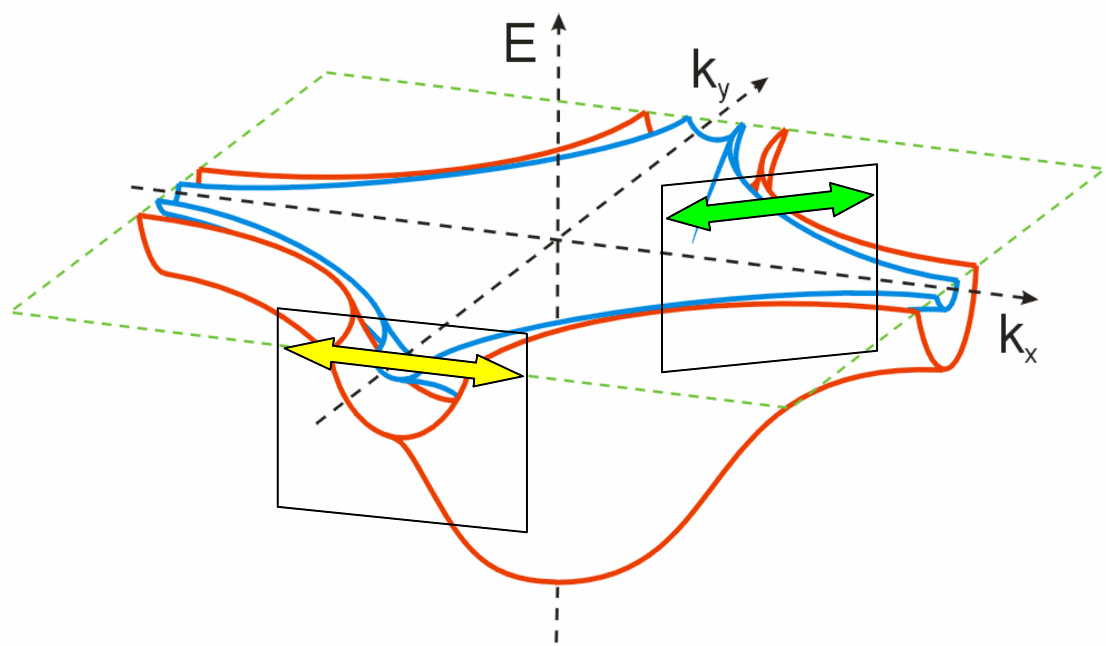


Kordyuk *PRB* 2004

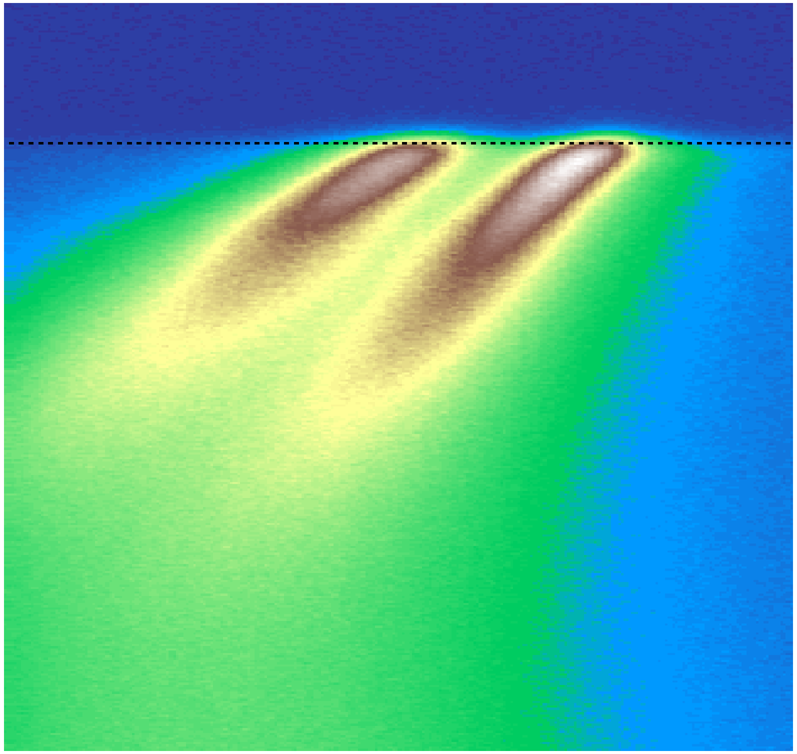
Electronic strucrure of HTSC is bare band dispersion + self-energy



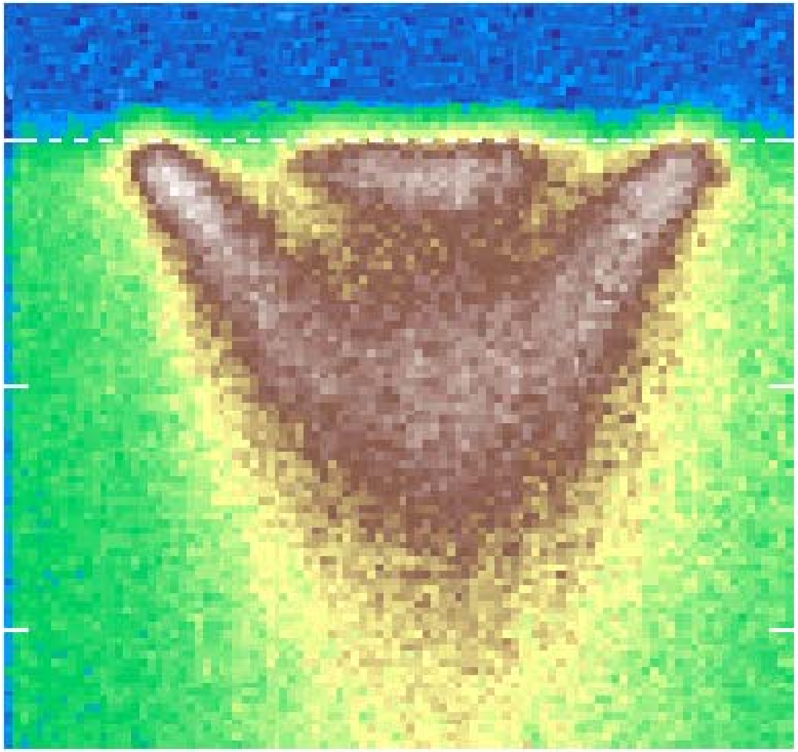




Electronic strucrure of HTSC is bare band dispersion + self-energy



2006



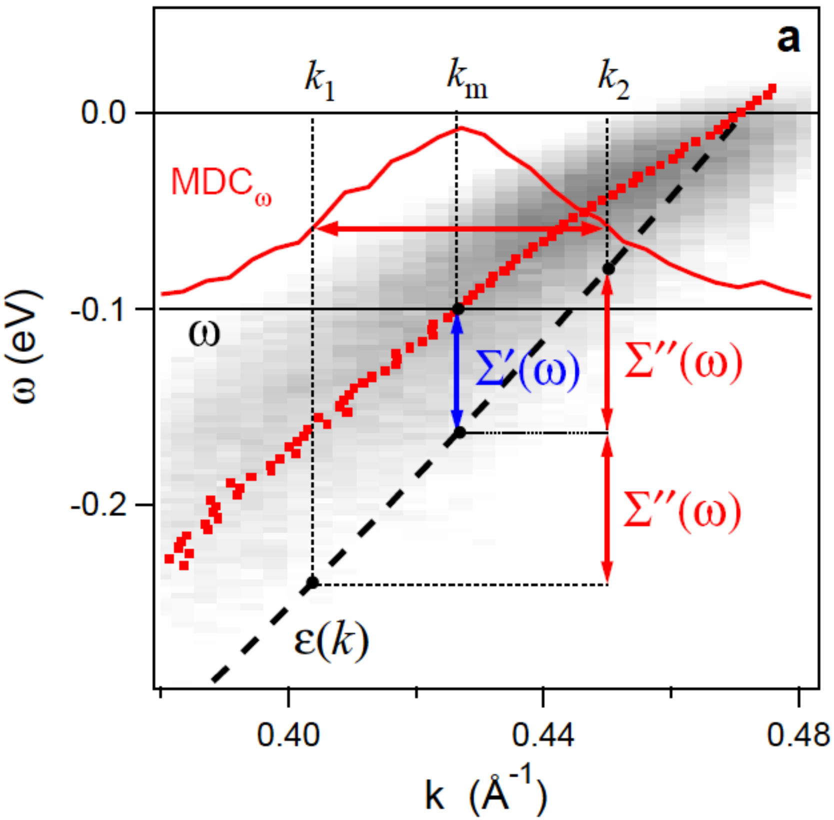
2002

Borisenko *PRL* 2003

Unadulterated spectral function

Introduction to the nodal spectra analysis

$$A(\omega, \mathbf{k}) = -\frac{1}{\pi} \frac{\Sigma''(\omega)}{(\omega - \varepsilon(\mathbf{k}) - \Sigma'(\omega))^2 + \Sigma''(\omega)^2}$$



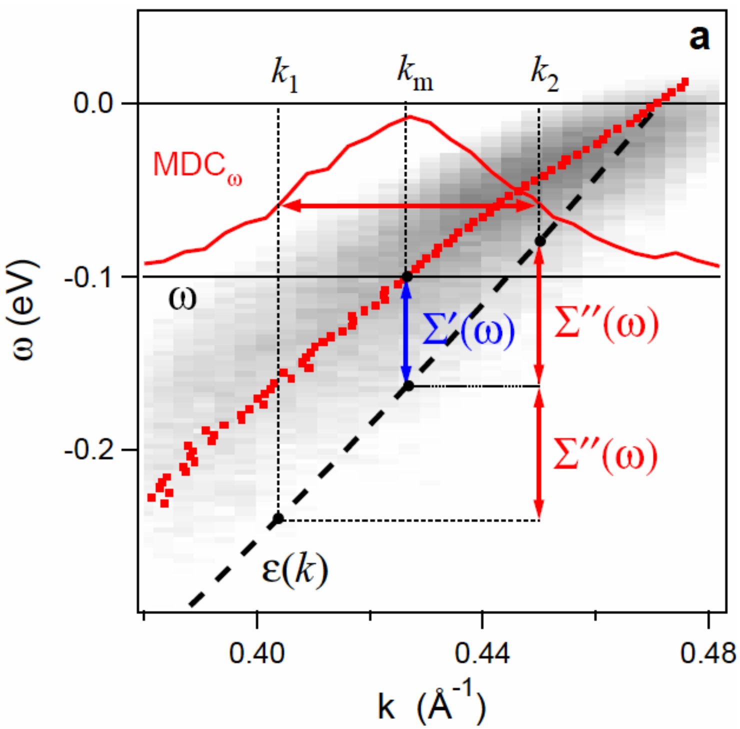
$$\Sigma'(\omega) = \omega - \varepsilon(k_m)$$

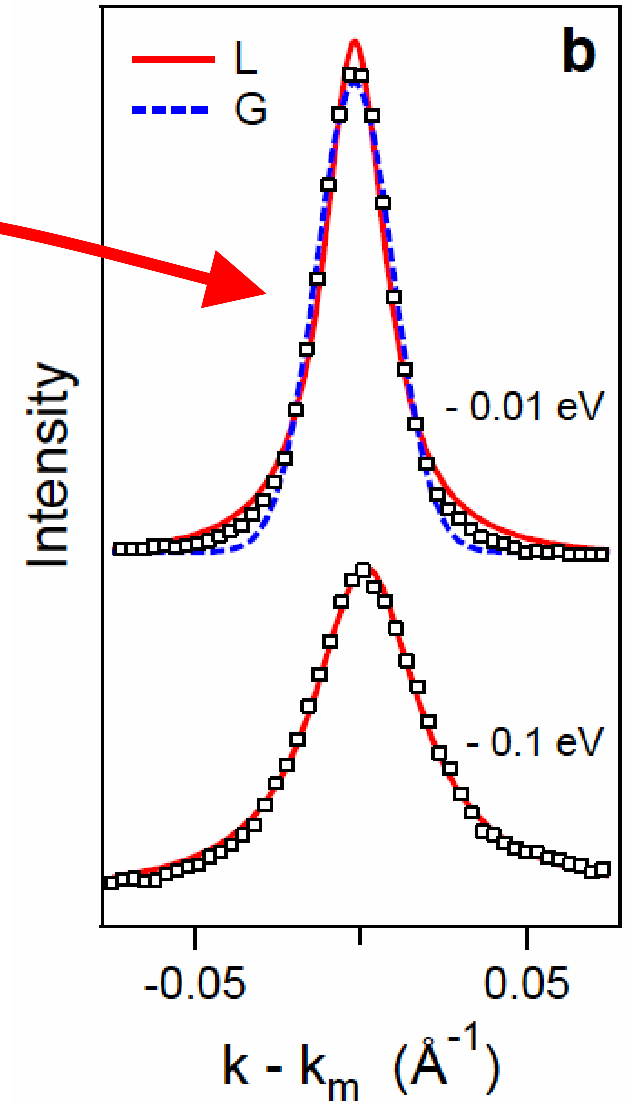
$$\Sigma''(\omega) = -v_F W(\omega)$$

cond-mat/0510421

Lorentzian to Gaussian

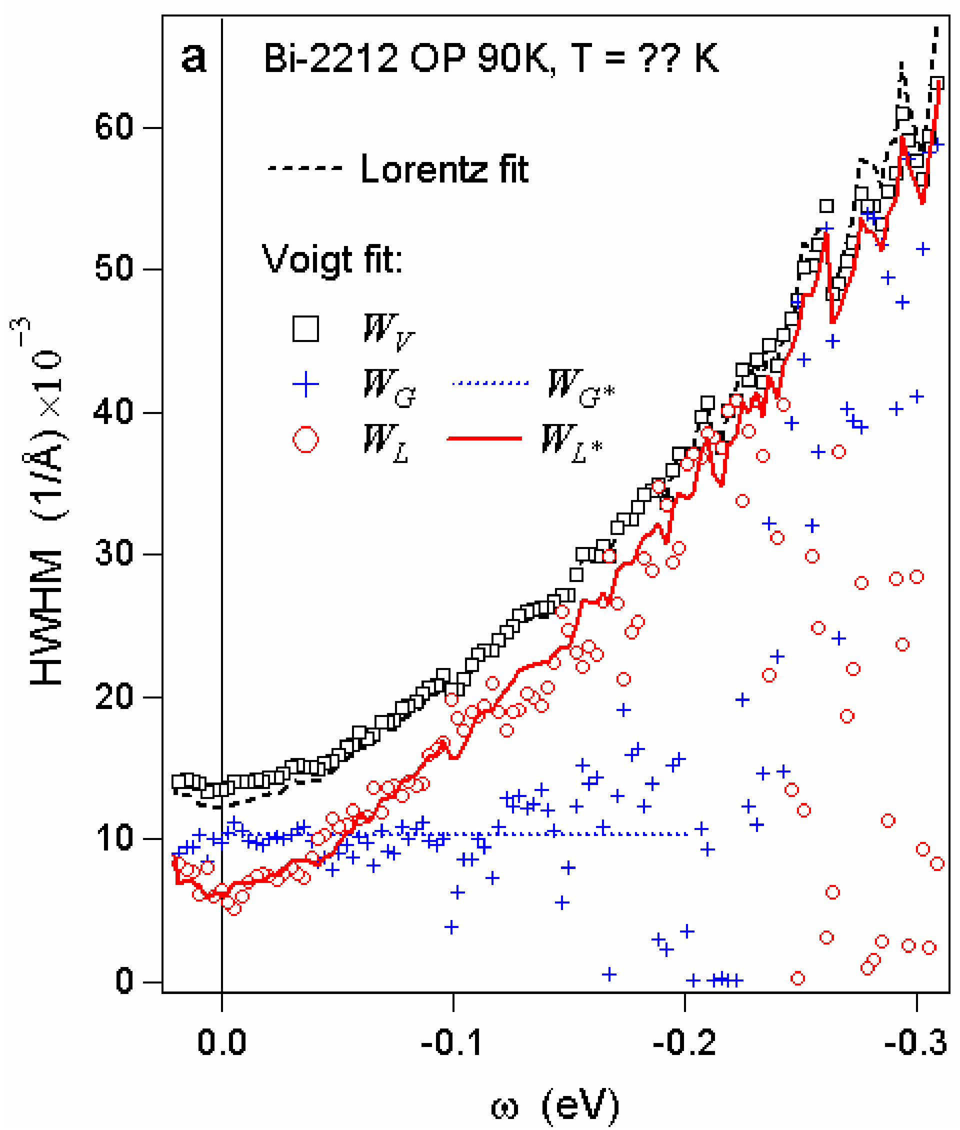
Voigt profile = Lor ⊗ Gauss

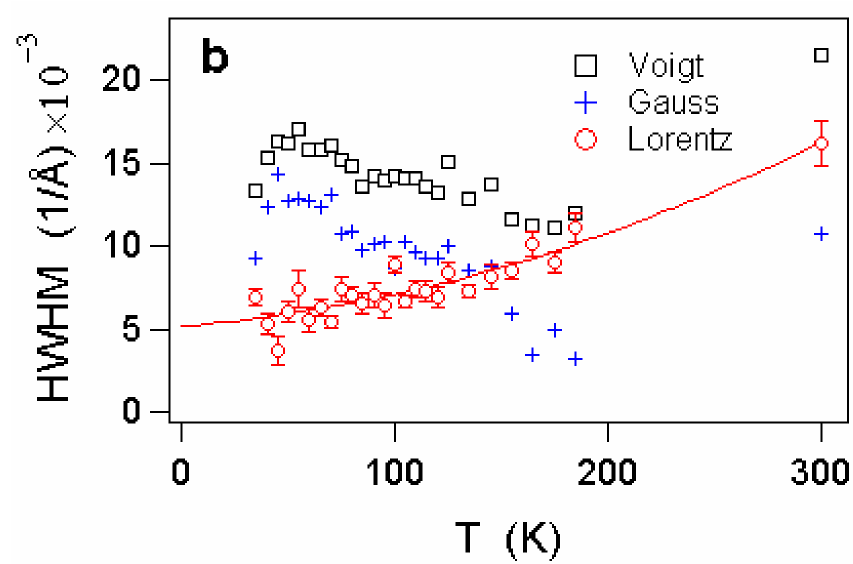




Evtushinsky *PRB 2006*

Voigt fitting procedure





$$W_V = V(W_L, W_G)$$

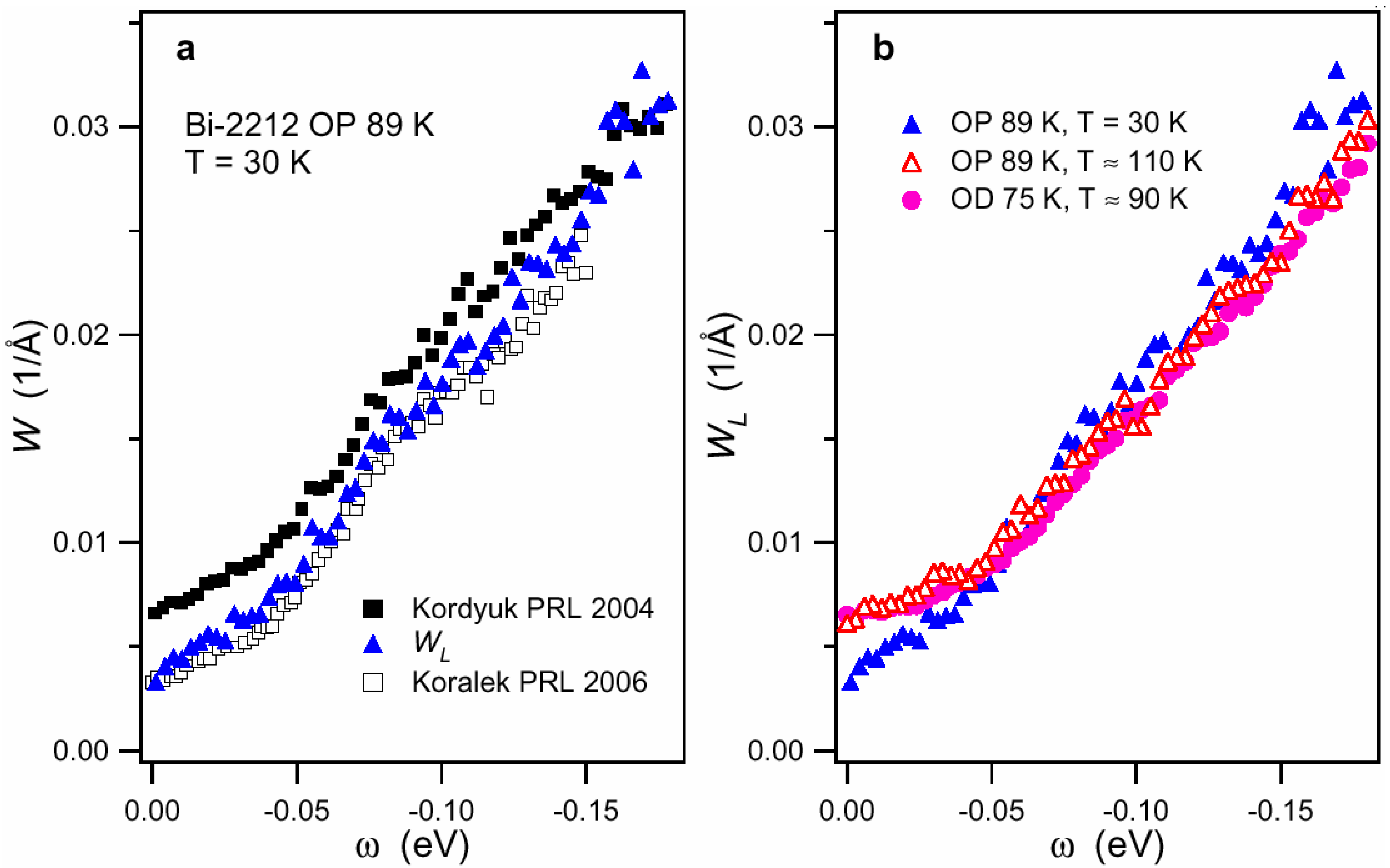
$$= \frac{W_L}{2} + \sqrt{\frac{W_L^2}{4} + W_G^2}$$

Evtushinsky *PRB 2006*

Now for the self-energy:

1. Real impurity scattering
2. Careful energy dependence
3. Careful temperature dependence

Energy dependence



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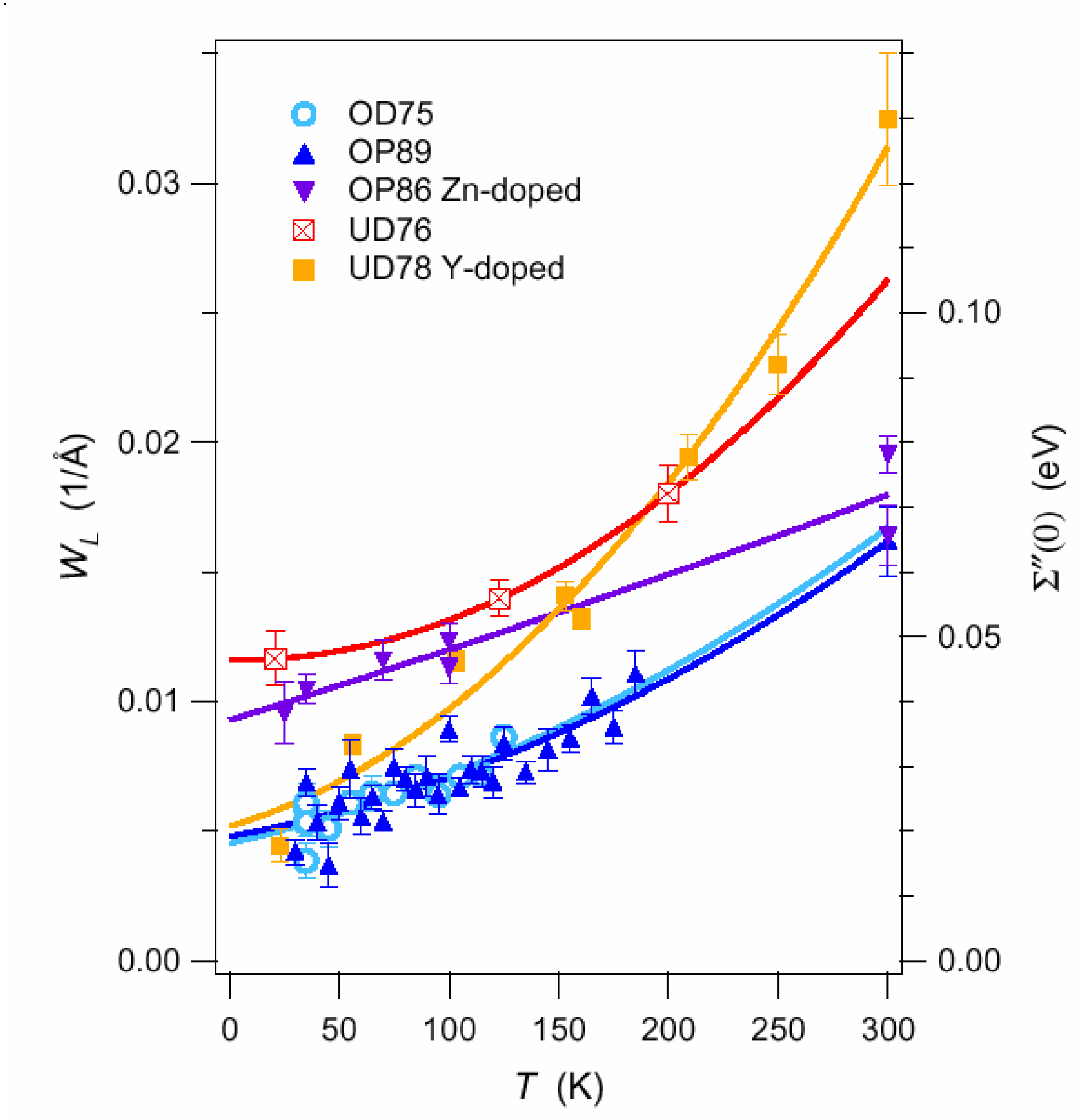
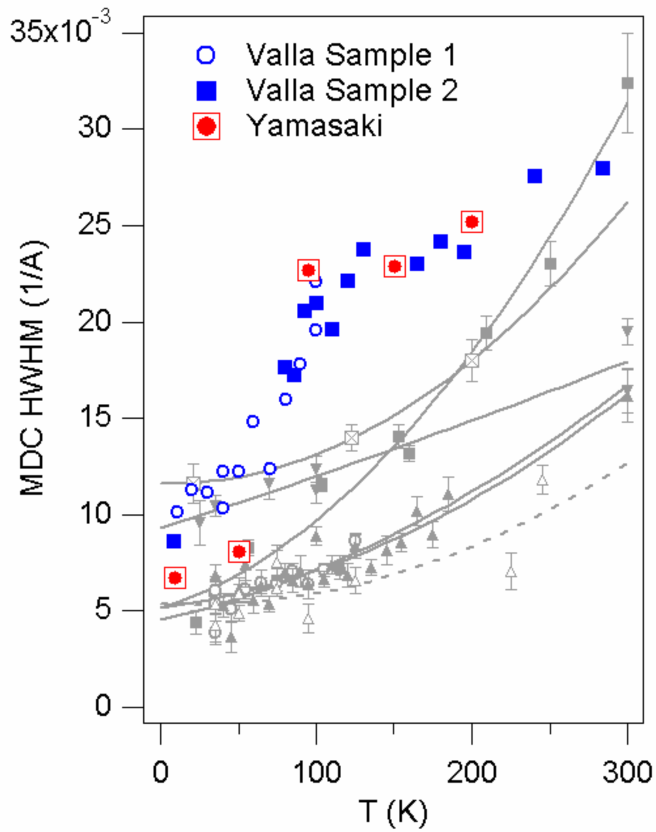
Temperature dependence





pseudo-gap

no "arcs" !

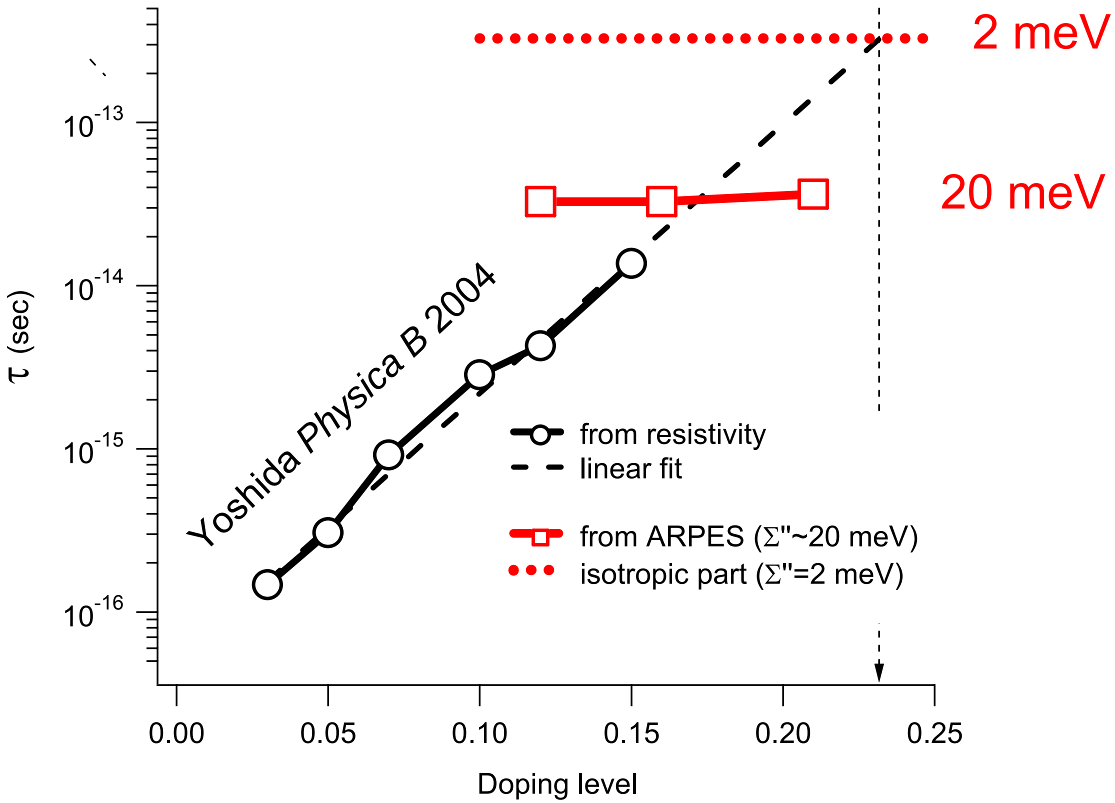
Evtushinsky *PRB 2006*

Impurity scattering

$$\rho_0 = \frac{m^*}{ne^2\tau} \approx \frac{k_F}{ne^2\hbar}\frac{\Sigma''_{im}}{v_r}$$

forward and isotropic (unitary)?

$$n \sim 1 - x$$



$$n(x)\ ?$$

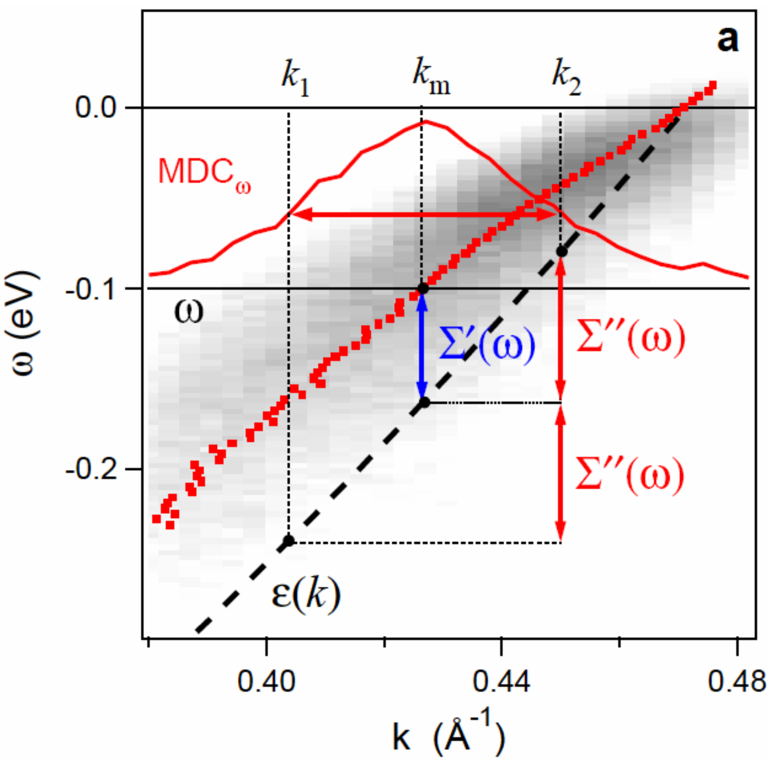
inhomogeneity

How Kramers-Kronig consistency works

Why we believe it is applicable

Bare Fermi velocity from the nodal spectrum

$$A(\omega, \mathbf{k}) = -\frac{1}{\pi} \frac{\Sigma''(\omega)}{(\omega - \varepsilon(\mathbf{k}) - \Sigma'(\omega))^2 + \Sigma''(\omega)^2}$$

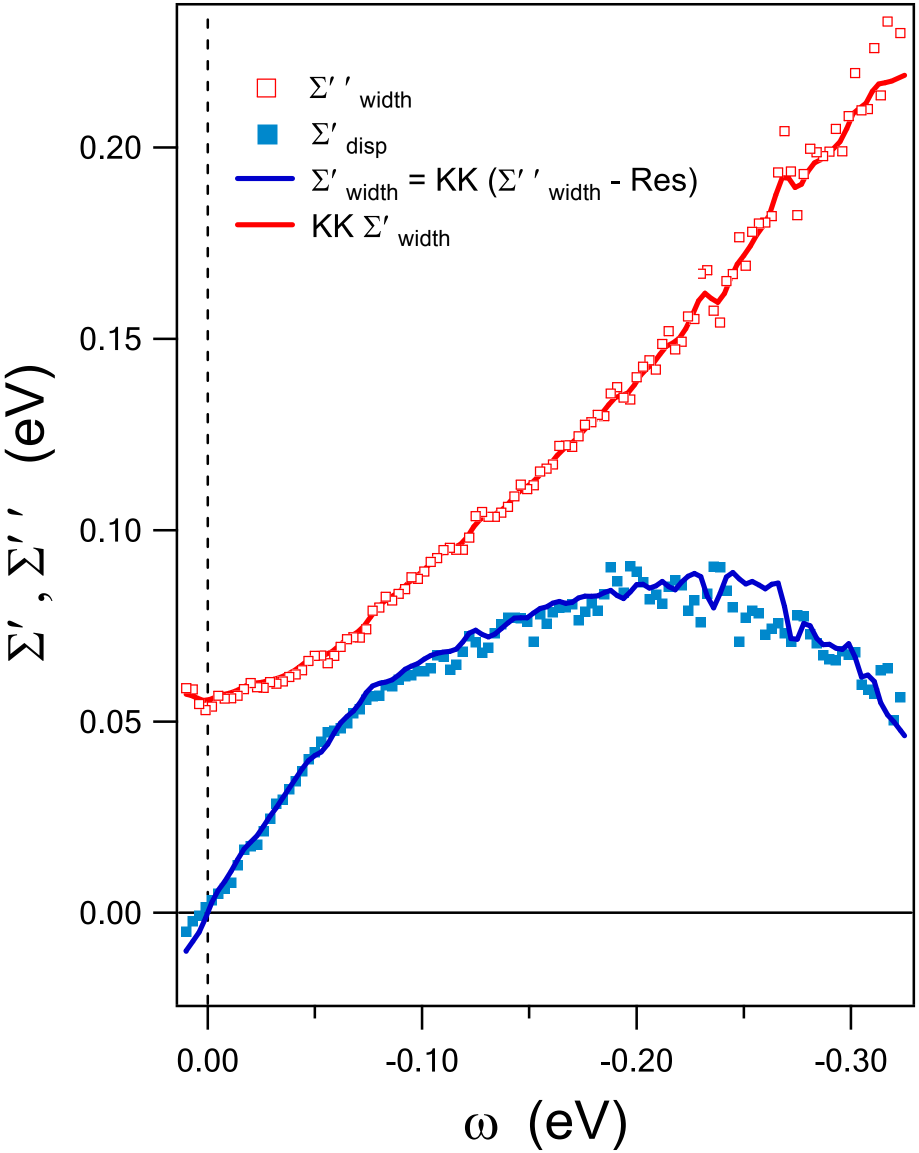


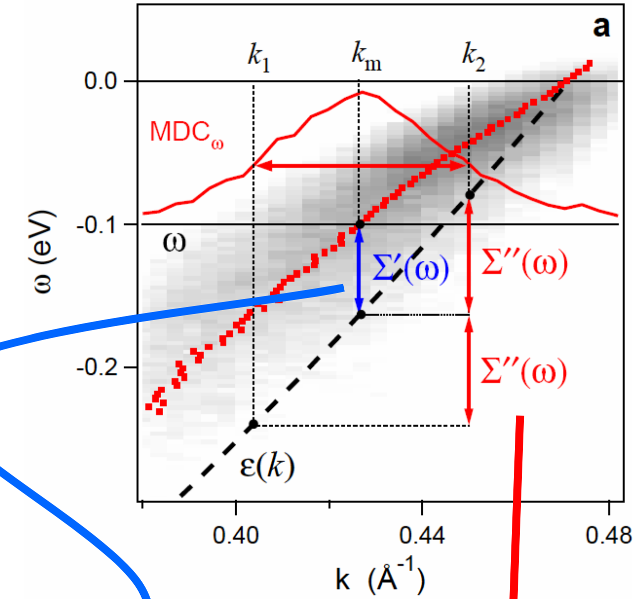
$$\Sigma'(\omega) = \omega - \varepsilon(k_m)$$

$$\Sigma''(\omega) = -v_F W(\omega)$$

$$\Sigma'(\omega) = \mathrm{KK}\ \Sigma''(\omega)$$

Kramers-Kronig transform





$\Sigma'(\omega)$

$\Sigma'(\omega) = \mathbf{KK}\ \Sigma''(\omega)$

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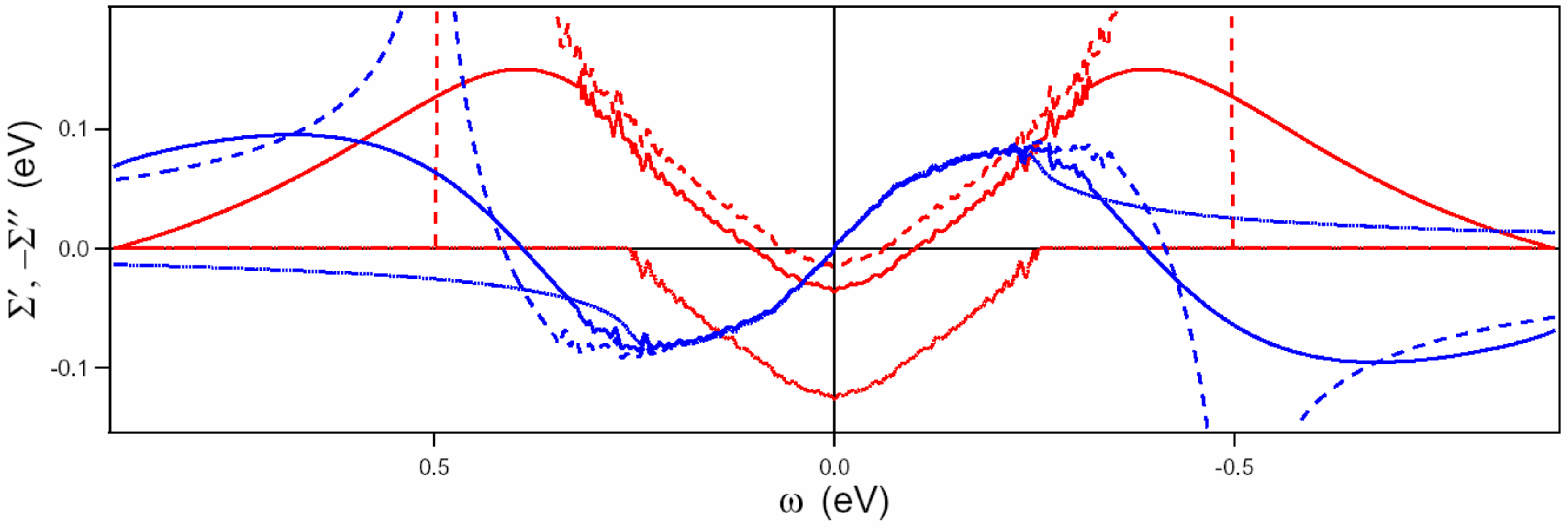
Kramers-Kronig transform $\Sigma'(\omega) = \mathrm{KK}\,\Sigma''(\omega)$



$$\Sigma''(\omega) = \begin{cases} \Sigma''_{width}(|\omega|) & \text{for } |\omega| < \omega_m, \\ \Sigma''_{mod}(\omega) & \text{for } |\omega| > \omega_m, \end{cases}$$

$$\Sigma''_{mod}(\omega) = -\frac{\alpha\,\omega^2 + C}{1 + \left|\frac{\omega}{\omega_c}\right|^n},$$

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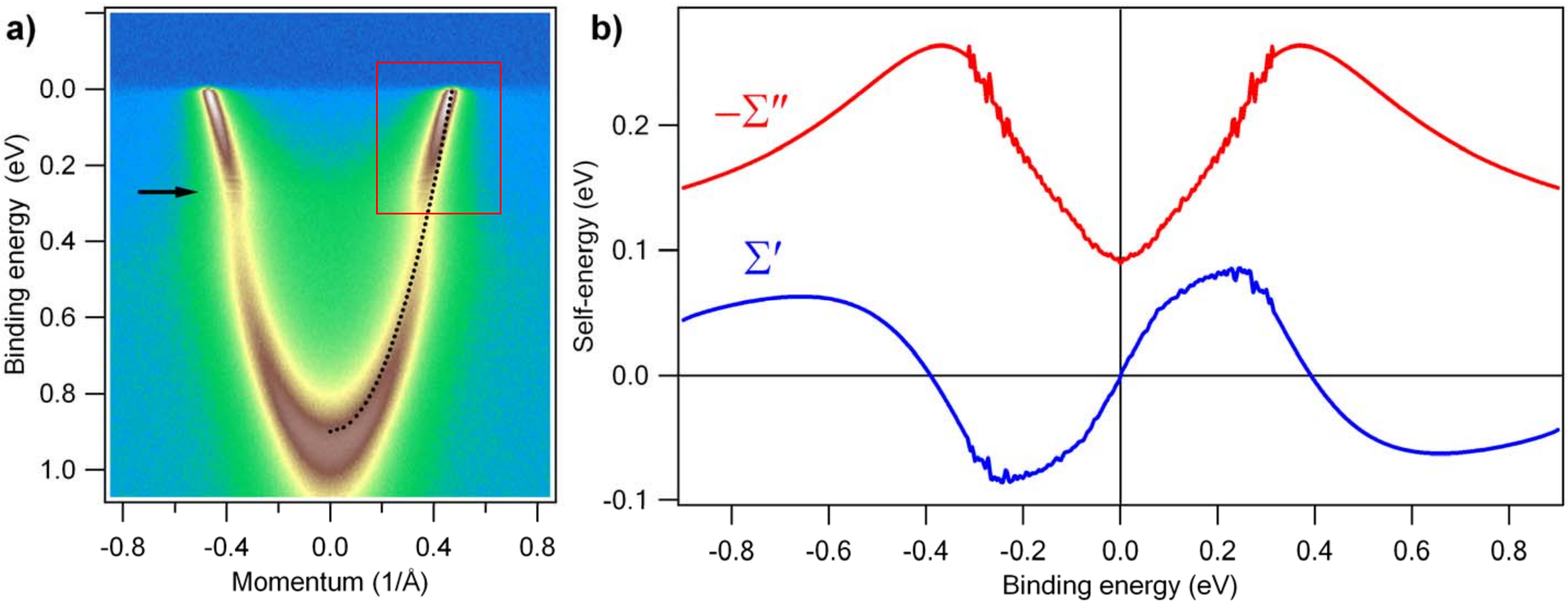
"High-energy scale"



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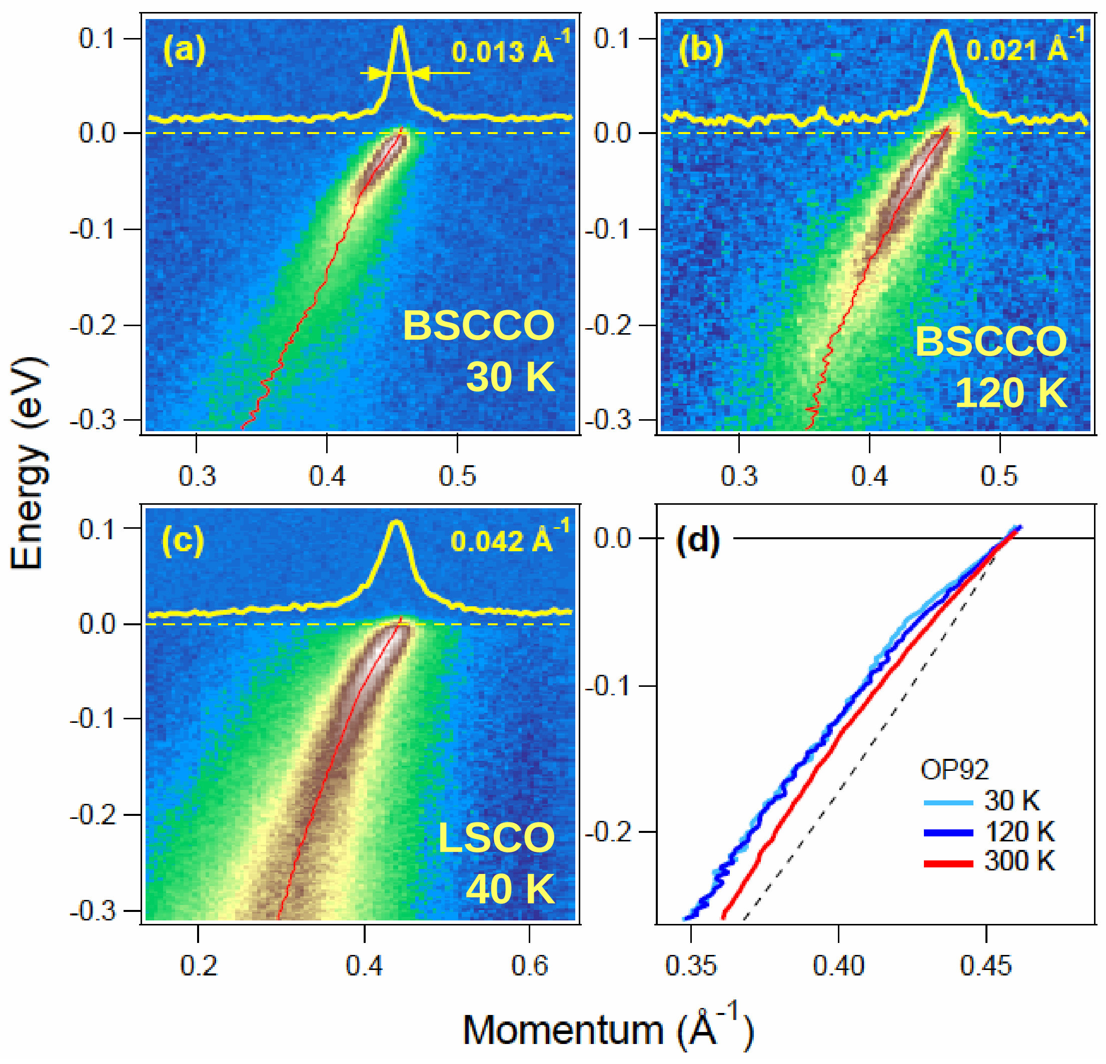
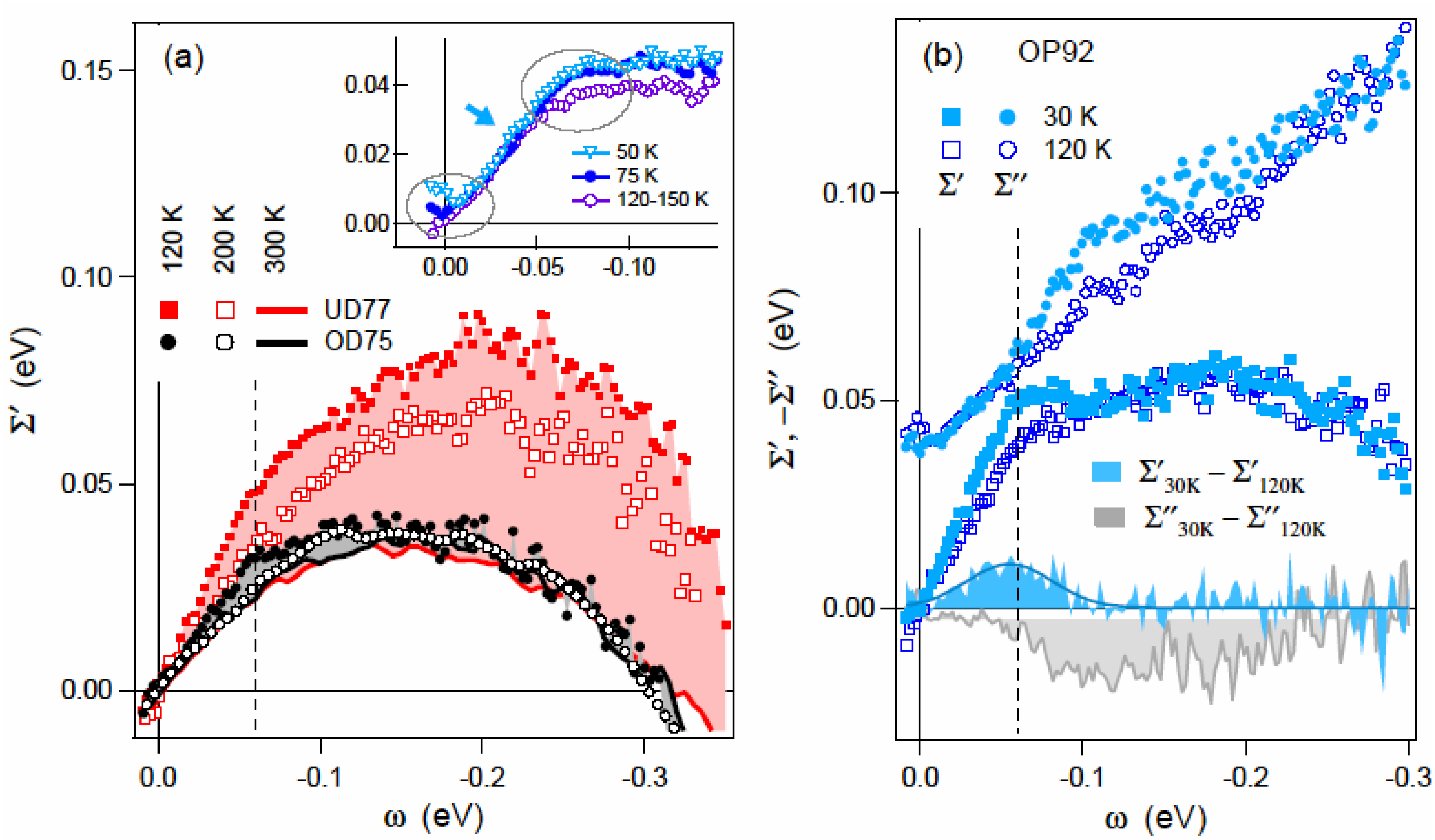
Evolution of the kink



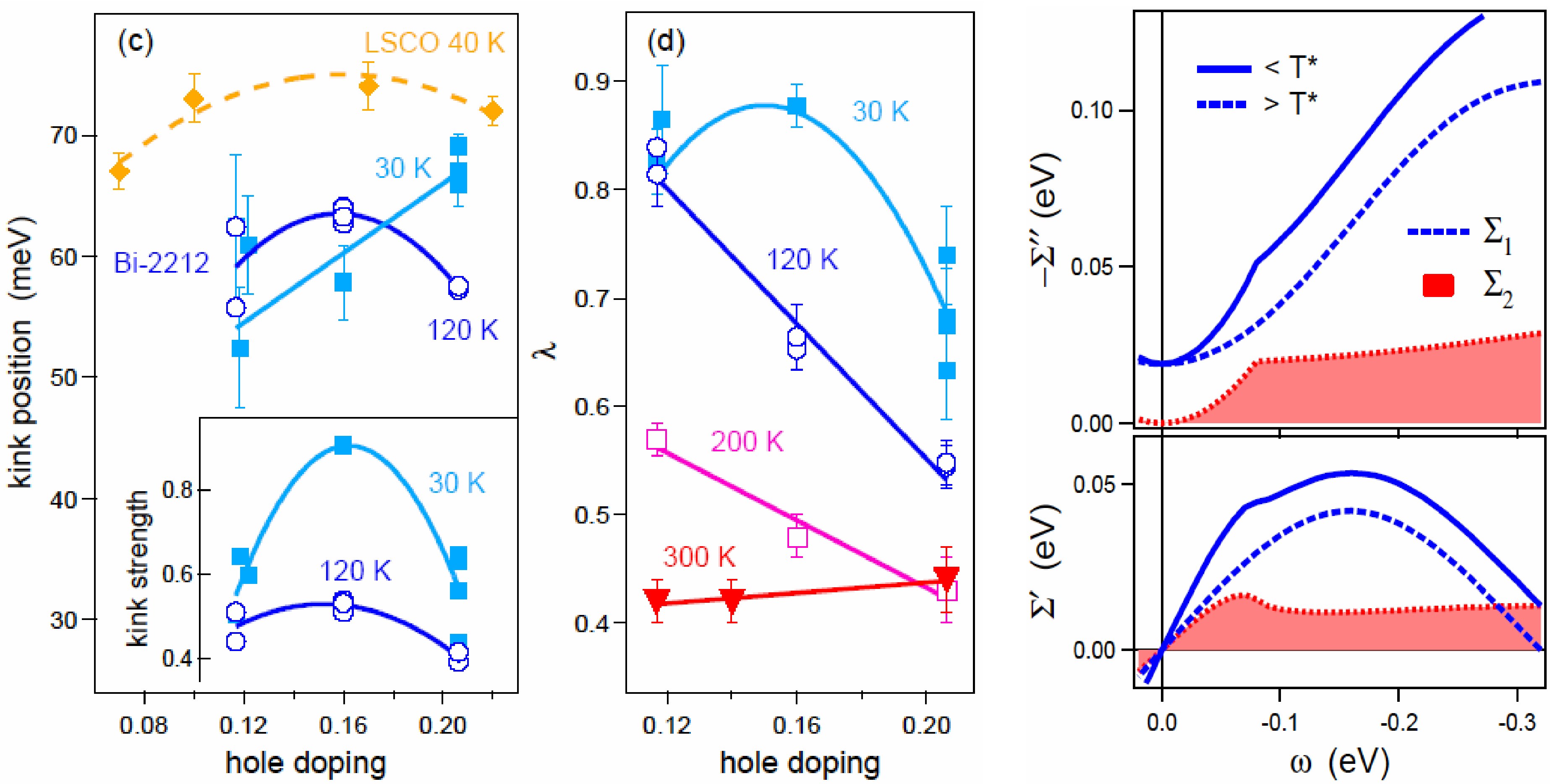
Kordyuk *PRL* 2006

Evolution of the self-energy



Kordyuk *PRL* 2006

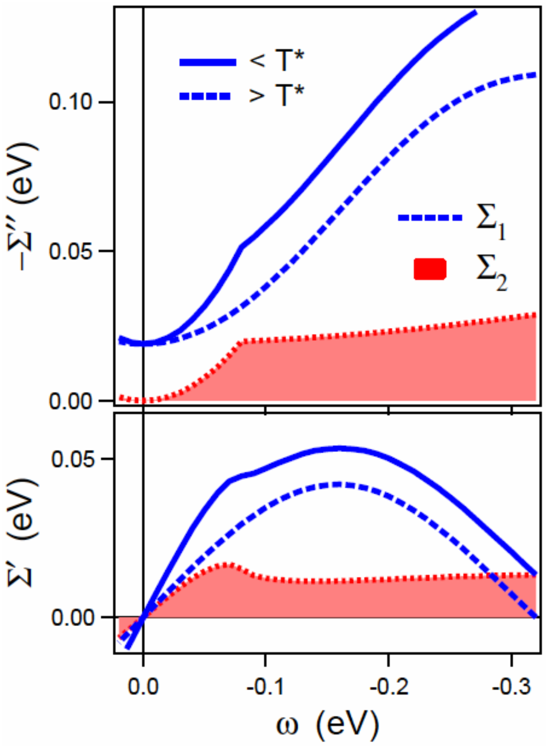
Parameters of the kink ⟶ 2 channels

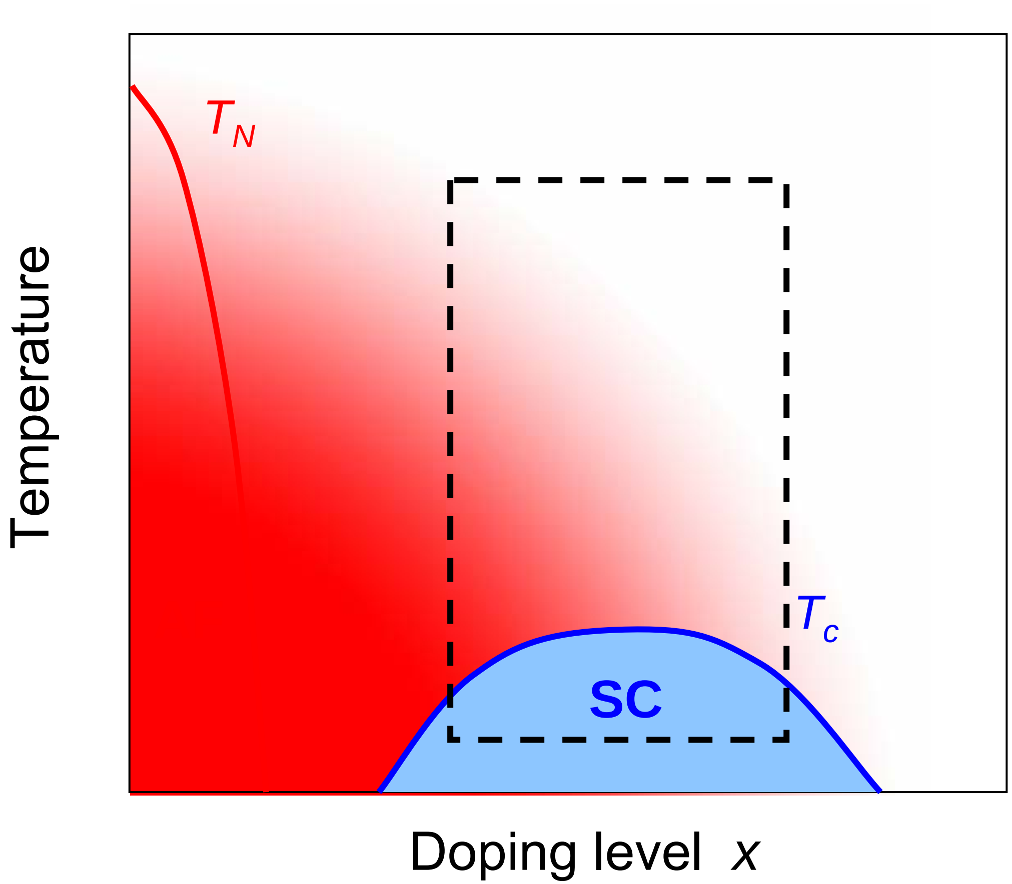


$$\lambda = -\left(\frac{d\Sigma'}{d\omega}\right)_{\omega=0}$$

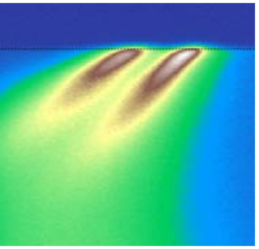
Kordyuk *PRL* 2006

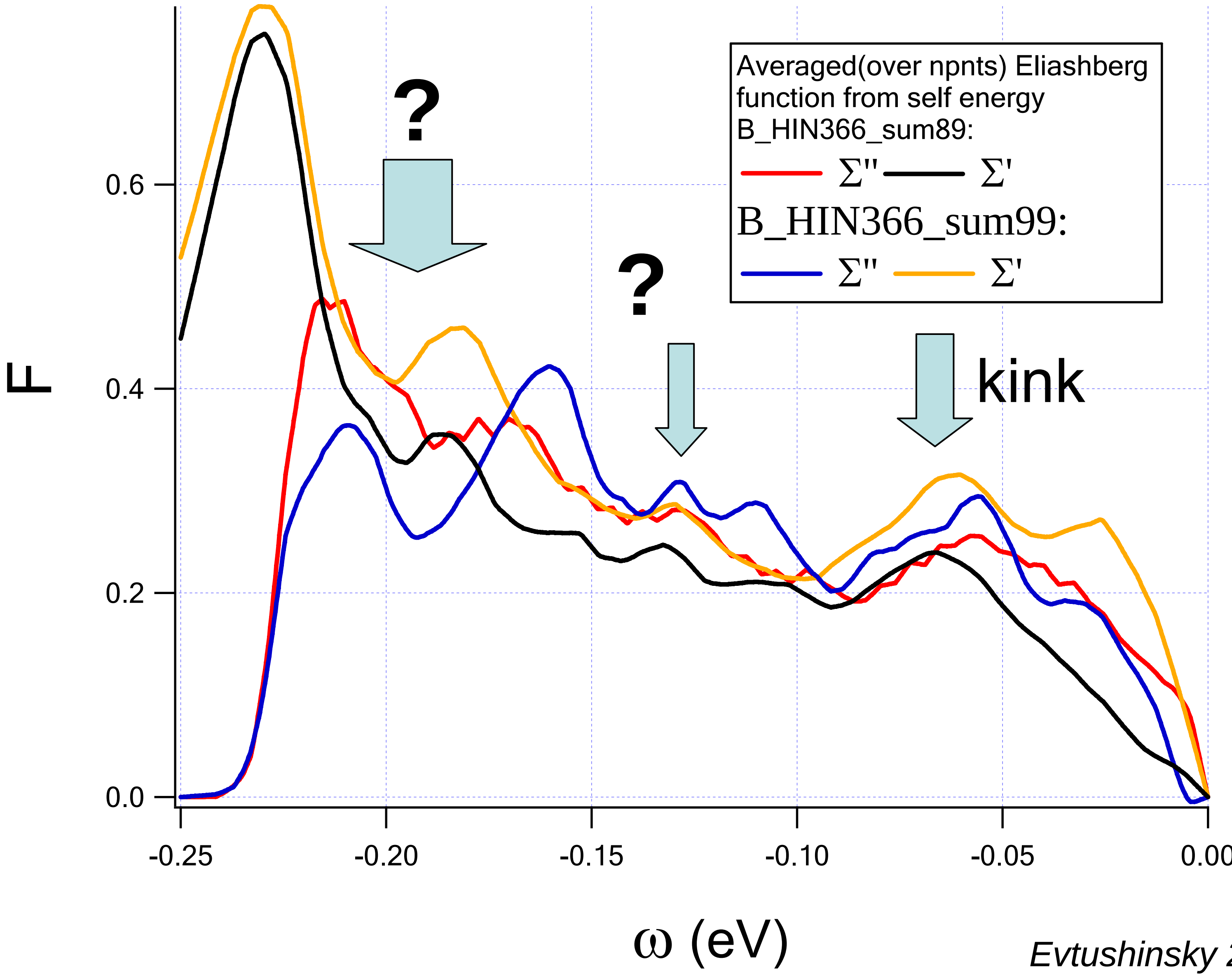
Intensity of the bosonic channel





Eliashberg function from YBCO





Evtushinsky 2007

Two channels

1 "Fermionic"

mainly *xT*-independent

featureless: $\Sigma'' \sim \omega^2$, $\Sigma' \sim \omega$

simple e-e interaction
(Auger-like decay)
FL

2 "Bosonic"

critically depends on (x,T)

energy structure:

(i) kinky,
ω_k *mainly* *xT*-independent

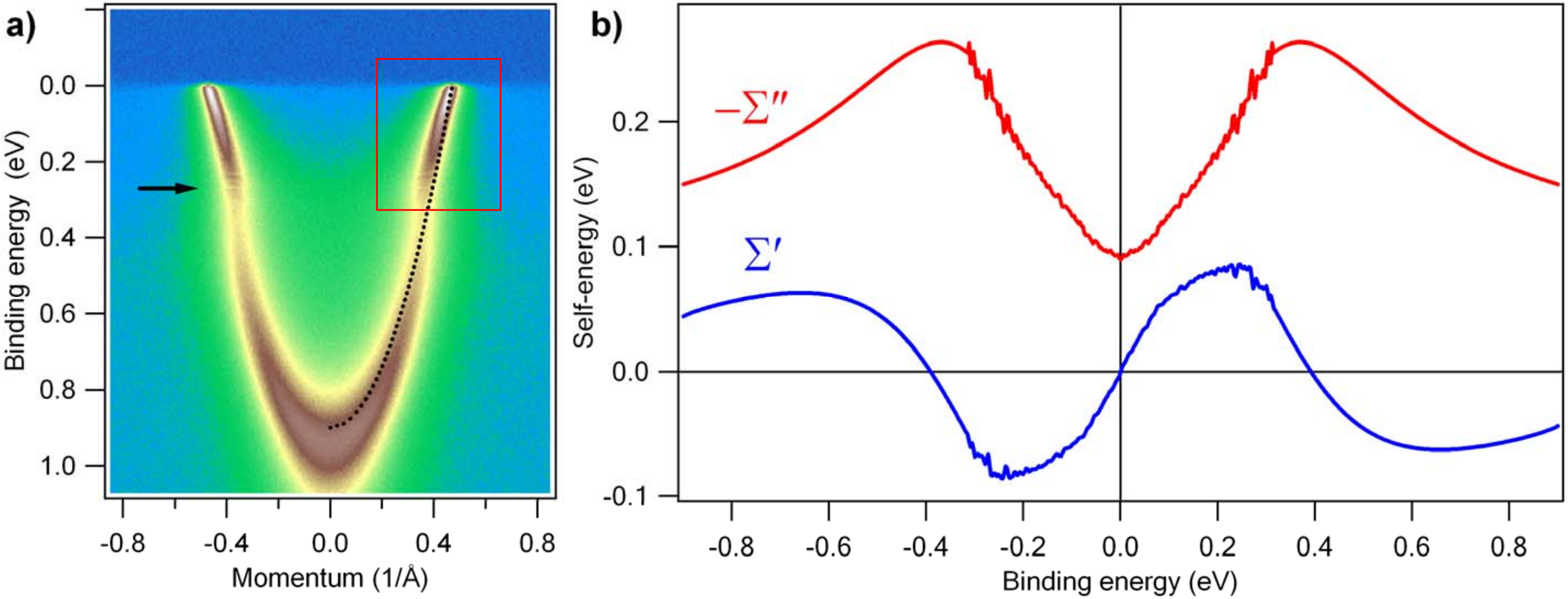
(ii) step-like,
does not confined at low ω

~~phonons~~, ~~gap~~ → SF

The "waterfalls"

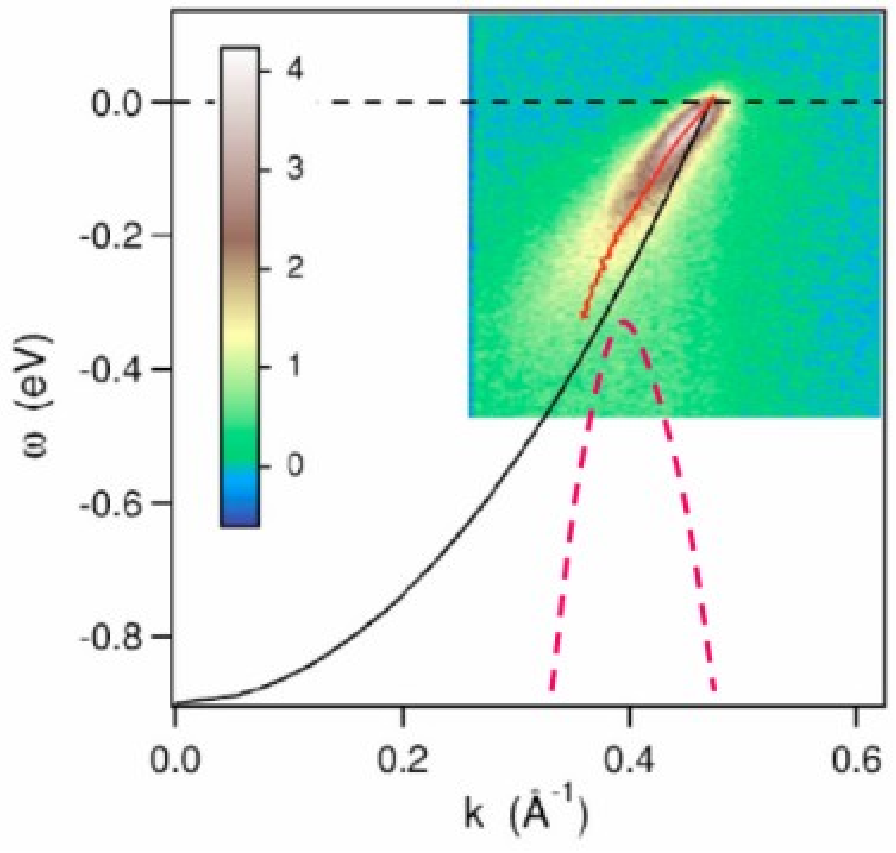
Where the consistency stops

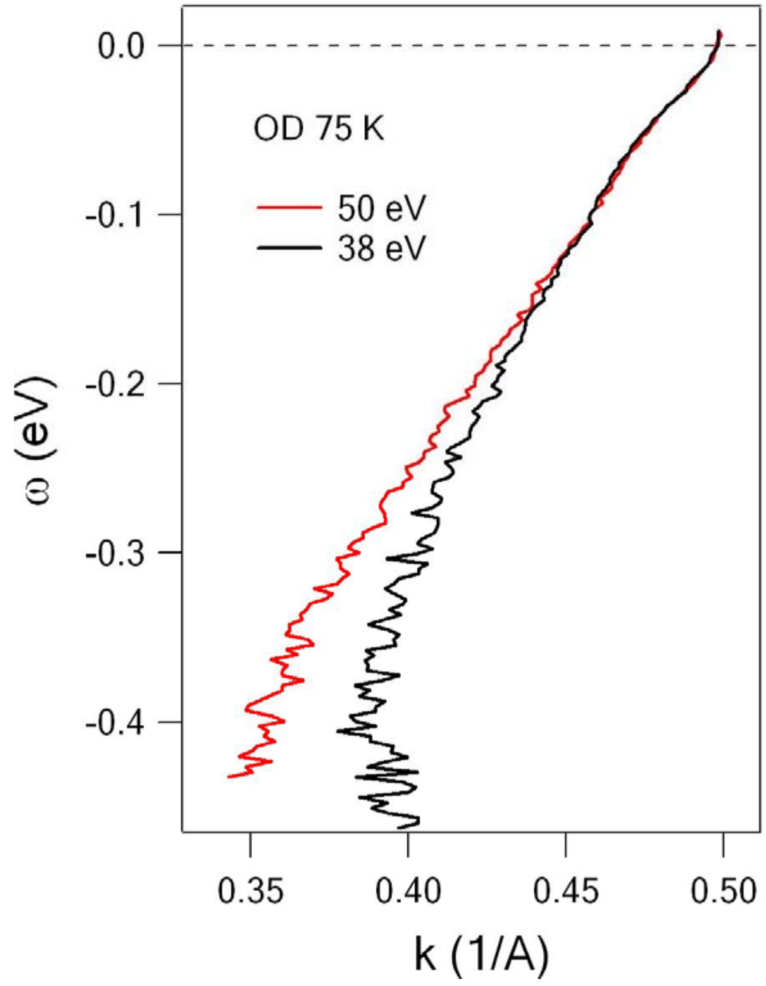
"High-energy scale"



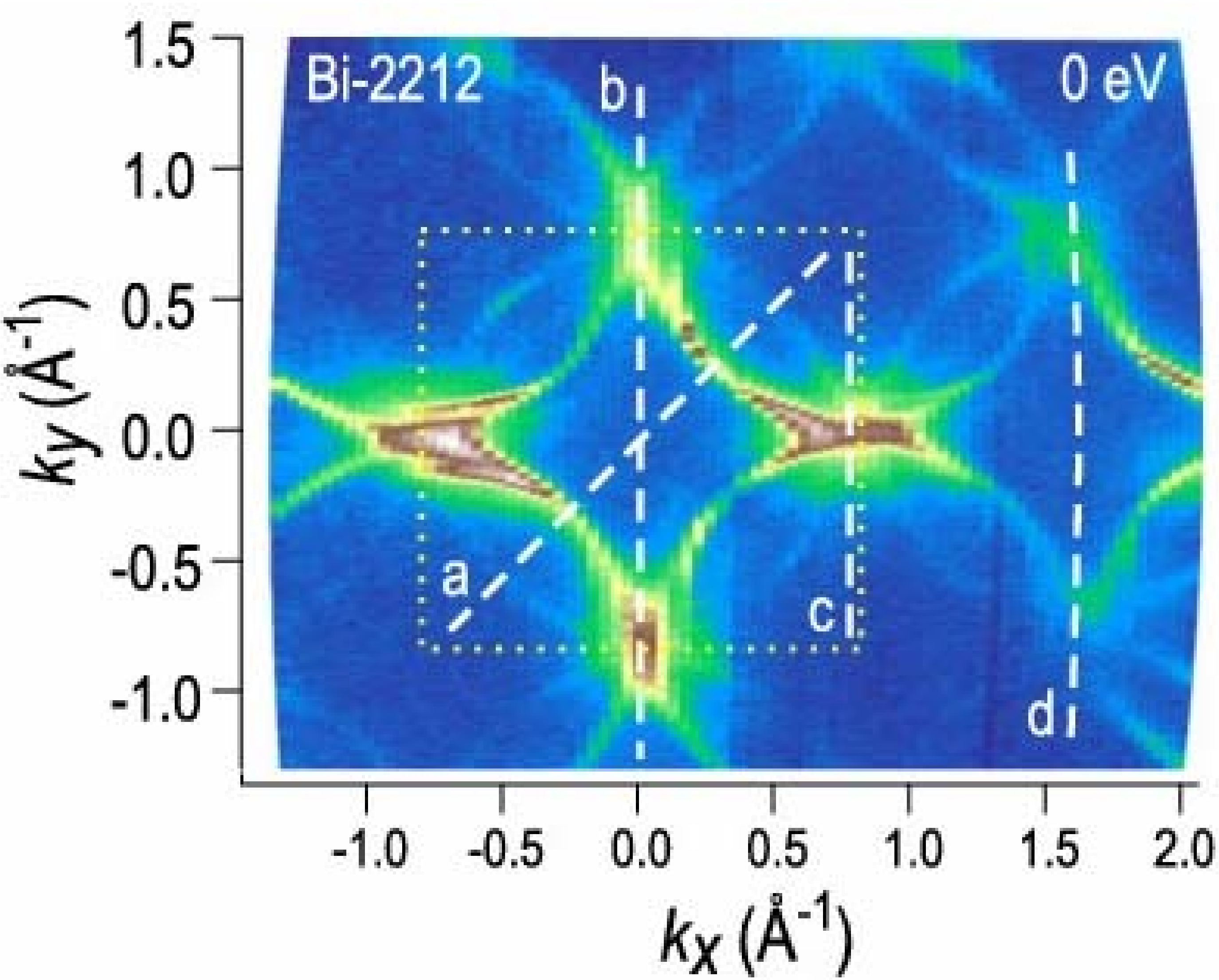
Kordyuk *PRB* 2005

Extrinsic spectral weight



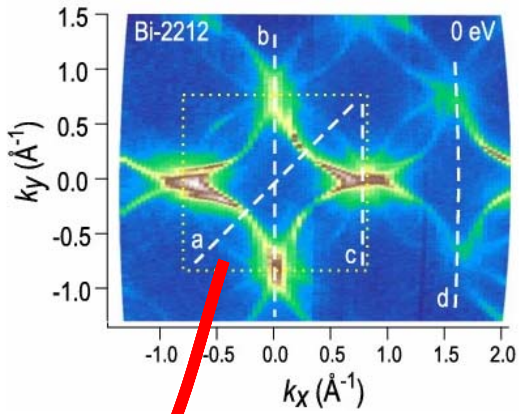


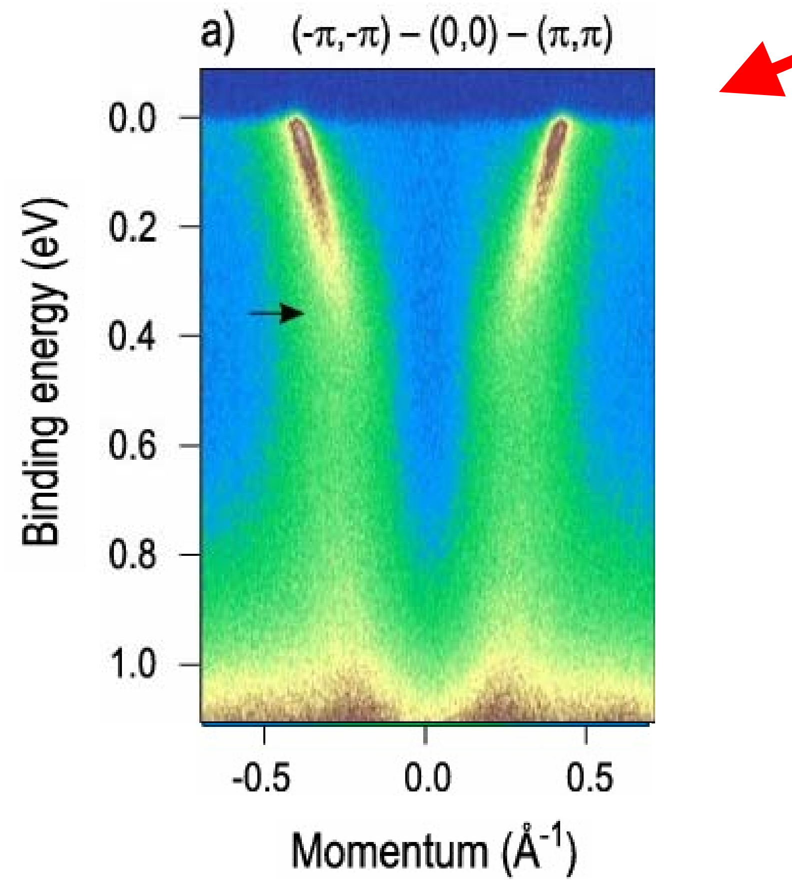
Waterfalls phenomenon



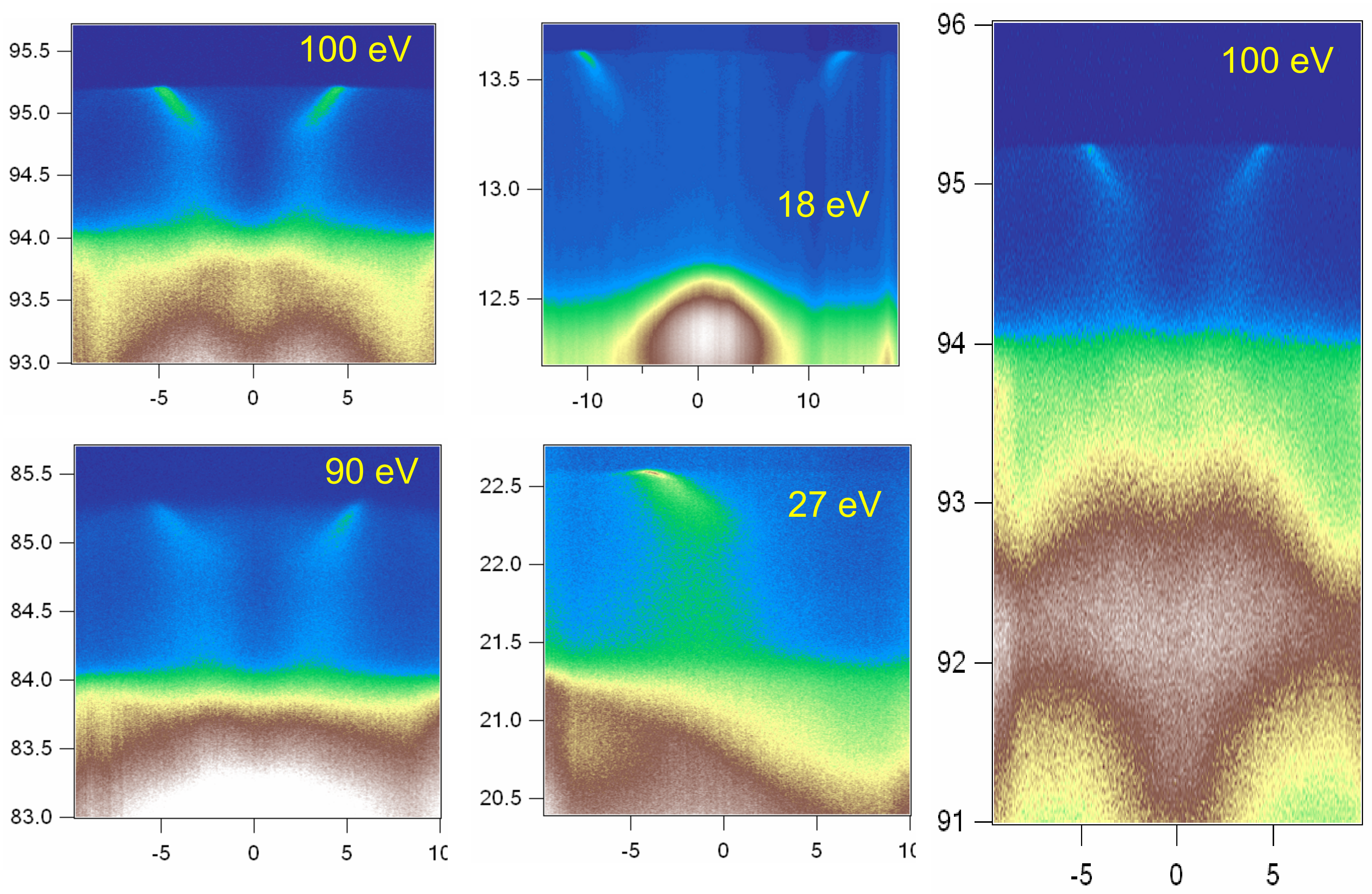
Inosov *cond-mat/0703223*

Waterfalls phenomenon

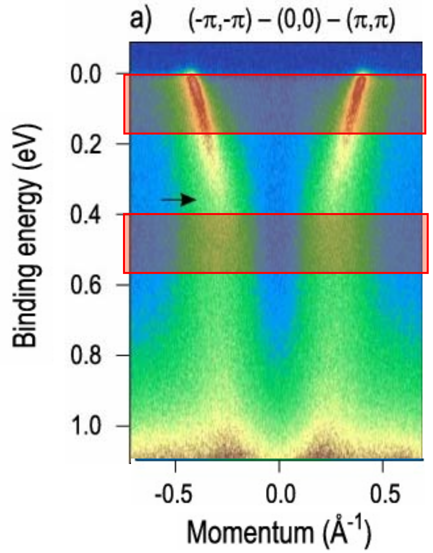


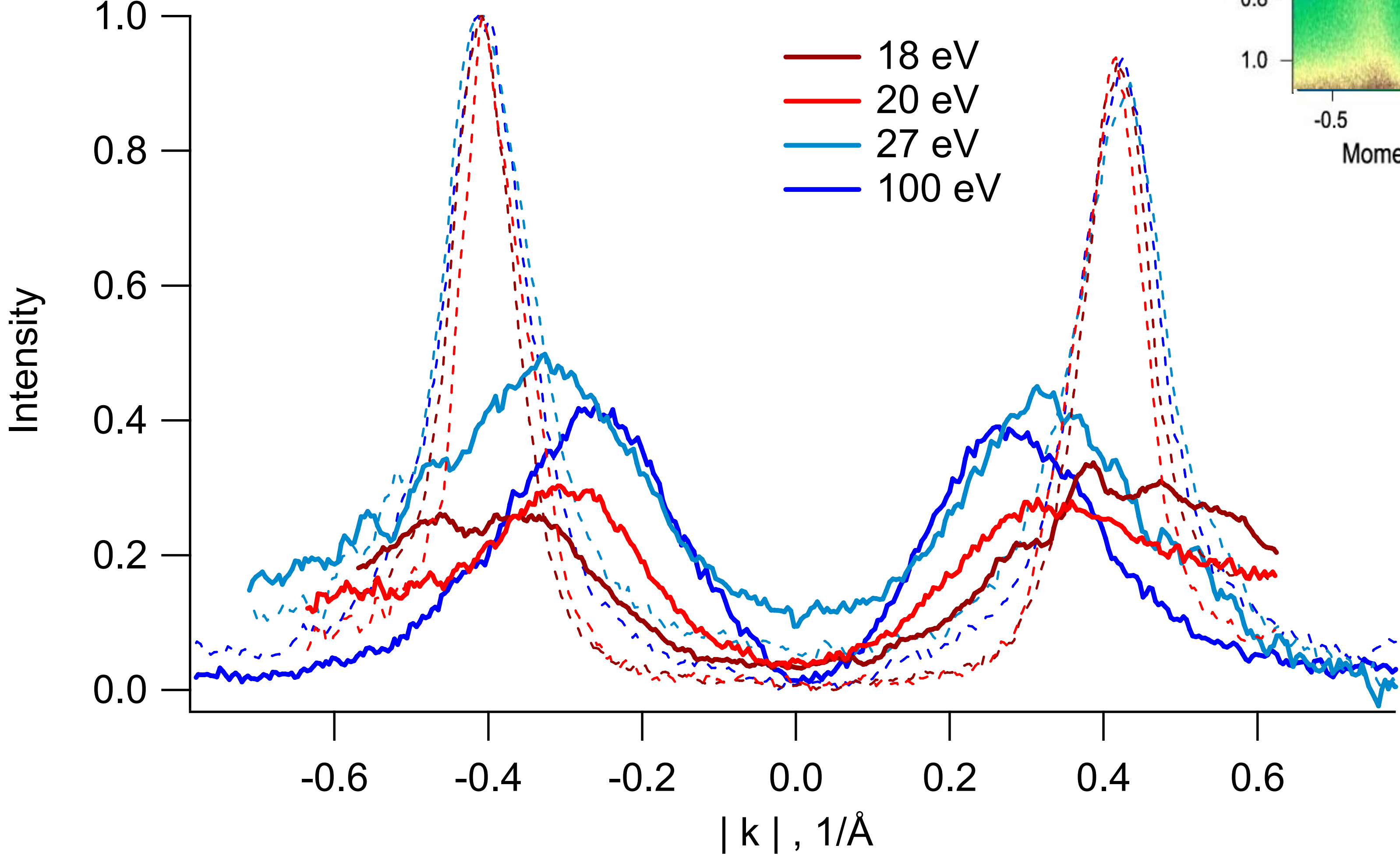


Waterfalls phenomenon

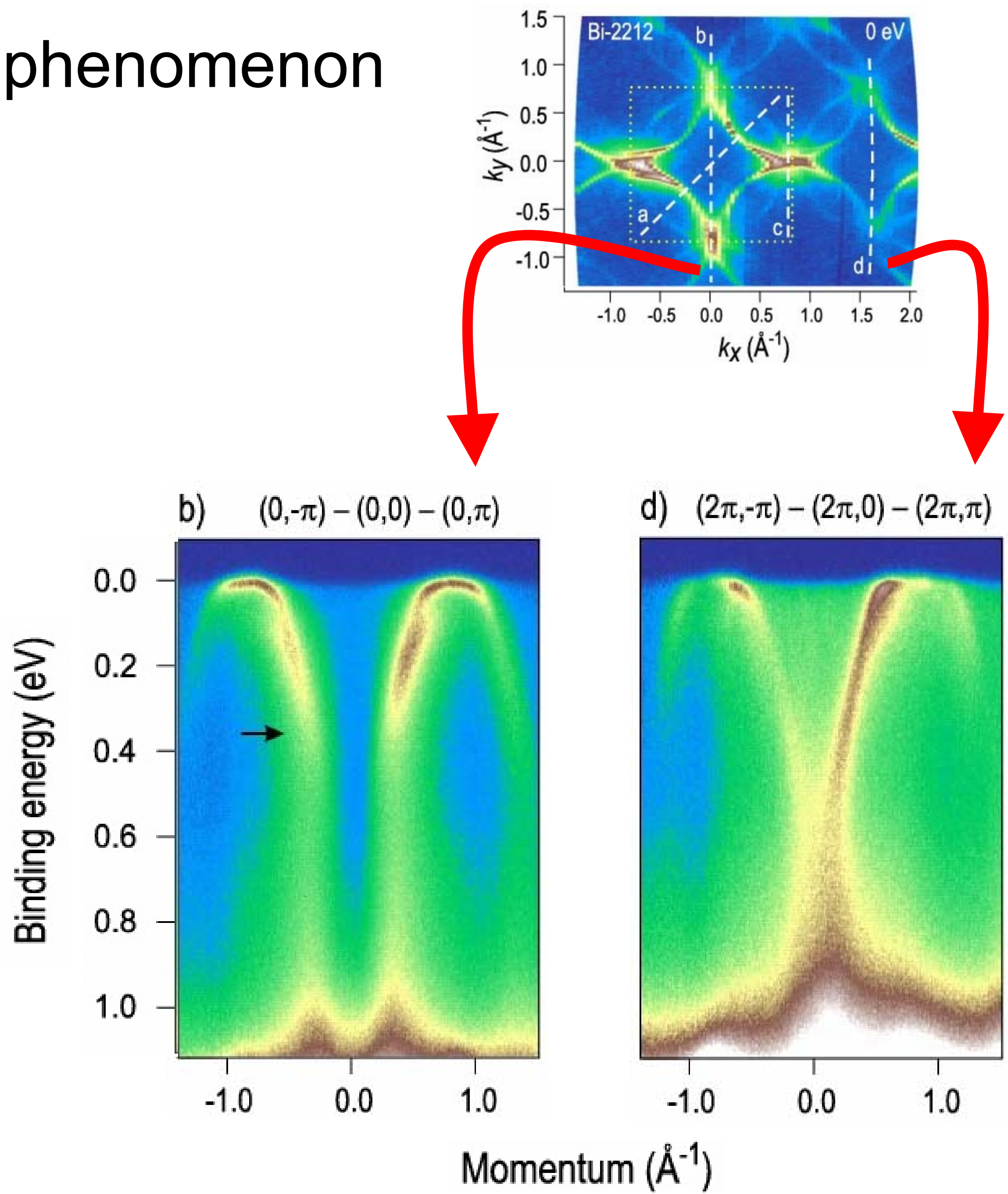


Waterfalls phenomenon





Waterfalls phenomenon



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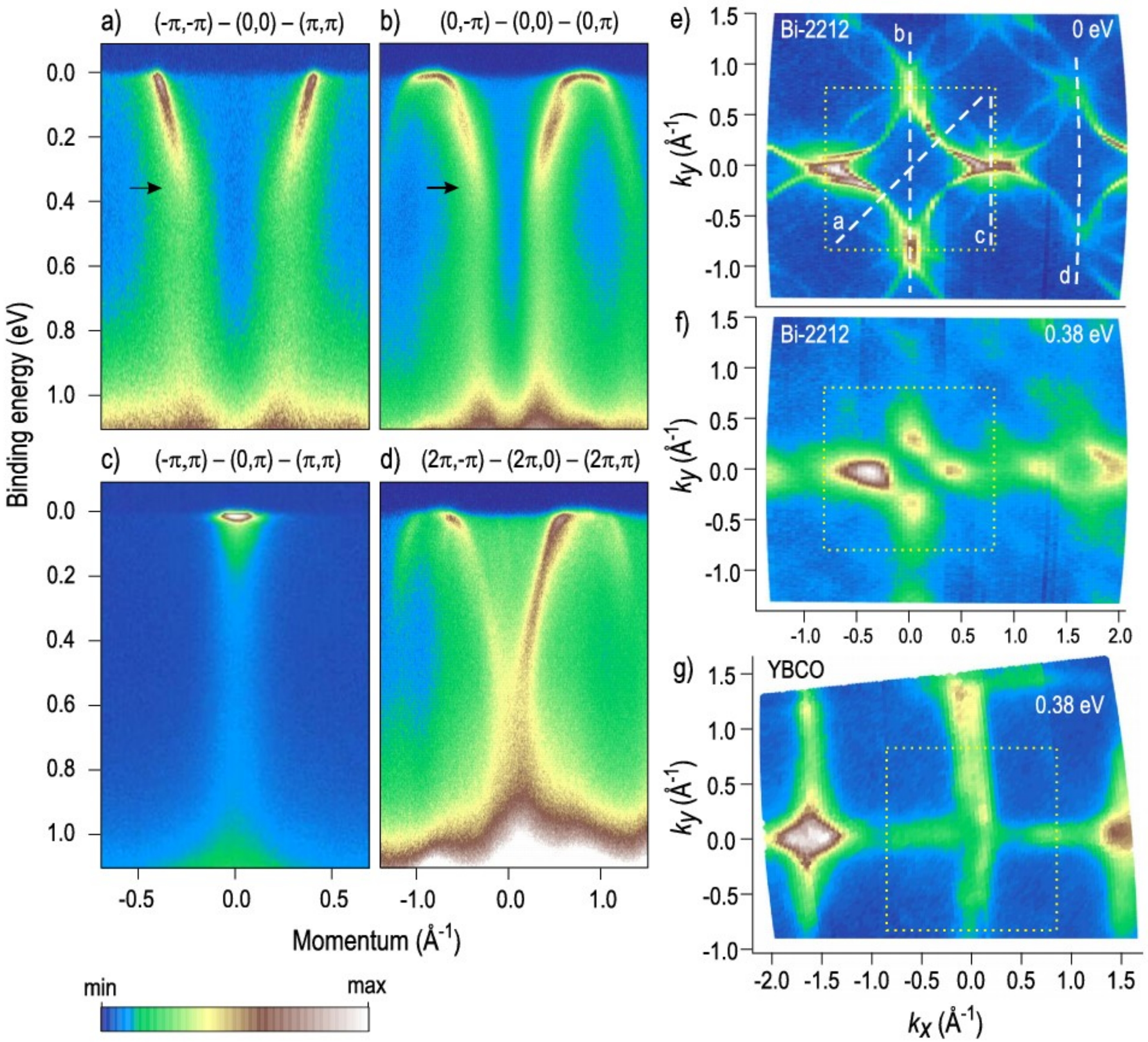
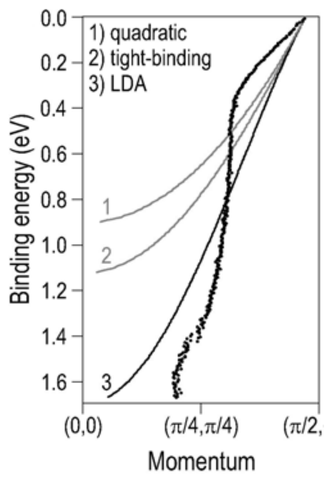
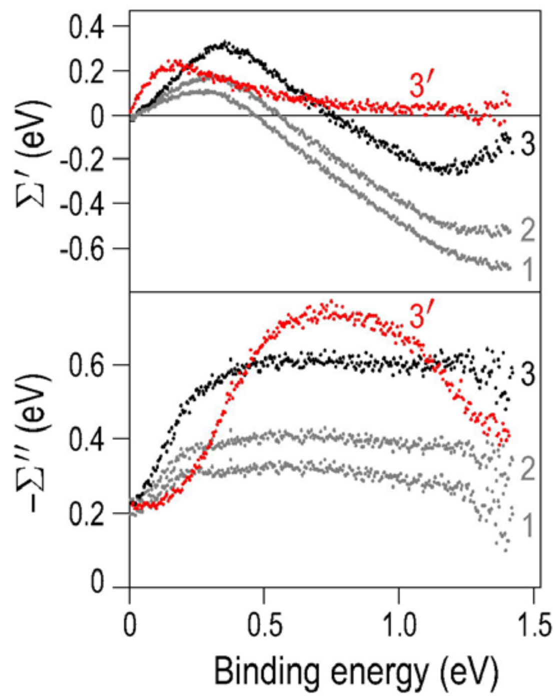




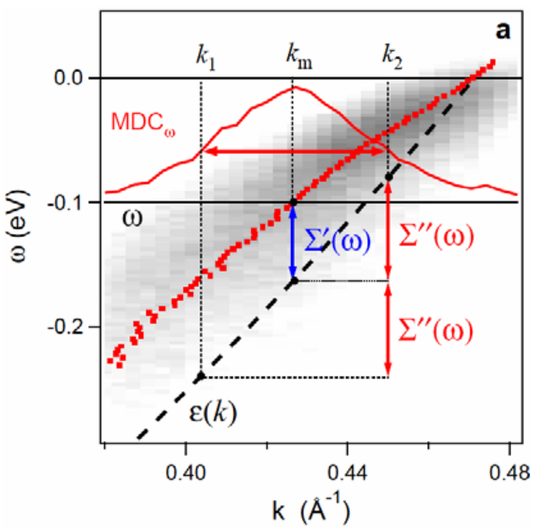


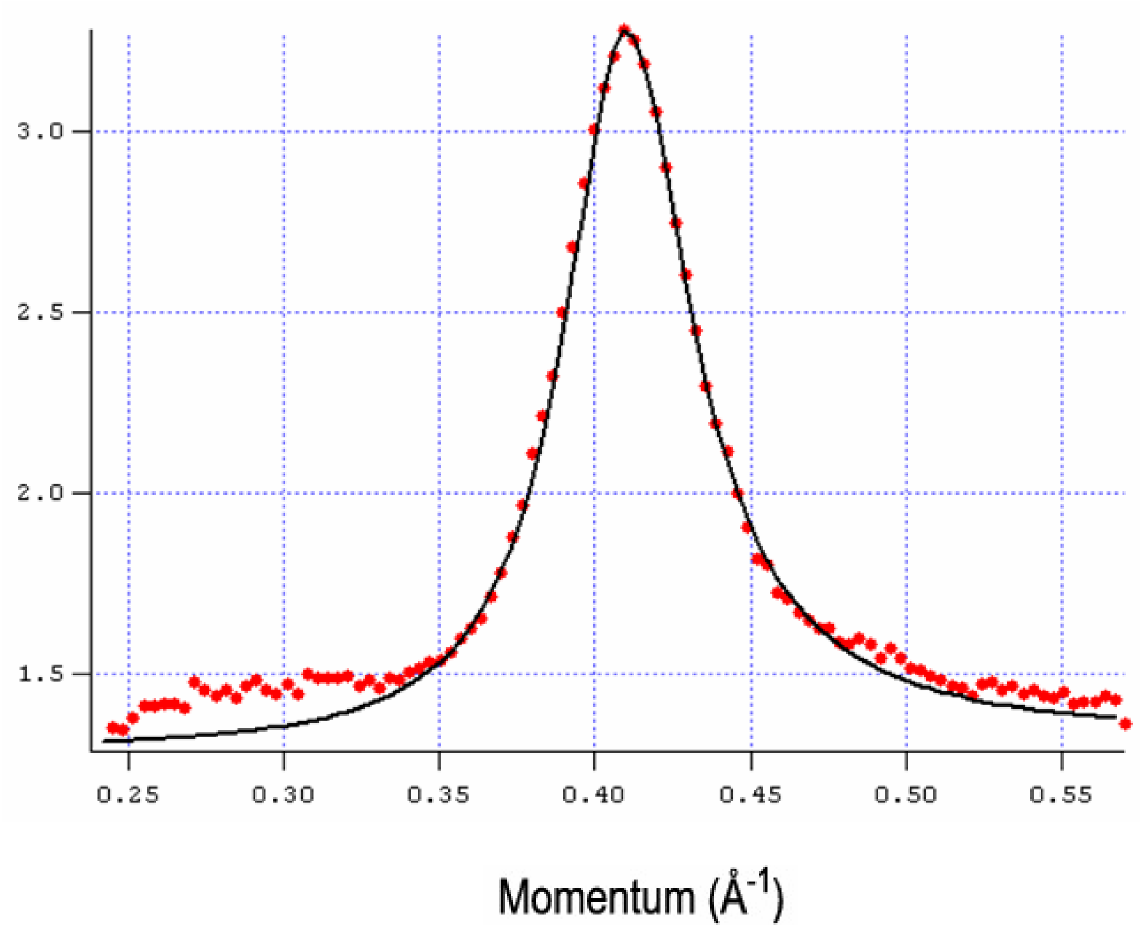
Inosov *cond-mat/0703223*

Room for complexity of the photoemission process

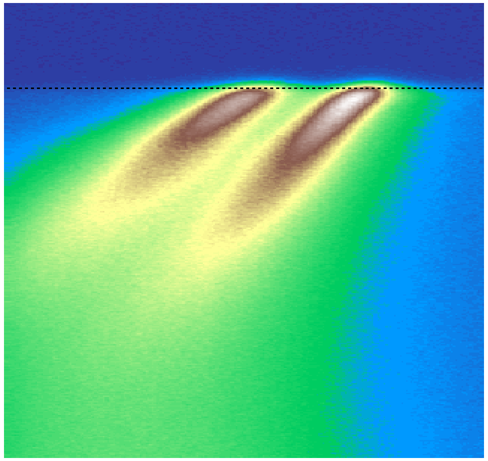
MDC asymmetry

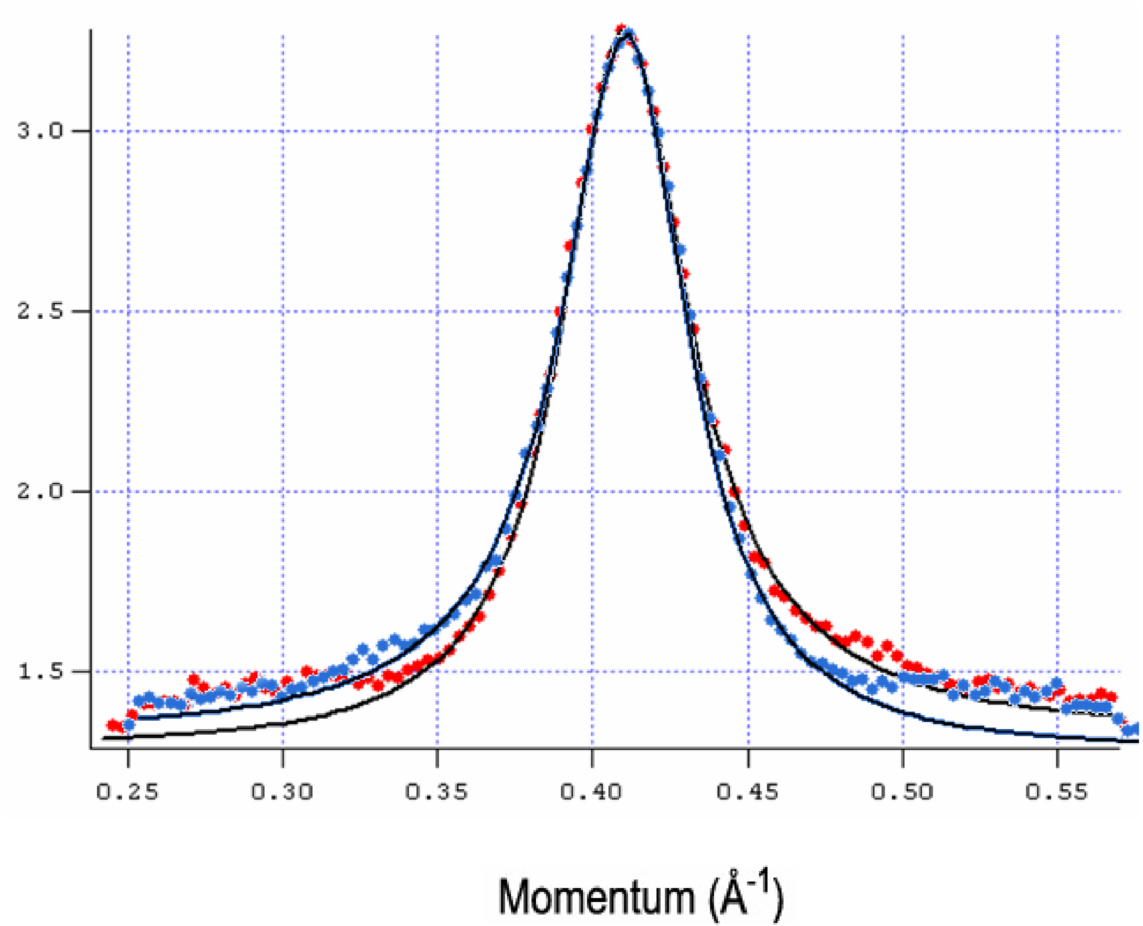
Σ_{min} = 16 meV





MDC asymmetry





Fingerprints of the bosonic spectrum

Quasiparticle spectrum in the whole Brillouin zone
k-dependent self-energy
ARPES – INS

①

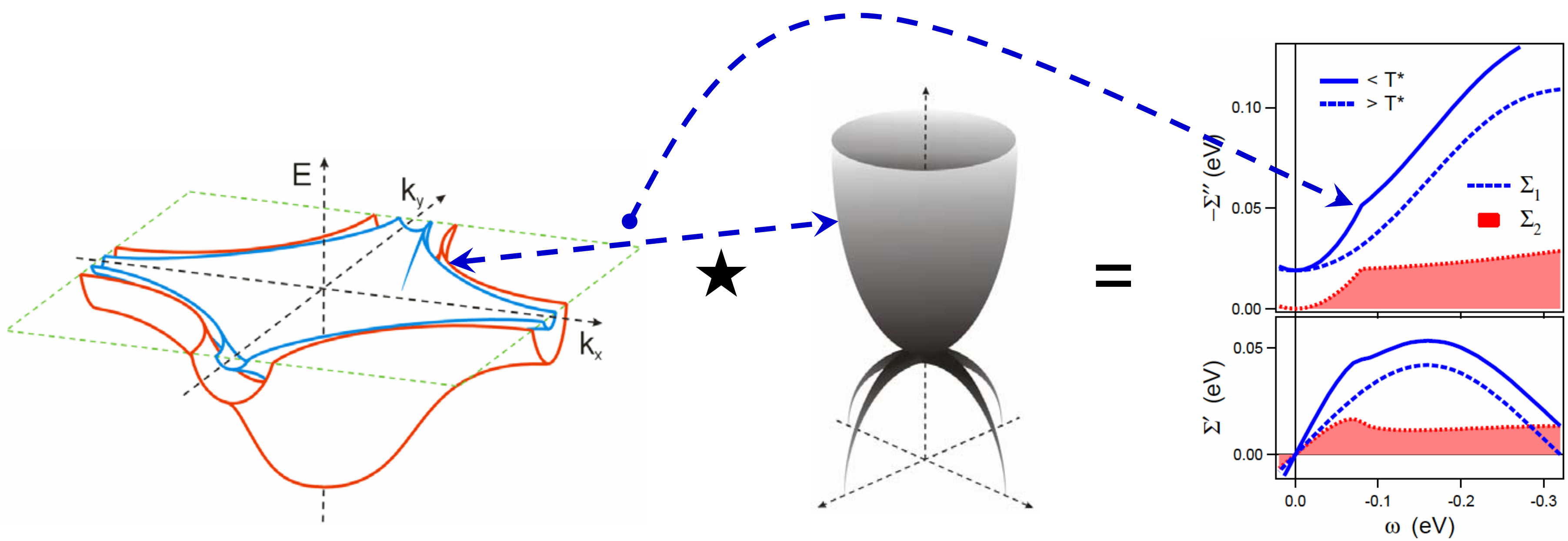
LDA or ARPES

$$G_0 \star \chi_{exp} \sim \Sigma_i$$

INS

$$G_i^{-1} = G_0^{-1} + \Sigma_i$$

ARPES



k, ω　　**Q**, Ω　　**k**, ω

IFW + Forschergruppe + Dahm & Scalapino 2006

Looking for "fingerprints"

of $\chi(\mathbf{k},\omega)$ in $\Delta(\mathbf{k},\omega)$

ARPES: $A(\mathbf{k},\omega)\, f(\omega)$ —?→ $\Delta(\mathbf{k},\omega)$

← $\Delta(\mathbf{k},\omega)$, $\Sigma(\mathbf{k},\omega)$, $\varepsilon_{\mathbf{k}}$

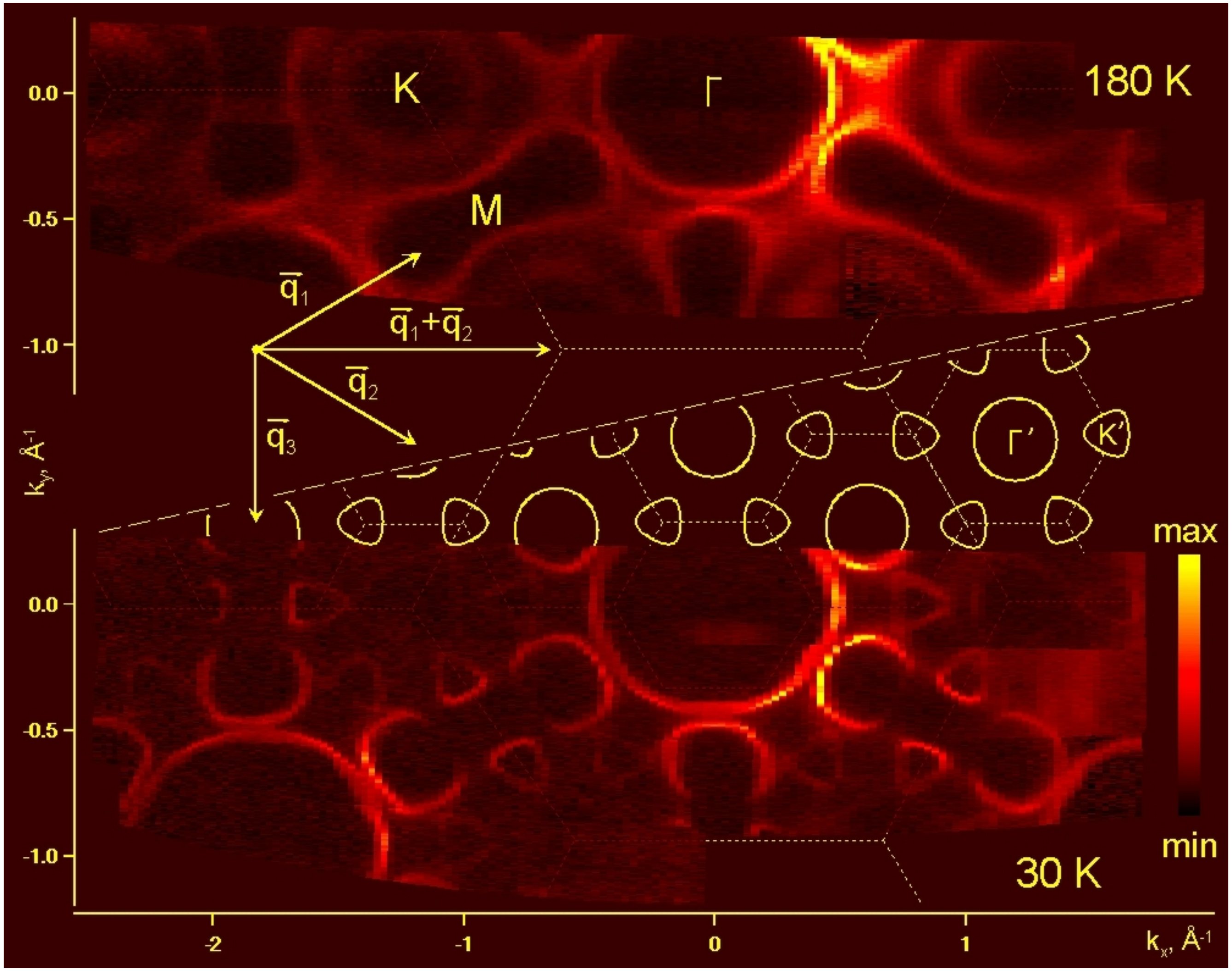
(if)

$$(\Delta,\Sigma) = \mathrm{EE}(\Delta,\Sigma,\varepsilon,\chi)$$ **SC**

$$\Sigma \sim G \star \chi$$ **N**

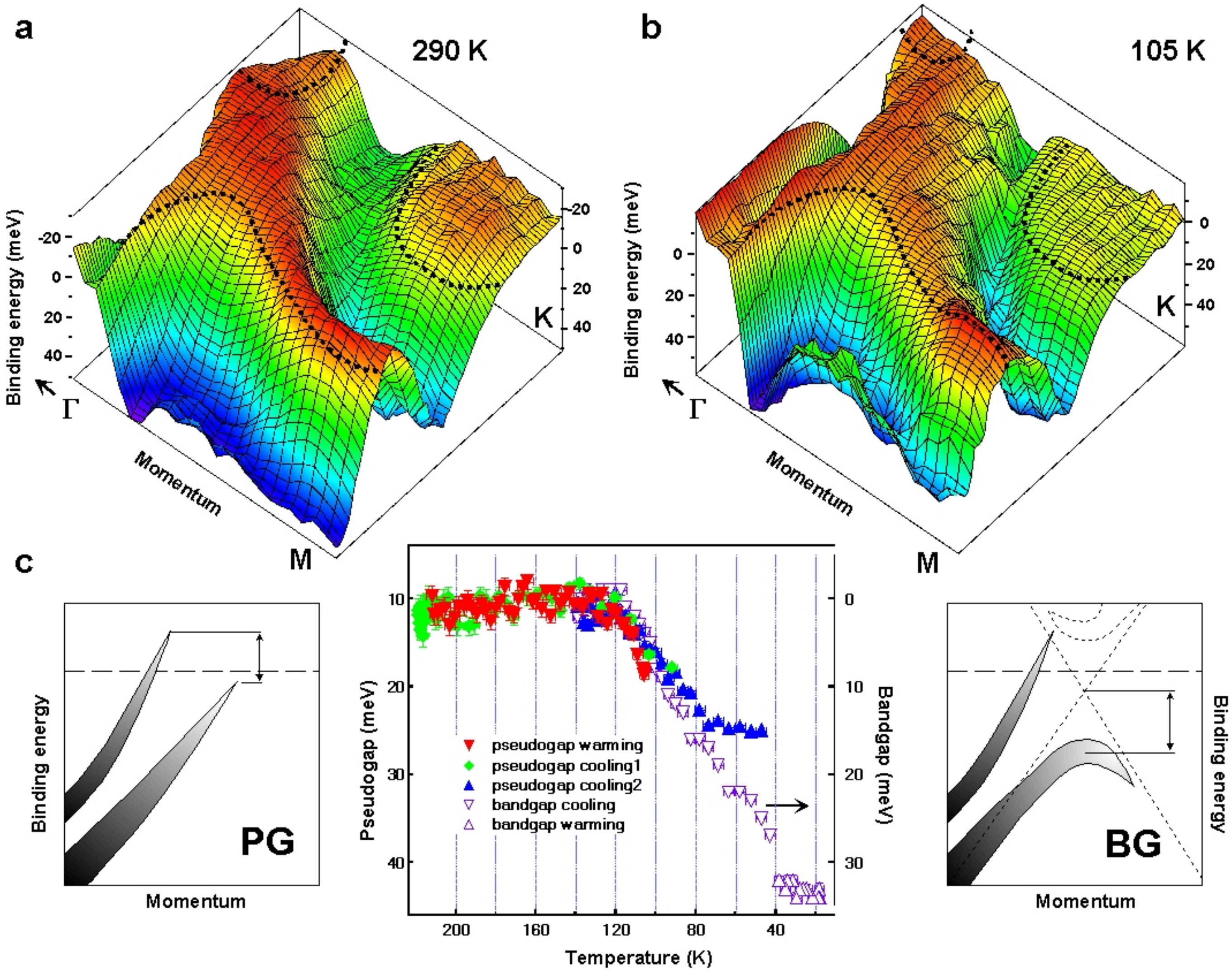
Pseudogap and CDW in two dimensions

$TaSe_2$



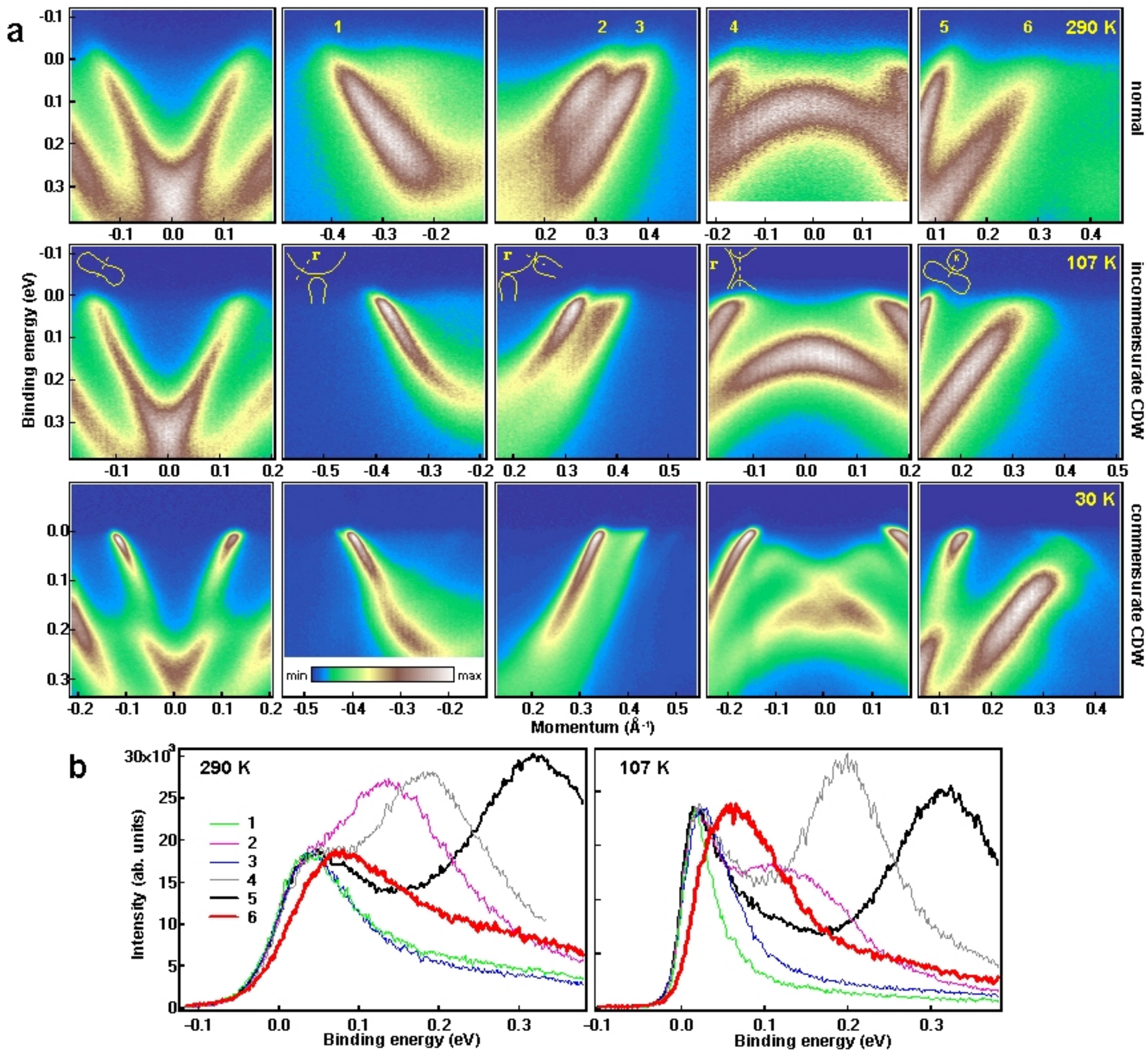
Borisenko *arXiv:0704.1544*

Pseudogap and CDW in two dimensions



Borisenko *arXiv:0704.1544*

Pseudogap and CDW in two dimensions



Borisenko *arXiv:0704.1544*

Conclusions

- Magnetic excitations strongly couples to the conduction electrons—and are, thus, the most probable candidate for mediation of the electron pairing in HTSC.

- The unification of the momentum resolving techniques are required:
  (1) to identify **ultimately** the "fingerprints" of the relevant bosonic spectrum in both $\Sigma(\mathbf{k}, \omega)$ and $\Delta(\mathbf{k}, \omega)$;
  (2) to determine the origin of the bosonic spectrum (the degree of itinerancy, in case of spin-fluctuations);
  (3) to understand the role of space inhomogeneity in pairing.

- The current rate of improvement of all of the momentum resolving techniques suggests that these problems will be solved very soon.

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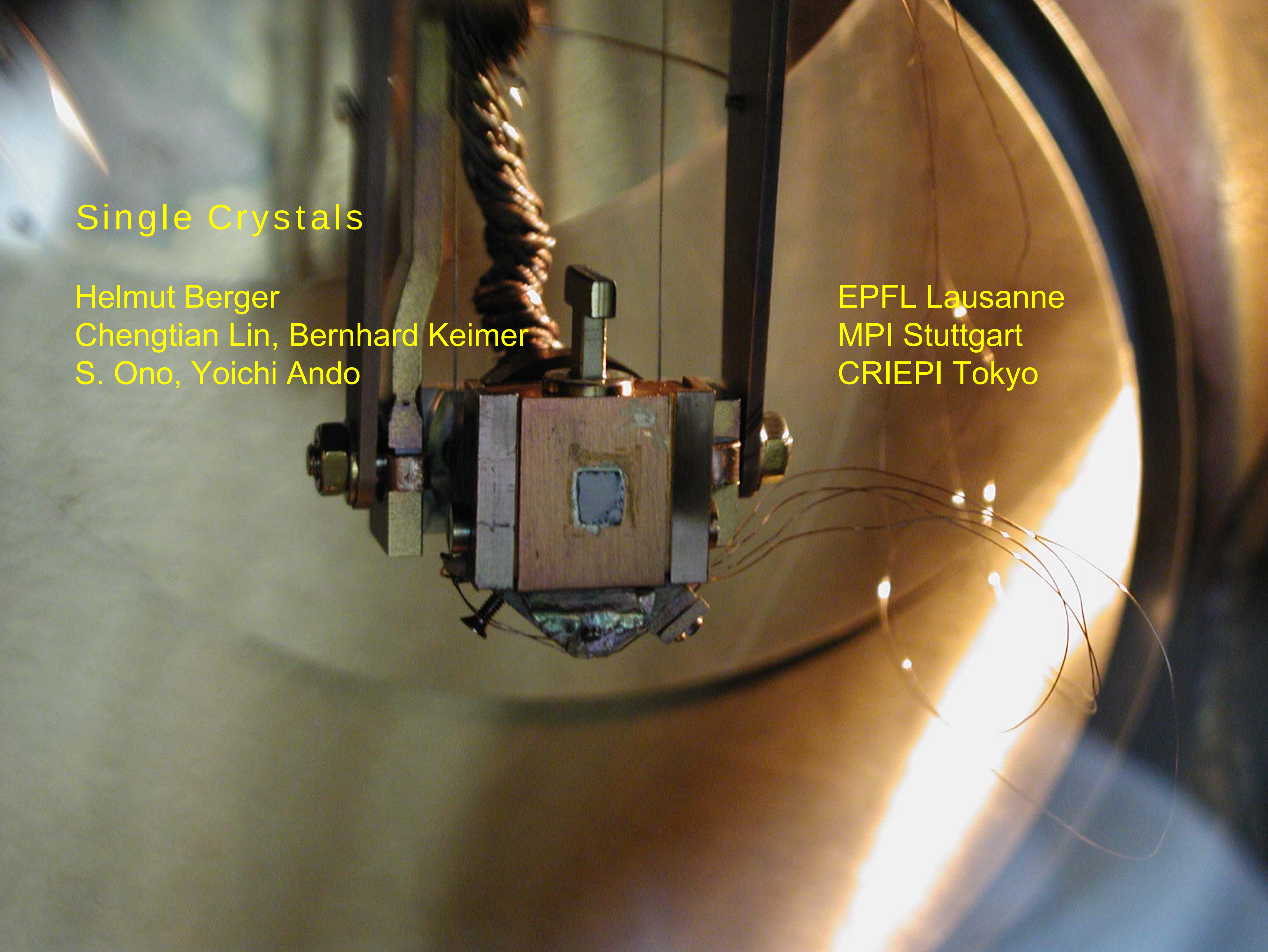
Single Crystals
Helmut Berger
Chengtian Lin, Bernhard Keimer
S. Ono, Yoichi Ando
EPFL Lausanne
MPI Stuttgart
CRIEPI Tokyo

Synchrotron Light

Rolf Follath — BESSY Berlin

Ming Shi, Luc Patthey — SLS Villigen