

SMR.1572 - 33

**Workshop on  
Novel States and Phase Transitions in Highly Correlated Matter  
12 - 23 July 2004**

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**Infrared and optical spectroscopy of High-T<sub>c</sub> cuprates**

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CA 92093-0319 La Jolla  
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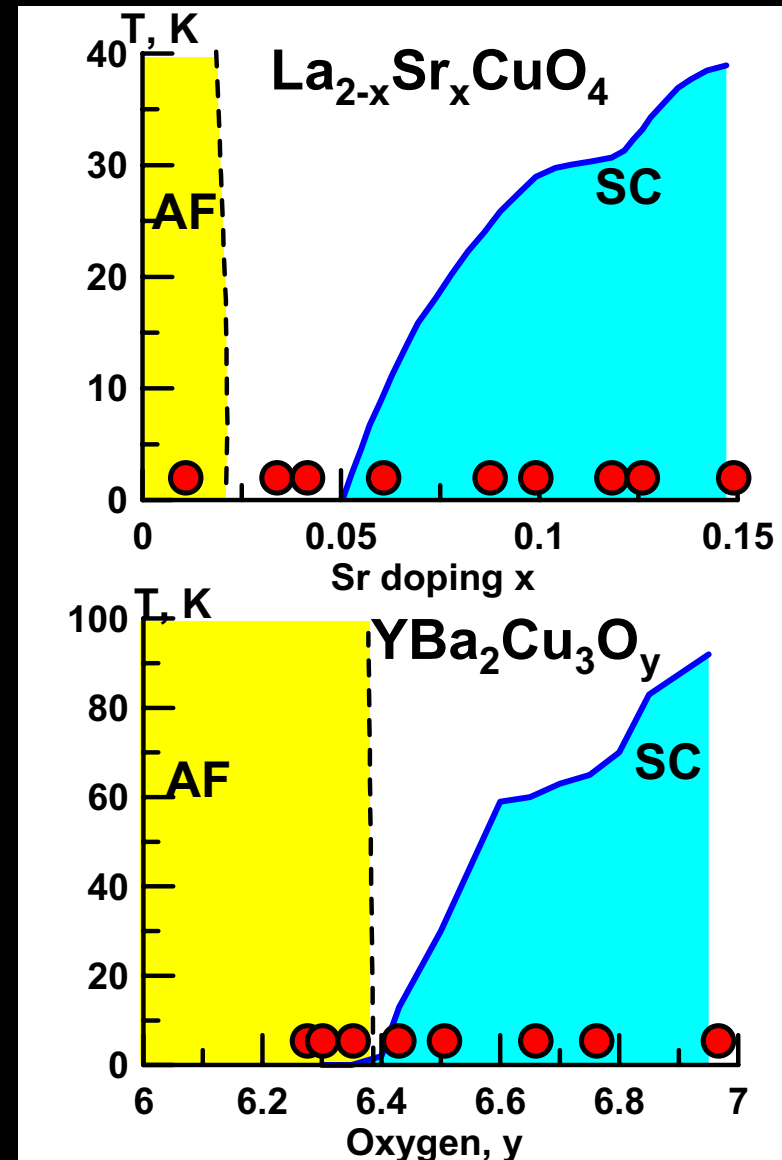
These are preliminary lecture notes, intended only for distribution to participants

# Infrared and optical spectroscopy of High-T<sub>c</sub> cuprates

D.N. Basov

University of California, San Diego

- *Nodal QP and metallic state in AF phases*
- *Two-component transport/optics*
- *Spin/charge ordering and electronic anisotropy*
- *Constant  $m^*_{opt}$  across the phase diagram*
- *Two-component response and pseudogap state*
- *Inhomogeneous superfluid response from Josephson plasmon microscopy*



# Infrared and optical spectroscopy of High-T<sub>c</sub> cuprates

D.N. Basov

University of California, San Diego

## Collaborators:

*S. Dordevic*

*W.J. Padilla*

*M. Dumm*

*Y.S. Lee*

*K.S. Burch*

*Z.Q. Li*

*A. Laforge*  
(UCSD)

*Seiki Komiyama*

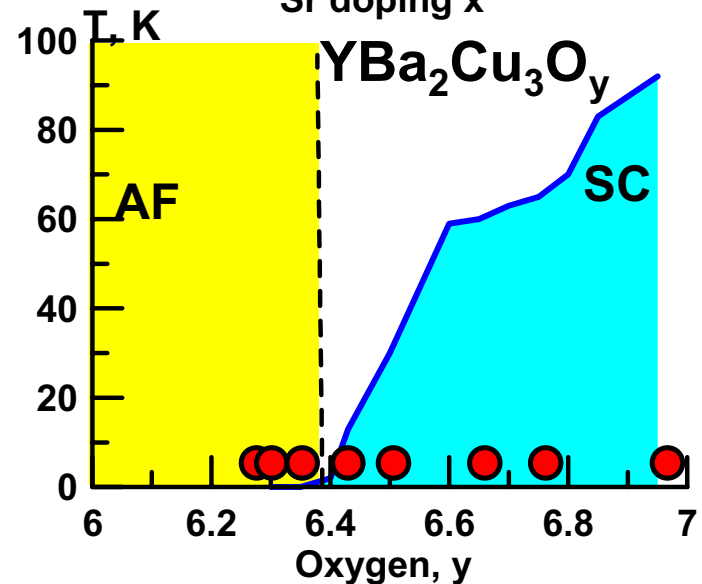
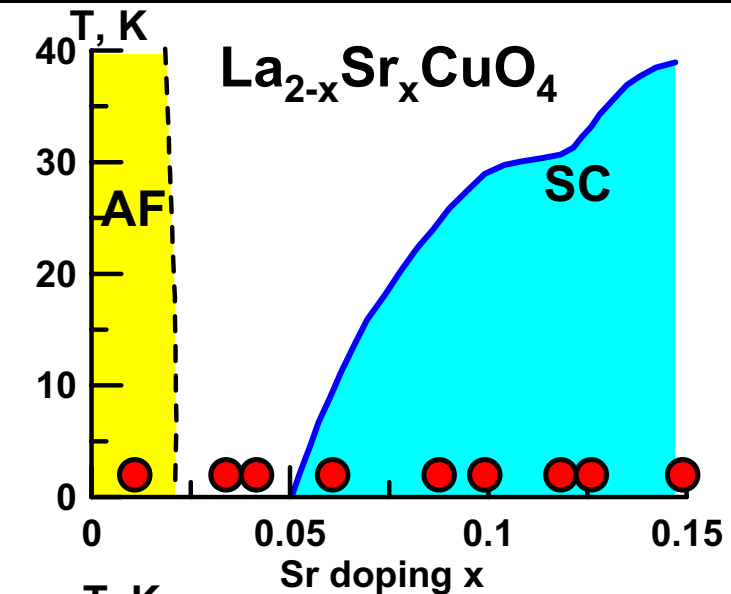
*X.F. Sun*

*Yoichi Ando*

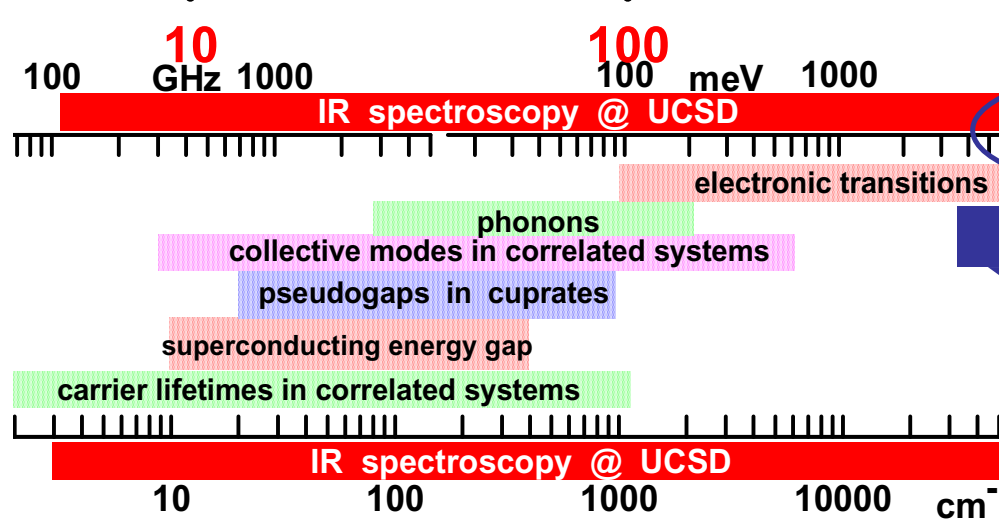
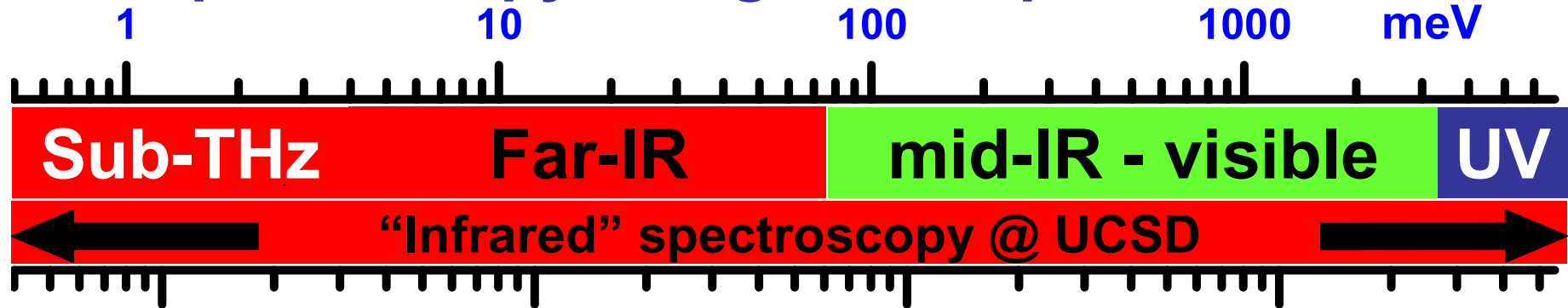
(CREIPI)

*G. Blumberg*

(Lucent)

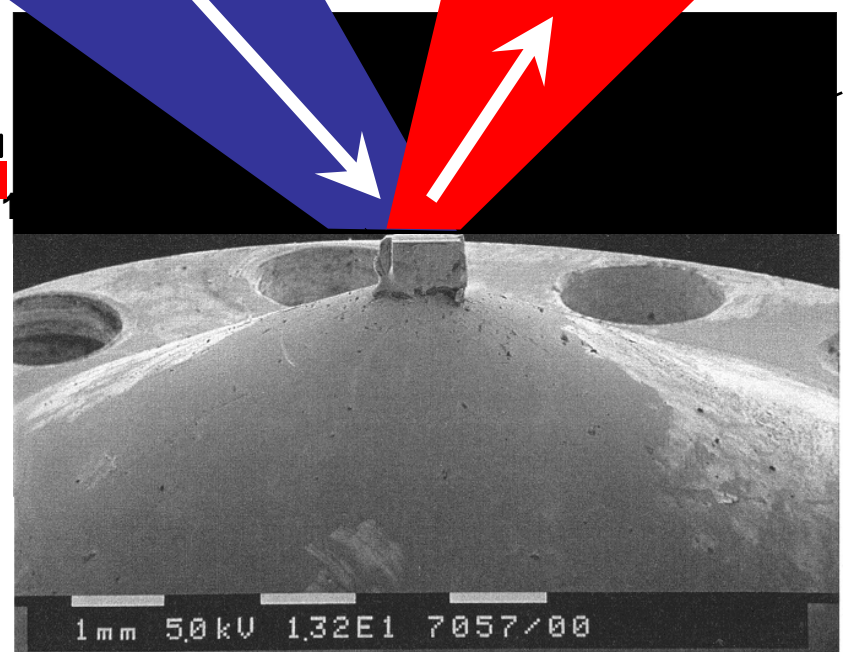


# IR spectroscopy of high-Tc superconductors



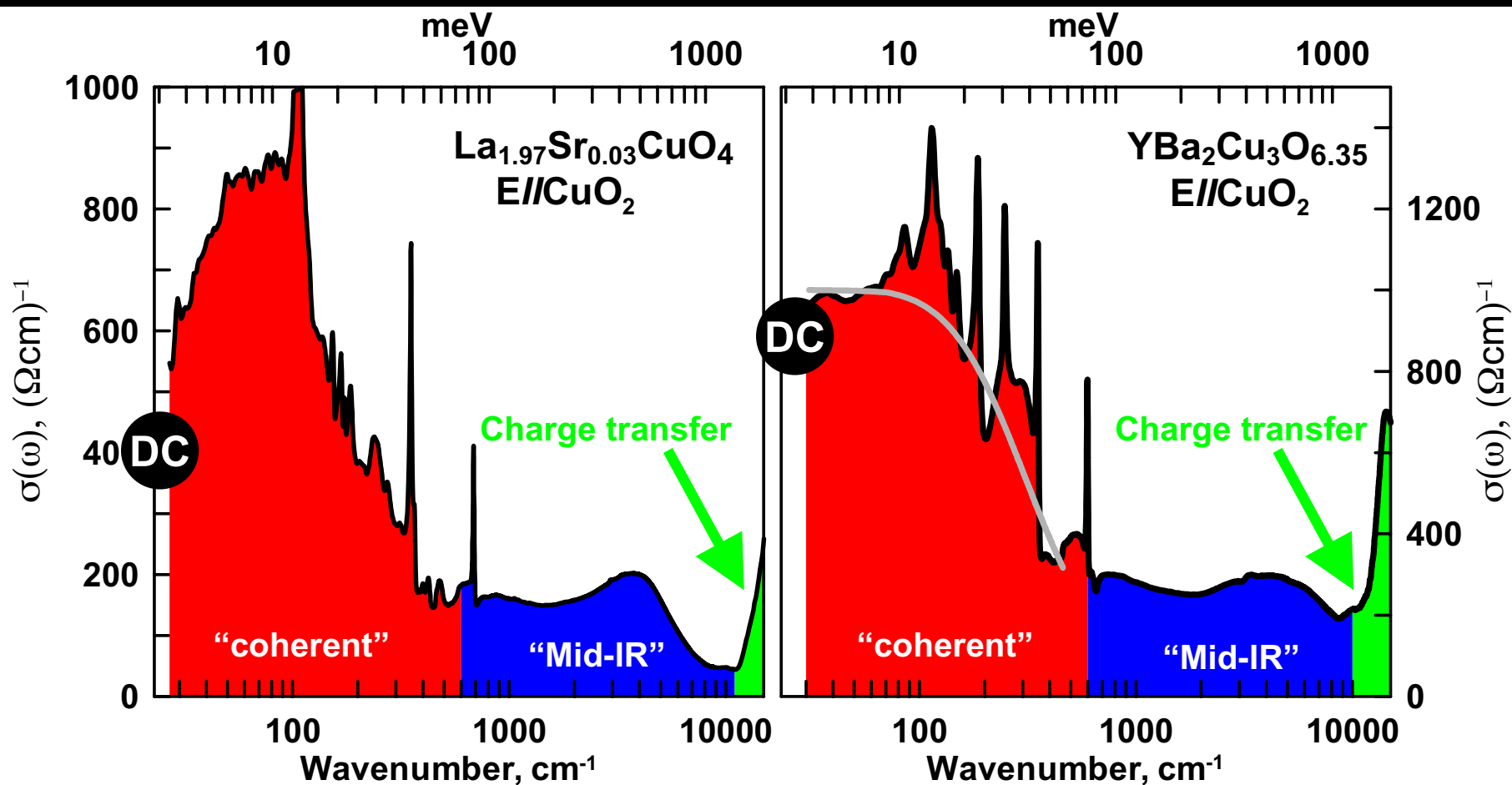
interferometer

detector

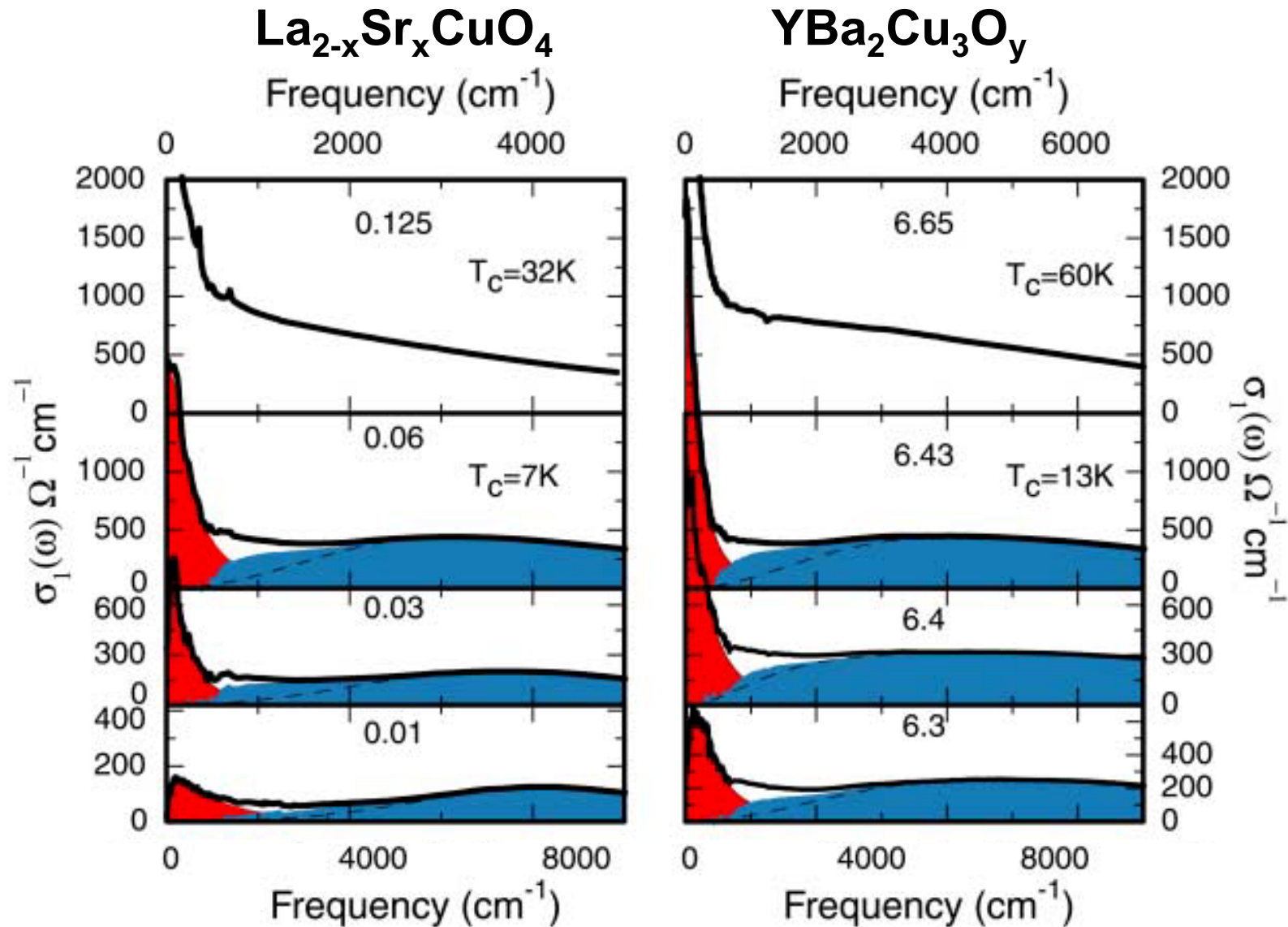


**Extreme conditions:**  
 magnetic field < 17 T  
 T down to 320 mK  
 electric field  
 high pressure

# Charge dynamics in weakly doped $\text{CuO}_2$ planes



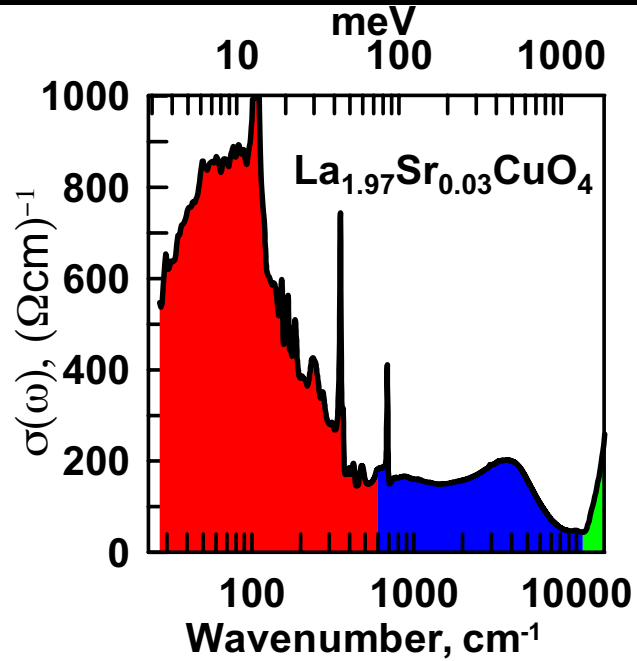
# Charge dynamics in weakly doped $\text{CuO}_2$ planes: generic trends



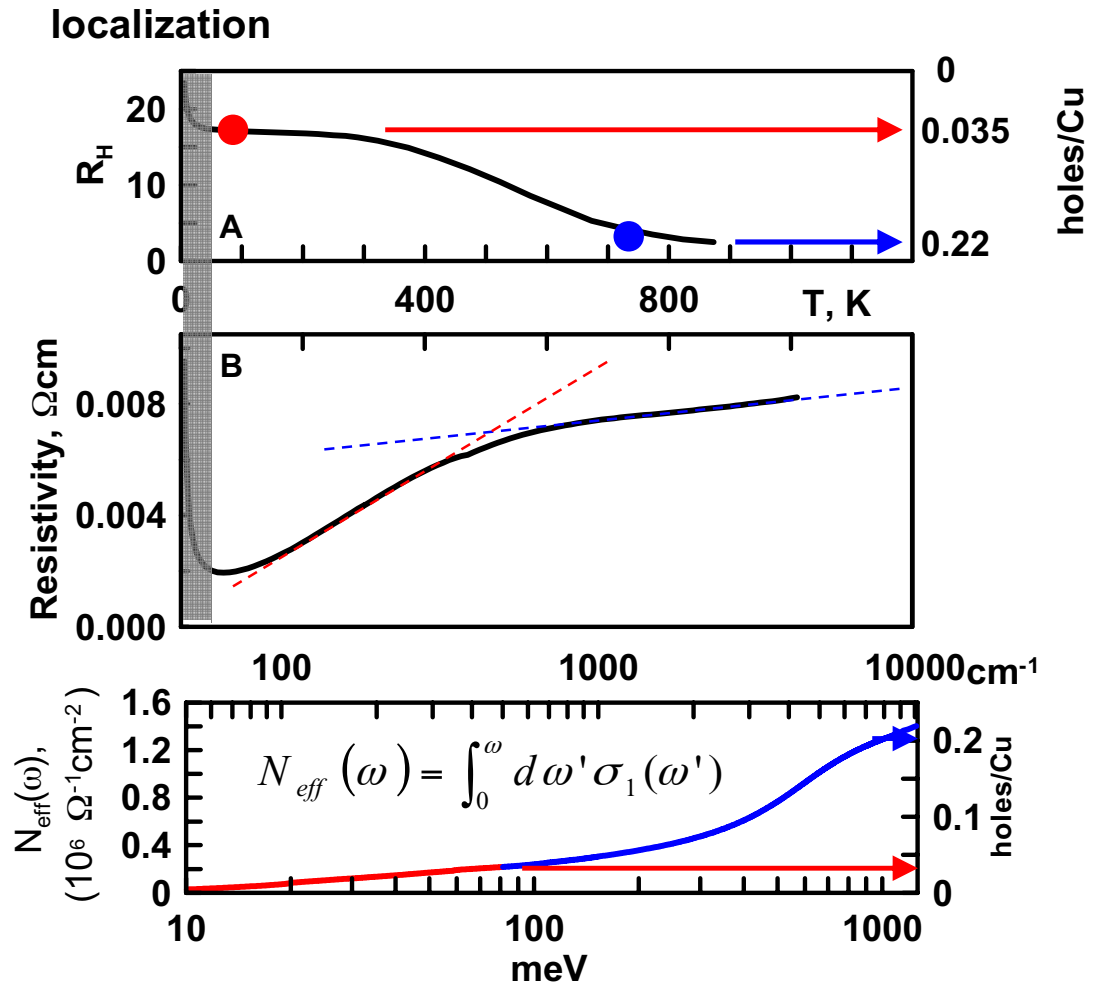
Y.S. Lee et al. *PRB* 69 (2004)  
M.Dumm et al. *PRL* 91, 077004 (2003)  
*PRL* 88, 147003 (2002)

**Two-component conductivity**

# 2-component $\sigma(\omega)$ : implications for transport

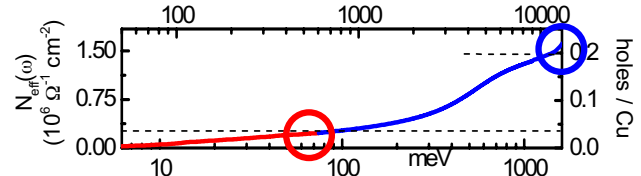
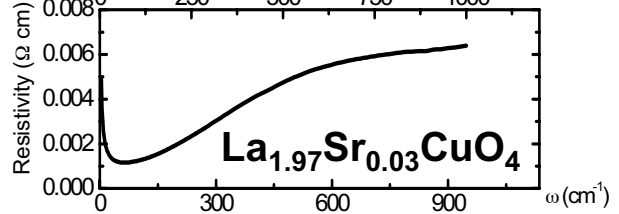
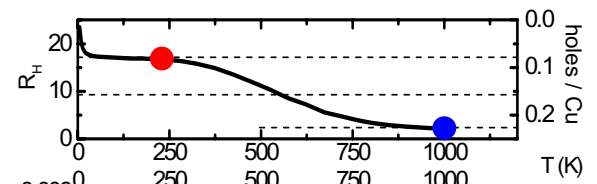
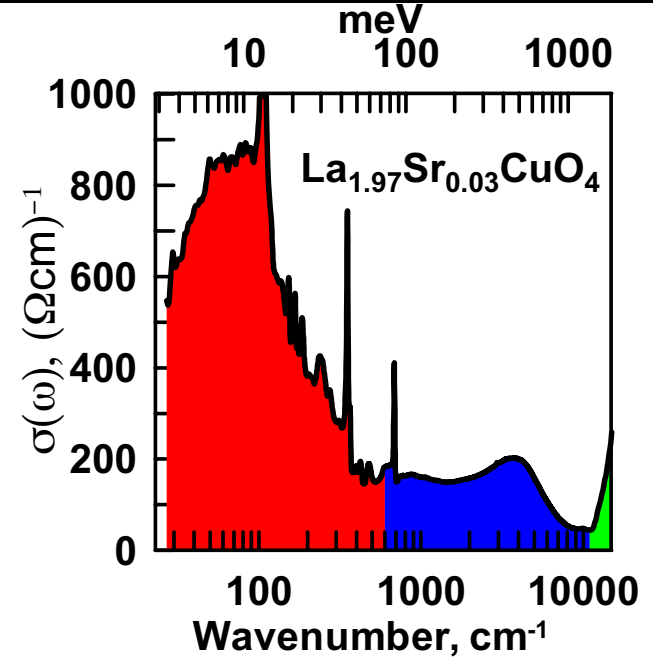


**2-component  $\sigma(\omega)$**

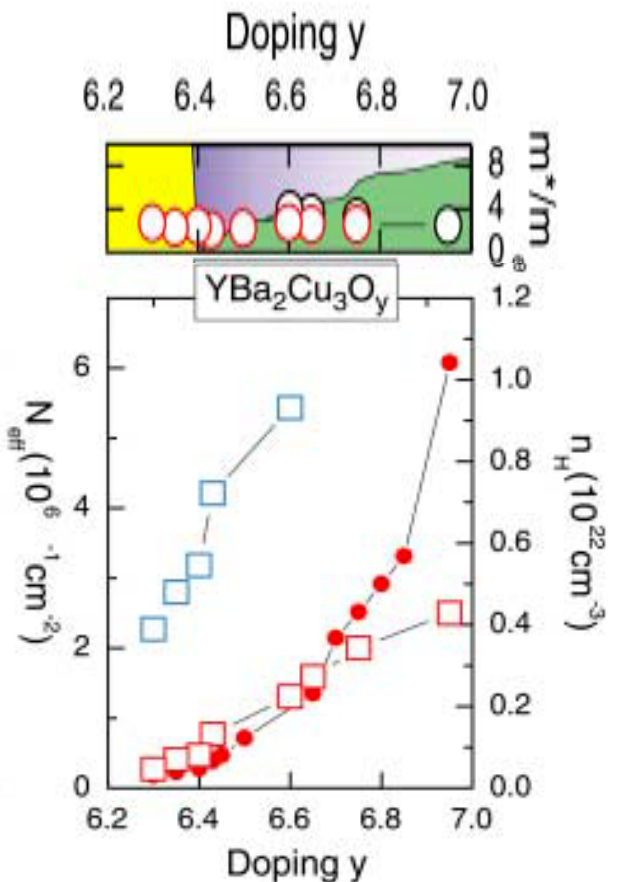
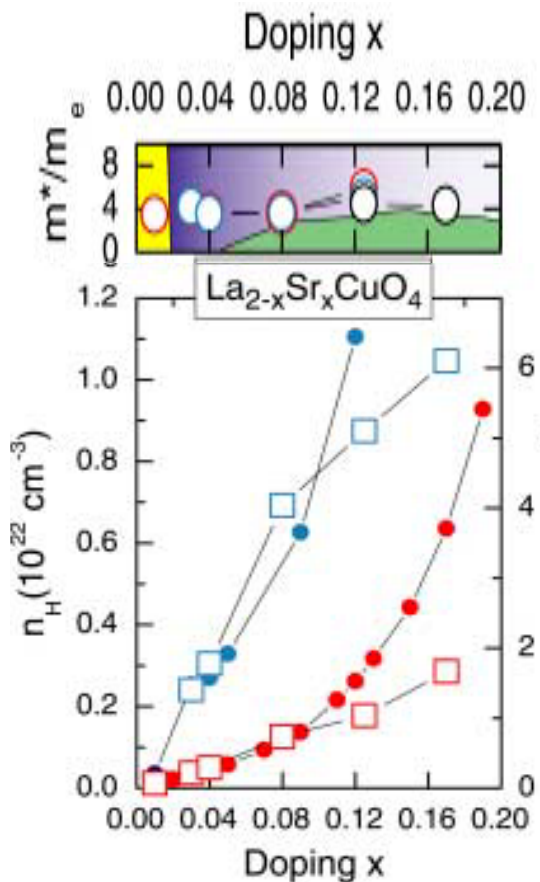


**Two-component transport**

# 2-component $\sigma(\omega)$ /transport: $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ and $\text{YBa}_2\text{Cu}_3\text{O}_y$



W.J.Padilla (submitted)



- Low- $\omega$   $N_{\text{eff}}$
- Low-T Hall
- high- $\omega$   $N_{\text{eff}}$
- high-T Hall

$$R_H = \frac{1}{ne}; \quad N_{\text{eff}} = \frac{4\pi ne^2}{m^*}$$

$$\frac{m^*}{m_b} = -\frac{\omega_p^2}{4\pi\omega} \text{Im} \left[ \frac{1}{\sigma(\omega)} \right]$$



# Universal transport and spectroscopic properties of cuprates

## 1. $n \sim x$

Hall, optics 1987-90

## 2. Constant $m^*$

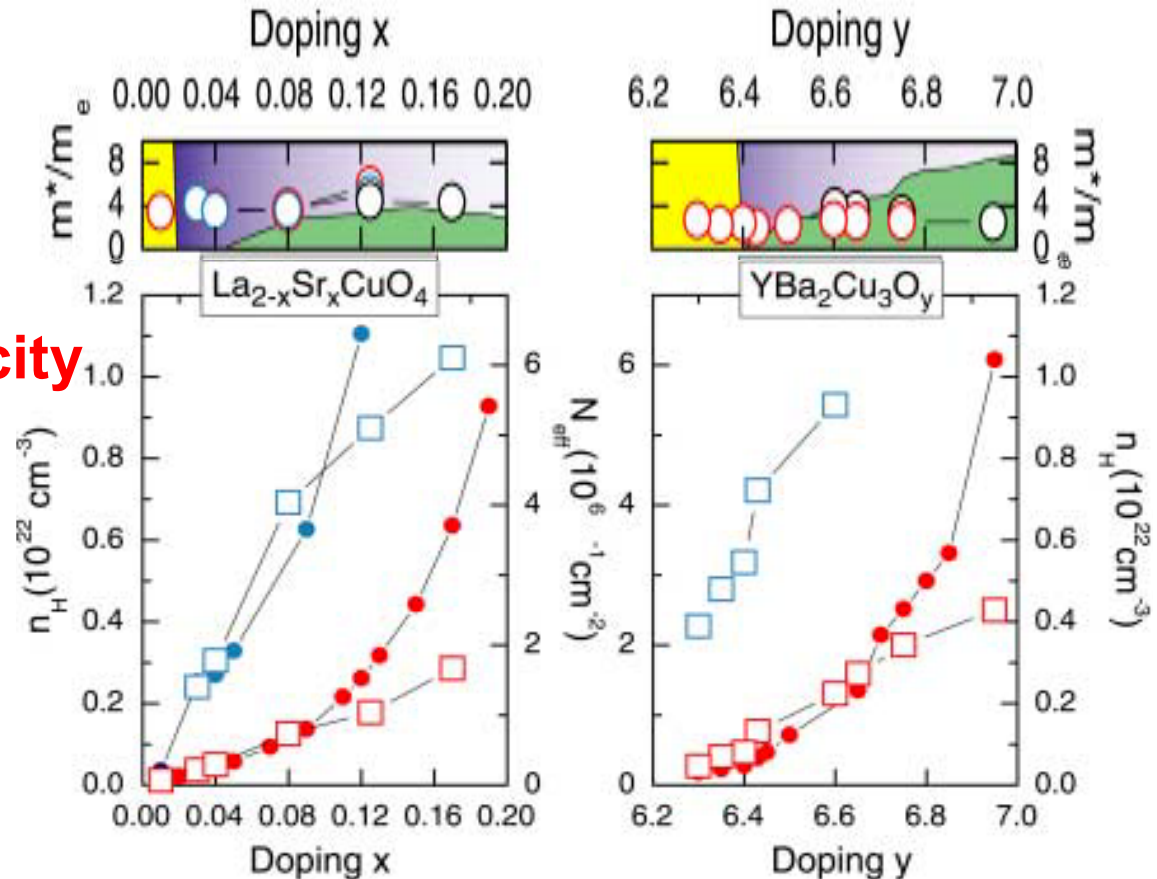
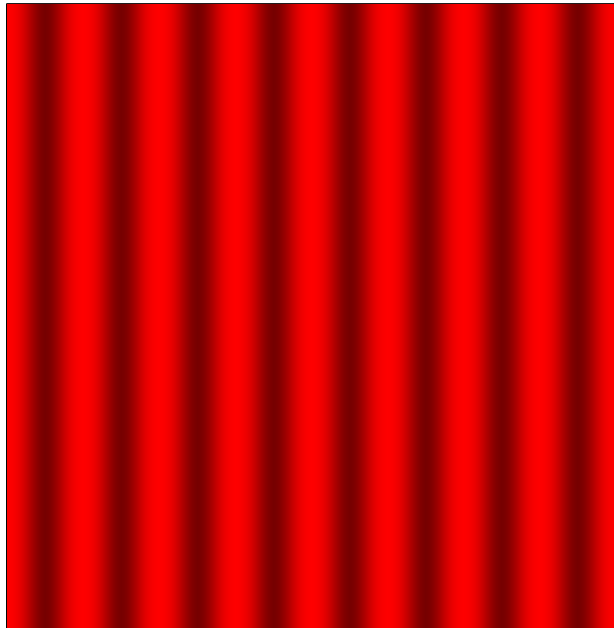
Padilla *et al.* 2004

## 3. Constant mobility

Ando *et al.* 2001

## 4. Constant nodal velocity

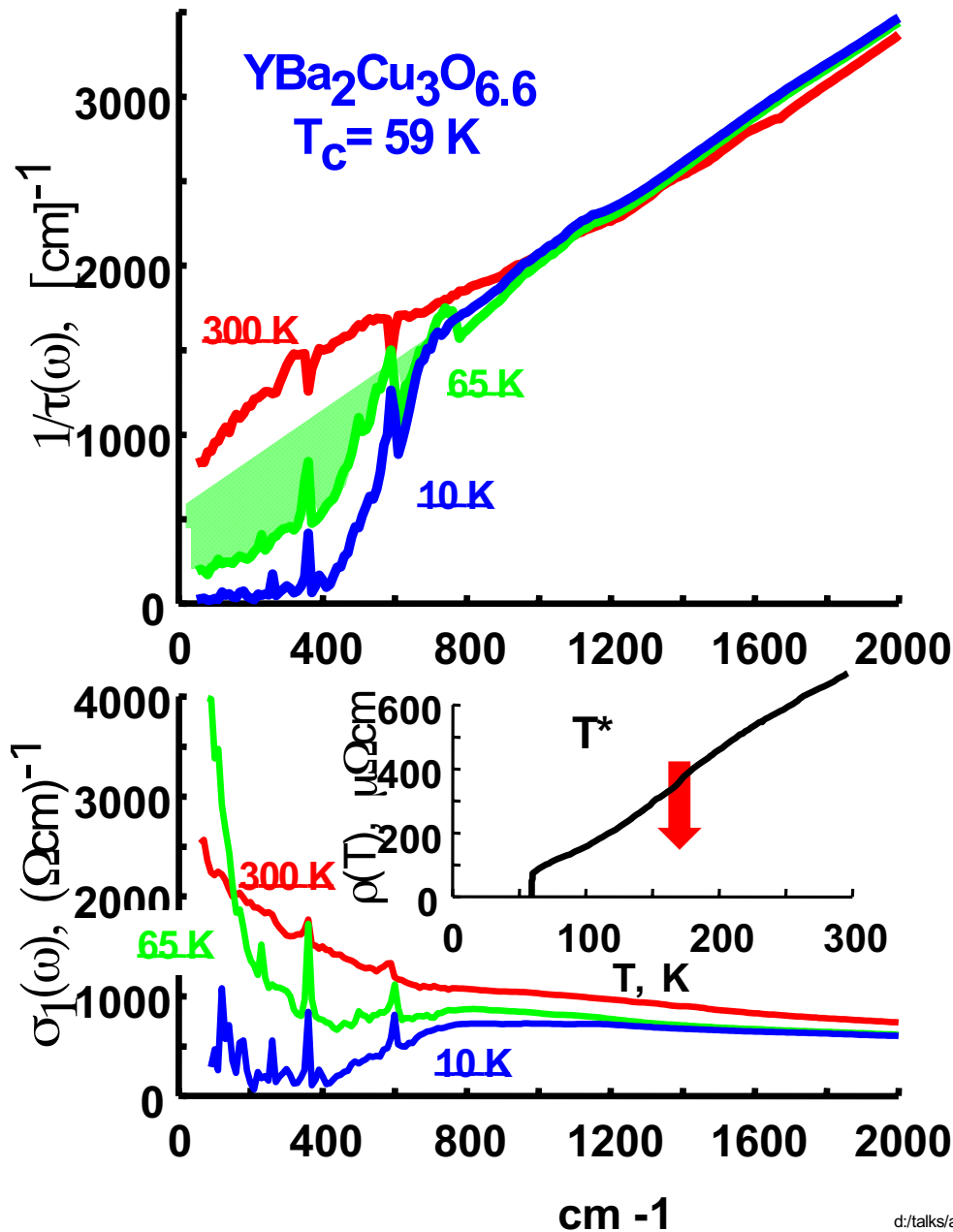
Zhou *et al.*  
Johnson *et al.*



Inhomogeneous electron liquid

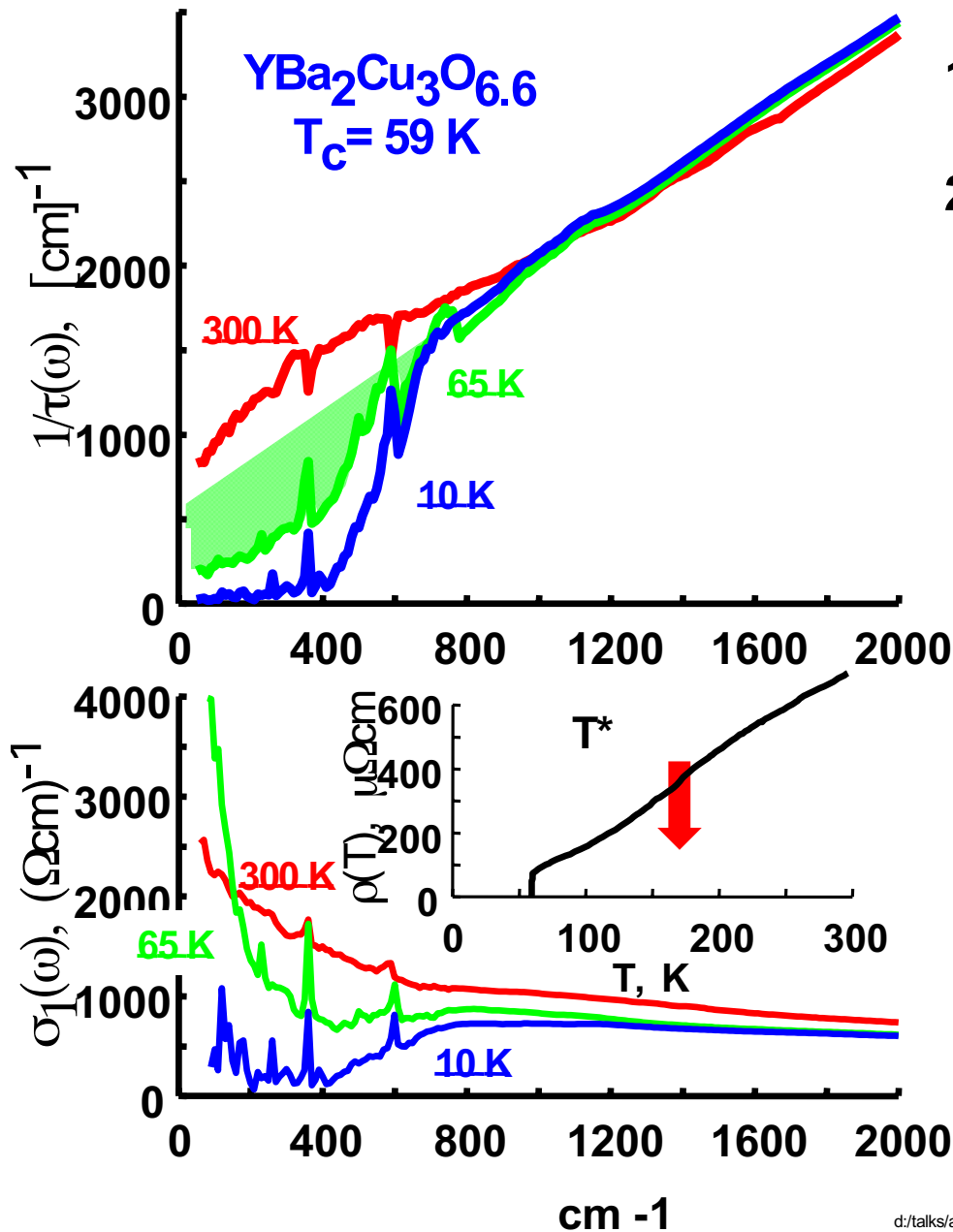


# Revisiting the pseudogap state and strong coupling effects



$$\frac{1}{\tau(\omega)} = \frac{\omega_p^2}{4\pi} \operatorname{Re} \left( \frac{1}{\sigma(\omega)} \right)$$

# Revisiting the pseudogap state and strong coupling effects

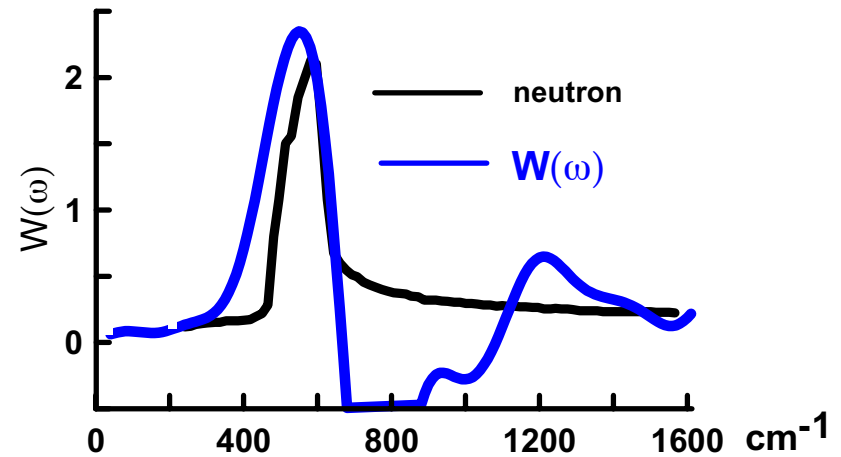


1. Gap in the electronic DOS?

2. Strong coupling?

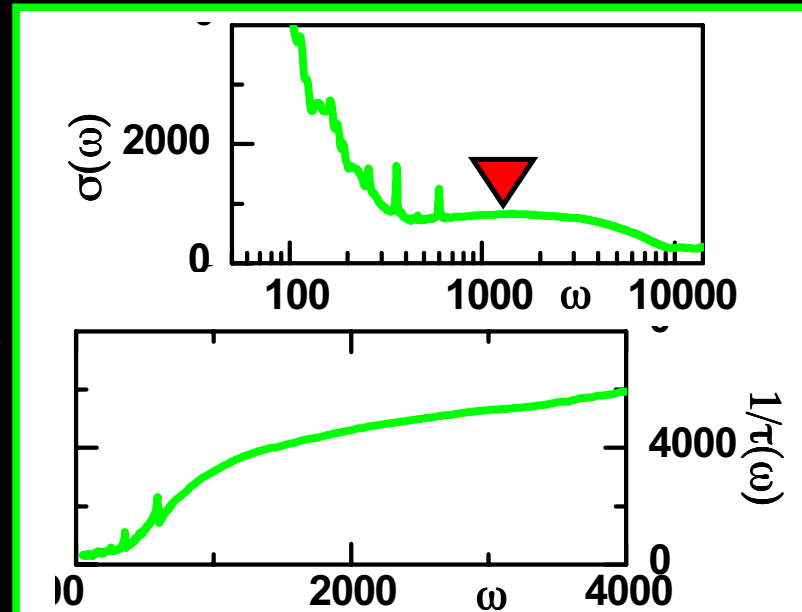
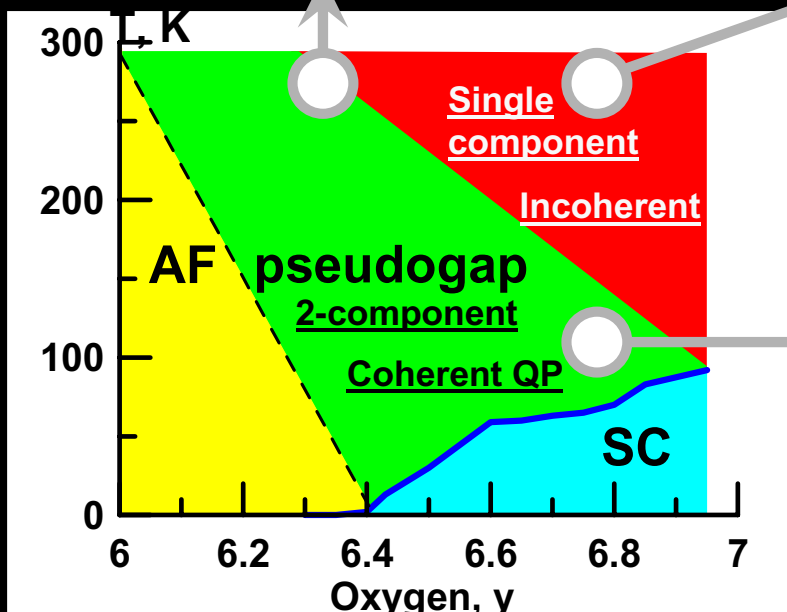
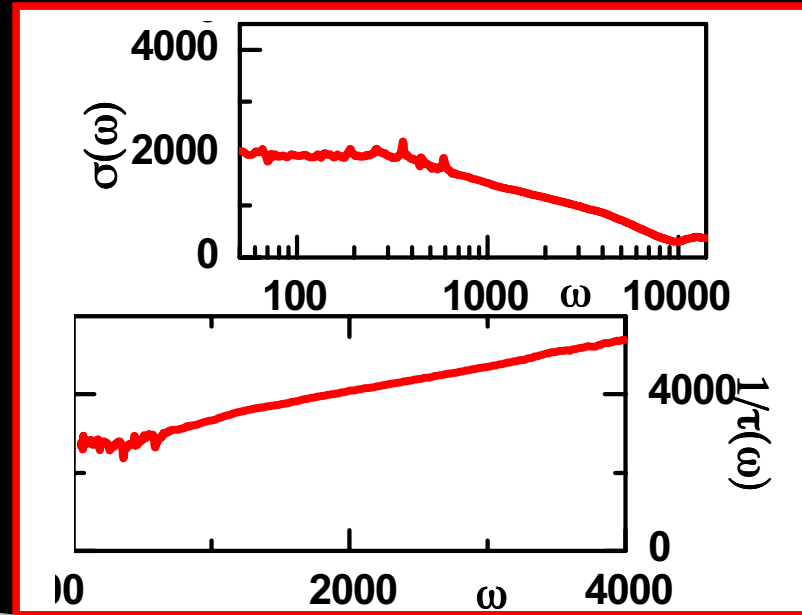
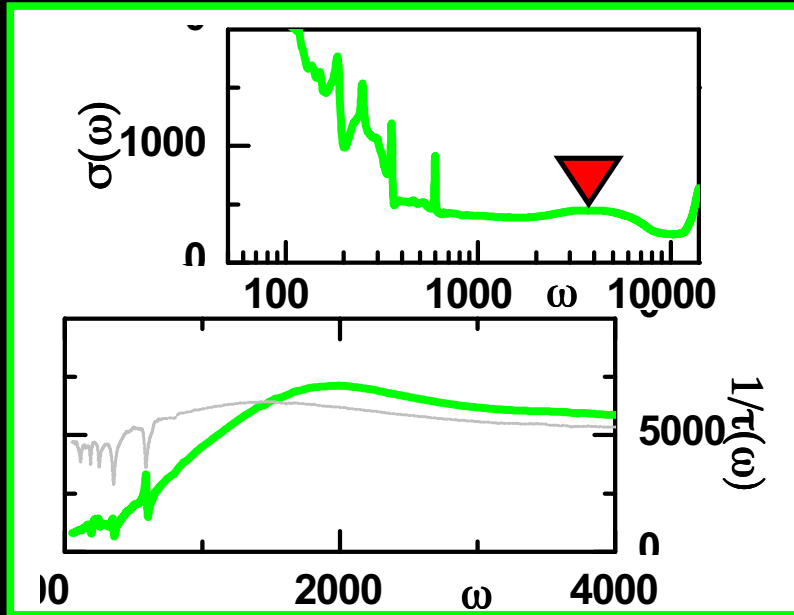
$$\frac{1}{\tau(\omega)} = \frac{2\pi}{\omega} \int_0^\omega d\omega' (\omega - \omega') W(\omega')$$

Carbotte, Schachinger and Basov  
*Nature* 401, 354 (1999)

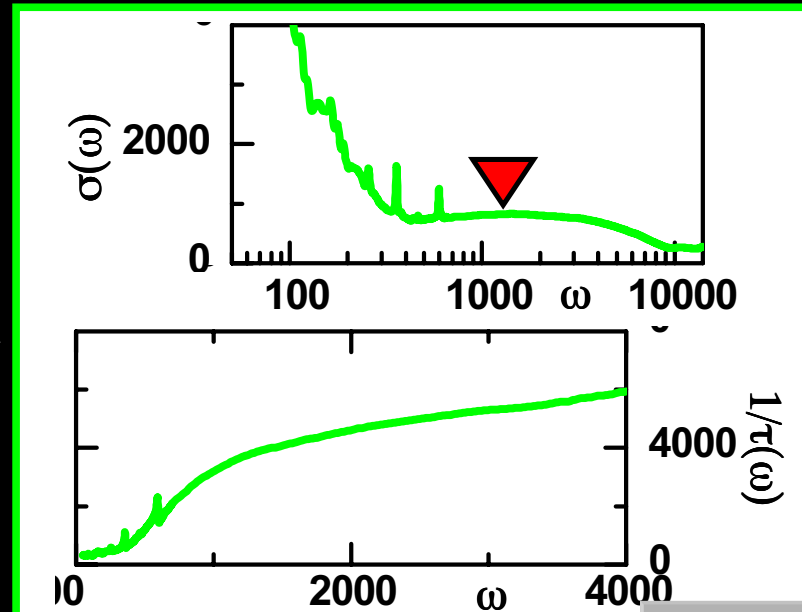
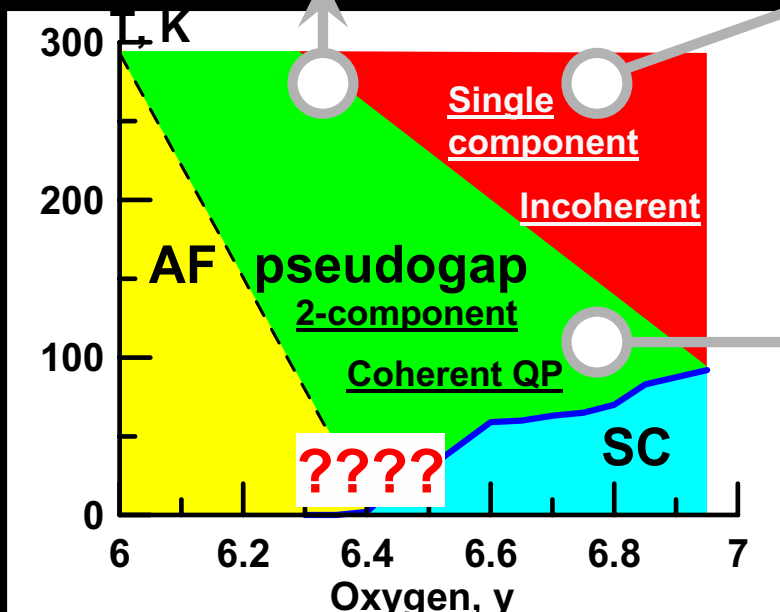
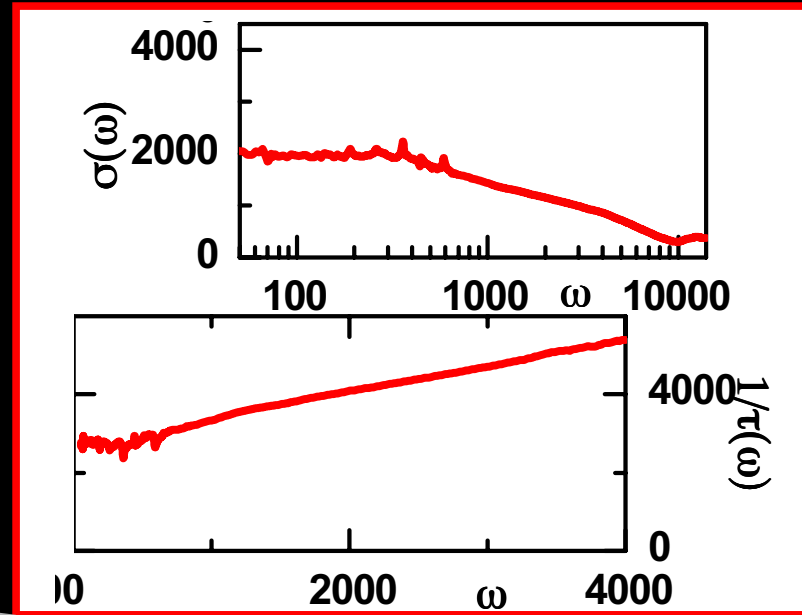
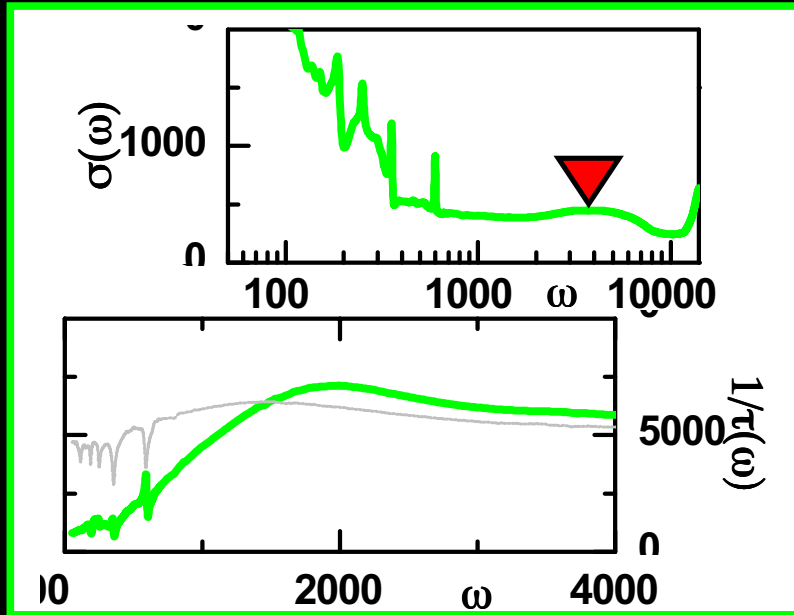


A. Chubukov,  
M. Norman

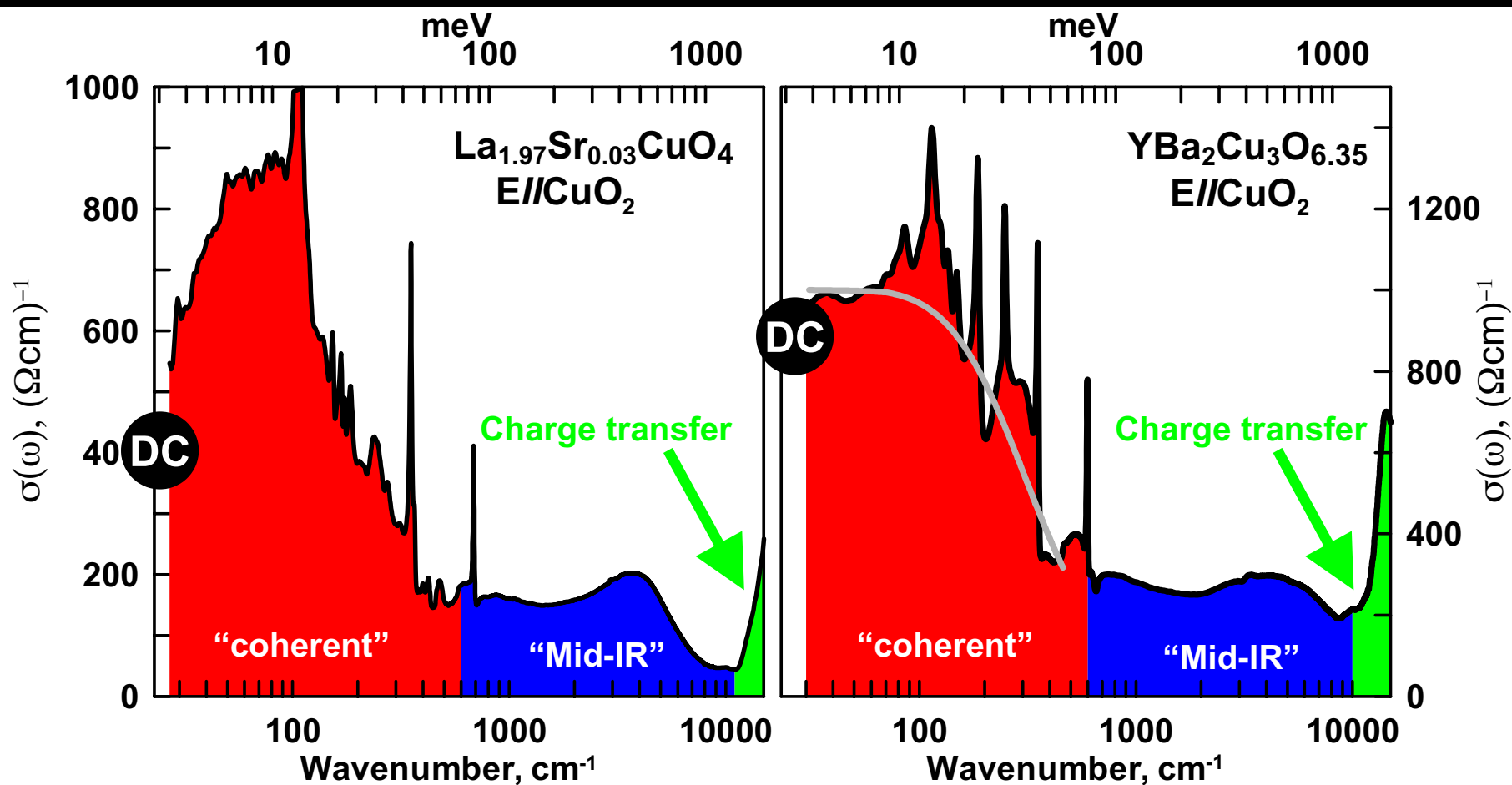
# Revisiting the pseudogap state and strong coupling effects



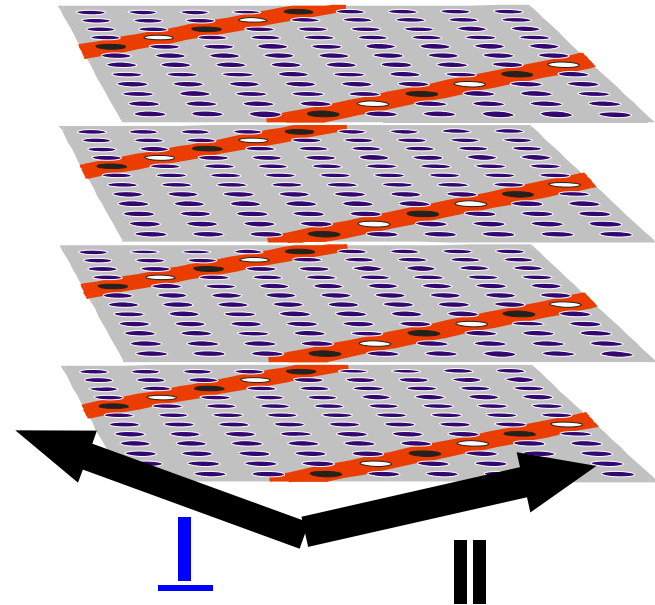
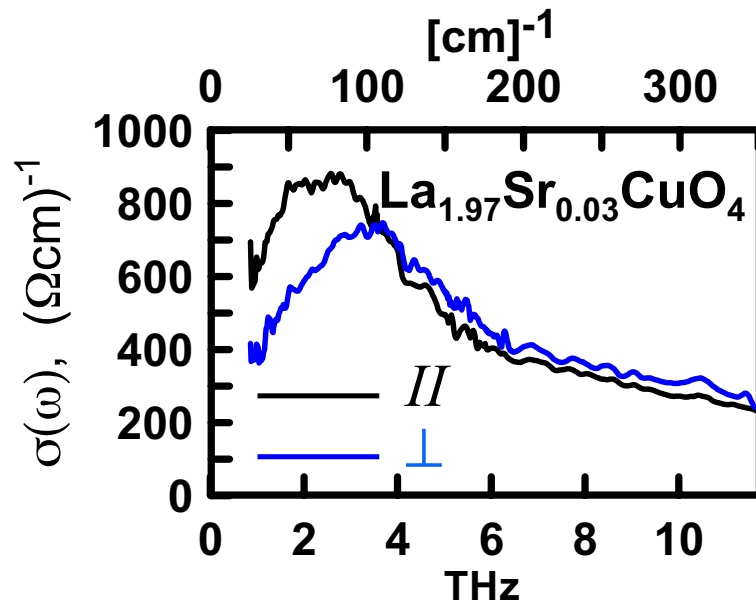
# Revisiting the pseudogap state and strong coupling effects



# Charge dynamics in weakly doped $\text{CuO}_2$ planes



# Spin and charge order in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$

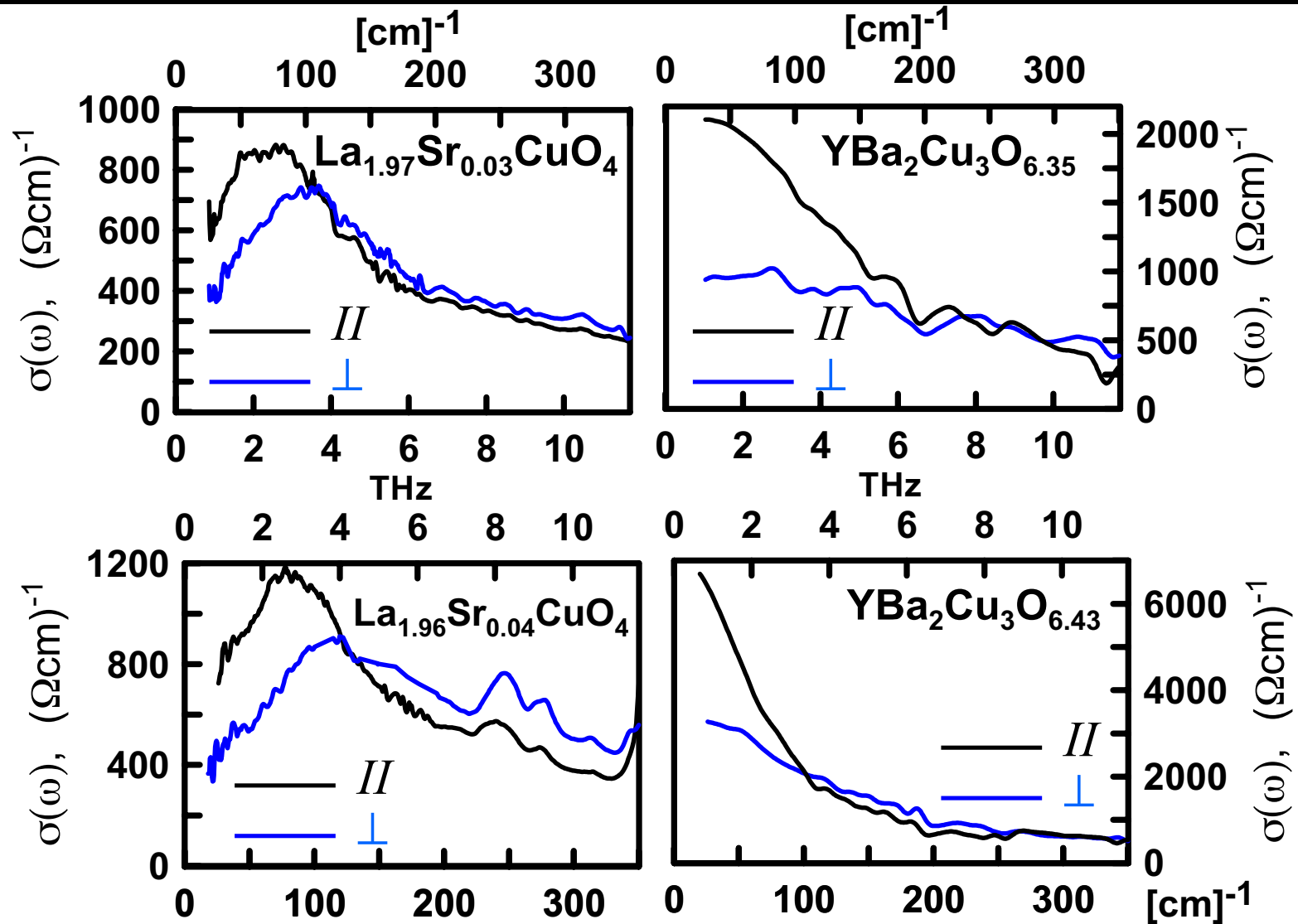




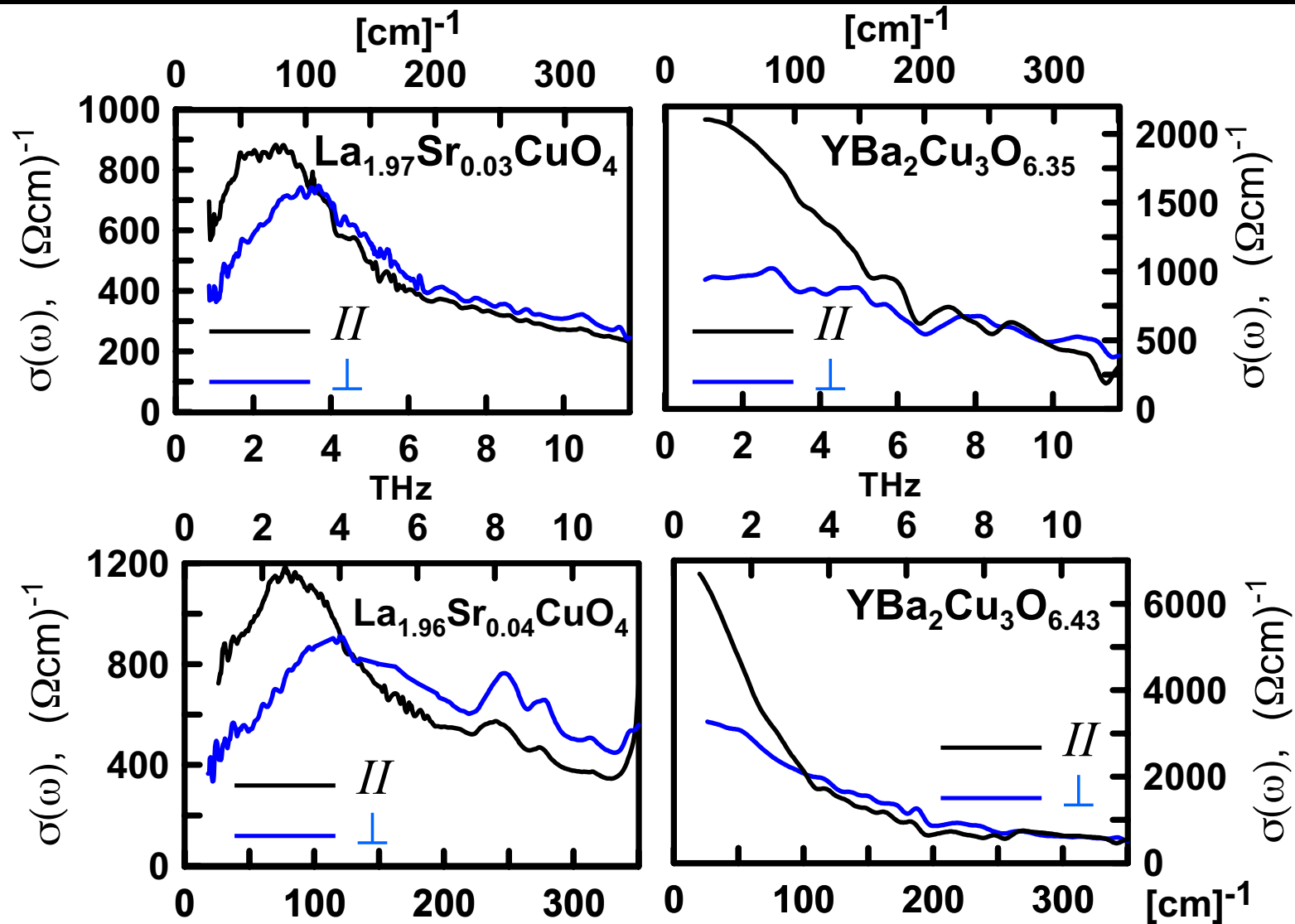




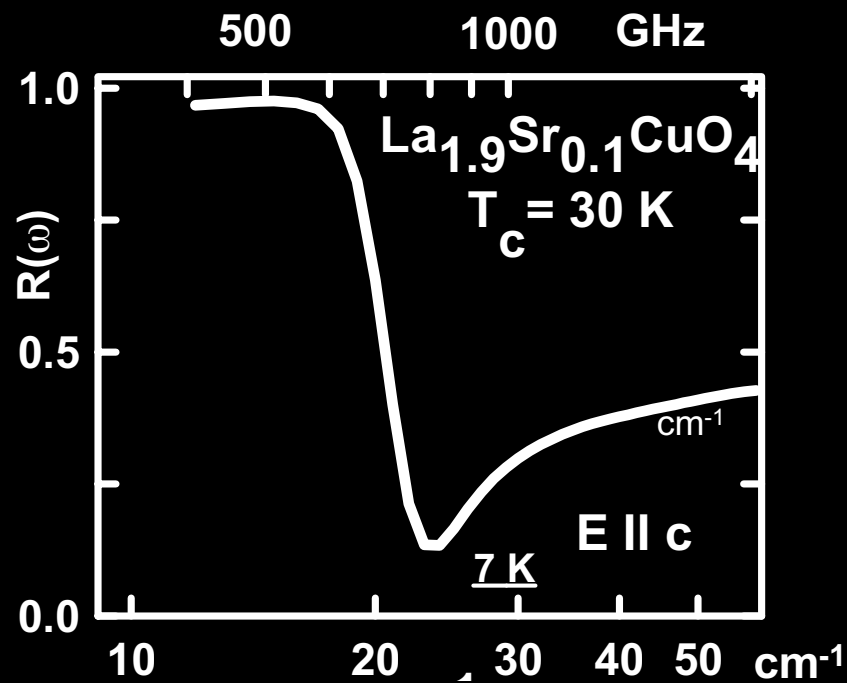
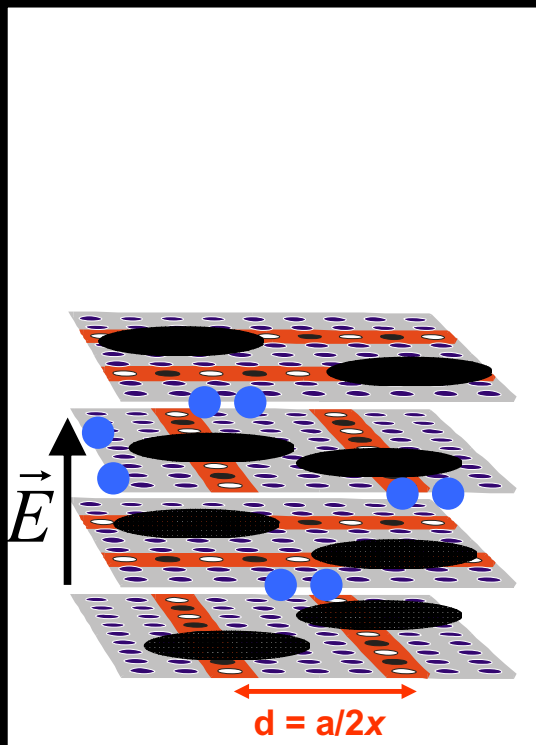
# Charge ordering and anisotropy: $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ and $\text{YBa}_2\text{Cu}_3\text{O}_y$



# Charge ordering and anisotropy: $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ and $\text{YBa}_2\text{Cu}_3\text{O}_y$



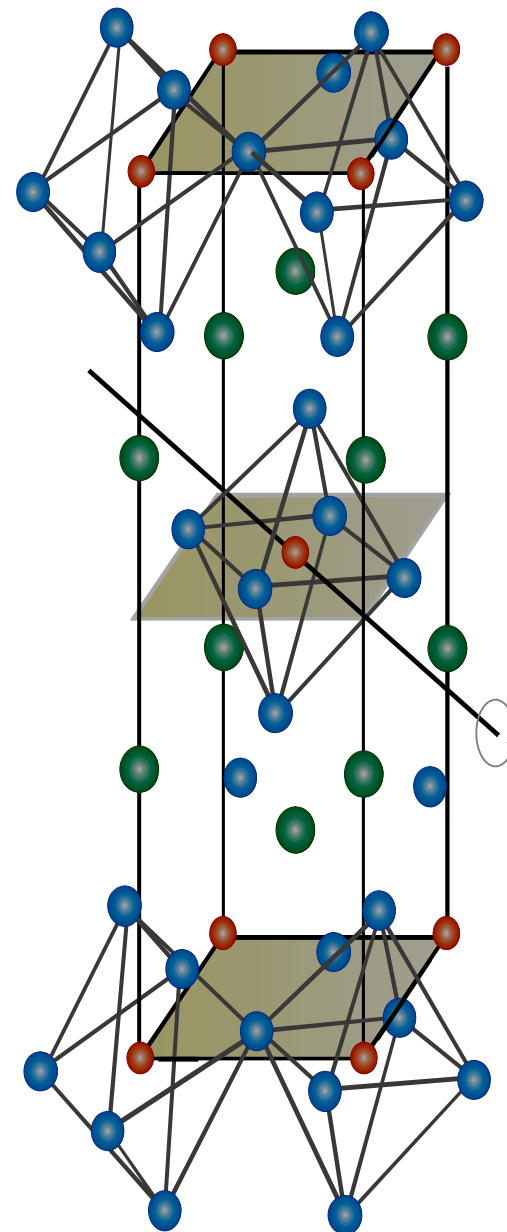
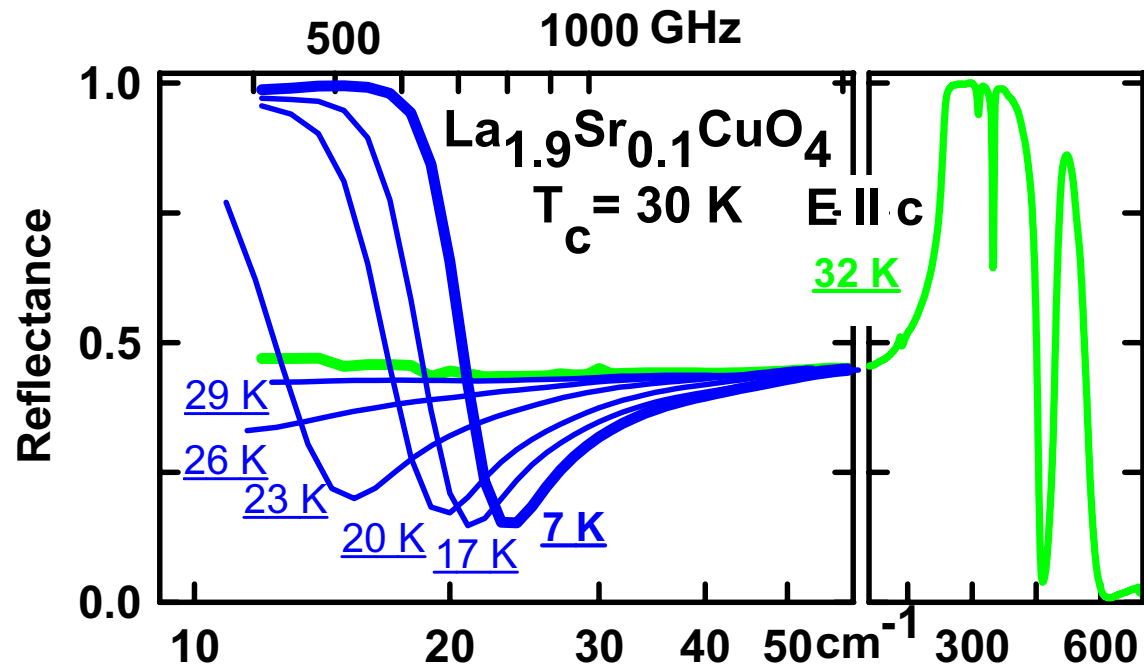
# Josephson plasmon "microscopy"

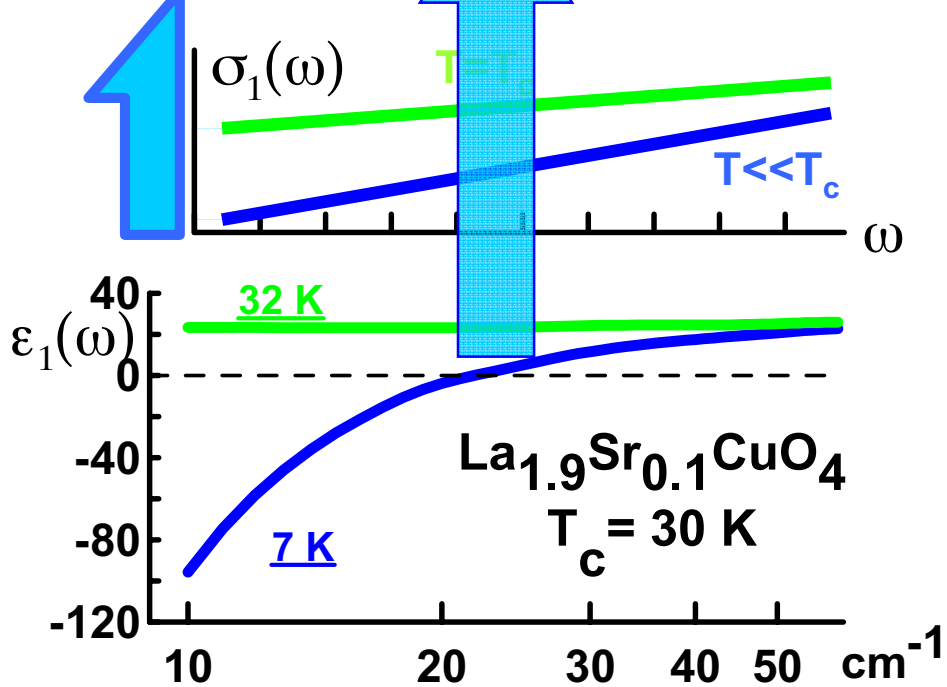
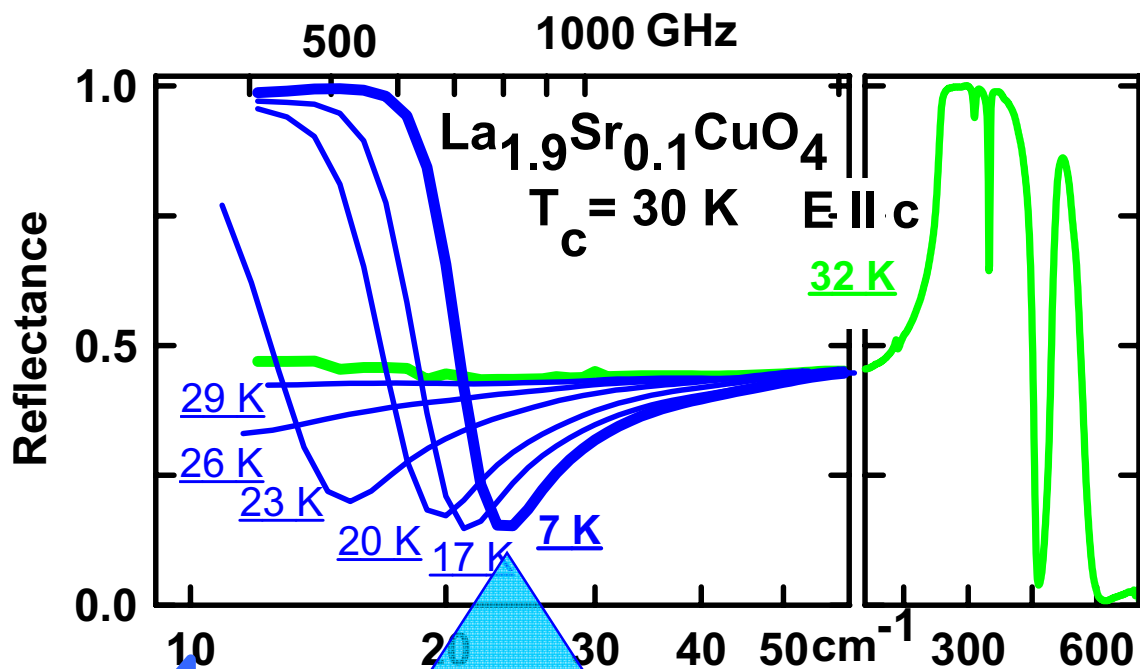


*S. Dordevic et al. PRL 91, 167401 (2003)*

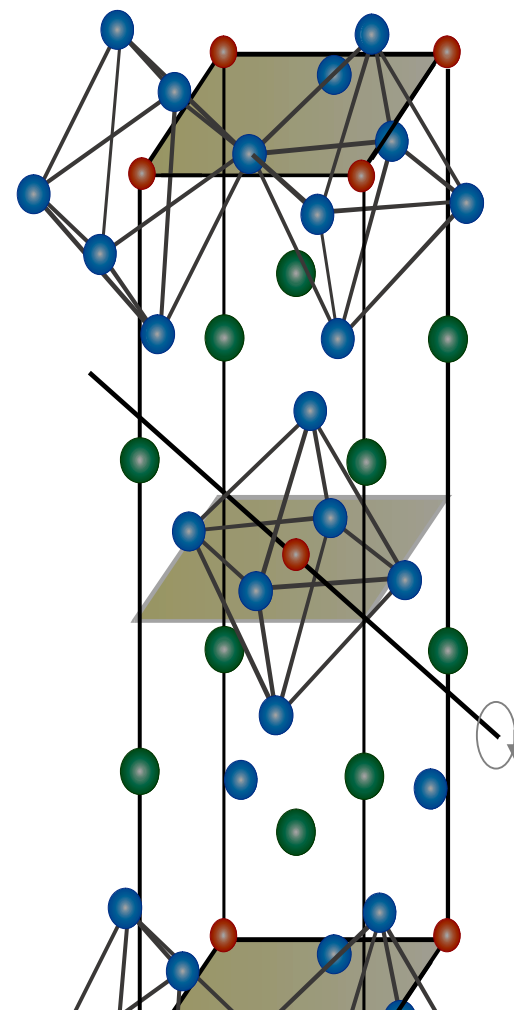


# Josephson plasmon



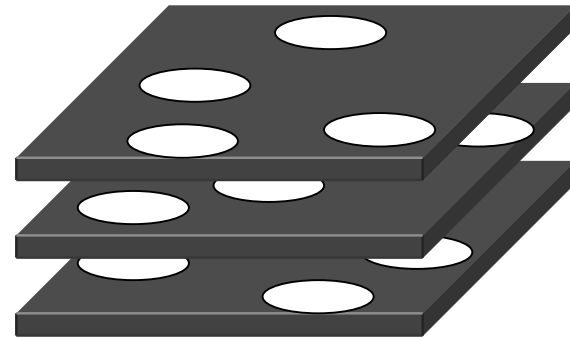
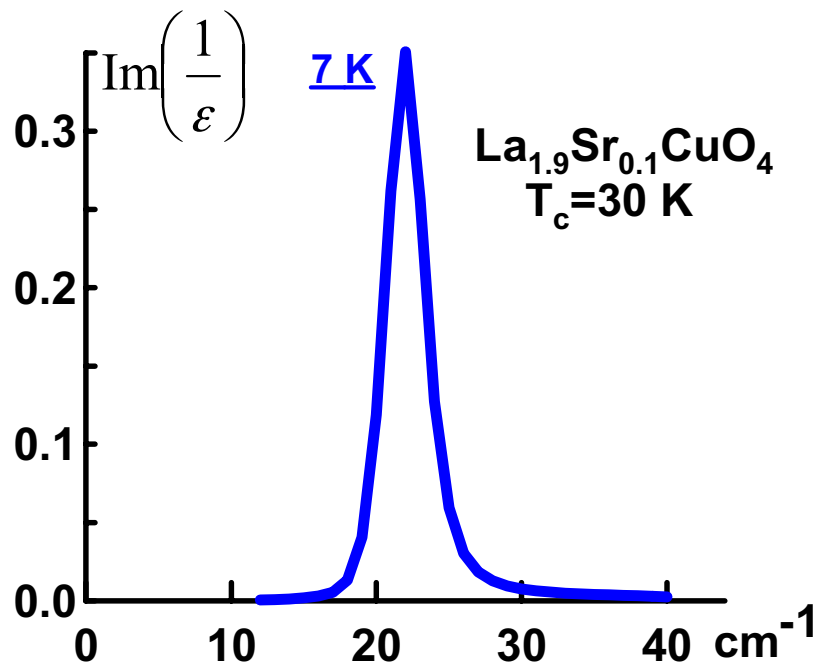
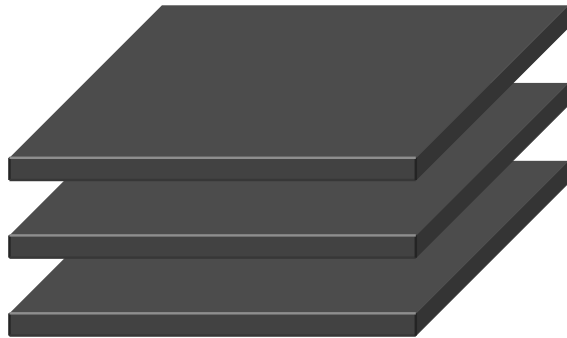


## Josephson plasmon

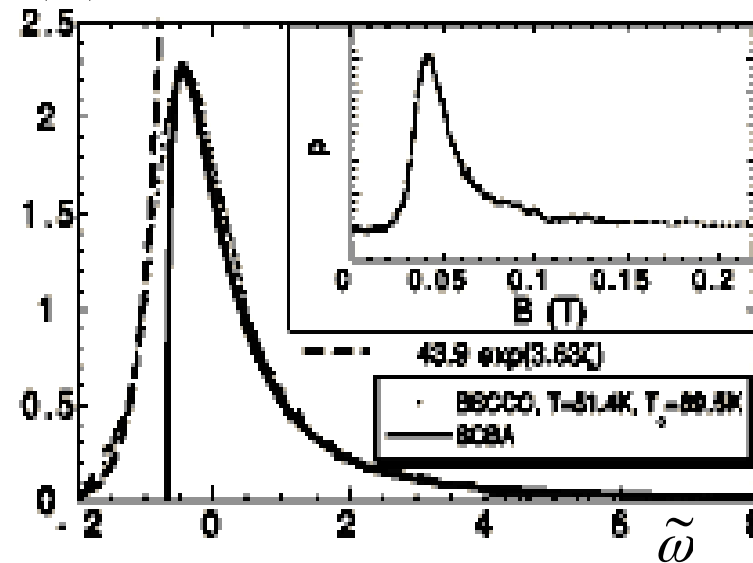


$$\epsilon_1(\omega) = \epsilon_{\text{phonon}} - \frac{\omega_s^2}{\omega^2}$$

# Josephson plasmon and loss function



$\rho(\omega)$   $\lambda_J = 120 - 500 \text{ \AA}$  in La214



*Bulaevskii, Ong (96)*

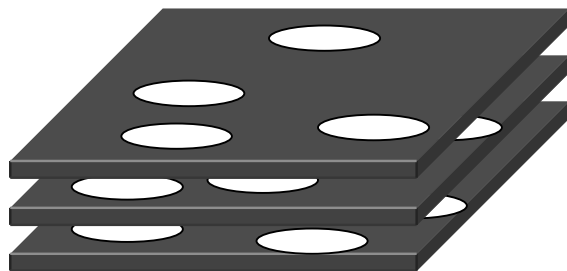
*Koshelev, Bulaevskii (99)*

*van der Marel (1996)*

# Inhomogeneous superconductivity in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$



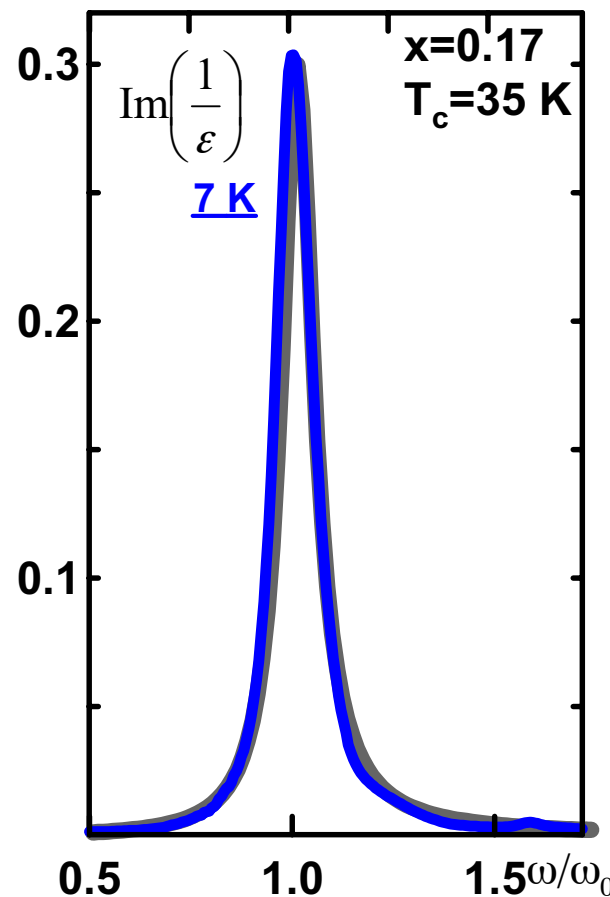
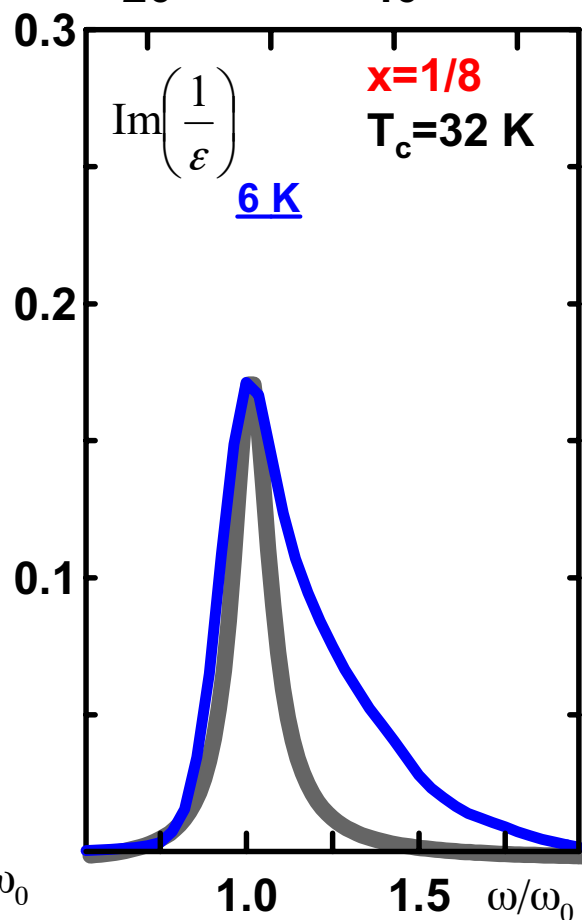
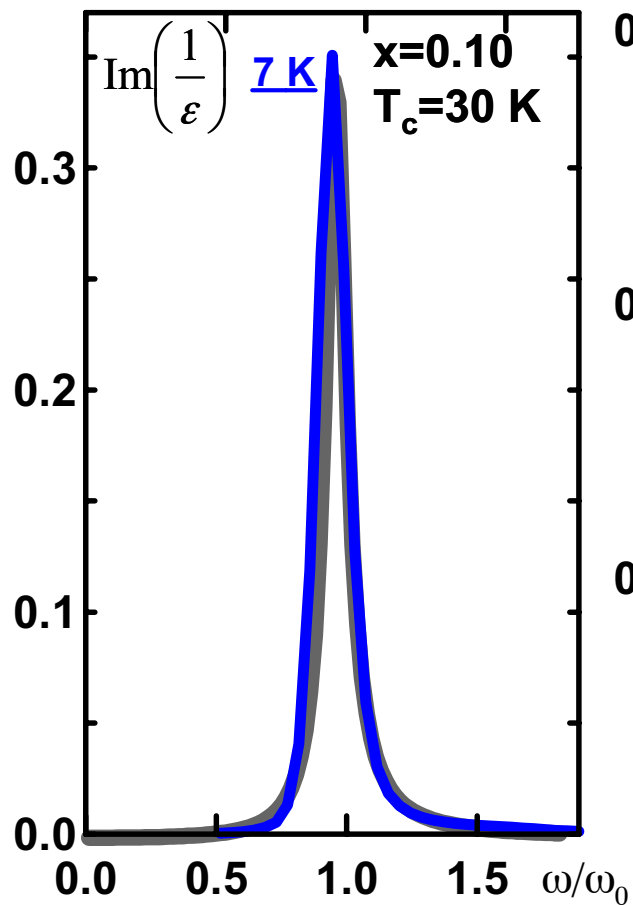
0 25  $\text{cm}^{-1}$



20 40  $\text{cm}^{-1}$

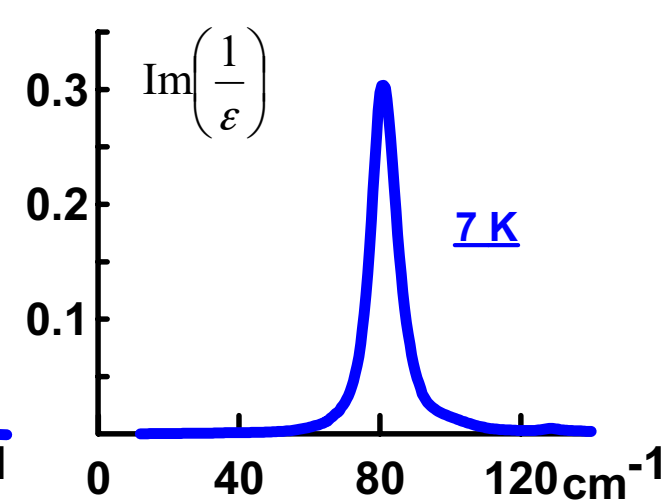
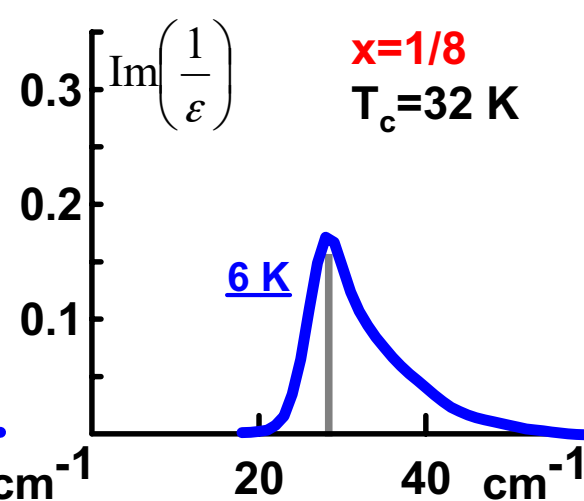
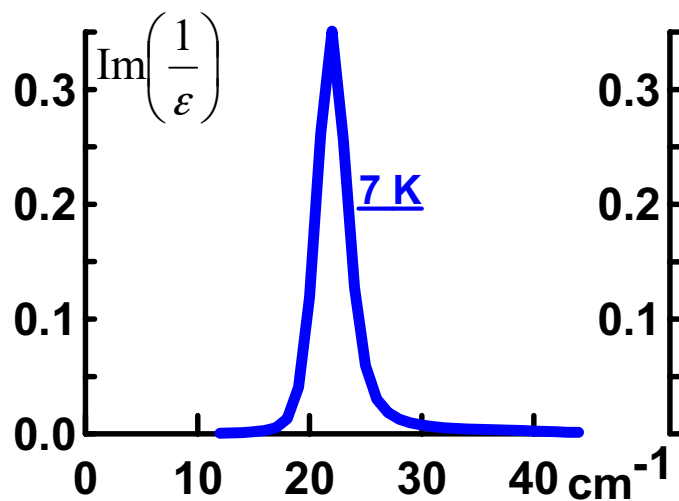
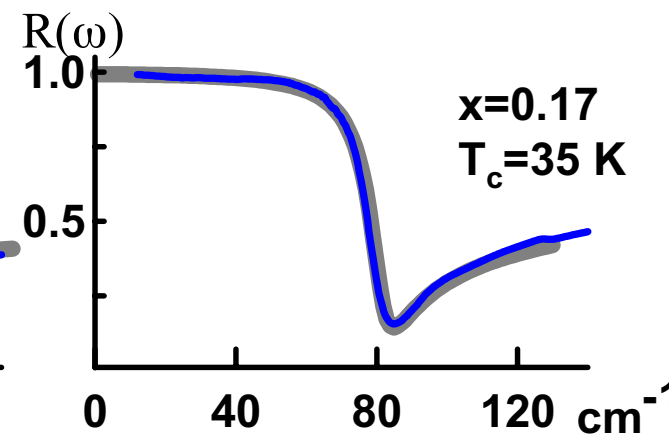
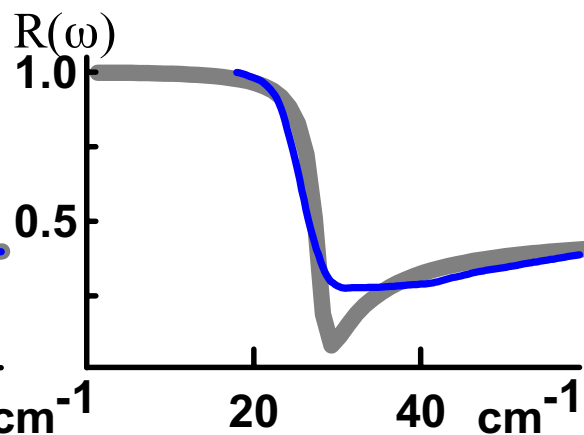
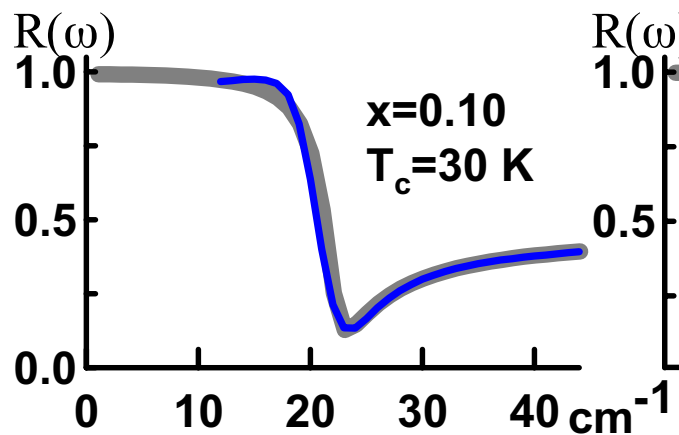
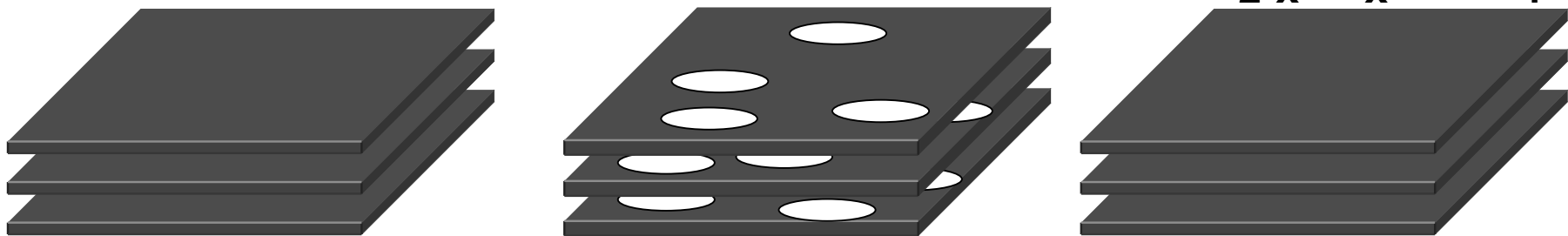


40 60 80 100 120  $\text{cm}^{-1}$

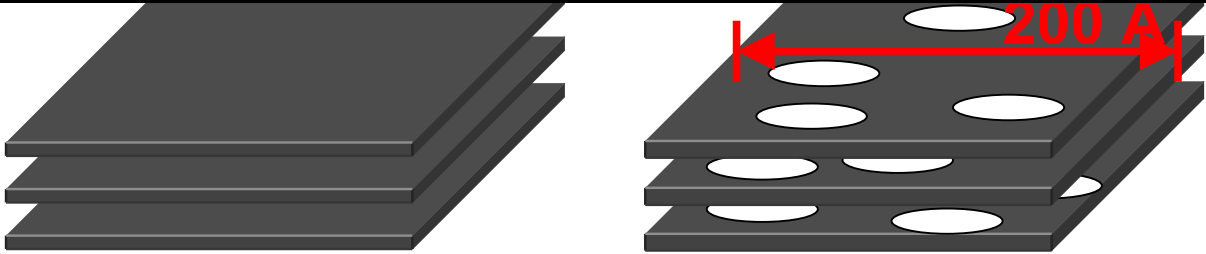




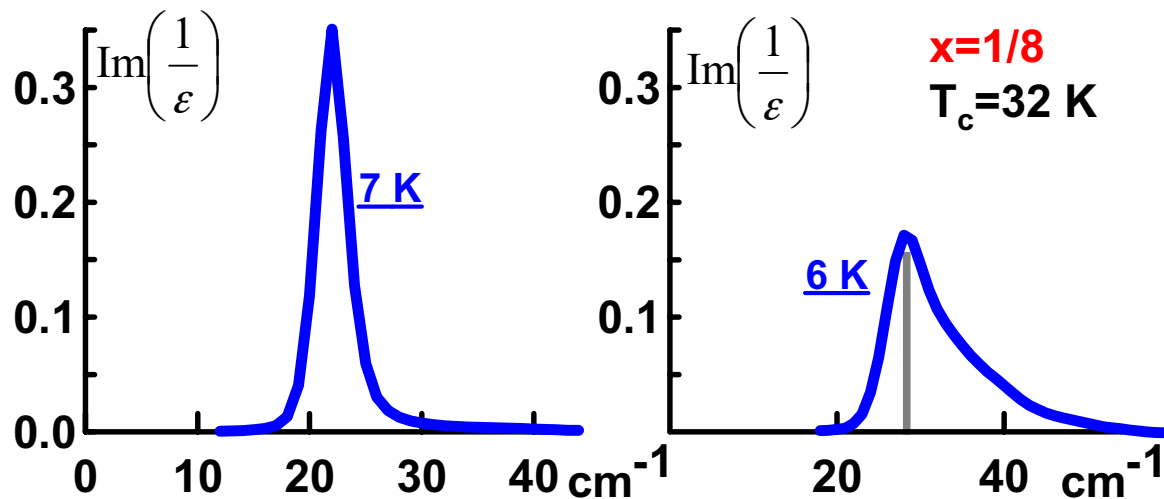
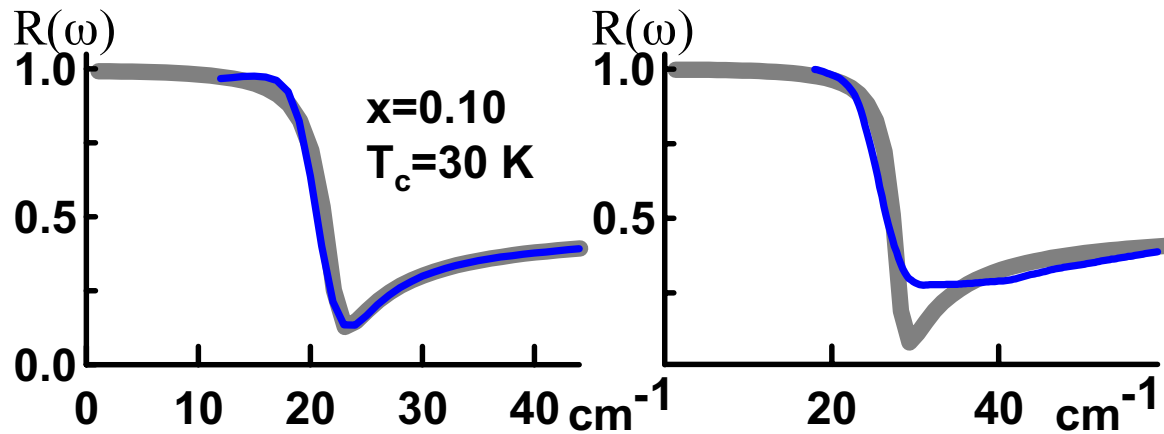
# Inhomogeneous superconductivity in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$



# Inhomogeneous superconductivity in $\text{La}_{1.875}\text{Sr}_{0.125}\text{CuO}_4$ :



~~“Bad sample”?~~



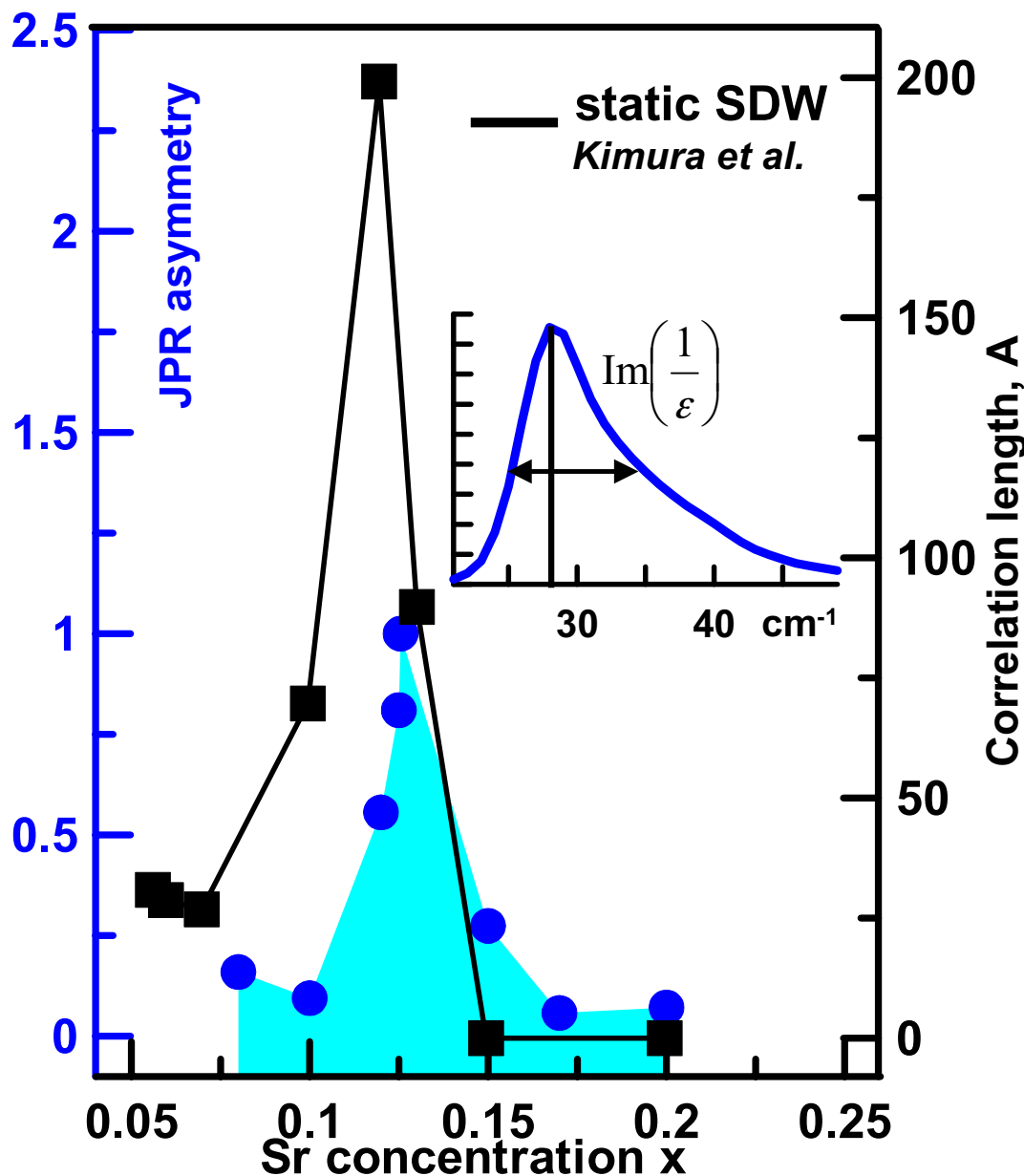
distribution of  $\rho_s$ ?

normal metal,  
superconductor?

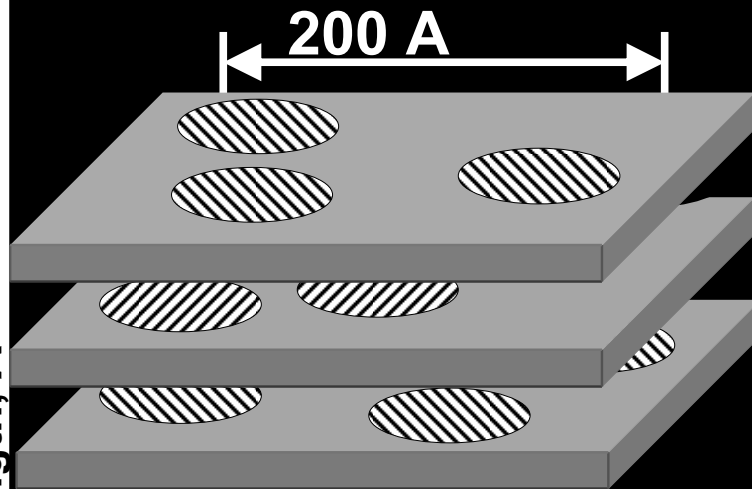
insulator,  
superconductor?

stripes?

# Spin and charge order in $\text{La}_{1.875}\text{Sr}_{0.125}\text{CuO}_4$



S. Dordevic et al. PRL 91, 167401 (2003)



distribution of  $\rho_s$ ?

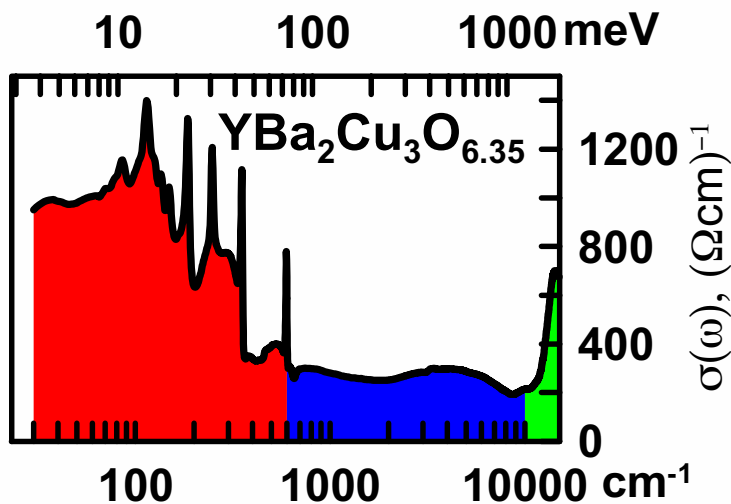
normal metal,  
superconductor?

insulator,  
superconductor?

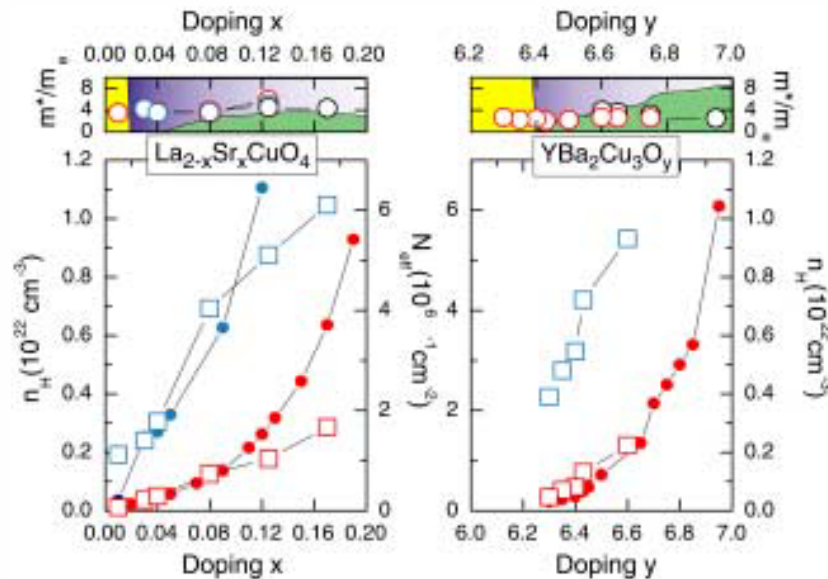
**stripes**



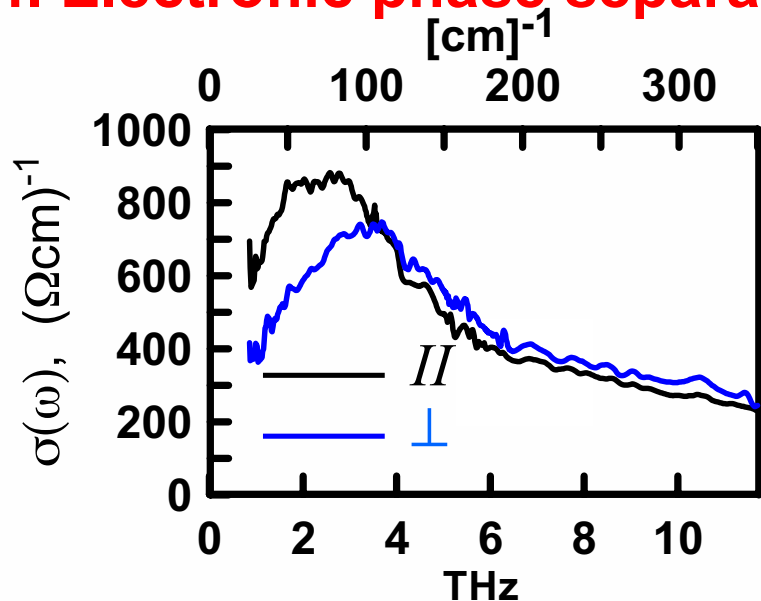
# 1. Metallicity of AF phases and two-component transport/optics



# 2. Constant effective mass



# 4. Electronic phase separation



# 3. P-gap and 2-component response

