IR Magneto-Transport in the Cuprates

Dennis Drew

University of Maryland
Physics Department
Center for Superconductivity
Research

supported in part by NSF

Outline

1. Introduction

Magneto-Transport

DC - IR

2. IR Magneto-transport

a. far –IR

b. mid -IR

3. Discussion

models

4. Underdoped YBCO

6. Conclusions

Collaborators

University of Maryland

- M.A. Grayson
- L. Rigal
- D.C. Schmadel
- J. Cerne
- G.S. Jenkins
- J.R. Simpson

McMaster University- YBCO/LSGO films

- R. Hughes
- J.S. Preston

Centro Atómico Bariloche

- B. Maiorov
- E. Osquiguil

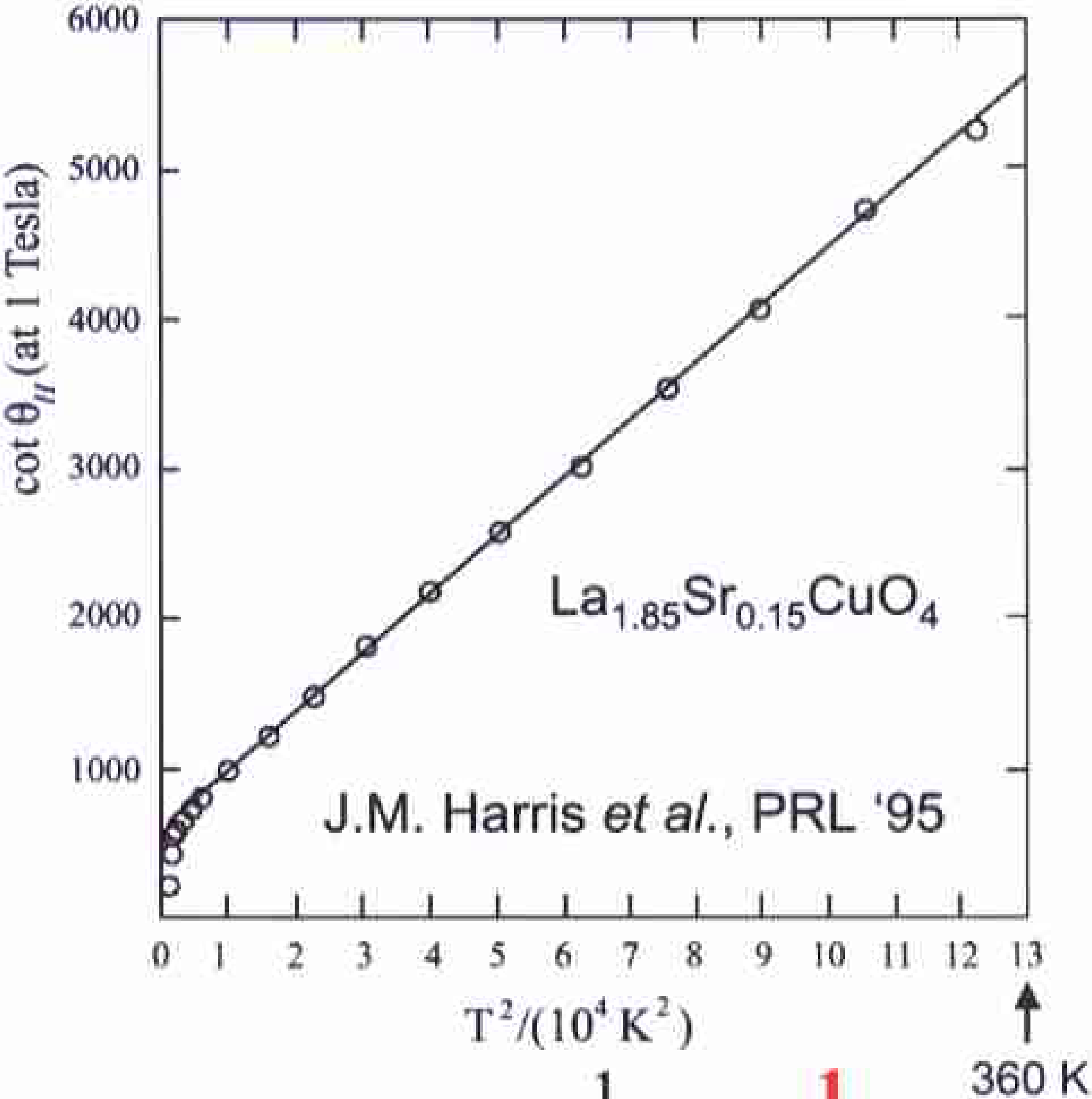
Theorists

- P. Coleman
- V. Yakovenko
- A. Millis

$1/\theta \propto c_i + BT^\alpha$

Anomalous DC Hall Effect

T.R. Chien *et al.*, PRL '91



$$\tan\theta_H = \frac{1}{\cot\theta_H} \propto \frac{1}{T^2}$$

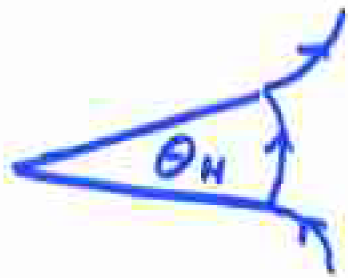
$\tan\theta_H = \omega_H \tau_H$

HALL EFFECT – WEAK FIELD

$$\rho_{xy} = R_H B \cong \frac{\sigma_{xy}}{\sigma_{xx}^2}$$

$$\tan \theta_H \simeq \theta_H \simeq \frac{\sigma_{xy}}{\sigma_{xx}} << 1$$

$\omega \neq 0$



DRUDE

$$\sigma_{xx} = \frac{ne^2/m}{1/\tau - i\omega} \qquad \theta_H = \frac{\omega_H}{1/\tau - i\omega}$$

SUM RULE:

$$\int_0^\infty \theta_H \, d\omega = \frac{\pi}{2}\omega_H$$

Anderson-Ong Model

holon spinon

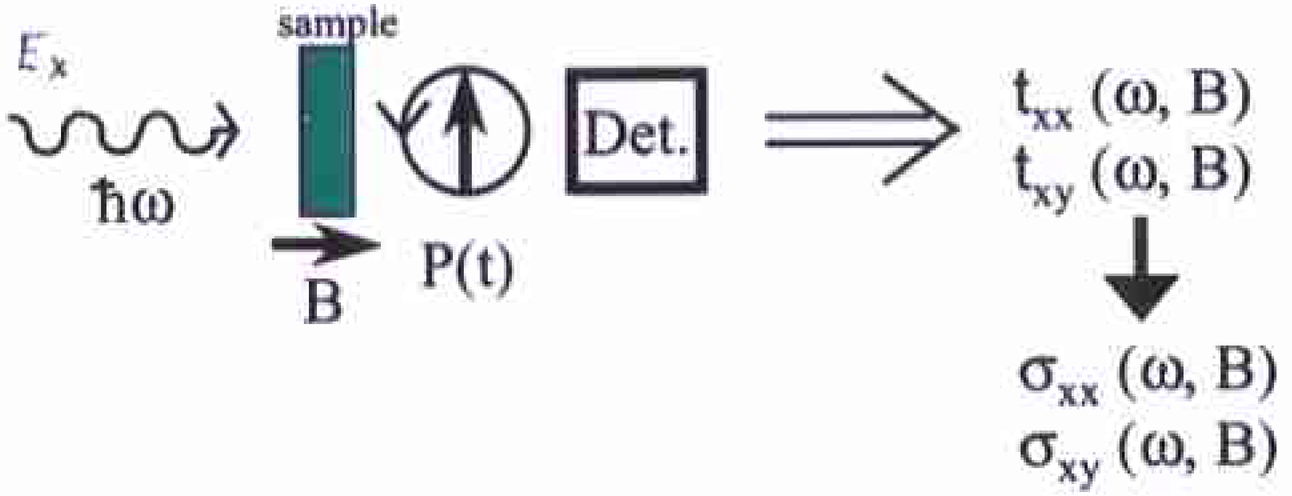
$$1/\tau_{tr} \sim T \qquad 1/\tau_H \sim T^2$$

$$\tilde{\tau} = \frac{1}{1/\tau - i\omega}$$

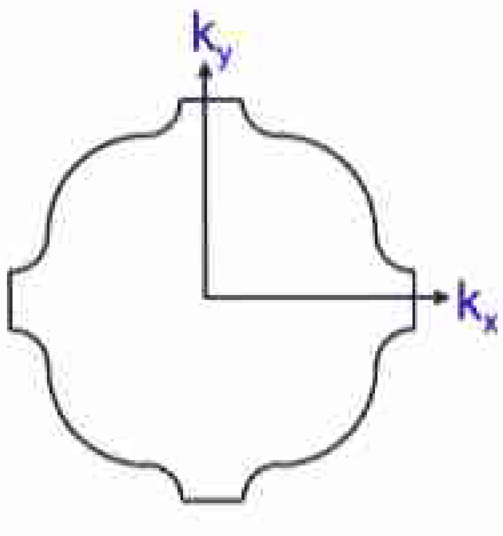
$$\sigma_{xx} = \frac{ne^2}{m}\tilde{\tau}_{tr}$$

$$\sigma_{xy} = \frac{ne^2}{m}\tilde{\tau}_{tr}\omega_H\tilde{\tau}_H \quad \rightarrow \quad \theta_H = \frac{\sigma_{xy}}{\sigma_{xx}} = \omega_H\tilde{\tau}_H$$

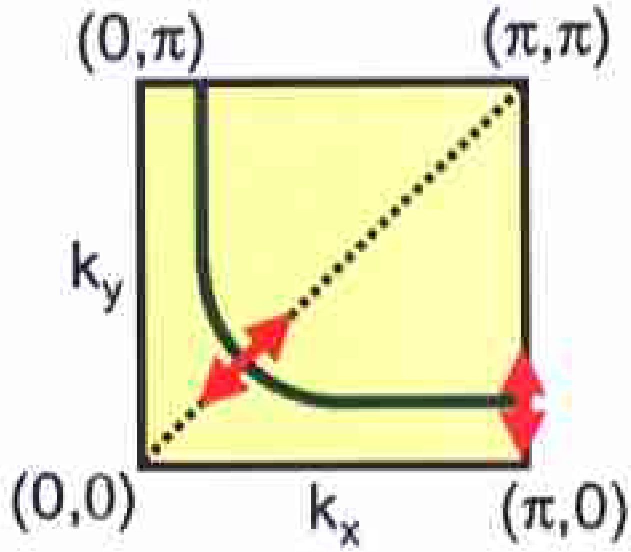
AC Hall Effect: IR Measurements



Fermi surface anisotropy in noble metals

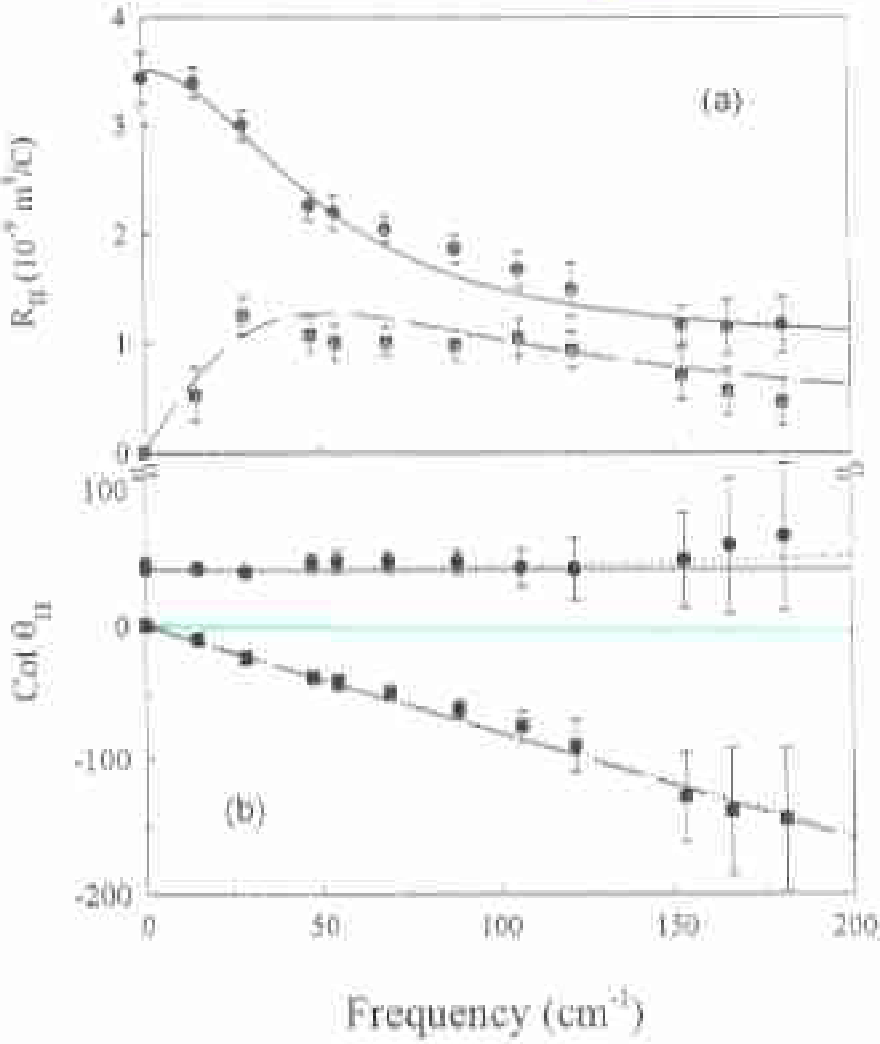


High temperature superconductors?



Kaplan PRL '96

T = 100 K



$$\cot \theta_H = -i \frac{\omega}{\omega_H} + \frac{1}{\omega_H \tau_H}$$

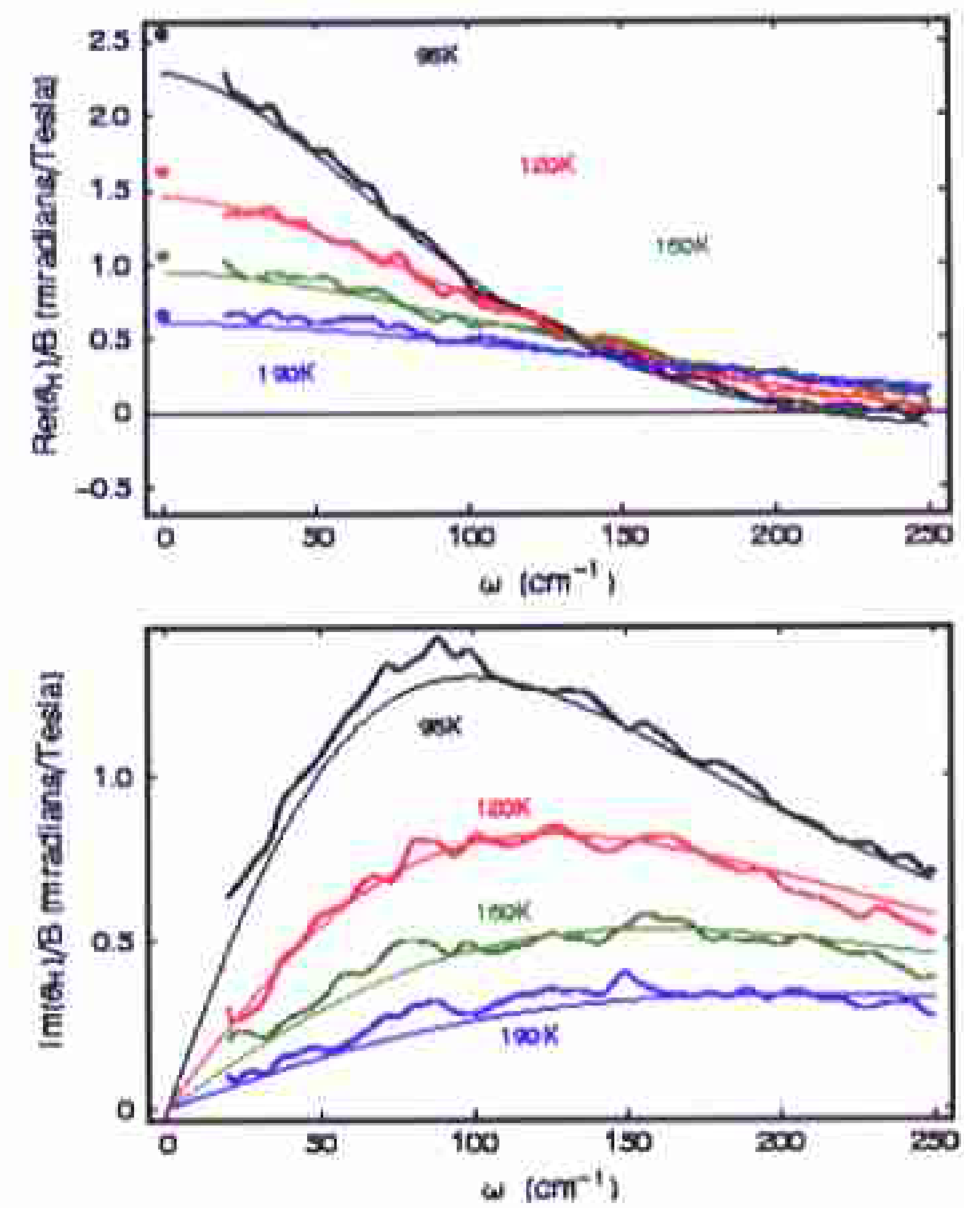
$$1/\tau_H \sim \frac{1}{2} \frac{1}{\tau_t}$$

$$1/\tau_H = \frac{T^2}{W}$$

$$W \sim 100\,K$$

$$\tan\theta_H$$

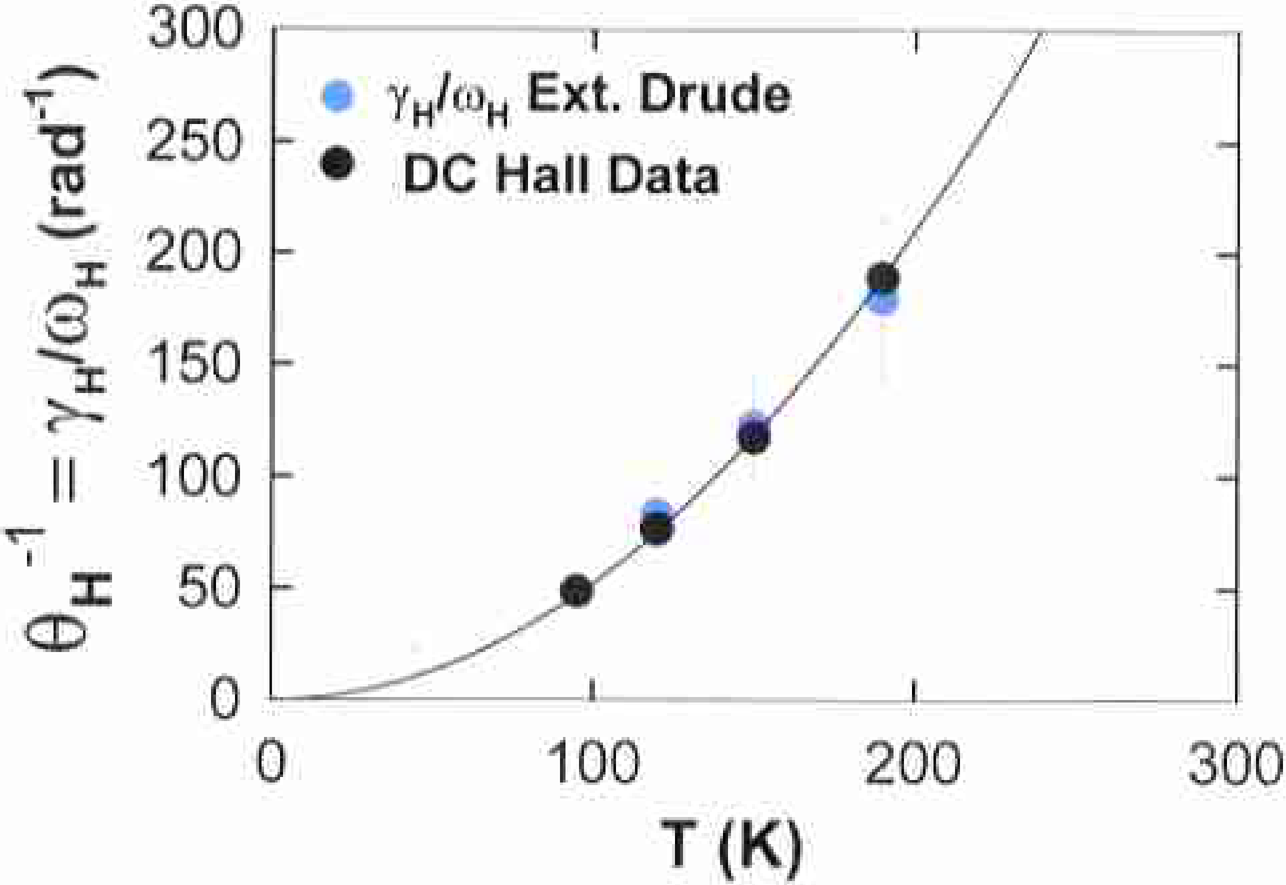
$$Drude : \tan\theta_H = \frac{\omega_H}{\gamma - i\omega}$$



[illegible] drag model [illegible]

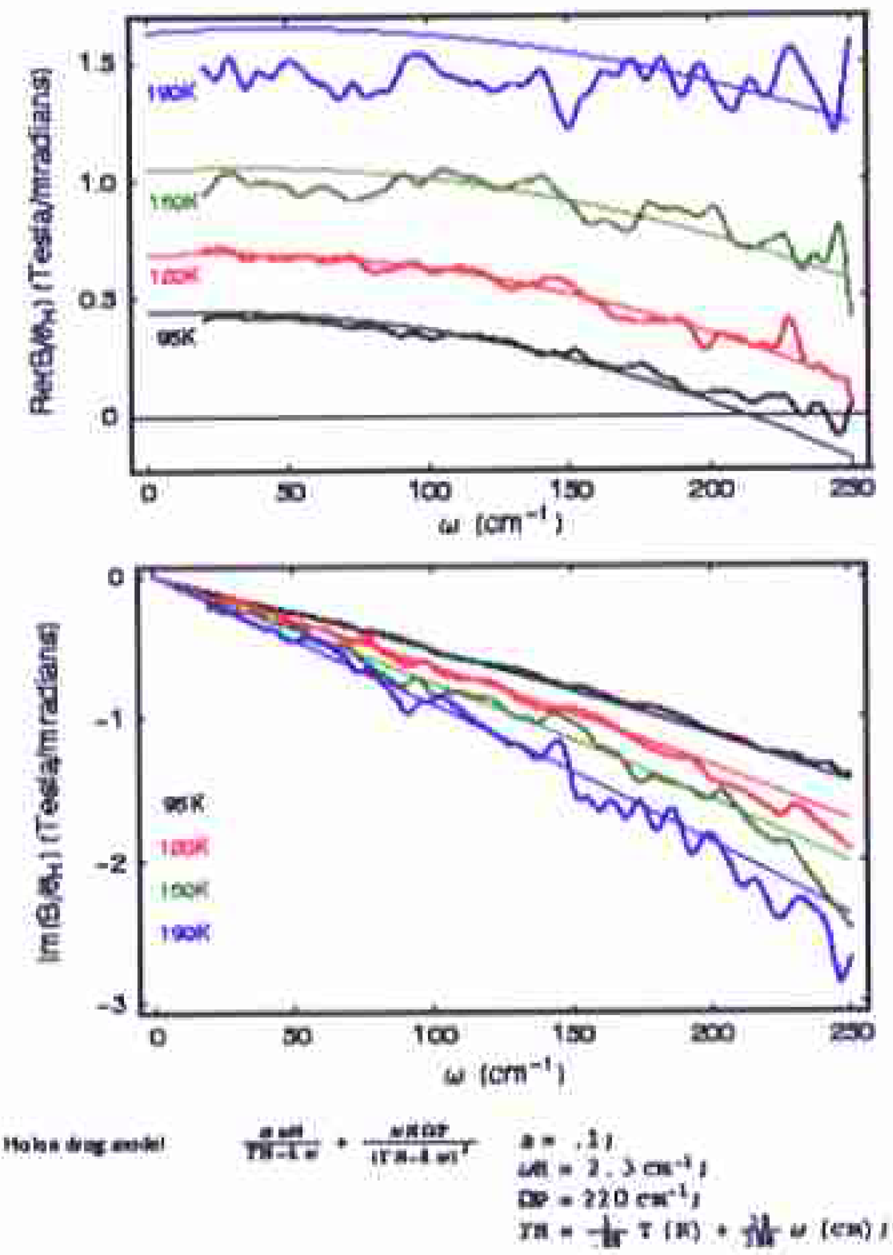
a = .1;
ω_H = 2.3 cm^{-1};
ω_p = 220 cm^{-1};
[illegible] T (K) + [illegible] ω (cm);

Comparison to DC



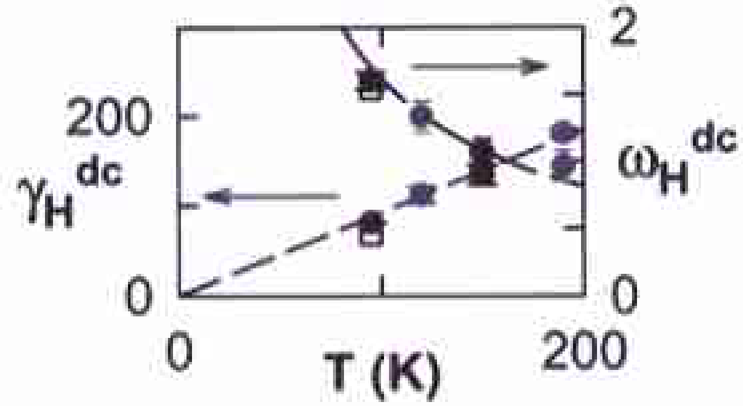
$$\cot\theta_H$$

$$Drude: \cot\theta_H = \frac{\gamma - i\omega}{\omega_H}$$

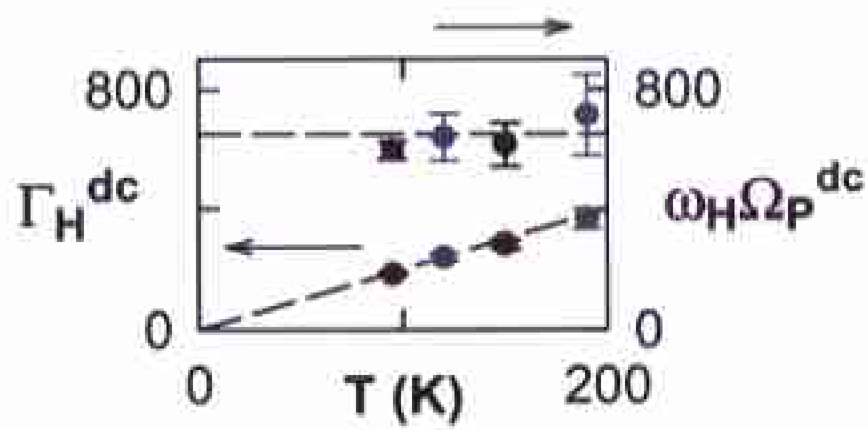


Hall scattering rates – Far IR

$$\theta_H = \frac{\omega_H}{\gamma - i\omega}$$



$$\theta_H = \frac{\omega_H \Omega}{(\Gamma - i\omega)^2}$$



Spinon-Holon fluid model

D. K. K. Lee and P. A. Lee, J. Phys.: Condens. Matter 9 10421 (1997).
D. K. K. Lee and P. A. Lee, Physica B **259-261**, 481 (1999).

Only hole "sees" magnetic field.

Kinetic equation for hole:

$$m\dot{v} + mv\gamma = eE + \frac{e}{c}\eta(T)\,\nu\times B,$$

$$\gamma = 1/\tau, \quad \eta = \frac{T_h}{T_b + T_h}$$

$$\tan\theta_H = \frac{\omega_H \eta(T)}{\gamma - i\omega}, \qquad \omega_H = \frac{eB}{mc}$$

$$DC: \qquad \tan\theta_H = \omega_H \tau \eta(T) \propto T^{-2},$$

$$if\, \eta(T) \propto 1/T$$

Marginal Fermi Liquid Model

Varma & Abrahams, Phys. Rev. Letters, **86**, 4652 (2001).

Quasiparticle scattering rate:

$$\Gamma = \Gamma(\theta) + \lambda T$$

Boltzmann transport equation:

$$\tan\theta_H = \omega_H \tau_i + \omega_H \tau_i^2 \gamma_i$$

$\Gamma(\theta) \Rightarrow$ elastic scattering from dopant ions $\Rightarrow$ ~~$1/\tau_i$~~ γ_i

$\lambda T \Rightarrow$ inelastic scattering $\Rightarrow$ ~~γ_i~~ $1/\tau_e$

IR Hall angle:

$$\tan\theta_H = \frac{\omega_H}{1/\tau_i - i\omega} + \frac{\omega_H \gamma_i}{(1/\tau_i - i\omega)^2}$$

Carter, Schofield – POSTER

Holon – Drag model

Only hole "sees" magnetic field,
but there is a drag force between hole and holon.

Kinetic equation for hole:

$$m\dot{v} + mv\gamma = eE + \frac{e}{c}\eta(T)\, v \times B,$$

$$\gamma = 1/\tau, \quad \eta = \frac{T_h}{T_b + T_h}$$

Kinetic equation for holon:

$$\dot{v}_b + \gamma_b v_b = eE/m_b + \Gamma v,$$

$$\tan\theta_H = \omega_H \eta \left(\frac{\beta}{(\gamma_b - i\omega)(\gamma - i\omega)} + \frac{1}{\gamma - i\omega} \right),$$

$$\beta = \Gamma \frac{T_b}{T_h}$$

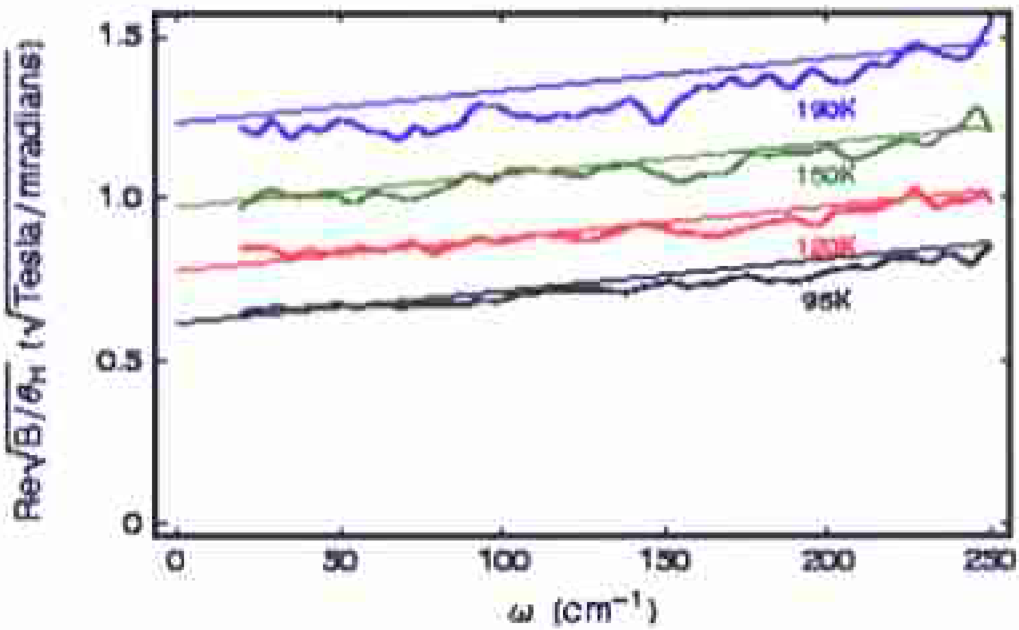
$$ARPES \Rightarrow T_h^{-1} \propto T$$

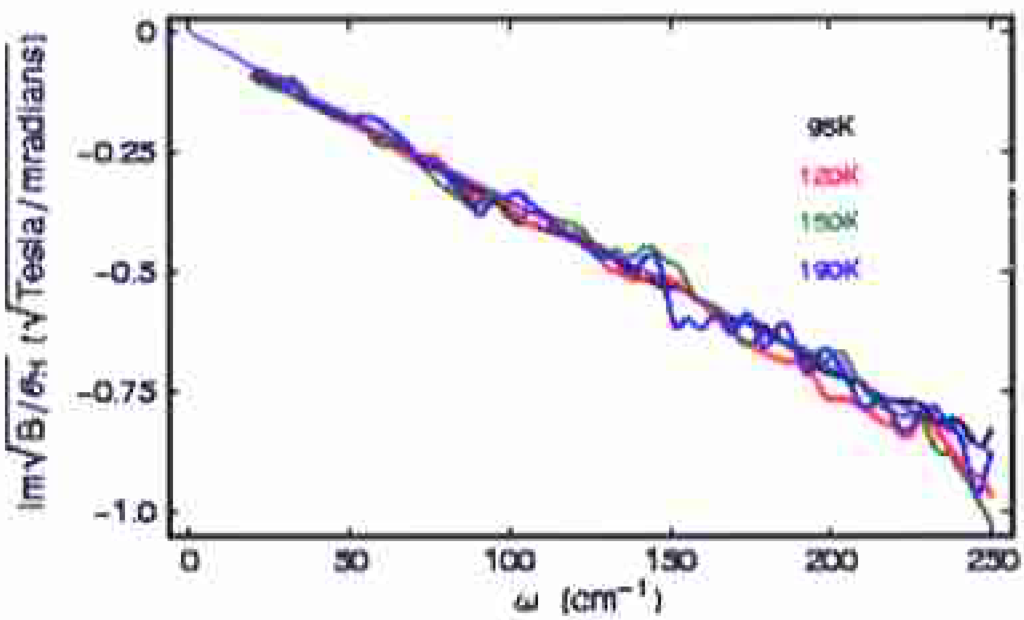
$$IR \quad \Rightarrow \quad \gamma \propto T$$

$$assume \quad T_b^{-1} \propto \gamma_b \propto T \Rightarrow \beta \text{ is } T \text{ independent}$$

Fit to:

$$\tan\theta_H = \frac{\omega_H \Omega}{(\Gamma - i\omega)^2}$$





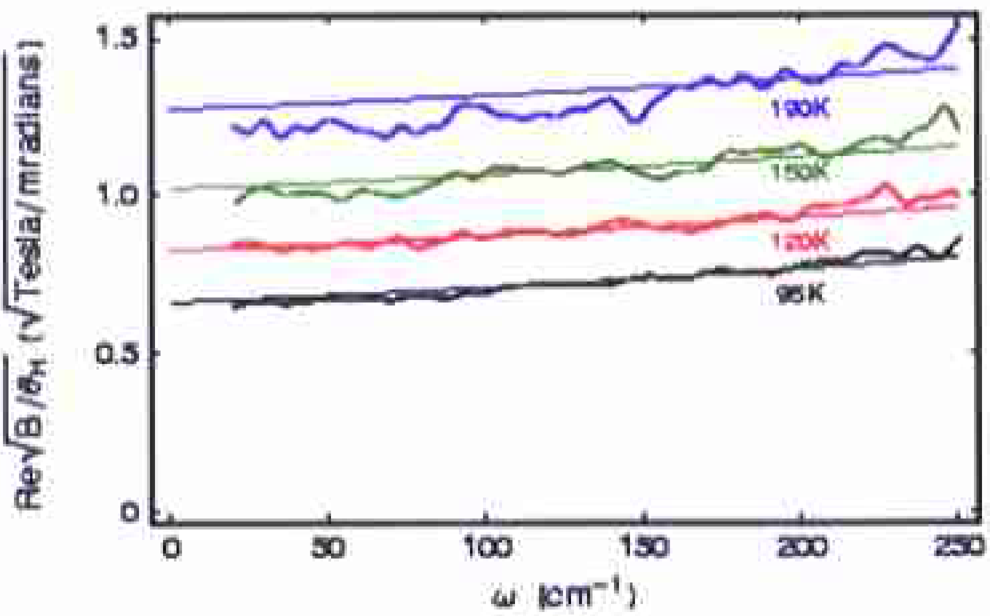
Dennis's hole drag model

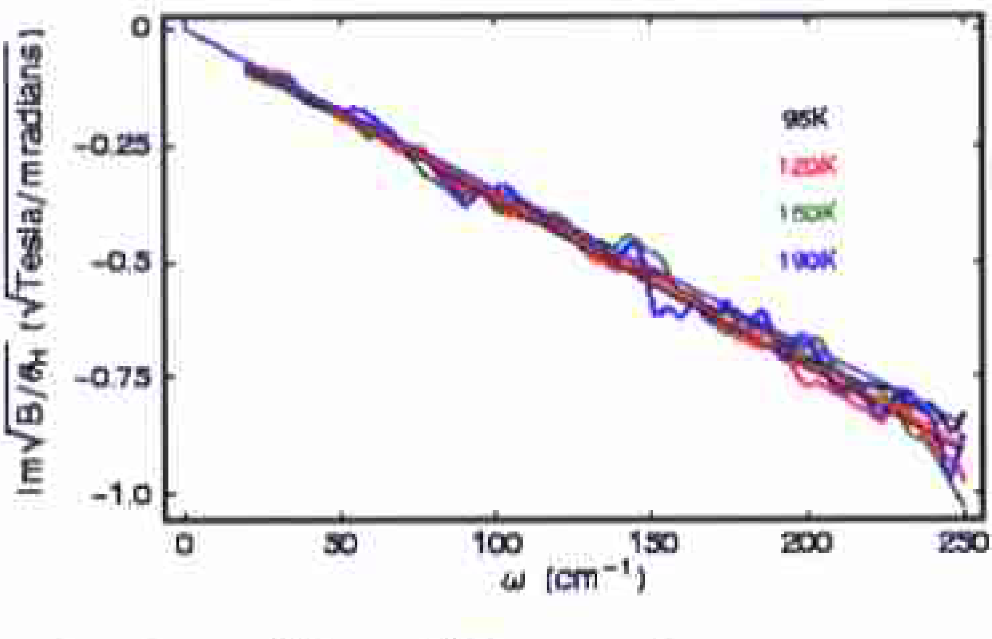
[illegible] SquaredLorentz tan[ω_, TH_] := [illegible]

ω[illegible] = (25.5)^2 cm^-2;

TH[T_, ω_] = [illegible];

$$\sqrt{\cot\theta_H} = \frac{\Gamma - i\omega}{\omega_H \Omega}$$





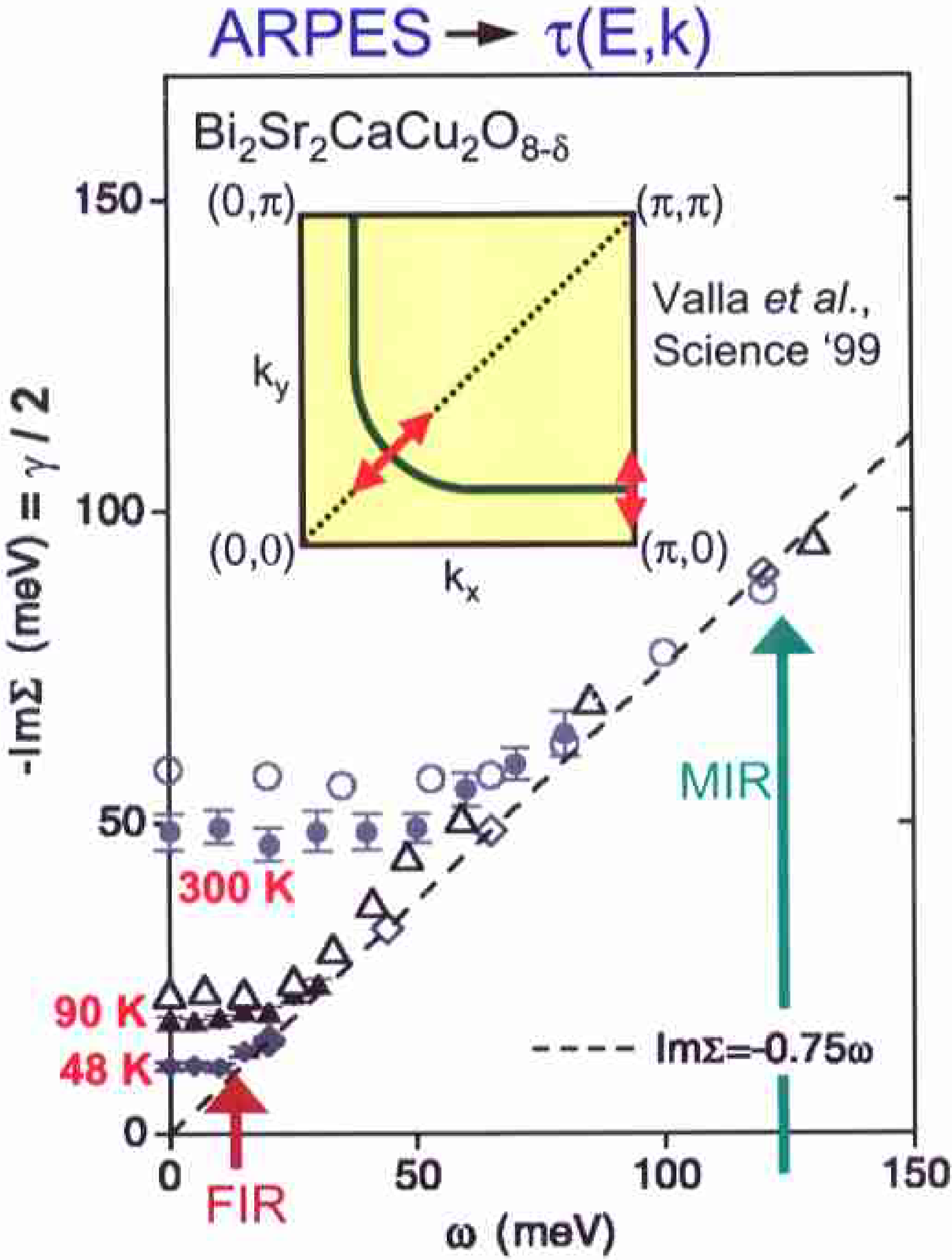
Holon drag model $\quad \frac{a\,\omega H}{\gamma H - i\omega} + \frac{\omega H\,\Omega P}{(\gamma H - i\omega)^2}$

$a = .1;$
$\omega H = 2.3\ cm^{-1};$
$\Omega P = 220\ cm^{-1};$
$\gamma H = \frac{1}{[illegible]} T\ (K) + \frac{[illegible]}{[illegible]} \omega\ (cm);$

HALL ANGLE SUM RULE

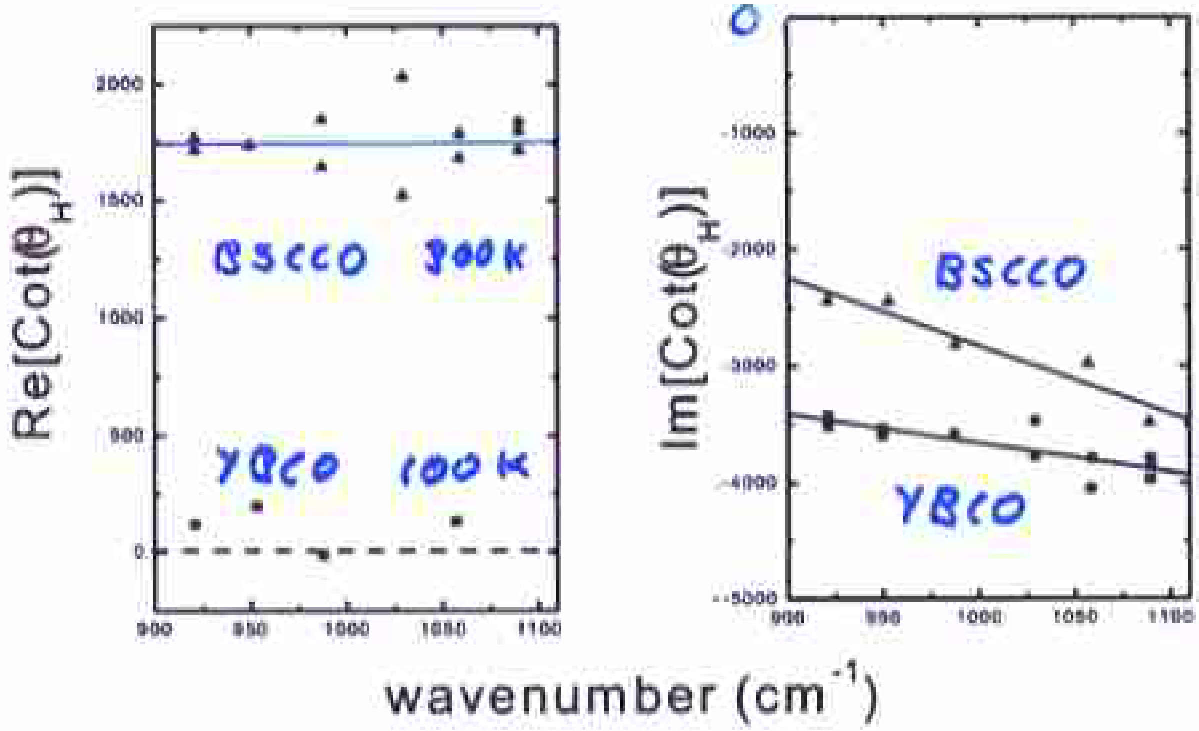
$$\int_0^\infty d\omega\, \theta_H = \frac{\pi}{2}\omega_H$$

$$\int_{-\infty}^{\infty} \frac{d\omega\, \omega_H \tau_t^{-1}}{(\gamma - i\omega)^2} = 0$$



ARPES → τ(E,k)
Bi2Sr2CaCu2O8-δ
(0,π)
(π,π)
(0,0)
(π,0)
ky
kx
Valla et al., Science '99
-ImΣ (meV) = γ / 2
150
100
50
0
300 K
90 K
48 K
MIR
FIR
- - - - ImΣ=-0.75ω
0
50
100
150
ω (meV)

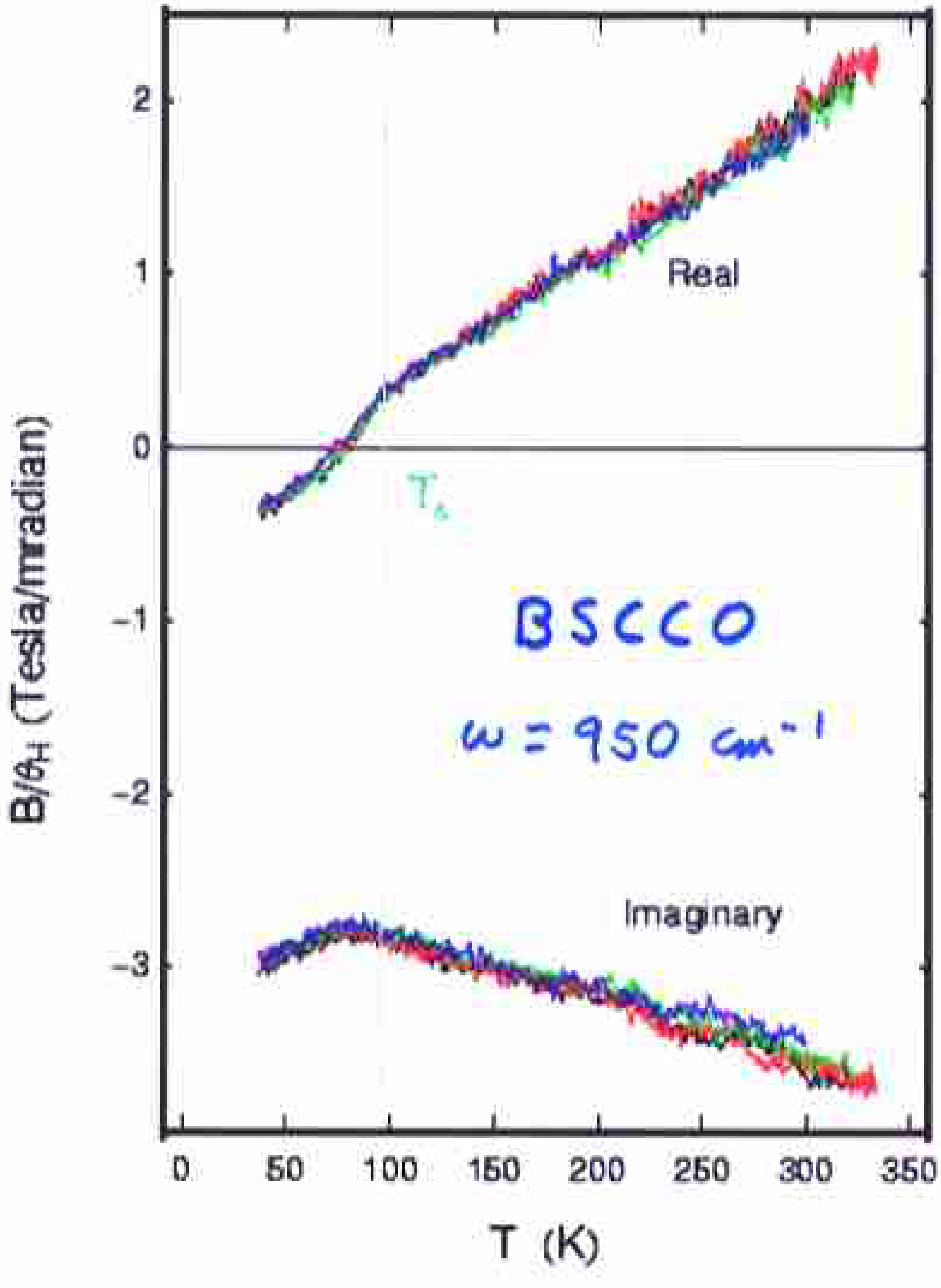
Mid-IR Hall angle



Drude:

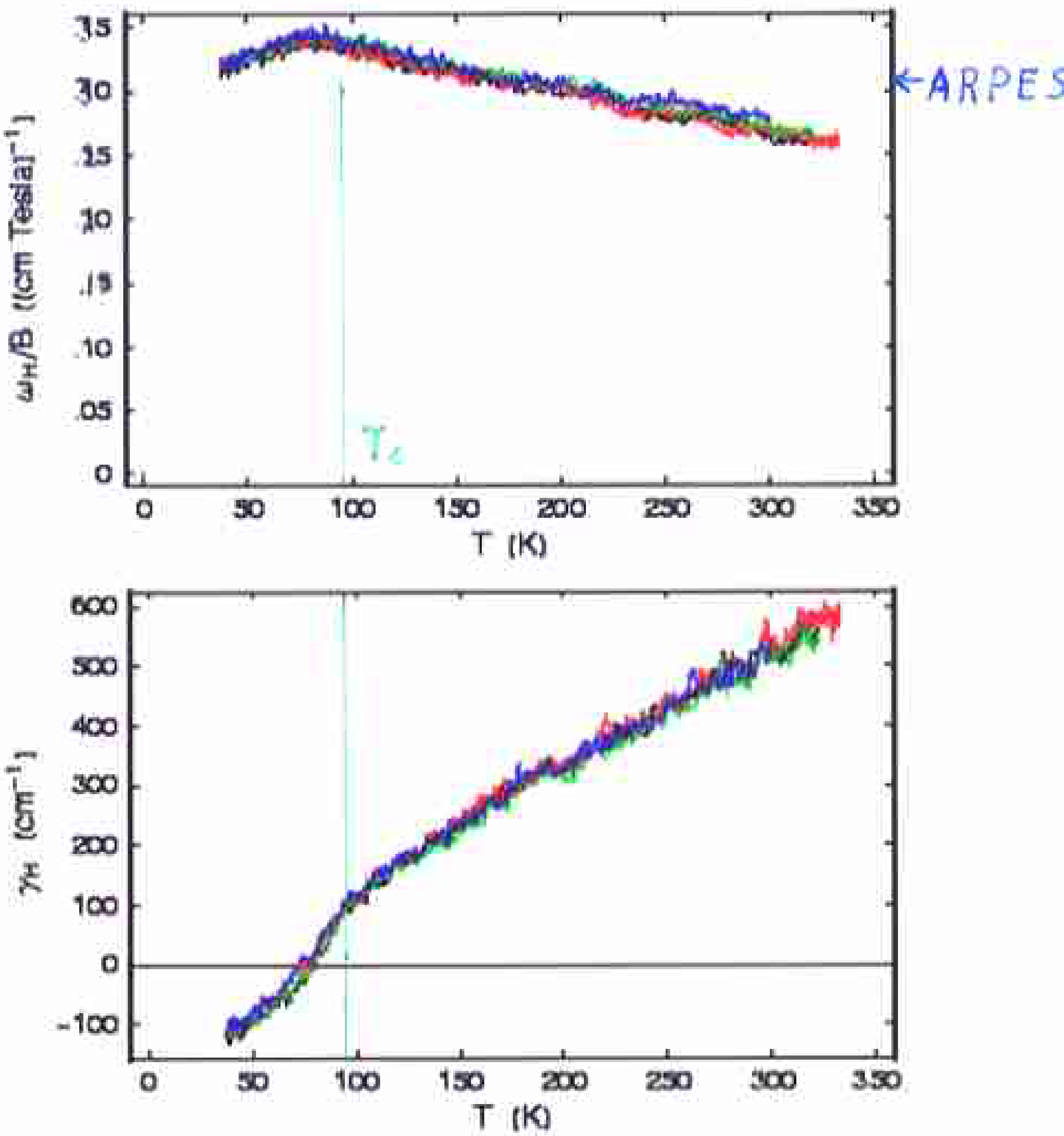
$$Cot(\theta_H) = \frac{\gamma - i\omega}{\omega_H}$$

Mid IR $$\cot\theta_H = \frac{\gamma - i\omega}{\omega_H}$$



$$\cot\theta_H = \frac{\gamma - i\omega}{\omega_H}$$

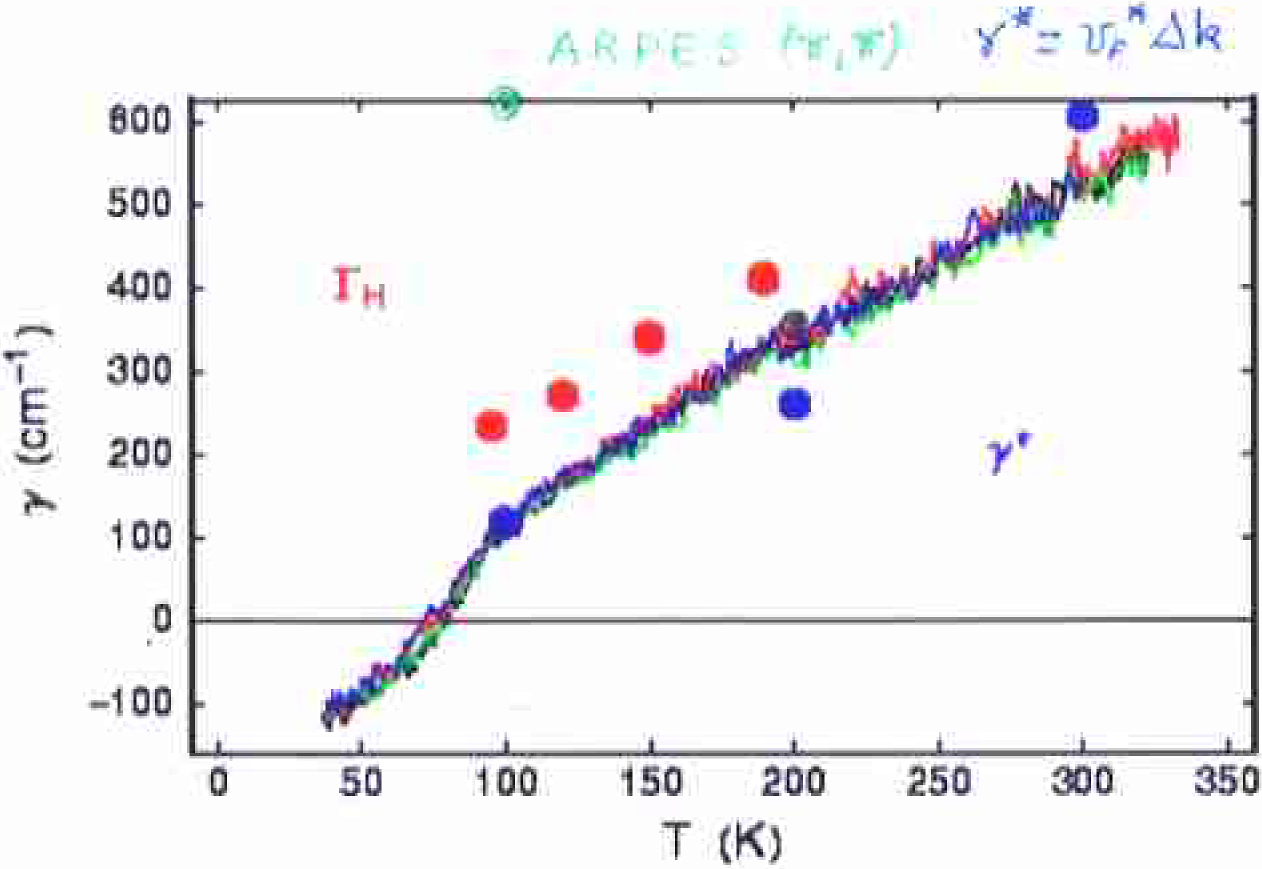
ω_H , γ



Scattering rates compared:

Mid IR Hall angle: BSCCO — 950 cm⁻¹

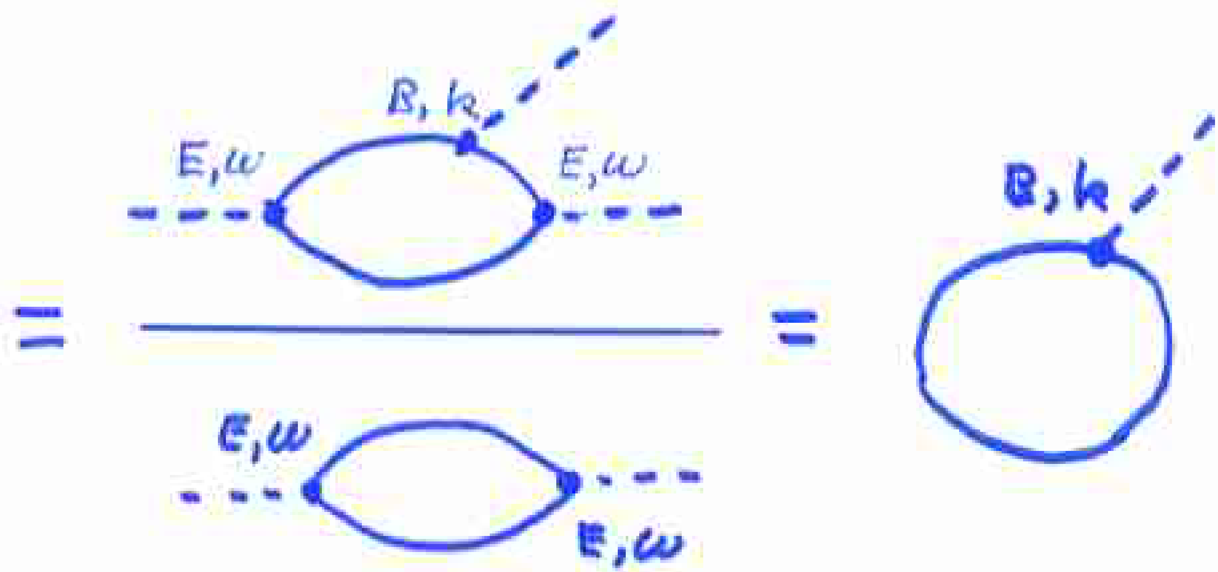
- Far IR σ_{xx}: BSCCO — 200 cm⁻¹
- Far IR Hall angle: YBCO — 200 cm⁻¹
- TH — 30 cm⁻¹



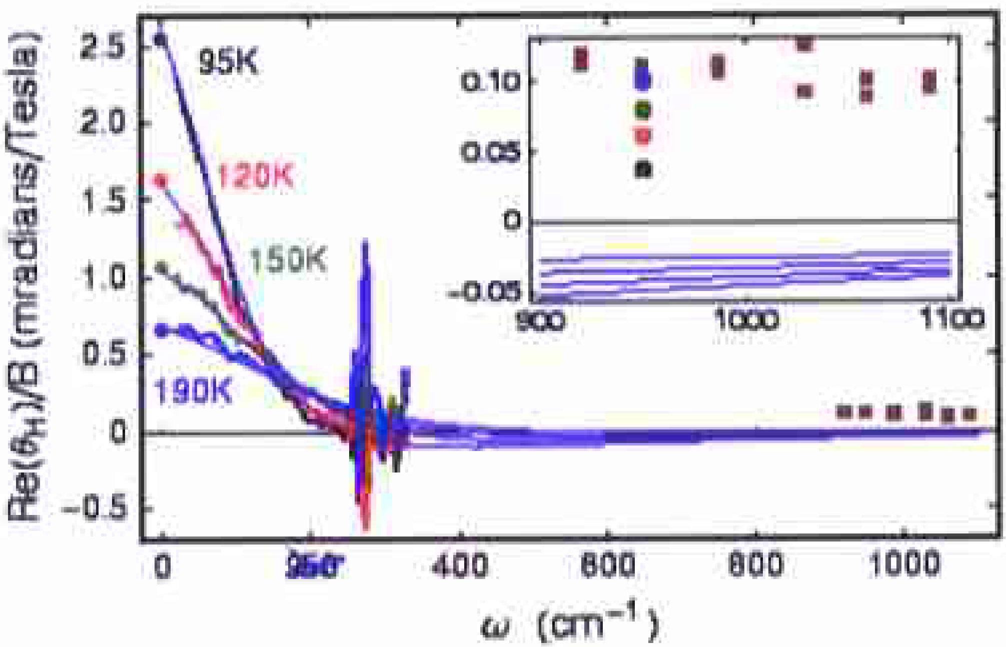
Tu & Homes

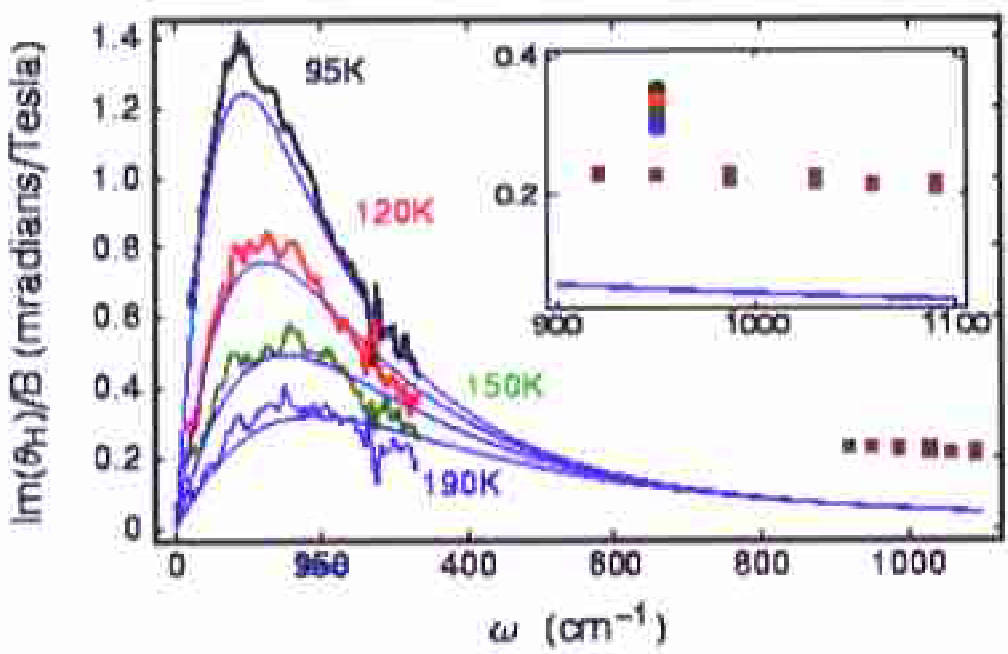
FREQUENCY INDEPENDENT γ ?

$$\tan \theta_H = \frac{\sigma_{xy}}{\sigma_{xx}}$$



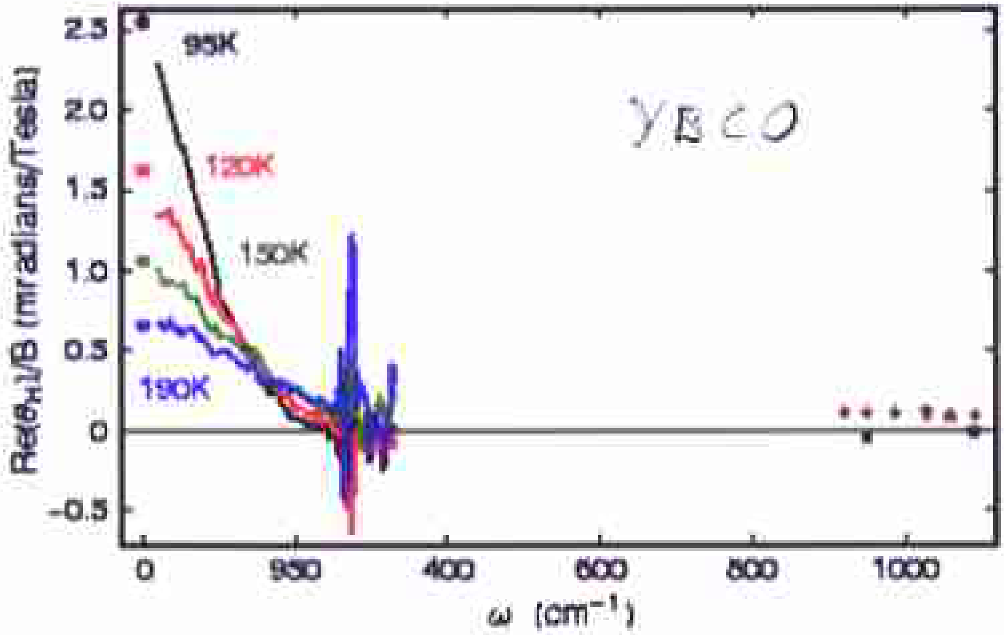
Far IR & Mid IR compared

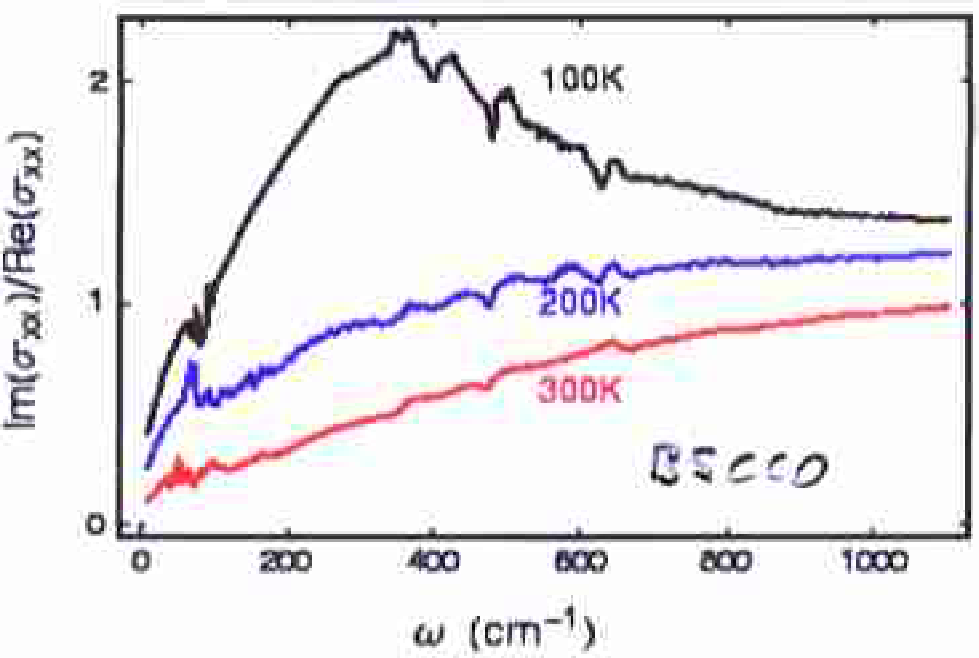




$$\tan\theta_H$$

$$\tan\vartheta = \frac{\operatorname{Im}\sigma_{xx}}{\operatorname{Re}\sigma_{xx}} \sim \omega\tau_{IR}$$

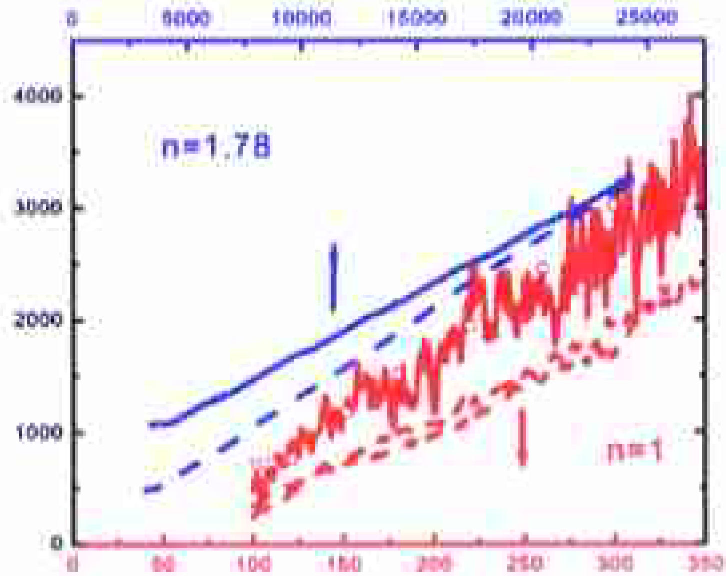




Tu & Homes

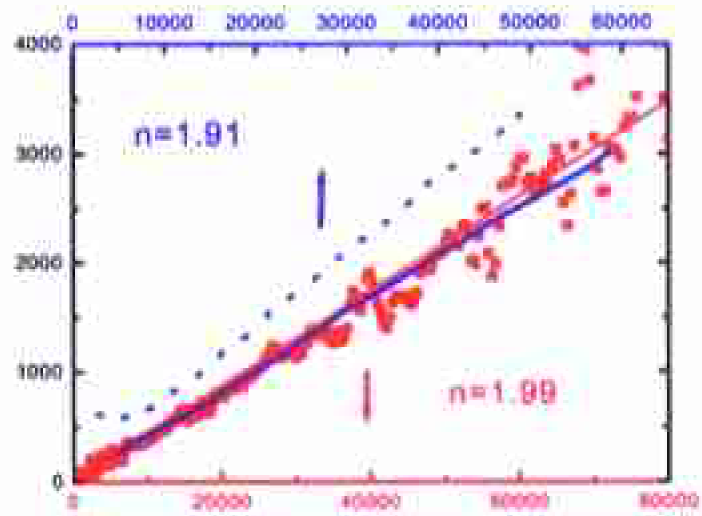
$$\gamma = aT^n$$

Optimally Doped



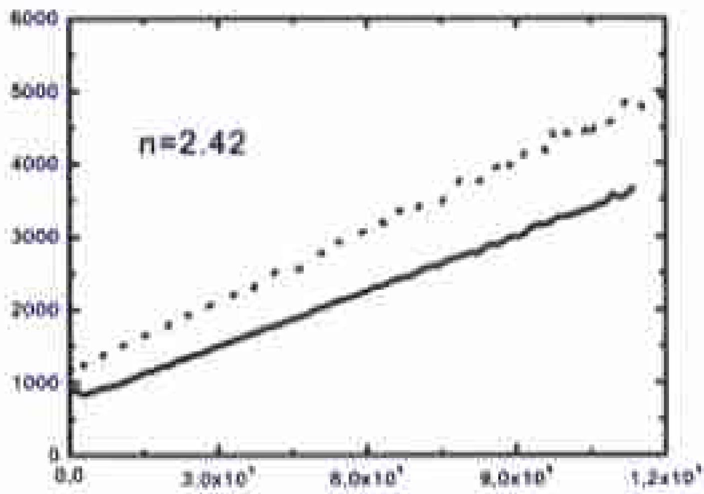
Underdoped

X=6.7



Underdoped

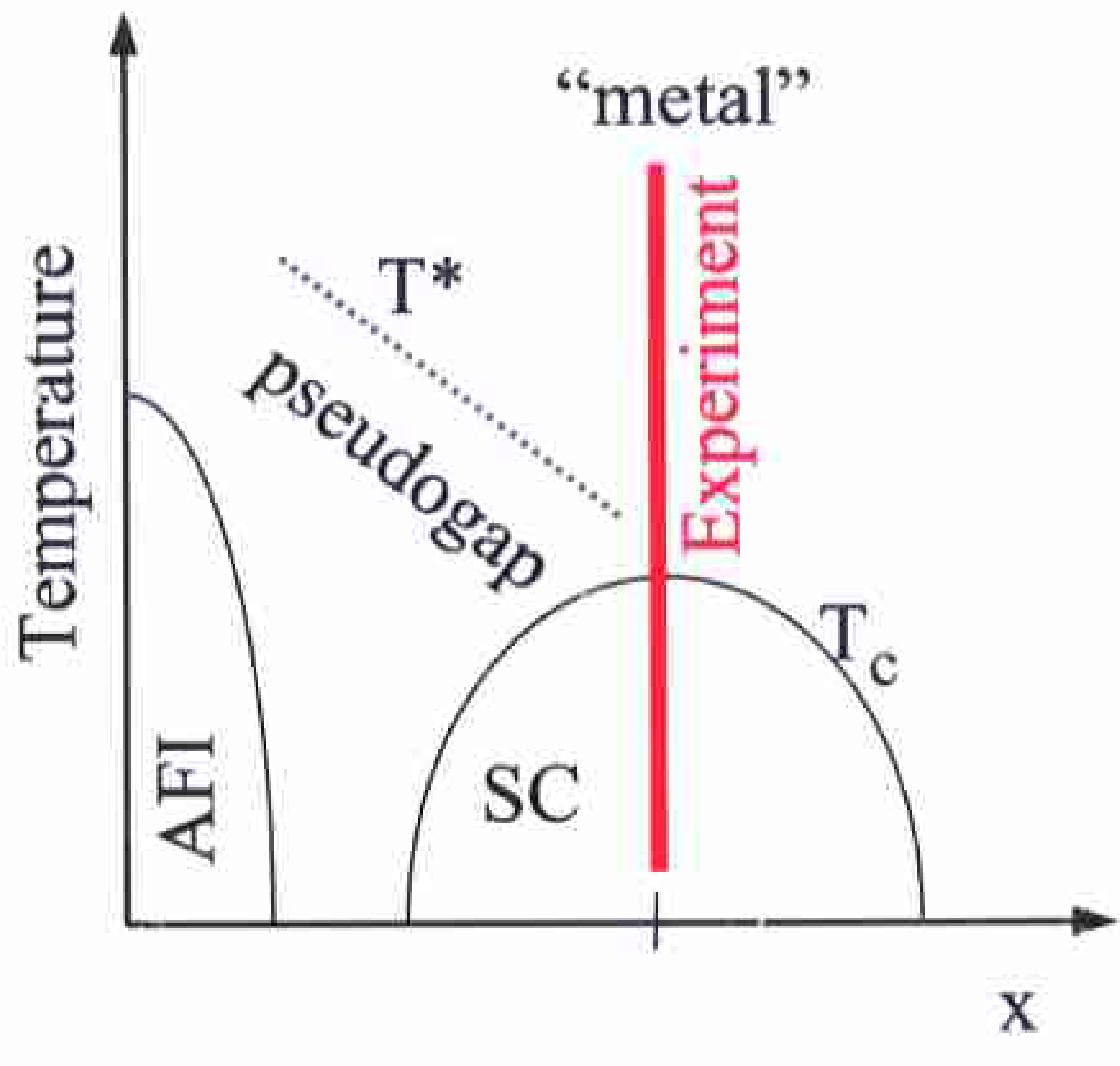
X=6.4



T^n

L. RIGAL, POSTER

2. IR Hall Effect High Temperature Superconductors



CONCLUSIONS

LOW FREQUENCIES: 0 ~ 30 meV

- HALL ANGLE RESPONSE IS LORENTZIAN SQUARED
- DC $\tan\theta_H \sim \omega_H \Omega / \Gamma^2$

  $\Gamma \propto T$
- REQUIRES INTERACTING MULTICOMPONENT FLUID

HIGH FREQUENCIES: ~ 100 meV

- HALL ANGLE RESPONSE IS NEARLY DRUDE (LORENTZIAN)
- $\gamma(\omega, T) \simeq \gamma(0, T) \propto T$
- $\Rightarrow$ QUASI ELASTIC HALL SCATTERING

FUTURE: