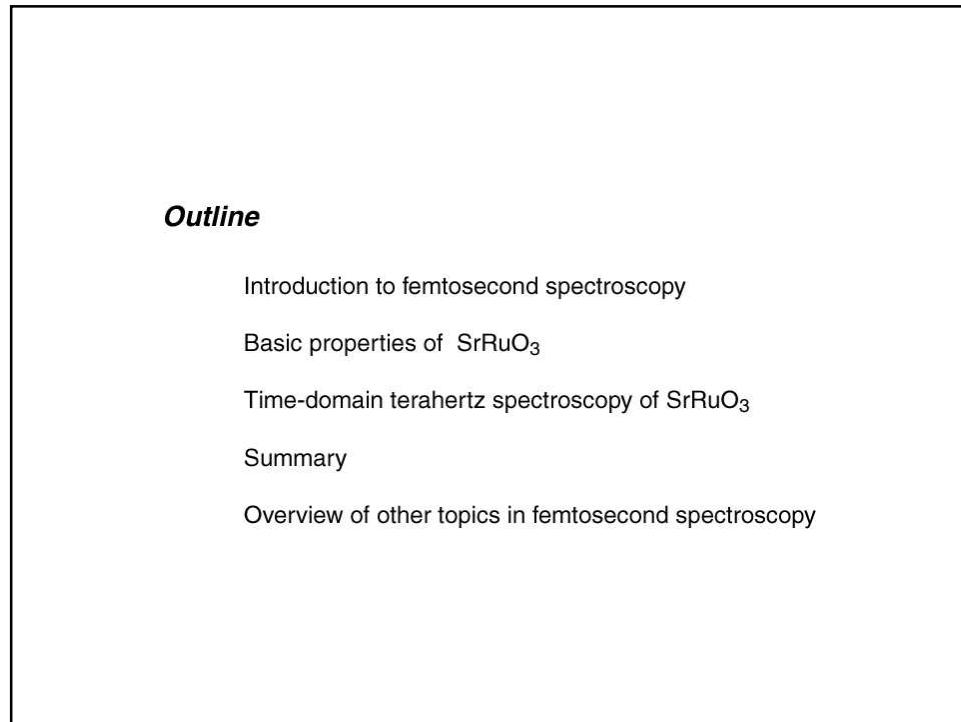
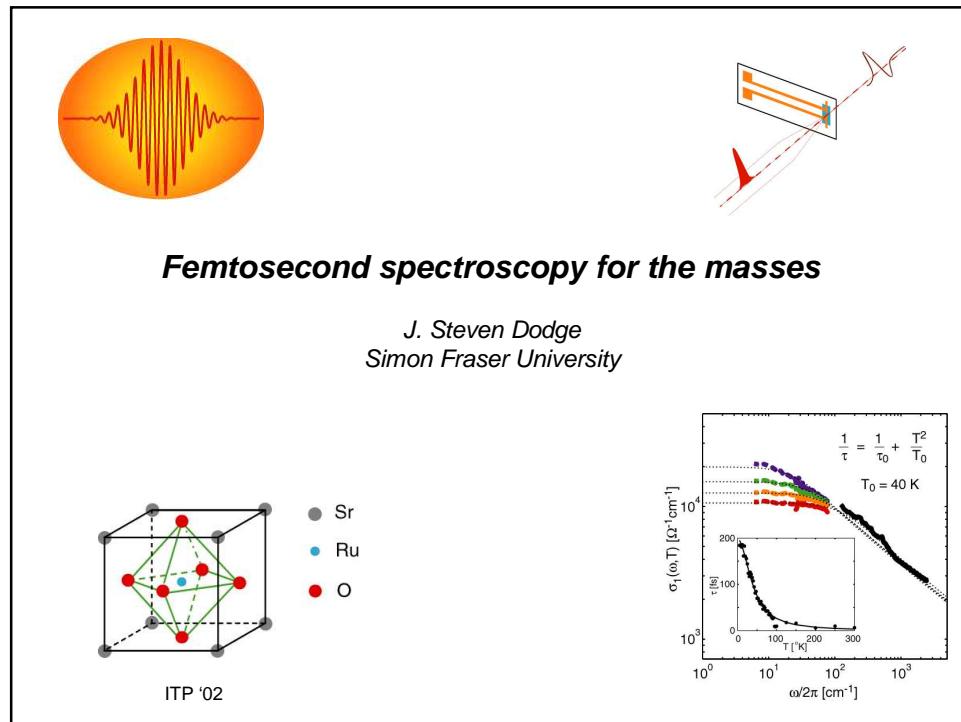


Correlated Electron Dynamics in SrRuO₃



Correlated Electron Dynamics in SrRuO₃

What modern lasers provide

Intensity (>PW/cm²)

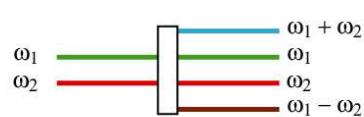
Temporal and spatial coherence

Tunability (meV - eV)

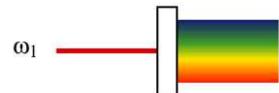
Temporal resolution (~10 fs)

Ease of use

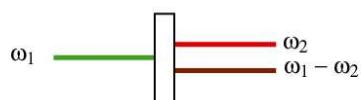
Experimental bag of tricks



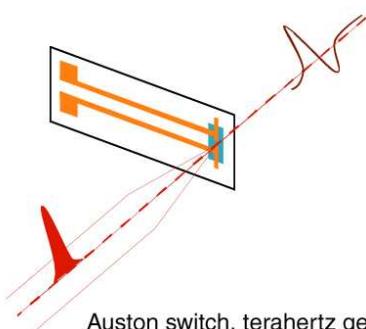
Sum and difference frequency generation



Self-phase modulation, continuum generation

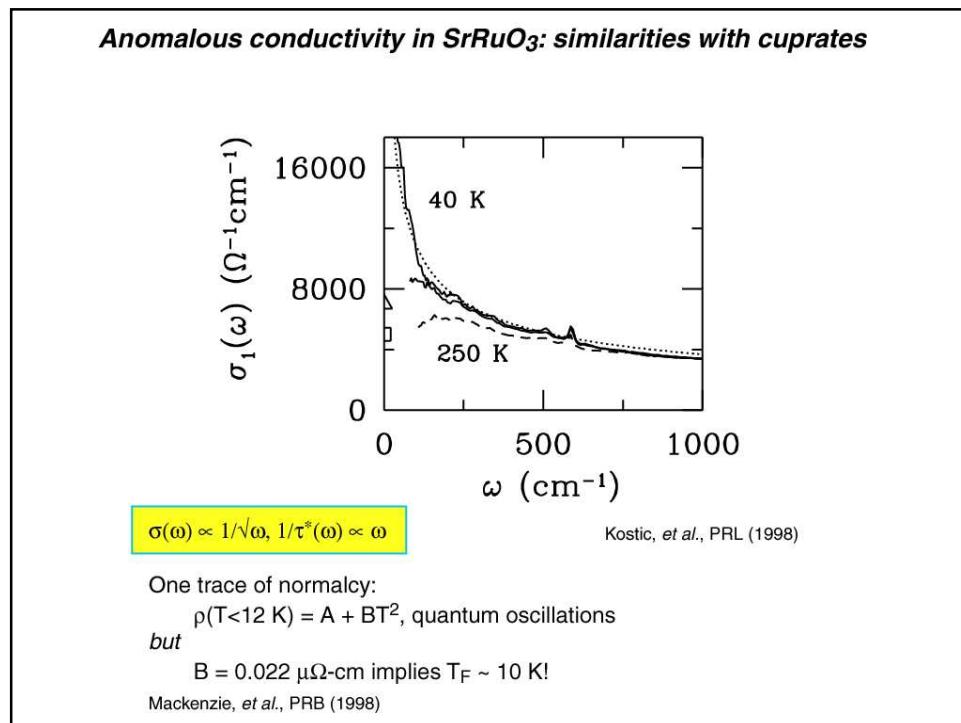
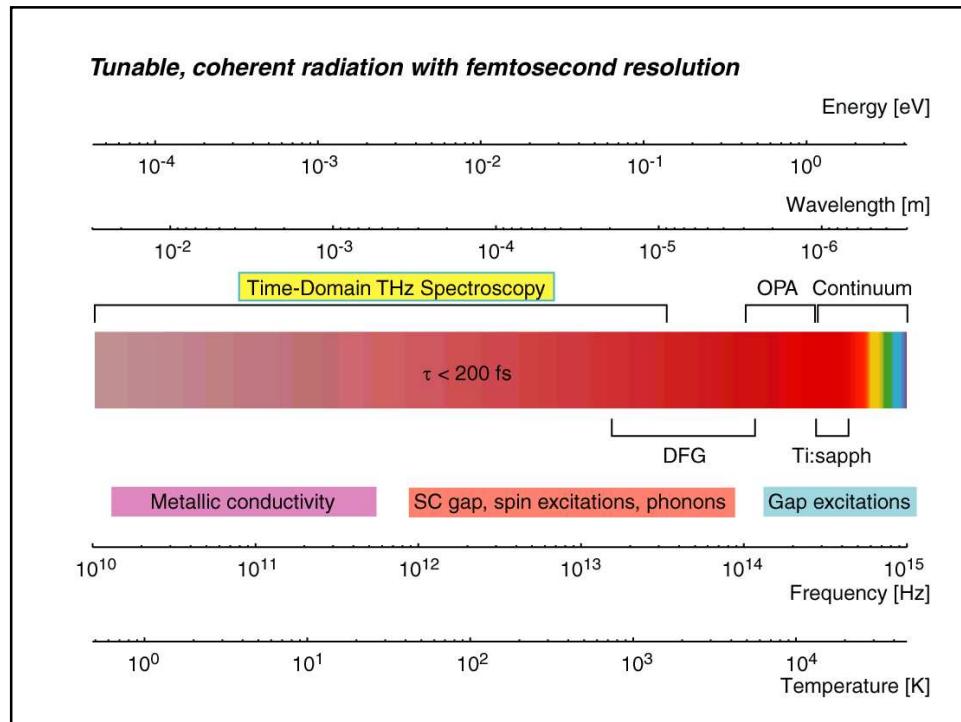


Parametric generation and amplification

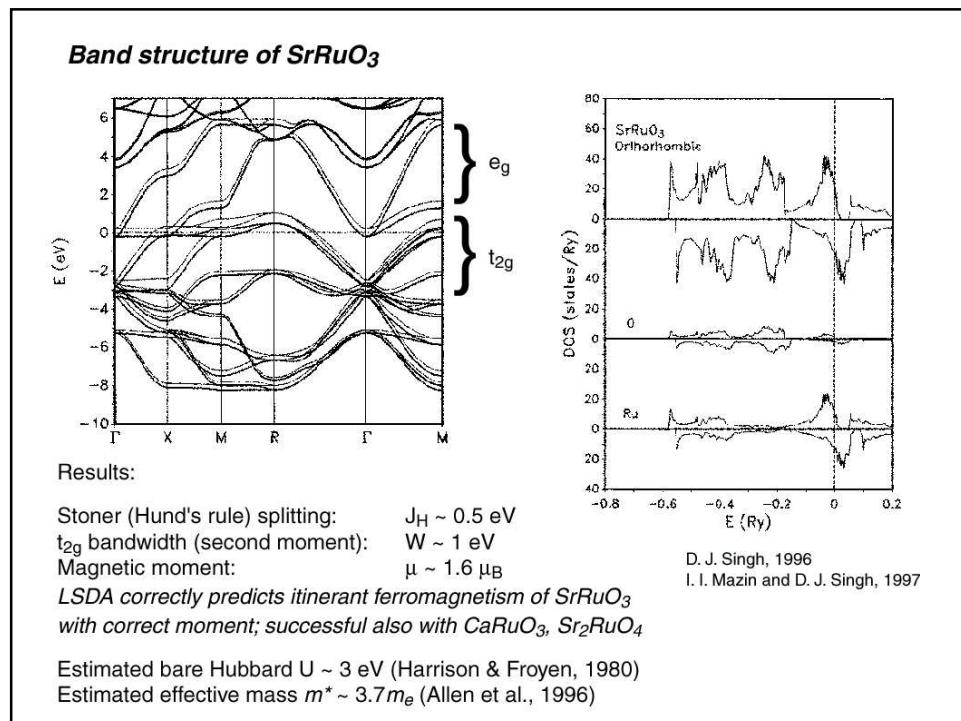
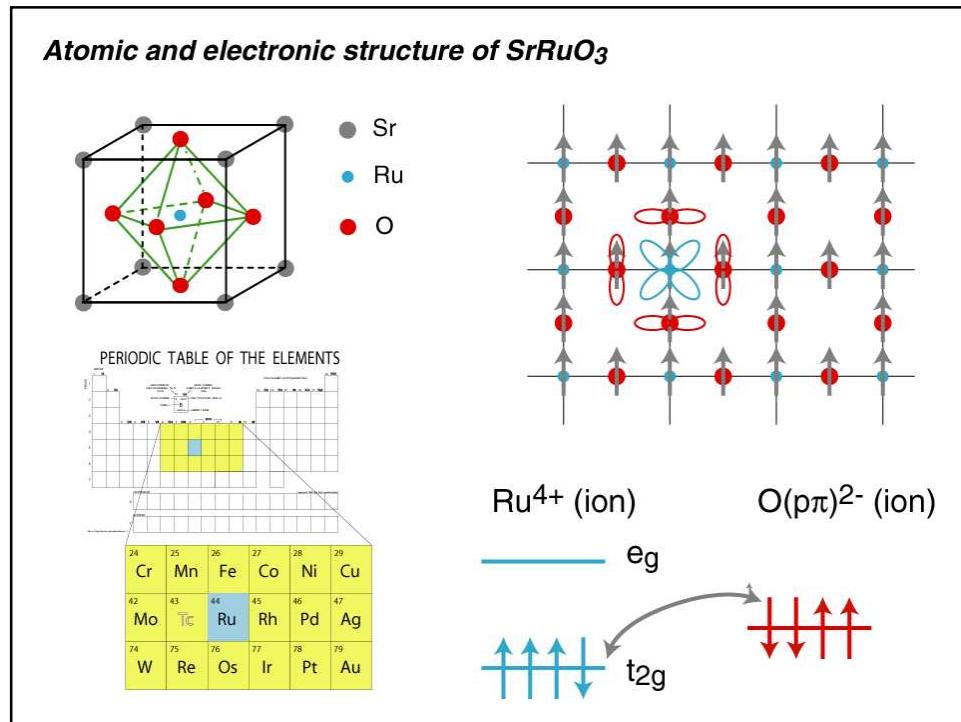


Auston switch, terahertz generation

Correlated Electron Dynamics in SrRuO₃



Correlated Electron Dynamics in SrRuO₃

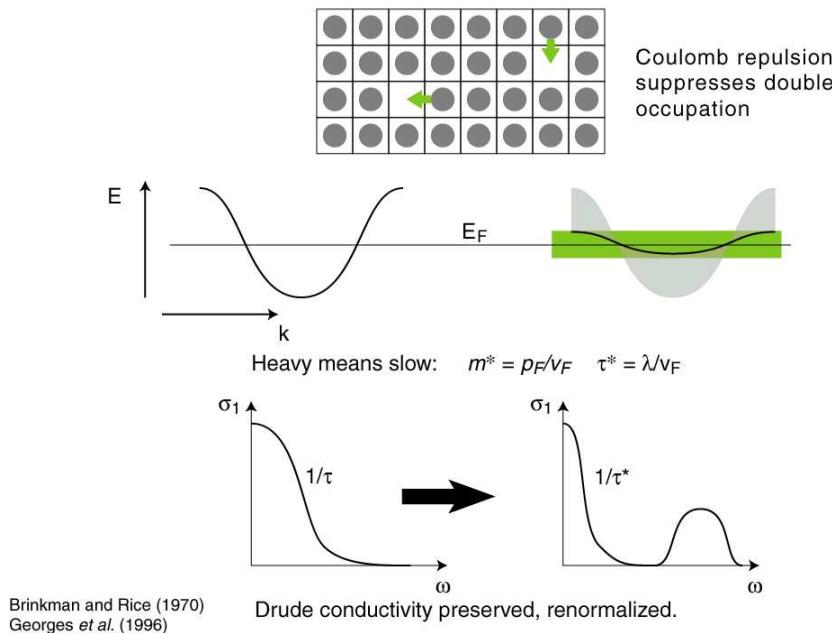


Correlated Electron Dynamics in SrRuO₃

Ruthenate diversity

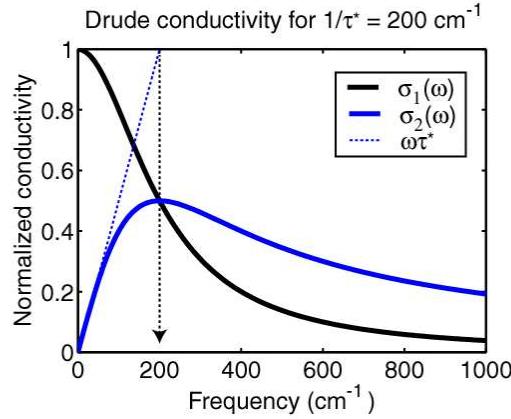
CaRuO ₃	Paramagnetic metal (AF Weiss temperature)
SrRuO ₃	Ferromagnetic metal, T _C ~ 150 K
Ca ₂ RuO ₄	Antiferromagnetic insulator, T _N ~ 110 K, LSDA fails
Sr ₂ RuO ₄	unconventional superconductor, T _C ~ 1.5 K
Ca ₃ Ru ₂ O ₇	antiferromagnet, T _N ~ 56 K, with MIT at T _{MI} ~ 48 K
Sr ₃ Ru ₂ O ₇	paramagnetic metal, possibly near a metamagnetic quantum critical endpoint

Mass enhancement in a doped Mott insulator



Correlated Electron Dynamics in SrRuO₃

Direct measurement of τ^* from $\sigma_2(\omega)$

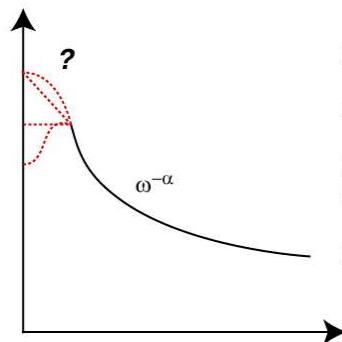


$$m^* = (1 + \lambda)m \quad \tau^* = (1 + \lambda)\tau \quad \sigma_0 = \frac{n e^2 \tau}{m} = \frac{n e^2 \tau^*}{m^*}$$

$$\sigma(\omega) = \frac{\sigma_0}{1 - i\omega\tau^*} \cong \sigma_0 e^{i\omega\tau^*}$$

$$\tau^* \equiv \frac{\phi}{\omega}$$

What is the low frequency, low temperature behavior of $\sigma(\omega, T)$ in anomalous metals?



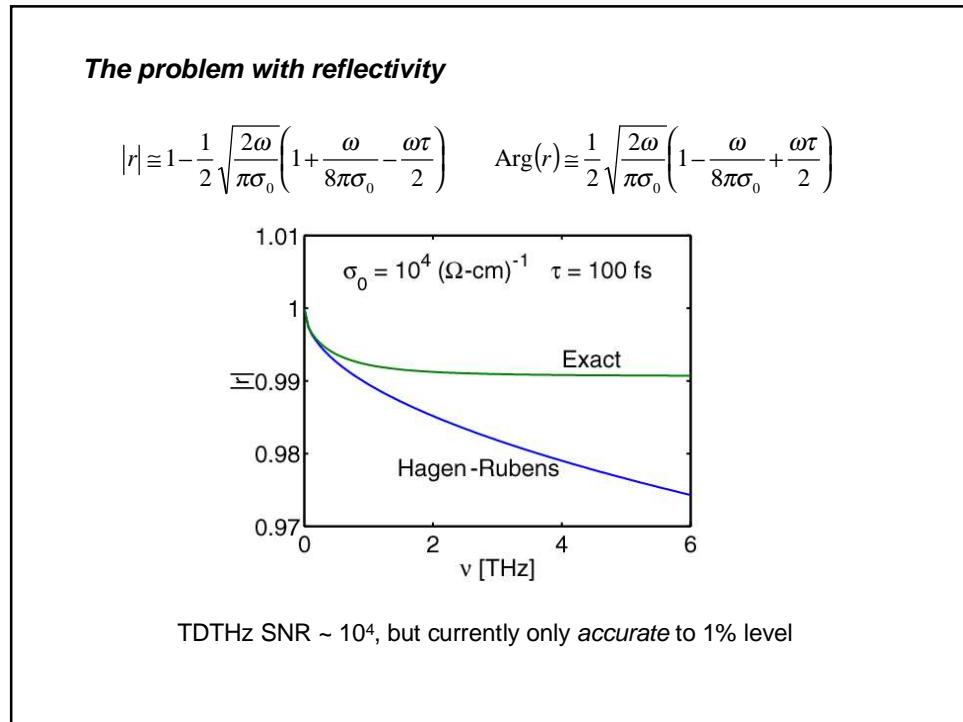
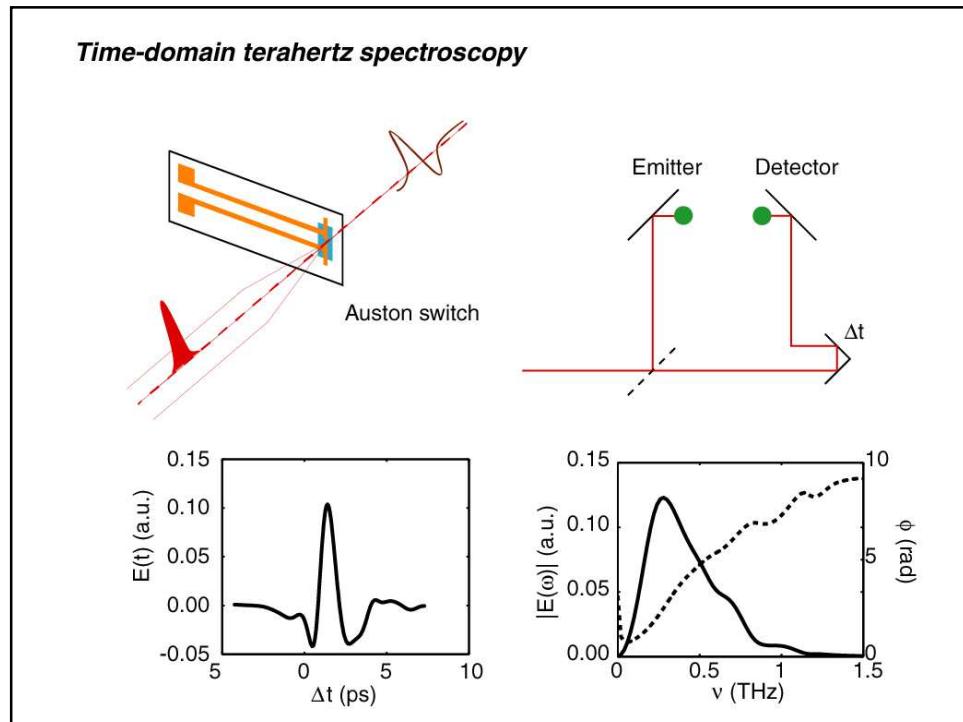
Infrared reflectivity shows $\omega^{-\alpha}$ for $\omega > 60 \text{ cm}^{-1}$ (2 THz)

In metals, $\sigma_1(\omega \rightarrow 0) = C$. How?

Important limit of FLT is $\omega \rightarrow 0$, detailed behavior very difficult to obtain from reflectivity

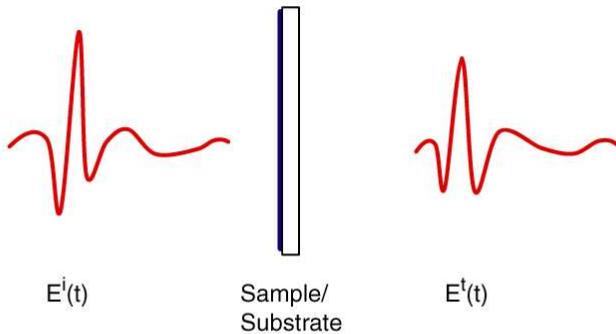
Relevant range for THz spectroscopy
(1 THz = 4 meV = 50 K)

Correlated Electron Dynamics in SrRuO₃



Correlated Electron Dynamics in SrRuO₃

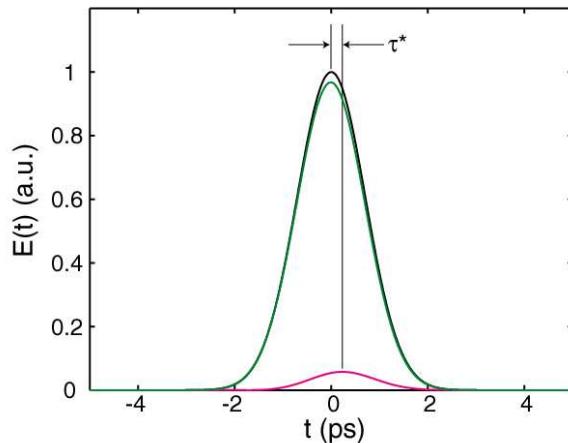
Time-domain THz spectroscopy measures complex conductivity



$$t(\omega) = E^t(\omega)/E^i(\omega) = \frac{4n/(n+1)}{n+1 + Z_0\sigma(\omega)d}$$

Direct relationship, no Kramers-Kronig

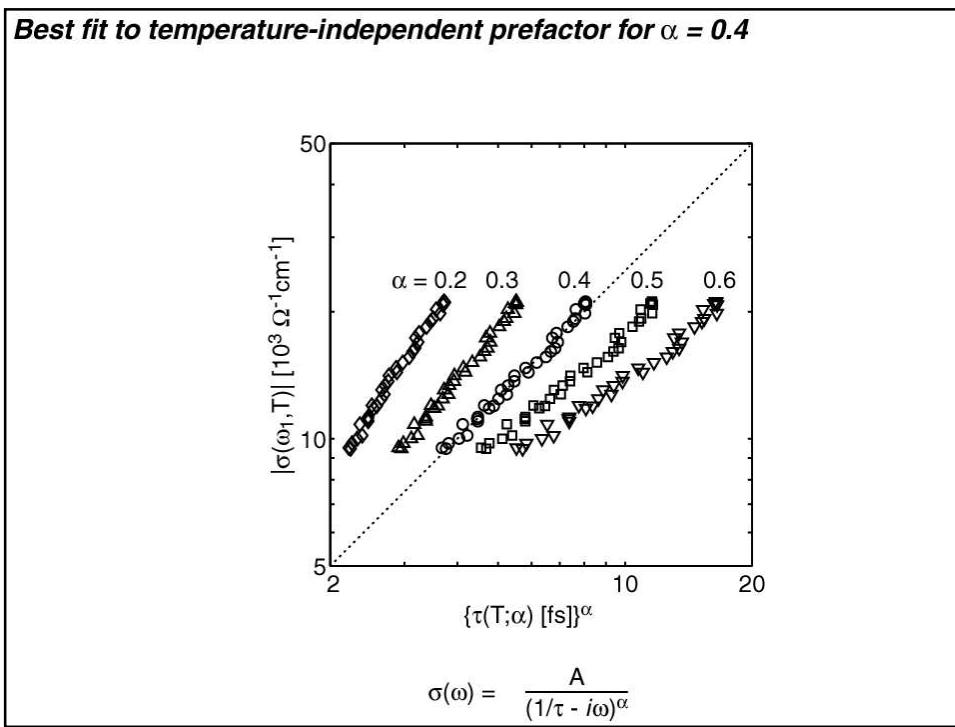
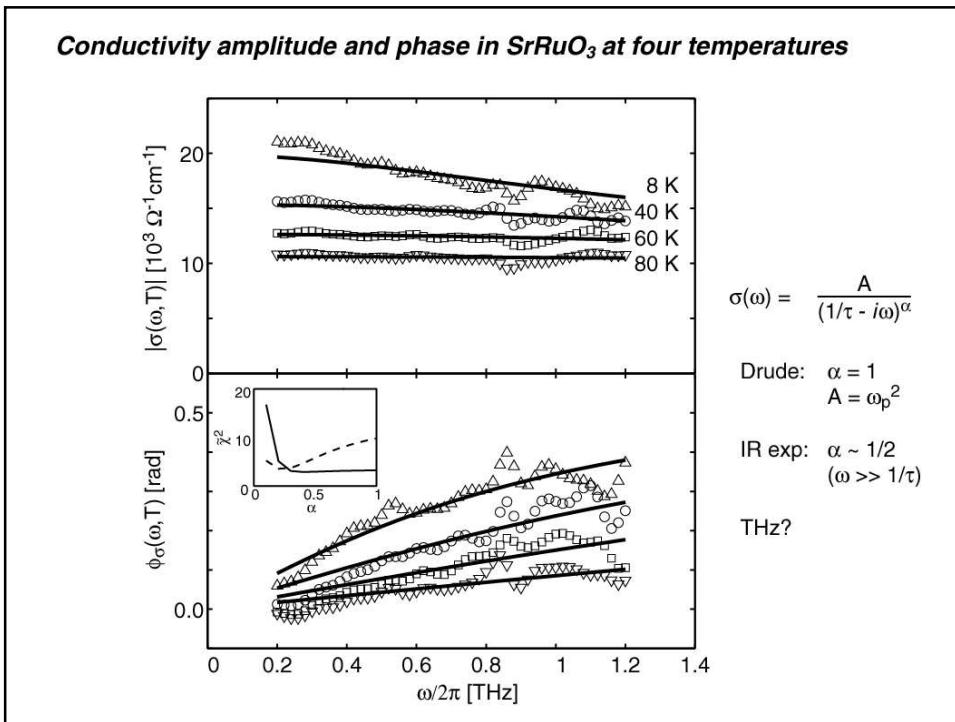
Metallic film advances the pulse upon transmission by τ^*



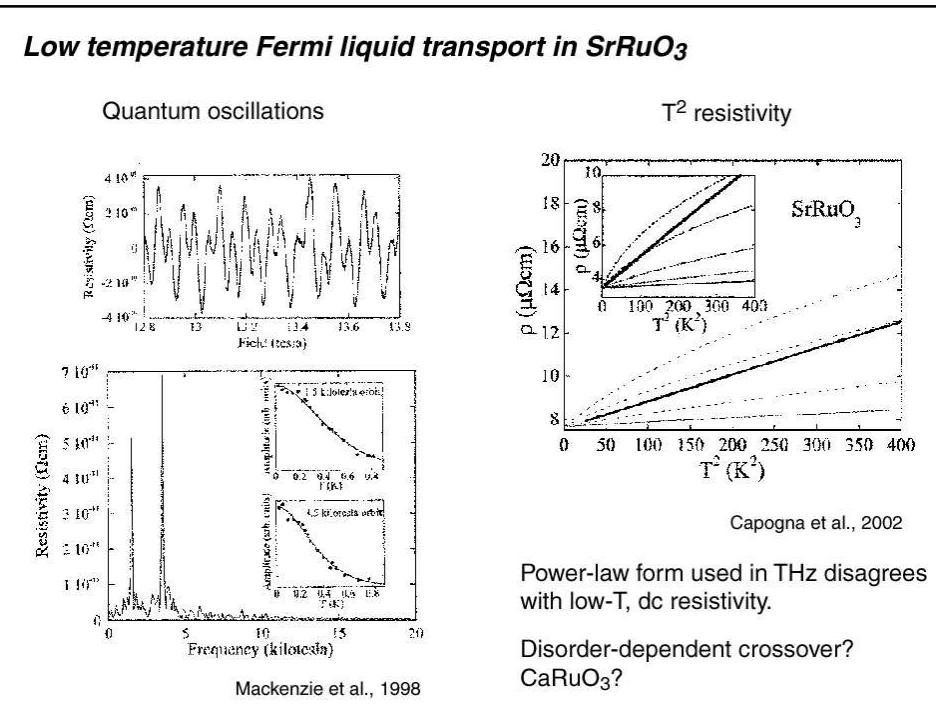
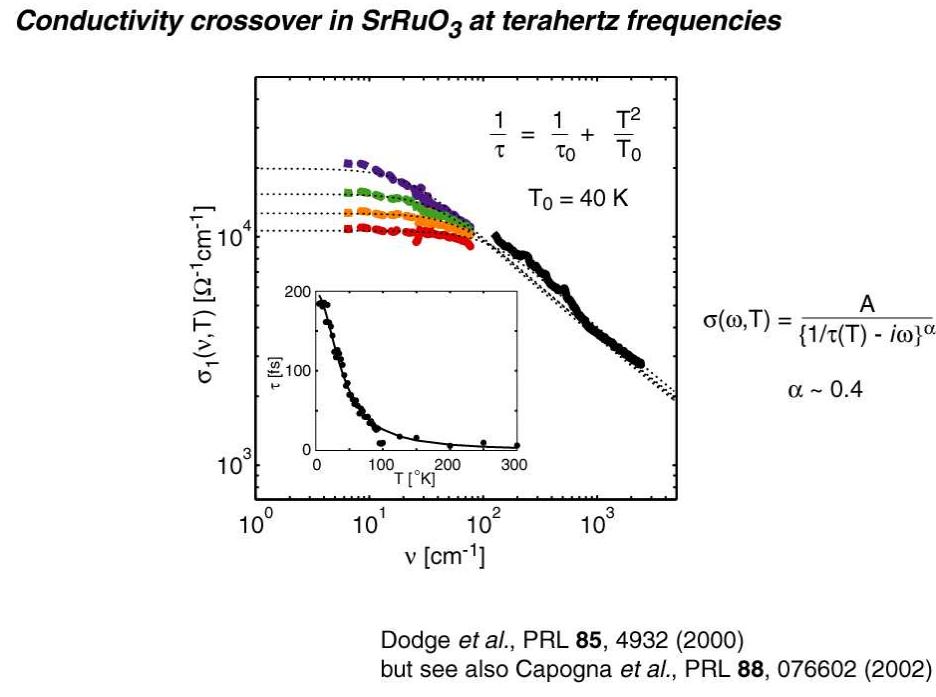
$$\sigma(\omega) \cong \sigma_0(1 + i\omega\tau^*) \quad t(\omega) \cong t_0(1 - i\omega\tau^*)$$

$$t(\omega) \propto e^{-i\omega t} \cong t_0 \propto e^{-i\omega(t+\tau^*)}$$

Correlated Electron Dynamics in SrRuO₃



Correlated Electron Dynamics in SrRuO₃

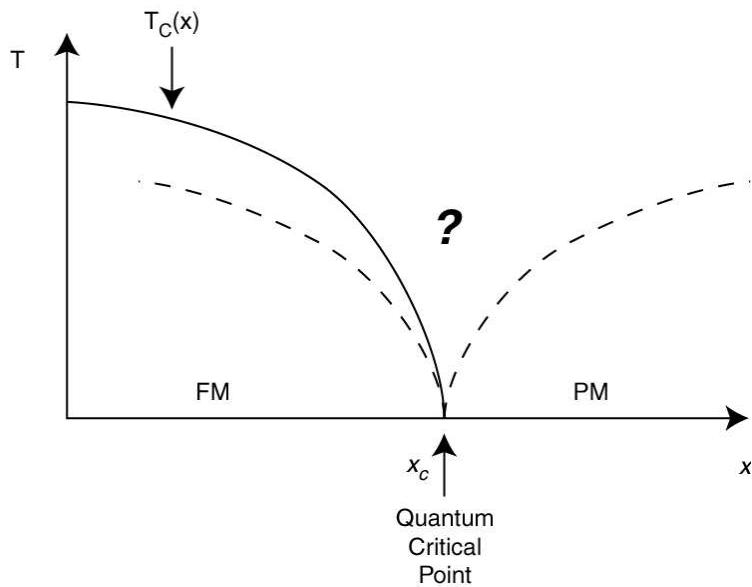


Correlated Electron Dynamics in SrRuO₃

Conclusions

- Nonlinear relationship between σ and τ^* reflects non-Fermi liquid behavior in the temperature regime studied
- Simple power-law form describes both low-frequency and high-frequency regimes
- Apparent coherence regime at temperatures two orders of magnitude lower than expected
- Time-domain THz spectroscopy offers a uniquely direct and simple measurement of dynamical renormalization in metals

Quasiparticle scattering at quantum phase transitions



Correlated Electron Dynamics in SrRuO₃

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