SAND2019-4615C

OPTICAL PROPERTIES OF ULTRAFAST LASER HEATED SOLID

PRESENTED BY

Tommy Ao

Warm Dense Matter Workshop 2019, Travemünde, Germany
May 5-11, 2019

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Background

- Warm Dense Matter: a personal account
- "Idealized Slab Plasma"

Optical reflectivity and transmission measurements

- Model-independent, femtosecond pump-probe measurements of electrical conductivity of single-state, warm dense gold

Frequency domain interferometry measurements

- Phase shift is sensitive to expansion hydrodynamics

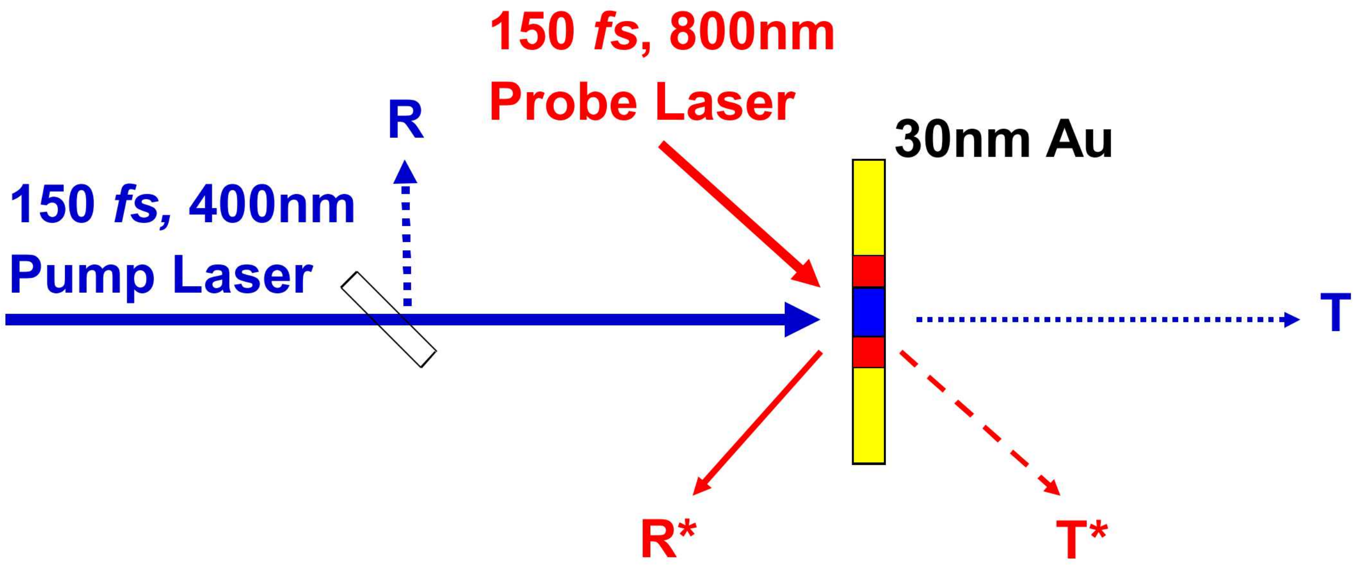
Vancouver, 2000

New approach realize single-state measurements on WDM

- Planar plasma that can be considered as a single, uniform state in which any residual non-uniformity has insignificant impact on the measurement of its uniform properties
- The state is characterized by direct measurements

Single-state measurement of electrical conductivity based on fs-laser heating of an ultrathin freestanding foil

- Isothermal heating produced by laser skin-depth deposition and ballistic electron transport
- Isochoric condition maintained by material inertia and strength



A. Forsman, A. Ng, G. Chiu, and R.M. More, PRE **58**, 1248 (1998)

Isochoric & uniform heating of sample

- Thickness of ISP = initial thickness of sample
- Mass density of ISP = Au initial density

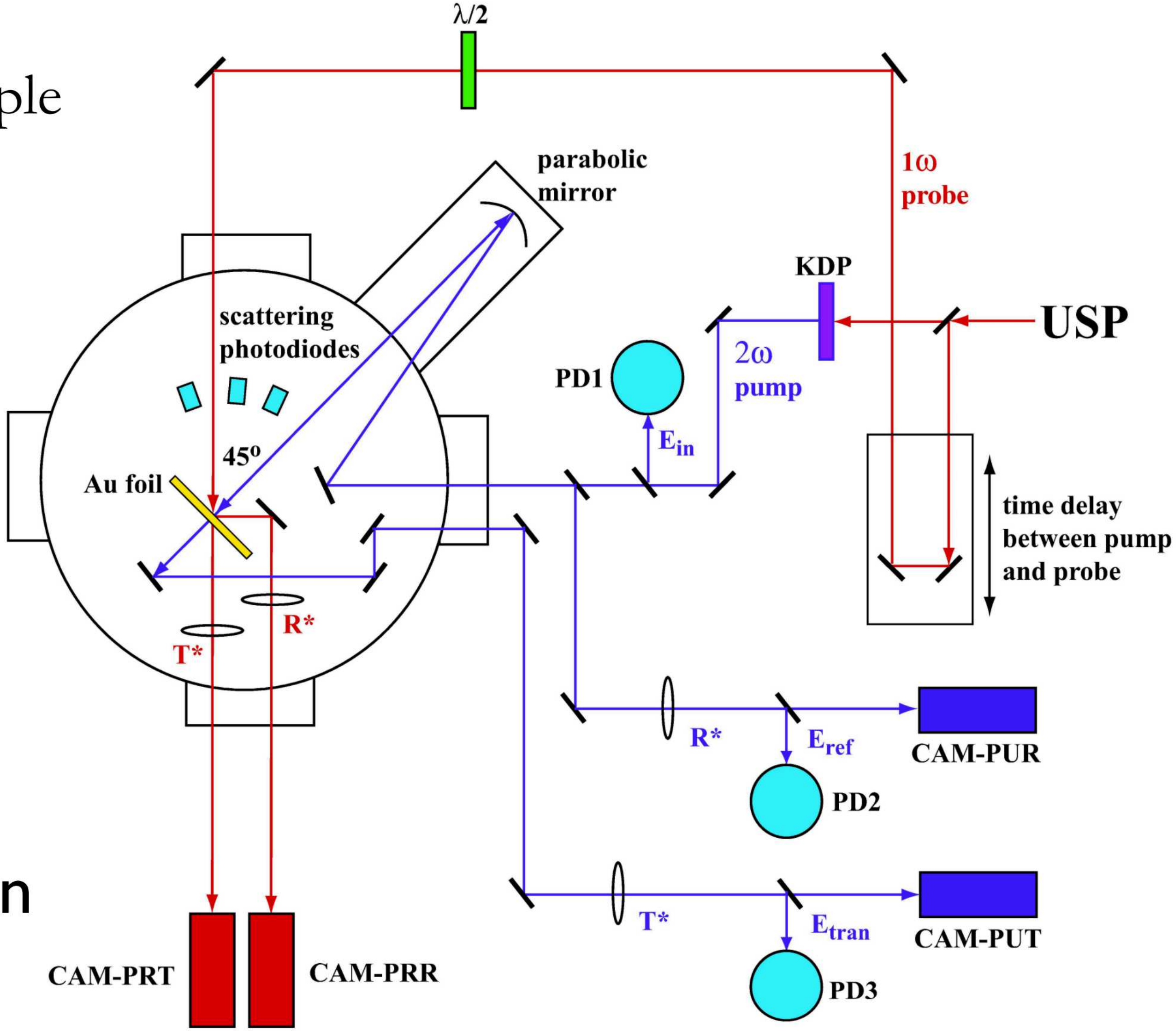
Pump laser {R,T}

- Energy density increase $\Delta\varepsilon$

Probe laser {R*,T*}

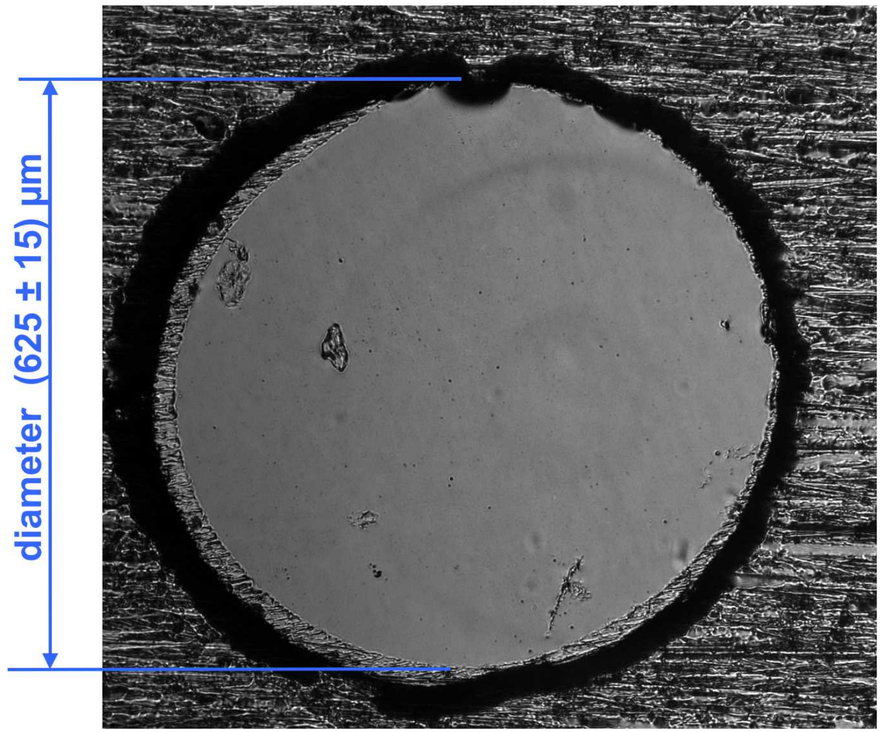
- AC conductivity $\sigma_\omega = \sigma_r + i\sigma_i$ is given by solution to the Helmholtz equations

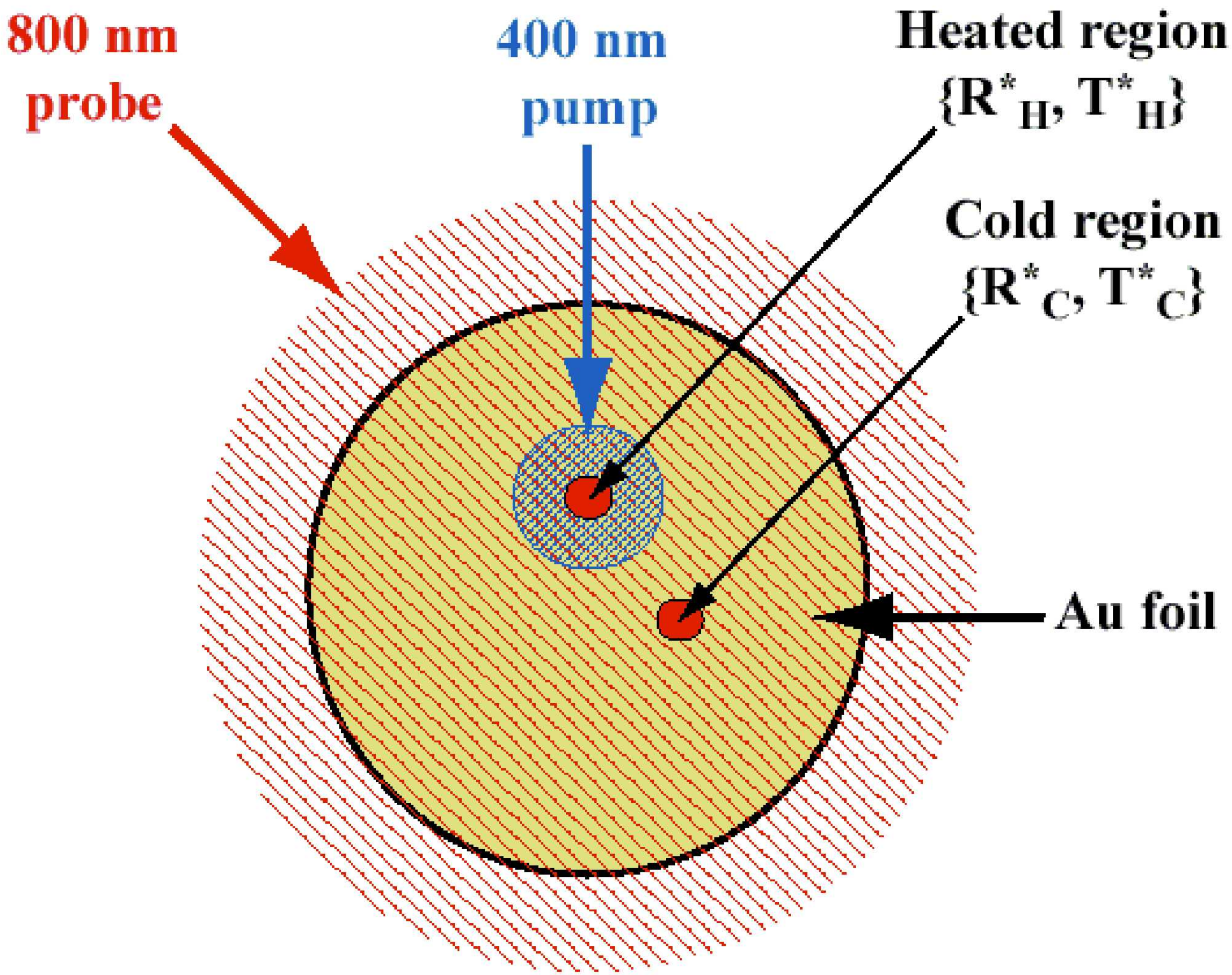
Yields $\sigma_\omega(\rho_o, \Delta\varepsilon)$ for direct comparison with theory



In-situ calibration of reflectivity, transmission

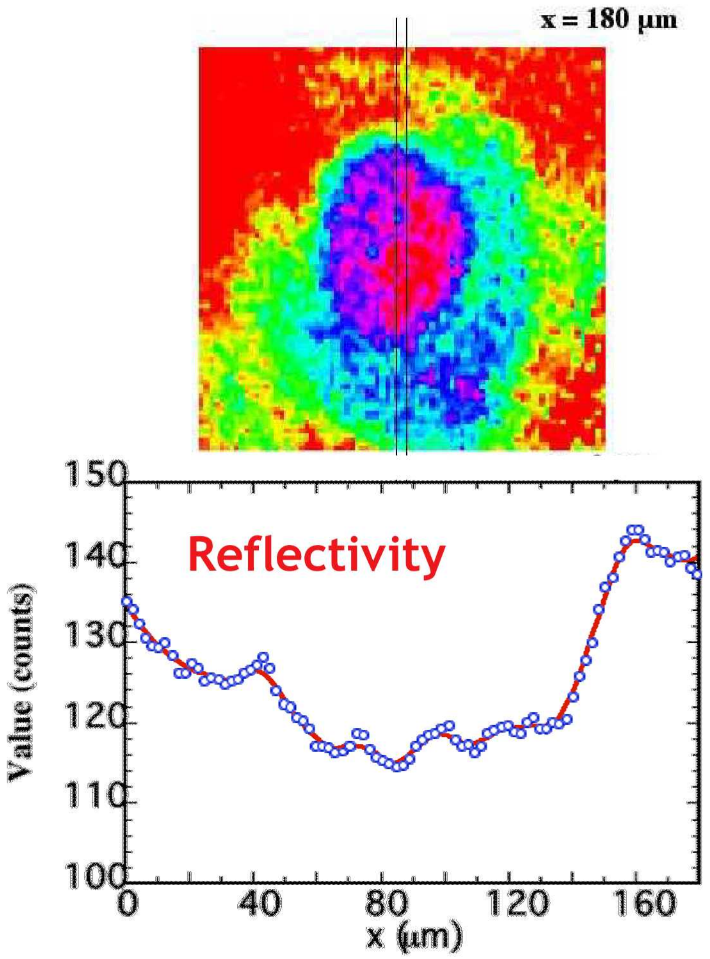
- Mitigates problem of shot-to-shot variations in probe pulse
- Probe data: R^*_H/R^*_C , T^*_H/T^*_C

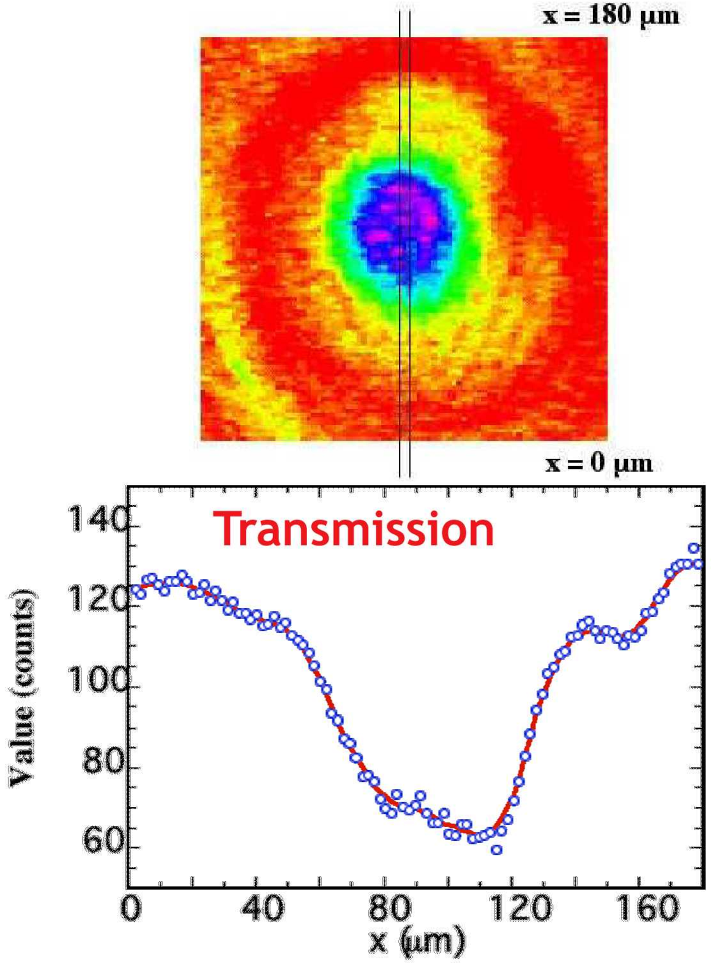


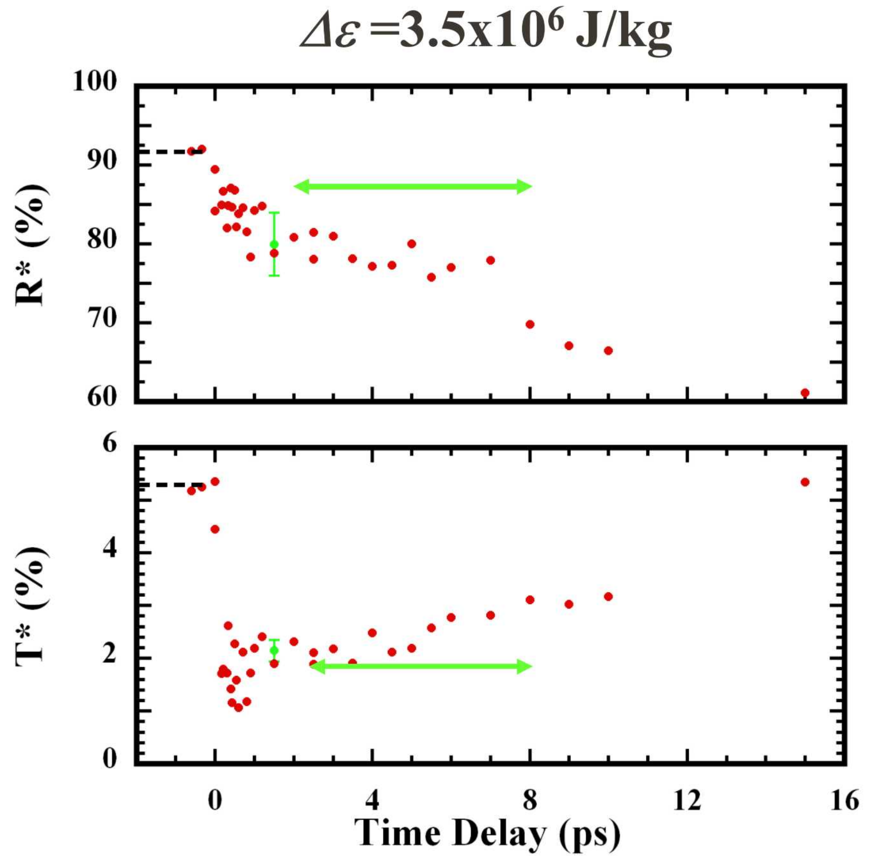


Probe {R*,T*} reveals three stages of development

- An initial transient induced by laser heating
- Appearance of a quasi-steady-state
- Followed by rapid changes (target disassembly)

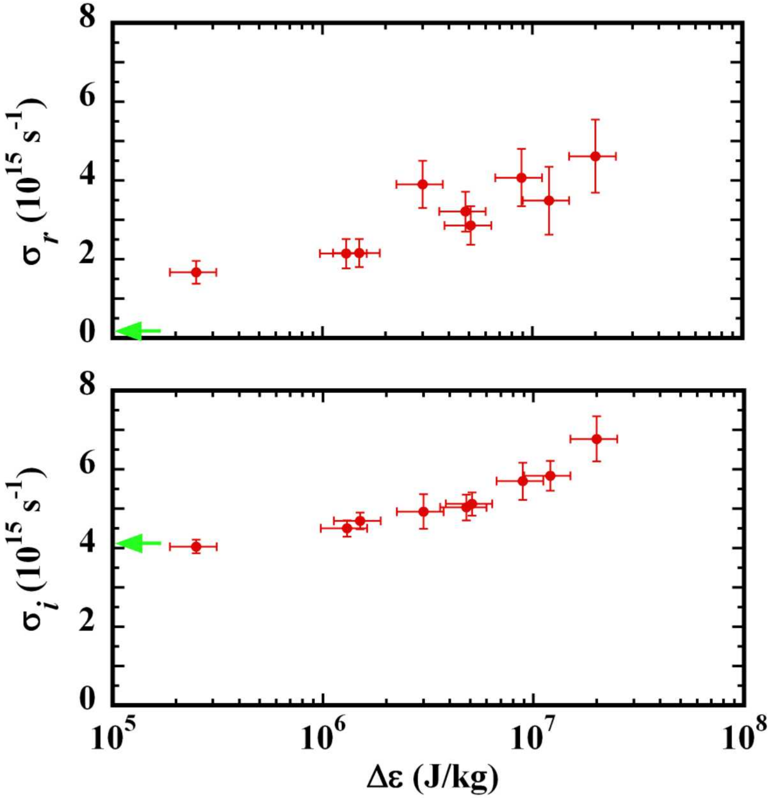


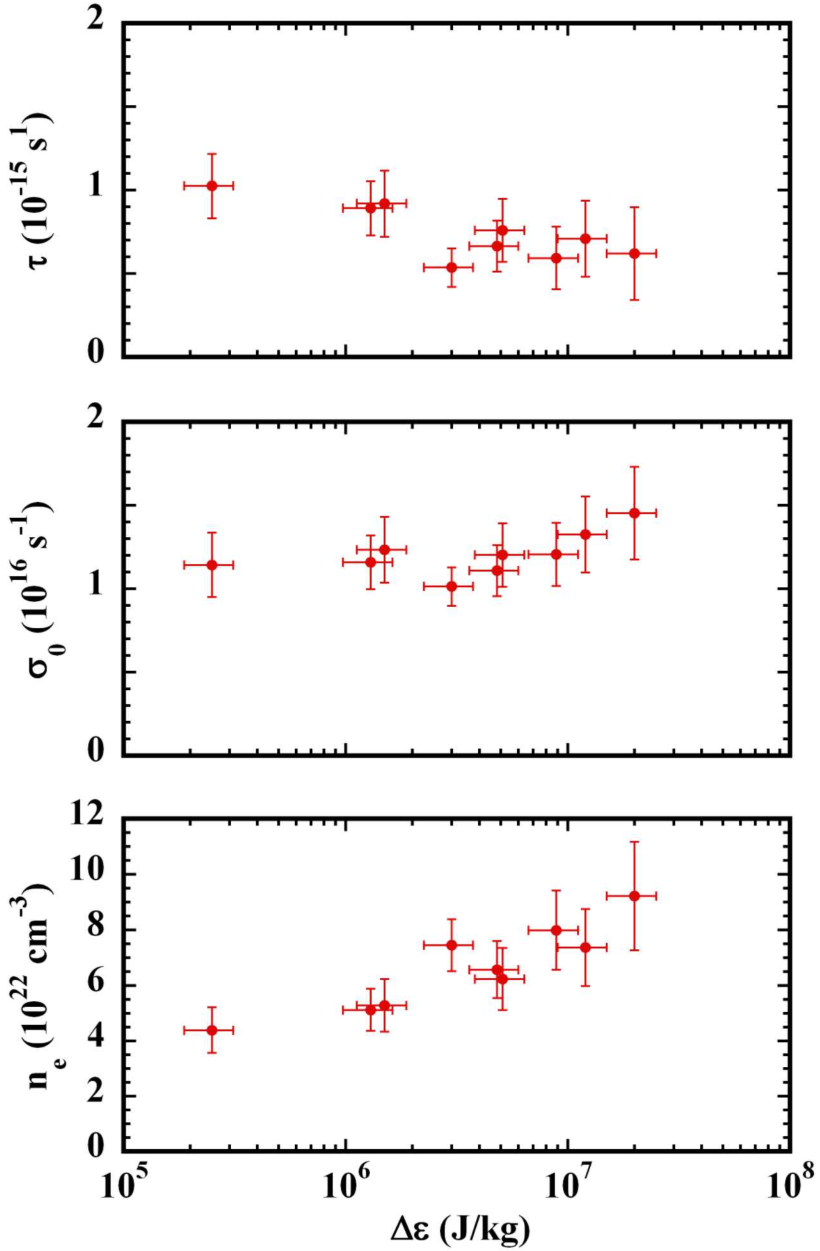




Obtained single-state AC conductivity from {R*, T*} values at start of quasi-steady-state stage

- Single-state measurement of *e-i* collision time, DC conductivity and average ionization

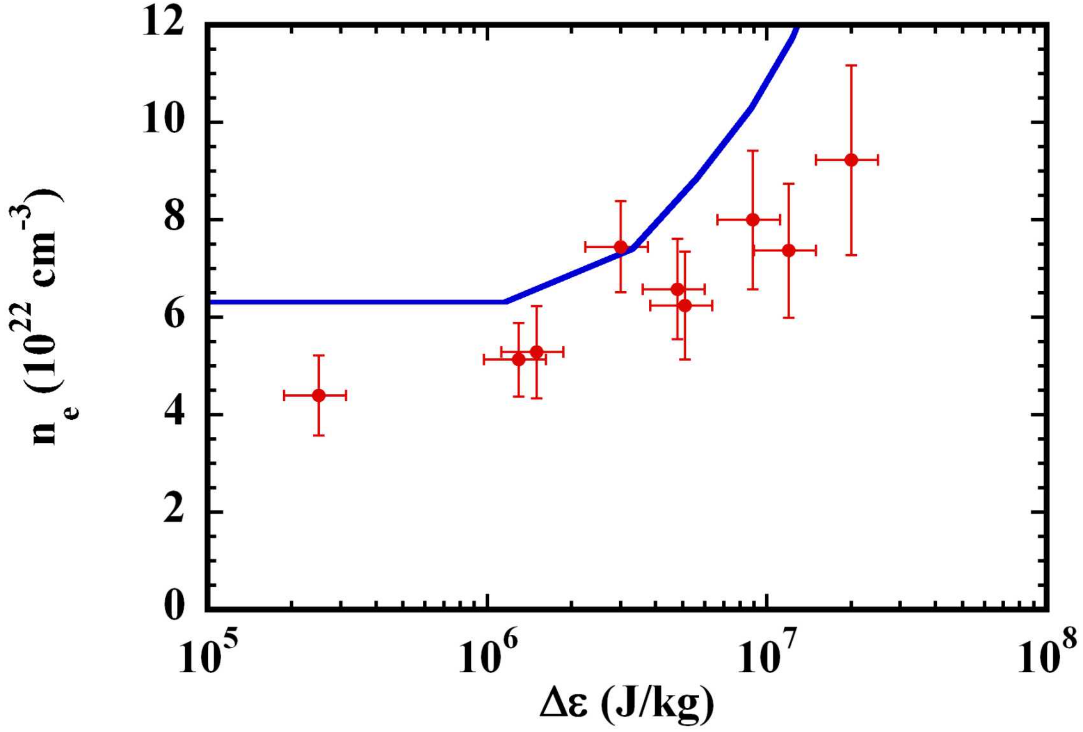


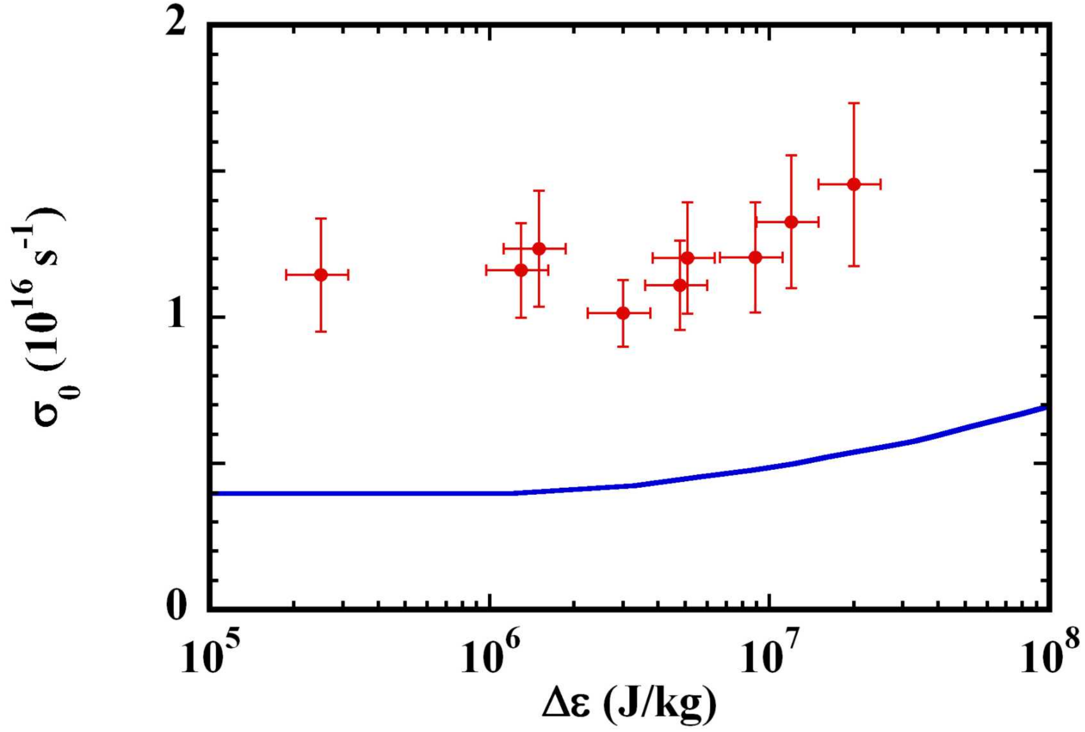


K. Widmann, T. Ao, M. Foord, D. Price, A. Ellis, P. Springer & A. Ng, PRL **92**, 125002 (2004)

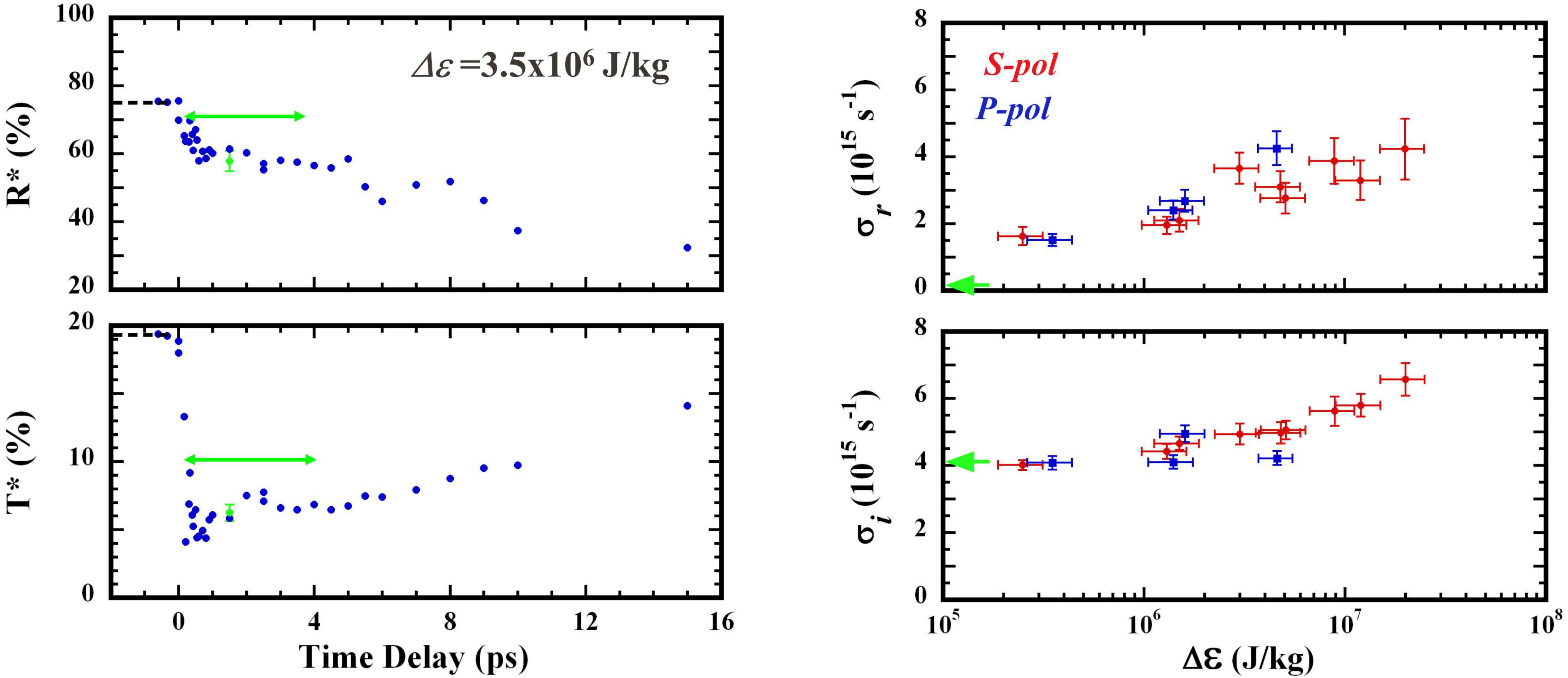
Comparison is unfair

- Data are for a highly non-equilibrium system
- Sesame describes equilibrium properties

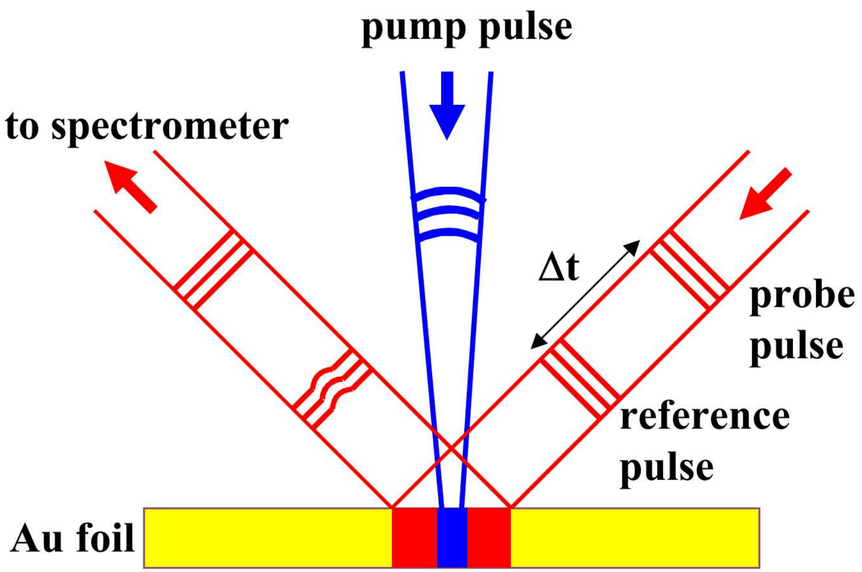


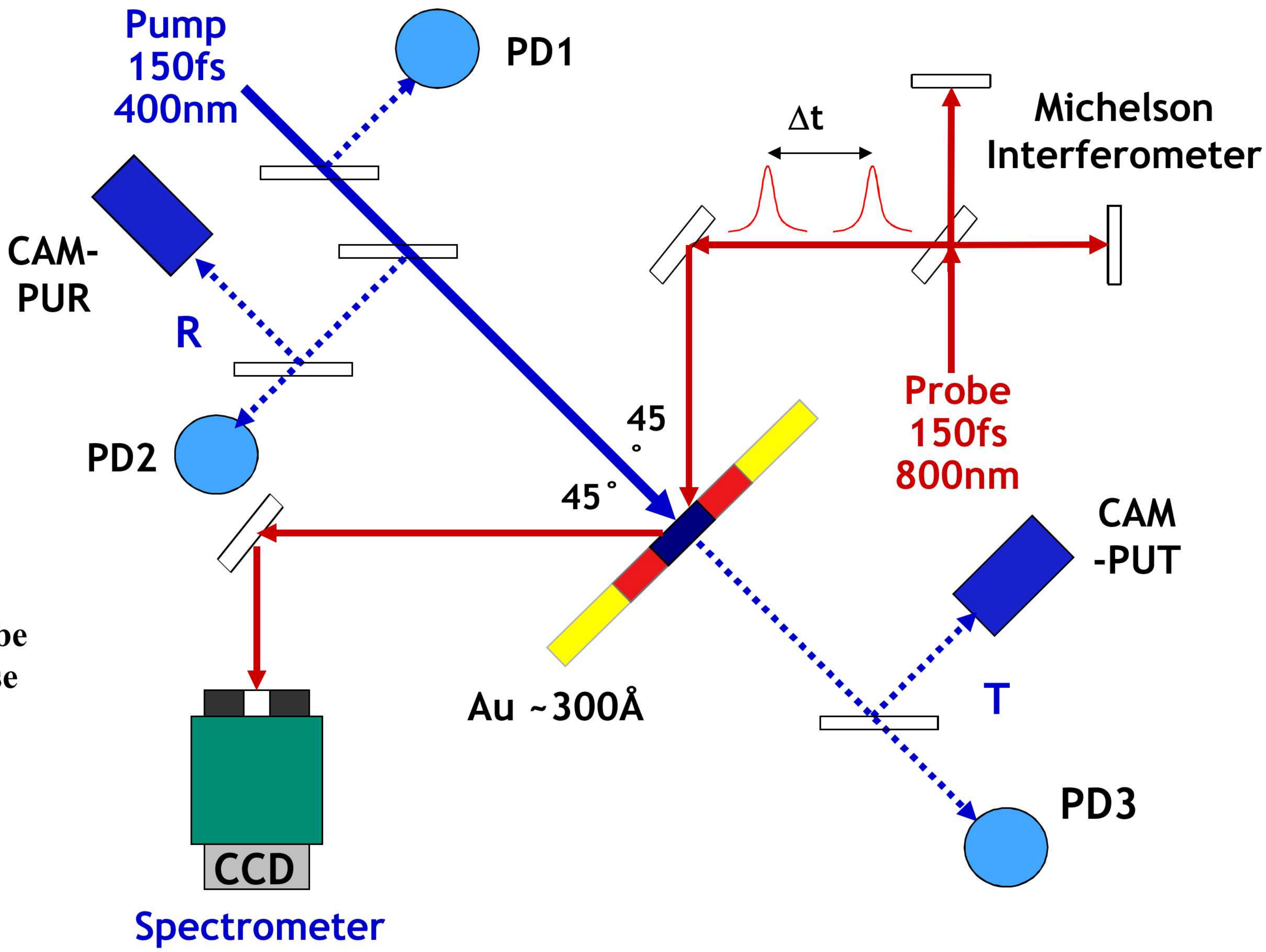


Showed same 3 stages of temporal evolution
P-pol results corroborate S-pol conductivity results



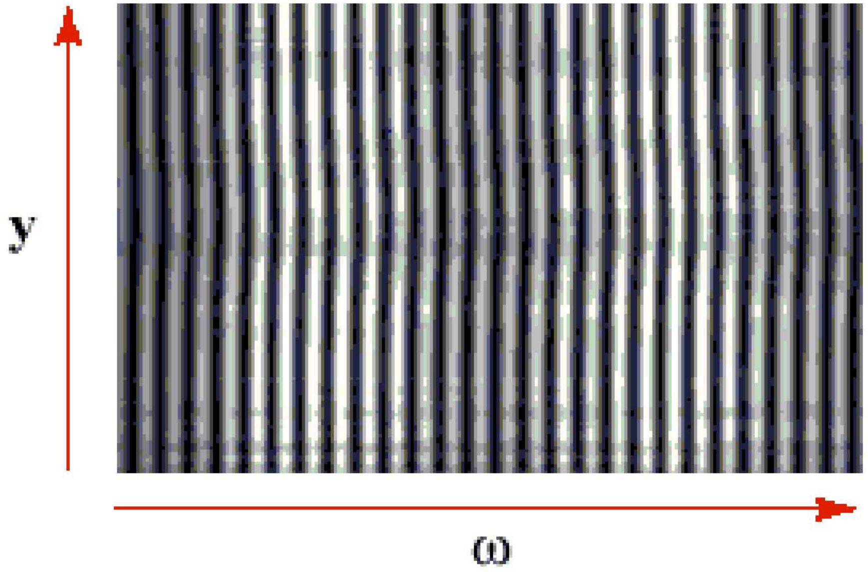
Measurement of expansion velocity due to change in the path length

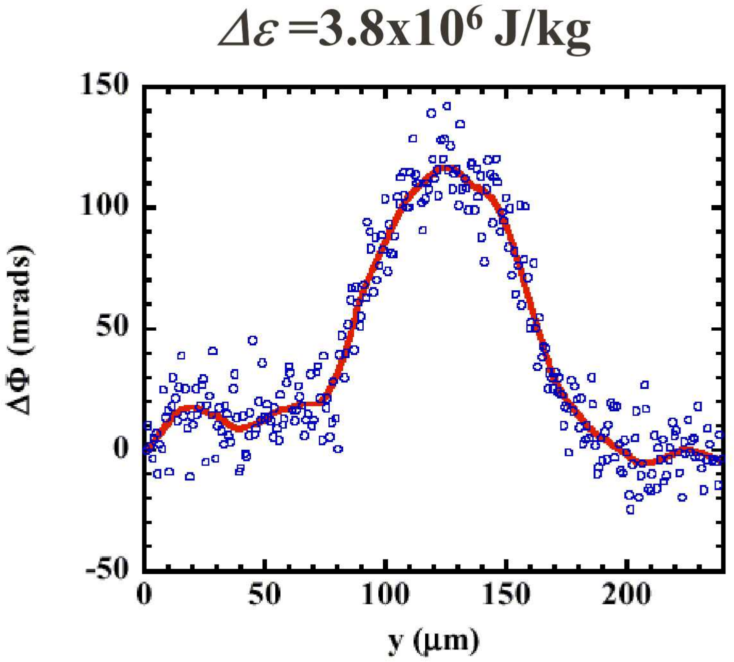


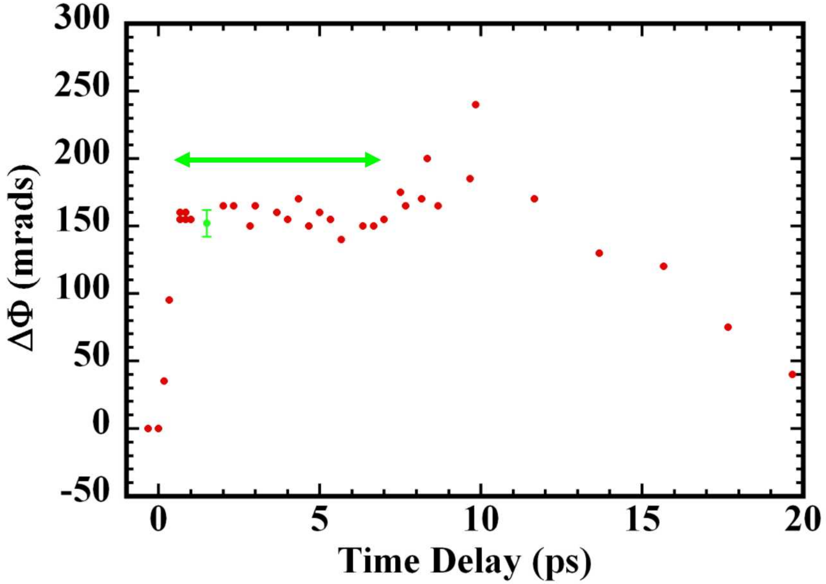


FDI phase shift measurements

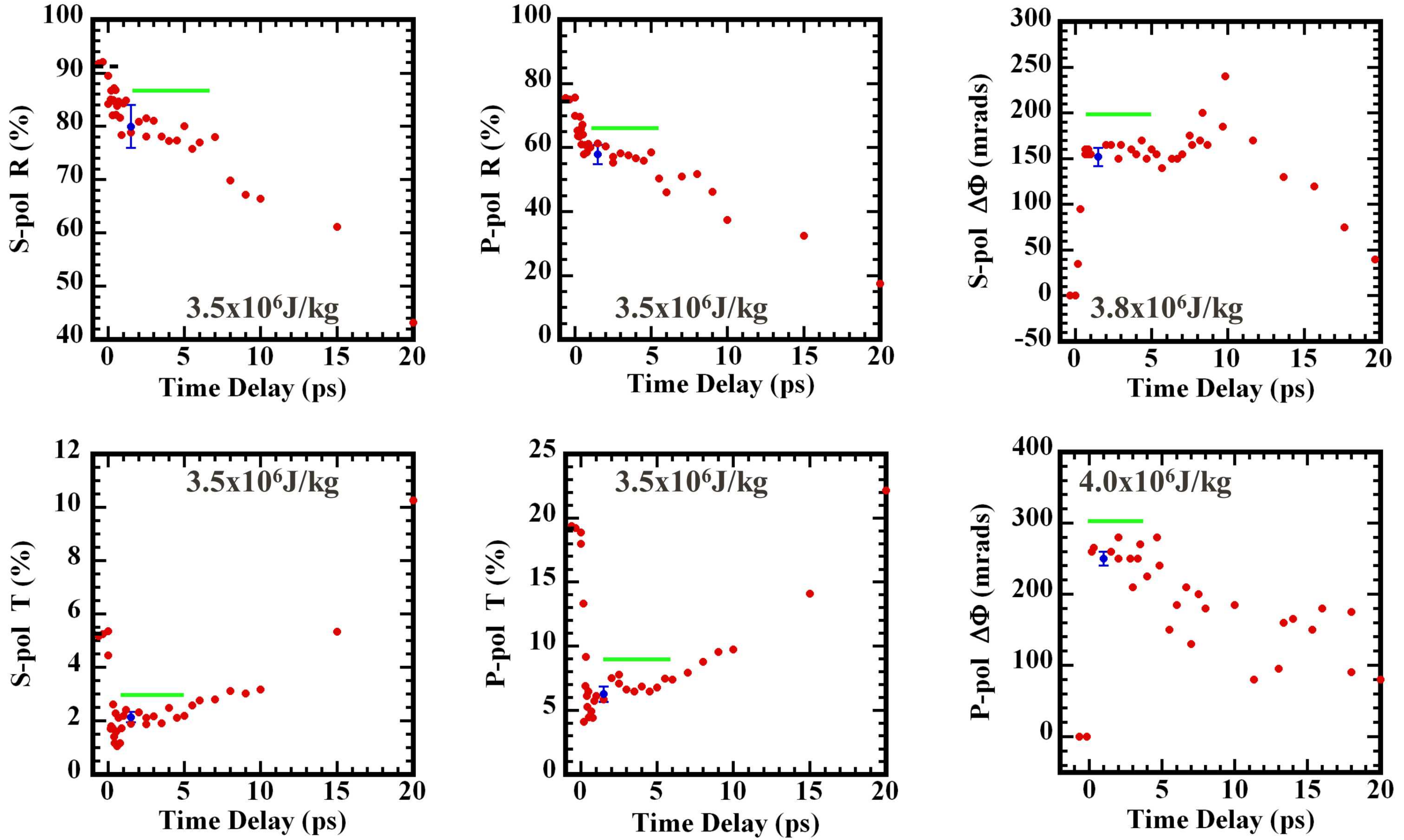
- Able to detect small changes in phase shift (~ 10 mrads)





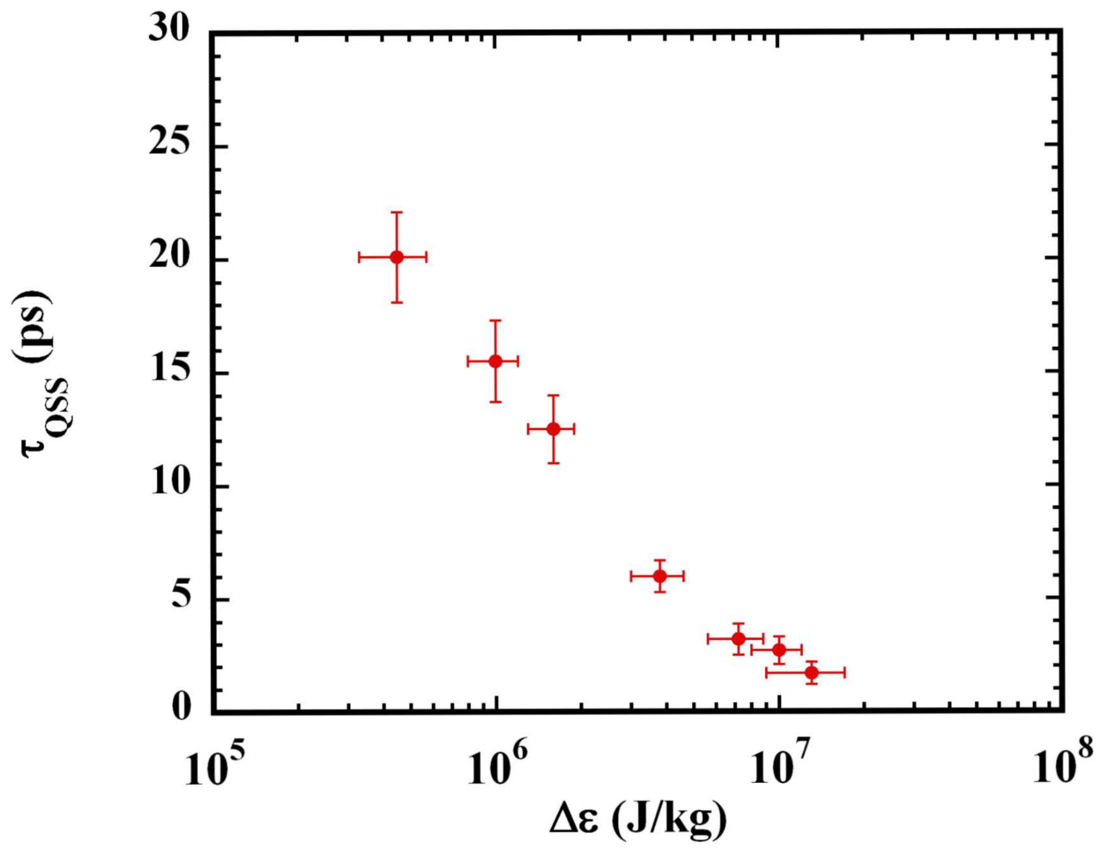


QUASI-STEADY-STATE BEHAVIOR IS OBSERVED IN 6 DIAGNOSTICS



To understand the onset of hydrodynamic disassembly

- Clear functional dependence on excitation energy
- Assess electron-ion equilibration process with modified Two-Temperature model



$$C_e(T_e)\frac{dT_e(t)}{dt} = -g\left[T_e(t) - \varepsilon_l(t)\frac{\rho_{Au}}{C_l}\right] + S(t)$$

$$\rho_{Au}\frac{d(\varepsilon_l(t))}{dt} = g\left[T_e(t) - \varepsilon_l(t)\frac{\rho_{Au}}{C_l}\right]$$

$$C_e(T_e) \rightarrow \begin{cases} A_e T_e, & T_e << T_F \\ \frac{3}{2}nk, & T_e \approx T_F \end{cases} \qquad \varepsilon_l(t) = \frac{C_l T_l(t)}{\rho_{Au}}$$

Electron-ion coupling: $g = (2.2\pm0.3)\text{x}10^{16}$ **W/m³·K**

Heat capacities: C_l**=2.5x10⁶ J/m³·K ,** A_e**= 68 J/m³·K²**

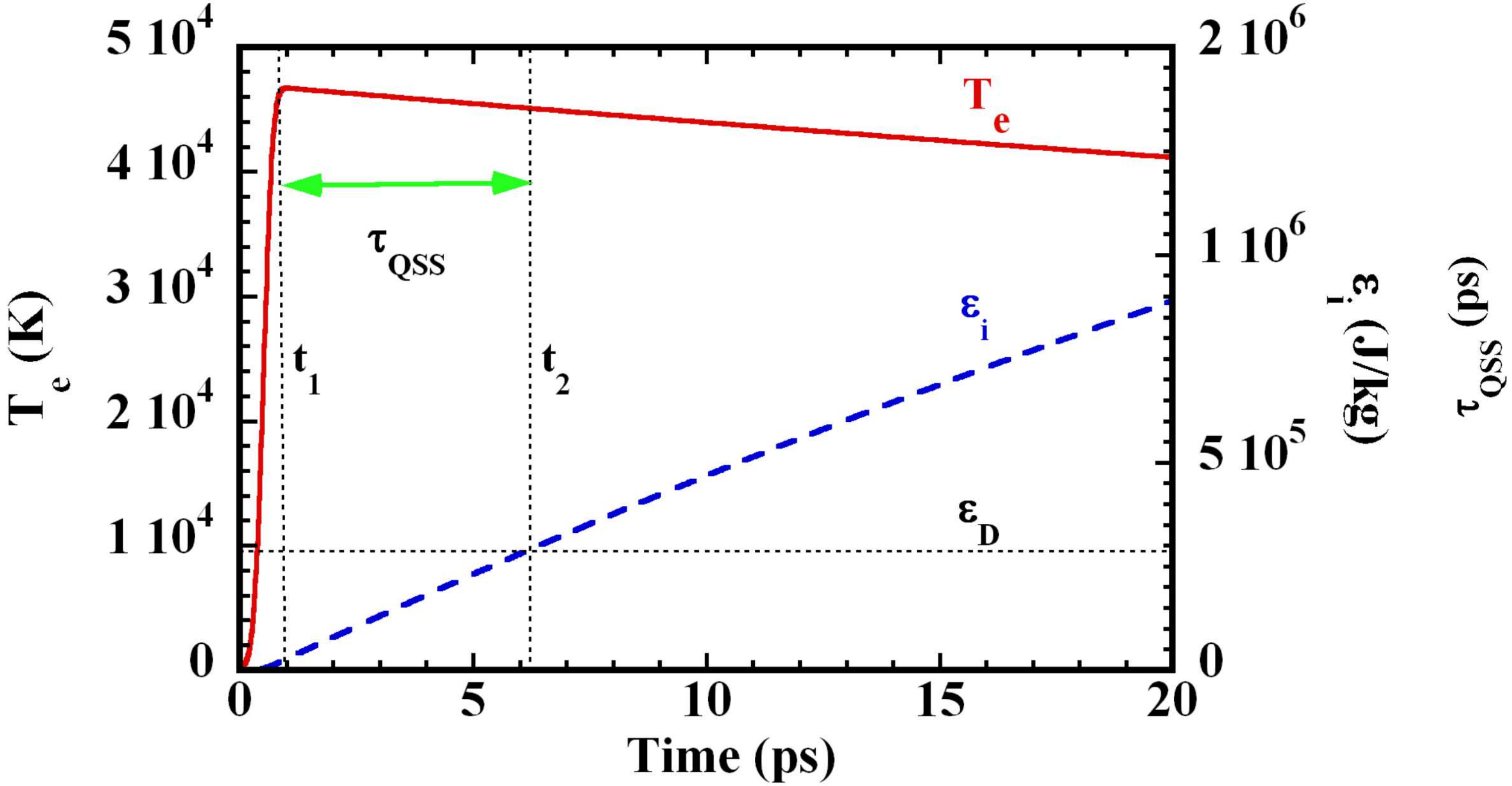
Laser energy deposition: $S(t) = \frac{\Delta\varepsilon\rho_{Au}}{\tau_P\sqrt{\pi}}\exp\left(-\frac{t^2}{\tau_P^2}\right)$

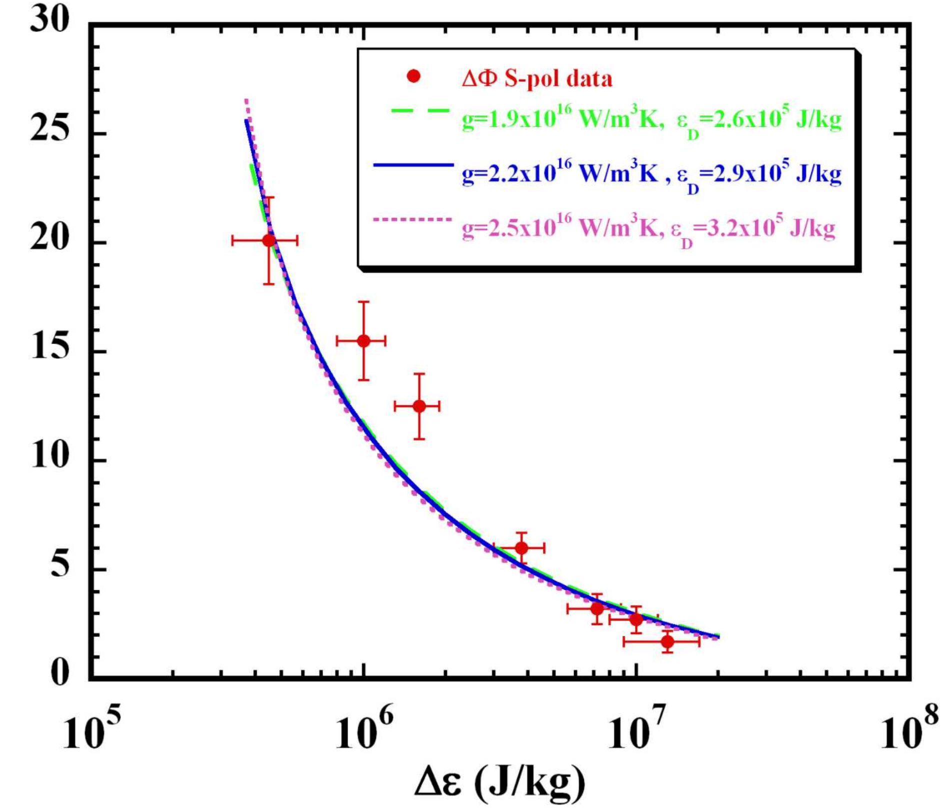
Results of model calculation show reasonable agreement with data

- The critical energy density for Au is found to be

$$\varepsilon_D = (2.9 \pm 0.3) \times 10^5 \text{ J/kg}$$

$$6.4 \times 10^4 \text{ J/kg} = \varepsilon_M < \varepsilon_D < \varepsilon_V = 1.7 \times 10^6 \text{ J/kg}$$





T. Ao , Y. Ping, K. Widmann, M. Foord, D. Price, E. Lee, H. Tam, P. Springer & A. Ng, PRL **96**, 055001 (2006)

Demonstrated Idealized Slab Plasma concept based on isochoric heating of an ultrathin foil using fs laser

Obtained single-state data on AC conductivity, DC conductivity, electron-ion collision time and average ionization

- Results for comparison with first principle theories

Correlation of solid-plasma phase transition

- Measured critical disassembly energy density

This work formed foundation for exploration of basic properties under extreme conditions