Picosecond Time-Resolved Temperature and Density Measurements with K-Shell Spectroscopy

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Laser: 10 J, <1 ps
Intensity: >10^{18} W/cm^2

0.2-μm buried Al layer

Plastic tamper

Electron temperature (eV)

- 10 J; Al surface layer
- 10 J; 1 μm CH

Time (ps)

0 5 10 15 20 25 30

0 100 200 300 400 500

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Bulk plasma conditions were inferred from picosecond time-resolved measurements of the He$\alpha$ thermal line from a buried Al tracer layer

- High-intensity, short-pulse laser interactions have been used to produce dense, high-temperature plasmas
- Picosecond streaked x-ray spectroscopy measured He$\alpha$ thermal line emission from a CH foil containing a buried Al tracer layer
- The plasma conditions were inferred from the thermal linewidth and satellite intensity ratio using a nonlocal thermodynamic equilibrium (NLTE) collisional-radiative atomic physics model*

**Summary**

Experimental uncertainties in the inferred plasma conditions are quantified in a self-consistent model-dependent framework.

*J. J. MacFarlane et al., High Energy Density Phys. 3, 181 (2007).*
Collaborators

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High-energy-density radiative and material properties studies require homogeneous, well-characterized plasmas

- The plasma conditions in dense, high-temperature plasmas are typically inferred with ultrafast thermal x-ray spectroscopy
- Previous work has demonstrated how the plasma conditions can be inferred by $\chi^2$ fitting or from line ratios and widths;* rigorous evaluation of experimental and statistical uncertainties is uncommon
- Statistical uncertainties must be evaluated and quantified in a self-consistent, model-dependent framework

Experiments using buried-layer targets access the dense, high-temperature plasma regime

- The target is plastic and contains a buried Al spectroscopic tracer layer

- The buried layer heats through collisional dissipation of a resistive return current

- Buried-layer emission is studied with an ultrafast streaked x-ray spectrometer

The data are compared to simulated spectra to infer the plasma conditions.

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\** D. J. Hoarty et al., High Energy Density Phys. 9, 661 (2013).
A focusing, time-resolved Hall spectrometer measured $\text{He}_\alpha$ emission from a buried Al layer

- Conically curved focusing potassium acid phthalate (KAP) crystal
- Spectral range $\pm 90$ eV around Al $\text{He}_\alpha$
- Spectral resolution $E/\Delta E \sim 1000$
- Temporal resolution $\sim 2$ ps

The measured spectra are averaged over the streak-camera temporal impulse response
Statistical uncertainties are quantified from detector photométrics and gain

- Uncertainty* in the He$_\alpha$ satellite intensity ratio is calculated from statistical uncertainties in the measured signal and background.
- Uncertainty in the He$_\alpha$ FWHM** is based on the likelihood that statistical signal fluctuations could be spuriously detected as FWHM crossing points.


**FWHM: full width at half maximum.
The instantaneous temperature and density were inferred by comparison to a NLTE collisional-radiative atomic physics model.

The calculation considers satellite production from Al IX to XIV ions with Doppler, Stark, natural, Auger, and opacity broadening contributions.

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*J. J. MacFarlane et al., High Energy Density Phys. 3, 181 (2007).*
Preliminary analysis shows the time-dependent plasma conditions for Al layers driven by a 10-J, 0.7-ps laser pulse.

K-shell atomic model dependence introduces an additional uncertainty of ~5% in $T_e$ and ~30% in $n_e$.

*T. Nagayama et al., High Energy Density Phys. 20, 17 (2016).*
The bulk plasma conditions were inferred using picosecond time-resolved measurements of the Al He$_\alpha$ thermal line from a buried tracer layer.

- High-intensity, short-pulse laser interactions have been used to produce dense, high-temperature plasmas
- Picosecond x-ray spectroscopy was used to measure the thermal line emission from a buried aluminum tracer layer
- The plasma conditions were inferred from the thermal linewidth and satellite intensity ratio using a NLTE collisional-radiative atomic physics model*

Experimental uncertainties in the inferred plasma conditions are quantified in a self-consistent model-dependent framework.