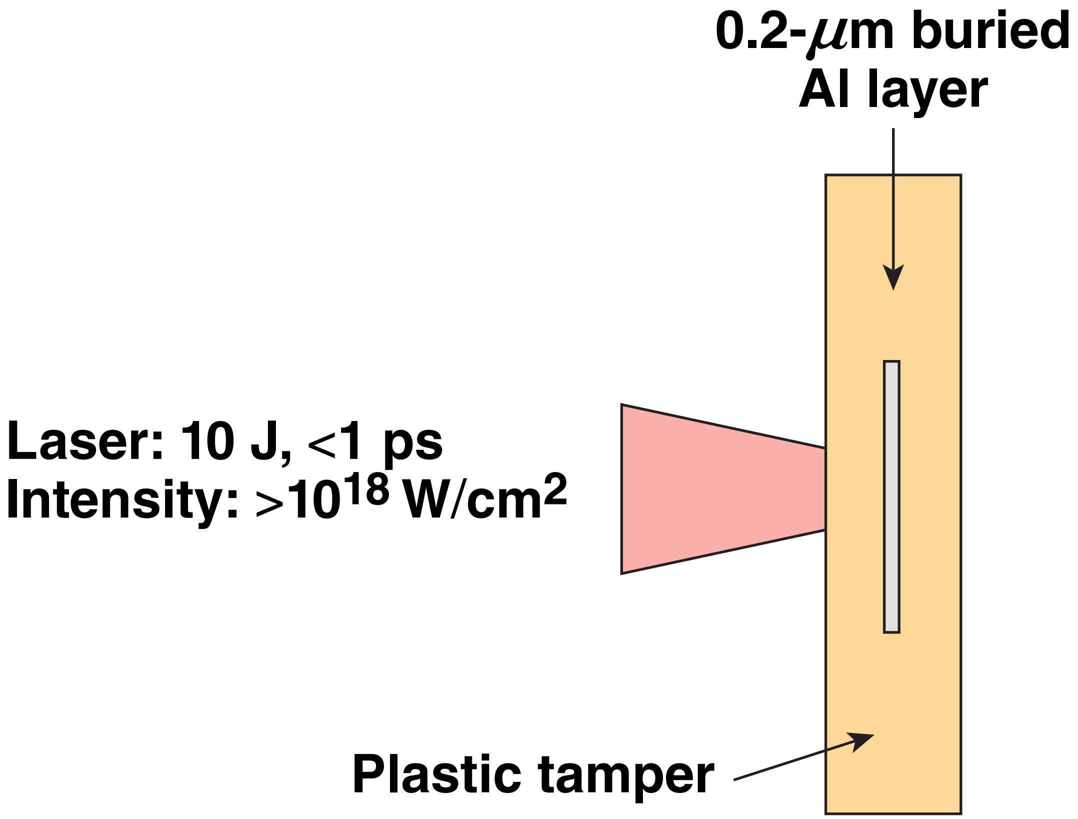
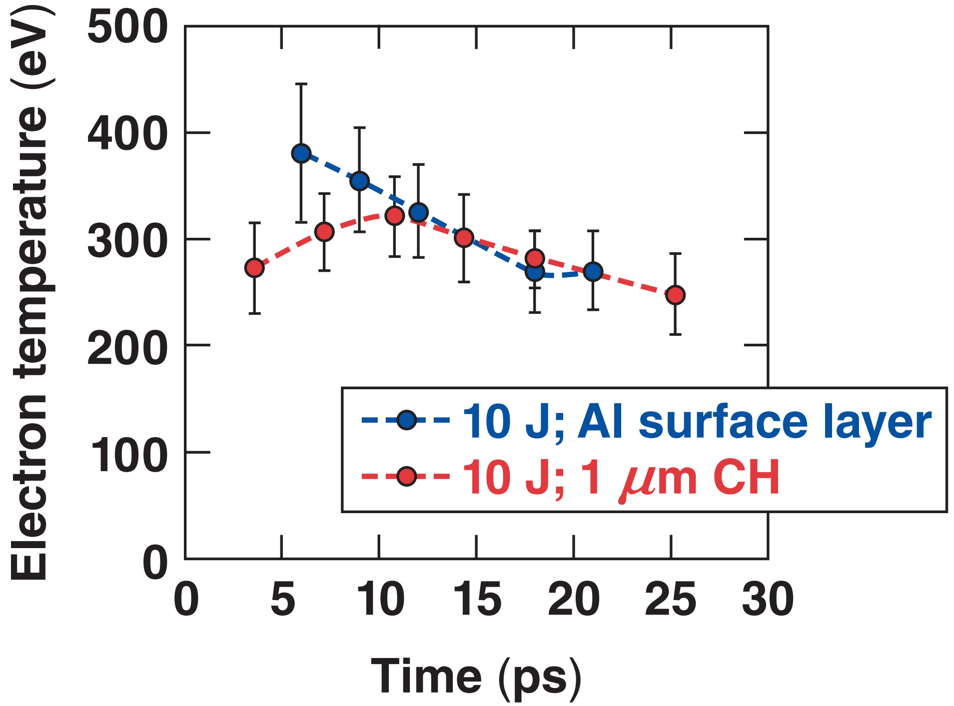
Picosecond Time-Resolved Temperature and Density Measurements with K-Shell Spectroscopy





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Summary

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*

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

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

Collaborators

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Prism Computational Sciences

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 χ^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

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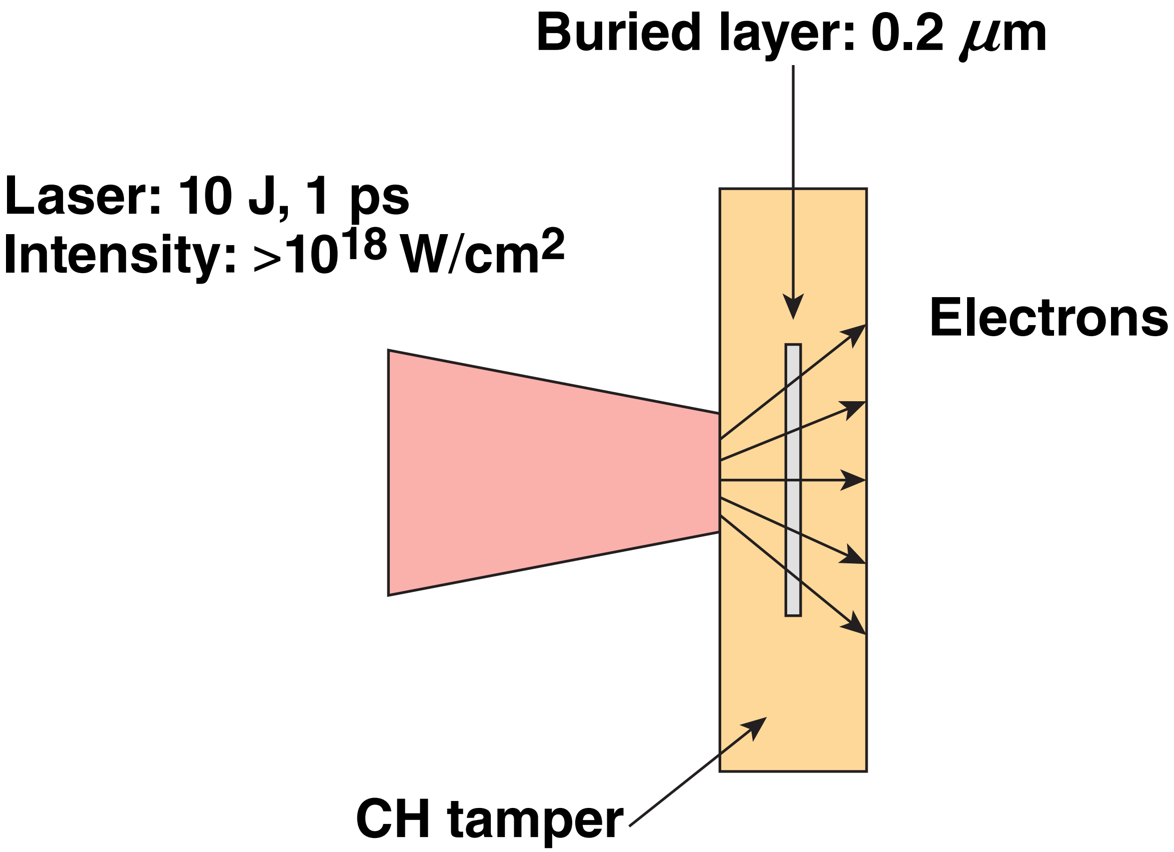
*H. R. Griem, *Principles of Plasma Spectroscopy* (Cambridge University Press, Cambridge, England, 1997).

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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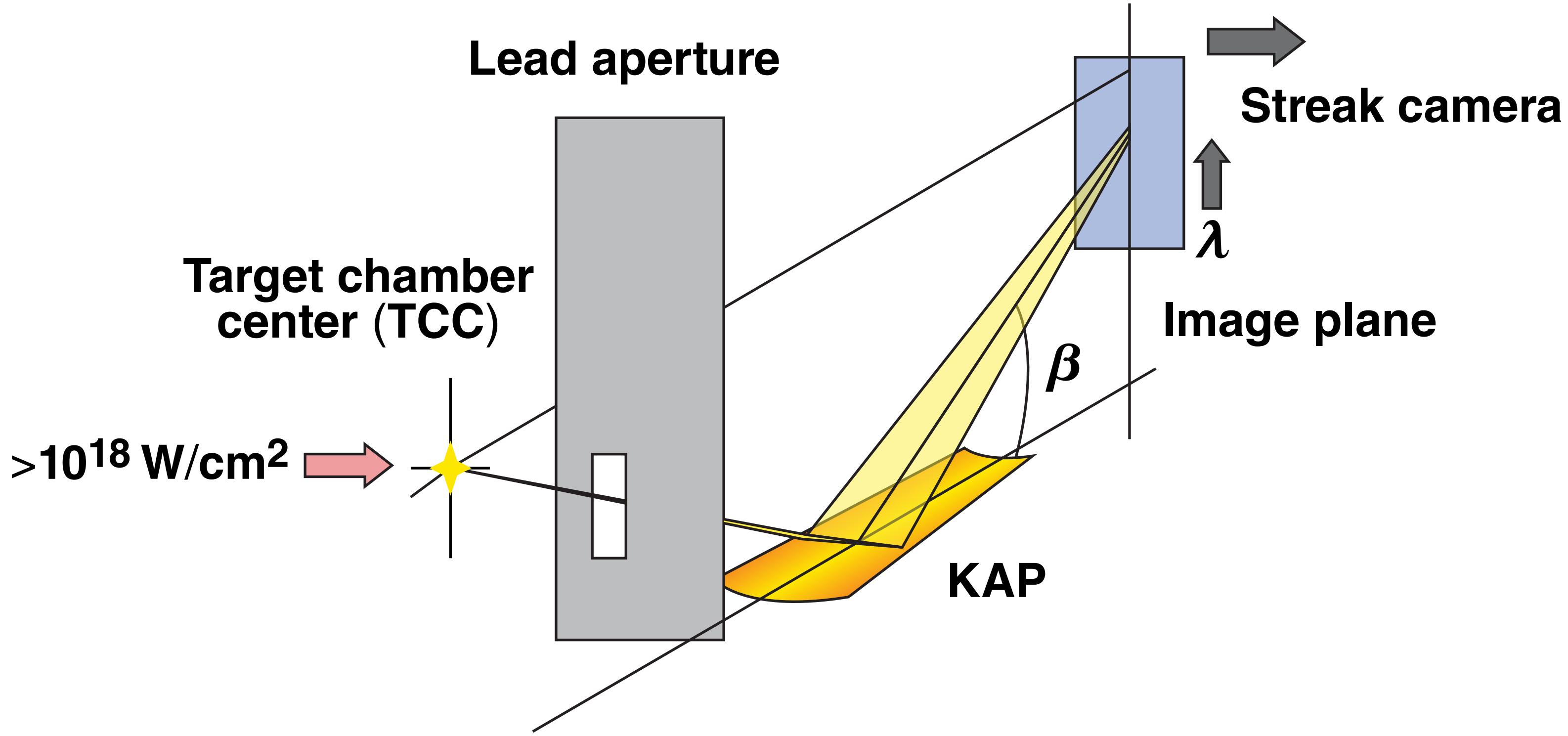
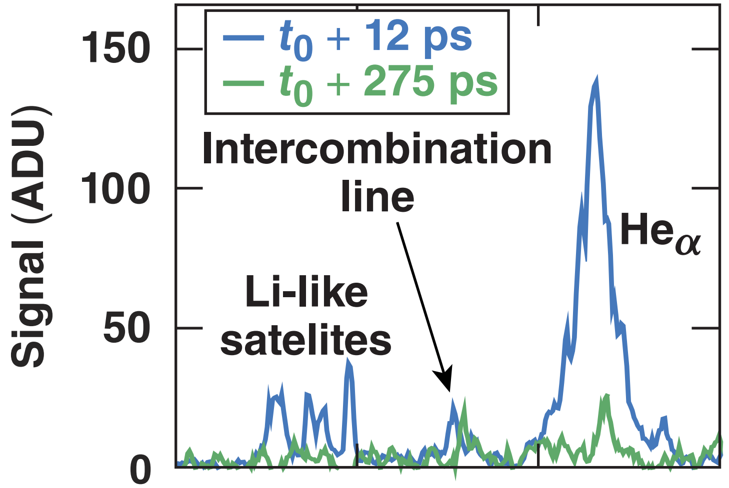
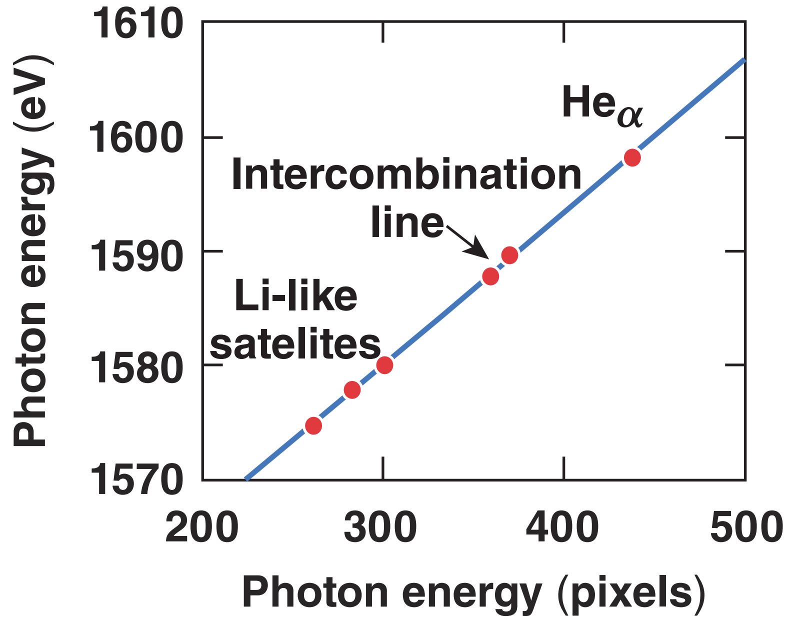
[*] C. R. D. Brown *et al.*, Phys. Rev. Lett. 106, 185003 (2011).
[**] D. J. Hoarty *et al.*, High Energy Density Phys. 9, 661 (2013).

A focusing, time-resolved Hall spectrometer measured He$_\alpha$ emission from a buried Al layer



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





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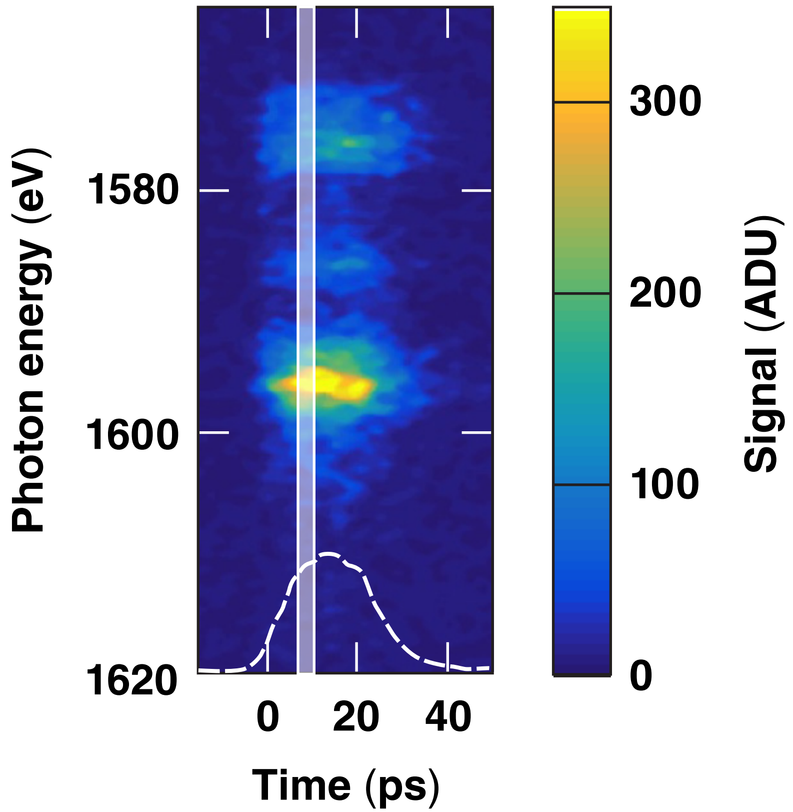
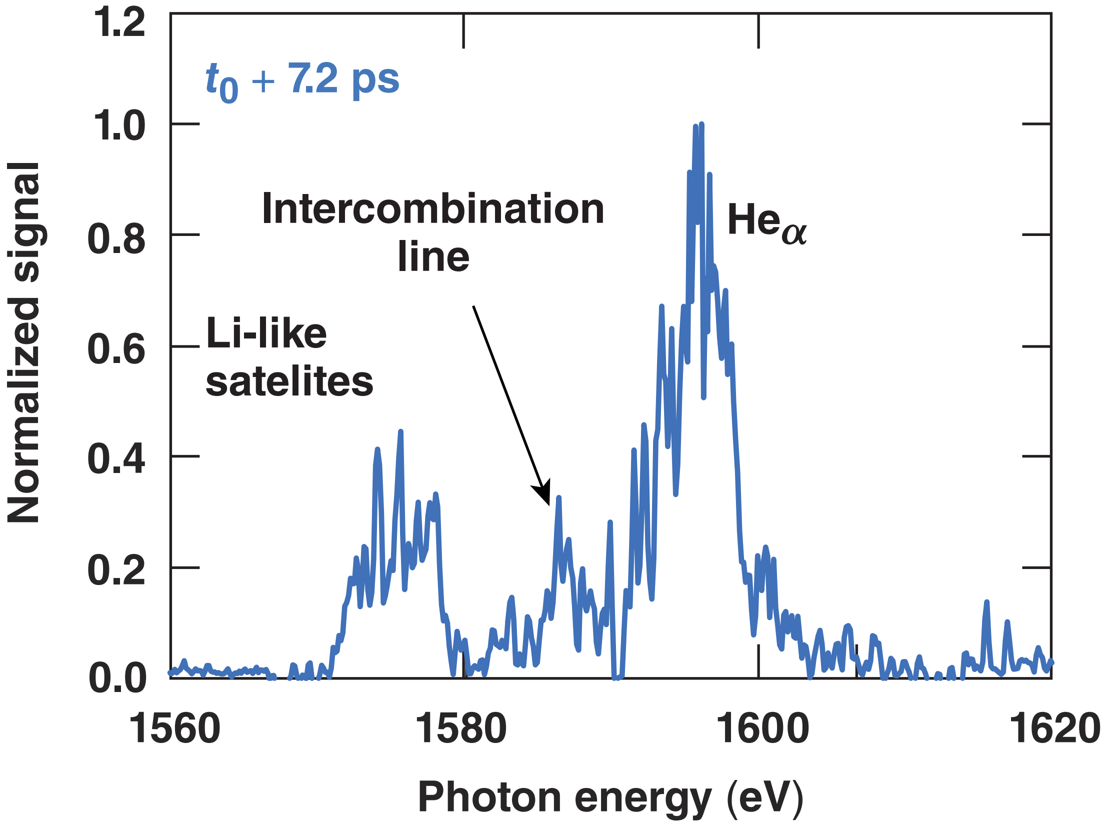
*T. A. Hall, J. Phys. E: Sci. Instrum. 17, 110 (1984).

The measured spectra are averaged over the streak-camera temporal impulse response





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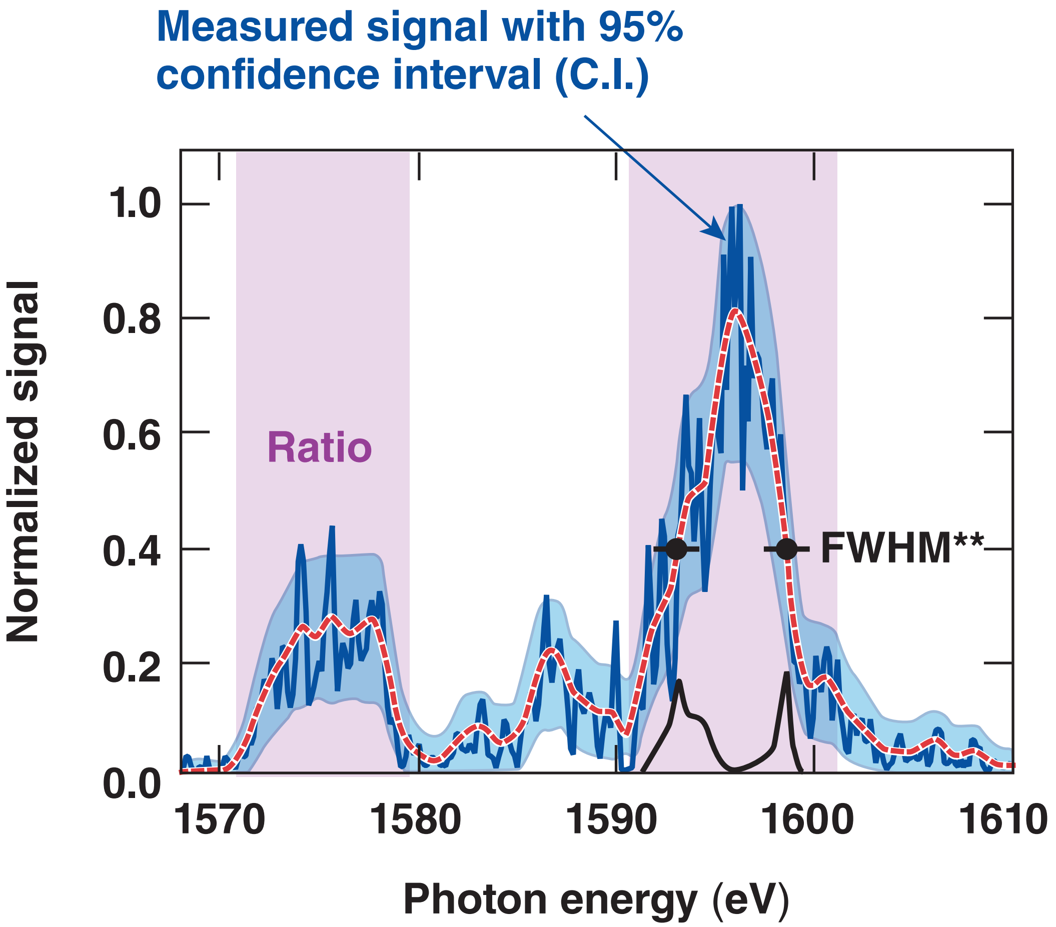
Statistical uncertainties are quantified from detector photometrics and gain



- 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

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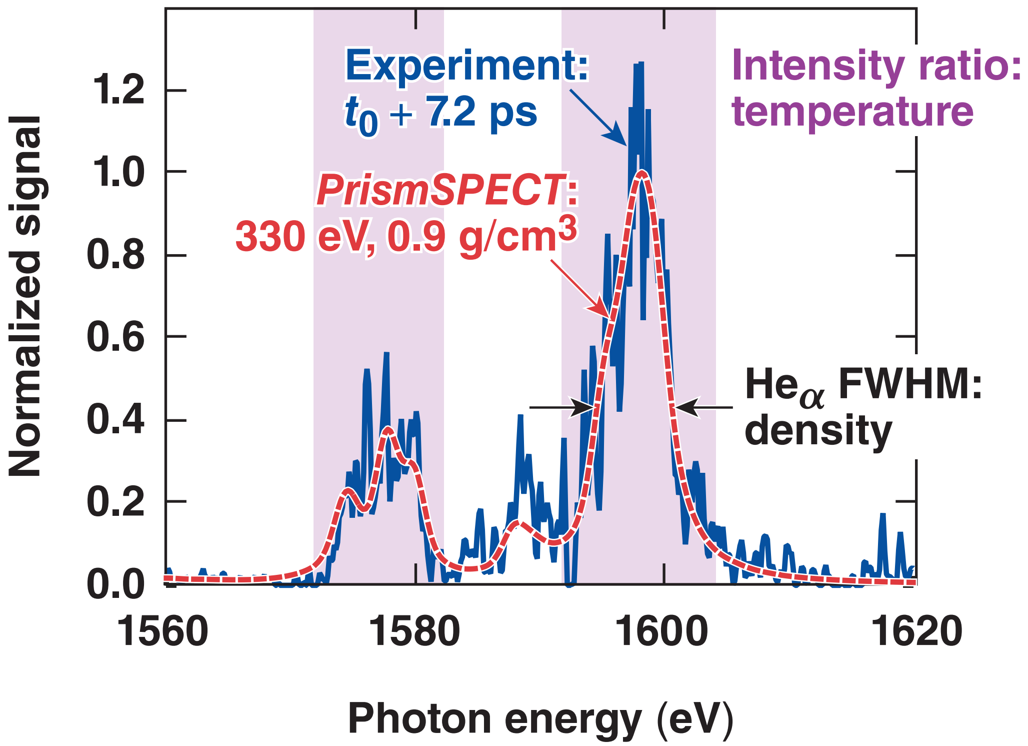
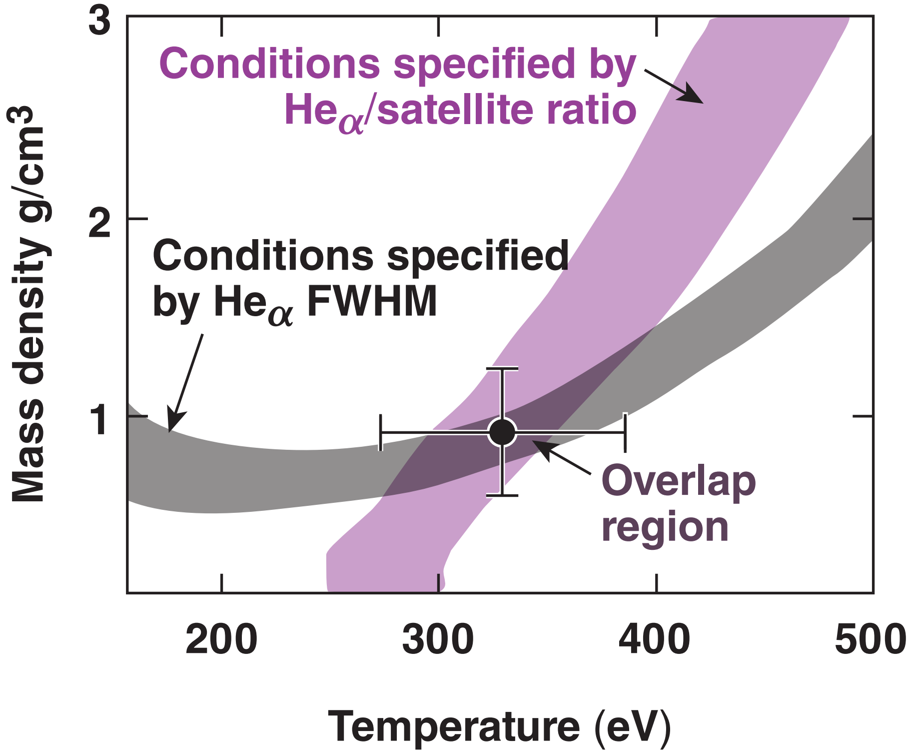
*P. R. Bevington and D. K. Robinson, *Data Reduction and Error Analysis for the Physical Sciences*, 3rd ed. (McGraw-Hill, Boston, 2003).

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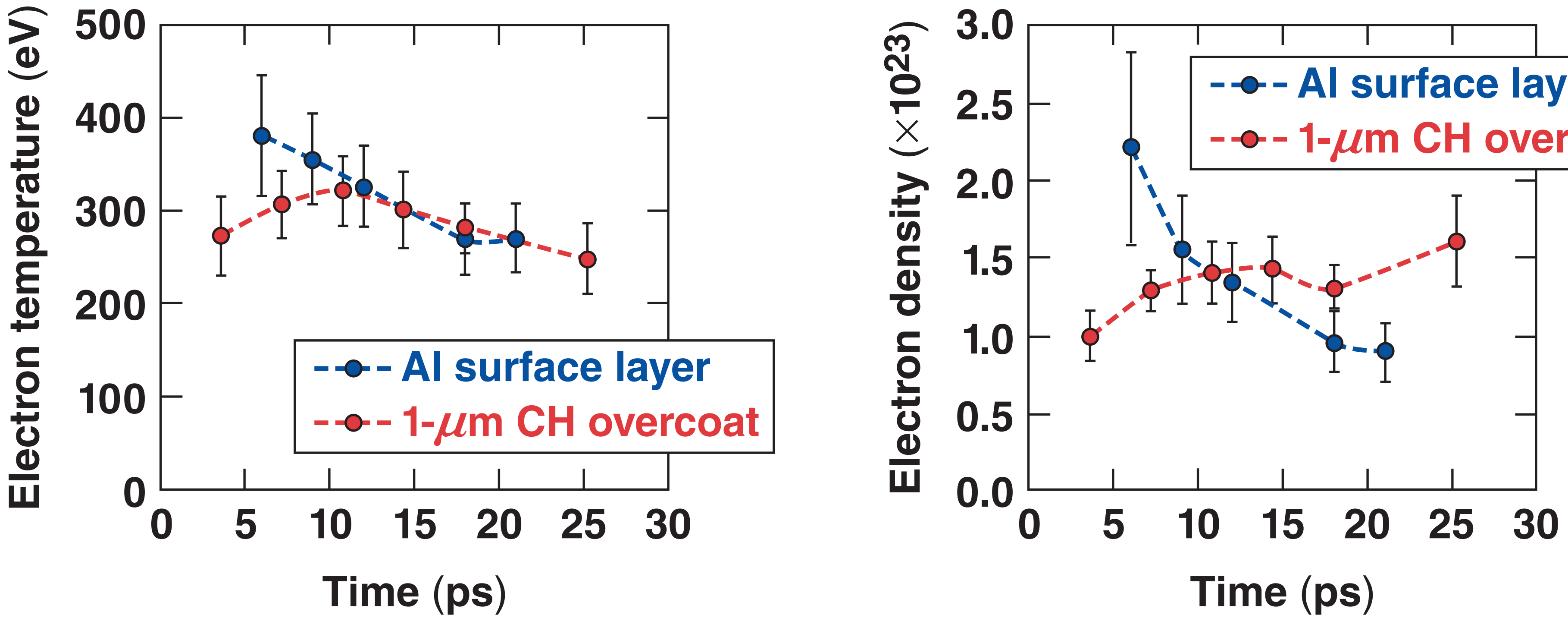
*J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).

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.*

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*T. Nagayama *et al.*, High Energy Density Phys. 20, 17 (2016).

Summary/Conclusions

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.

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