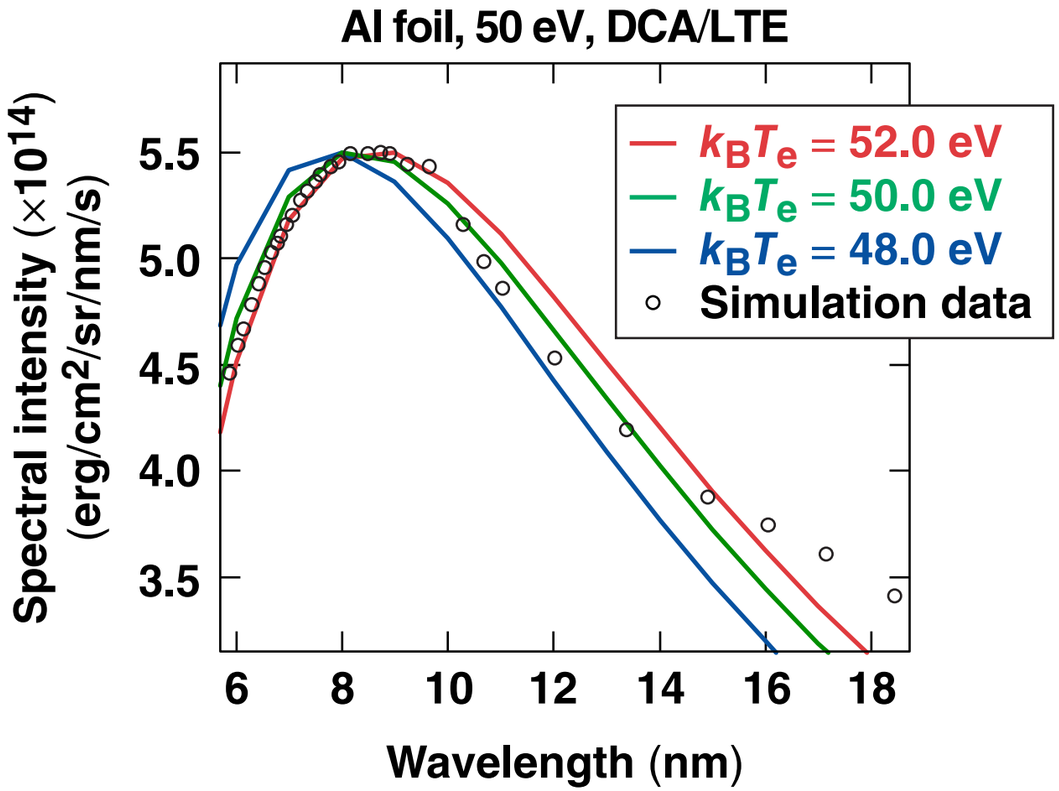
Design of an Extreme Ultraviolet Spectrometer Suite for Isochoric-Heated, Warm-Dense-Matter Studies



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Summary

A new extreme ultraviolet (XUV) spectrometer is sought to make high-precision temperature measurements (<5%) of releasing high-energy-density (HED) material

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- An experimental platform is being developed to study the off-Hugoniot equation of state (EOS) of rapidly heated solids
- An optimized spectrometer incorporating a toroidal mirror and custom holographic grating have been designed
  - a high-throughput (600-$\mu m^2 \cdot$ sr) design yields a signal-to-noise ratio (SNR) of 200
  - simulated emission spectra suggest requiring at least an SNR of 50 to discriminate 2 eV at 50 eV
- Target diagnostics in the XUV will give a measure of the surface temperature of the heated sample, providing a complementary measure to higher-energy spectroscopic measurements (e.g., K_α line spectroscopy) of a mass-averaged temperature

Collaborators

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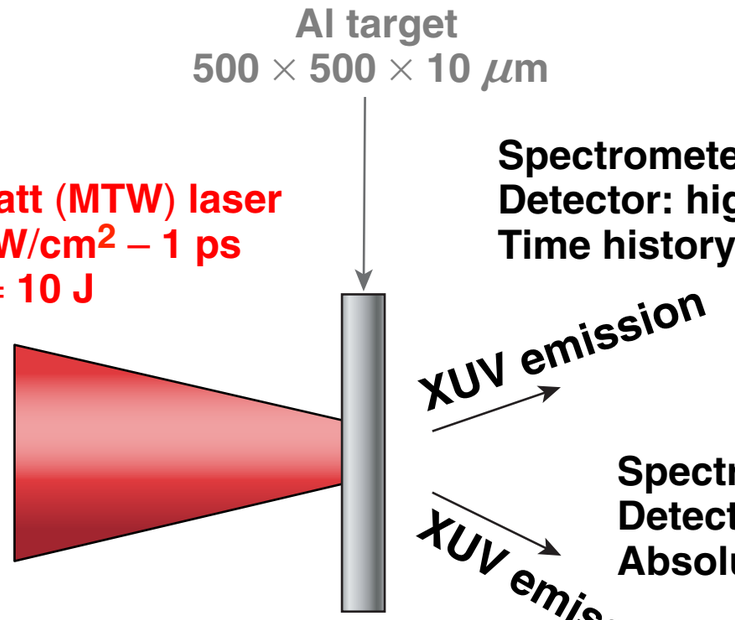
Motivation

An experimental platform is being developed to study the creation of HED matter by laser-generated electron heating



Spectrometer: XUV Spec 1
Detector: high-speed streak camera
Time history of emission (2 ps)

XUV emission

Spectrometer: XUV Spec 2
Detector: SI-800 charge-coupled device (CCD)
Absolute XUV photon yield

XUV emission

- Initial experiments will infer temperature dynamics at the target surface
- Future experiments will be combined with side-on radiography to measure the release isentrope* simultaneously

The data will be compared to simulated spectra to infer the surface temperature.

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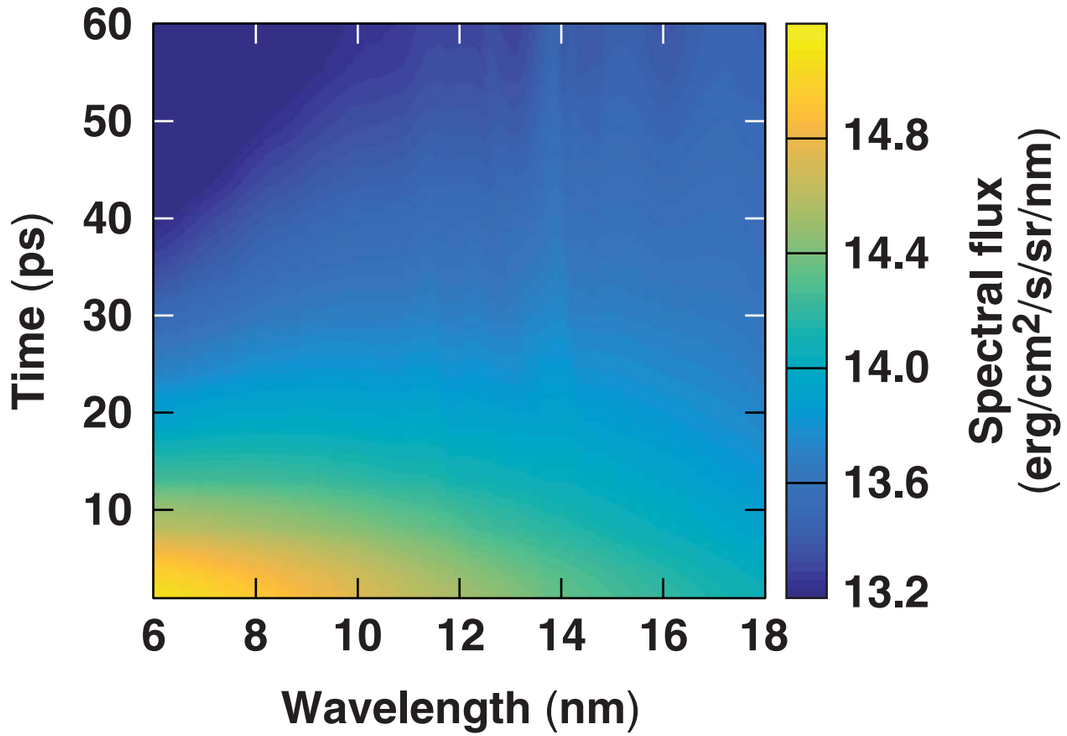
*M. E. Foord, D. B. Reisman, and P. T. Springer, Rev. Sci. Instrum. 75, 2586 (2004).

A synthetic streak image of the XUV emission from a target shows a smooth continuum emission early in time

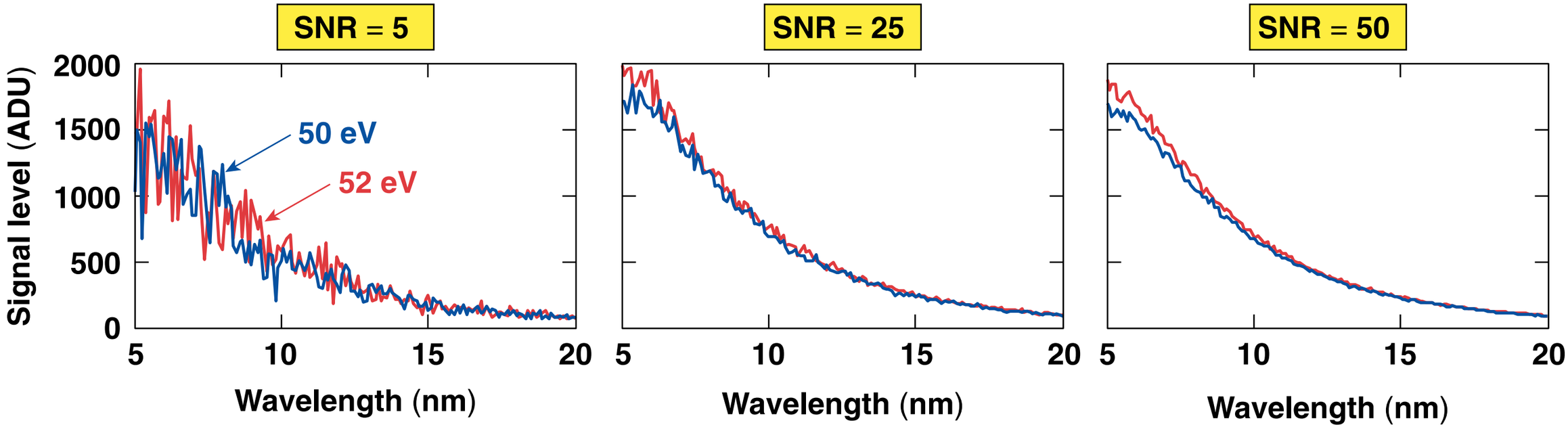
- Al target, 50-eV initial temperature, 10 μm thick, free expansion
- *LILAC* simulation postprocessed in *Spect3D**
  - detailed-configuration accounting (DCA) atomic model
  - local thermodynamic equilibrium (LTE) radiative model
- Simulated detector parameters
  - $E/\Delta E = 70$
  - $\delta t = 2$ ps



The temperature of the target can be inferred from the local slope of the continuum emission.

*Prism Computational Sciences, Inc., Madison, WI 53711.

A signal-to-noise ratio of >50 in the continuum is required for 2-eV discrimination at 50 eV in the region of interest



- Solid Al at 50 and 52 eV, respectively, 5 ps into expansion
- Synthetic Gaussian noise spectrum applied

A high-throughput, low-background spectrometer is required to constrain the measured temperature to a few eV.

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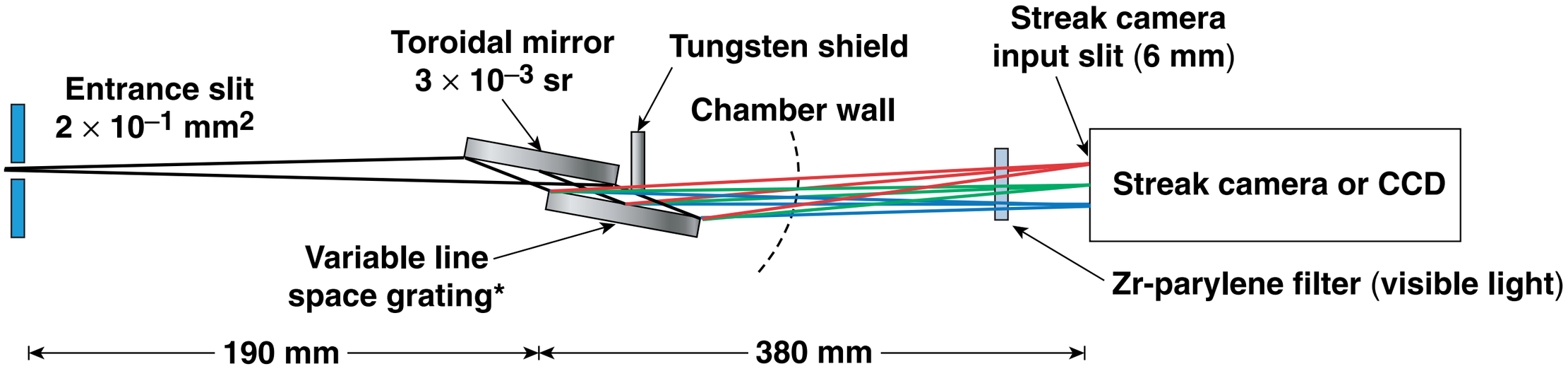
Conceptual Design

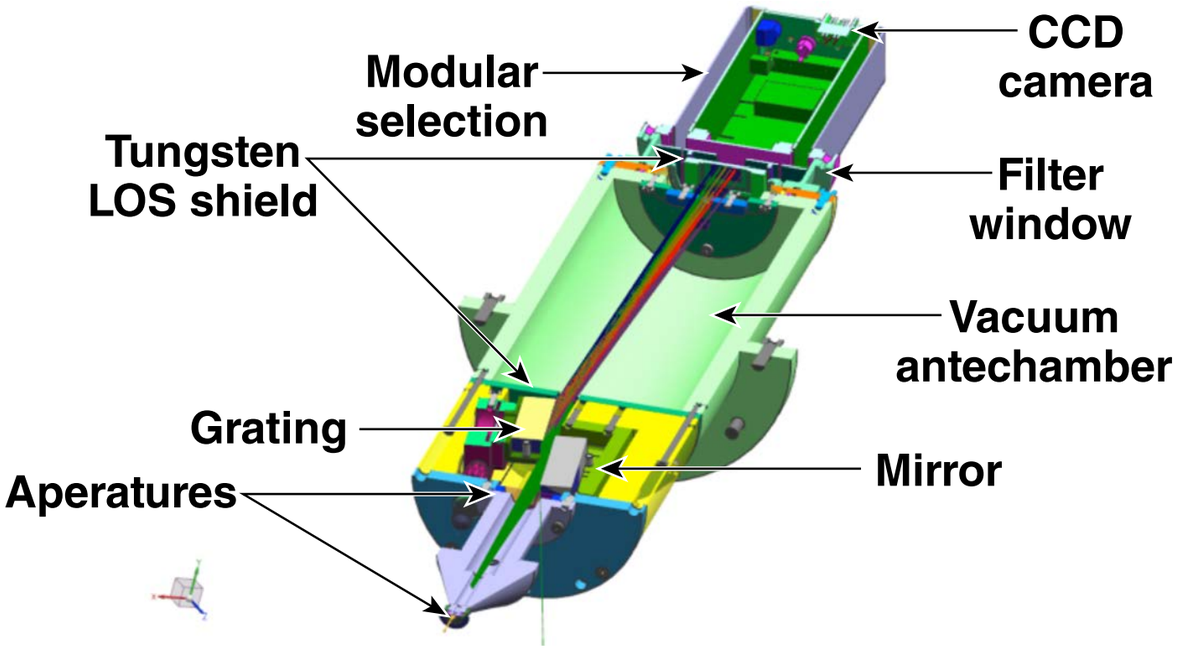
High throughput can be obtained with a toroidal mirror and grating pair



- A shield blocks the direct line of sight (LOS) to the target, minimizing the background signal
- A variable line space grating eliminates the need to collimate, disperse, and refocus the beam, allowing for high throughput in a compact system

*HORIBA Scientific, Edison, NJ 08820.

The expected spectral emission combined with spectrometer throughput suggests SNR > 50 should be attainable with the design



Quantity	Value
Power emitter	1×10^{23} W/m^3 sr
Collection solid angle	3×10^{-3} sr
Emitter area	2×10^{-3} cm^2
Mirror reflectivity	0.75
Grating efficiency	0.25
Dwell time	0.5 ps
Zr filter (2 μm)	1.1×10^{-2}
Energy in signal	2.8×10^{-12} J
XUV photon yield	1.3×10^{5} photons
Photocathode quantum efficiency (QE)	0.04
Streak tube gain	170 to 368 CCD e$^-$/absorbed photon
CCD ADU	2.2×10^{4} CCD ADU
Noise ADU on MTW 10 J, 1-ps shot	100 CCD ADU
Estimated SNR	220

- Modular architecture allows the spectrometer body to mate with either scientific CCD back or streak camera back

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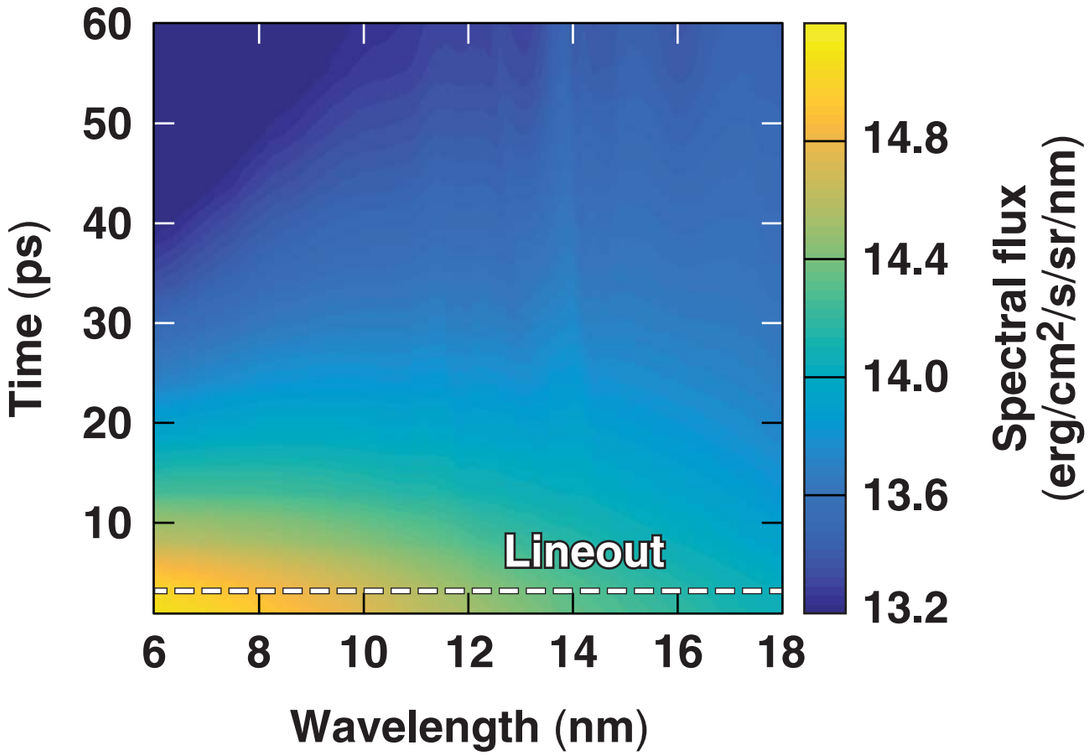
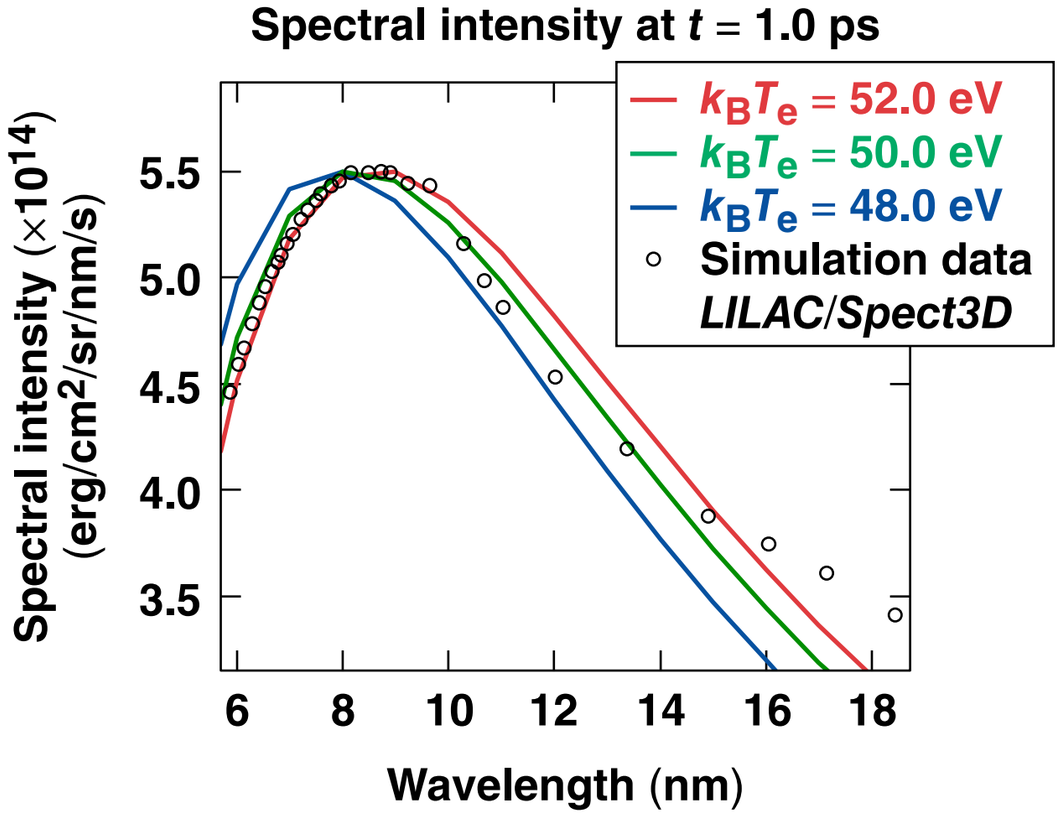
The inferred initial surface temperature from the simulation agrees to within the expected error (±2 eV)





- 1-D *LILAC* simulation post-processed with *Spect3D*

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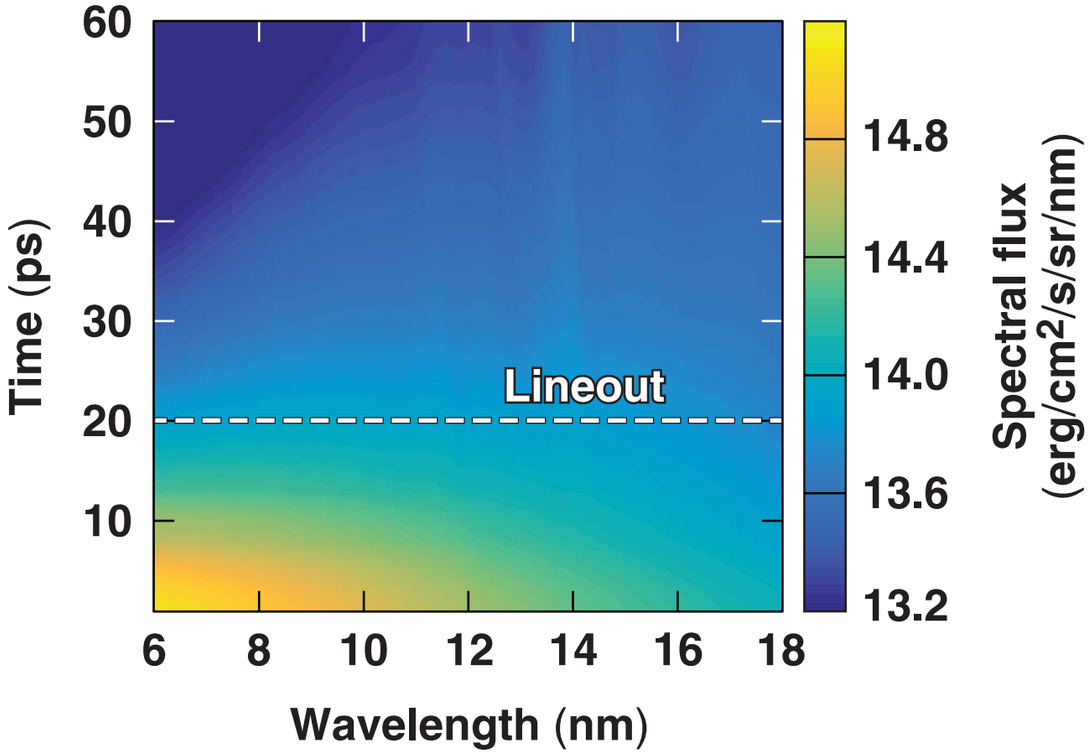
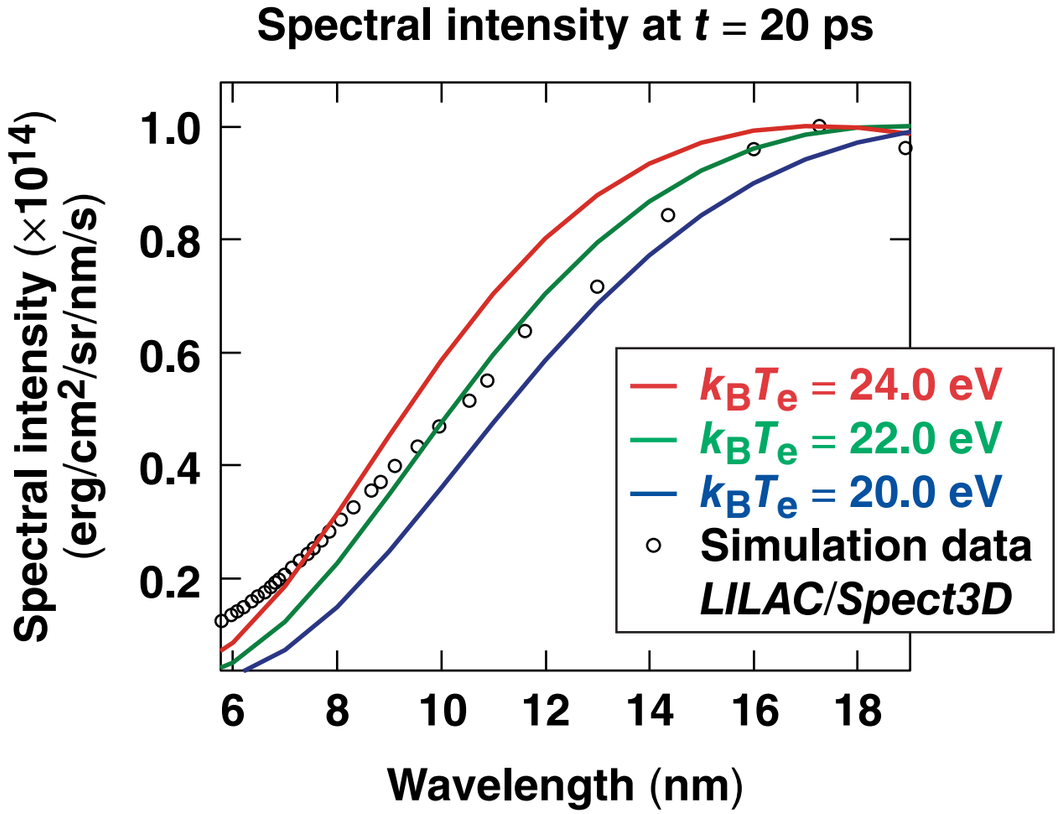
The target surface cools to 22±2 eV in 20 ps





- 1-D *LILAC* simulation post-processed with *Spect3D*

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Summary/Conclusions

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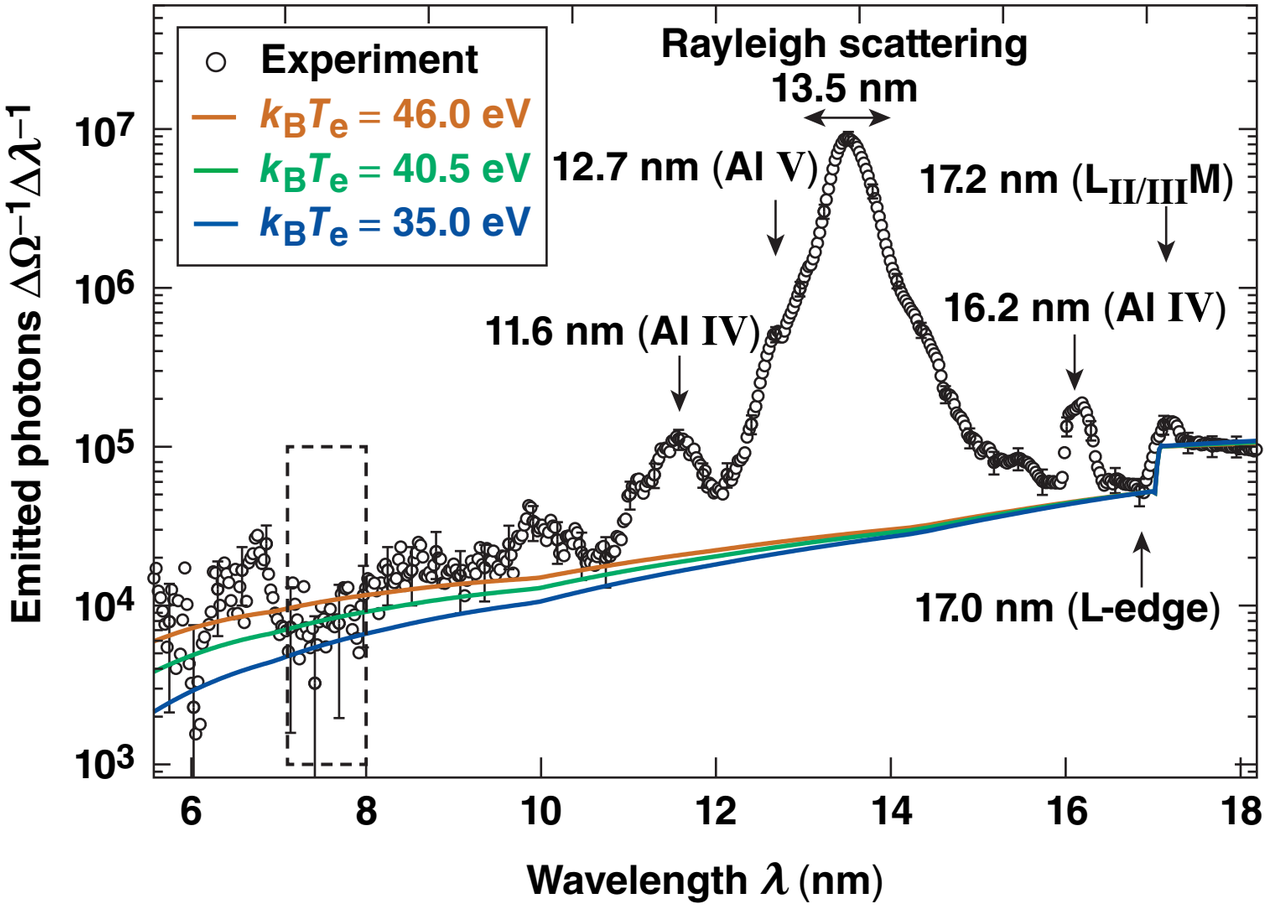
XUV spectroscopy makes it possible for the temperature and density to be inferred at the target surface

- The temperature is inferred in two ways:* continuum (40±5 eV) and line ratio at 11.6 and 16.2 nm (34±6 eV) $n_e = 4 \times 10^{22}$ cm^{-3}
- Compliance between thermal line radiation and continuum may be caused by emission at different times in the expansion



*U. Zastrau *et al.*, Phys. Rev. E 78, 066406 (2008).