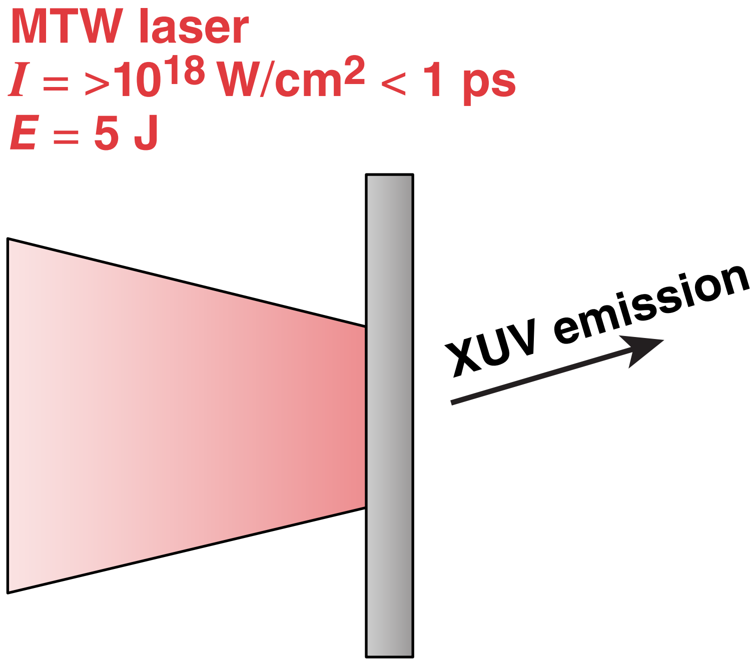
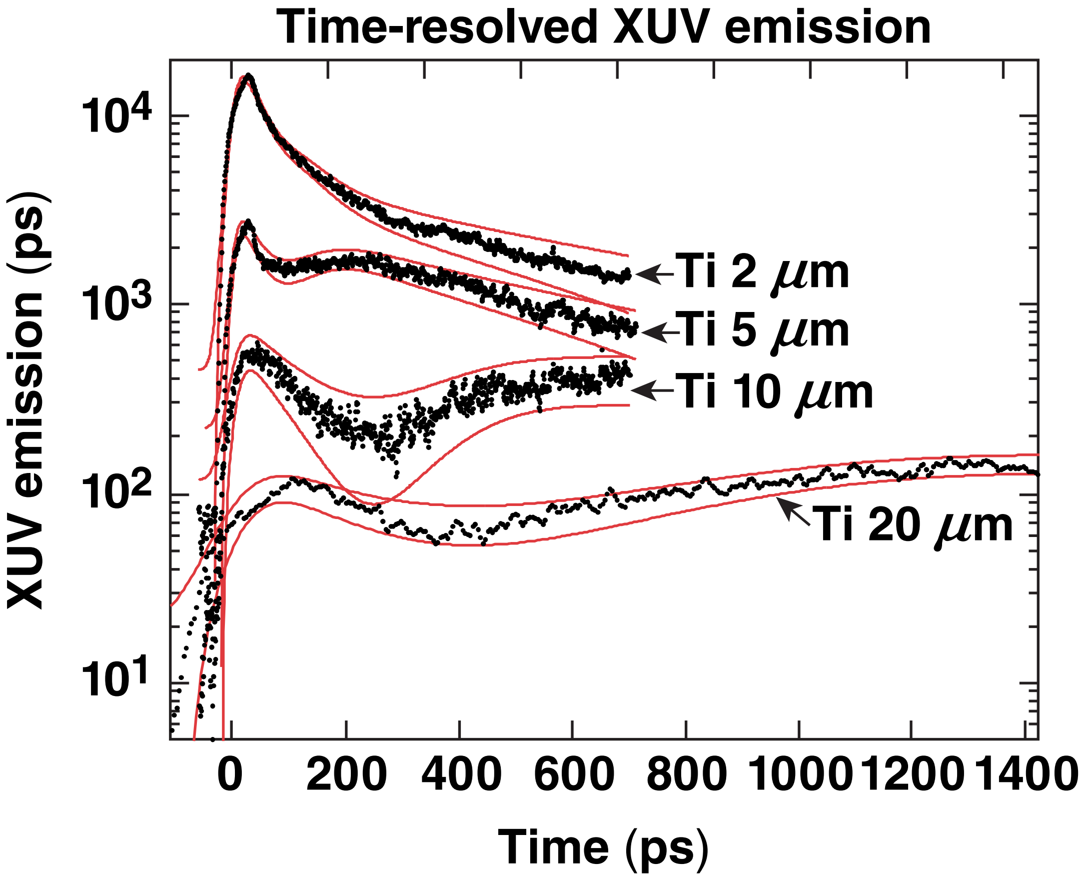
Blast-Wave Generation and Propagation in Rapidly Heated Laser-Irradiated Targets





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Summary

Experiments with laser-heated foils have measured the energy deposition into a blast wave from a high-intensity laser

- A blast wave is observed to emerge from the rear surface of a target heated by a short-pulse laser
  - the time between the prompt emission (electron-driven x-ray emission) and the blast-wave arrival is used to estimate the energy deposition in the wave
  - the data are consistent with a Sedov–Taylor blast wave, with energy transfer from the laser to the blast of up to 20 mJ
- Streaked extreme ultraviolet spectroscopy measured the time history of the thermal radiation emitted from the target
- These data represent the first quantitative assessments of the blast-wave energy following ultrashort heating from a laser

Collaborators

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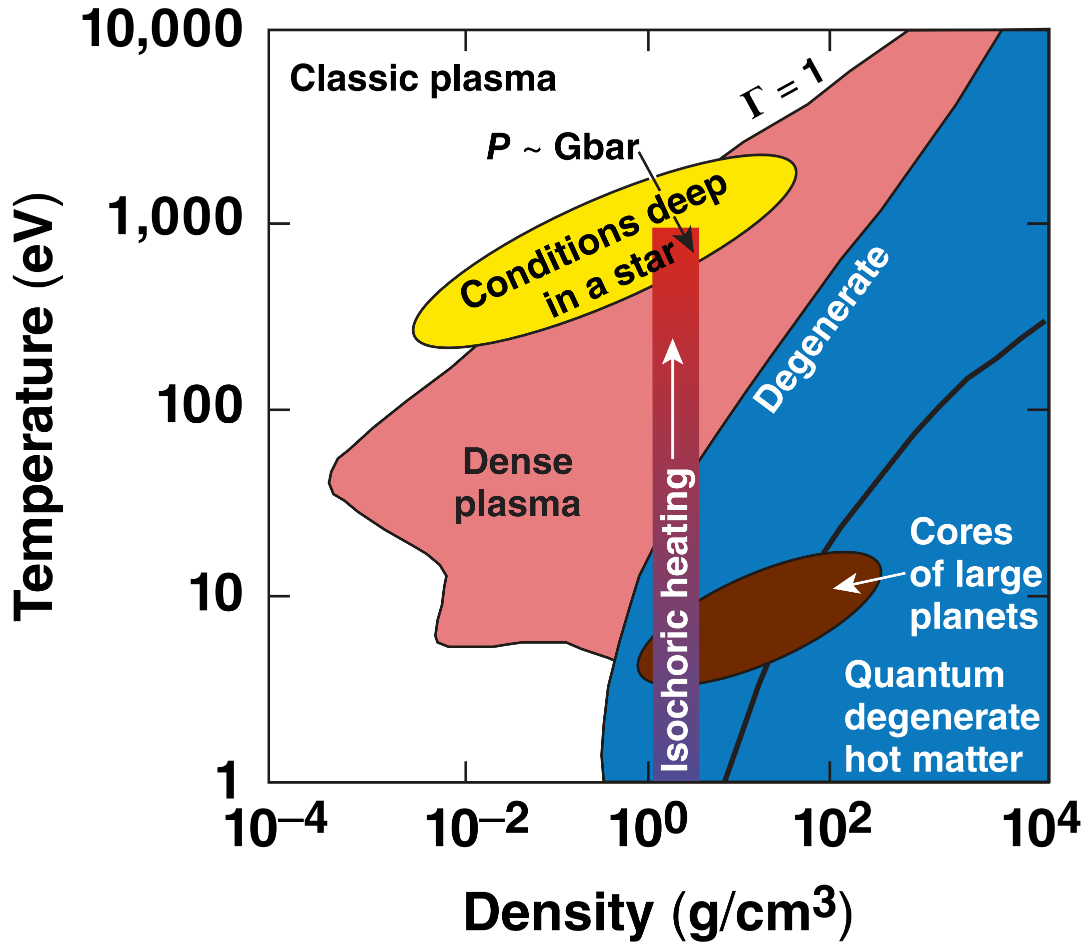
Motivation

The controlled production and characterization of extreme pressures is a current driver in high-energy-density (HED) science

- High-energy (kJ), long-pulse (ns) lasers are used to shock compress material to <100 Mbar in conventional shock experiments
- Short-pulse heating of a target allows access to off-Hugoniot states not readily achievable with other shock platforms
- By generating hot dense matter with a short pulse at the target surface and allowing it to sweep up the surrounding colder material, we can generate extremely high pressure states >100 Mbar on MTW,* and possibly >1 Gbar on OMEGA EP

Short-pulse laser–solid interaction provides a path to create high temperature dense plasmas, but understanding their initial conditions remains a challenge.



A Report on the SAUUL Workshop, Washington, DC (17–19 June 2002).
K. Nazir *et al.*, Appl. Phys. Lett. 69, 3686 (1996).
J. E. Bailey *et al.*, Nature 517, 56 (2015).
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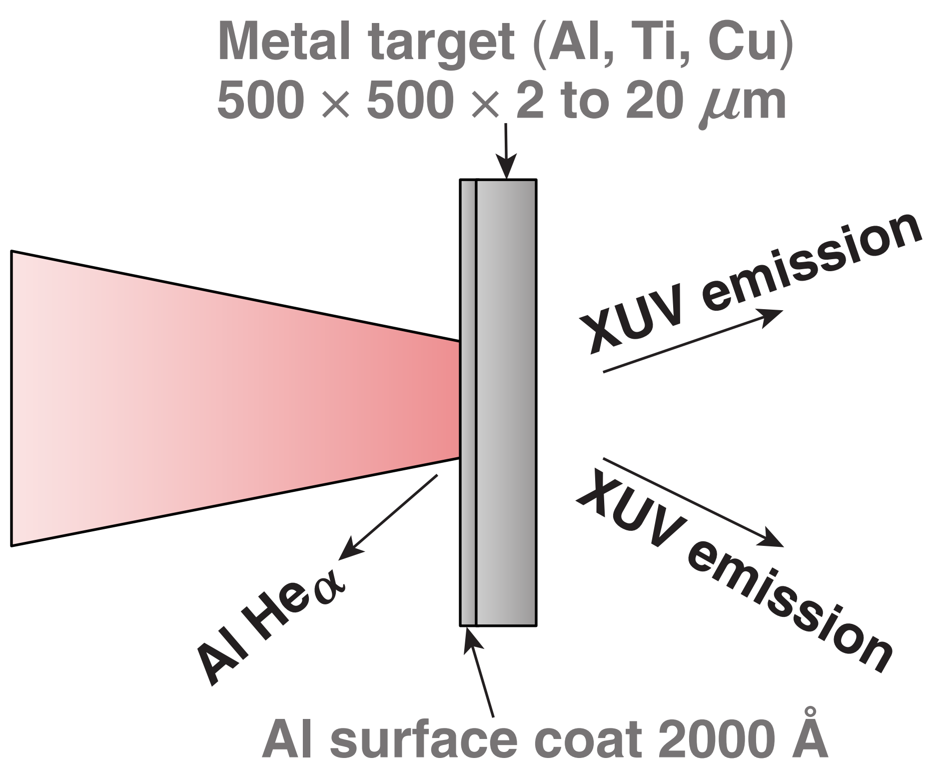
M. E. Foord, D. B. Reisman, and P. T. Springer, Rev. Sci. Instrum. 75, 2586 (2004).

*MTW: Multi-Terawatt Laser

E21173j

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

MTW laser
I = >10^{18} W/cm^2 < 1 ps
E = 5 J
1.054 μm
Focal spot <5 μm



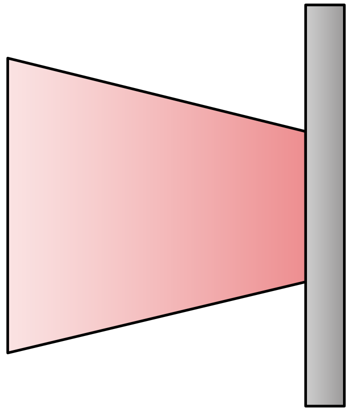
XUV spectrometer 1**
Detector: high-speed streak camera
Time history of emission

XUV spectrometer 2**
Detector: SI-800 CCD†
Absolute XUV‡ photon yield

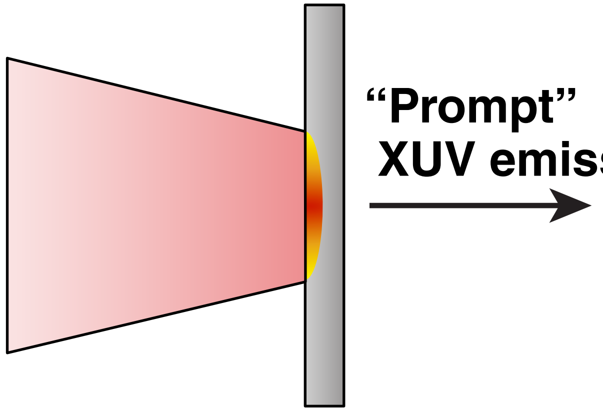
Al Von Hamos Spectrometer*
Detector: high-speed streak camera
Surface temperature and density

*C. R. Stillman *et al.*, YO6.00008, this conference.
**S. T. Ivancic *et al.*, Rev. Sci. Instrum. 87, 11E538 (2016).
†CCD: charge-coupled device
‡XUV: extreme ultraviolet

The blast wave is created in a conversion from fast electron to thermal energy

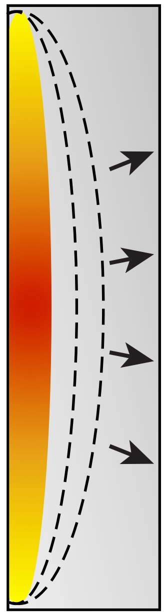


A high-contrast, short-pulse laser is incident on a solid metal target

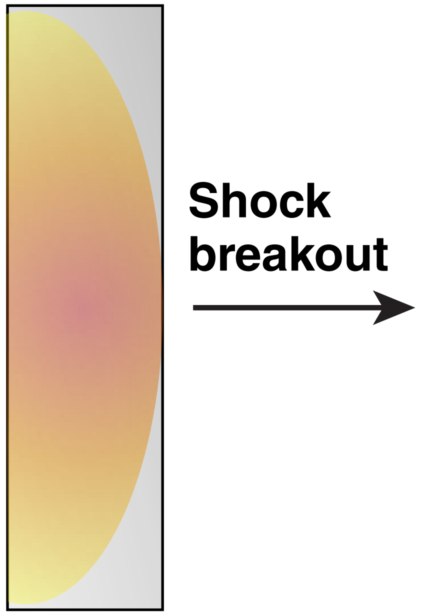


“Prompt” XUV emission

A large proportion of the energetic electrons deposit their energy in a hot layer near the surface of the target; electrons that make it through the target create rapid XUV emission on the back surface



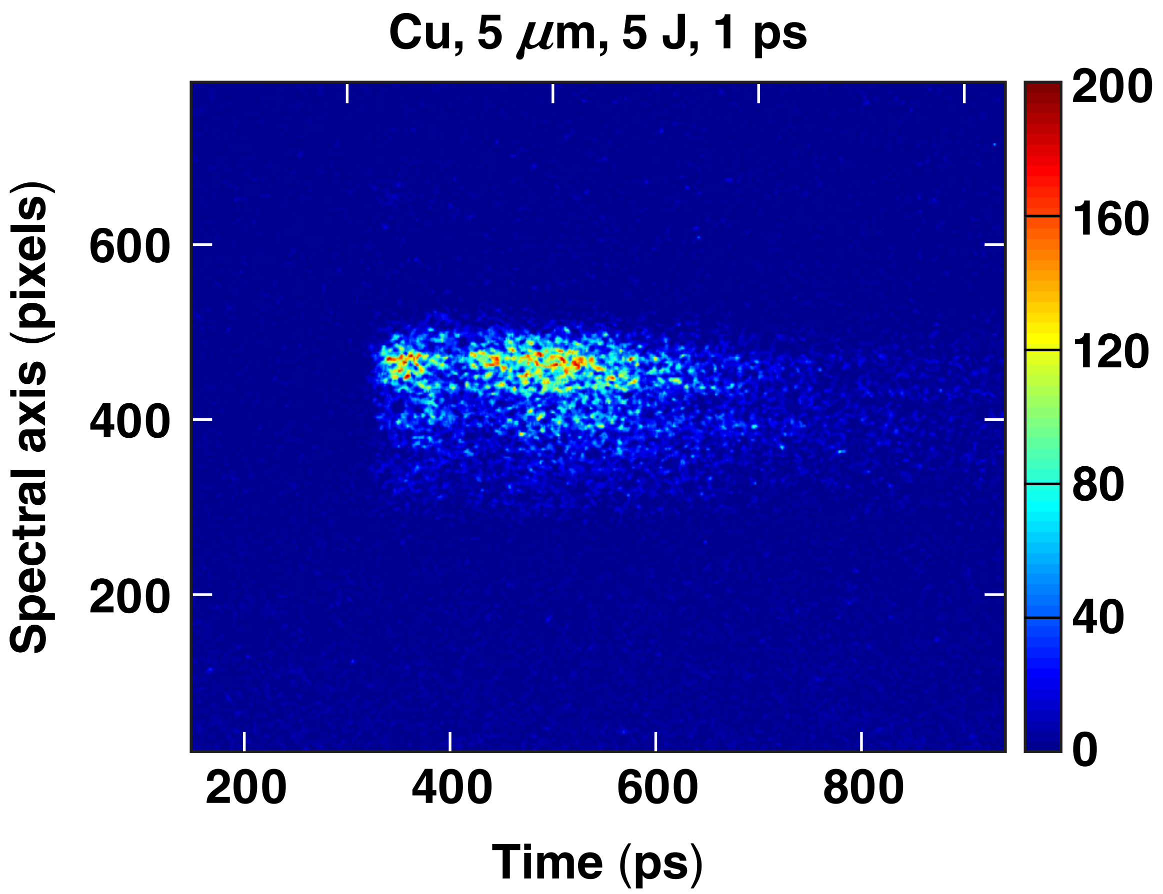
A blast wave is formed if a sufficiently high-pressure gradient is introduced in the target

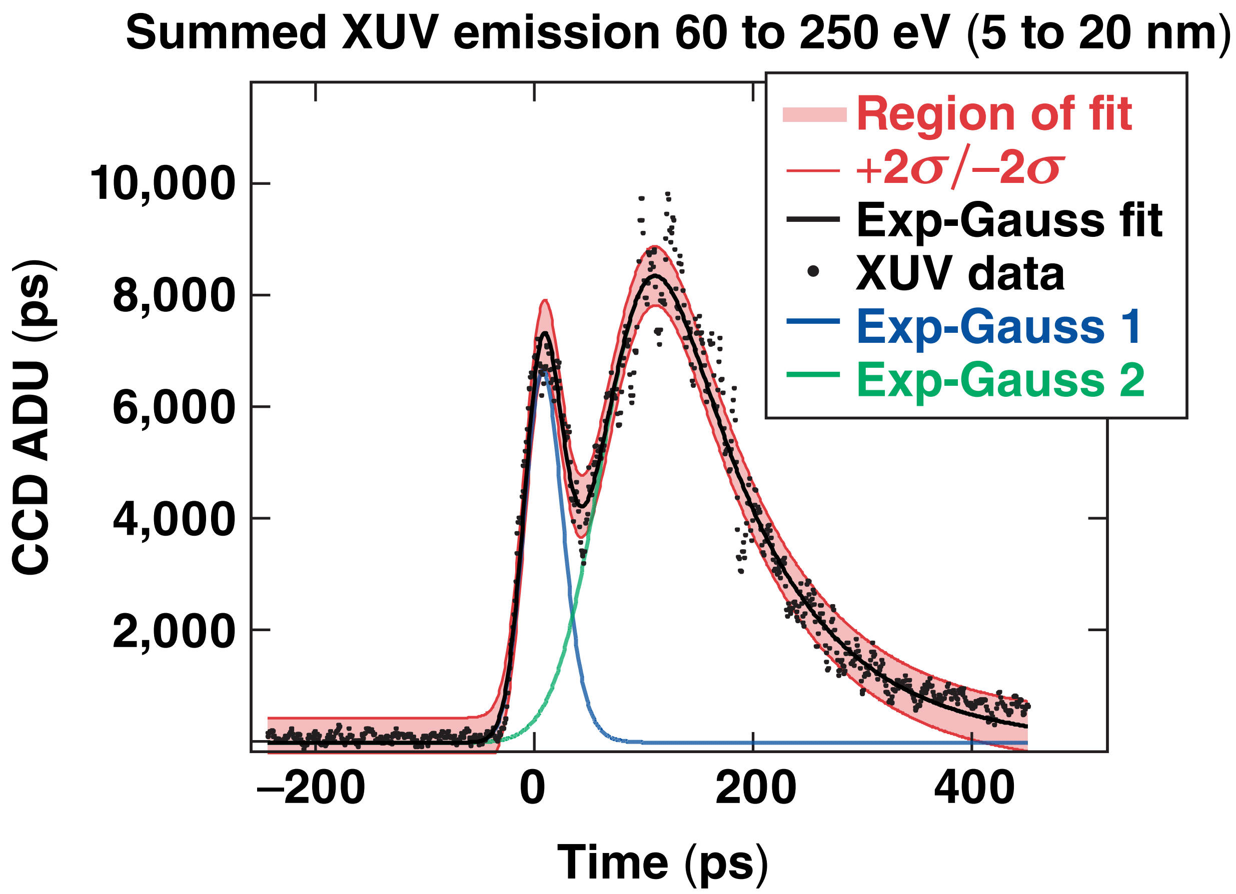


Shock breakout

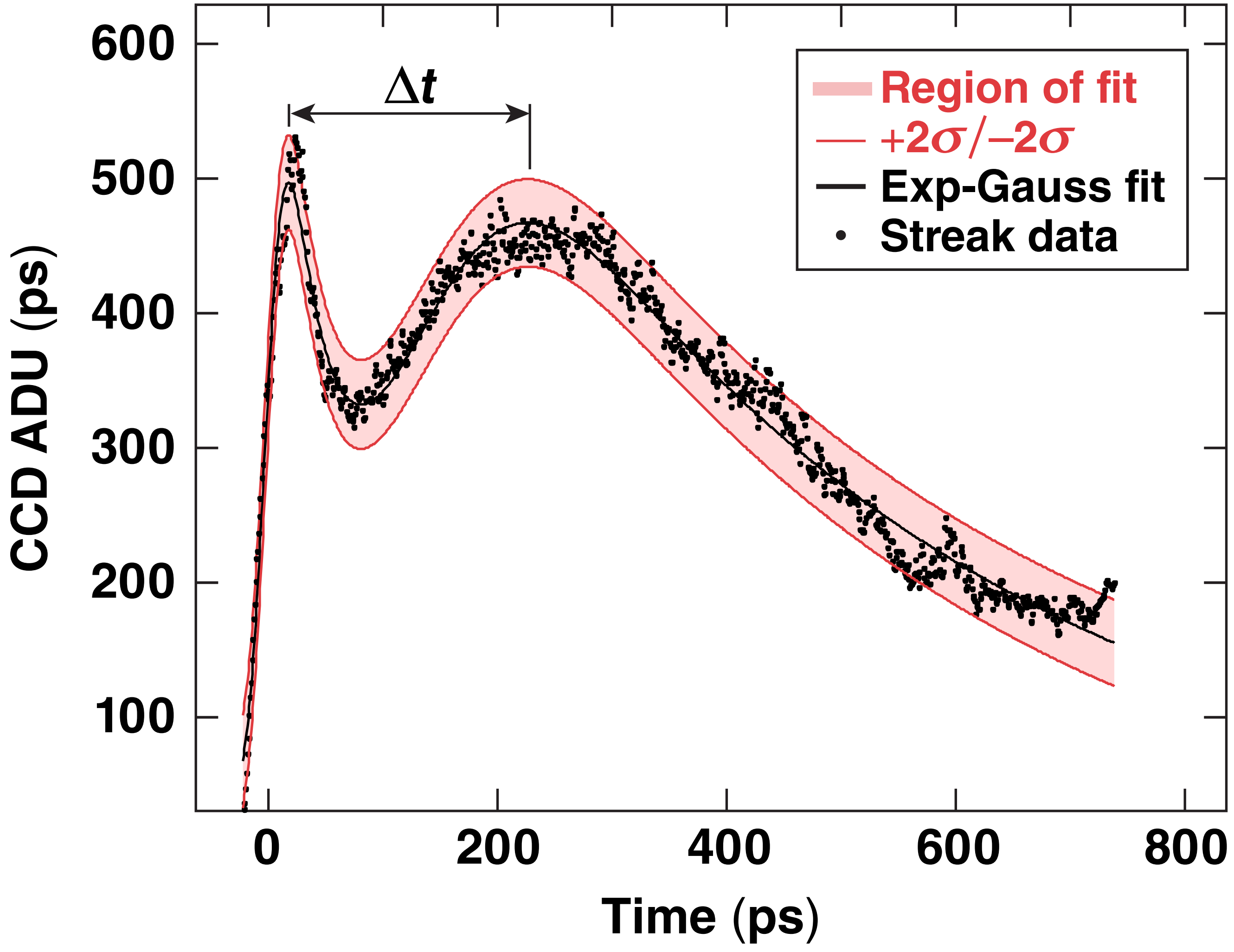
The supersonic blast wave emerges from the target rear surface causing a delayed jump in XUV brightness

XUV emission shows a characteristic double-peaked temporal profile





The breakout time is quantified by the temporal separation of the fitted exponential-modified Gaussians



- Data are fit to two exponential-modified Gaussian functions
- Uncertainty in the delay considers statistical uncertainty in fitting (shown by 2σ contours) as well as systematic uncertainty from time-base calibration (±5%); these factors add in quadrature

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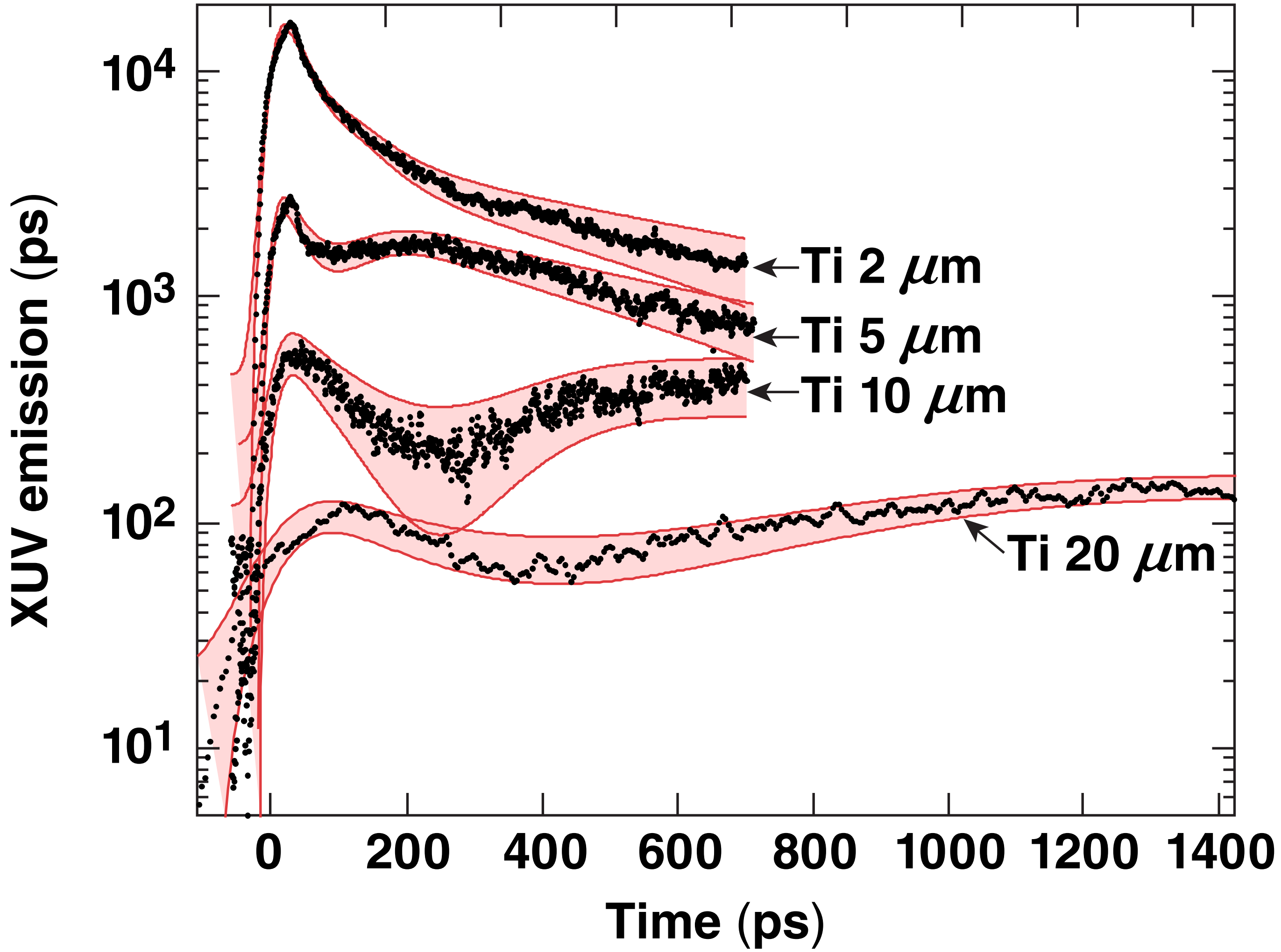
The two flashes separation in time increases as a function of material thickness



- Overall brightness of the emission is a strong function of the target thickness; data have scaled for filtration and sweep speed
- The data have been time shifted so the peak of the first flash occurs at $t = 0$

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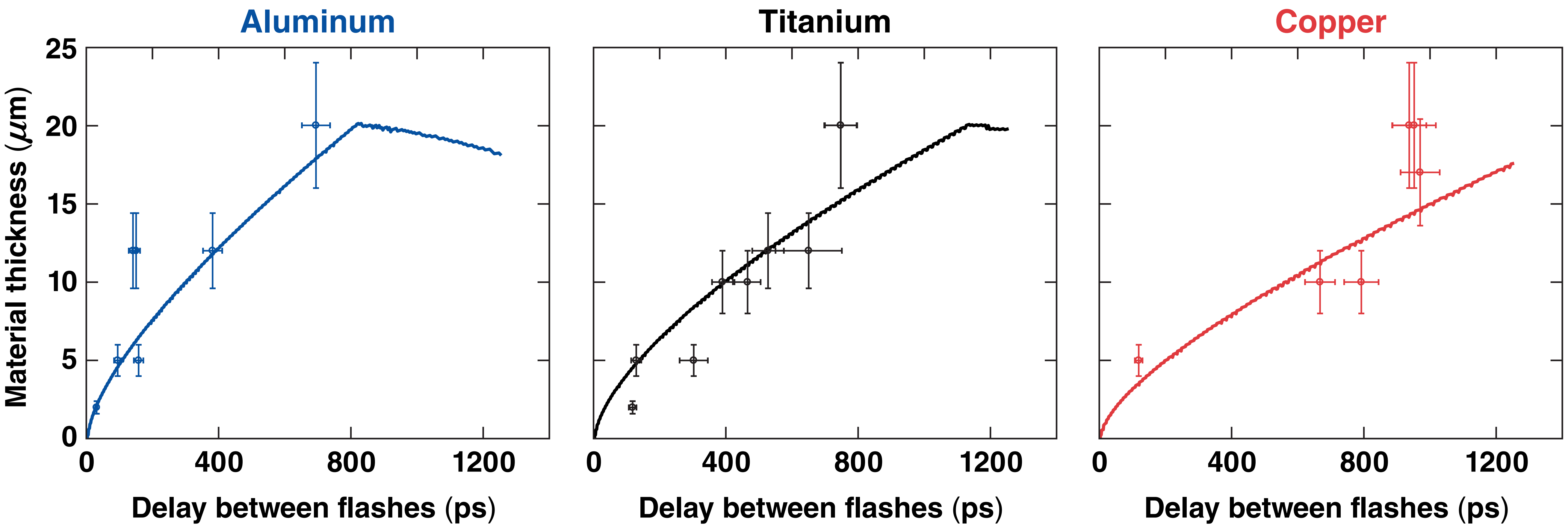
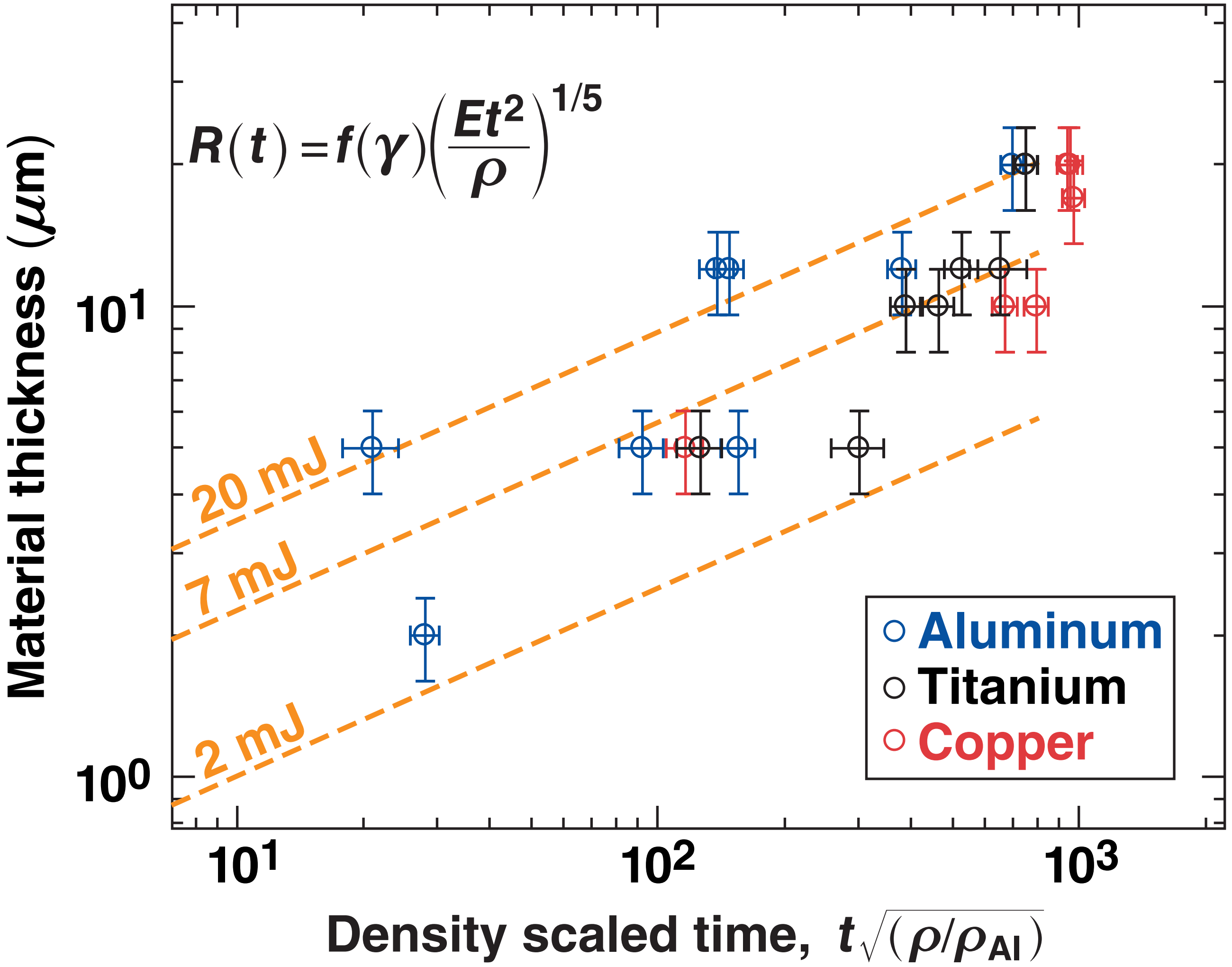
The breakout times follow a general trend with thickness and material composition



Each material cannot be directly compared without considering density.

When the breakout time is adjusted for the material density, the points are consistent with Sedov–Tayor blast wave



- Estimates show 2- to 20-mJ laser energy is converted to explosive energy
- More energy is coupled to thicker targets
- Systematic uncertainty in measurements is being investigated

*G. Brown *et al.*, JP11.00043, this conference.

E26718

Experiments with laser-heated foils have measured the energy deposition into a blast wave from a high-intensity laser

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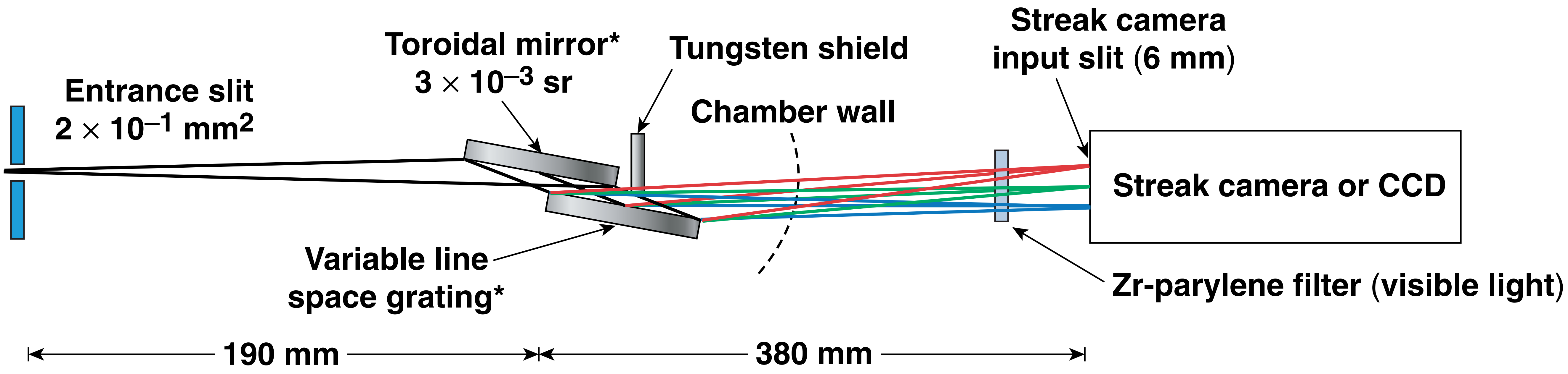
The target emission is observed with a compact XUV spectrometer*



- 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 and disperse and refocus the beam, allowing high throughput in a compact system

HORIBA Scientific, Edison, NJ 08820-3097.
*S. T. Ivancic *et al.*, Rev. Sci. Instrum. 87, 11E538 (2016).

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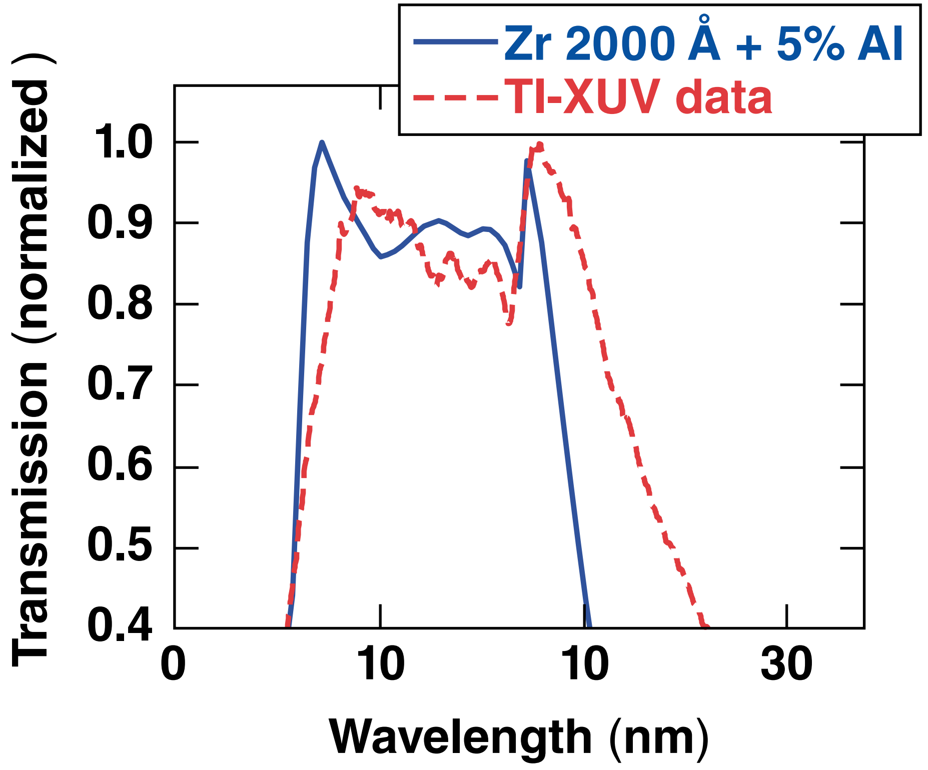
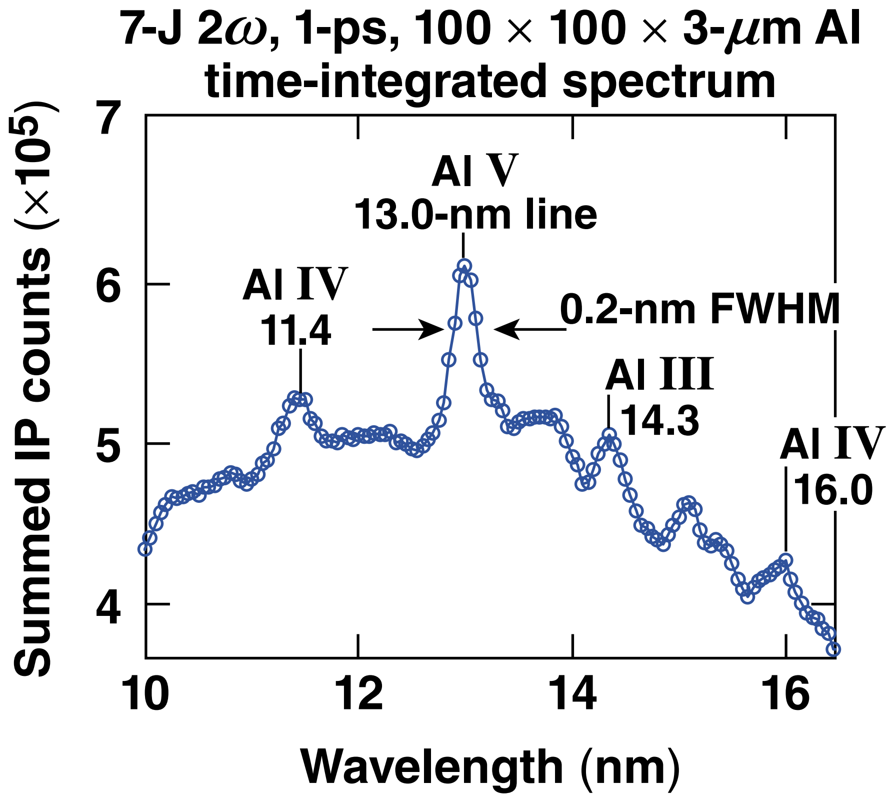
The transmission of the XUV spectrometer is between 5 to 20 nm*





- A thin light block filter (2000 Å Zr + 1000 Å C_8H_8) is used to reject long wavelengths, the shortest wavelengths are limited by the mirror reflectivity

Ion	Experimental data (nm)	Reference data (nm)	Relative intensity	Oscillator strength
Al IV	11.4±0.2	11.646	250	0.332
Al V	13.0±0.2	13.085	1000	0.175
Al IV	16.0±0.2	16.169	700	0.017
Al III	14.3±0.2	14.395	–	–

*S. T. Ivancic *et al.*, Rev. Sci. Instrum. 87, 11E538 (2016).

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