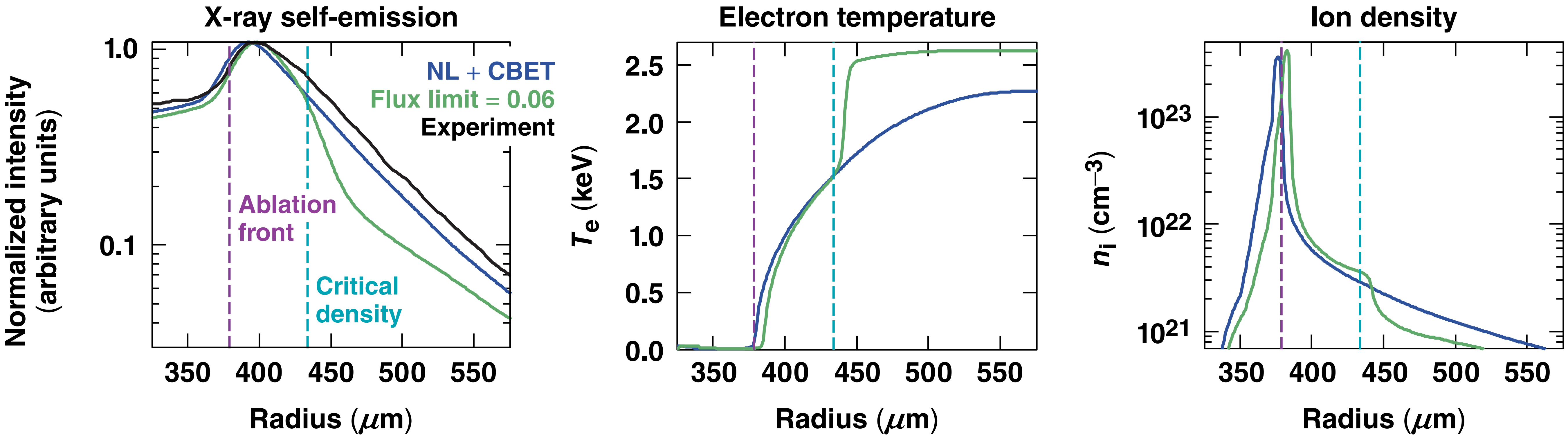
Conduction-Zone Measurements Using X-Ray Self-Emission Images



Shot 80650, t = 0.56 ns

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Summary

X-ray self-emission measurements were used to identify discrepancies in modeling conduction-zone plasma conditions

- Different models disagree on the early-time density and temperature profiles in the conduction zone, which affects predictions of the laser imprint, scattered light, and shock timing
- X-ray self-emission intensity profiles show good agreement between measurements and simulations for low-intensity experiments, but not for high-intensity experiments
- A method was developed to use self-emission profiles to determine the temperature and density profiles in the conduction zone of the plasma

This diagnostic will measure plasma parameters where neither optical diagnostics nor x-ray backlighting can probe.

Collaborators

D. T. Michel, S. X. Hu, Y. Ding, R. Epstein, J. P. Knauer, and D. H. Froula

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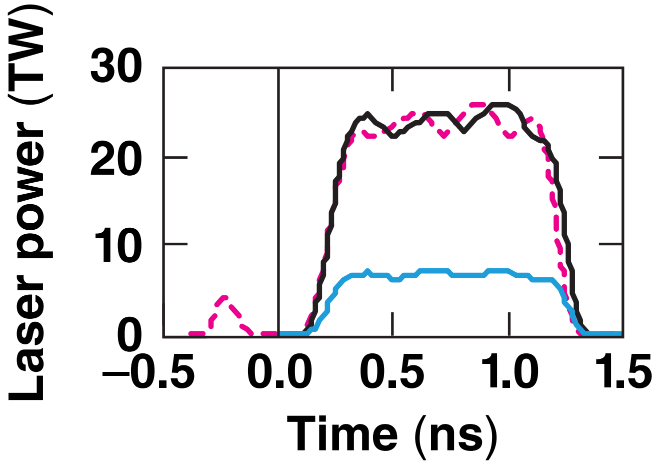
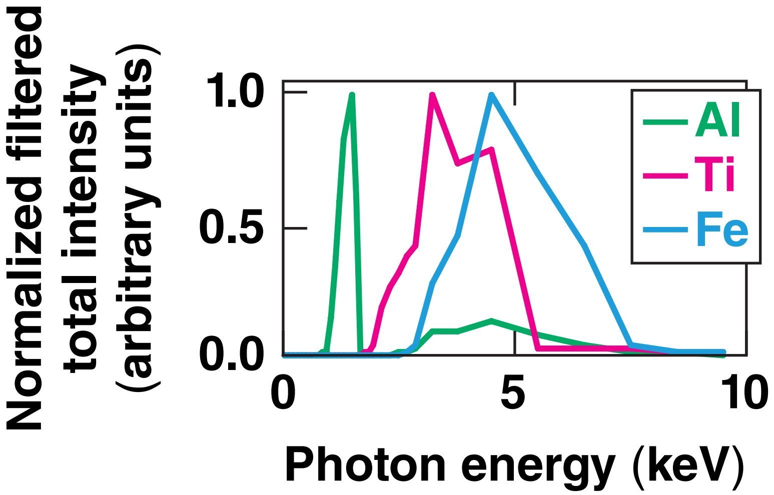
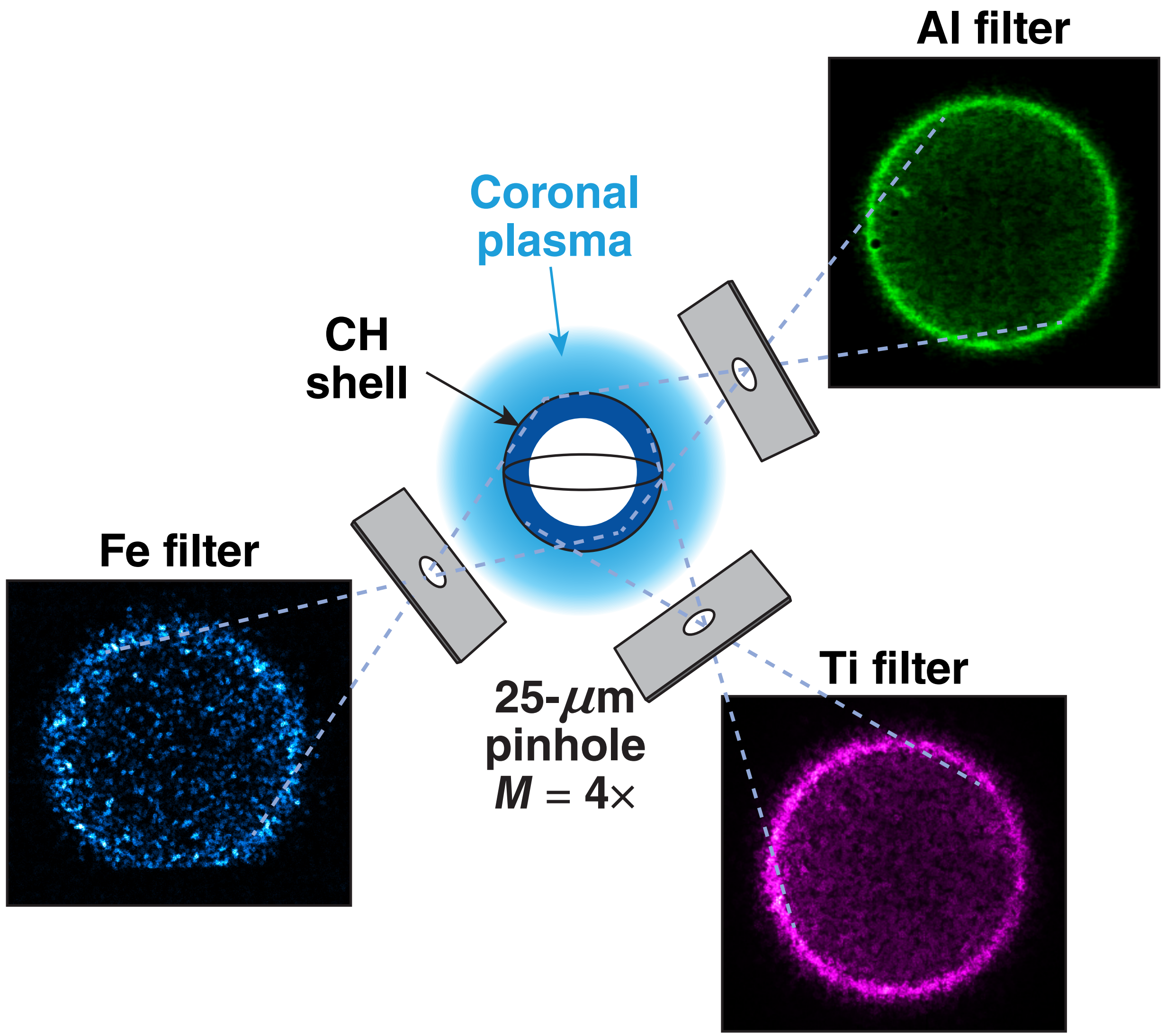
Experiments measured the x-ray self-emission to obtain the spatially and temporally resolved emission spectrum for three laser configurations







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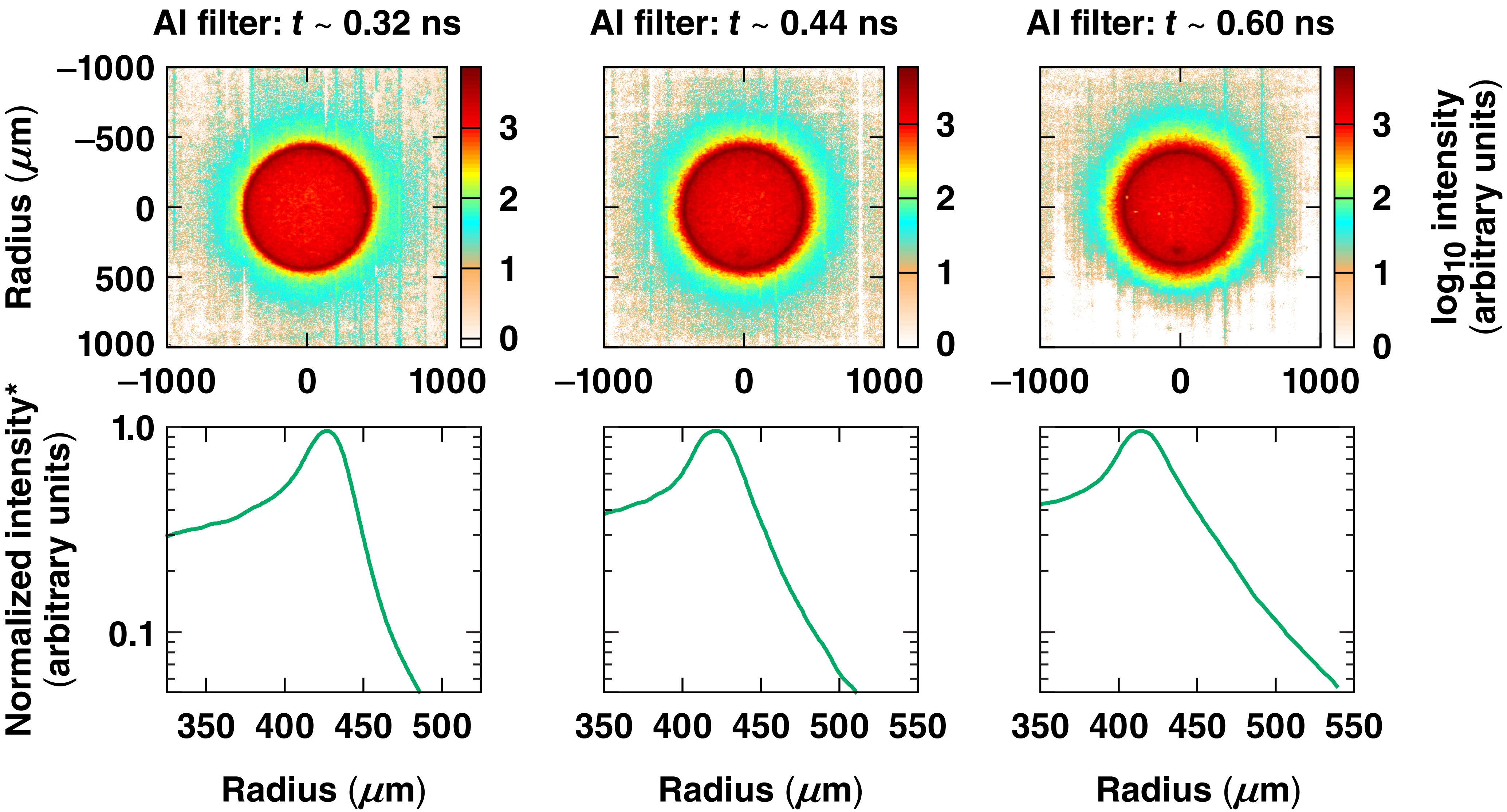
Self-emission images taken at different times show the expansion of the coronal plasma



Shot 80647
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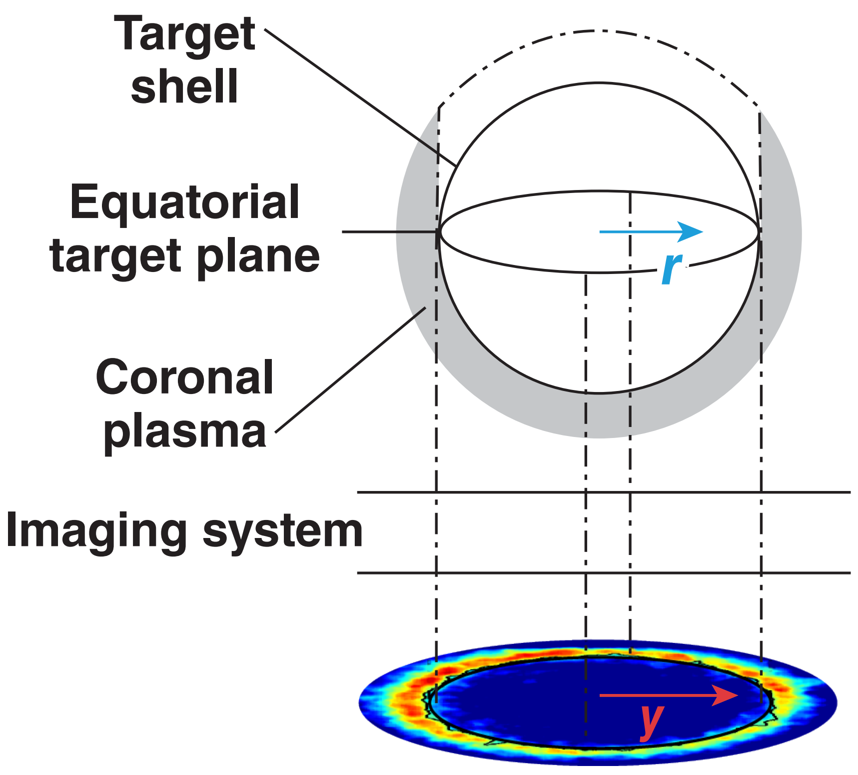
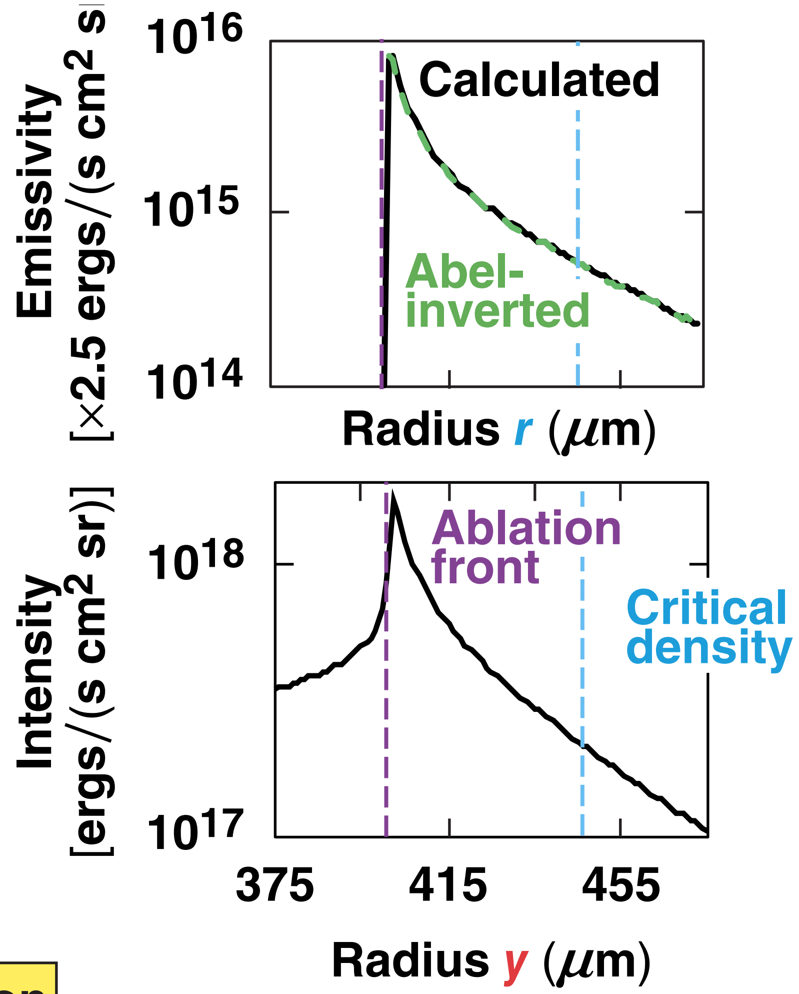
*D. T. Michel *et al*., High Power Laser Science and Engineering 3, e19 (2015).

Synthetic x-ray self-emission images are calculated from simulated density and temperature profiles to facilitate comparison with experiments



X-ray framing-camera (XRFC) diagnostic plane



Emissivity**

Self-emission at diagnostic plane

Intensity profiles can be Abel-inverted because absorption is negligible ~5 µm outside the ablation surface.

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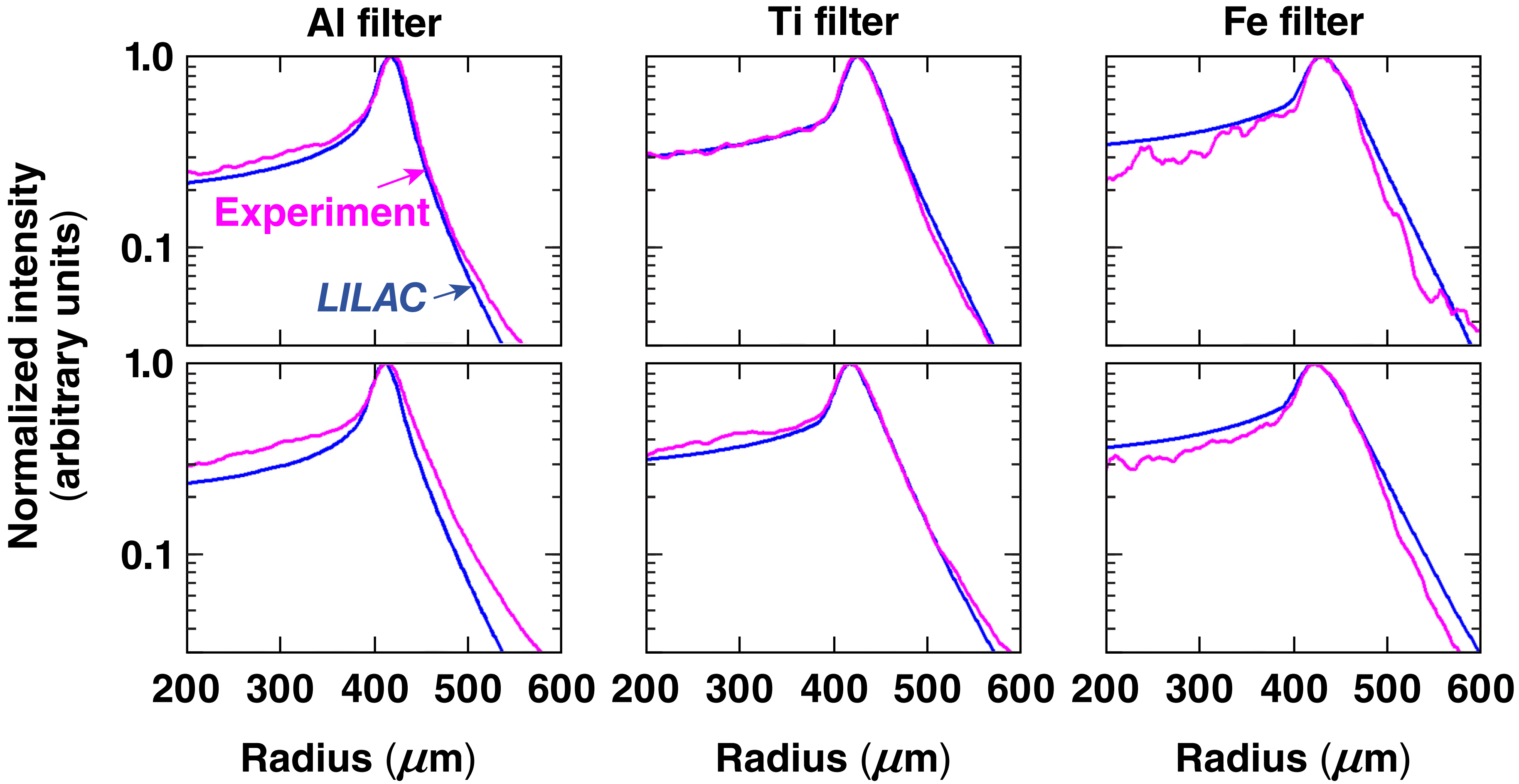
*D. T. Michel *et al.*, Rev. Sci. Instrum. 83, 10E530 (2012).

**$\epsilon\Delta s$, Δs = 1 µm

Comparisons of measured and simulated self-emission intensity profiles show good agreement for a low-intensity square laser pulse but not for a high-intensity pulse

Shot 80645, t = 0.62 ns
$I = 2 \times 10^{14}$ W/cm^2

Shot 80647, t = 0.61 ns
$I = 1 \times 10^{15}$ W/cm^2



This could indicate a higher temperature near the ablation front or a density profile that is expanding in the experiment more rapidly than in the simulation.

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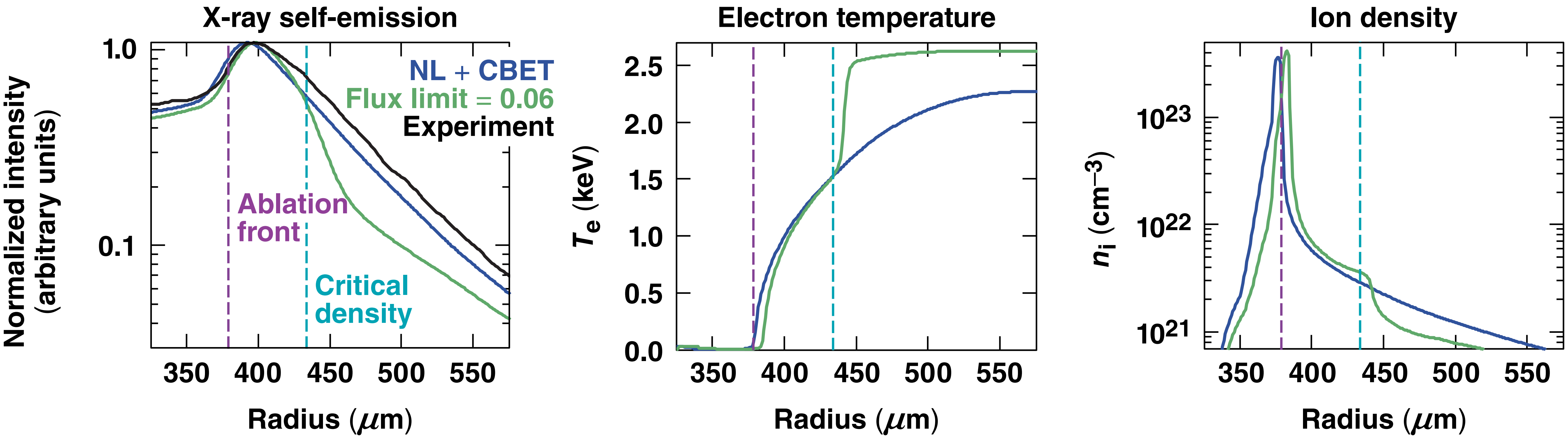
To investigate the source of the disagreement, simulations using different thermal transport models were compared with measurements



Shot 80650, t = 0.56 ns

To determine the density and temperature profiles, the ratio between the emissivity measured over the three spectral bands can be used

Measured emissivity:

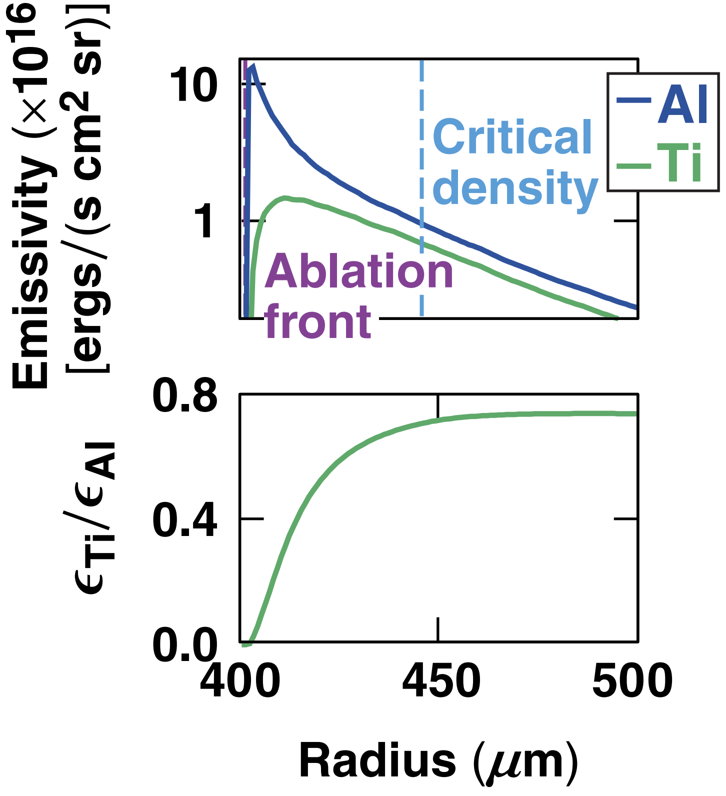
$$\epsilon = \int \underbrace{f(\nu) * B(\nu, T_e) * C(\nu)}_{\text{Varies with filter and temperature}} d\nu * \underbrace{g(n_i, T_e)}_{\text{Cancels with ratio}}$$

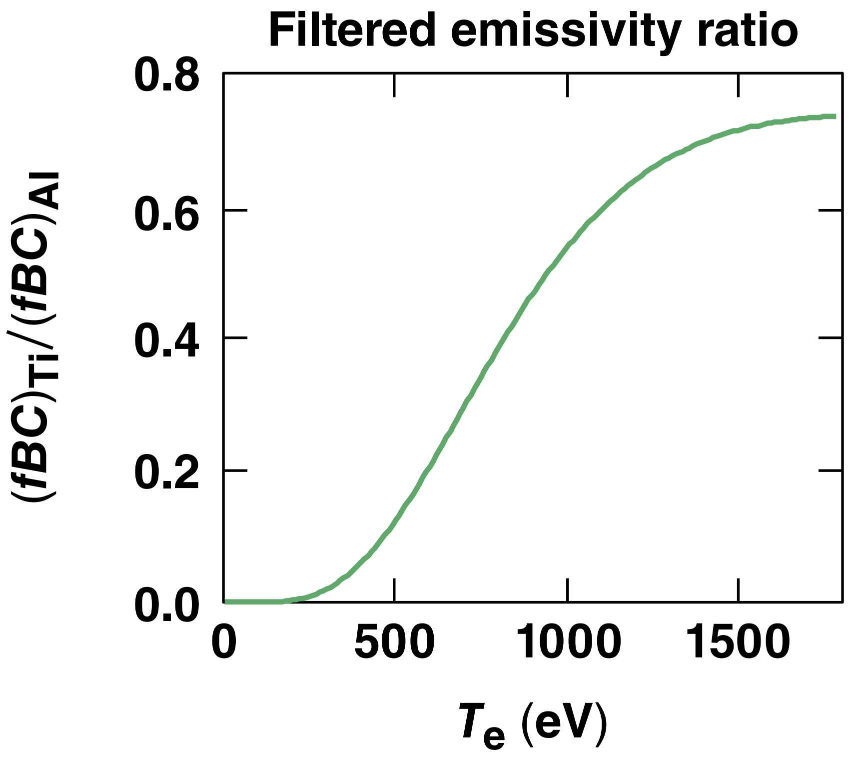
ϵ = specific emissivity

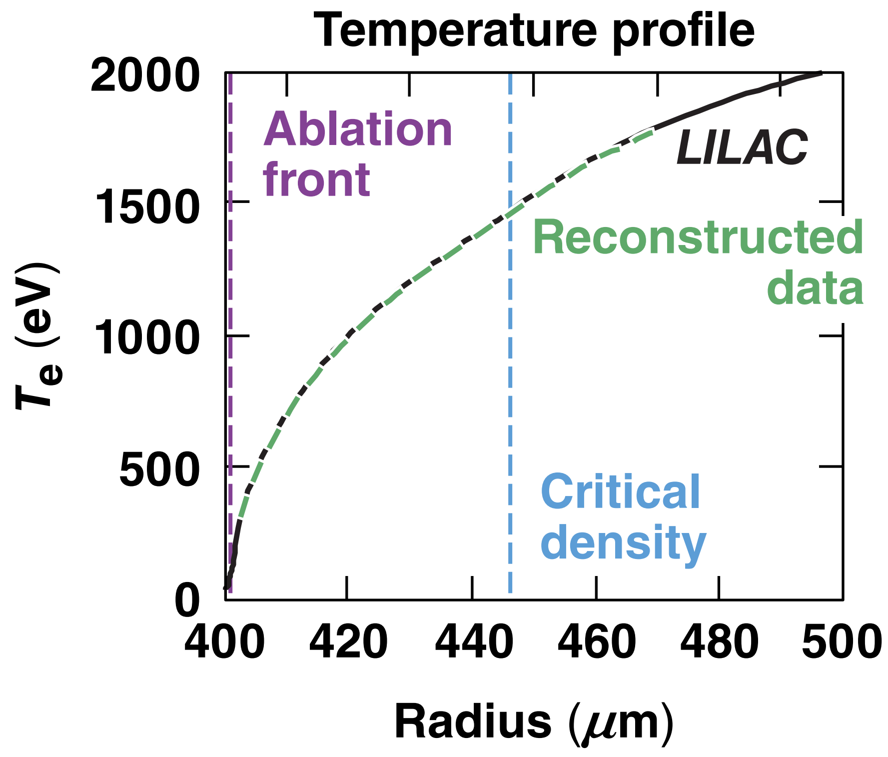
$f(\nu)$ = filter response

$B(\nu, T_e)$ = blackbody source term

$\kappa'(\nu, n_i, T_e)$ = specific opacity $\approx C(\nu) * g(n_i, T_e)$







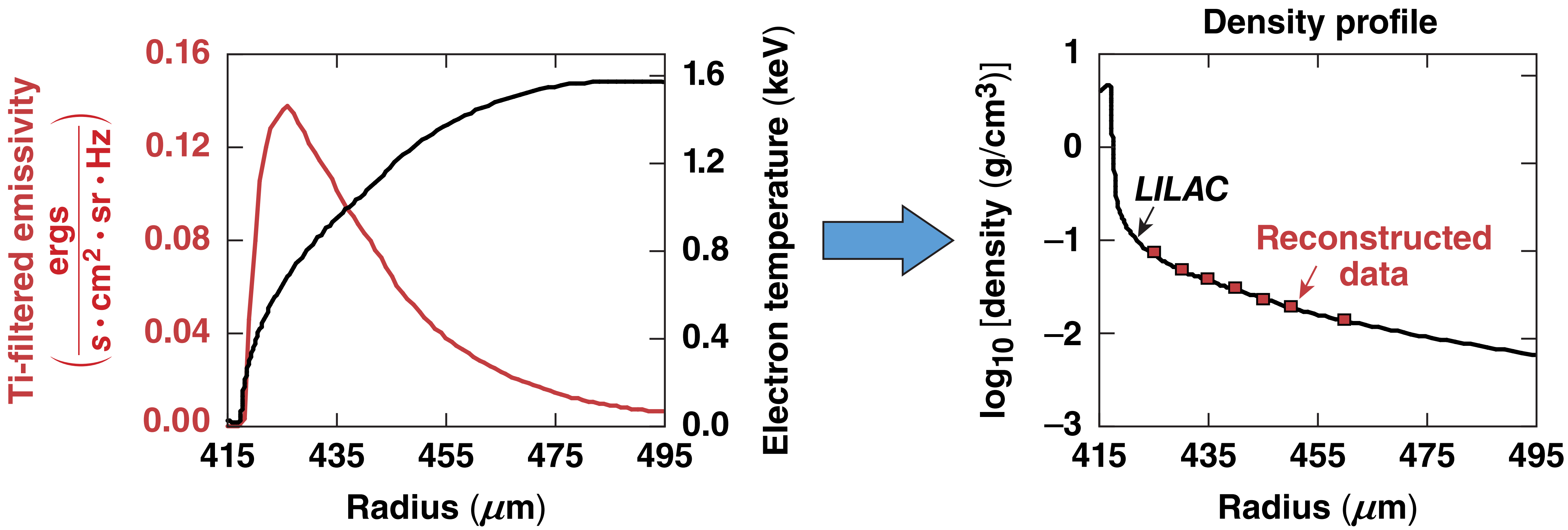
A method has been developed to relatively calibrate image intensities between filters so that the absolute temperature profile can be determined.

Density

With the measured emissivity and temperature, the opacity can be calculated and the density determined using opacity tables*

Measured emissivity:

$$\epsilon = \int \underbrace{f(\nu) * B(\nu, T_e)}_{\substack{\text{Calculated}\\ \text{from } T_e}} * \underbrace{C(\nu) * g(n_i, T_e)}_{\substack{\kappa'(\nu, n_i, T_e)\\ \text{known } T_e \to n_i}} d\nu$$



Future work will apply this analysis to measured images to determine the density and temperature profiles in the conduction zone.

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*Astrophysical Opacity Tables: W. F. Huebner *et al.*, Los Alamos National Laboratory, Los Alamos, NM, Report LA-6760-M (1977).

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X-ray self-emission measurements were used to identify discrepancies in modeling conduction-zone plasma conditions

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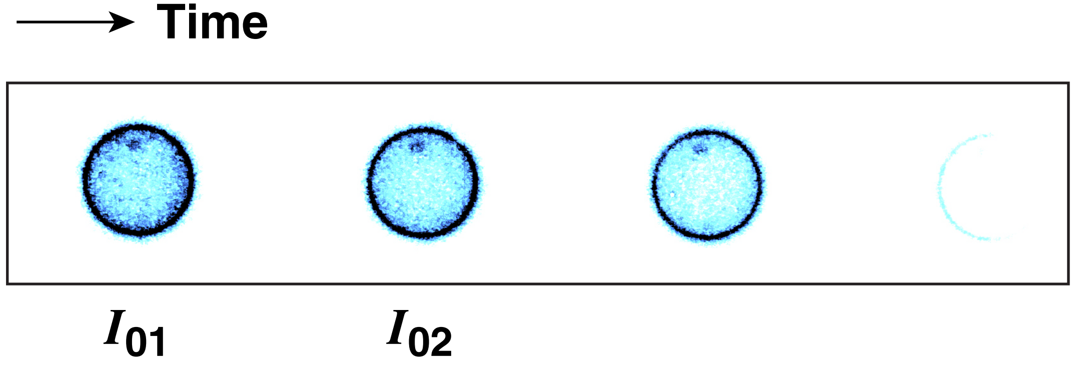
Image intensities on a single camera will be calibrated relative to each other to obtain an absolute temperature measurement

(1)

Flat field with Ti filter



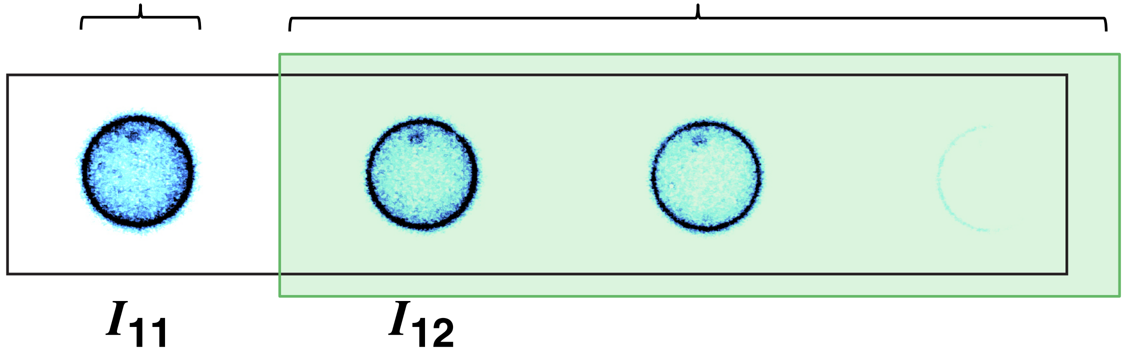
Flat field:

$$\frac{I_{02}}{I_{01}} = \text{constant}$$

(2)

Keep Ti on first image to determine shot-to-shot change in signal

Use Al filter over later images

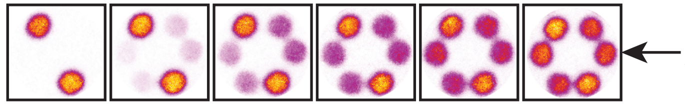


Adjust for changing absolute level:

$$I_{12}\left(\frac{1}{I_{02}}\;\frac{I_{01}}{I_{11}}\right) = \text{Al}/\text{Ti}$$

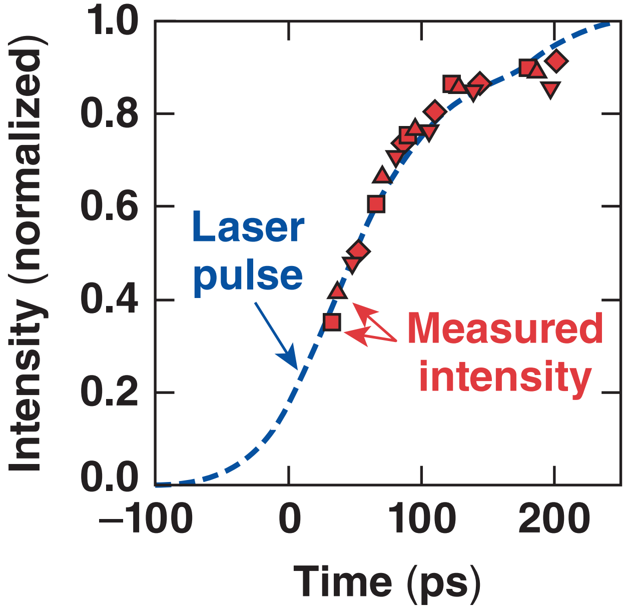
This is possible because the gain droop across each strip is consistent between shots when the incident intensity and image locations are conserved.

Absolute-timing calibrations within 20 ps for the three framing cameras were obtained by measuring the rise of the laser pulse and the ablation-front trajectory with all three cameras*

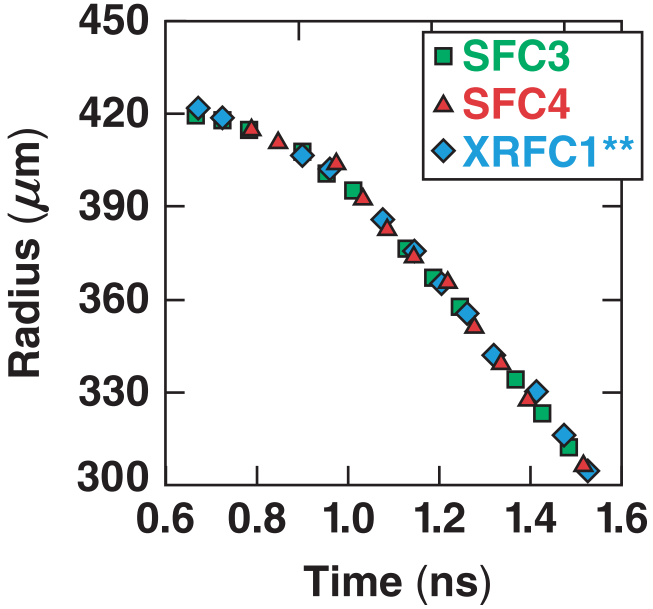


XRFC images of laser pulse rise on Au sphere

Increasing XRFC intensity aligned with pulse shape



Ablation-front trajectories for relative camera timing



More-precise relative timing was obtained by cross-calibrating the absolute timing between the cameras using the trajectory of an imploding shell as a reference.

SFC: Sydor framing camera

*D. T. Michel *et al*., High Power Laser Science and Engineering 3, e19 (2015).

**15-ps shift from absolute-timing calibration