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

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Normalized intensity (arbitrary units)

X-ray self-emission

Electron temperature

Ion density

Normalized intensity

NL + CBET
Flux limit = 0.06
Experiment

Ablation front
Critical density

Electron temperature

Ion density

Shot 80650, \( t = 0.56 \text{ ns} \)

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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


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Experiments measured the x-ray self-emission to obtain the spatially and temporally resolved emission spectrum for three laser configurations.
Self-emission images taken at different times show the expansion of the coronal plasma.

Al filter: $t \approx 0.32$ ns

Al filter: $t \approx 0.44$ ns

Al filter: $t \approx 0.60$ ns

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

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

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

- **X-ray self-emission**: The plot shows the normalized intensity as a function of radius. The curves represent different simulations (NL + CBET, Flux limit = 0.06) compared to the experimental data.

- **Electron temperature**: Plotted for different radii, the temperature is given in keV. The critical density and ablation front are also marked.

- **Ion density**: The plot shows ion density as a function of radius, with a flux limit of 0.06. The region of interest is marked by vertical lines indicating radius values.

**Shot 80650, t = 0.56 ns**

- **Flux limit**: 0.06
- **Critical density**: Reference for ion density analysis.
- **Ablation front**: Reference for electron temperature analysis.
To determine the density and temperature profiles, the ratio between the emissivity measured over the three spectral bands can be used.

\[
\epsilon = \int f(\nu) \cdot B(\nu, T_e) \cdot C(\nu) \, d\nu \cdot g(n_i, T_e)
\]

- Measured emissivity: \(\epsilon\)
  - Varies with filter and temperature
  - Cancels with ratio
- \(\epsilon\) = specific emissivity
- \(f(\nu)\) = filter response
- \(B(\nu, T_e)\) = blackbody source term
- \(\kappa'(\nu, n_i, T_e)\) = specific opacity \(\approx C(\nu) \cdot g(n_i, T_e)\)

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*

\[ \epsilon = \int f(\nu) \cdot B(\nu, T_e) \cdot C(\nu) \cdot g(n_i, T_e) \, d\nu \]

Measured emissivity:

- Calculated from \( T_e \)
- Known \( T_e - n_i \)

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

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

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*

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.

**15-ps shift from absolute-timing calibration

SFC: Sydor framing camera


**15-ps shift from absolute-timing calibration