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


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X-ray self-emission images are used to diagnose the evolution of the electron temperature and density in the coronal plasma to determine the growth of the conduction zone.

- The self-emission in these conditions can be described by a blackbody spectrum, which allows for the separation of the density and temperature contributions to the emissivity.
- Spectral symmetry of the implosions and negligible absorption in the coronal plasma to determine the growth of the conduction zone.
- From the temperature and emissivity, the density in the conduction zone is determined for each measurement time.
- Initial comparisons with LLE/C simulations show good agreement between measurements and simulations.

The emissivity of the plasma is determined by Abel-inverting the measured self-emission profile.

In directly driven inertial confinement fusion implosions, the laser imprint is smoothed through electron thermal conduction once the conduction-zone length is larger than the size of the nonuniformities ($d_0 > d$).

The x-ray filtration was varied to isolate the effect of the temperature on the emissivity.

Images are taken at different times early in the laser pulse to determine the development of the conduction zone.

Three x-ray framing cameras were used in experiments to simultaneously measure the self-emission profiles at three wavelengths.

The length of the conduction zone is determined by measuring the temperature and density in the coronal plasma.

With the measured emissivity and temperature, the opacity is calculated and the density is determined using opacity tables.

Early comparisons show good agreement between measured and simulated self-emission profiles.

Future work will apply the described method to reconstruct the density profile in several images and determine the growth of the conduction zone.

- The framing-camera images will be absolutely calibrated to quantitatively reconstruct the temperature and density profiles in the experiments.
- The growth of the conduction zone will be determined for various laser intensities.
- The growth of the conduction zone will be compared for a square pulse and a square pulse with a pivot.

Results will be compared with simulations using several models for thermal transport and equation of state to benchmark the early-time evolution of the plasma.

Absolute-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.

With the measured emissivity and temperature, the opacity is calculated and the density is determined.

Summary

Simulations show good agreement between measurements and simulations.

- Spherical symmetry of the implosions and negligible absorption in the coronal plasma to determine the growth of the conduction zone.
- The x-ray filtration was varied to isolate the effect of the temperature on the emissivity.

With the measured emissivity and temperature, the opacity is calculated and the density is determined using opacity tables.

Emittance in corona:

\[ \epsilon = \frac{e_{\text{abs}}}{\epsilon_{\text{total}}} = \frac{1}{\epsilon_{\text{total}}} \]

\[ \epsilon_{\text{total}} = \text{specific opacity} \]

\[ B_{\text{abs}}(T, \lambda) = \text{blackbody source term} \]

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Absorption Oscillator Conductance (blackbody):

\[ \frac{d^2r}{dr^2} + \left( \frac{2}{r} - \frac{v^2}{c^2} \right) \frac{dr}{d} = 0 \]

\[ v = \frac{1}{\sqrt{\frac{m}{k_B T}}} \]

\[ T = 2 \left( \frac{2 \pi m}{k_B} \right)^{1/2} \]

\[ k = \frac{1}{2} \left( \frac{m}{k_B T} \right)^{1/2} \]

\[ r_{\text{abs}} = \frac{d}{r} \]

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Summary

X-ray self-emission images are used to diagnose the evolution of the electron temperature and density in the coronal plasma to determine the growth of the conduction zone.

- The self-emission in these conditions can be described by a blackbody spectrum, which allows for the separation of the density and temperature contributions to the emissivity.

- Spherical symmetry of the implosions and negligible absorption in the corona allow for the self-emission profiles to be Abel-inverted to find the emissivity.

- Emissivity profiles are simultaneously measured with three different filters to determine the emission spectrum and temperature profile.

- From the temperature and emissivity, the density in the conduction zone is determined for each measurement time.

- Initial comparisons with LILAC simulations show good agreement between measurements and simulations.
In directly driven inertial confinement fusion implosions, the laser imprint is smoothed through electron thermal conduction once the conduction-zone length is larger than the size of the nonuniformities \((d_c > \lambda)\)

Characterizing the growth of the conduction zone is critical to determine the size of the nonuniformities imprinted on the target surface by the laser.
The length of the conduction zone is determined by measuring the temperature and density of the coronal plasma.

Emissivity in corona:

\[ \epsilon \approx B(\nu, T_e) \times C(\nu) \times f(n_i, T_e) \times \kappa'(\nu, n_i, T_e) \]

- \( \epsilon = \) specific emissivity
- \( I = \) specific intensity
- \( B(\nu, T_e) = \) blackbody source term*
- \( \kappa'(\nu, n_i, T_e) = \) specific opacity**

The temperature \( T_e(r) \) and density \( n_i(r) \) are determined from x-ray self-emission images \( \epsilon(\nu, r) \).

*Local thermodynamic equilibrium (LTE) approximation
**Tabulated
The emissivity of the plasma is determined by Abel-inverting the measured self-emission profile.

Discretized radiation-transfer equation:

\[ I(\nu, s + \Delta s, y) = I(\nu, s, y) e^{-\kappa' \Delta s} + (1 - e^{-\kappa' \Delta s}) B(\nu, s, y) \]

For \( \kappa' \Delta s \ll 1 \) (negligible absorption):

\[ I(\nu, s + \Delta s, y) = I(\nu, s, y) + B(\nu, s, y) \kappa' \Delta s \]

Intensity at diagnostic plane:

\[ I(\nu, DP, y) \approx \int_{-\infty}^{\infty} \epsilon [(s - s_0)^2 + y^2] ds \]

The Abel inversion is possible because the absorption is negligible in the corona a few microns outside of the ablation front for the x-ray frequencies measured.
The x-ray filtration was varied to isolate the effect of the temperature on the emission.

Each filter selects a known frequency:

\[ \frac{B(\nu_2, T_e)}{B(\nu_1, T_e)} \approx \frac{\epsilon(\nu_2, n_i, T_e)}{\epsilon(\nu_1, n_i, T_e)} \frac{C(\nu_1)}{C(\nu_2)} \]

Adjusted emissivity \[ \epsilon(\nu_1) \]

Blackbody spectrum \( (T_e = 0.9 \text{ keV}) \)

Measuring the ratio of the emissivity for different frequencies makes it possible to determine the temperature by fitting it with a blackbody spectrum.
With the measured emissivity and temperature, the opacity is calculated and the density is determined using opacity tables.
Three x-ray framing cameras were used in experiments to simultaneously measure the self-emission profiles at three wavelengths.

**DANTE** and the ultrafast x-ray streak camera (UFXRSC) were used to cross-calibrate the emission between the three cameras.
Images are taken at different times early in the laser pulse to determine the development of the conduction zone.

Profiles are angularly averaged around the target to improve the signal-to-noise ratio.
Early comparisons show good agreement between measured and simulated self-emission profiles.

A more in-depth analysis is in progress.
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.

SFC: Sydor framing camera


**15-ps shift from absolute-timing calibration
Absolute calibrations for the three framing cameras were obtained by simultaneously measuring the emission on the ultrafast x-ray streak camera.

Similar absolute-calibration measurements were obtained using the DANTE diagnostic.
Future work will apply the described method to reconstruct the density profile in several images and determine the growth of the conduction zone.

- The framing-camera images will be absolutely calibrated to quantitatively reconstruct the temperature and density profiles from the experiments.
- The growth of the conduction zone will be determined for various laser intensities.
- The growth of the conduction zone will be compared for a square pulse and a square pulse with a picket.

Results will be compared with simulations using several models for thermal transport and equation of state to benchmark the early-time evolution of the plasma.