Heat-Flux Measurements from Collective Thomson-Scattering Spectra

$\dot{k}_{2\omega}$

(\(\lambda_{2\omega} = 526 \text{ nm}\))

3\(\omega\) drive beams

(2 ns, 1.3 \times 10^{14} \text{ W/cm}^2)

$\nabla T_e$ down

$q_{SH} = -\kappa \nabla T_e$

$q_{TS}$

$q_{SH} = -\kappa T_e$

Heat flux at $t = 2.5$ ns

Distance from target (\(\mu\)m)

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Summary

Thomson scattering from ion-acoustic waves (IAW’s) and electron plasma waves (EPW’s) was used to measure heat flux in coronal plasmas.

- Changes in Landau damping caused by heat flux were seen in the relative amplitudes of Thomson-scattering spectra from IAW’s and EPW’s.
- Local plasma conditions obtained from Thomson scattering provide an independent measurement of the heat flux using the Spitzer–Härm (SH) thermal-transport model.
- The two methods of measuring the heat flux are in good agreement over the locations probed.
Collaborators

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An experiment was designed to test Spitzer–Härm thermal transport in laser-produced coronal plasmas.

These experiments measured the heat flux, electron temperature, and density as functions of space in a coronal plasma.
Collective Thomson scattering can measure the heat flux and local plasma conditions

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\begin{align*}
P_s &\propto \left(1 + \frac{2\omega}{\omega_i}\right) S(k, \omega) \\
S(k, \omega) &= \frac{2\pi}{k} \left| 1 - \frac{\chi_e}{\epsilon} \right|^2 f_e \left(\frac{\omega}{k}\right) + \frac{2\pi Z}{\epsilon} \left| \frac{\chi_e}{\epsilon} \right|^2 f_i \left(\frac{\omega}{k}\right) \\
\chi_e &= \int_{-\infty}^{\infty} \text{d}v \frac{4\pi e^2 n_e}{m_e k^2} \frac{k \cdot \partial f_e}{\partial v} \frac{\omega - k \cdot v - i\gamma}{\omega - k \cdot v - i\gamma} \\
f_e &= f^M_e + f^{\text{SH}}_e
\end{align*}
\]
Changes in the electron distribution function caused by heat flux affect the Thomson scattering from EPW’s.

Effect of heat flux on electron distribution function

Effect of heat flux on EPW scattering feature \((q/q_{fs} = 0.035)\)
Thomson scattering was used to measure the heat flux, electron temperature, and electron density in coronal plasmas.

- Thomson scattering (TS) provides local measurements of $T_e$, $n_e$, and $q$ in an $\approx 50 \times 50 \times 50$-μm$^3$ volume.
- Probing five different locations provides values for $\nabla T_e$.
- An independent measure of $q$ is obtained from $T_e$, $n_e$, and $\nabla T_e$.

Thomson scattering provides two separate measurements of heat flux by probing plasma waves along the direction of the temperature gradient.
The up- and downshifted EPW features were measured with a large signal-to-background ratio.
Thomson-scattering spectra obtained at five locations in the corona were used to measure the heat flux.
The scattering spectra are fit to determine the electron temperature and density.

- Ion feature, 1500 μm from target
- Electron feature, 1500 μm from target
- IAW lineout, 1500 μm from target, \( t = 2.5 \) ns
- EPW lineout, 1500 μm from target, \( t = 2.5 \) ns

Data lineout, fit

- \( T_e = 1.0 \) keV
- \( n_e = 5.3 \times 10^{19} \) cm\(^{-3}\)
The electron temperature and density measurements are used to infer the heat flux.

Electron temperature and density profiles at $t = 2.5$ ns

Thermal conductivity at $t = 2.5$ ns

SH heat flux at $t = 2.5$ ns
The relative amplitudes of the EPW scattering features were used to measure heat flux.

**EPW lineout, 1100 μm from target, t = 2.5 ns**

- Data lineout
- $q = 0$
- $q = 0.015 \, q_{fs}$

$T_e = 1.1 \text{ keV}$

$n_e = 1.19 \times 10^{20} \text{ cm}^{-3}$

**EPW lineout, 1500 μm from target, t = 2.5 ns**

- Data lineout
- $q = 0$
- $q = 0.043 \, q_{fs}$

$T_e = 1.0 \text{ keV}$

$n_e = 5.2 \times 10^{19} \text{ cm}^{-3}$
Two experimental configurations measured heat flux parallel and perpendicular to the target normal.
Differences in the relative amplitudes of the EPW scattering features between the two configurations show the effect of heat flux.

EPW feature 1400 μm from target, 1.75 ns k∥q

Amplitude (normalized)

Wavelength (nm)

Data lineout
q = 0
q = 0.015 q\_fs

EPW feature 1100 μm from target, 1.75 ns k\perp q

Data lineout
q = 0
The heat-flux values obtained by matching electron feature amplitudes are in good agreement with the temperature-gradient measurements.
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