Scattered Laser-Light Spectroscopy in Direct-Drive Implosion Experiments

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Scattered-light modeling indicates that additional physics is needed in hydrocode coronal modeling

- FABS measures temporally and spectrally resolved scattered light from OMEGA implosions in the SBS range (351±1 nm)

- Time-dependent scattered-light spectra are modeled by a combination of hydrodynamic and ray-tracing codes
  - predicted spectra vary with the electron-heat transport model
  - no satisfactory predictions of both the spectral shifts and scattered power with same model

- Indicates some additional physics is occurring in the coronal plasma
  - enhanced absorption early in the pulse
  - enhanced scattering later in the pulse
  - nonlinear LPI cross-beam power transfer via EM-seeded SBS might explain both phenomena
Collaborators

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Time-dependent absorbed fraction observed during OMEGA implosions does not match hydrocode predictions.

Motivation

- Time-dependent absorbed fraction during OMEGA implosions is inferred from full-aperture backscatter station (FABS) diagnostic scattered-light measurements.
- Measured time-integrated power usually matches modeling using $f = 0.06$ flux limiter.

Detailed modeling of time-dependent scattered-light spectra has been developed to investigate discrepancies between predictions and FABS.
Modeling Scattered Spectra

Time-dependent scattered-light spectra are modeled for OMEGA implosions

- **LILAC**: 1-D hydrodynamic code predicts time-dependent implosion profiles
  - using different electron-heat transport models: fixed flux-limited, CEA nonlocal model,\(^1\) Goncharov nonlocal model\(^2\)

- **SAGERAYS**: Ray traces 351-nm-drive laser light through plasma and calculates spectral shift along each path\(^3\)

\[
\Delta \omega = -\omega_0 \frac{\partial \tau_f}{\partial t} = + \frac{\omega_0}{2c} \int \left( 1 - \frac{n_e}{n_c} \right)^{-1/2} \frac{\partial}{\partial t} \left( \frac{n_e}{n_c} \right) ds
\]

- **MATLAB code** calculates total spectrum collected by FABS from all 60 beams

The heat transport model used by hydrocode significantly affects the plasma-density profiles and its rate of change.

- The Goncharov nonlocal transport model in comparison with the $f = 0.06$ fixed flux-limiter model transports more thermal energy inside the plasma critical surface:
  - Lower corona temperature
  - More absorption in corona
  - More mass ablation
  - Higher plasma velocities
  - Longer coronal density scale lengths

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Experimental Comparisons

Predicted spectral shifts vary significantly with the electron-heat transport model used by hydrocode.
Predicted spectral shifts vary significantly with the electron-heat transport model used by hydrocode.

Experimental FABS Spectrum

Modeled FABS Spectrum

Laser power

Observed scattered power

LILAC scattered power

Initial blue shift matches

“Fan” tail too wide

Best match to observed spectral shifts, worst match to scattered power
Predicted spectral shifts vary significantly with the electron-heat transport model used by hydrocode.

Experimental FABS Spectrum

Modeled FABS Spectrum

Good compromise match for the observed spectral shifts and scattered power.
Various Other Pulse Shapes

Spectral shifts have been well modeled for a variety of pulse shapes and targets.
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Spectral shifts have been well modeled for a variety of pulse shapes and targets.
Modeling of coronal plasma is currently insufficient to predict both scattered power and spectral shifts.

- **Spectral shifts**
  - best matched (particularly the initial strong blue shift) using the CEA nonlocal model *which is known to overestimate absorption*.

- **Scattered Power**
  - all models predict more absorption than observed to some degree during the later part of the pulse.

- **Hydrocode needs additional physics to match observations**
  - enhanced absorption at earliest points in pulse
  - enhanced scattering in latter points

- **$2 \omega_p$ cannot explain enhanced scattering at 351-nm**

*Nonlinear cross-beam power transfer may explain the differences*
Cross-beam effects funnel power from shorter wavelengths to higher

- Ion-acoustic wave (IAW) transfers energy from a “pump” EM wave to a “seed” EM wave
  - Early in the pulse, the light leaving the plasma is at a higher frequency (blue shifted) than the incoming laser light
    - energy could be funneled back into the target increasing absorption
  - Late in the pulse, the light leaving the plasma is at a lower frequency (red shifted) than the incoming laser light
    - energy could bypass the target, increasing scattering

\[ \omega_{\text{pump}} = \omega_{\text{seed}} + \omega_{\text{IAW}} \]

\[ \mathbf{k}_{\text{pump}} = \mathbf{k}_{\text{seed}} + \mathbf{k}_{\text{IAW}} \]

\[ \omega = c_s |\mathbf{k}| + \mathbf{v}_f \cdot \mathbf{k} \]

Observed shifts of the order of Angstroms of the order needed to satisfy this dispersion relation
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