Time-Resolved Scattered-Light Spectroscopy in Direct-Drive-Implosion Experiments

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Scattered-light spectrum simulations indicate that anomalous absorption affects the latter part of implosions.

- Time-dependent scattered-laser-light spectra in the SBS range (351±1 nm) are modeled by a combination of hydrodynamic and ray-tracing codes.
- Most features observed in the scattered-light spectra are well reproduced by the modeling.
- The largest discrepancy in the modeling suggests that absorption is over-estimated in the later part of the pulse, but scaling the total absorption to match observations still does not accurately reproduce the spectra.
- Cross-beam transfer of energy out of the beam-profile center might be the physical process behind the discrepancy.
Collaborators

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Time-dependent scattered-laser-light spectra in the SBS range (351±1 nm) are modeled for OMEGA implosions.

- A combination of codes is used
  - *LILAC*\(^1\): 1-D hydrodynamic code predicts time-dependent implosion profiles
  - *SAGERAYS*\(^2\): Ray traces laser light through the corona and calculates spectral shift\(^3\)
  - *MATLAB* code calculates total spectrum collected from all 60 OMEGA beams

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Modeled spectra show all the basic structures of the experimental spectra but differ in some details.
Modeling with the pulse power scaled to reproduce the observed time-dependent absorption does not significantly improve the spectral shift predictions.

Where the energy is absorbed seems important, not just how much is absorbed.
Cross-beam transfer of energy from the beam profile center toward the profile edge might be consistent with the observations

- Removes energy from rays closest to center of beam profile that penetrate furthest towards the critical surface and are responsible for the uppermost finger of the spectrum tail
- Redistributes that energy to rays farther out in the beam profile where absorption is less
- Should result in a spectrum that better matches observations
  - removes energy from the uppermost finger
  - decreases total absorption/increases total scattered energy
Cross-Beam Power Transfer

EM-seeded SBS cross-beam power transfer might cause some laser energy to “bypass” the high-absorption zone

- Ion-acoustic wave (IAW) transfers energy from a “pump” EM wave to a “seed” EM wave
  \[
  \omega_{\text{pump}} = \omega_{\text{seed}} + \omega_{\text{IAW}} \\
  \mathbf{k}_{\text{pump}} = \mathbf{k}_{\text{seed}} + \mathbf{k}_{\text{IAW}} \\
  0 = \pm c_s |k_{\text{IAW}}| + \mathbf{v}_f \cdot \mathbf{k}_{\text{IAW}} - \omega_{\text{IAW}}
  \]

- Light entering the plasma can transfer energy to light that is leaving the plasma so that some laser energy “bypasses” the high-absorption region, reducing the total absorbed power

Because the EM seed amplitude is of the same order as the pump, very small gains of only a few percent could significantly affect the absorbed energy.
Beamlet crossings calculated from ray-trace and OMEGA beam geometry indicate that energy is typically lost by incoming beamlets.

Resonance function* ($P$) is a measure of how close the conditions are to resonance for SBS cross-beam transfer:

$$0 = \pm c_s |k_{IAW}| + \vec{v}_f \cdot \vec{k}_{IAW} - \omega_{IAW}$$

The strength of the transfer is estimated using the spatial gain length* $L_{\text{SBS}}$ for crossing planar waves.

\[ L_{\text{SBS}}^{-1} = 2.8 \times 10^{-2} \frac{1}{\nu_i \lambda_{0,\mu m}} \sqrt{1 - \frac{n_e}{n_c}} \frac{I_{14} \mu m}{T_e, \text{keV} (1 + 3T_i/ZT_e)} P(\eta) \left( \mu m^{-1} \right) \]

For one set of beamlets from one beam crossing, the reference beam is at 40°.

Calculating the energy lost/gained along each beamlet supports the transfer of energy out of beam center

\[ d(IA) = -IA \left( \frac{1}{L_{\text{abs}}} + \sum_{\text{all beams}} \sum_{\varphi} \frac{1}{L_{\text{SBS}}} P \right) ds \]

Intensity along beamlet with impact parameter = 350 µm

The rate of change in intensity caused by cross-beam transfer and absorption can be integrated along each path to determine the intensity

Summed over all sets of beamlets from all beams crossing the reference beam
Cross-beam transfer scattered-light modeling improves the match to experimental data later in the implosion.

- Early in the implosion modeling now shows too much scattered light.
- Integrating cross-beam transfer into the hydrocode may improve the agreement.
Summary/Conclusions

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