Laser–Plasma Interaction Processes Observed in Direct-Drive-Implosion Experiments

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Summary

Time-resolved scattered-light diagnostics provide unprecedented constraints for hydrodynamic simulations

- Time-resolved absorption constrains the electron-heat transport in hydrodynamic simulations.
  → nonlocal electron-transport model* in LILAC

- The coronal evolution is recorded in the overall scattered-light spectrum and further constrains heat transport.

- Laser–plasma interaction processes are identified through their spectral signatures.
  - enhanced scattering (cross-beam energy transfer)
  - two-plasmon-decay instability

- High-Z doping of plastic shells reduces energetic electron production due to two-plasmon-decay instability.

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Collaborators


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Outline

• Time-resolved absorption measurements

• Overall scattered-light spectrum near $\lambda_L$
  ➔ coronal plasma evolution ➔ electron-heat transport

• Enhanced absorption at early times
  ➔ critical for first shock in implosion experiments

• Decreased absorption due to cross-beam energy transfer during the main pulse

• Two-plasmon-decay instability
  ➔ fast-electron preheat
Time-Resolved Absorption

Time-resolved absorption is inferred from scattered-light measurements

- Isotropic scattering is assumed (supported by simulations).
- Scattered light is measured with calorimeters behind and between focusing lenses.
- Time-resolved spectroscopy of scattered laser light provides detailed information on interaction processes.
- Scattered light power \( r = 1 - \alpha \) will be compared to simulations.
Time-resolved scattered-light measurements require reexamination of electron-heat transport in simulations.
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Enhanced scattering likely due to cross-beam energy transfer.

LILAC with nonlocal electron heat transport and resonance absorption.

Cryo shot 10 μm CH shell 77 μm DT ice 0.9 THz SSD

$I_{14} = 5.97$
The frequency shift is proportional to the rate of change of the optical path

\[ \Delta \omega \propto - \frac{\partial}{\partial t} \int \mu ds, \quad \mu = \sqrt{1 - n_e/n_c} \]

An increasing path length through the plasma causes a blue shift in the spectrum

For details, see D. H. Edgell NO6.00009
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The scattered-light spectrum near $\lambda_L$ is affected by the temporally changing optical-path length inside the corona.

$$\Delta \omega \propto -\frac{\partial}{\partial t} \int \mu ds, \mu = \sqrt{1 - n_e/n_c}$$

→ an increasing path length through the plasma causes a blue shift in the spectrum

- All 60 beams of OMEGA contribute to the scattered-light signal seen by the camera
- The intensity and spectrum due to each beam varies with time and location of the beam relative to the camera
Including nonlocal thermal transport in *LILAC* reproduces the observed spectrum quite well.

*LILAC, LLE nonlocal transport*

Experimental scattered-light spectrum

Cryo shot, 10 μm CD shell, 95 μm D₂ ice, no SSD

*V. N. Goncharov (Gl1.00001), D. H. Edgell (NO6.00009)*
Simulating the scattered-light spectrum requires fine-tuning of electron-heat transport

Experimental spectrum

Standard *LILAC, f = 0.06*
Simulating the scattered-light spectrum requires fine-tuning of electron-heat transport.

*Experimental spectrum

45062 FABS25

**LILAC, LLE nonlocal transport**

*V. N. Goncharov (Gl1.00001)
Nonlocal transport is required to model absorption during the first 100 to 200 ps

Power (arbitrary units)

Time (ns)

Incident

Measured reflected

45062 FABS25

Warm 20 μm CH shell
60 beams
no SSD
Nonlocal transport is required to model absorption during the first 100 to 200 ps.
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LILAC with nonlocal transport reproduces experimental absorption at early times

Absorption fraction

Peak intensity ($10^{12}$ W/cm)

Laser pulses: 200 ps

20 μm CH shell
60 beams
no SSD
**LILAC with nonlocal transport reproduces experimental absorption at early times**

Precise modeling of initial absorption is essential for setting up low-adiabat-implosion experiments.
Enhanced Scattering

Enhanced scattering at later times is consistent with SBS cross-beam energy transfer.

- Scattered-light spectrum is almost always red-peaked
  - nonlinear process must be involved
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Late-time increased scattering likely to be due to beam-to-beam energy transfer via EM-seeded SBS.
Cross-beam energy transfer has been observed in OMEGA EM-seeded SBS experiments* as well as in LLNL** experiments.

Enhanced scattering more modestly affects the second shock in implosion experiments with complex pulse shapes.


The two-plasmon-decay (TPD) instability is observed in direct-drive spherical implosion experiments.

Characteristics of this instability:

- Decay of an incident photon into two plasmons near $n_c/4$
- Low-intensity threshold:
  - for plane waves in linear density gradient:
    $$\eta_{th} \sim I_{14} \frac{L_n}{230 T_e}$$
    (threshold parameter)**
- Energetic electron production
- Practical theories applicable to real experimental conditions are not presently available.
- TPD instability is identifiable in $3\omega/2$, $\omega/2$, and hard-x-ray spectra

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** J. A. Delettrez, JO3.00003
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![Graph showing intensity scaling](image-url)
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- Cryo shot
- 4.5 μm CH shell
- 95 μm D₂ ice
- 1 THz SSD
The 3/2 harmonic emission depends sensitively on intensity, density scale length, and electron temperature.
Summary/Conclusions

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