Measurements of the Conduction-Zone Length and Mass Ablation Rate in Cryogenic Direct-Drive Implosions on OMEGA

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Summary

NL* electron transport and CBET** models are required in 1-D LILAC simulations to reproduce the mass ablation rate and the length of the conduction zone in cryogenic implosions on OMEGA.

- The averaged mass ablation rate of the outer CD layer in cryogenic implosions was measured by imaging the self-emission x rays emitted by the target.
- The length of the conduction zone was determined from the combination of the measurement of the self-emission x-ray imaging and the scattered-light spectrum.
- This experiment cannot be reproduced with a time-dependent flux limiter.
- One-dimesional LILAC simulations, including NL electron transport and CBET, reproduce the experimental observables.

* NL: Nonlocal
** CBET: Cross-beam energy transfer
Collaborators


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Direct-drive inertial confinement fusion implosions are driven by laser energy absorbed near the critical density and transported by electrons to the ablation surface.

Measurement of the mass ablation rate and the size of the conduction zone constrain the hydrodynamic coupling.
In a cryogenic implosion, the averaged mass ablation rate of the CD outer layer was determined from the measurement of the time to burn through the CD.

Self-emission x-ray imaging:

- 20-μm pinhole
- 300-nm Al
- 1-μm PP**
- 50-ps microchannel plate

** PP: polypropylene
After the laser burns through the CD layer, the inner peak corresponds to the ablation surface and the outer peak corresponds to the CD/DT interface.

The ablation-front trajectories were determined from a series of self-emission images.
The CD/Dt interface trajectory was measured from the CD emission peak after the CD burnthrough*.

The CD burnthrough corresponds to the time when the CD expands from the ablation surface.

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When matching shell trajectory, time-dependent flux-limited (FL) simulations underestimate the averaged mass ablation rate of the CD by 10%
The averaged mass ablation rate of the CD was reproduced when using NL and CBET models.
The scattered-light spectrum provides a measure of the time when the CD/DT interface reaches the laser-absorption region.

The scattered-light diagnostic collects the light coming from every beam with various angles of incidence.
The more red-shifted light comes from the rays with a lower angle of incidence that penetrate closer to the ablation surface. The closer to the turning point is to the ablation surface, the larger the inward velocity of the reflecting surface and the larger the red shift.

\[ n_{tp} = n_c \cos^2(\theta) \]

Moving mirror* 
\[ \Delta \lambda \approx \frac{2V_{tp} \lambda_0}{c} \]

*Calculated for normal incident rays
When the DT reaches the absorption region, the velocity of the critical-surface jumps, resulting in a jump in the maximum red-shifted wavelength*.

This jump in a red-shifted light provides a measure of the time when the DT reaches the absorption region.

The combination of the scattered-light spectrum and the self-emission x-ray imaging allows the length of the conduction zone to be determined*.


When the DT reaches the absorption region, the length of the conduction zone corresponds to the distance between the CD/DT interface and the ablation front.
The size of the conduction zone is well reproduced when using NL and CBET models.

When matching shell trajectory, time-dependent flux-limited simulations underestimate the length of the conduction zone by nearly a factor of 2.
Summary/Conclusions

NL electron transport and CBET models are required in 1-D LILAC simulations to reproduce the mass ablation rate and the length of the conduction zone in cryogenic implosions on OMEGA

- The averaged mass ablation rate of the outer CD layer in cryogenic implosions was measured by imaging the self-emission x rays emitted by the target.
- The length of the conduction zone was determined from the combination of the measurement of the self-emission x-ray imaging and the scattered-light spectrum.
- This experiment cannot be reproduced with a time-dependent flux limiter.
- One-dimesional LILAC simulations, including NL electron transport and CBET, reproduce the experimental observables.
When the DT reaches the absorption region, the maximum red-shifted wavelength jumps in the scattered light spectrum.

When the DT reaches the absorption region, the velocity of the critical surface jumps, resulting in a jump in the maximum red-shifted wavelength in the scattered-light spectrum.
LILAC simulations that include NL and CBET reproduce both the absorption and the kinetic energy of the shell

The code accurately models the hydrodynamic coupling in cryogenic implosions.
DRACO simulations of cryogenic implosions show that perturbations have a minimal impact on the measurement of the burnthrough time*.

*DRACO simulations were performed with and without perturbations seeded by target offset, DT ice roughness, and laser imprint up to mode 150.
The growth of perturbations on the shell are governed by the mass ablation rate and the length of the conduction zone.

Conduction zone smoothing

- $\Delta P(n_c) \rightarrow \Delta P(\text{abl})$
- $\text{Reduce the imprint}$

Ablation velocity stabilization ($V_{\text{abl}} \propto \dot{m}_a$)

- Reduce the imprint:
  - reduce the time to create the conduction zone
  - reduce the amplitude of the modulations caused by the dynamic overpressure

- Reduce the Rayleigh–Taylor growth

$$\gamma_{RT} = \sqrt{kg - k^2 V_{\text{abl}}(V_{bl} - 4V_{\text{abl}}) - 2kV_{\text{abl}}}$$

The conduction zone smooths the laser imprint while the mass ablation rate reduces the imprint and the growth of the Rayleigh–Taylor instability.

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