Studies of Adiabat-Shaped Direct-Drive, Cryogenic-Target Implosions on OMEGA

Fluence (10^16 keV/keV) vs. Photon energy (keV)

Absorption related to $\rho R$

- Experimental data
- LILAC
- LILAC, opacity = 0

D_2 cryogenic implosion

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High fuel areal densities are observed in implosions on OMEGA that are energy-scaled from NIF ignition designs.

- Cryogenic target layering has produced ice smoothness that meets NIF specifications:
  - <1-μm rms in all modes in $\beta$-layered DT capsules,
  - <2-μm rms in all modes in D$_2$ capsules with auxiliary heating.

- Areal densities in excess of 100 mg/cm$^2$ are observed from x-ray and nuclear diagnostics.

- The Lawson criterion for these dense plasmas is $>7 \times 10^{20}$ s/m$^3$ and the fusion parameter is in excess of $10^{20}$ s-keV/m$^3$. 
Collaborators


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High-contrast pulse shapes are used to place the target on a low adiabat for high compression

- Cryogenic ice-layer smoothness is routinely below 2-μm rms.\(^1\)
- The picket shapes the target adiabat\(^2\)
- The peak intensity limits the core temperature for continuum measurements.

\(^{1}\text{See T. C. Sangster QT1.00001}\)
\(^{2}\text{K. Anderson and R. Betti, Phys. Plasmas 10, 4448 (2003).}\)
The neutron averaged areal density $\langle \rho R \rangle_n$ is greater than 100 mg/cm$^2$ for cryogenic D$_2$ implosions.

Cold, dense fuel shell

Hot, low-density core

$\langle \rho R \rangle_n$ is greater than 100 mg/cm$^2$ for cryogenic D$_2$ implosions.

$1. \ D + D \rightarrow ^3\text{He} \ (0.7 \text{ MeV}) + p$

$2. \ ^3\text{He} + D \rightarrow p \ (12.5–17.4 \text{ MeV}) + ^4\text{He}$

$\langle \rho R \rangle_n \sim 100 \text{ to } 110 \text{ mg/cm}^2$ over several lines-of-sight

• Low-energy tail suggests peak $\rho R$ approaches 200 mg/cm$^2$

Further analysis is underway to infer a $\rho R(t)$ by convolving the neutron emission rate with the measured proton spectrum*

The core x-ray continuum is measured with a pinhole-array spectrometer

~200 monochromatic images with 50-$\mu$m pinholes

Array tilt spreads images along energy axis

Core emission is well separated from ablation-region emission and background
The peak areal density $\rho R_{\text{peak}}$ may be inferred by using core self emission to backlight the fuel shell.

Emitted x-ray spectrum is the product of a source term and an attenuation term.

- $I \propto e^{-E/T} \times e^{-\mu \rho R_{\text{shell}}}$

The fuel–shell attenuation is proportional to $\rho^2 R$.

1-D simulations can be used to estimate $\rho$ and suggest the $\rho R_{\text{peak}}$ could be as high as 180 to 190 mg/cm$^2$.

2-D simulations are expected shortly to confirm fuel density estimates.
The Lawson criterion can be estimated from the core size and calculated density

- The average density is $\sim 30 \text{g/cm}^3 \rightarrow n_e \sim 7 \times 10^{24} \text{cm}^{-3}$
- The confinement (disassembly) time is greater than 100 ps
- $n_e \tau > 7 \times 10^{20} \text{s/m}^3$
- at 200 eV, $n_e \tau T > 10^{20} \text{keV-s/m}^3$
The fusion-confinement parameter in cryogenic implosions on OMEGA is comparable to those achieved in Tokamak experiments.
Summary/Conclusions

High fuel areal densities are observed in implosions on OMEGA that are energy-scaled from NIF ignition designs.

- Cryogenic target layering has produced ice smoothness that meets NIF specifications:
  - <1-μm rms in all modes in β-layered DT capsules,
  - <2-μm rms in all modes in D₂ capsules with auxiliary heating.

- Areal densities in excess of 100 mg/cm² are observed from x-ray and nuclear diagnostics.

- The Lawson criterion for these dense plasmas is >7 × 10²⁰ s/m³ and the fusion parameter is in excess of 10²⁰ s-keV/m³.