Numerical Investigation of X-Ray Core Images from OMEGA Implosions Driven with Controlled Polar Illumination

OMEGA Shot 34668, PDD, D$_2$(15)CH[20], 40 beams, 15.4 kJ

DD yield $2.9 \times 10^{10}$

KB3 time-integrated x-ray image

DD yield $4.1 \times 10^{10}$

DRACO/Spect3D

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Summary

2-D DRACO/Spect3D* simulated x-ray images show good agreement with images of imploded cores from polar direct drive experiments

- Successfully attributing the low-order asymmetry of implosion images to controlled polar drive in OMEGA experiments supports ongoing PDD (polar direct-drive) design work.

- The size, asymmetry, and history of observed images are reproduced by
  - 2-D hydrodynamic simulation
  - radiation-transport postprocessing

- Additional image asymmetry can be attributed to the viewing angle in some cases, rather than unintended illumination imbalance.

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Collaborators

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Simulated images are obtained from 2-D hydrodynamic simulation and 3-D radiation transport postprocessing

- **DRACO hydrocode**
  - 2-D Lagrangian hydrodynamics with interface tracking
  - PDD irradiation simulated with 2-D ray tracing

- **Spect3D* radiation-transport postprocessing**
  - Full 3-D straight-line integration of the equation of transfer
  - Tabulated LTE opacities valid for intended application
  - Camera filtering, response, and viewing angles included

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OMEGA experiments show the effects of known polar nonuniformities on the shape of compressed cores.

Shot 35173, prolate energy distribution
\[ \sigma_\ell = 2 = -13.2\% \]

Shot 35174, prolate energy distribution
\[ \sigma_\ell = 2 = 7.2\% \]

\[ I_{\text{laser}}(\theta) = I_0 \left[ 1 + \sigma_2 \hat{P}_2(\cos \theta) \right] \]
Target cores imploded with controlled polar asymmetry match the size and shape of 2-D DRACO and Spect3D\(^*\) simulations.

**Shot 35173**
- Prolate
- \(\sigma_{\ell=2} = 13.2\%\)

**gmxi (2 to 7 keV)**
- \(t = 1.4\) ns

**Shot 35174**
- Oblate
- \(\sigma_{\ell=2} = 7.2\%\)

**gmxi (4 to 7 keV)**
- \(t = 1.65\) ns

\(^*\)Prism Computational Sciences, Inc., Madison, WI
Image distortion parameters are estimated by fitting data with noncircular intensity contours

- Find image intensity contours:
  \[ r(\theta) = \rho (1 + a_1 \cos \theta + a_2 \cos 2\theta + a_4 \cos 4\theta), \] such that \( I(x,y) \approx I(\rho) \)

Shot 35173, prolate
\[ \sigma_{\ell} = 2 = 13.2\% \] P2 drive nonuniformity:
- \( I(x,y) \) data
- \( \text{gmxi (2 to 7 Kev)} \)
- \( a_2 = 0.20 \)
- fit to \( I(\rho) \) contour map
- \( t = 1.4 \text{ ns} \)
- Fit residual
Target cores imploded with controlled polar asymmetry match the size and shape of 2-D DRACO and Spect3D* simulations.

**Shot 35173**
- Prolate
- $\sigma_{\ell=2} = 13.2\%$
- $a_2 = 0.20$

**Shot 35174**
- Oblate
- $\sigma_{\ell=2} = 7.2\%$
- $a_2 = 0.21$

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A measured prolate core-image sequence with equatorial stagnation is reproduced with 2-D DRACO and Spect3D*

Shot 35173, prolate drive
\( \Delta t = 58 \text{ ps}, \; \sigma_{\ell=2} = -13.2\%, \; \text{xrfc}, \; \text{Be filter} \)

Peak compression

**DRACO and Spect3D**

\[ a_2 = 0.58 \quad 0.44 \quad 0.48 \quad 0.38 \quad 0.27 \quad 0.10 \]

\[ a_2 = 0.38 \quad 0.45 \quad 0.46 \quad 0.37 \quad 0.27 \quad 0.16 \]

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The observed time-resolved P2 harmonic distortion parameter of the prolate stagnation sequence is reproduced with a 2-D DRACO and Spect 3D* simulation.

Shot 35173, prolate drive, $\sigma_\ell = 2 = 13.2\%$, xrfc, Be filter

Intensity contours: $I(x,y) = I(\rho)$, $r(\theta) = \rho(1 + a_2 \cos2\theta + a_4 \cos4\theta)$
The NIF 48-quad PDD configuration was simulated on OMEGA by repointing 40 beams.

42° beams moved to 66.6°
58.8° beams moved to 83.5°
21° beams moved to 33.4°
The core-stagnation symmetry is affected by the illumination configuration.

Time-integrated KB microscope images

60 beams
- TCC: 15.6 kJ
- \( Y_{DD} = 8.4 \times 10^{10} \)

40 beams
- PDD: 15.4 kJ
- \( Y_{DD} = 2.9 \times 10^{10} \)

Shot 34644

Shot 34668

100 \( \mu \)m
DRACO simulations of the PDD experiments reproduce the qualitative shape of the compressed core.

OMEGA implosions at 15-atm, D₂-filled, 20-μm-thick CH shells

40 beams
PDD shot 34668
15.4 kJ

DD yield
2.9 \times 10^{10}

40 beams
PDD simulation*
shot 34668

DD yield
4.1 \times 10^{10}

KB microscope view

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PDD x-ray image asymmetry is due to the oblique viewing angle and absorption by the shell.

Mass density and electron temperature near peak compression
Shot 34668, t = 2.2 ns

\( \rho \text{ (g/cm}^3\text{)} \)

\( T_e \text{ (keV)} \)
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