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Hohlraum drive and implosion velocity scaling to 500 TW laser drive on NIF

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Plasma Physics
October 31
Providence, Rhode Island**

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Los Alamos National Laboratory**

Lawrence Livermore National Laboratory • National Ignition Campaign

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abstract

The scaling of nuclear performance with increasing laser power and hohlraum drive has been measured in high-velocity implosions of inertial confinement fusion capsules filled with equimolar deuterium-tritium fuel. Besides laser power, the experiments further scale the capsule ablator thickness and hohlraum wall material. Specifically, the first depleted uranium hohlraums for layered implosion experiments have shown an unambiguous improvement in capsule drive, which is equivalent to 25 TW over gold hohlraums at laser peak powers of 320 TW. Measurements of laser coupling up to 500 TW show little change indicating higher drives can be achieved with higher laser powers and more energy.

Collaborators

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A special thanks to the laser team for achieving 500 TW, 1.85 MJ operations

Isaac Bass, Mary Spaeth, Corey Bennett, Mark Bowers, Gordon Brunton, Jeffrey Bude, Scott Burkhart, Alan Conder, J.M. Di Nicola, Shamasundar Dixit, Gaylen Erbert, James Folta, John Heebner, Mark Henesian, Mark Hermann, Kenneth Jancaitis, Kai LaFortune, Lawrence Lagin, Douglas Larson, Brian MacGowan, Philip Miller, Marcus Montincelli, Mike Nostrand, Lawrence Pelz, Michael Shaw, Tayyab Suratwala, Bruno Van Wonterghem, Paul Wegner and Clifford Widmayer, and Ed Moses.

Data indicates that Laser Plasma Instabilities (LPI) are not limiting the allowable laser power and energy for the current hohlraum design

- **There is little change in laser-target coupling with increasing laser power and energy from 300 to 520 TW, and from 1.2 to 1.9 MJ**
 - Hot electrons increase with laser power but are still a small contributor to the adiabat of the implosion
- **With 520 TW and 1.85 MJ, depleted Uranium ignition hohlraums have reached radiation temperatures of 330 eV.**
 - The DU hohlraum is worth ~25 TW or ~10% in laser energy
- **At 520 TW, the inferred fuel velocities for the symcap are 350-370 km/s for capsules 20 μ m thicker than the nominal design**
- **Increasing the laser power and energy would increase implosion velocity and allow thicker capsules to mitigate ablative Rayleigh-Taylor**

NIF laser design is based on a trade off between the hohlraum and capsule physics

- Upper limit set by expected laser backscatter due to laser plasma instabilities, filamentation, Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS)
- Lower limit is set by hydro instabilities

Lindl, PoP (2004)

Measured hohlraum drive is somewhat higher than assumed when NIF requirements were set (circa 1992)

Power balance for hohlraum:

$$\begin{aligned} \eta_{CE}(P_L - P_{Backscatter}) \\ = P_W + P_{LEH} + P_{CAP} \\ = \sigma T^4 \left[(1 - \alpha) A_W + A_{LEH} + f_{CAP} A_{CAP} \right] \end{aligned}$$

Lindl, PoP (2004)

With higher laser powers and energies we could expand the operating region for ICF

- Going to higher laser powers and energies possible for these hohlraums
- Higher radiation temperatures drive higher implosion velocities increasing the margin for ignition, $v_{\text{imp}} \sim T_{\text{rad}}^{1/2}$
- Higher radiation temperatures provide more ablative stabilization of hydro instabilities $\gamma \sim -V_{\text{abl}}, V_{\text{abl}} \sim T_{\text{rad}}^{9/10}$
- Higher drives allows thicker ablators which help mitigate ablative hydro instabilities

The data indicate there is not LPI cliff at 520 TW, so we can go to higher laser powers and energies

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Hohlraum Coupling

Diagnostic set used to measure hohlraum coupling

The NIF has fired a laser pulse with 520 TW of peak power and 1.85 MJ of energy

- Measured values are at the target, i.e. loss for final optics taken into account.
- Hohlraum radiation drives of ~330 eV have been achieved in DU hohlraums with a 520 TW laser pulse laser shot
- 84% of the incident laser energy was coupled to the target

Measured laser pulse shape for 500 TW shot

The laser coupling shows little dependence on laser energy and power up to 520 TW and 1.9 MJ

Coupling for all symcaps and DT layered implosions shots vs power

Coupling for all symcaps and DT layered implosions shots vs energy

Coupling is $84\% \pm 3\%$ and includes changes to LEH size, DU/Au, rise times for this hohlraum design, it is possible to go to higher laser powers

Backscatter is dominated by stimulated Raman scatter (SRS) on the inner beams (~12% of incident energy)

Laser-target coupling

Typical backscatter from 1.4 MJ

While there is some trade-off between SRS and SBS, the coupling remains relatively constant

Qualitatively, the SRS spectra and time dependence of backscatter change little over large range of LPI risk

SRS spectrum on 30° cone

N120709
350 TW, 1.5 MJ

N111013
436 TW, 1.2 MJ

N120703
424 TW, 1.9 MJ

N120705
520 TW, 1.85 MJ

Time dependence of total backscatter

Increasing LPI risk →

SBS in the outer cone is increasing with laser pulse length, but remains small <5% of total incident

SBS on outer cones with increasing laser power

SBS on the outer cones increases with increasing pulse length

While the hot electrons do scale with increasing laser power, the data indicate we could go to higher powers

Hot electrons scale with laser power

Hot electrons come primarily near the end of the laser pulse

Hot electrons generated late in the pulse have less impact on the adiabat, $e^{\delta s}$ where $\delta s \sim \delta Q/T$

Hohlraum Radiation Drive

The hohlraum radiation drive is measured with Dante, an 18 channel soft x-ray spectrometer

k- and l- edge filters are used to measure the spectral flux in given bands

A spectrum is generated from the individual channels

This is repeated for each time step to generate the x-ray radiation time history

The Static X-ray Imager (SXI) views x-ray emission through the laser entrance hole with pinhole imaging

a) Hohlraum

X-ray intensity vs. time data and static LEH images can be used to infer the T_{RAD}^4 driving the capsule

DANTE provides x-ray intensity history Φ

$$\Phi_{DANTE} \sim A_{clear} \sigma T_{RAD}^4$$

3-5 keV SXI provides the “clear area” A_{clear} at peak x-ray intensity

Initial LEH

Clear aperture

890 eV SXI provides the fraction f_{clear} of flux within the clear area

$$T_{RAD} = \left(\frac{\pi f_{clear} \Phi_{DANTE}}{\sigma A_{clear} \cos \theta} \right)^{\frac{1}{4}}$$

This technique has been validated using simulated data from HYDRA calculations

In gold hohlraums, radiation temperatures of ~ 325 eV have been achieved with 1.89 MJ of energy

Peak radiation temperature corrected for LEH size

**For Peak Power of 420 ± 20 TW
peak power**

Peak xray flux normalized to LEH size

**For Peak Power of 420 ± 20 TW
peak power**

Depleted uranium (DU) hohlraums improve x-ray drive

- Higher opacity and lower heat capacity reduces wall losses, i.e. more energy radiated back into the hohlraum
- 0.7 μm gold coating on inside of hohlraum has three purposes
 - Gold prevents oxidation of the uranium
 - This thickness of Au will keep shock timing the same between Au and DU hohlraums
 - This allows use of Au keyhole targets
 - At low temperature, Au has higher opacity than DU
- Calculations show that all laser energy is deposited in Au so > 1.8 keV x-rays are same for DU and Au hohlraums
- Au layer on outside is for structural integrity

Gold hohlraum wall construction

Uranium hohlraum wall construction

The DU hohlraums are worth ~25 TW or ~10% in laser power

With 520 TW and DU hohlraums, we have achieved ~330 eV radiation temperatures

Peak radiation temperature corrected for LEH size

For Peak Power of 420 ± 20 TW
peak power

Peak xray flux normalized to LEH size

For Peak Power of 420 ± 20 TW
peak power

No difference in the fraction > 1.8 keV between the DU and Au hohlraums within the Dante measurements

Peak emittance > 1.8 keV vs total peak emittance

fraction of flux above >1.8 keV vs incident laser energy

Higher fraction of xray flux > 1.8 keV requires more Si dopant

Reproducibility

Three symcap shots with the same laser drive have shown the system is reproducible

Parameter	Goal	Meas. (RMS)
Laser Power (TW)	$\pm 3\%$	1%
Xray flux (TW/sr)	$\pm 3\%$	2%
Xray Bang time (ns)	50 ps	35 ps
DD Yield	$\pm 20\%$	4%
Ti (keV) [ntof]	$\pm 10\%$	8%

The primary difference between symcaps and layered implosions are the convergence and ice layer

Xray drive and laser time history for three repeat symcaps

Data for system shots **N120906**, **N120909**, and N120910

The backscatter data from the three reproducibility symcap implosions showed little variability shot-to-shot

Data for system shots N120906, N120909, and N120910

	23° cone SRS (kJ) RMS	30° cone SRS (kJ) RMS	50° cone SBS (kJ) RMS	Total (kJ) RMS
Three symcaps	1.9	0.5	0.25	18
All shots RMS	3.1	3.8	0.55	64

Capsule velocity

The back-lit ConA platform measures the trajectory and in-flight properties of the capsule ablator

Experimental Geometry

Backlit D-³He-filled capsule

Gated 9 keV X-ray radiography

Technique measures radius, velocity, ρR , and mass of ablator

Real streak

See Meezan's talk, this session
GO4.1 Dewald
GO4.2 Olson

A recent symcap experiment at 520 TW, 1.86 MJ was consistent with reaching $V_{\text{fuel}} = 350 - 370$ km/s

V_{COM} vs. x-ray bang-time from
1D HYDRA calculations

- Start with 1D HYDRA flux-scaling to get velocity vs. bang-time playbook
- Use a T_{RAD} history derived from DANTE data
- Use the measured 470 TW ConA experiment V_{COM} data to “pin” the playbook

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- 520 TW, 1.86 MJ experiment lies on the curve at $V_{\text{COM}} \approx 335$ km/s
- 1D HYDRA flux-scaling on DT layered capsules: this drive corresponds to $V_{\text{fuel}} \approx 370$ km/s

>95% of the fuel velocity needed for ignition with a capsule with **20 um thicker** ablator

- But a lot of extrapolation
See Meezan’s talk, this session

With higher powers, we can drive thicker capsules to ignition velocities

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