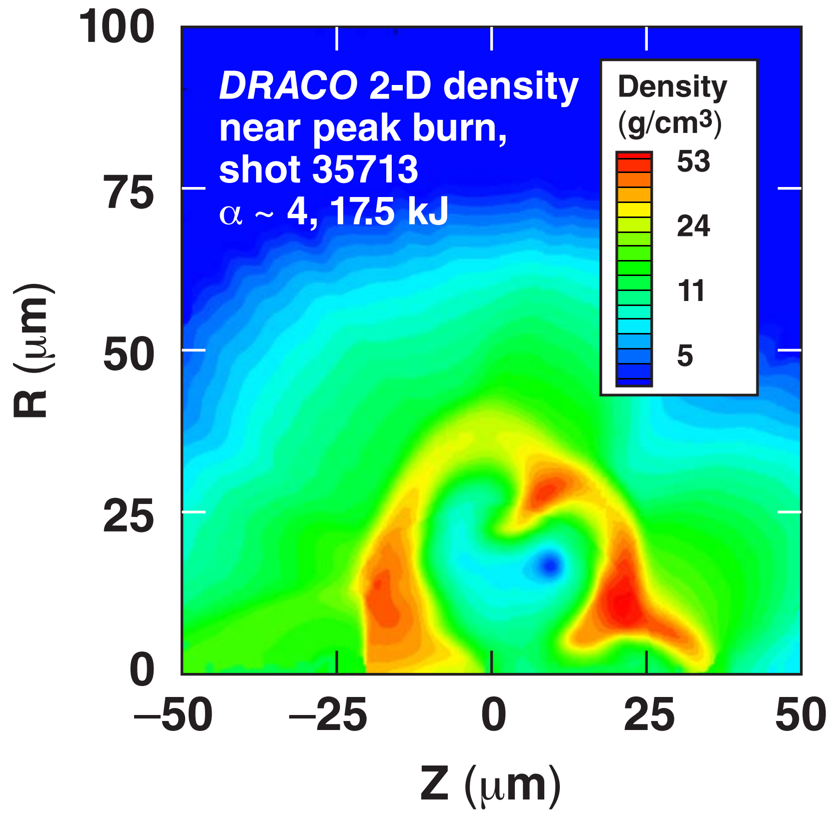
Direct-Drive Cryogenic Target Implosions on OMEGA



F. J. Marshall
University of Rochester
Laboratory for Laser Energetics

46th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Savannah, GA
15–19 November 2004

Collaborators

R. S. Craxton, J. A. Delettrez, W. R. Donaldson, D. H. Edgell, L. M. Elasky, R. Epstein, V. Yu. Glebov, V. N. Goncharov, D. R. Harding, P. A. Jaanimagi, D. Jacobs-Perkins, R. Janezic, J. P. Knauer, S. J. Loucks, R. L. McCrory, P. W. McKenty, D. D. Meyerhofer, P. B. Radha, S. P. Regan, C. Sangster, W. Seka, V. A. Smalyuk, J. M. Soures, and C. Stoeckl

Laboratory for Laser Energetics
University of Rochester

J. Frenje, C. K. Li, R. D. Petrasso, F. H. Séguin

Plasma Science and Fusion Center
Massachusetts Institute of Technology

Summary

Performance of ignition-scaled, direct-drive, cryogenic implosions on OMEGA is in good agreement with 2-D hydrocode simulations

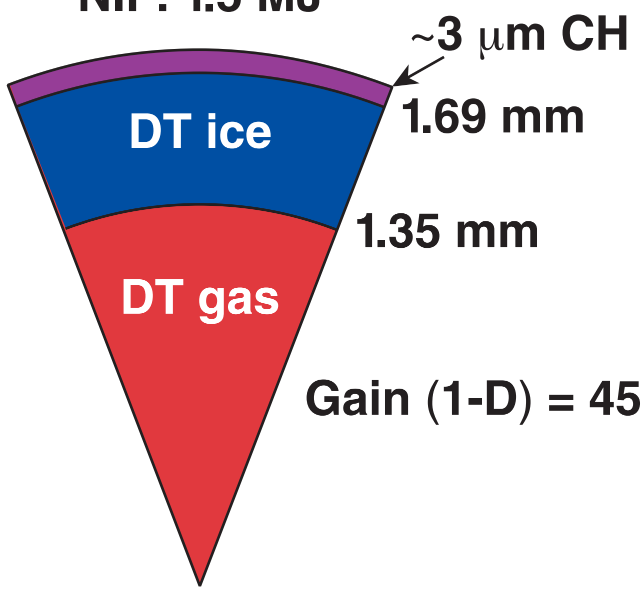
- There is good agreement between the measured and simulated laser absorption fraction for cryogenic implosions (within ± 2%).
- Cryogenic target preparation techniques have achieved 1-μm-rms D_2-ice layers, the NIF requirement.
- Directly-driven cryogenic implosions on OMEGA have produced compressed deuterium fuel areal densities of ~100 mg/cm^2.
- The results give increased confidence in the direct-drive approach to ICF ignition.

Cryogenic DT implosions will begin in 2005.

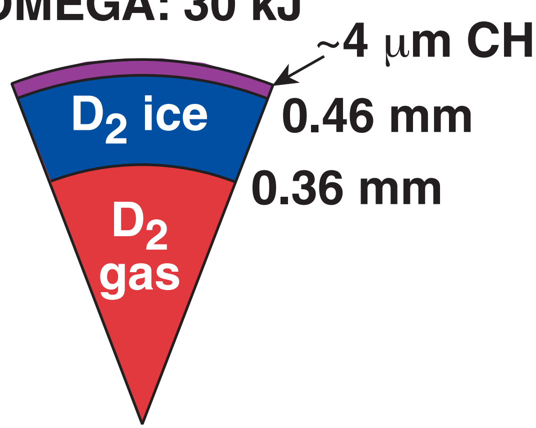
E13503

OMEGA cryogenic targets are energy scaled from the NIF symmetric direct-drive point design

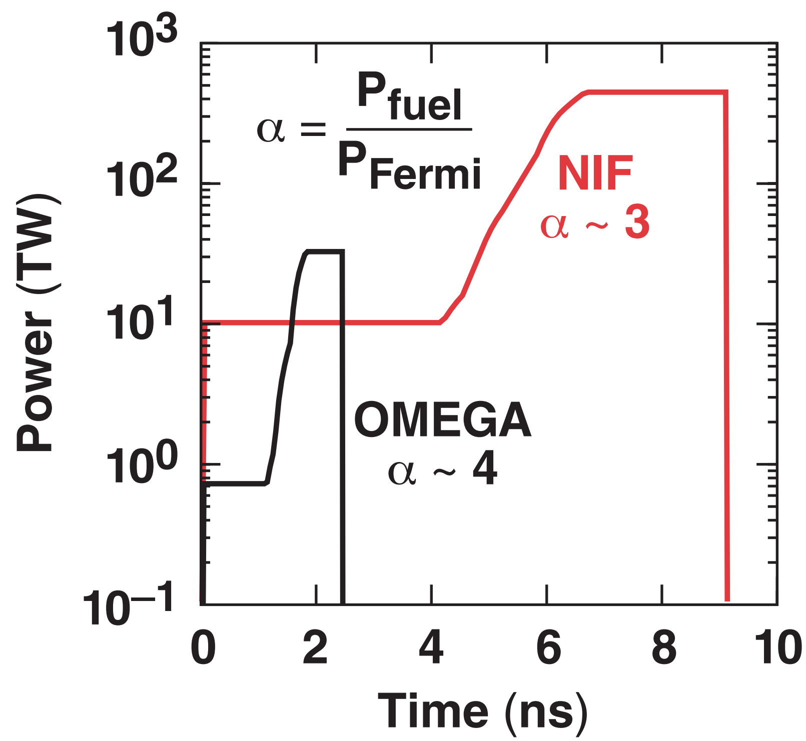
NIF: 1.5 MJ



OMEGA: 30 kJ



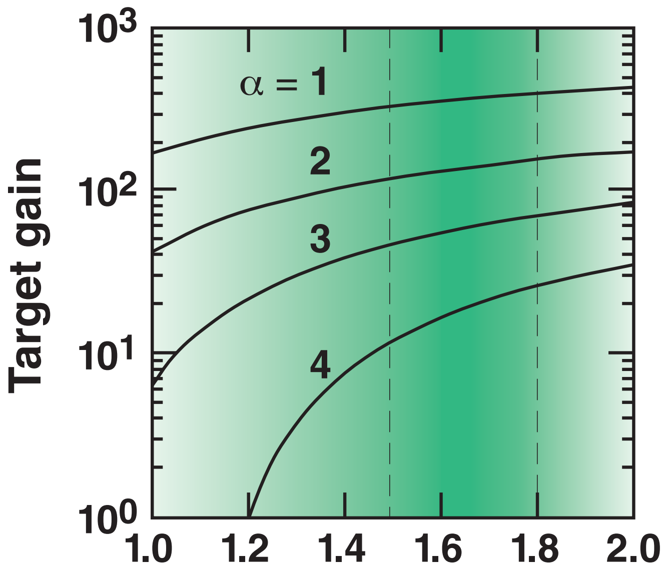
Energy ~ radius^3;
power ~ radius^2;
time ~ radius



E11251g

Direct-drive ICF has traditionally traded target performance for increased hydrodynamic stability

UR/LLE 351-nm direct-drive gain curves



$$\alpha = \frac{\text{Fuel specific energy}}{\text{Fermi-degenerate specific energy}}$$

$$E_{min} \cong \alpha^{1.9*}$$

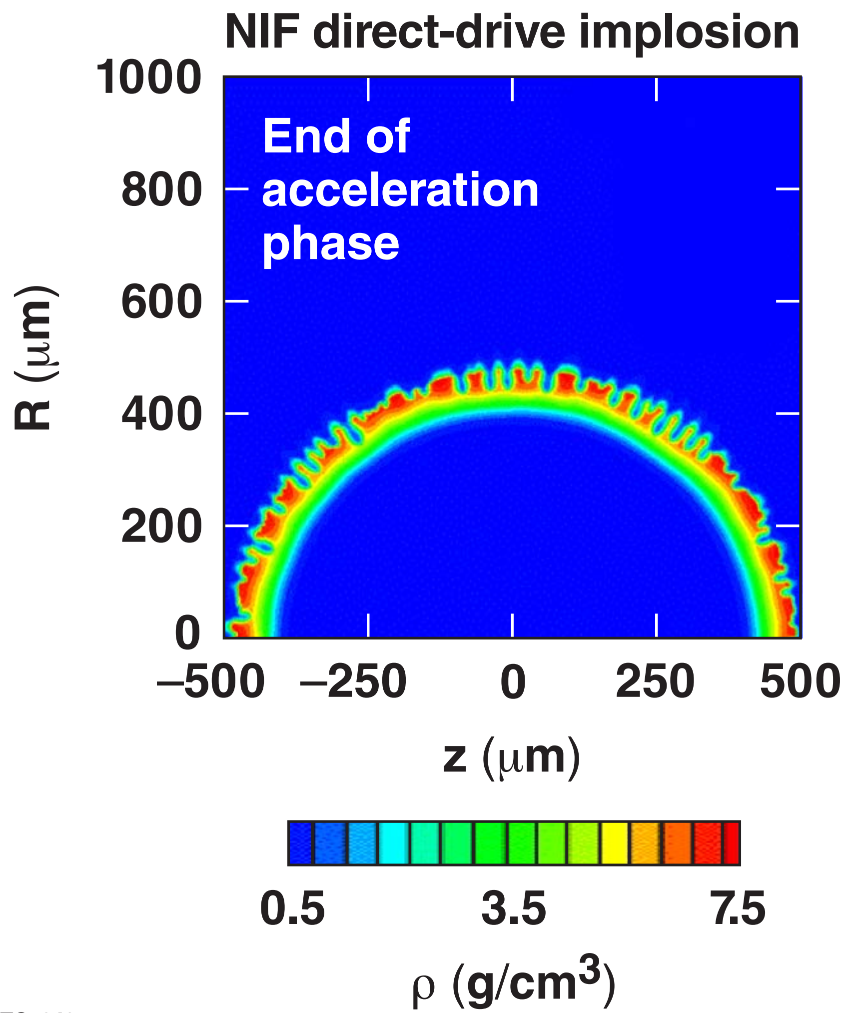
$$\gamma = 0.94\sqrt{kg} - 2.6\ kV_a$$

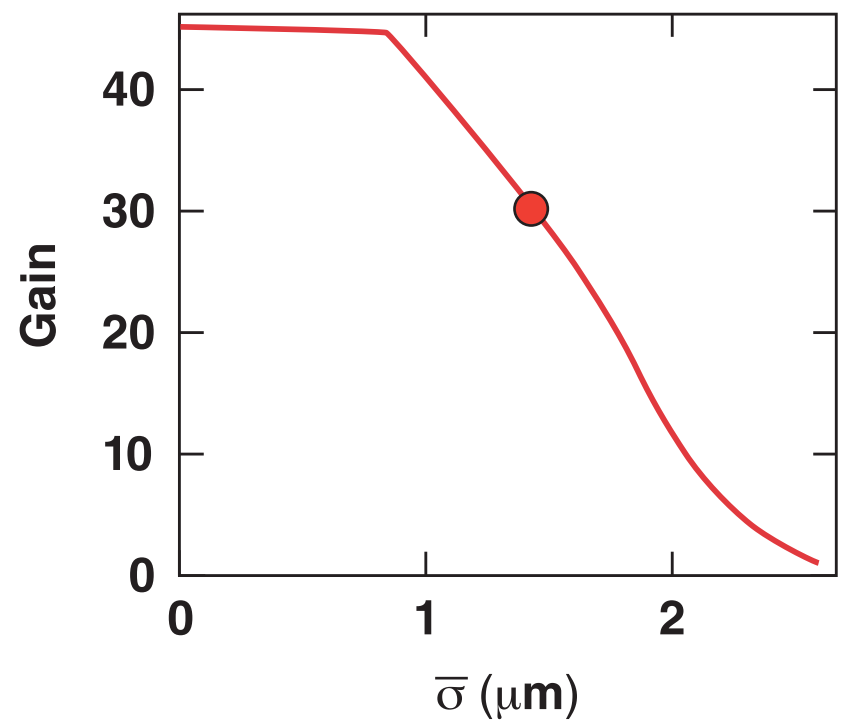
where $V_a \sim \alpha^{3/5}$.†

*M. C. Herrmann, *et. al.*, Nucl. Fusion 41, 99 (2001).
†R. Betti *et al.*, Phys. Plasmas 5, 1446 (1998).

TC3953g

Extensive 2-D simulations* have shown a correlation between target gain and the roughness of the inner ice surface at the end of the acceleration phase





$$\bar{\sigma}^2 = 0.06\sigma^2_{\ell<10} + \sigma^2_{\ell\geq10}$$

*P. McKenty *et al.*, Phys. Plasma 8, 2315 (2001).

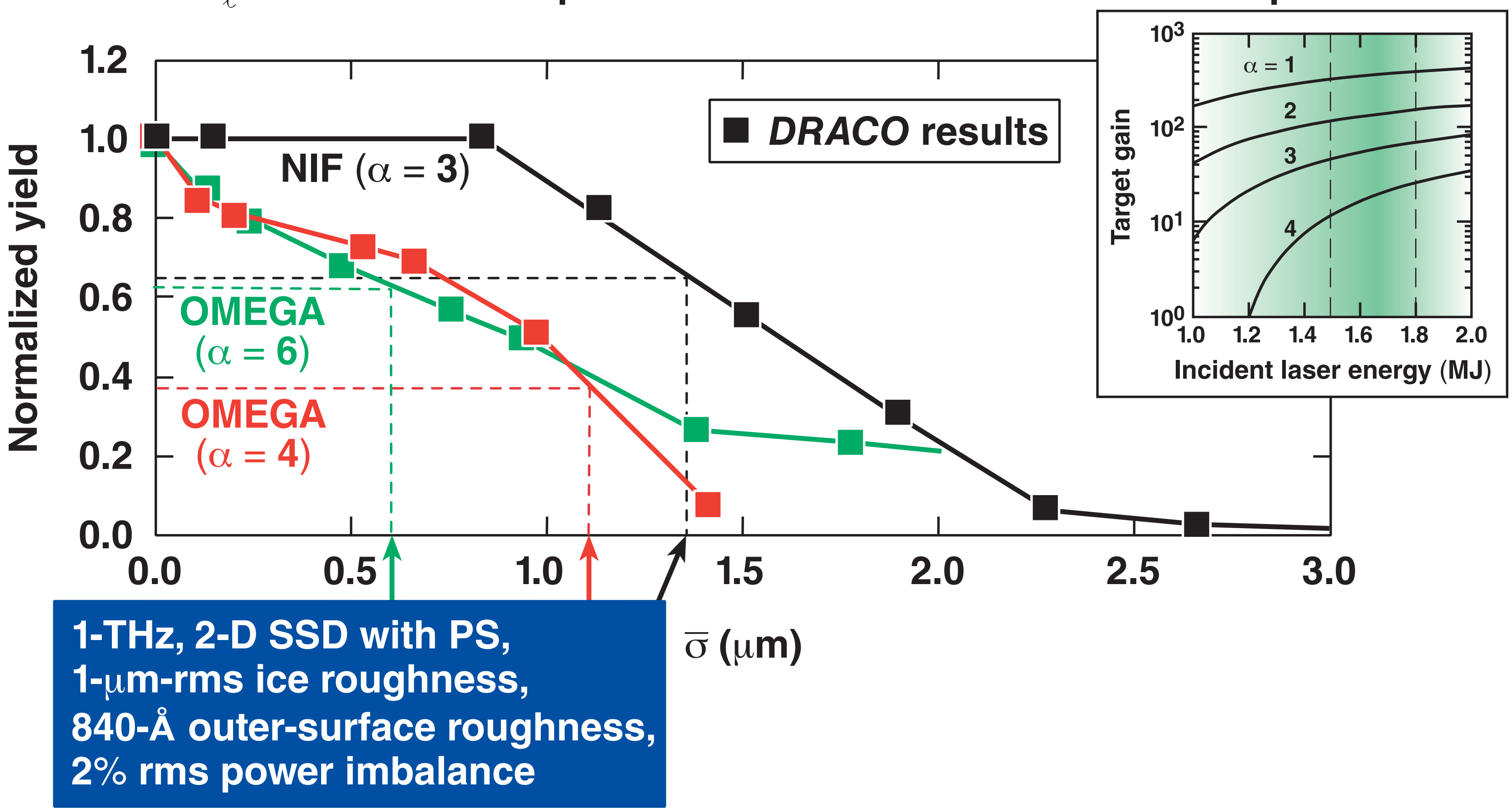
TC5942c

A stability analysis* defines the ignition-scaling performance window for low adiabat implosions

- The NIF gain and OMEGA yield can be related by

$$\bar{\sigma}^2 = 0.06\,\sigma^2_{\ell<10} + \sigma^2_{\ell\geq 10},$$

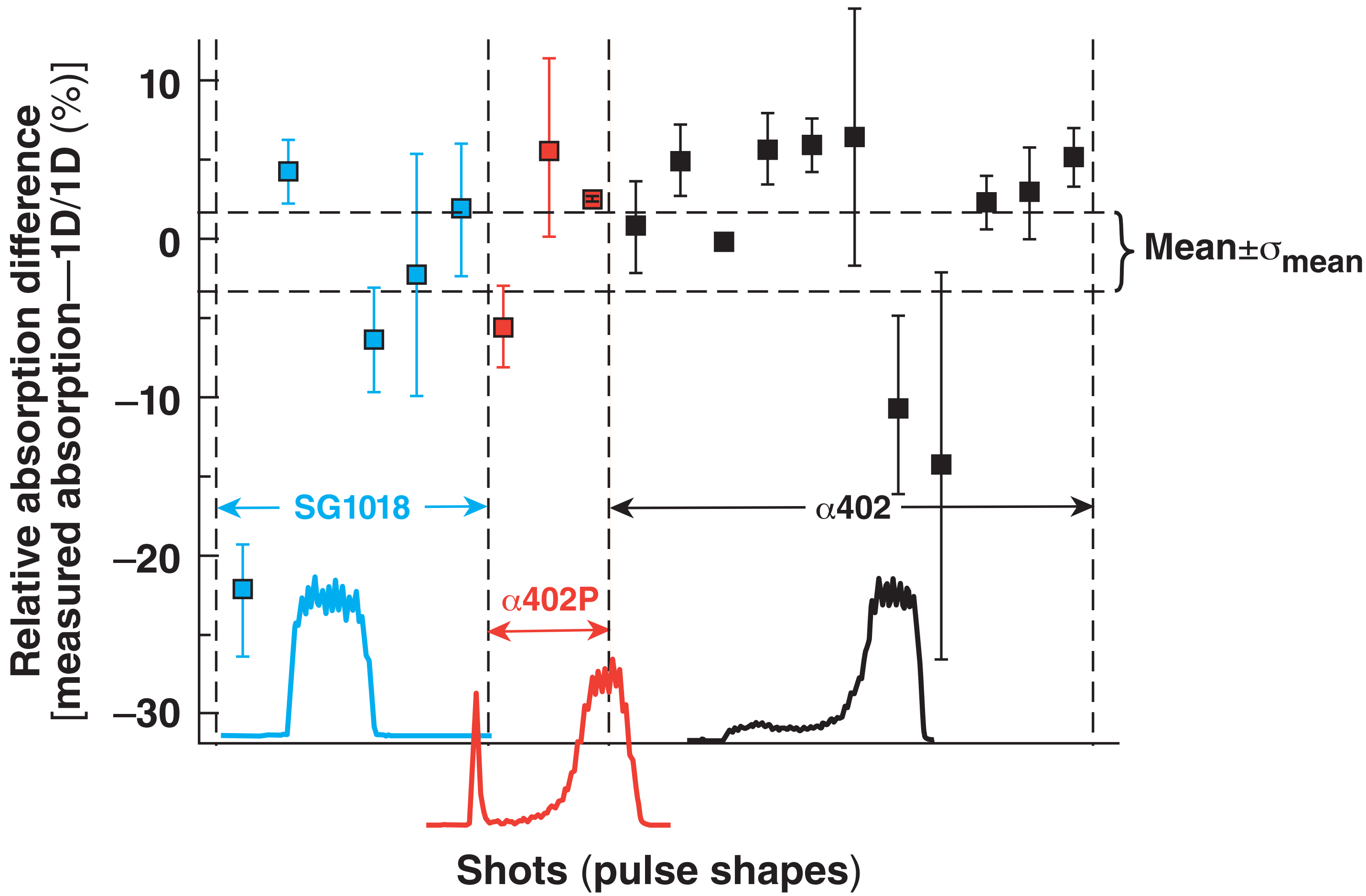
where the σ_ℓ's are the rms amplitudes at the end of the acceleration phase*.



E12008I

*P. W. McKenty *et al.*, Phys. Plasma 8, 2315 (2001).

Absorption measurements for cryogenic D_2 shots agree well with 1-D hydrodynamic simulations for all pulse shapes



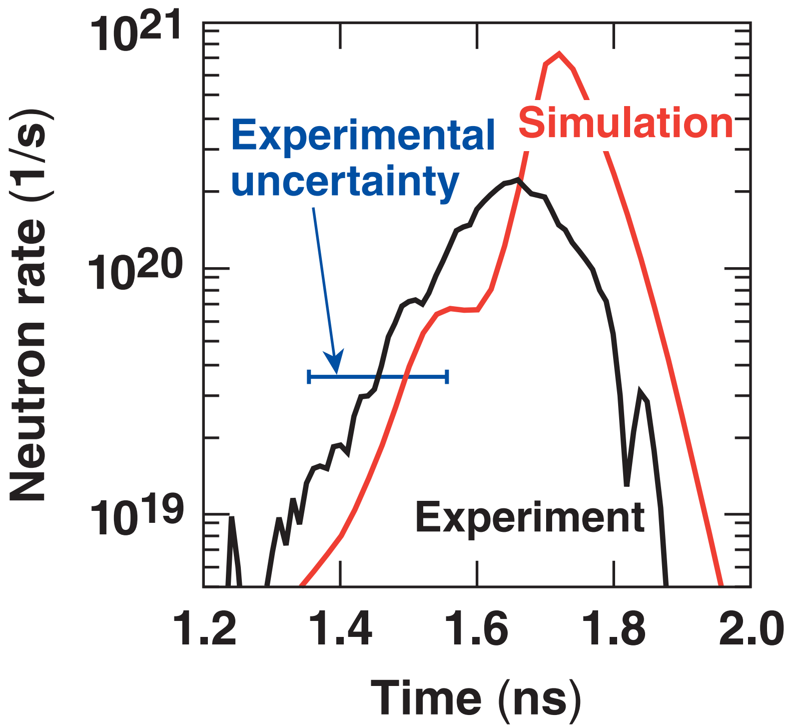
The average difference between 1-D predictions and absorption measurements is –1±2%.

E13392

W. Seka, HO1.009

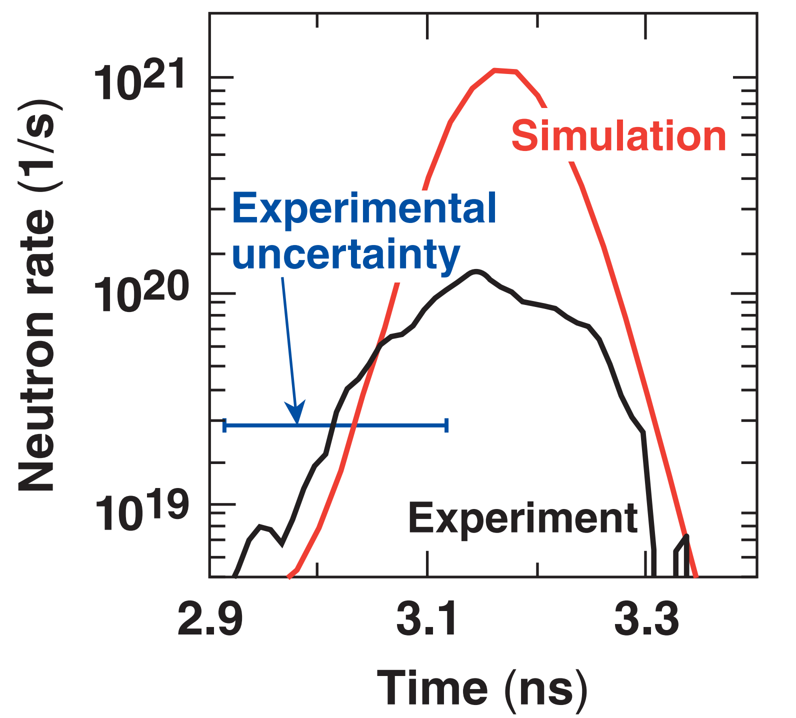
The reaction history and bang time for cryogenic D_2 implosions is close to the 1-D predictions

Shot 35970 (α ~ 25)
86-μm offset, 6.4 μm ice rms



f_{abs} { Exp.: 0.55±0.02
1-D: 0.57

Shot 35713 (α ~ 4)
15-μm offset, 4.1 μm ice rms



f_{abs} { Exp.: 0.57±0.01
1-D: 0.55

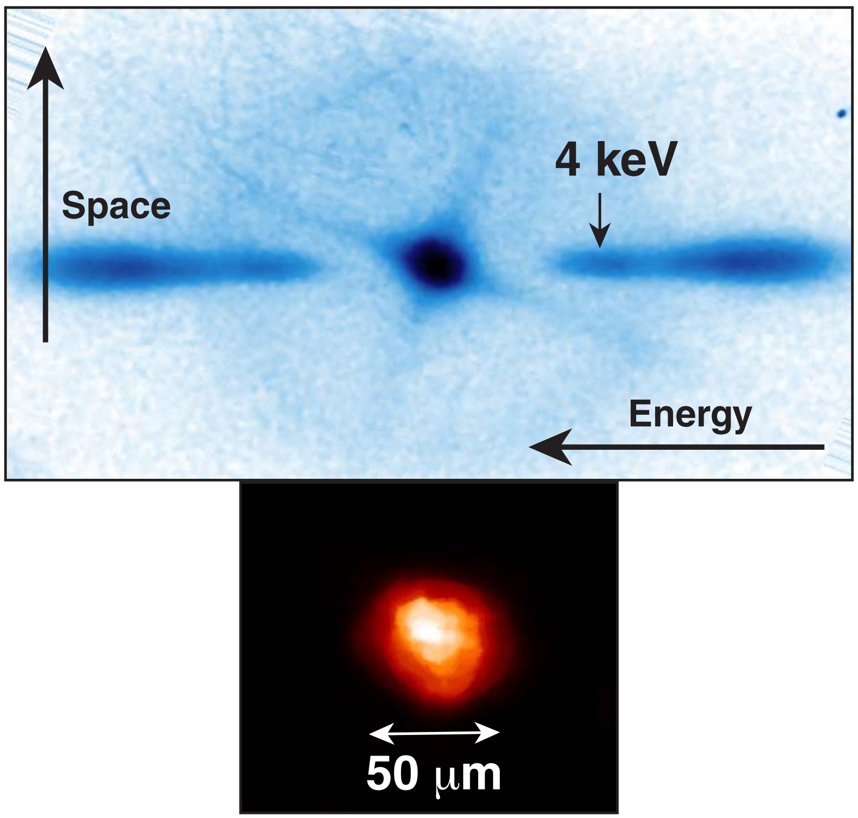
E13394

X-ray imaging of cryogenic implosions confirms that the size of the stagnation region is near 1-D

UR LLE

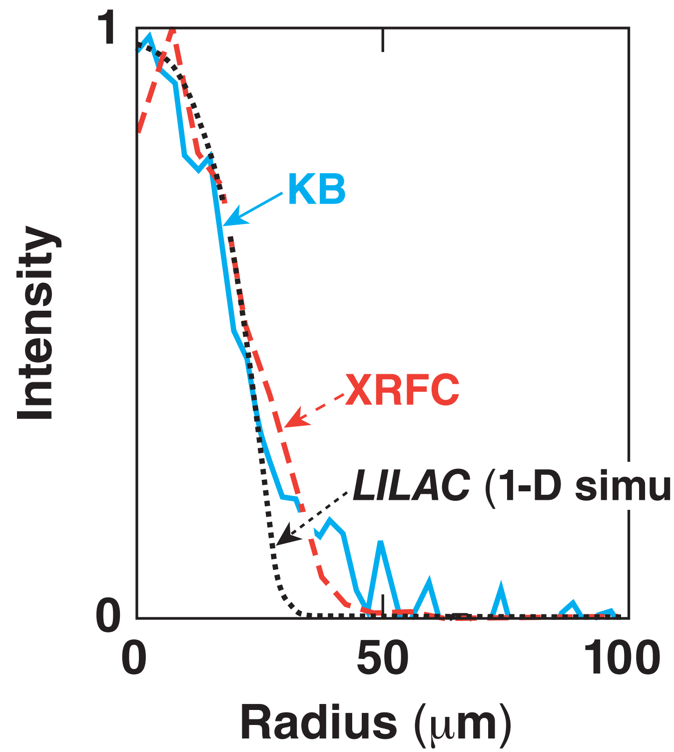
OMEGA Shot 35713 (4.1-μm ice rms, 15-μm offset)

Grating dispersed KB image



X-ray framing camera image (4–5 keV)

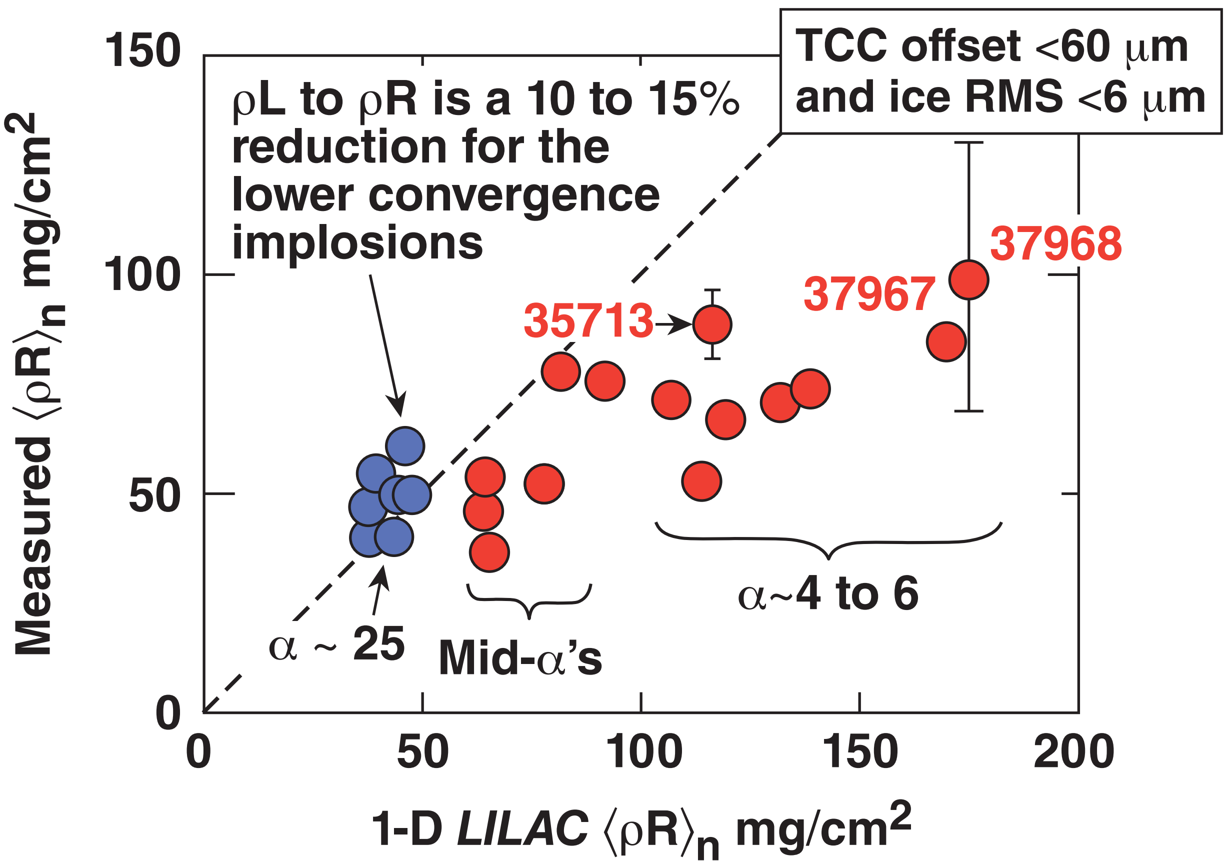
X-ray emission profiles at peak stagnation (4 keV)



E13388

The measured $\langle \rho R \rangle_n$ is close to 1-D for all but the lowest adiabat implosions

UR LLE

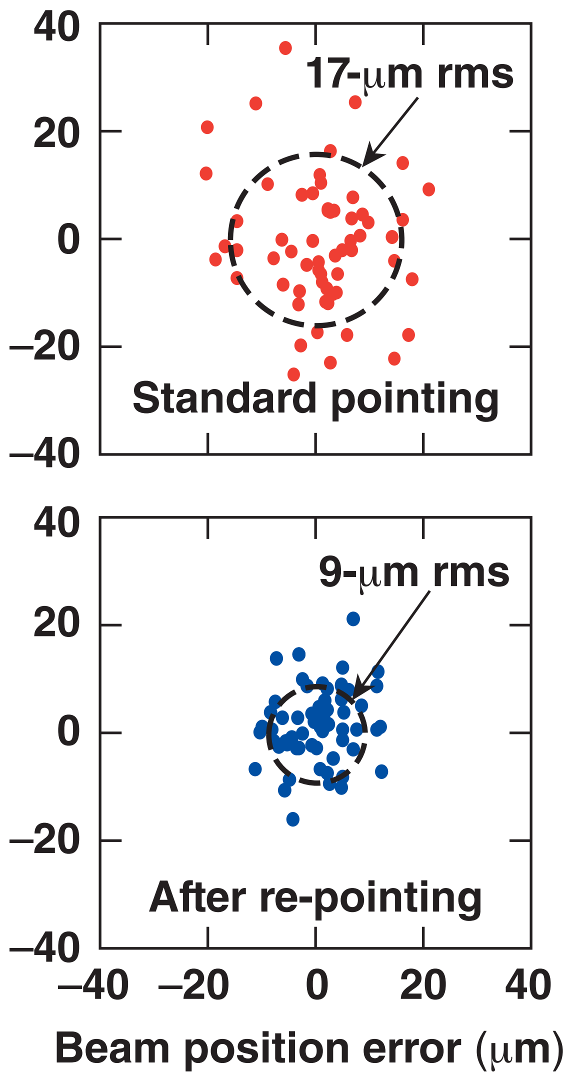


Ice roughness and target offset appear to limit the measured $\langle \rho R \rangle_n$ for higher convergence implosions.

E13492a

C. Sangster, C01.003

Low ℓ-mode drive nonuniformities due to OMEGA beams have been significantly reduced

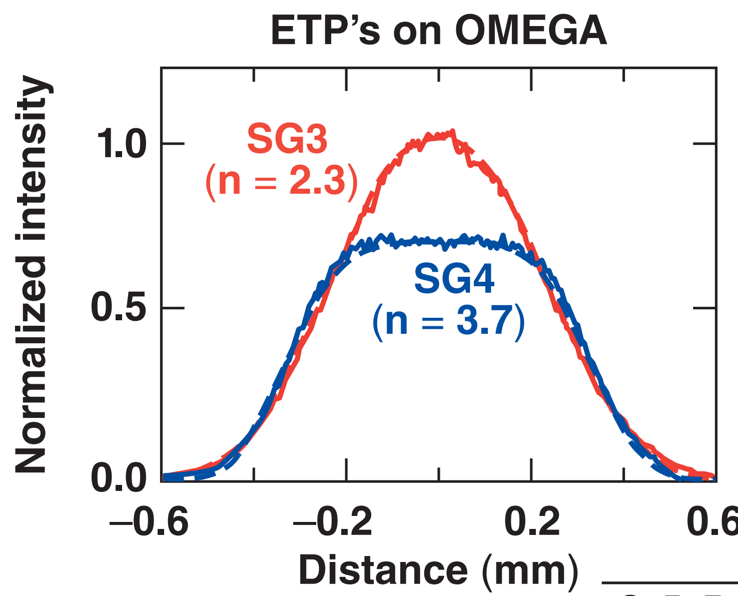


- **New DPP's, better overlap, and beam re-pointing have minimized low ℓ mode (ℓ < 6) contributions.**

$$\sigma^2_{tot} = \sigma^2_{size} + \sigma^2_{pntg} + \sigma^2_{balance}$$

$$SG3 = (1.5)^2 + (2.2)^2 + (1.3)^2, \ \sigma_{tot} = 3.0\%$$

$$SG4 = (0.6)^2 + (0.7)^2 + (0.6)^2, \ \sigma_{tot} = 1.1\%$$



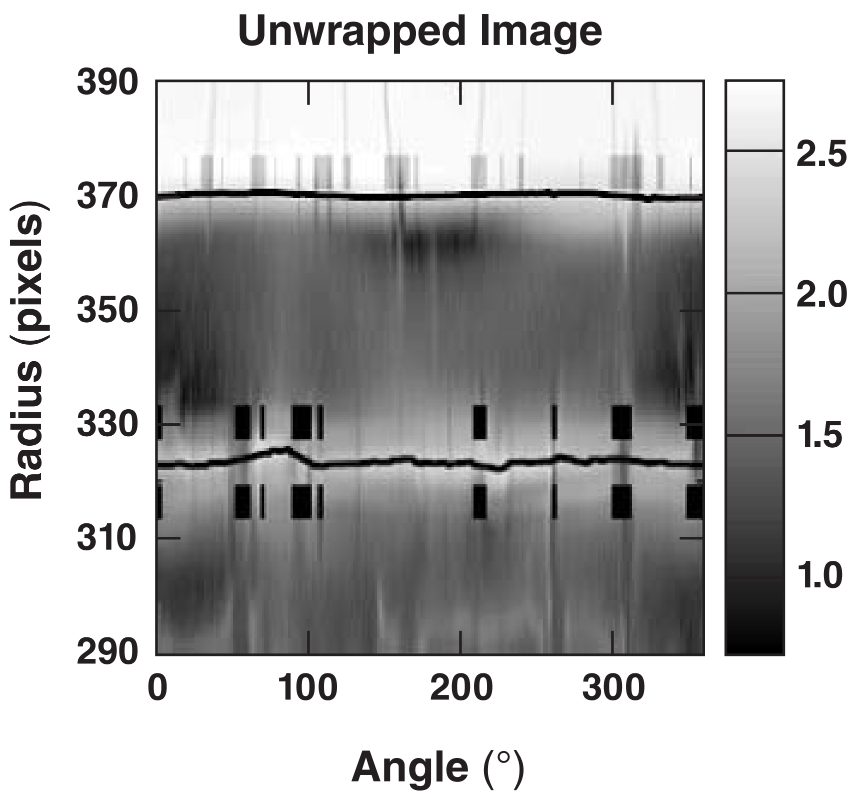
E13393

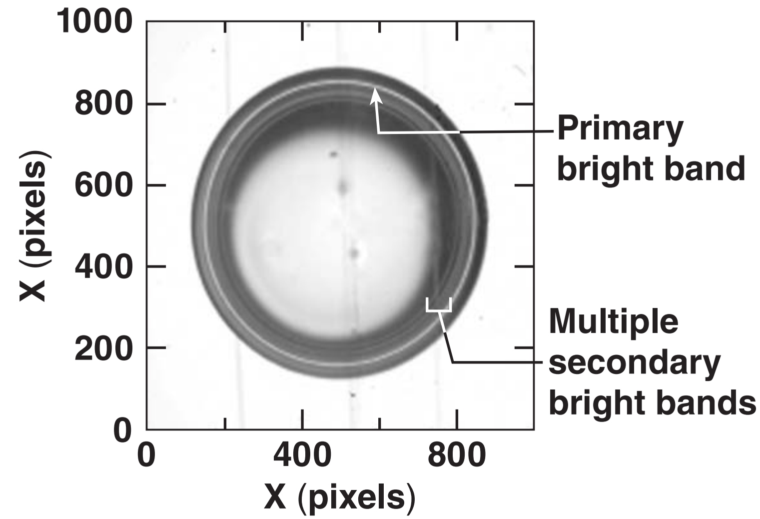
S. P. Regan, CO1.004

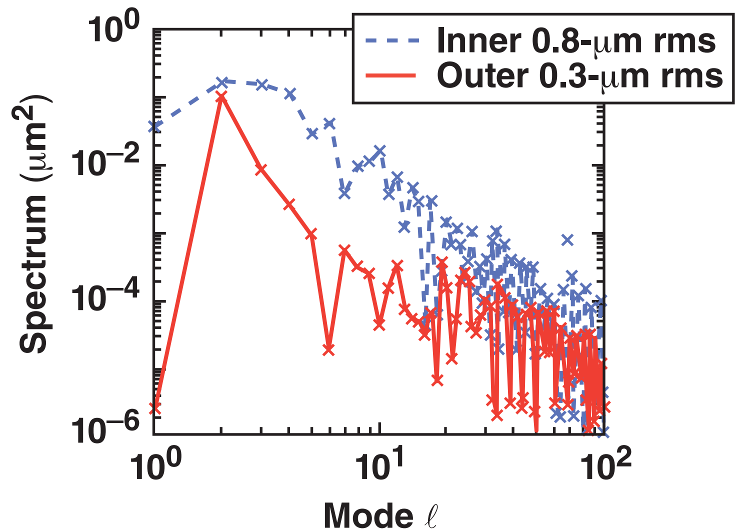
The best layer to date is 1.2-μm rms (all modes) with the best regions below 1.0-μm rms

UR LLE

- 24 shadowgraphic views of "x" and "y"



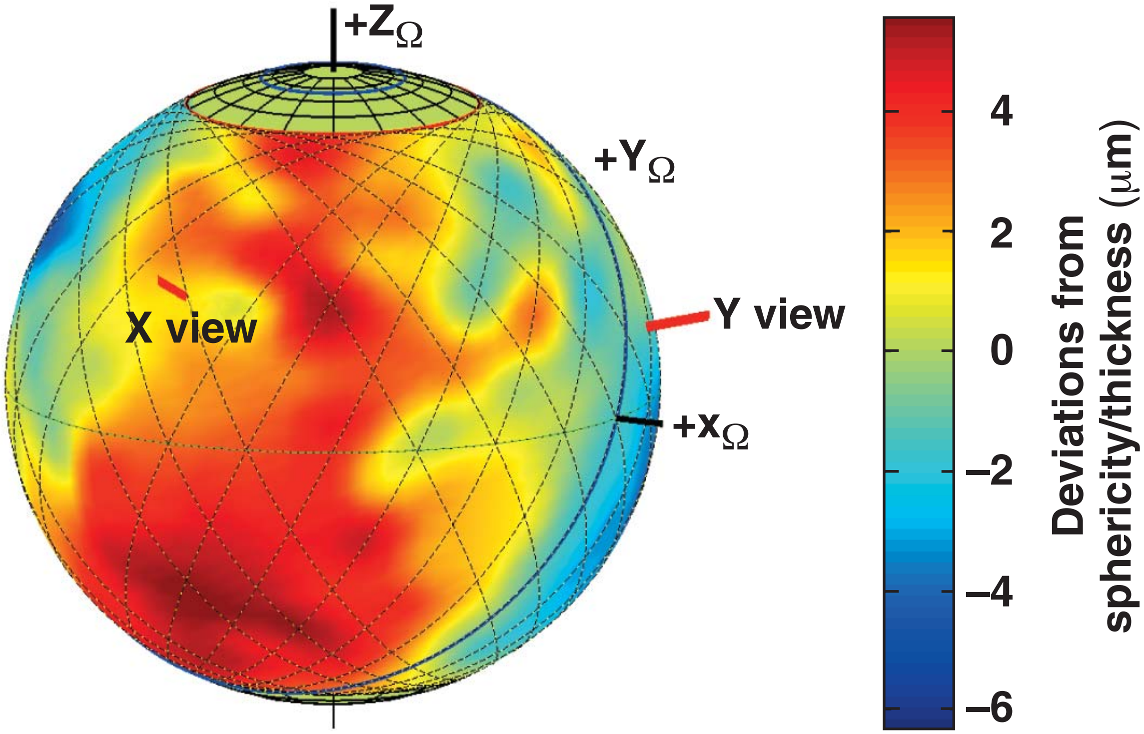


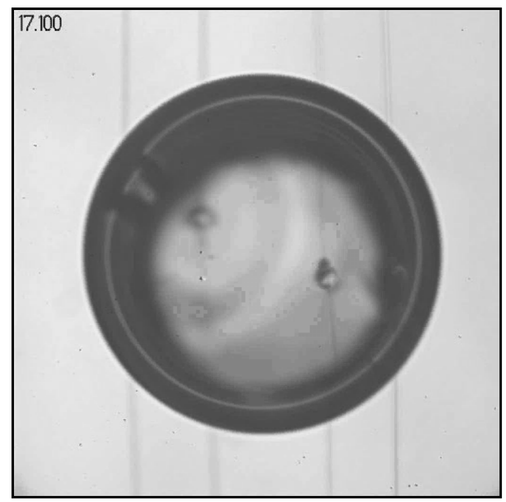


T1905e

D. H. Edgell, NP1.101

Low-order ℓ and m modes can be extracted from a 3-D reconstruction of the inner ice surface



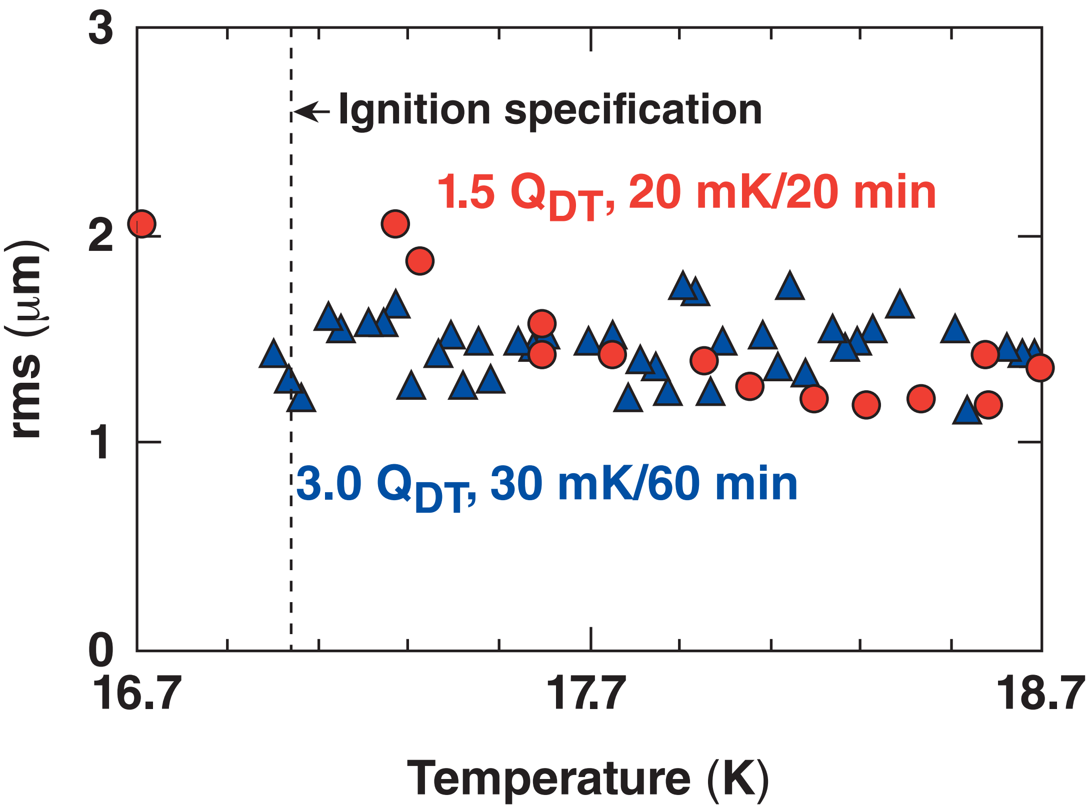


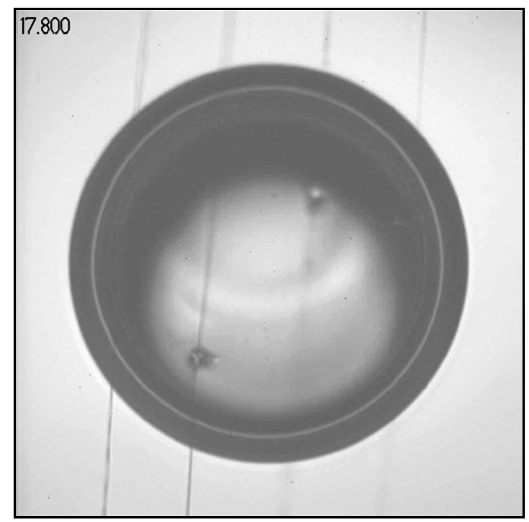
E12255e

Under controlled conditions, the layer quality can be maintained well below the triple point

UR LLE

- **Higher heat loads AND slower cooling rates produced smoother layers 1.7 K below the triple point.**

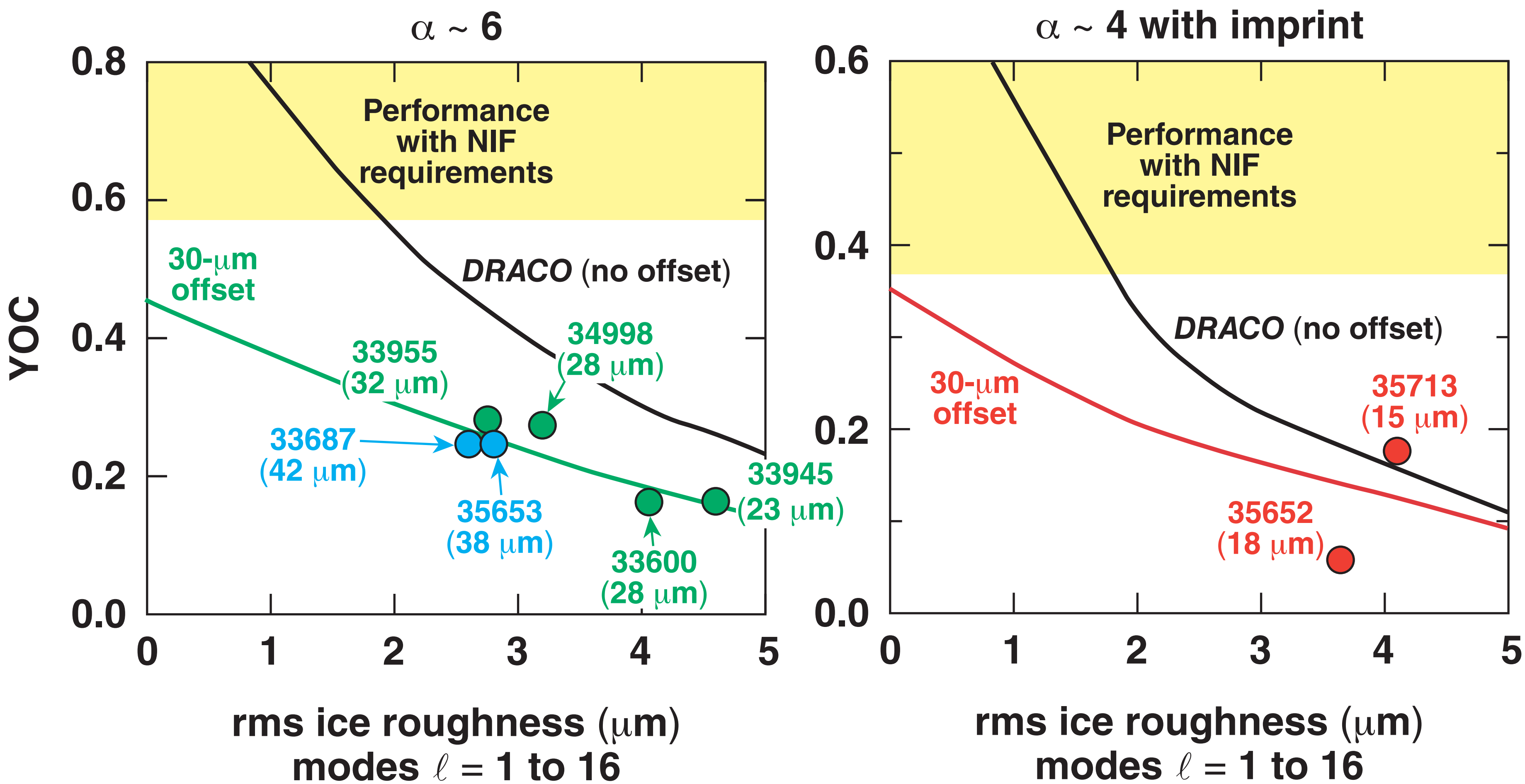




T1911c

D. R. Harding, FM2.001

Hydrodynamic simulations are consistent with implosion data over a wide range of ice roughness and target offset



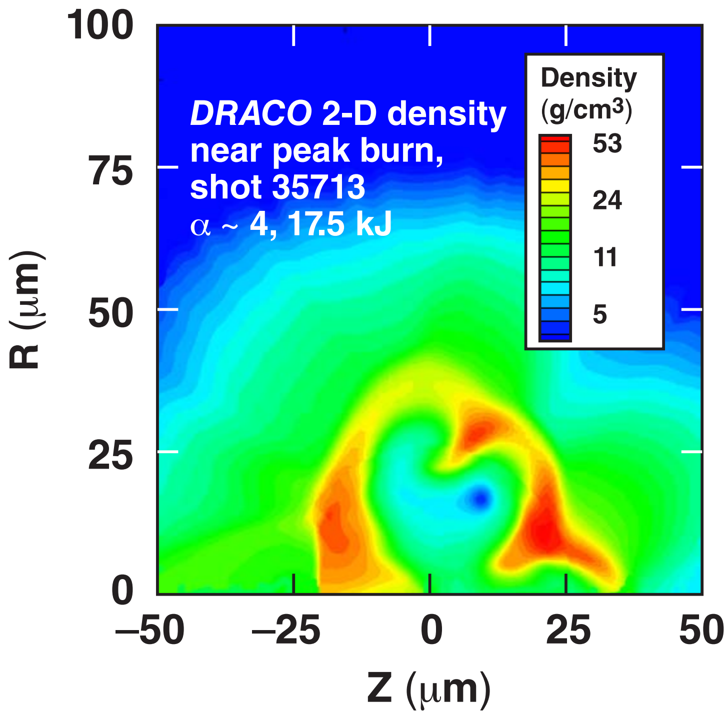
Average error of offset = 10 μm

E13085e

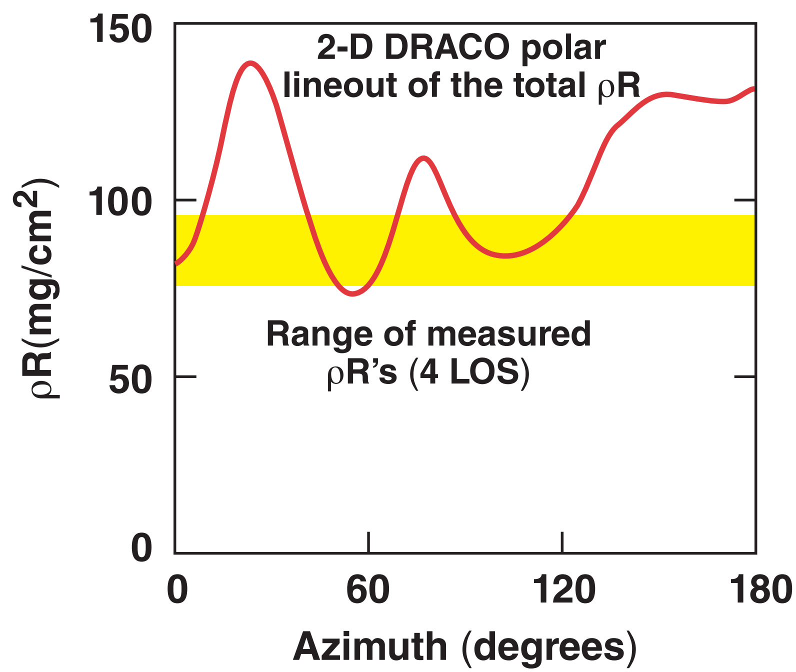
2-D *DRACO* demonstrates good agreement in predicting target performance for shot 35713 ($\alpha \sim 4$)

UR LLE

15μm offset, 4.1 μm ice rms

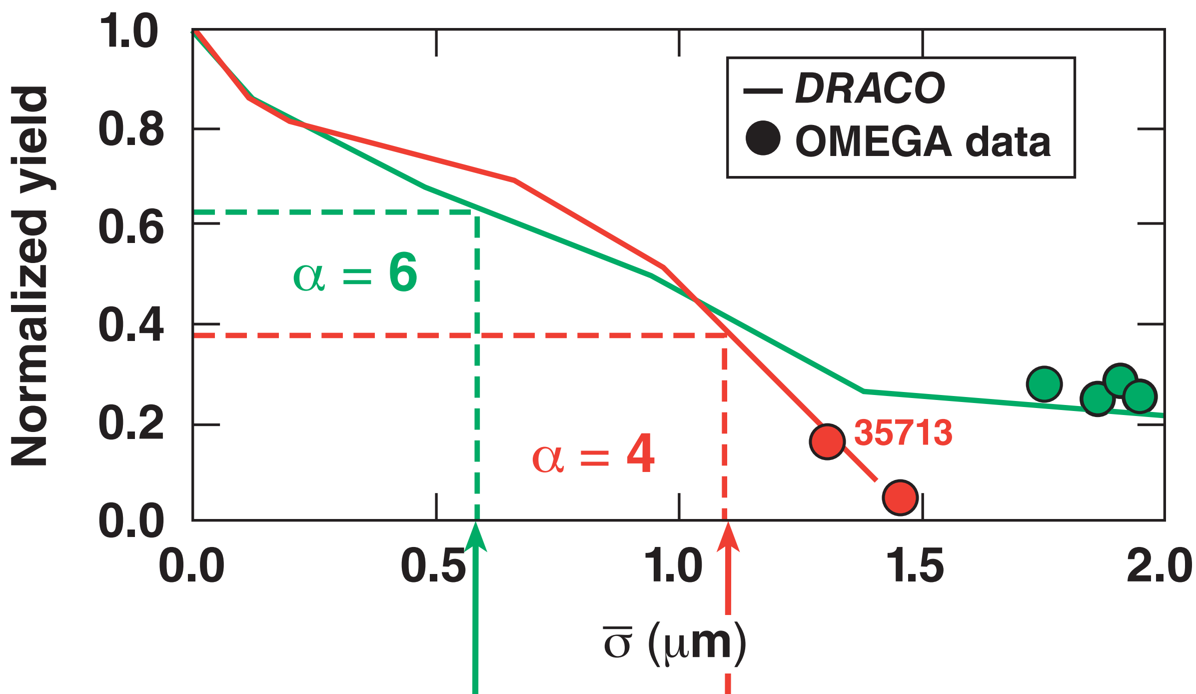


	Expt	1-D	2-D
Y_{1n}	1.6×10^{10}	9.1×10^{10}	1.8×10^{10}
Y_{2n}	2.6×10^{8}	1.7×10^{9}	2.8×10^{8}
$\langle\rho R\rangle$ (mg/cm^2)	88	117	101
T_{ion} (keV)	3.0	1.9	1.7



TC6465e

Scaled ignition performance on OMEGA is approaching the predicted equivalence of high gain on the NIF



1-THz, 2-D SSD with PS,
1-μm-rms ice roughness,
840-Å outer-surface roughness,
2% rms power imbalance

Target offset and ice quality presently limit access to low $\overline{\sigma}$ for $\alpha = 4$ campaign

E13398

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E13503