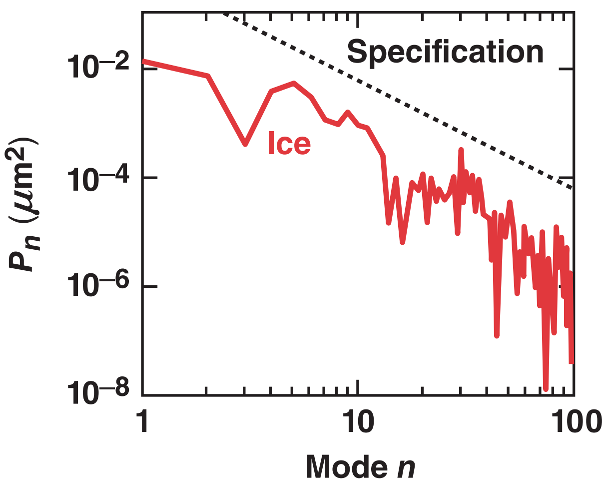
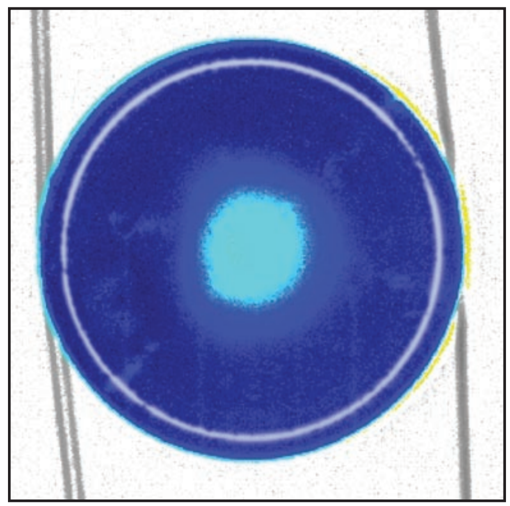
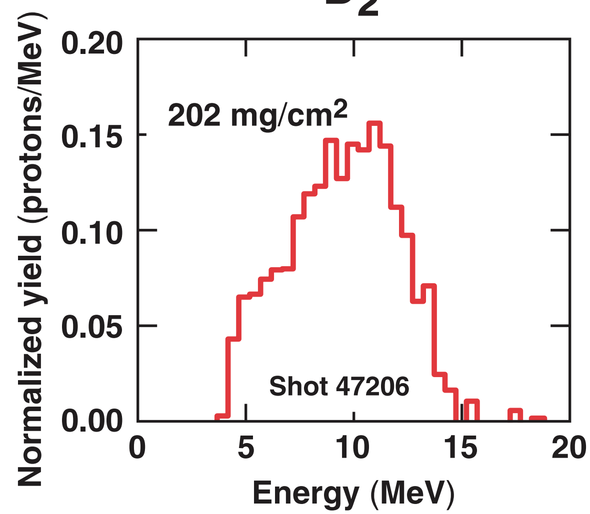
Cryogenic Implosion Experiments on OMEGA

DT





D_2



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Summary

High areal densities have been measured in cryogenic target implosions on OMEGA

- Ignition-relevant cryogenic target implosions are being carried out on OMEGA
- The OMEGA Cryogenic Target System has been improved to support the cryogenic experimental campaign
  - safe and reliable production: 8 D_2 and DT targets per month
  - improved target positioning: median displacement ~25 μm
  - median ice roughness is 1.0 μm for DT and 3.0 μm for D_2
- The compressed fuel areal density correlates with the adiabat driven by the shape of the laser pulse
- Preheat is minimized to maintain the adiabat in the fuel

Measured near-1-D calculated areal density, 202±7 mg/cm^2, highest ever hydrogenic areal density equivalent to 100 g/cm^3 or 500× liquid density.

T2362

Collaborators

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This Conference

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R. Betti	F01.2
P. W. McKenty	F01.1
D. Shvarts	Tu04.2

The production of cryogenic targets is a safe and reliable operation that paces the experimental campaign

- Deuterium implosion experiments began in 2001
  - imploded 162 D_2 targets
  - three-day production cycle
  - provide up to eight cryogenic targets per week

- Tritium implosion experiments began in 2006
  - imploded 36 cryogenic DT targets (D:T, 45:55)
  - targets are filled by permeation (no fill tube); requires 6000 Ci T_2.
  - safe operation: facility emissions $<$6 Ci/yr

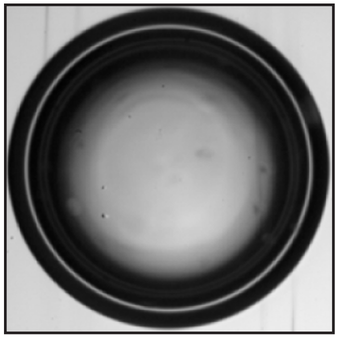
Improvements in the ice-layer quality and target position proceed in parallel with implosion experiments.

Cryogenic targets meet most of the requirements

- Routinely provide DT-ice layers with a roughness <1.0-μm rms
  - D_2-ice rms roughness <3.0 μm>, best is 1.3 μm, the source of the problem is understood
- Require 12 h to form a DT-ice layer
  - 60% probability of achieving the smoothness specification within 24 h
  - cooling the target 0.8 K (for D_2) and 0.25 K (for DT) roughens the ice
- Gas density and ice roughness are known at the time of the implosion
- Decay of tritium to form ^{3}He affects the ice smoothness
  - no evidence of He bubbles is observed.

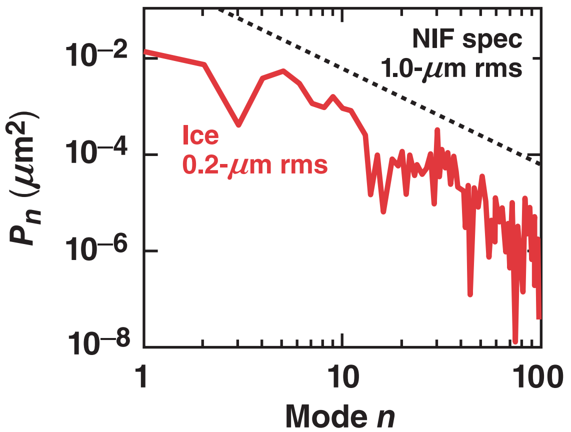
The ice layer roughness is characterized from an optical shadowgraph

- Optical system to locate the gas–ice interface (precision ±0.1 μm)

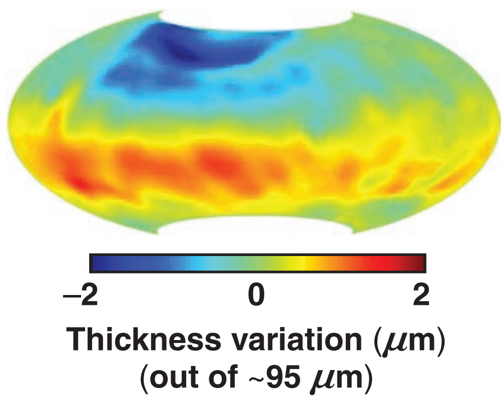


- Numerical analysis:

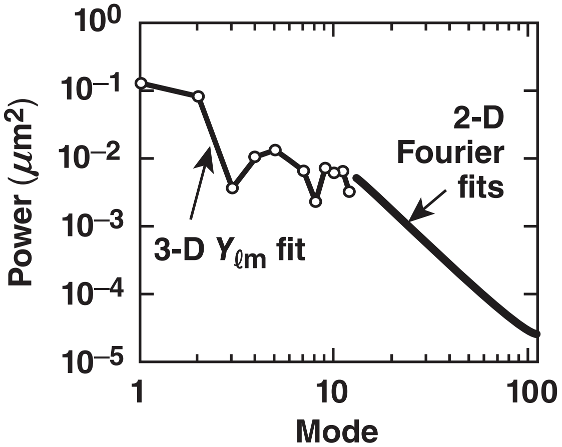
(i)
Fourier power spectrum of the great circle, roughness values include all modes



(ii)
compile a 3-D surface map



(iii)
generate a representative 2-D power spectrum



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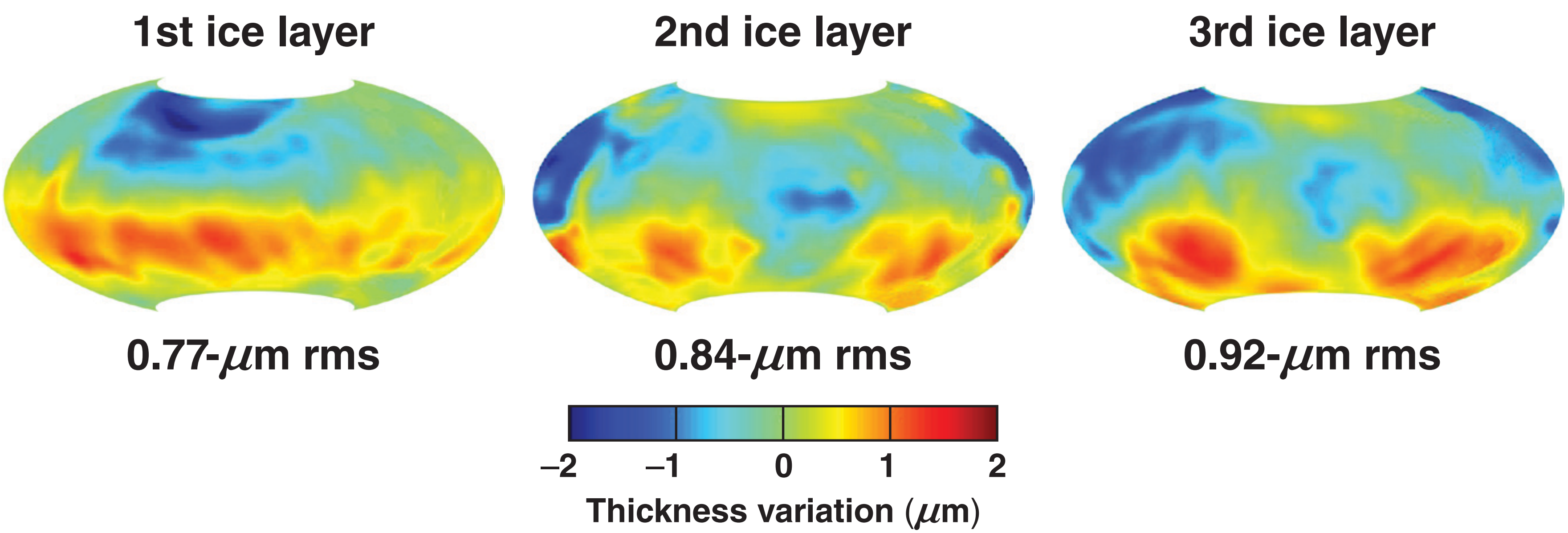
The layering process is very repeatable: melting and reforming the ice layer using the same protocol yields a similar roughness



- Variability in the ice roughness is attributed to the variability in the initial location of the seed crystal and how it grows.
- The average ice roughness of 25 targets is 1.1±0.4 μm. The median value is 1.0 μm.

Ice roughness results from two sources

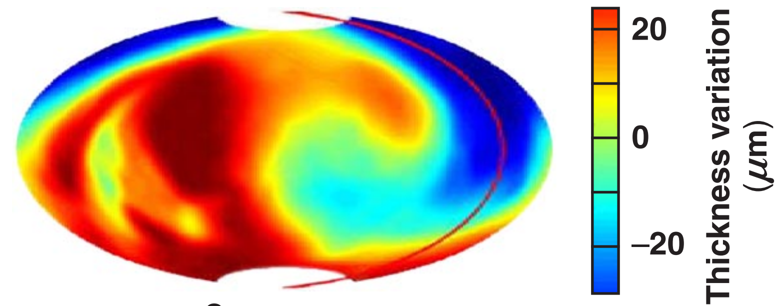
Thermal perturbation by the target support (D_2 targets only)

- affects the low modes
- addressed only by design changes

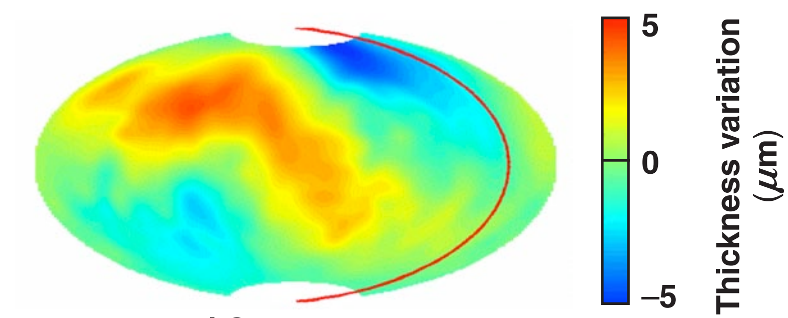
Cracks in the ice

- distort the shadowgraph
- less precise analysis
- eliminated by controlling the solidification process

Two extremes

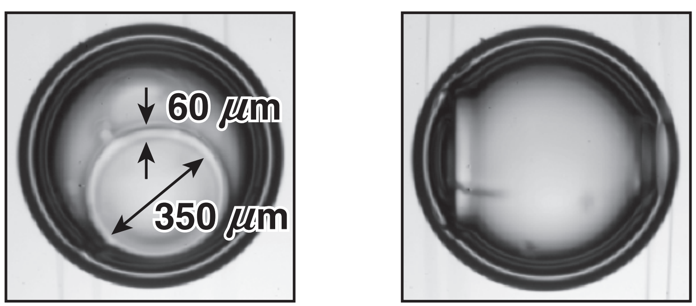


8-μm rms



1.3-μm rms

Orthogonal views of a DT target with a circular defect



8-μm-deep crack; $\simeq$ to a 25-μK temperature gradient on the surface

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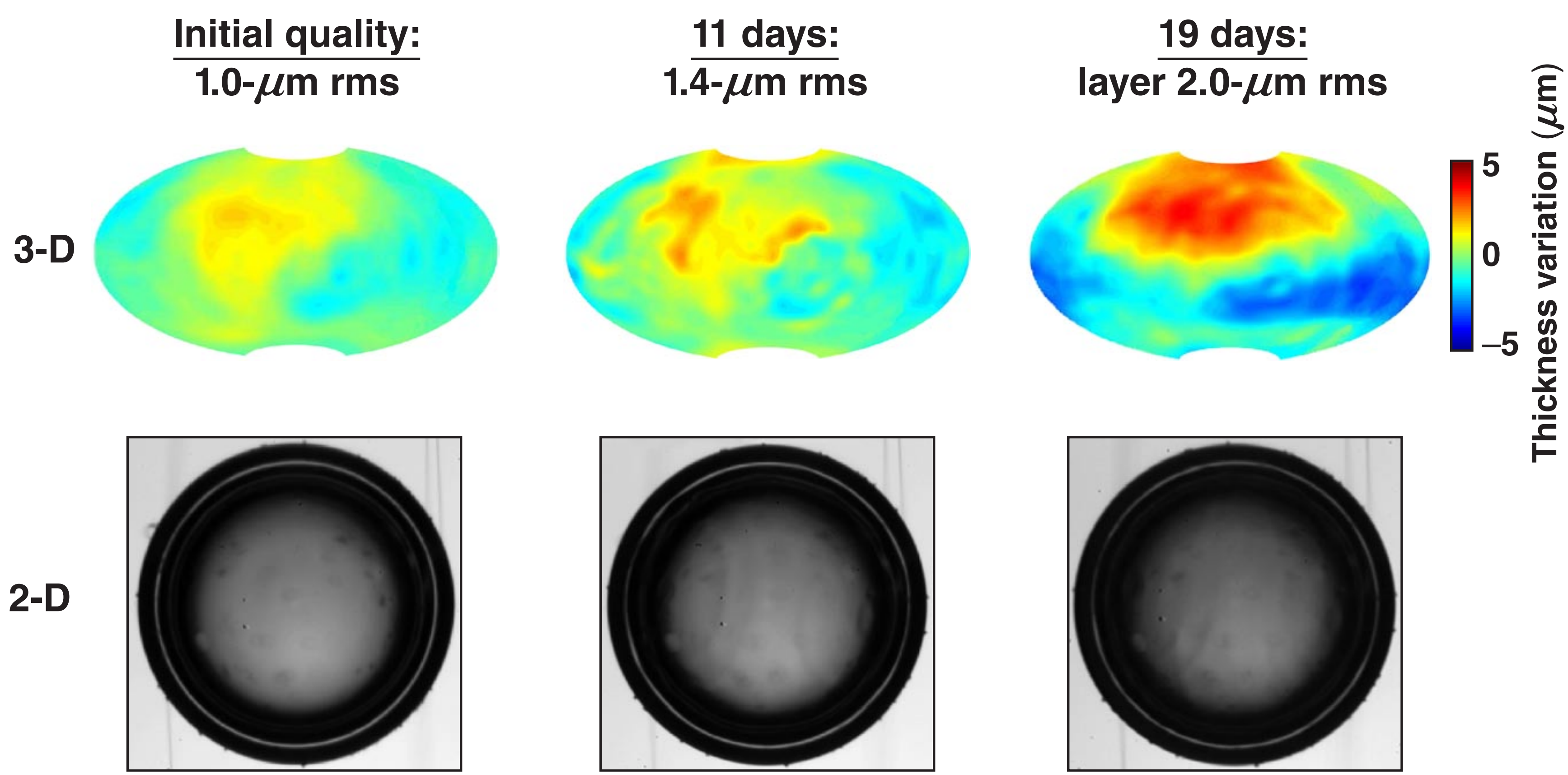
The roughness of a DT-ice layer increases with time; there is no similar behavior with D_2 targets

- Effect is attributed to the decay of tritium and accumulation of ^{3}He; there is no evidence of He bubbles in the ice layer.



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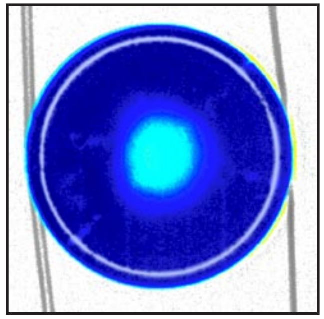
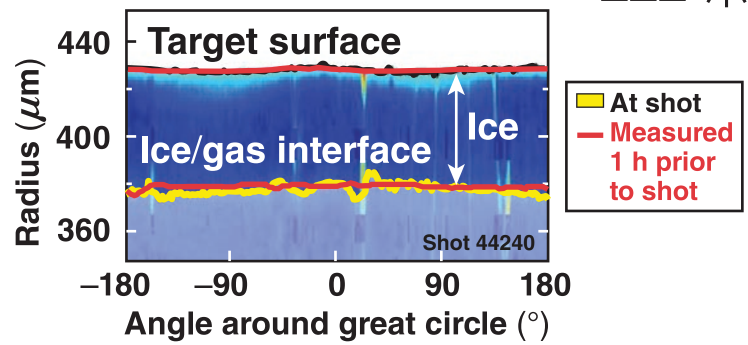
The ice roughness is confirmed at the implosion and the gas density is inferred by experiments and calculations

UR LLE

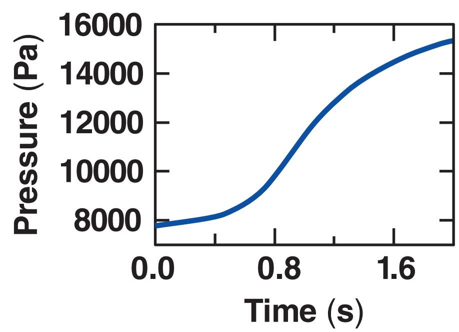
- Rapid shroud retraction limits target exposure to <0.1 s: layer quality is unaffected



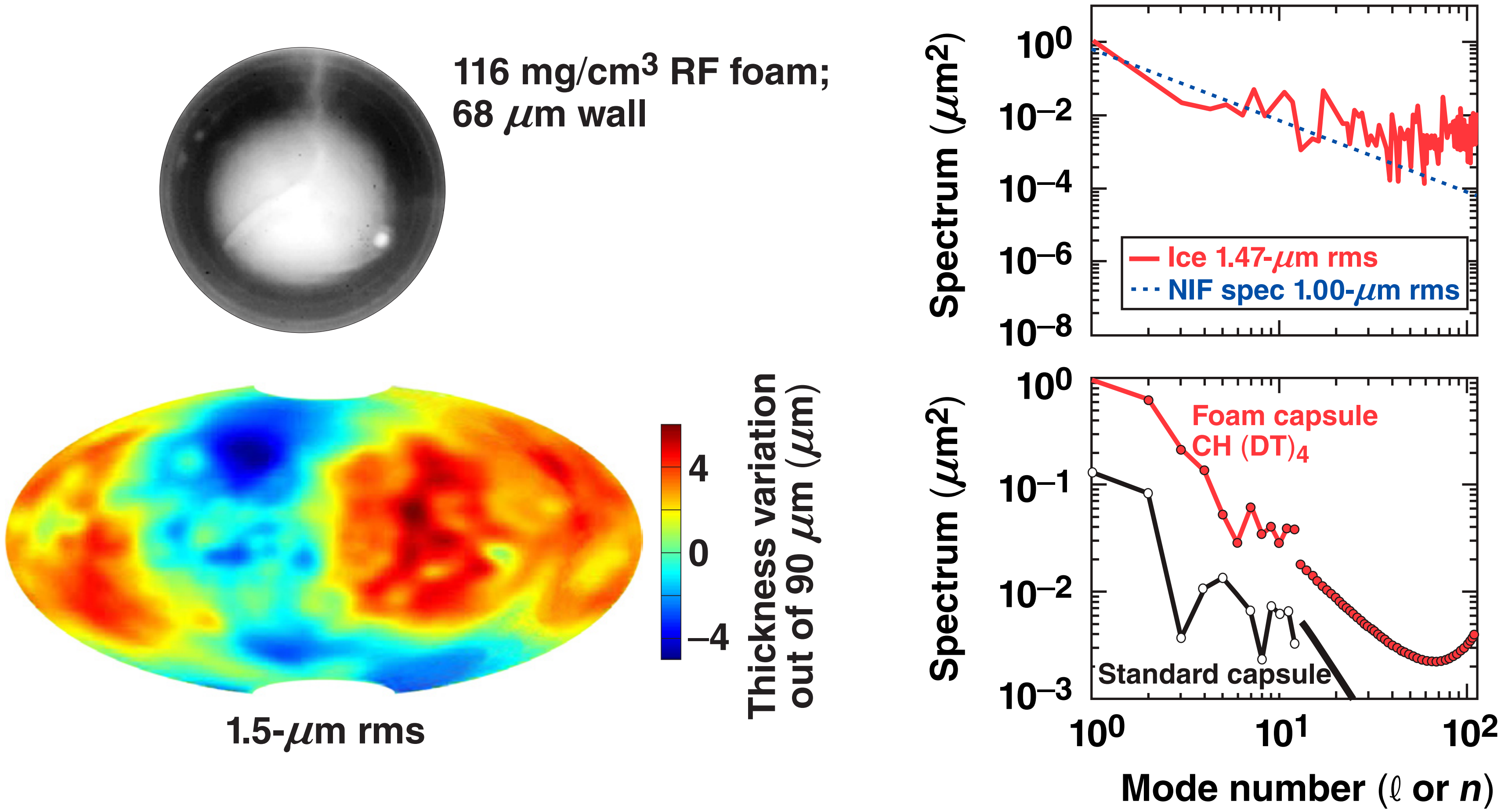


- Observing how rapidly the target melts allows the heat load into the target to be calculated (~0.17 mW)

- Calculations replicate the observed behavior
  - extrapolation to the first 0.1 s exposure show no change in gas density



The DT ice layer in a foam capsule possessed a greater roughness than typically obtained in non-foam capsules



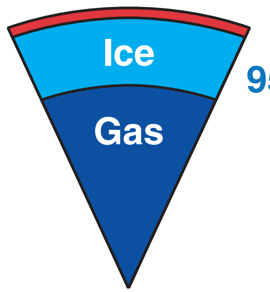
Transparent ice layers in foam targets are achieved by melting and refreezing the ice layer to reduce the void content.

T2383a

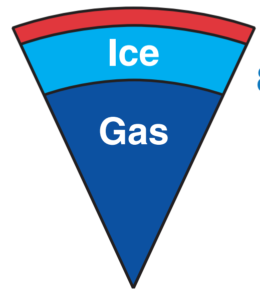
Implosion experiments are demonstrating compression of cryogenic hydrogen fuel to high areal densities

- Target designs are being refined based upon these experiments

<u>Standard target</u>



<u>Preheat mitigation target</u>



- Conducted a systematic scan of fuel adiabat and drive intensities
  - $2 < \alpha < 10$; α = fuel pressure/Fermi-degenerate pressure
  - $I_L = 2.5 \times 10^{14}$ W/cm^2 to 1.5×10^{15} W/cm^2
  - $V_{imp} = 2.5 \times 10^7$ to 4.0×10^7 cm/s
  - In flight aspect ratio: 30–50
  - Number of perturbation *e*-folds ~2 to 5
- Areal density was inferred from the energy loss of energetic protons*

Measured areal densities agree with calculated values when shock velocity is adequately modeled and hot-electron preheat mitigated.

T2365

*F. H. Séguin *et al.*, Rev. Sci. Instrum. <u>74</u>, 975 (2003).

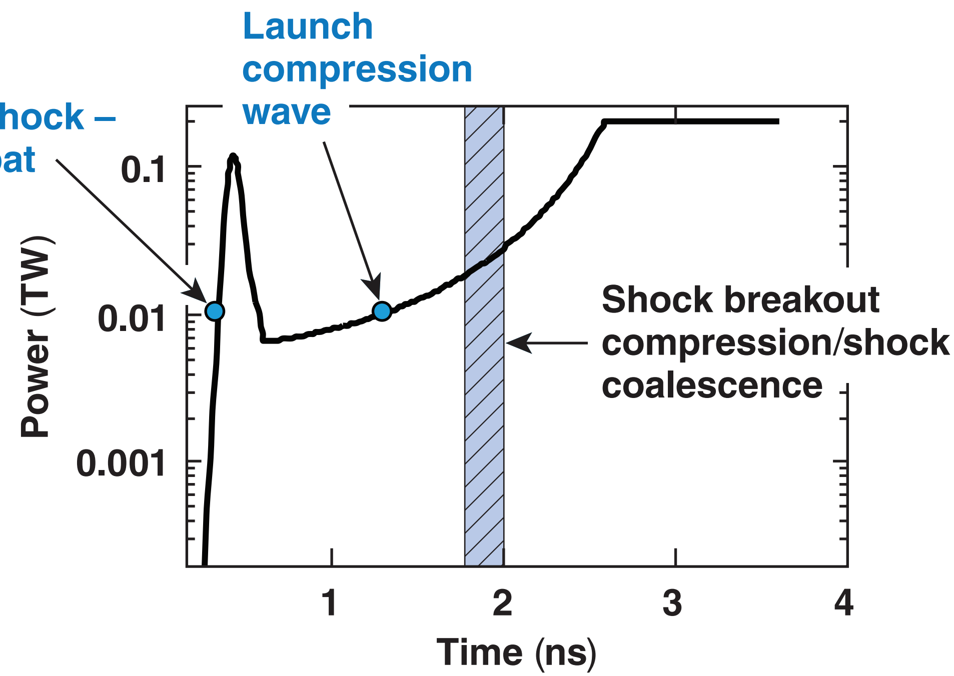
Areal density depends mainly on the in-flight fuel adiabat

UR LLE

$\rho R = 2.6\, E_L^{1/3}/\alpha^{0.54}$*

- Fuel adiabat (α) depends upon:
  - shock timing
  - hot electron preheat
  - growth of nonuniformities

- 1–D *LILAC* code used to design pulse shape
  - flux limited Spitzer conduction**
  - nonlocal thermal transport
  - required accuracy for the shock breakout $\Delta t/t \sim 5\%$; $\Delta t \sim 100$ ps
  - accuracy for the laser absorption during picket $\Delta E/E \sim 10\%$

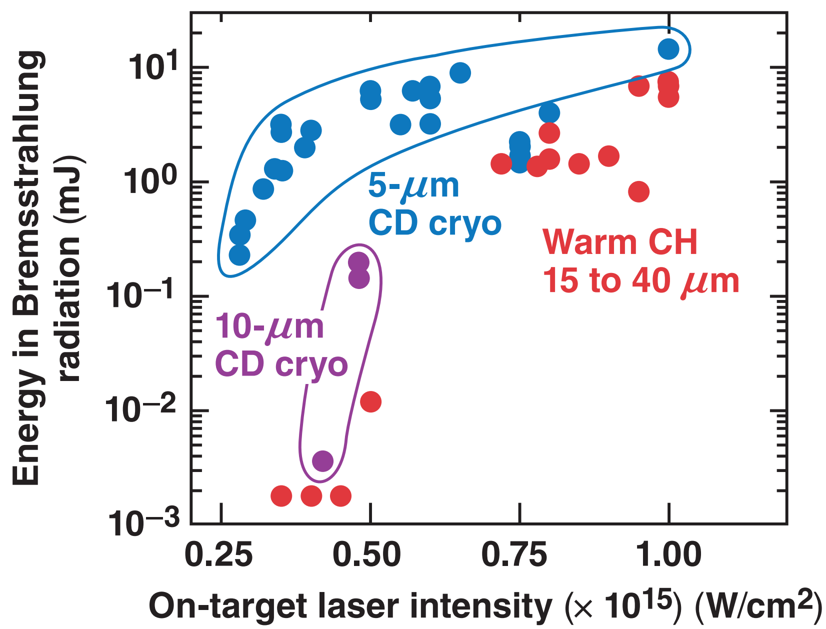


* R. Betti and S. Zhou, Phys. Plasma 12, 110702 (2005).
**R. C. Malone, R. L. McCrory, and R. L. Morse, Phys. Rev. Lett. 34, 721 (1975).

T2366

Preheating by energetic electrons from the two plasmon decay increases rapidly with laser intensity

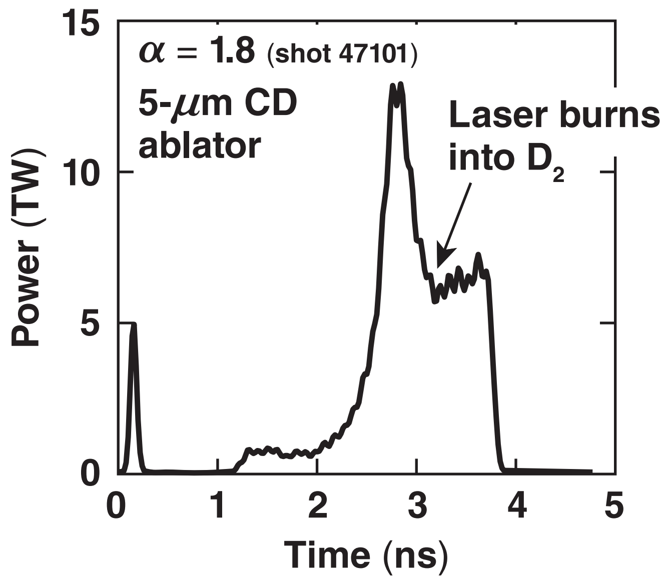
- Shocks adequately timed to not compromise adiabat
- Hot-electron preheat inferred using measured hard-x-ray signals produced by Bremsstrahlung radiation from fast electrons

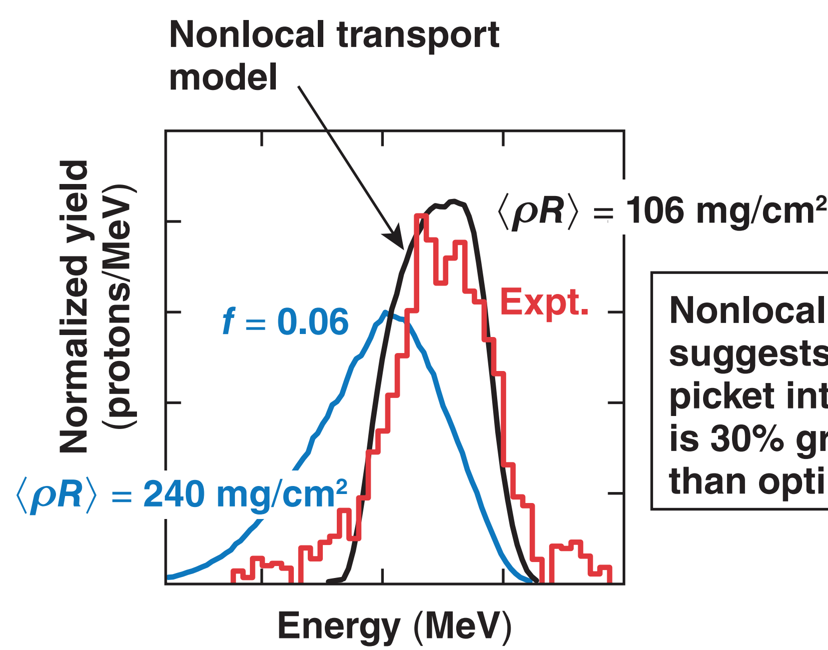


Fuel preheat from energetic electrons is reduced by increasing the CD thickness due to the lower two plasmon decay instability threshold in D_2.

Effect of shock timing on the adiabat is tested by changing the pulse shape

- Pulse shape designed to raise the adiabat at the back of the fuel layer and minimize preheat
- Measured little preheat (HXRD = 12 pC)

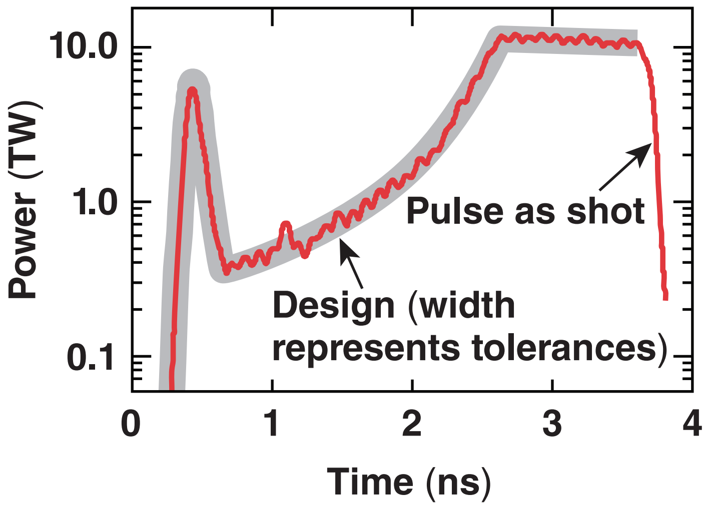


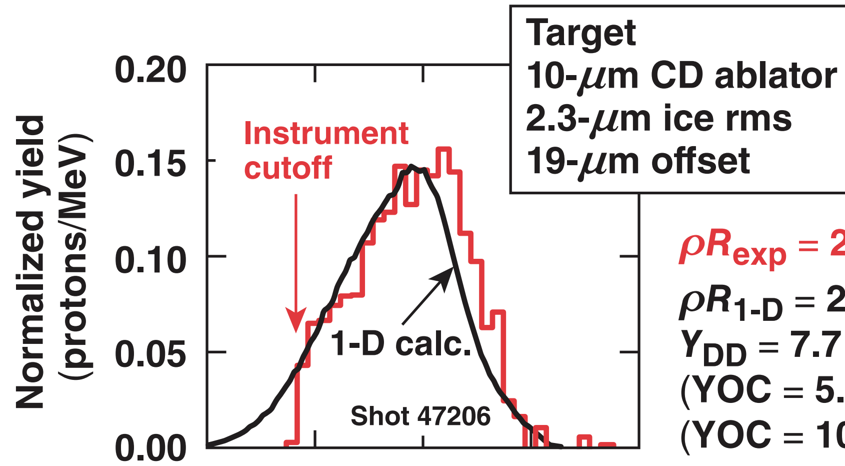


Nonlocal model suggests that the picket intensity is 30% greater than optimal

Modeling resonance absorption and nonlocal transport is essential for comparing with experimental results

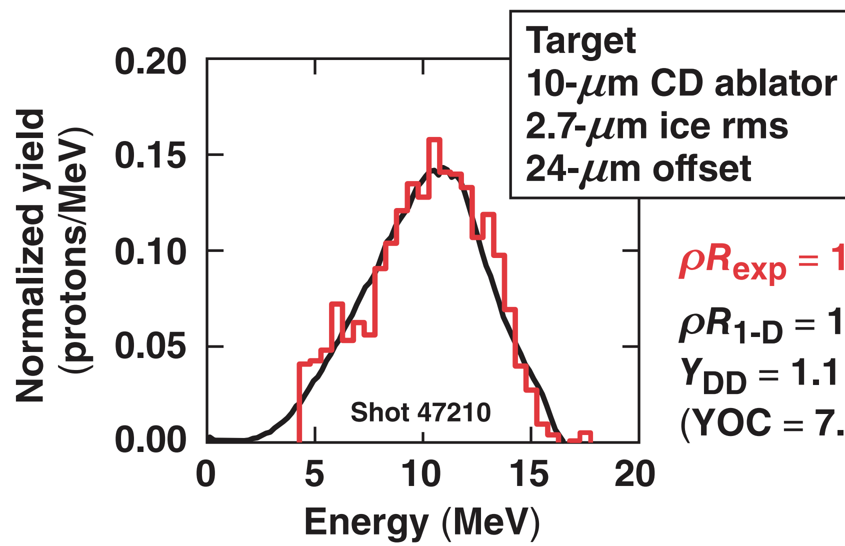
Using an optimal pulse shape and ablator thickness allowed the fuel assembly to proceed according to the 1-D calculation





ρR_{exp} = 202 mg/cm^2
$\rho R_{1\text{-}D}$ = 224 mg/cm^2
Y_{DD} = 7.7 × 10^9
(YOC = 5.1%)
(YOC = 10% for DT)

Changing the timing of the picket by 200 ps reduced the areal density in the measurements and simulations



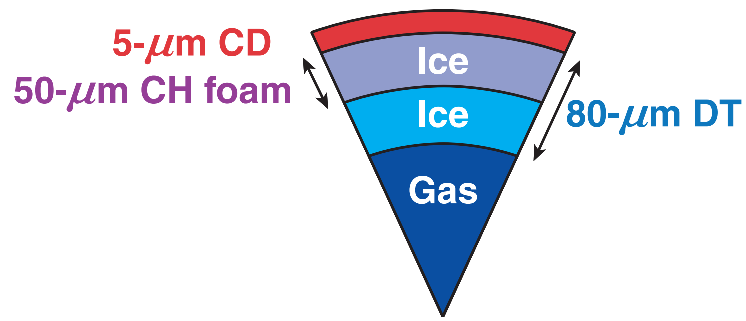
ρR_{exp} = 182 mg/cm^2
$\rho R_{1\text{-}D}$ = 192 mg/cm^2
Y_{DD} = 1.1 × 10^{10}
(YOC = 7.3%)

T2368

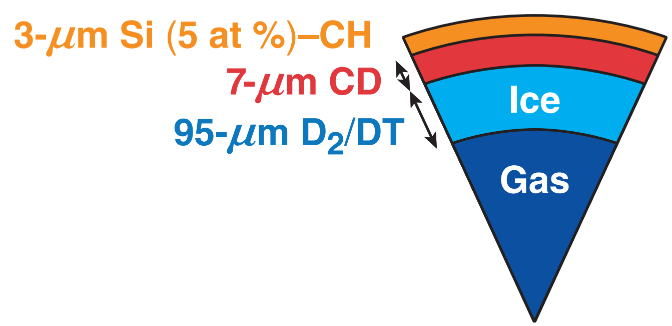
Future experiments, and those in progress, will address conditions required for ignition

- Increase the implosion velocity to 3.5×10^7 cm/s
  - thinner ice layer (65-μm D_2)

- Alternative methods to minimize energetic-electron preheat and reduce RT growth
  - foam targets



  - laser pulses with multiple pickets
  - doped ablators (Si and Ge) to radiatively preheat the ablation surface



T2371

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