Forming Smooth Cryogenic Targets for OMEGA Direct-Drive ICF Implosions and Prospects for Direct-Drive Targets for the NIF

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Summary

Our experiences with cryo targets for OMEGA have better prepared us to achieve the ignition specifications for NIF direct-drive targets

1. Demonstrated high-quality ice layers approaching the 1-μm-rms smoothness requirement (in all modes)
2. Developed characterization and analysis tools to fully define the ice layer
3. Using experiments and 3-D thermal models, we are correlating the sensitivity of ice roughness with the thermal environment
4. Demonstrated good repeatability of the layering process
5. Determined that a shroud retraction time much less than 0.8 s is required for both OMEGA and NIF targets
6. Further work is needed to routinely achieve the thermal uniformity required to eliminate the remaining low-mode ice roughness

The ice layer is sensitive to external temperature variations at the 1-mK level.

T2178

Achieving the ice-smoothness requirement is the most complex part of the OMEGA cryogenic project

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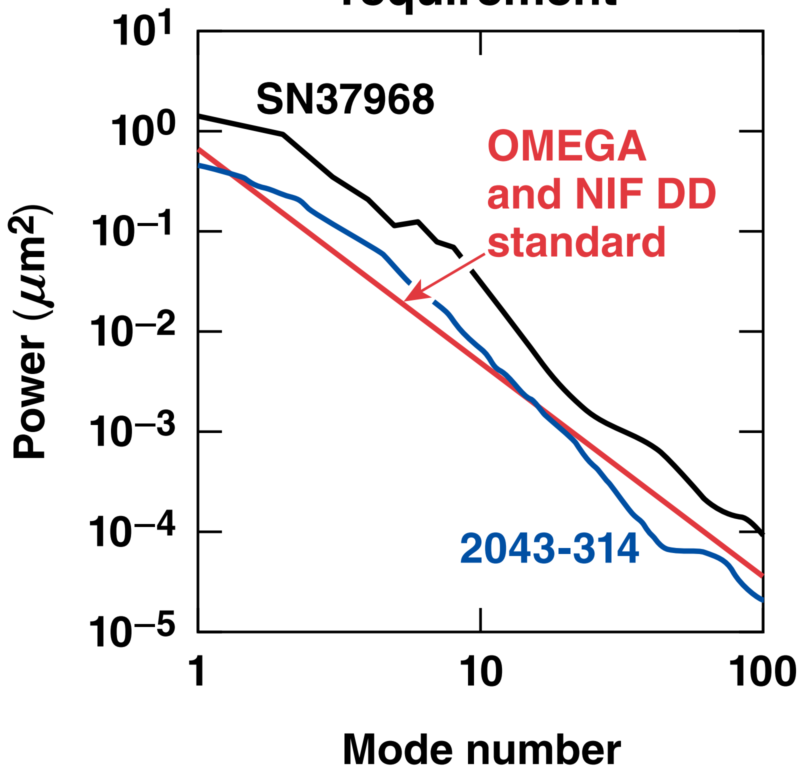
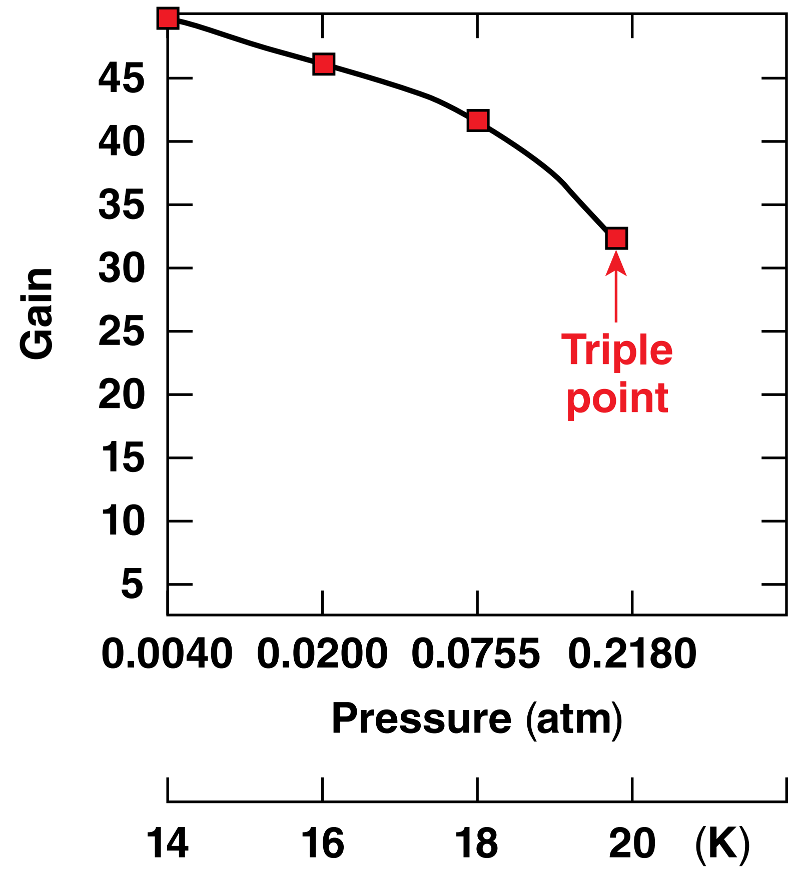
Ice smoothness requirement



Gas pressure requirement



- Issues are thermal uniformity and mechanical stability with a rapid shroud retraction

T2179

The ice layer is extremely sensitive to its thermal environment and the time it is exposed prior to implosion

Approach

1. Maximize the thermal uniformity around the target by encapsulating it in a copper sphere.

    • <u>Design issues</u>

        – location of heaters

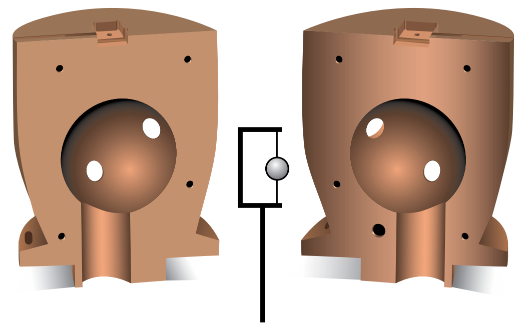
        – opening to insert/ remove target

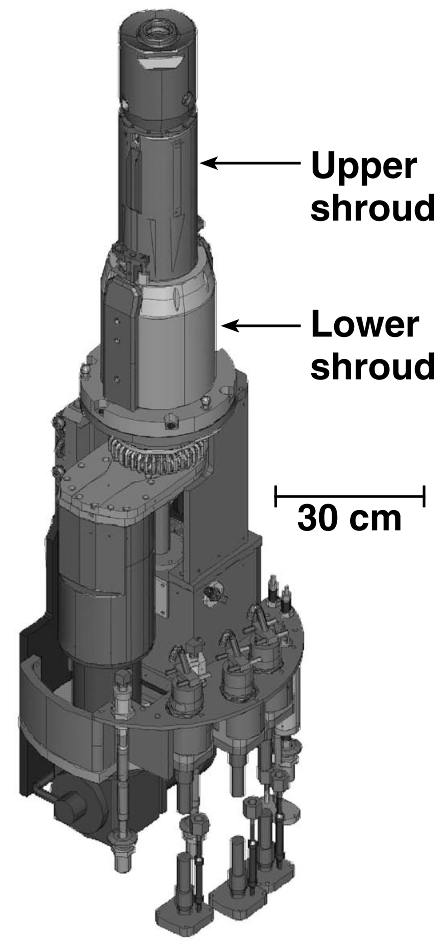
        – target support

2. Optimize shroud retraction process

    • preserve ice quality

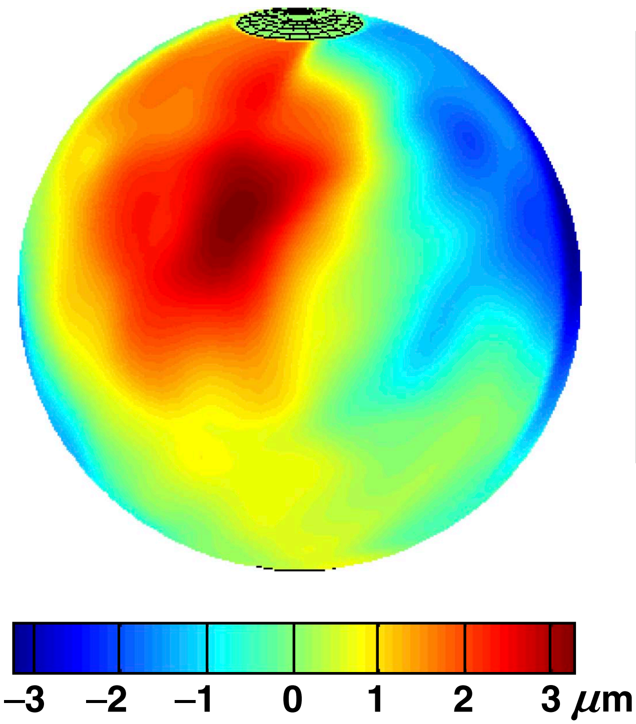
    • minimize vibration



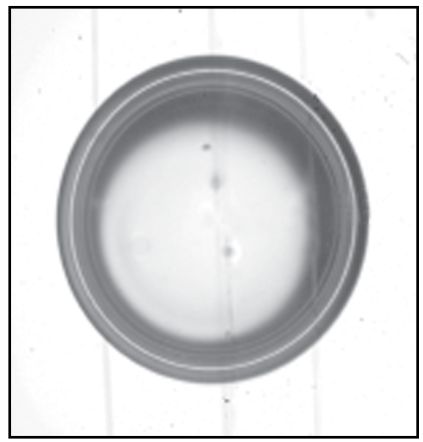


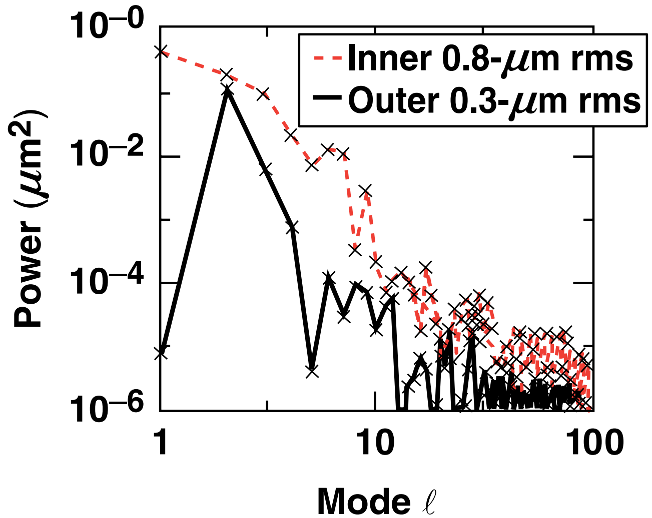
Cryostat assembly is for target positioning and life support

We have achieved the smoothness specification for modes 5 and higher in our best targets and have identified sources for the remaining roughness in modes 1 and 2



3-D ice thickness variation





Average rms = 1.2 μm

This study has required
- a 3-D construction of the ice layer to orient the low mode,
- a 3-D thermal model to correlate ice distribution with equipment design, and
- statistics—a sizeable sample size and flexibility to make changes.

Gradual solidification of the liquid is a requirement but not a guarantee of a high quality ice layer

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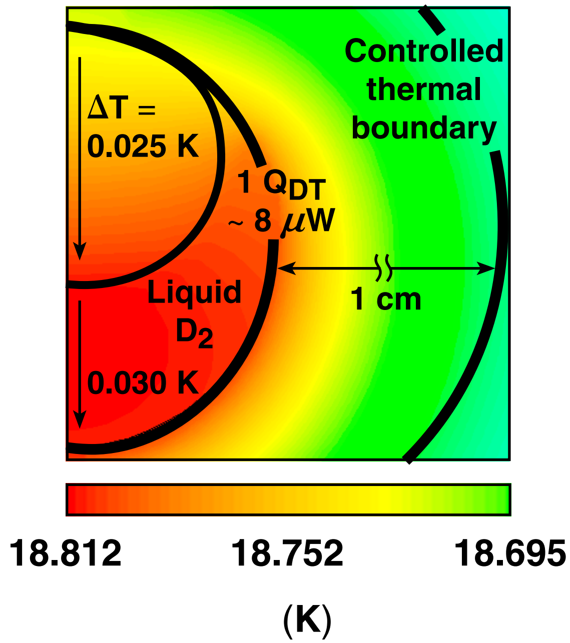
The seed crystal forms at the equator.

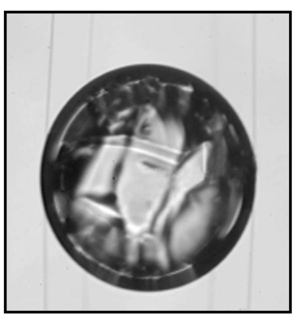


Achieved by controlling the heat flux from the target with a 1-mK ΔT

X-view camera

Y-view camera

(Time lapse ~ 1 h)

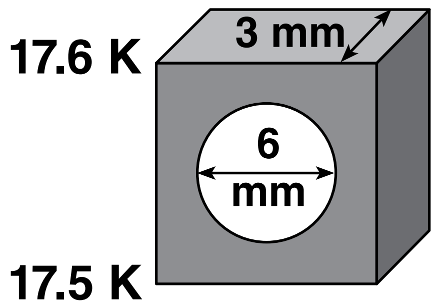


Rapid freezing adds 2+ μm to the rms roughness

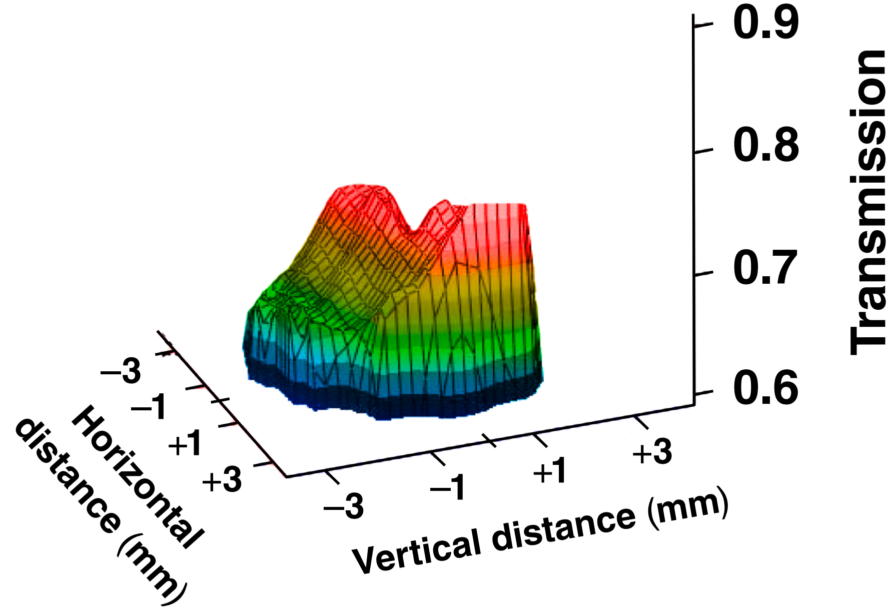
T1934

Slow solidification and disparate freezing temperatures for D_2, DT and T_2 may cause partial fractionation

- Based upon measured fractionation of D_2 in a mixture of D_2 and H_2.



9% variation in H_2 over 1-mm distance in a D_2/H_2 solid mixture (0.75:0.25).



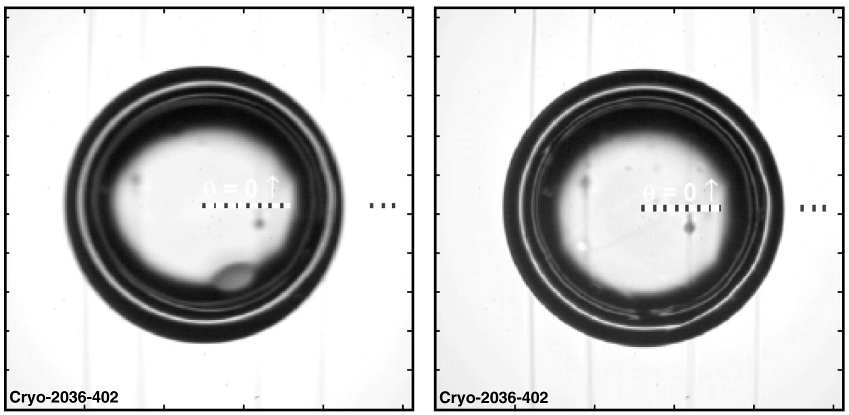
IR transmission probe of the D_2 distribution

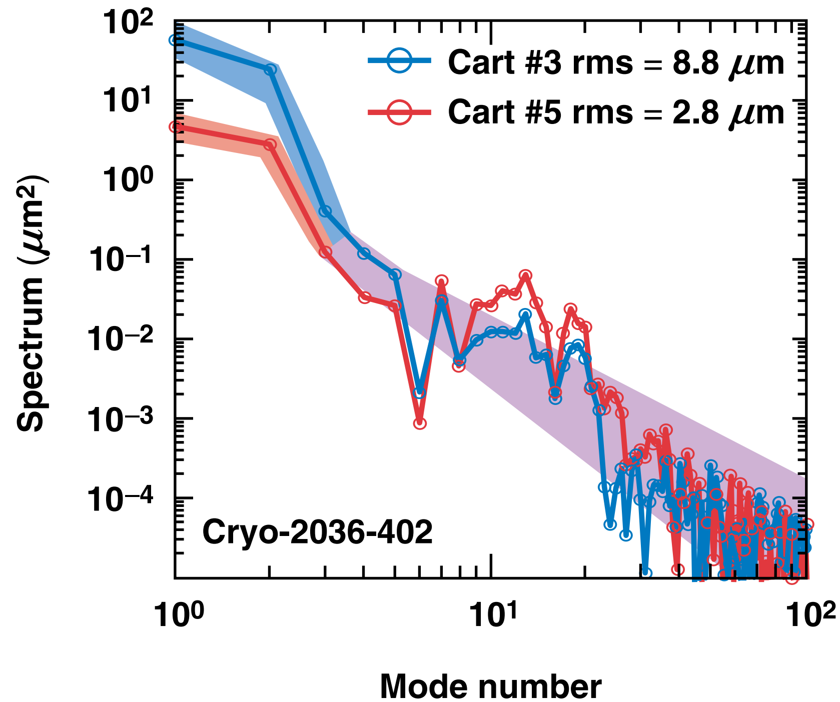
Expect less than 10% difference in T_2 concentration at the outer and inner surfaces of the bottom of a NIF DD ice layer, which will not affect the implosion.

P. W. McKenty, FO3.15, Tuesday

The smoothness of the ice layer is strongly affected by the layering sphere, which consistently produces targets of similar quality

Same target behaved differently in two separate layering spheres

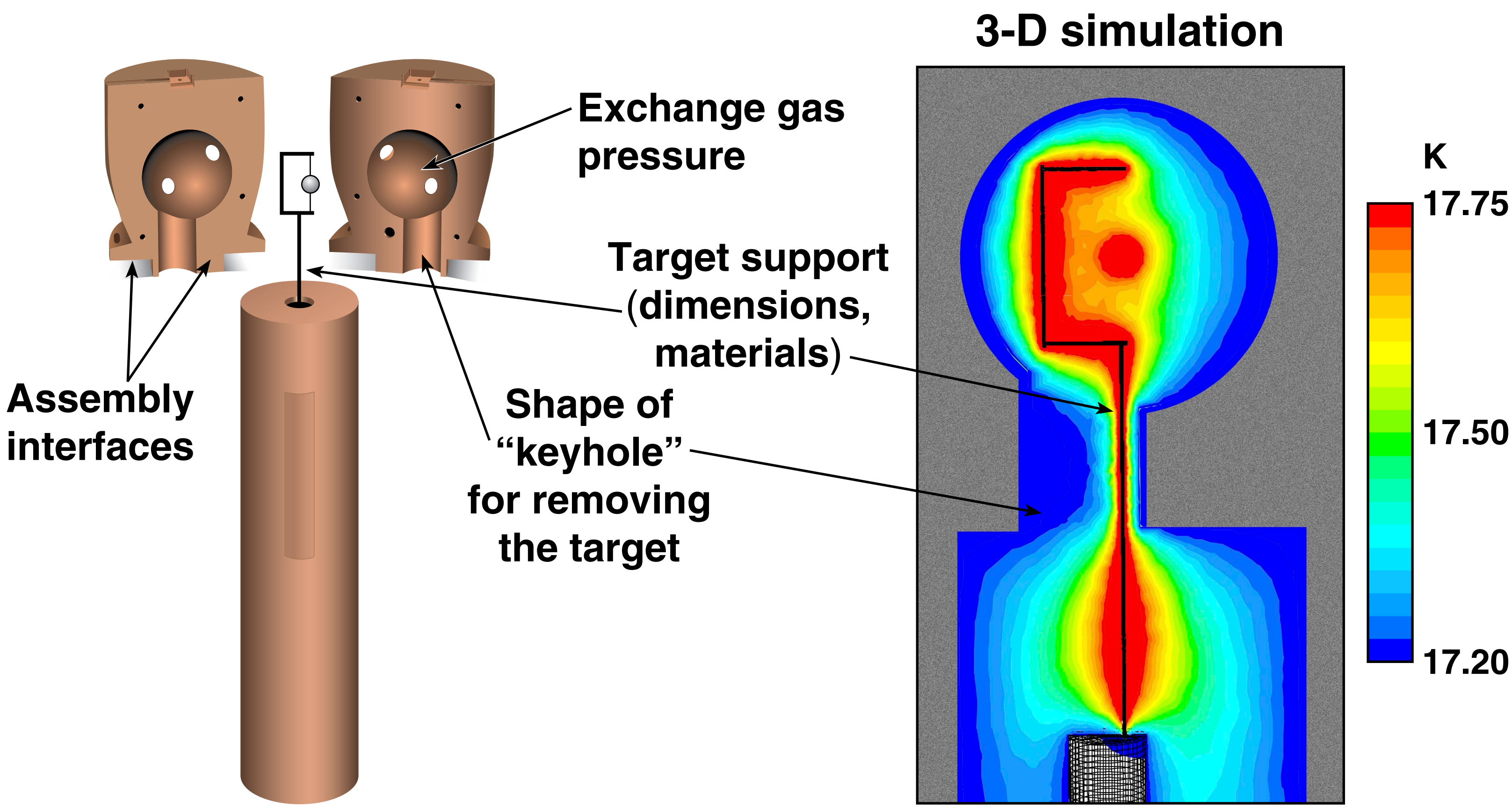




- The repeatable layer quality achieved in each layering sphere will be beneficial once each environment is optimized.
- Each layering sphere performs differently, despite identical design specifications.

T2182

The uniformity of the thermal environment is affected by four engineering features

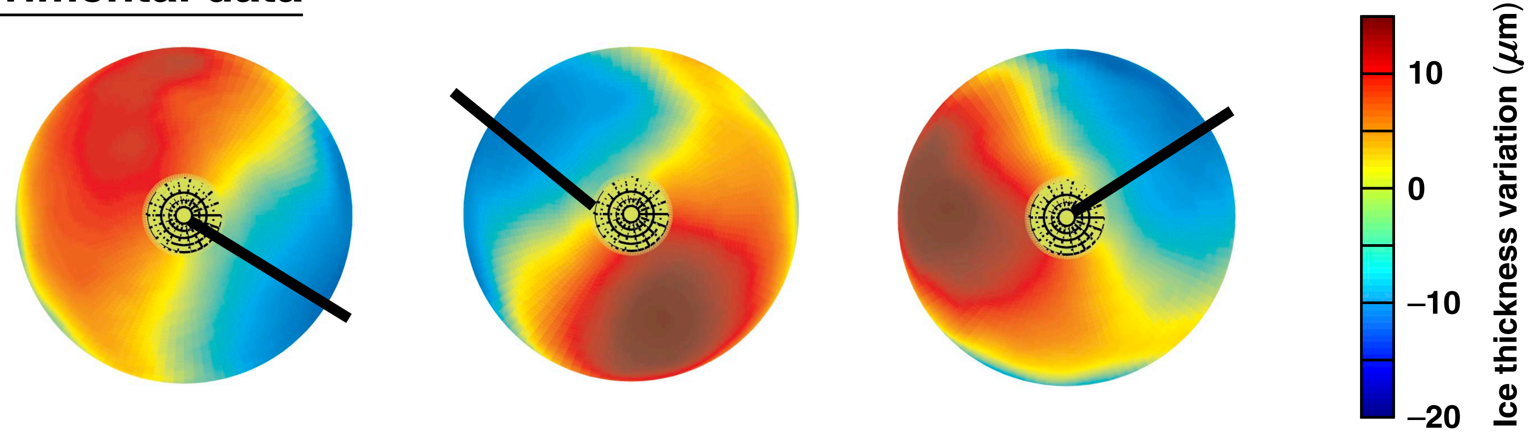


Actively controlling the temperature gradient is not an option. Must minimize gradients with a robust design that is insensitive to variabilities in assembly.

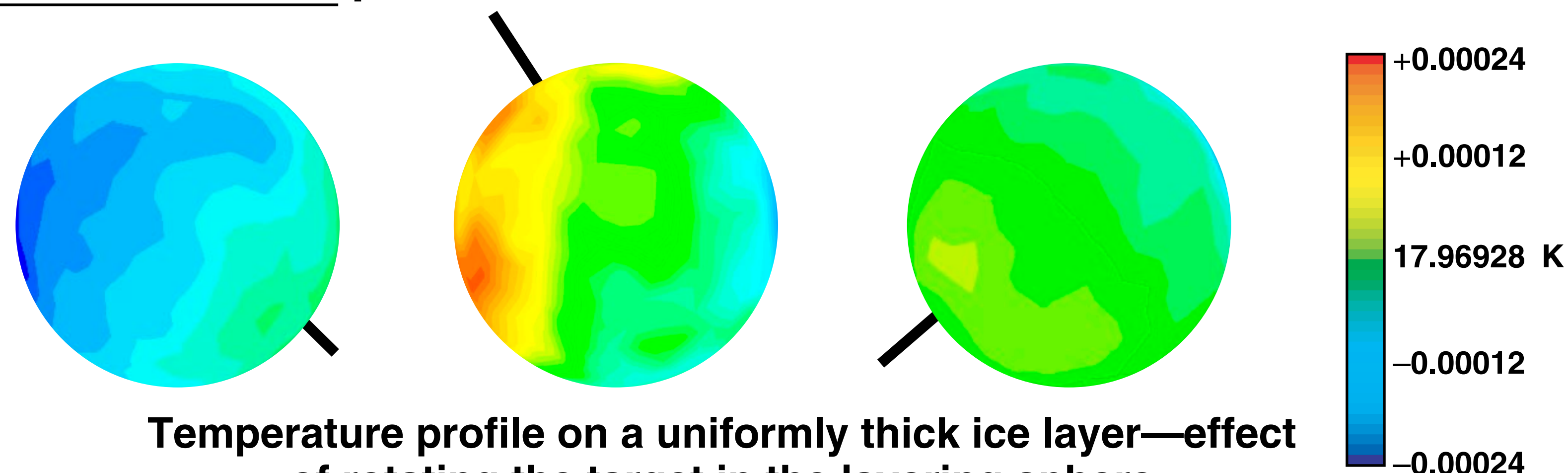
All ice layers possess a variation in thickness along the north–south axis and around the equator

- The target support is responsible for the variation around the equator.

Experimental data



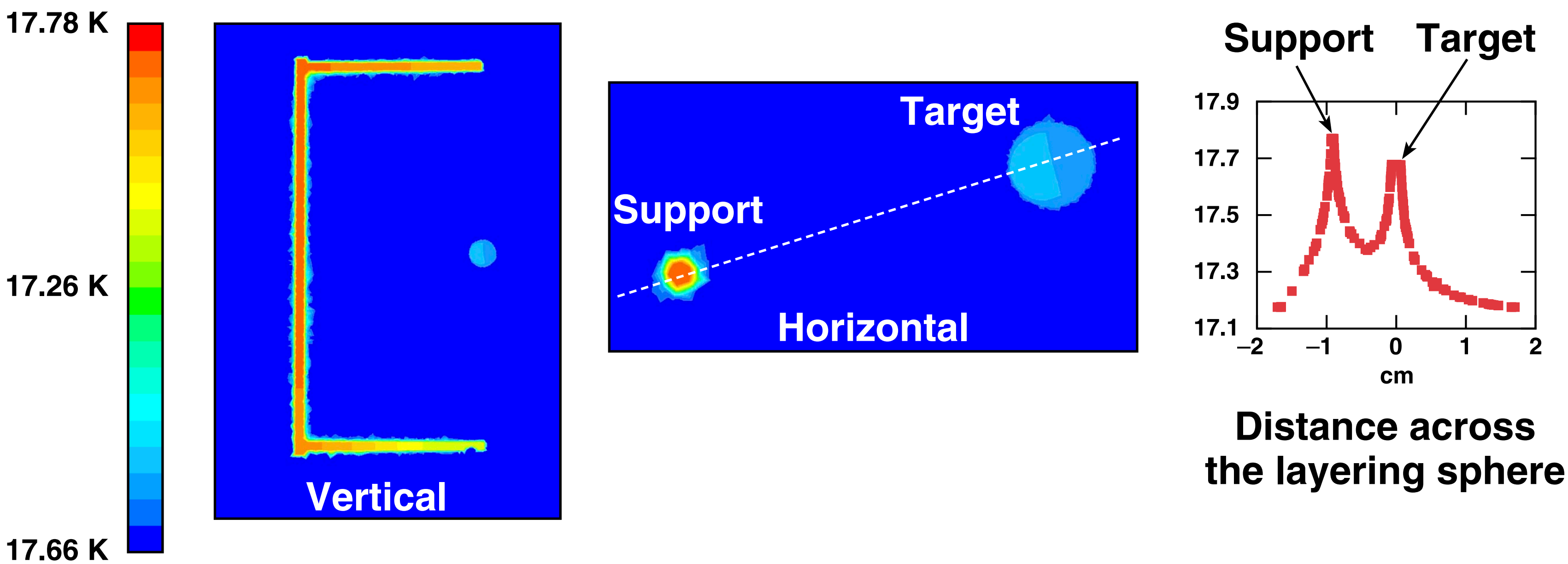
Thermal mode data: predicts the same effect



Temperature profile on a uniformly thick ice layer—effect of rotating the target in the layering sphere

T2183

A 3-D thermal model of the target's environment indicates that the target support is warmer than the surrounding gas, and its proximity to the target affects the ice



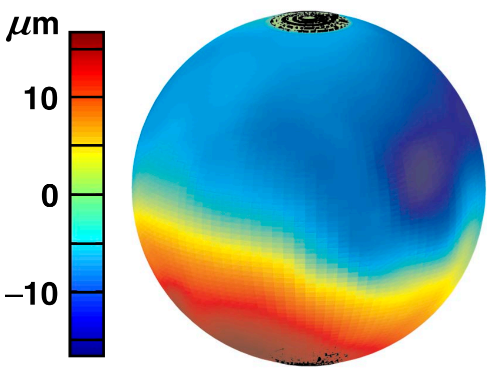
Temperature profile around the target—worst case

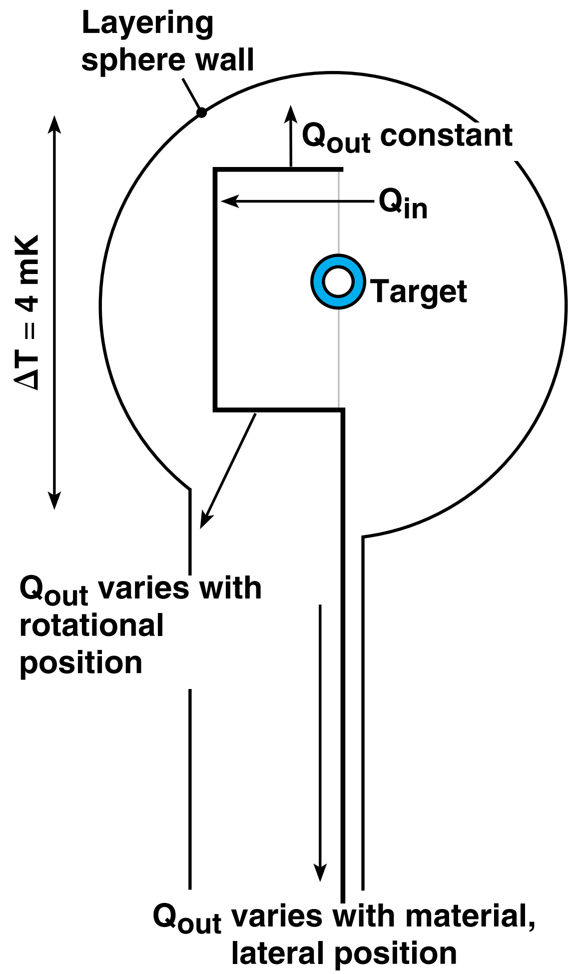
- A 300-μm-diam support 75-mK warmer than the target and 7 mm away imprints a 1.6-mK gradient onto the target
- Effect minimized in DT targets as β layering doesn't require IR

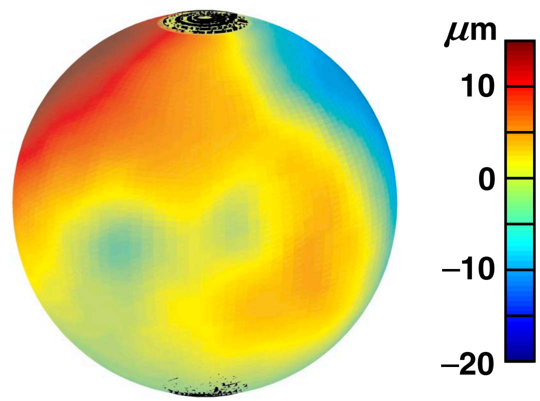
T2184

The target support interacting with the layering sphere affects the ice thickness along the vertical axis

- **Specifically, (I) the materials for the support and (II) its angular position**







Target support
1.5-mm steel tube cools the base of the C-mount, making the ice thicker at the base.

Target support
1-mm plastic tube: poor thermal conduction and IR absorption heats the base of the C-mount making the ice thicker at the base.

T2185

Implementing design changes in the 3-D thermal model reduces the temperature gradient on the target from 1±0.5 mK to ~0.15 mK

These include

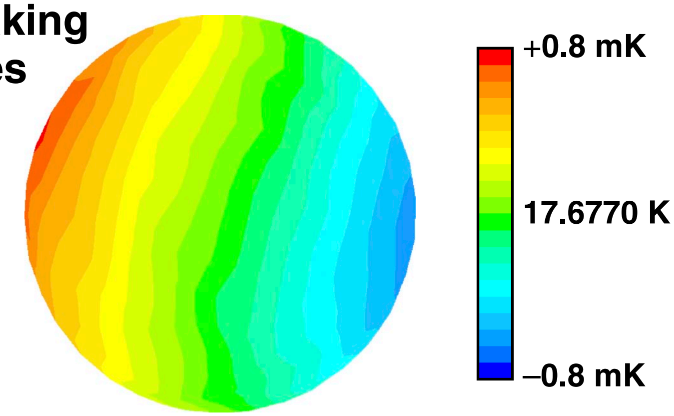
1. make the target support thermally "invisible,"
2. eliminate variable contact resistances
3. ensure adequate He pressure

Changes that will make the design less sensitive to assembly variabilities

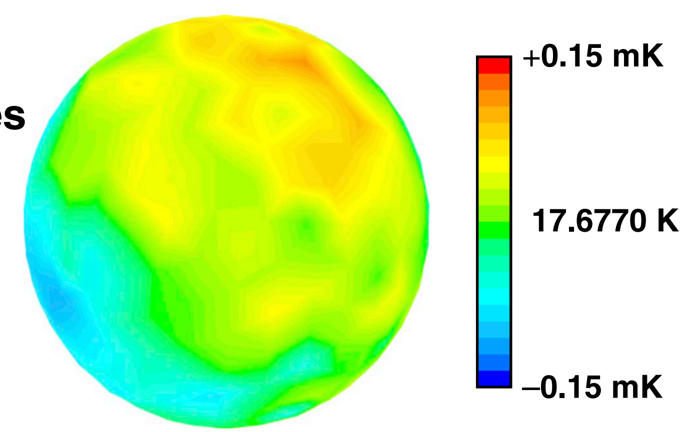
1. Reshape/shrink the entry hole in the layering sphere
2. Increase separation between the target and support

Temperature profile on a target

Before making changes



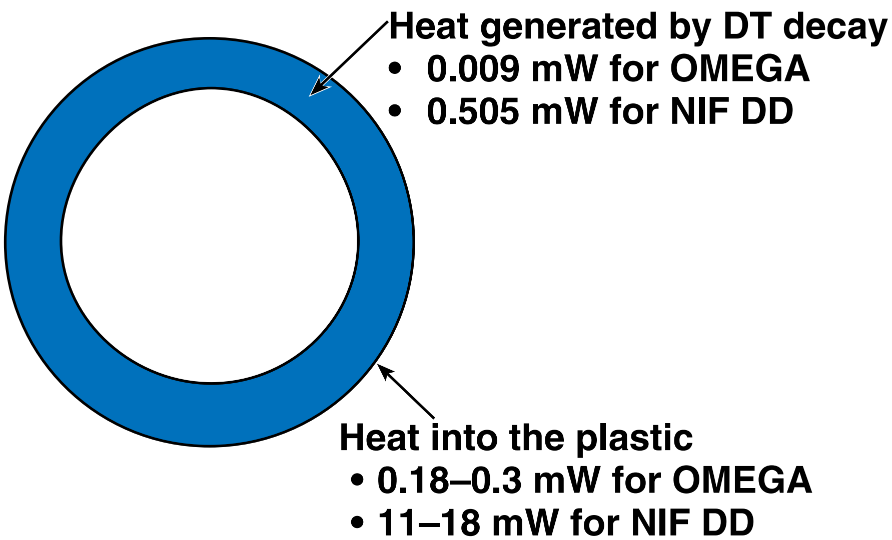
After changes

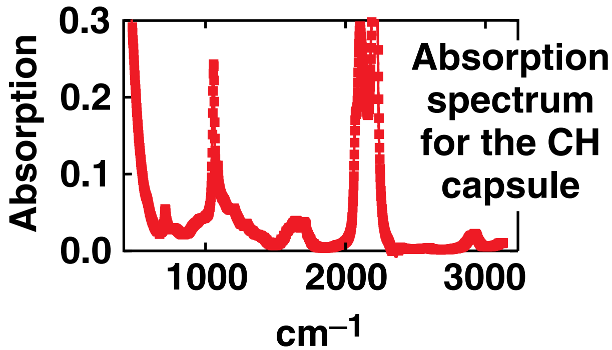


T2186

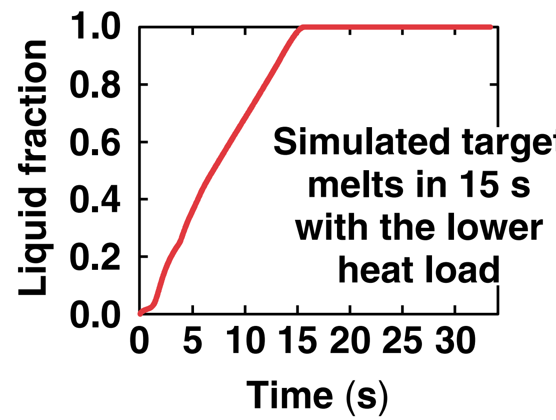
Achieving the ice layer specification requires knowing how the target behaves when the shroud is retracted

- Use experiments to qualify a thermal model and extrapolate the model to subsecond target-exposure times





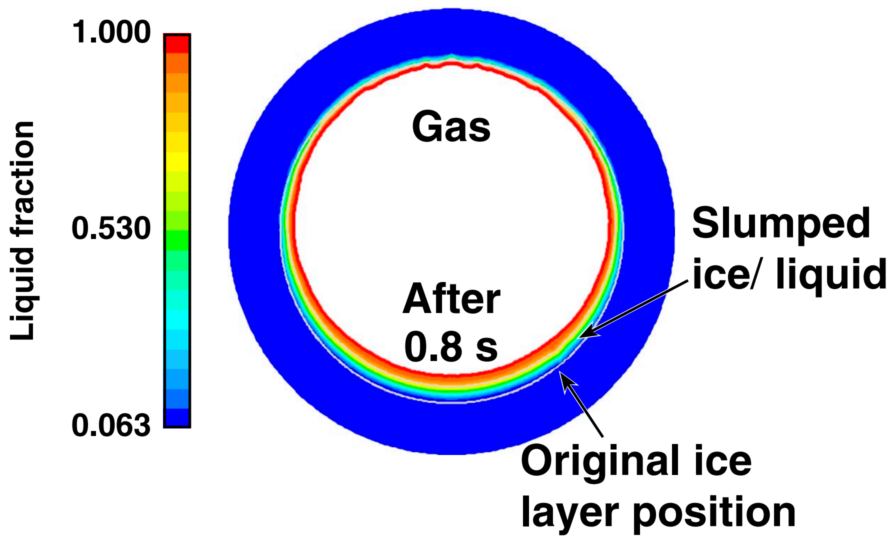
Exposed OMEGA D_2 target slumps within 2 s and melts within 11 s



T2188

A 0.8-s exposure to ambient radiation has a minimal effect on the gas pressure <u>but</u> an unacceptable effect on the ice/liquid thickness

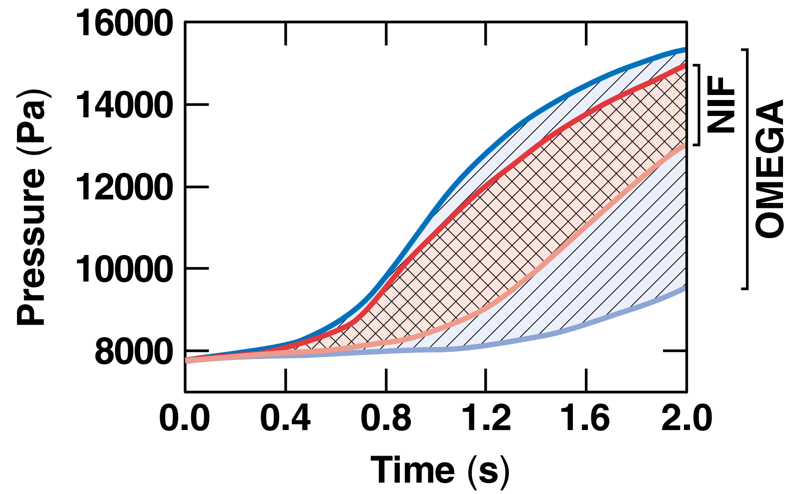
- 2-D axisymmetric model includes solid-to-gas and solid-to-liquid phase changes



<u>After 0.8 s</u>

OMEGA DT target: rms ~ 10 μm

NIF DT target: rms ~ 12 μm



Pressure increase is not a problem for even the highest heat load

Target exposure times shorter than 0.1 s are available for OMEGA, and are desirable for NIF DD targets.

T2189

Summary/Conclusions

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