OMEGA Direct-Drive Cryogenic Deuterium Targets

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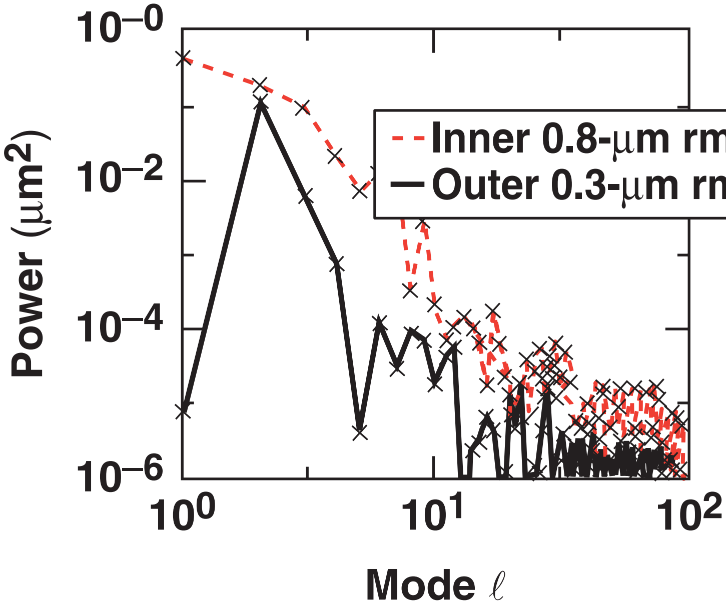
Overview

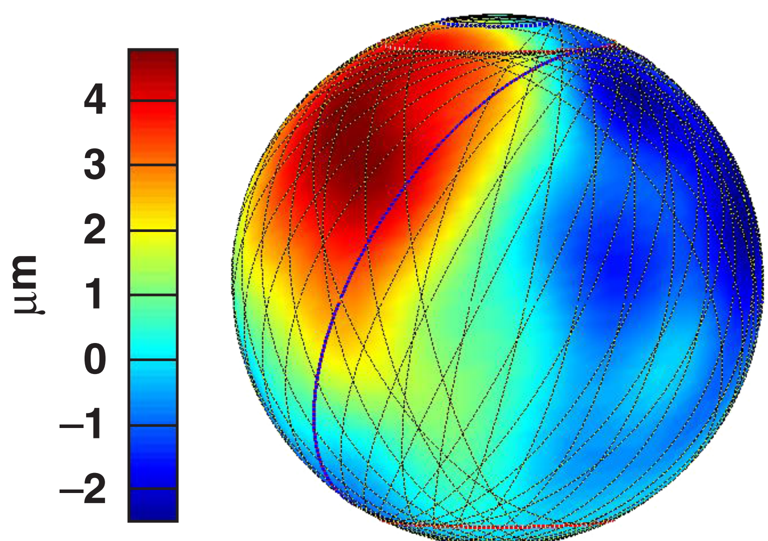
UR LLE

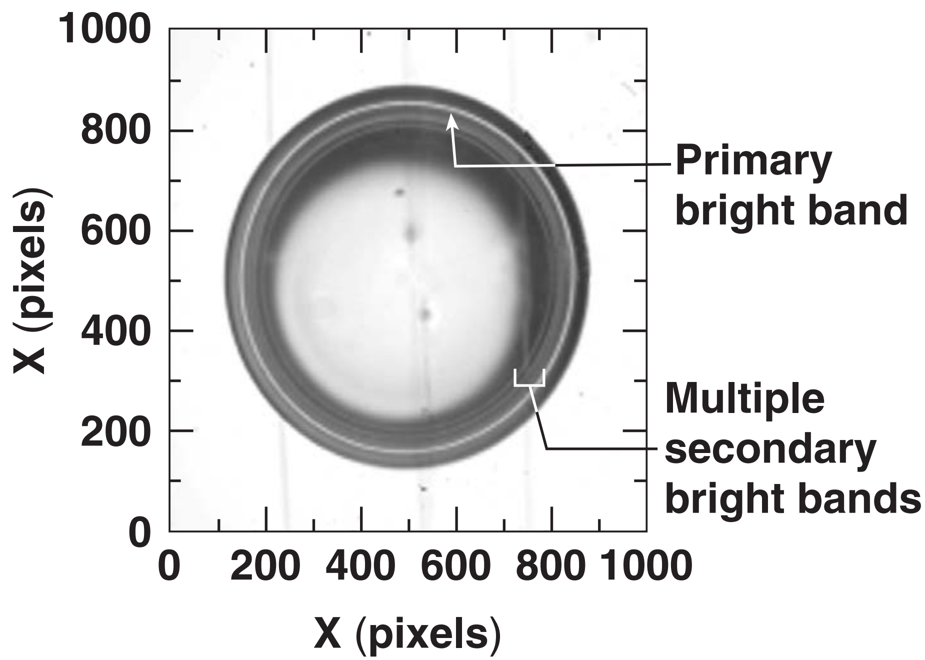
- Current status
  - statistics of the layering process
  - demonstrated <1-μm rms layers (all modes); but not throughout the target
  - layer smoothness varies for different MC's; the layering sphere is the limiting factor
- Foam targets
  - improved transparency
- Cooling targets below the triple point
  - variable behavior
- Effect of shroud retraction on target condition

High quality ice layers were attained; ice roughness was below 1 μm (rms) for all modes for ~16% of the ice surface



The average ice rms roughness of 24 2-D great circles was 1.2 μm in the y view and 1.7 μm in the x view





T1968

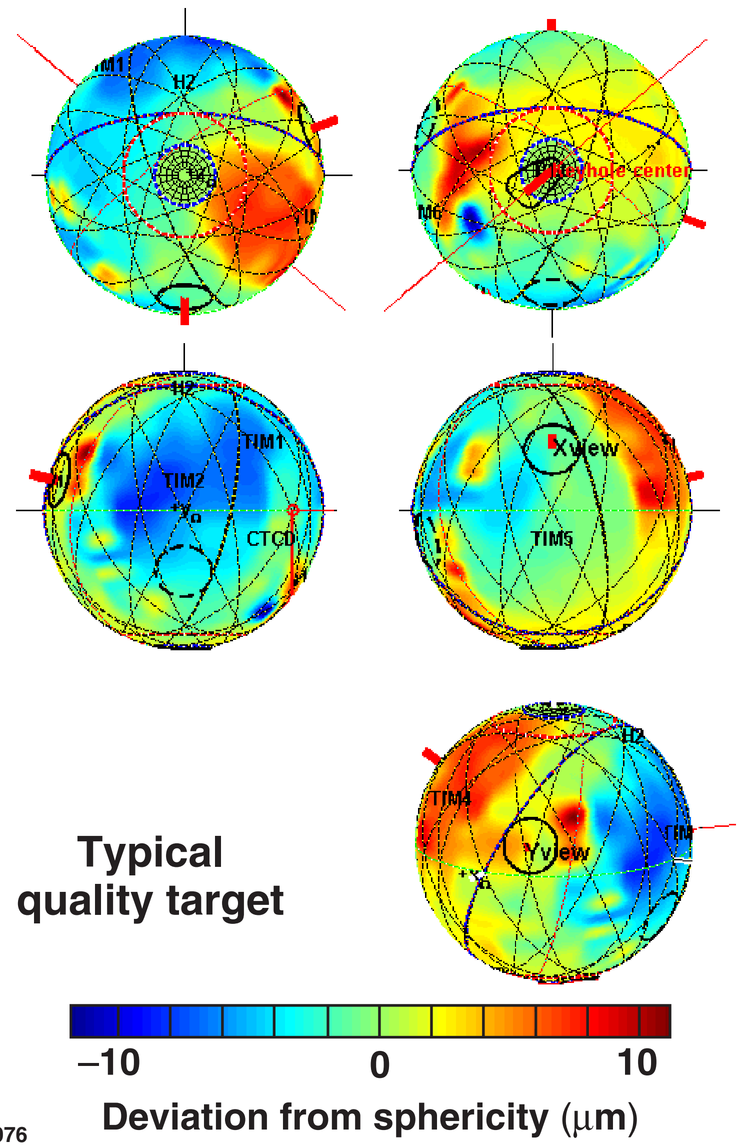
The ice layer is formed using a stepwise temperature ramp without any subjective intervention from the operator

Sequence:

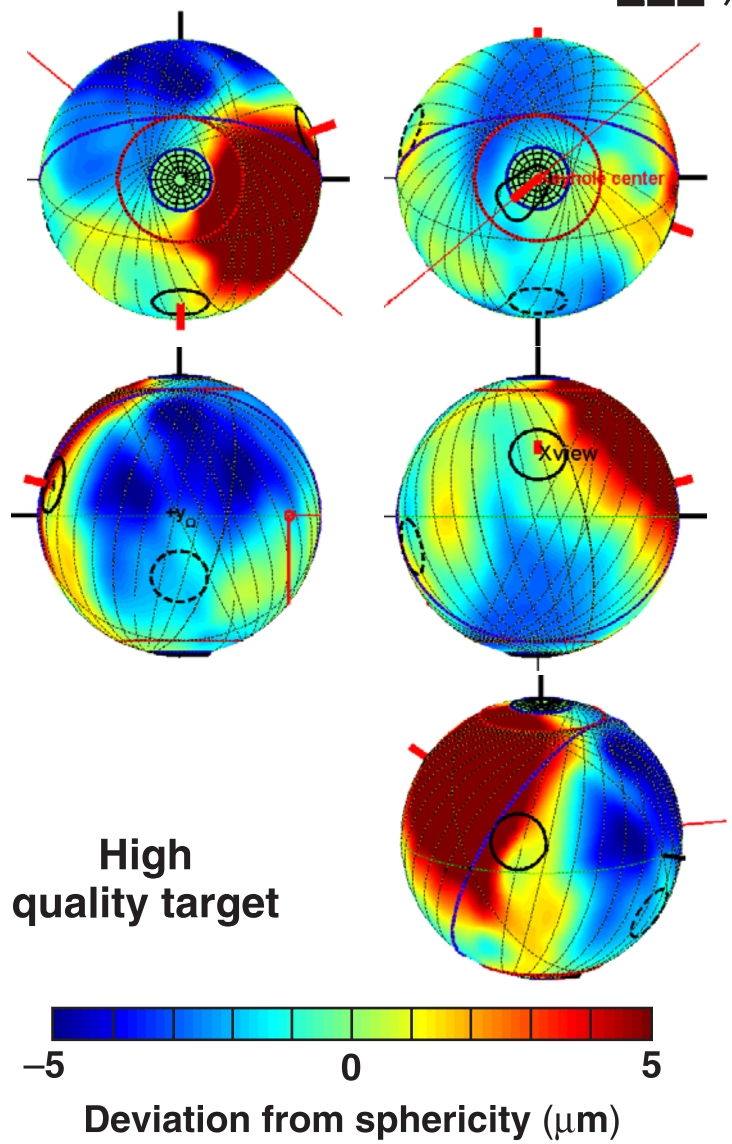
- Initial state: liquid D_2 and OPO power = 1 to 2 Q_{DT}
- Step 1: Determine the temperature on the layering sphere where the liquid freezes; (ΔT = –50 mK/2 h)
  - Issues
    - the best layers are formed with a small ΔT between the target and the boundary
    - lengthy thermal time constant to remove the H_{fusion} (~ 1 mJ).
- Step 2: Melt the ice and repeat the freeze, starting closer to the triple point temperature; (ΔT = –10 mK/2 h)
  - melting a good quality target and relayering it using the same protocol returns a "similar" layer (both rms roughness and crystallographic quality)

T1967

A full 3-D surface profile of the ice layer is critical for proper characterization and also to identify sources of ice perturbations



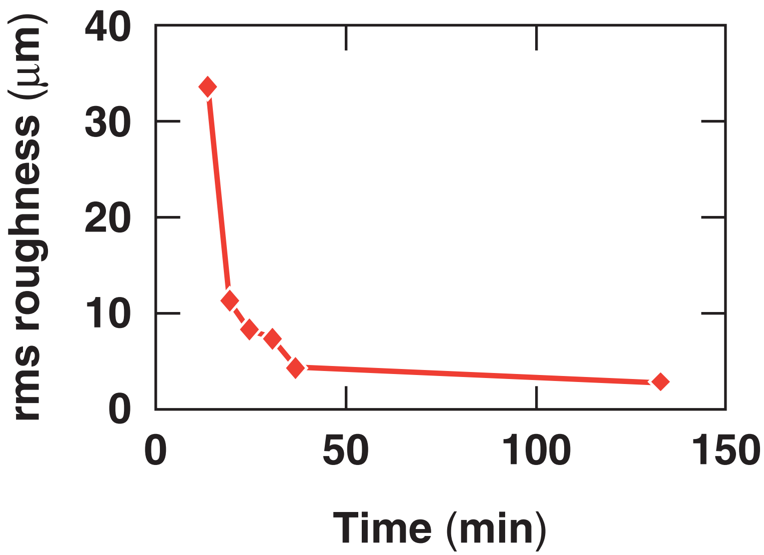
Typical quality target

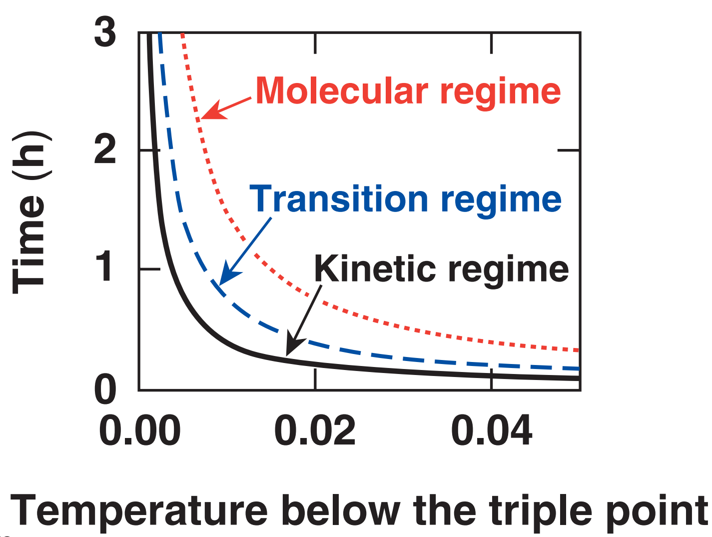


High quality target

T1976

Ice layer formation is rapid (<3 h) with 1 to 2 Q_{DT}; determining the initial conditions for forming the ice layer can take days





T1970

Good News

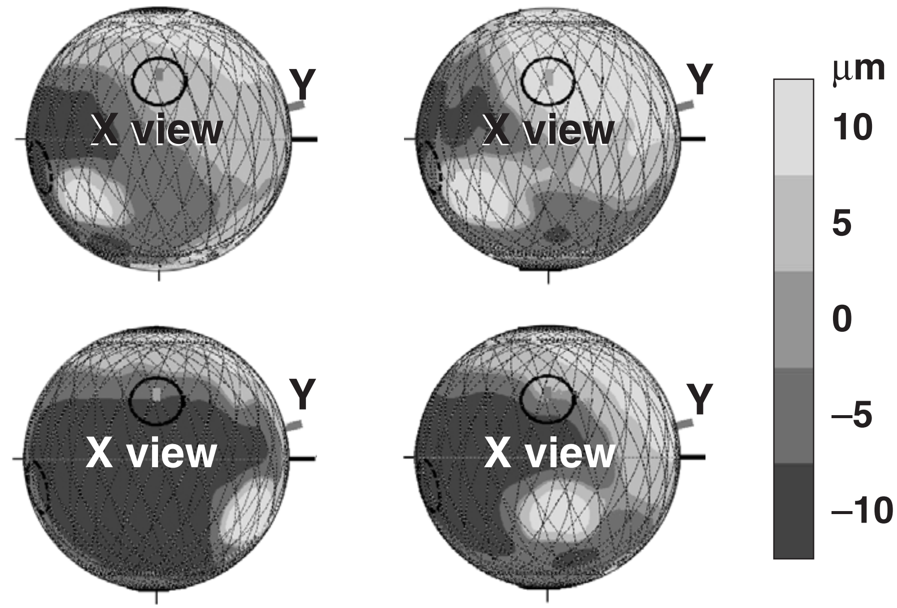
- Time to form a 2-µm rms layer < 3 h

Bad News

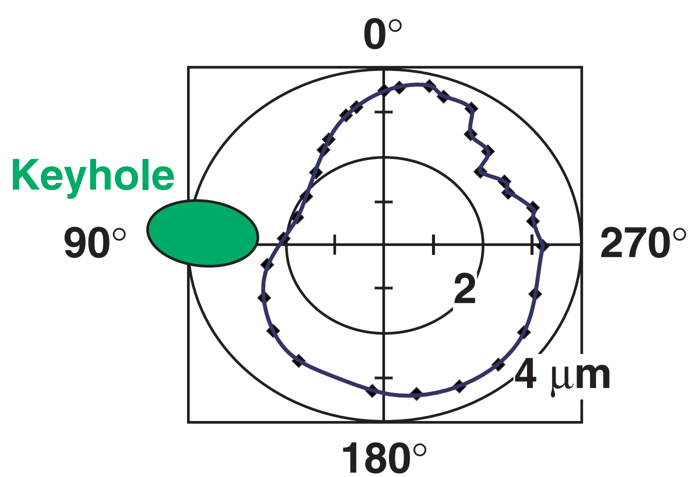
- Good layers require slow solidification
  - requires the H_{fusion} (~1 mJ) to be removed slowly
  - small ΔT decrement to go from liquid to solid
- Since Q is proportional to ΔT, a 10 mk step requires an ~2 h dwell; depends upon gas pressure

Layering, melting, and relayering the target using the same protocal resulted in a 0.6-μm variability in the rms roughness

- **Four separately formed ice layers (in the same capsule) have a similar thickness distribution.**
  - **demonstrates the variability of the solidification process**
  - **preferred low mode orientation**



- **The ice layer shows significant variation azimuthally within the layering sphere.**

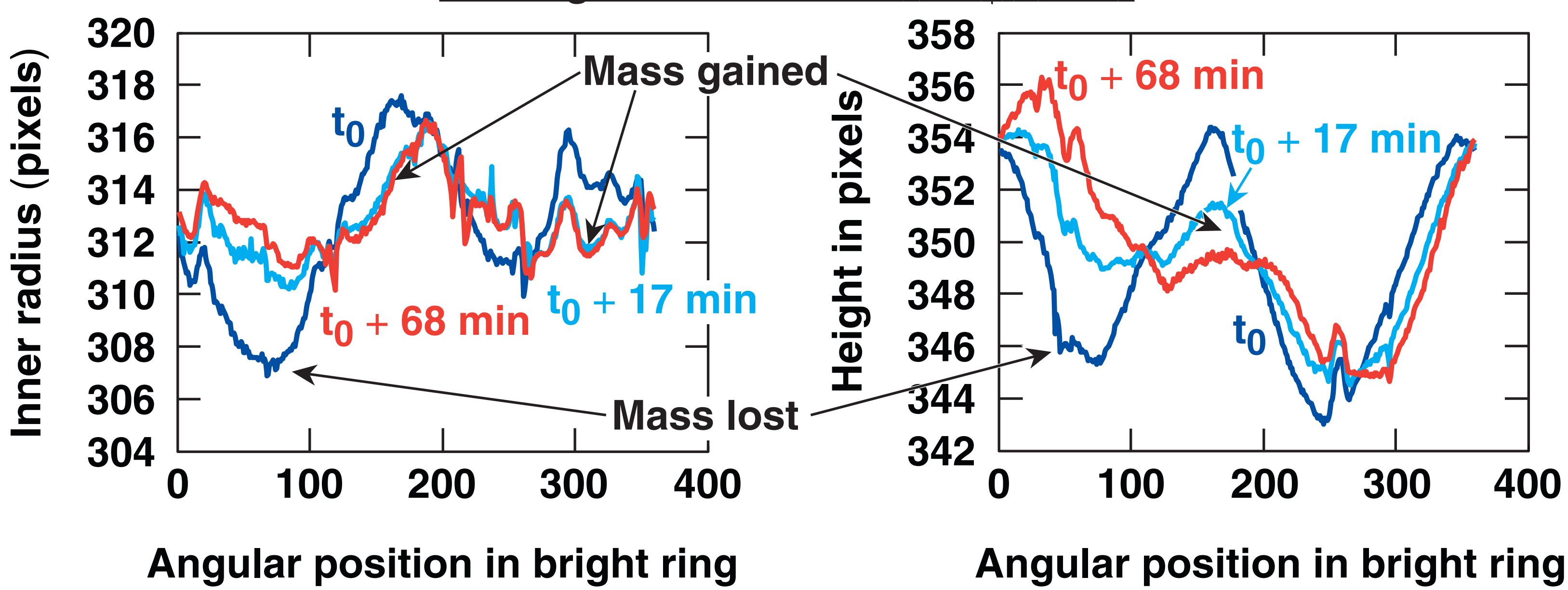


T1969

The ice layer "relayered" when it was rotated at the center of the layering sphere

- Conclusive evidence in one layering sphere: $\tau < 20$ min
  – the response repeated for a second target, to a lesser extent
- Ice moved laterally within the target, transposing the $\ell = 2$ mode into a $\ell = 1$ mode.

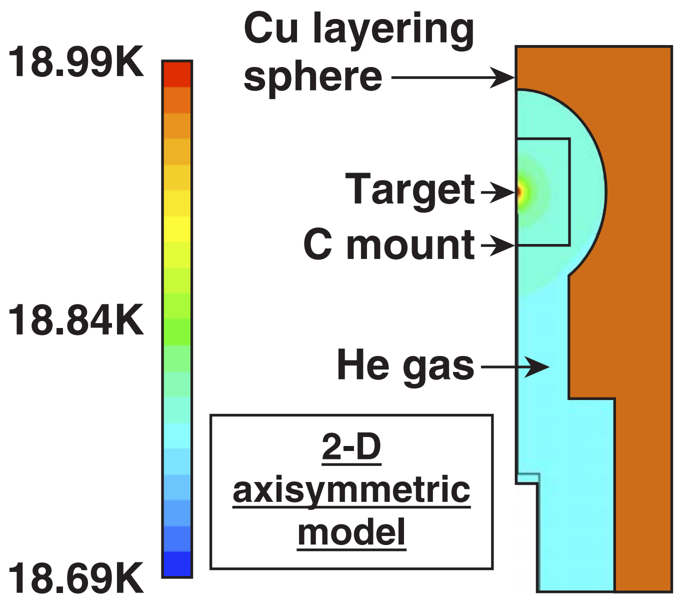
<u>Change in the position of the brightband with time when the target is rotated 180° to $\phi = 150°$</u>



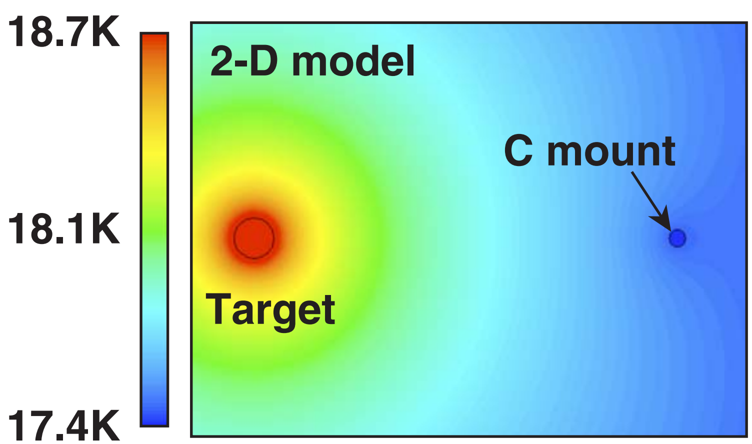
Possible causes: nonuniform IR illumination, temperature gradients within the layering sphere, the Be target support, or the "keyhole."

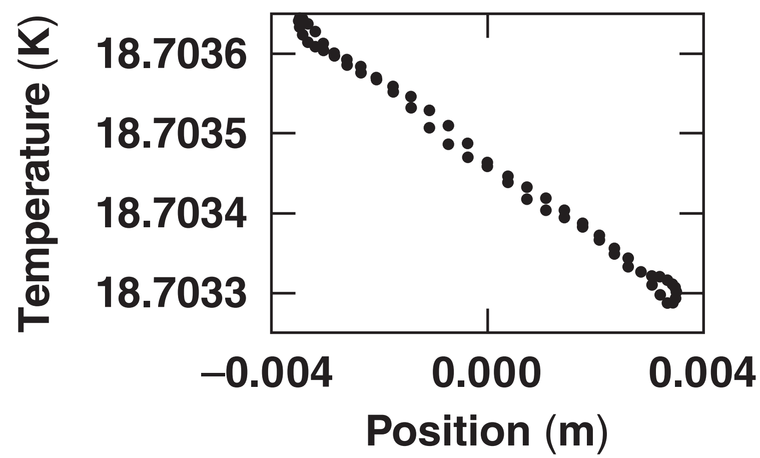
T1971

Determining the effect of small thermal gradients within the layering sphere requires a full 3-D model of the upper shrouds



- 0.4-mK vertical temperature gradient on the layering sphere corresponds to a 0.08-mK ΔT on the target
  - modeled without thermal resistance at the component interfaces
  - doesn't account for azimuthal variation
- C-mount intersects isotherms within the layering sphere covering a 5 mK range: ($T_{\text{layering sphere}} - T_{\text{target}} \sim 1.3$ K)
- The effect of the C-mount on the temperature profile of the inner ice surface is 0.33 mK



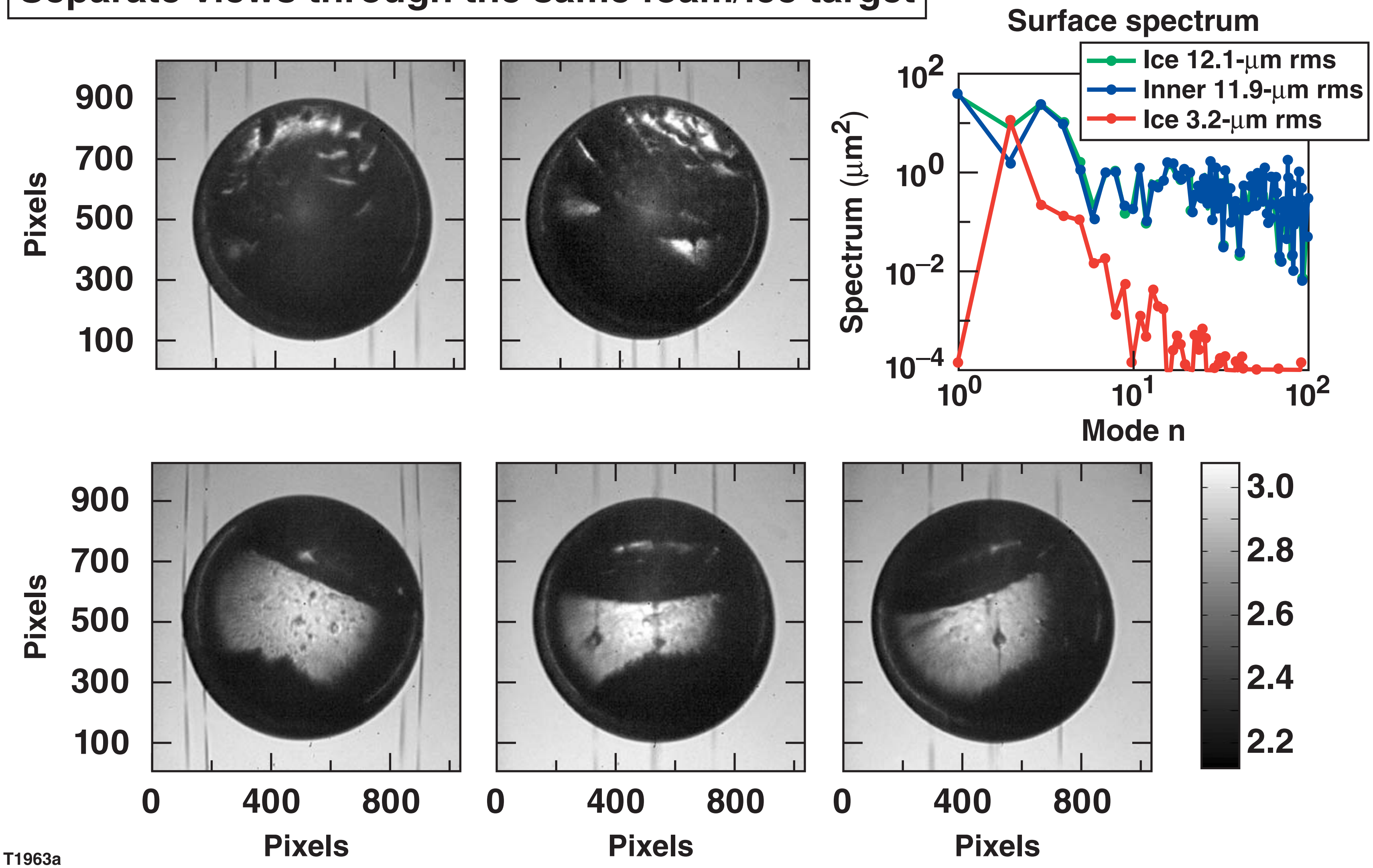


The magnitude of these effects depends upon the He gas pressure and the Q_{DT} in the target.

T1972

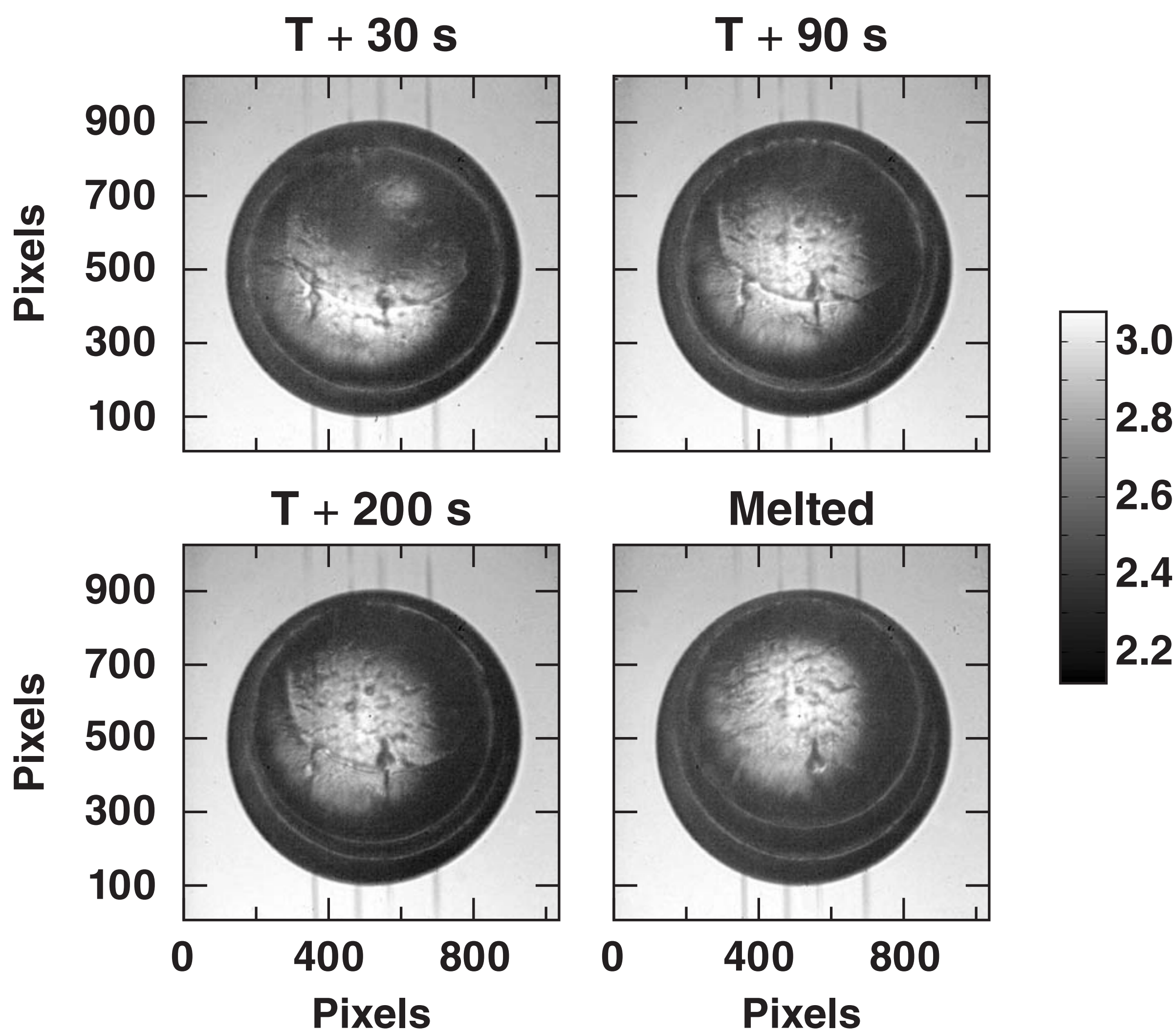
A 0.25 μm pore foam with IR illumination (950 nm) allows the inner ice layer in a foam target to be observed

Separate views through the same foam/ice target



T1963a

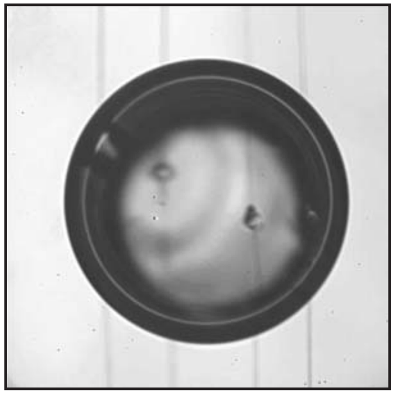
Melting the ice in a foam target revealed clearly defined brightbands



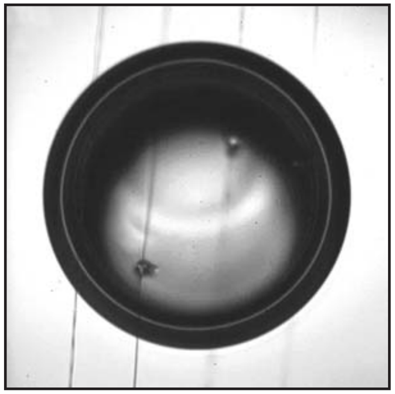
T1964

Cooling targets below the triple point temperature

- The behavior of a target when cooled below the triple point varies!
  - from no observable effect to a substantial effect
  - usually, the first 0.5 to 1.0 K has little effect—the next 1.0 K can affect the target
  - there is a weak correlation between the likelihood of the target roughening and the initial crystallographic quality of the ice



Initial rms = 3.6 μm
Final rms = 3.7 μm



Initial rms = 2.1 μm
Final rms = 1.7 μm

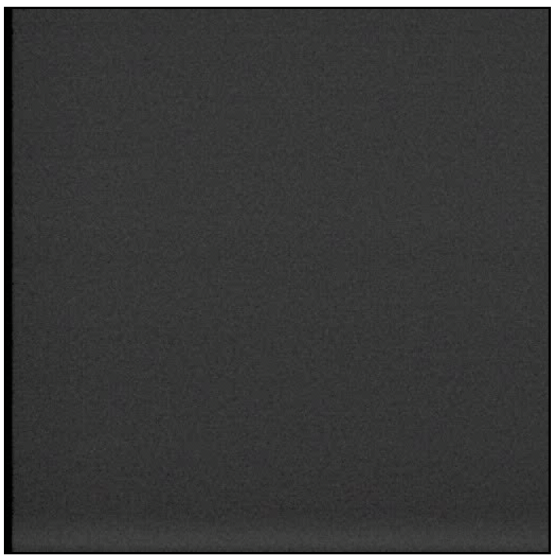
Cooling rate 0.02K/20 min

Defect-free ice is more likely to survive the thermal contraction associated with the temperature gradient.

T1965a

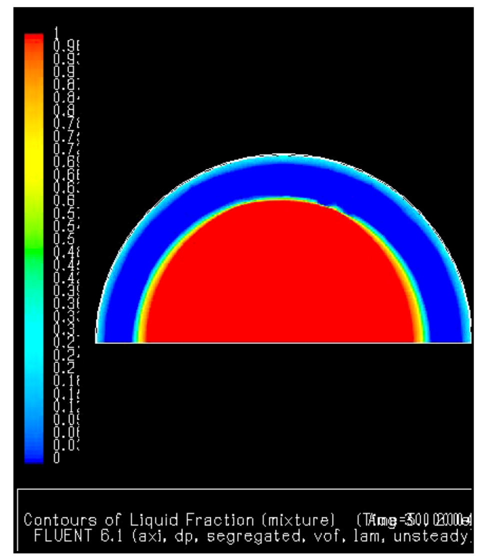
Target behavior when, exposed to ambient radiation, allows the effect of the shroud opening time on target conditions to be calculated

- Monitoring how rapidly a cryogenic target melted and exploded when the shrouds were retracted allowed the heat flux to the target to be calculated.



Experiment: target melting and exploding

- 10 s to melt ice
- 78 s to explode target (42°K)
- Radiance on target
- 0.173 mW (calc.)
- 14 mJ required to explode (based on time to explode and enthalpies of deuterium)

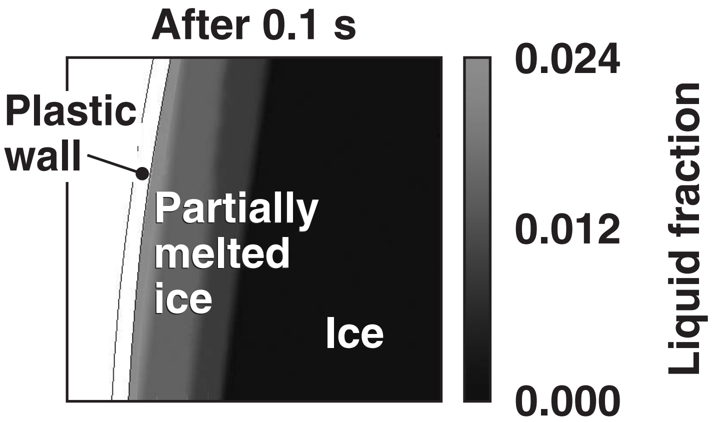


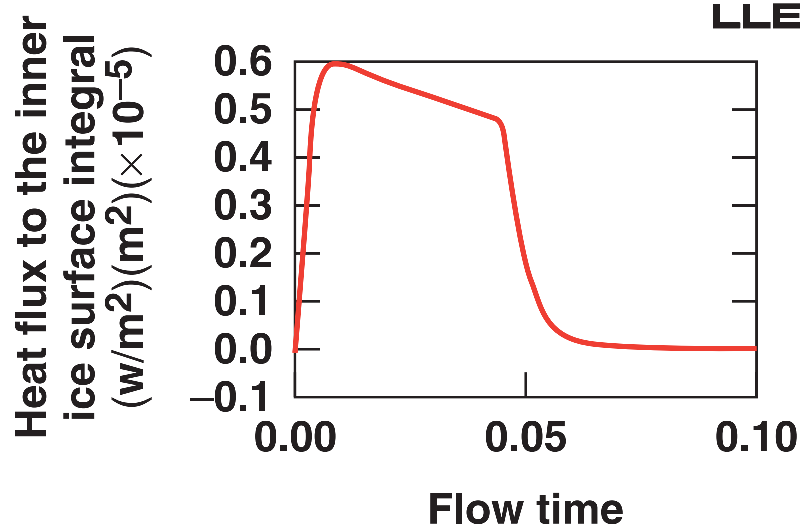
Model of ice melting

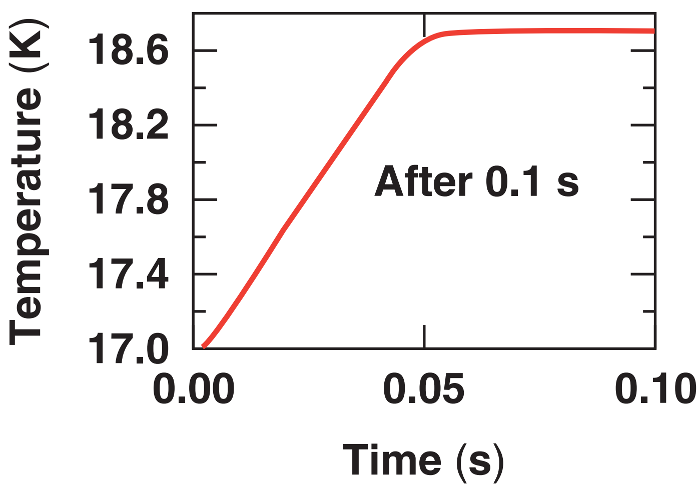
This heat flux allowed the rise in temperature of the ice and the rise in density of the deuterium gas in the interior to be calculated.

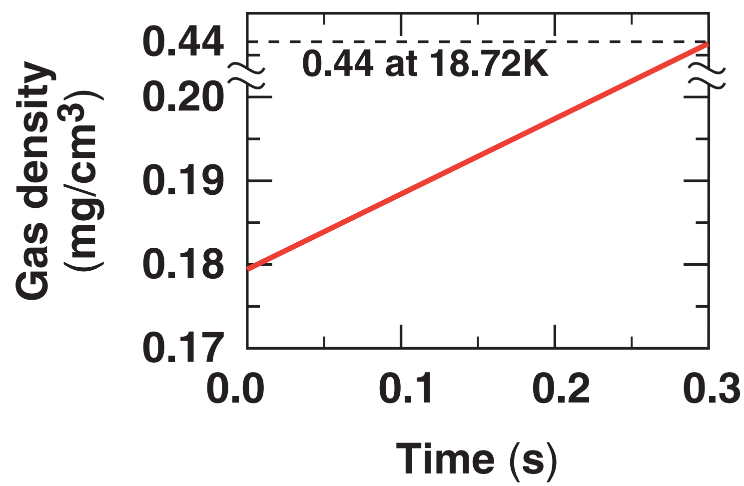
T1973

The thermal model indicates that the ice heats rapidly but that the gas density changes gradually









The ice temperature rose to the triple point after 0.05 s, but the gas density rose more slowly. If the ice roughens unacceptably with heating (volumetric expansion) then the exposure time will have to be very short, otherwise a longer exposure is acceptable.

T1944

Summary

We have made significant progress improving the quality of the ice layers; more work remains

- Demonstrated 1-μm rms roughness (over a portion of the target)
- Minimum time to adequately layer and characterize a target is 2 days.
- Need to identify the source of the residual low-mode roughness—layering sphere
- An ice layer surface is observed in a foam target.
- The ice layer quality is preserved when it is cooled 0.8 K below the triple point
- When the shroud is removed from a cryo target,the temperature rises rapidly and the gas density rises slowly.
- Improving the layer quality will be achieved by redesigning aspects of the layering sphere

T1975