Deuterium Ice Layering and Target Injection Studies

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Outline

- Update on target-layering efforts
- Target-heating issues
  - response of an OMEGA target to ambient radiation (experiment and model)
  - demonstrate a Monte Carlo model used to estimate gas dynamic loads on an IFE target
    - to define parameter space for experiments
  - planned experiments

We quantified the accuracy and repeatability of the ice layering and measurement process

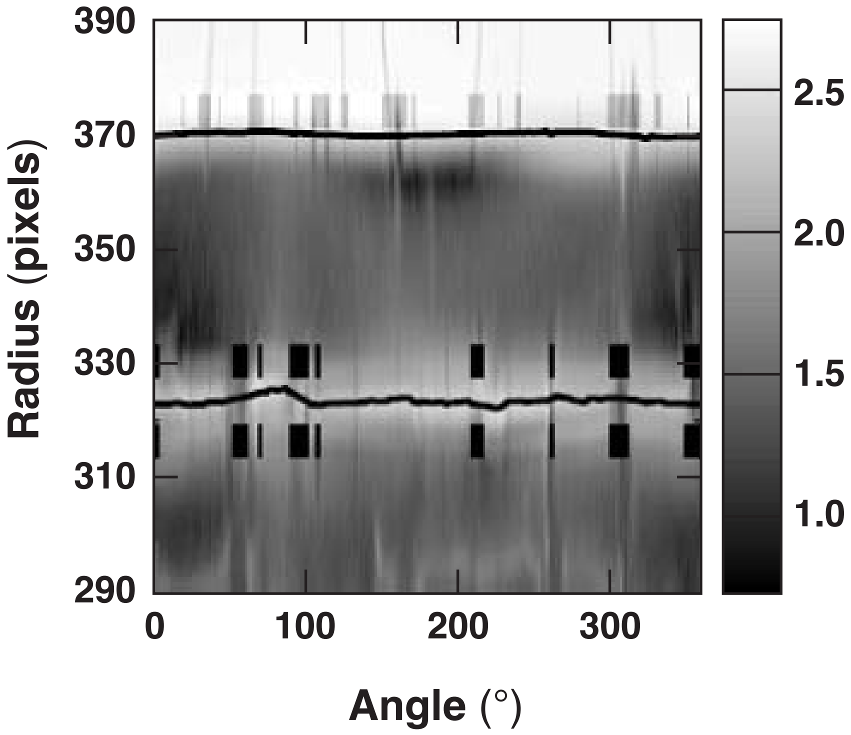
We have determined:

- **the accuracy threshold of shadowgraphy (CTHS system)**
  - **~0.3 μm—value obtained for a "near perfectly smooth" reference**
- **the repeatability of the ice-roughness measurement process (7 repeats of a single view)**
  - **±0.11 μm (95% confidence limit)**
  - **variables: target vibration, focusing, internal ice defects**
- **the repeatability of the ice-*layering* process (6 repeats)**
  - **constant solidification rate (controlled Q_{in}, Q_{out} and ΔTemp)**
  - **±0.5 μm (smoothest region <2 μm); 0.7 μm (roughest region ~4 μm)**
- **the ice roughness distribution in the capsule is repeatable**

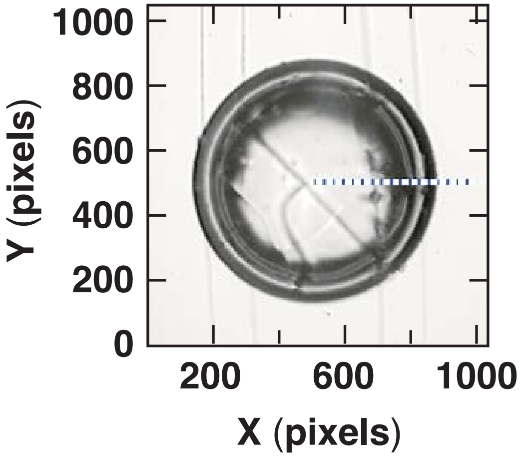
Submicron rms ice layers were demonstrated; the smoothest layers were confined to a localized region of the target

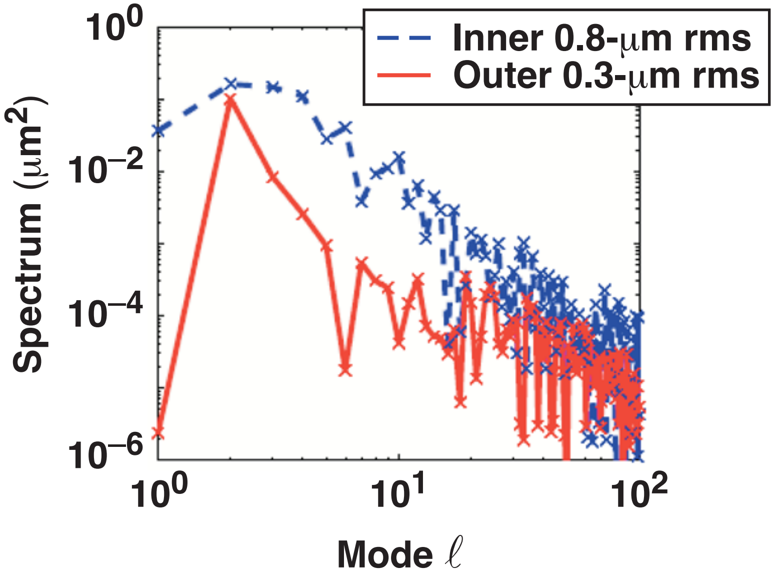
- 0.8-μm rms layer—best demonstrated
- 0.8 to 1.4 μm over 1/4 of target's surface

Unwrapped Image

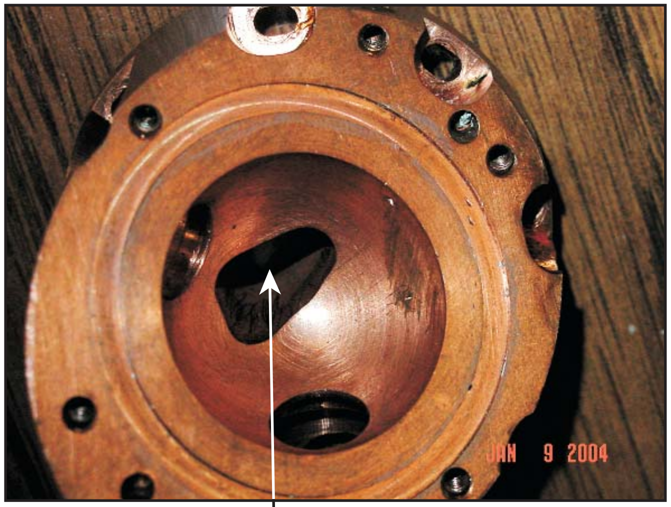


Cryo target 2035-291
ϕ = 165



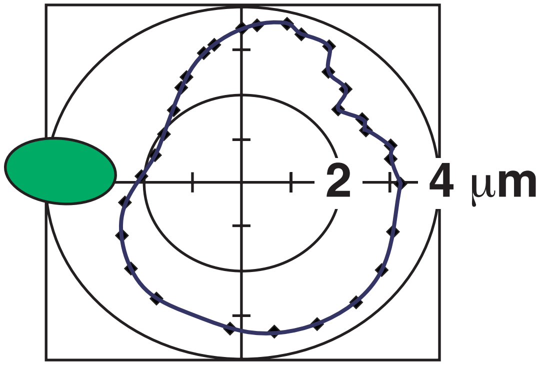


The variation in the ice roughness is repeatable AND correlates with the *hole* in the layering sphere

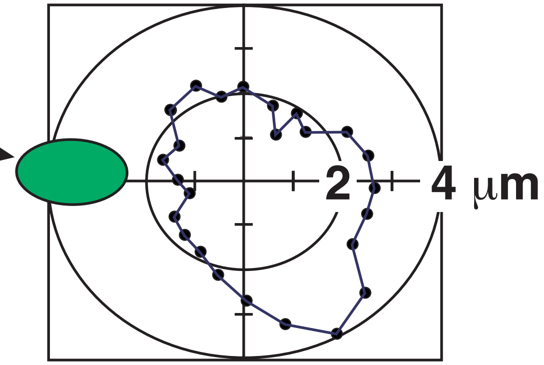


Hole where the target
is inserted into the
isothermal integrating sphere.

Polar plot: great circle rms roughness versus ϕ



Target ID: cryo-2035-294



Target ID: cryo-2035-291

Average of three separate layers.

The primary source of the azimuthal roughness variation appears to be the illumination nonuniformity

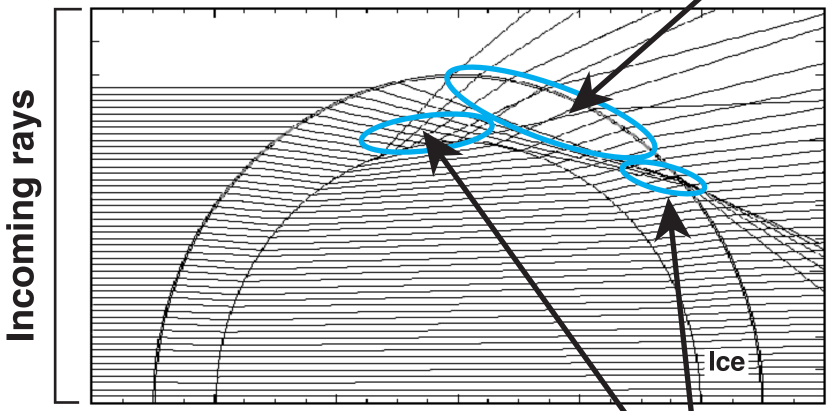
- Layering D_2 ice requires uniform IR radiation – integrating sphere.
- The largest source of nonuniformity is the “hole” used to insert and remove the target.
- The effect of the “shadow” on the ice thickness is quantified using ray tracing and a thermal model.

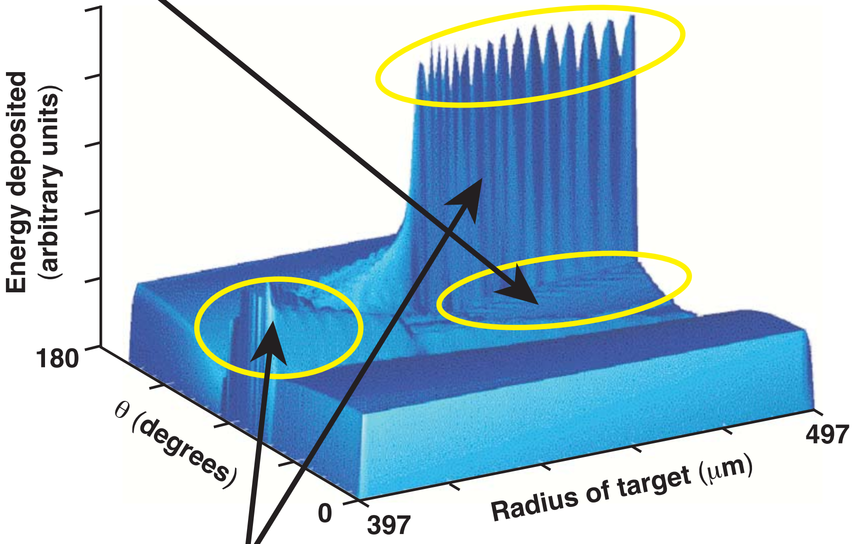
Concerns: – It causes an initial variation in the ice layer thickness.

– The target relayers as it is rotated (to acquire 3-D information).

The lack of illumination from the “hole” causes a mostly uniform 2% decrease in volumetric heating

Fewer rays traverse this volume; Q decreases only 1%.



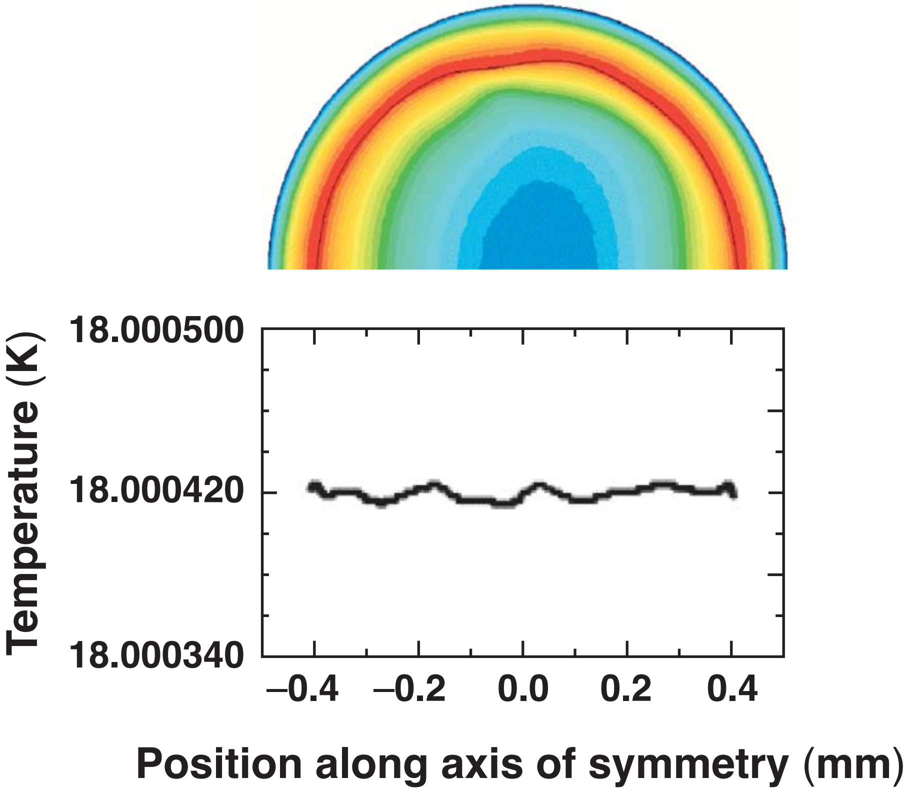


More rays traverse these regions; Q decreases 3 to 4%.

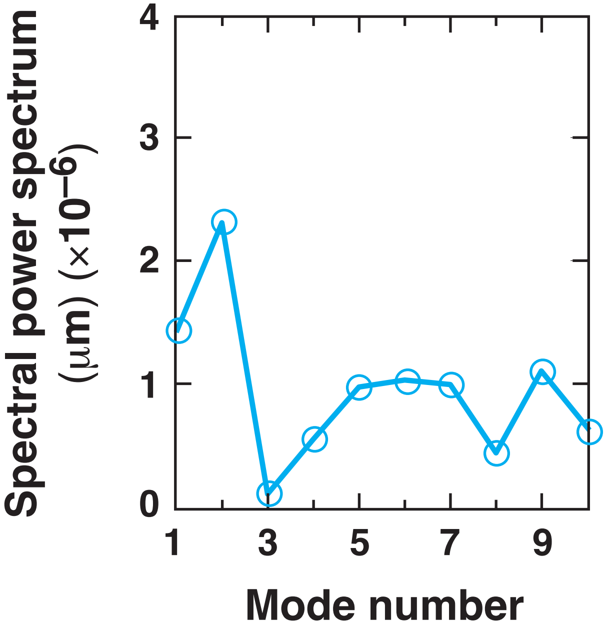
The focusing effect of the ice and internal reflection from the interior ice surface are responsible for this behavior.

The nonuniform heat load creates an ice rms roughness of ~4 μm

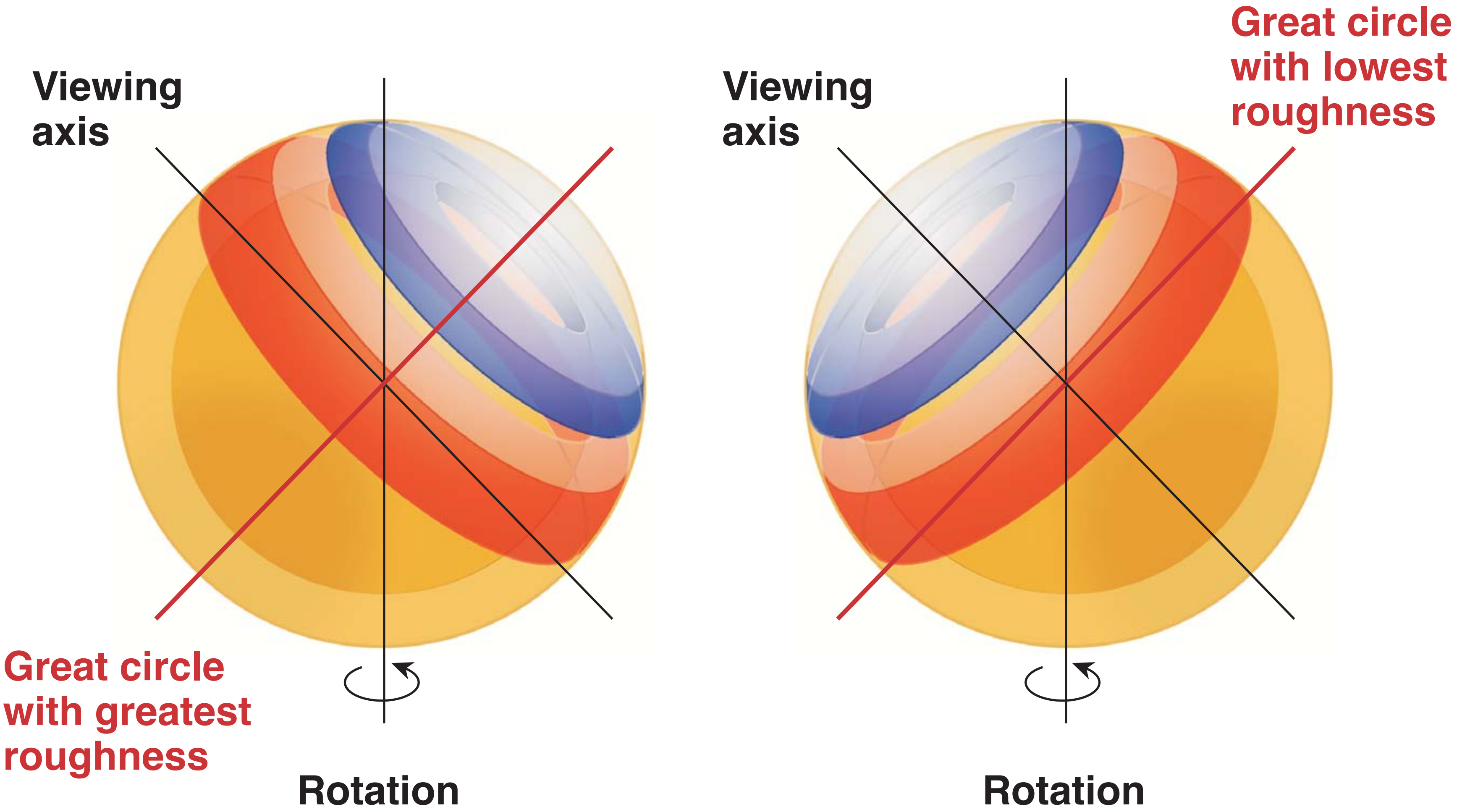
Ice layer thickness adjusted to create an “isothermal” inner layer



Resulting power spectrum



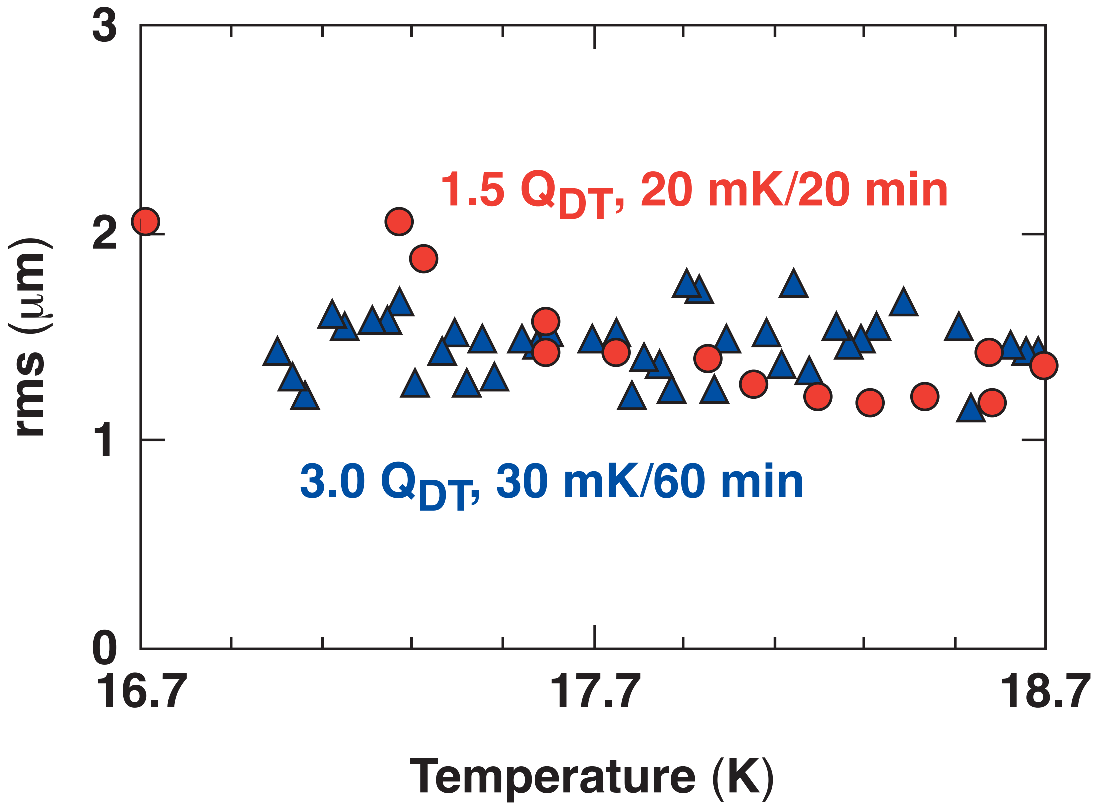
The geometry of the layering sphere/viewing system allows a varying fraction of the perturbed region to be viewed, depending upon the target rotation



T1910

Target smoothness deteriorated at temperatures more than 1 K below the triple point

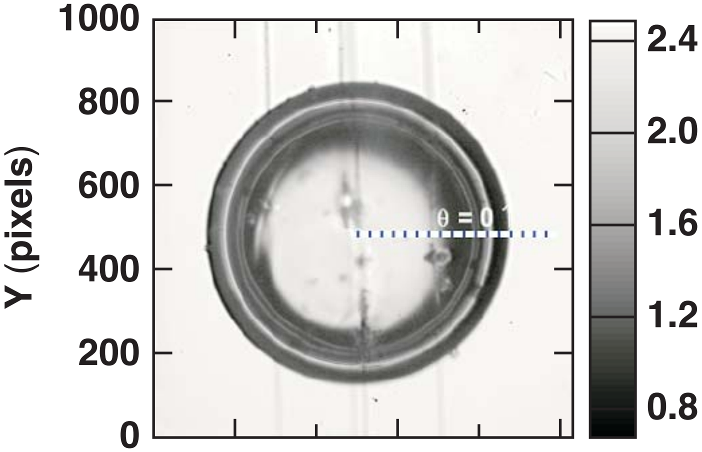
- **Higher heat loads AND slower cooling rates produced smoother layers 1.7 K below the triple point.**



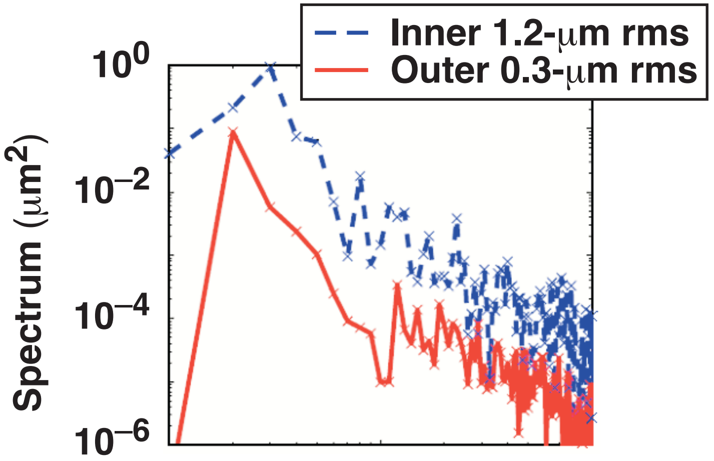
T1911

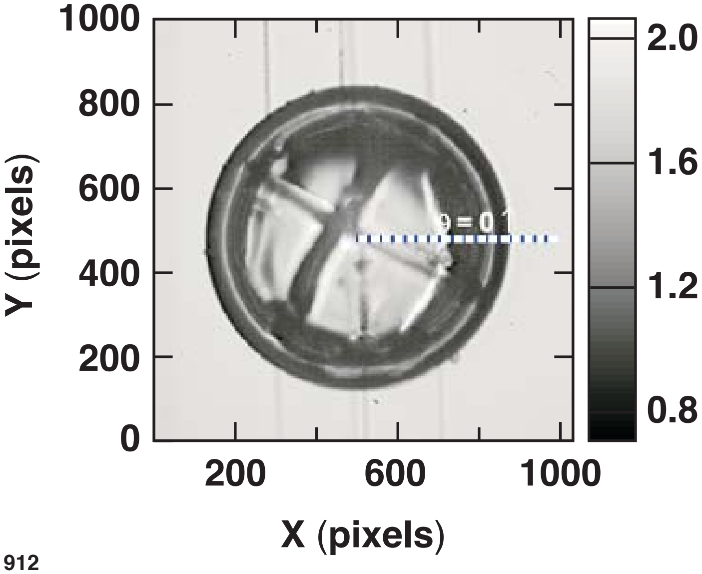
Increased roughness at lower ice temperatures is primarily observed in modes 1 and 2

Q_{DT} = 1.5; cooling rate = 20 mK/20 min

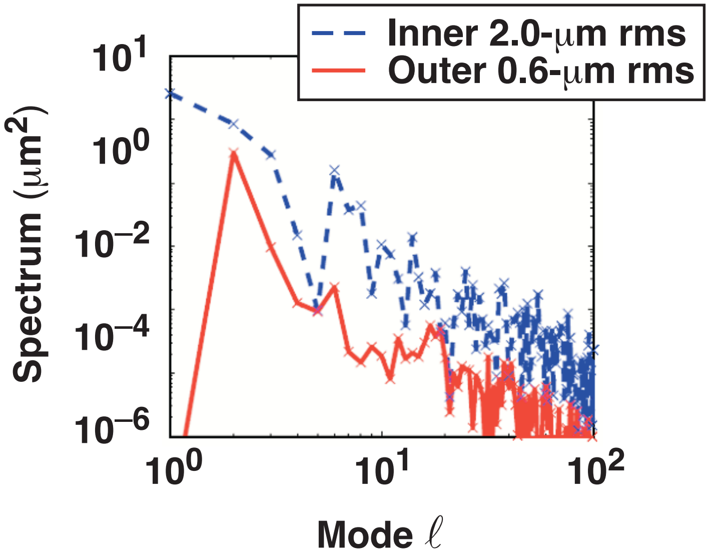


T = 18.7 K





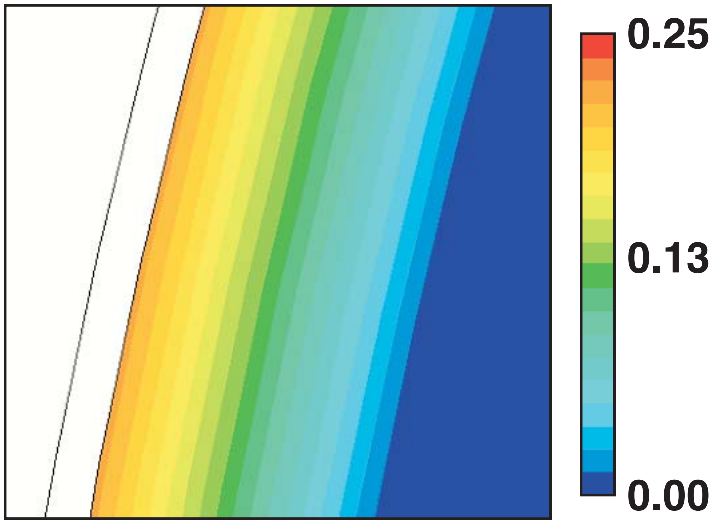
T = 17.0 K



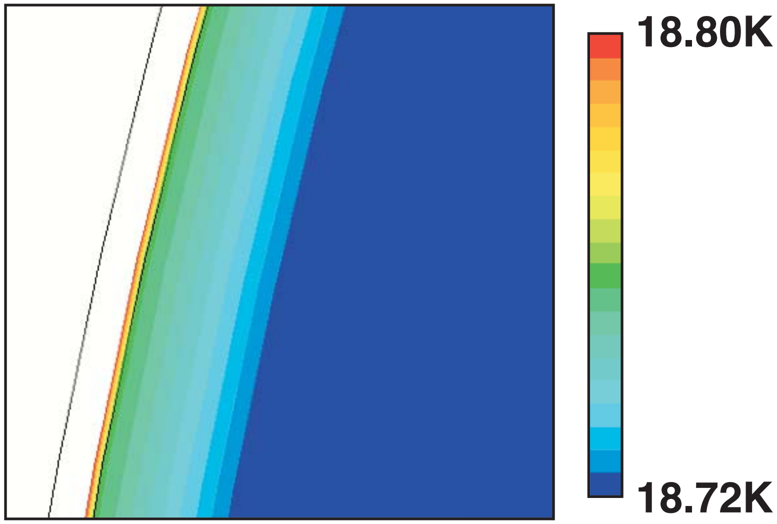
T1912

Effect of ambient radiation on OMEGA targets

- Target exposure to room temperature depends upon the shroud retraction time (0.05 s to 0.25 s).
  - Gas heats at 5 K/s.
- The measured time for the target to burst equals 45 s.
  - $P_{burst} \sim 12$ atm → $T_{target} \sim 38$K
- How rapidly does the melt zone propagate?



Fraction melted after 1 s



Temperature after 1 s

New task—IFE-relevant work: estimate the thermal load on a target injected into an IFE chamber

Issues:

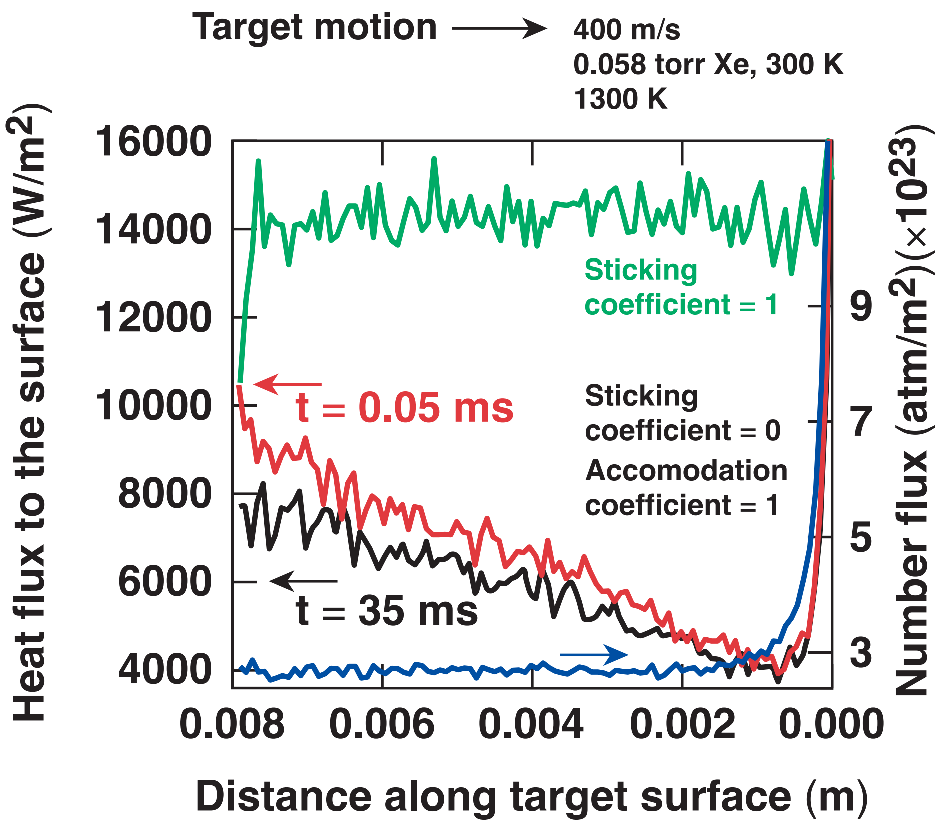
1. What is the heat load to the target?
    - First step: Monte Carlo calculation of the gas dynamics
        - determine atom flux and temperature ranges
        - effect of sticking probability and accommodation coefficient
        - attempt to measure these values
2. How does the ice layer respond to this heat load?
    - CFD model
    - planar cryo target experiment

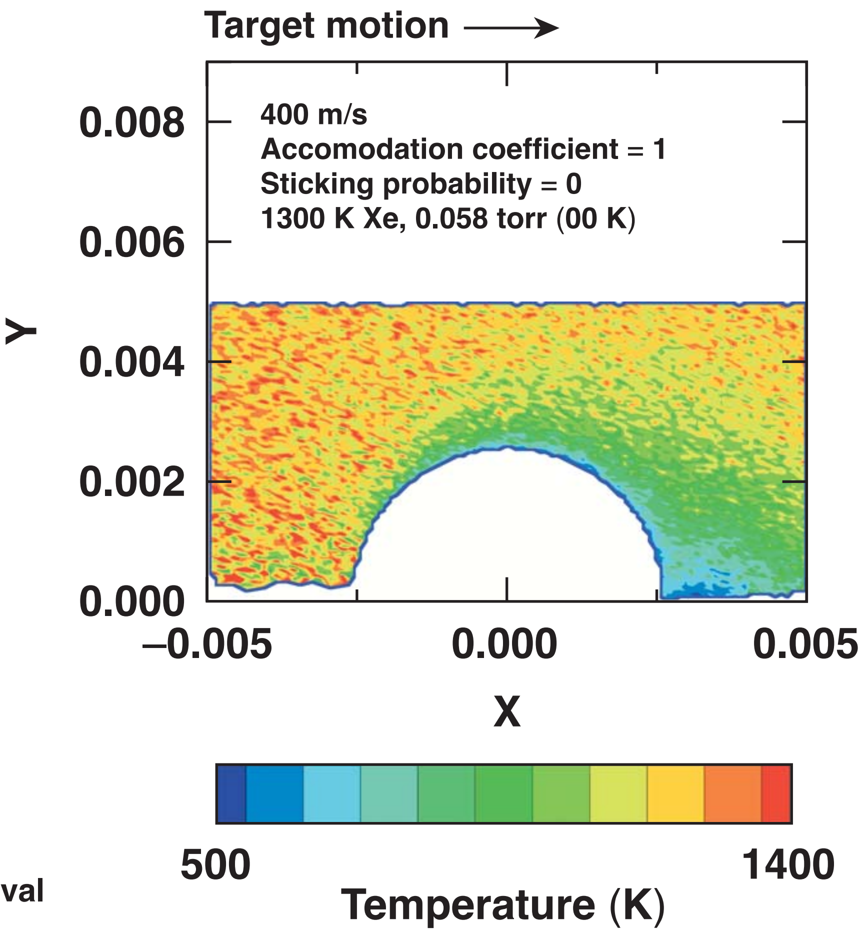
An IFE-scale capsule can be fielded in the LLE target chamber to measure the time to melt/slump.

IFE has assumed the highest (most conservative) gas-to-target heat load. A lower value may simplify target fabrication

- Assumption: Xe at 1300 K is fully absorbed onto the 18-K surface.
  - Brown *et al*., 100% adsorption for N_2, CO_2, and Ar when $T_{surface} < 25$ K and $T_{gas} < 1400$ K
  - Baglin *et al*., ~1% adsorption for H_2, CH_4, CO, and CO_2 when $T_{surface} < 15$ K
- Lower adsorption → lower heat load, AND, what if the accommodation coefficient is also <1, an even lower heat load?
- An insulating outer foam layer would protect the target, but this may not be needed. We need experimental data.

Monte Carlo calculations are used to quantify the effect of gas adsorption and the high thermal accommodation of Xe on the target surface





Heat load only includes the energy from the gas impact

H^{Xe}_{fusion} = 50 × 10^6 W/m^2 if S = 1; data averaged over 25-μs interval

T1916

Experimental design requires parameter limits that are obtained from calculations

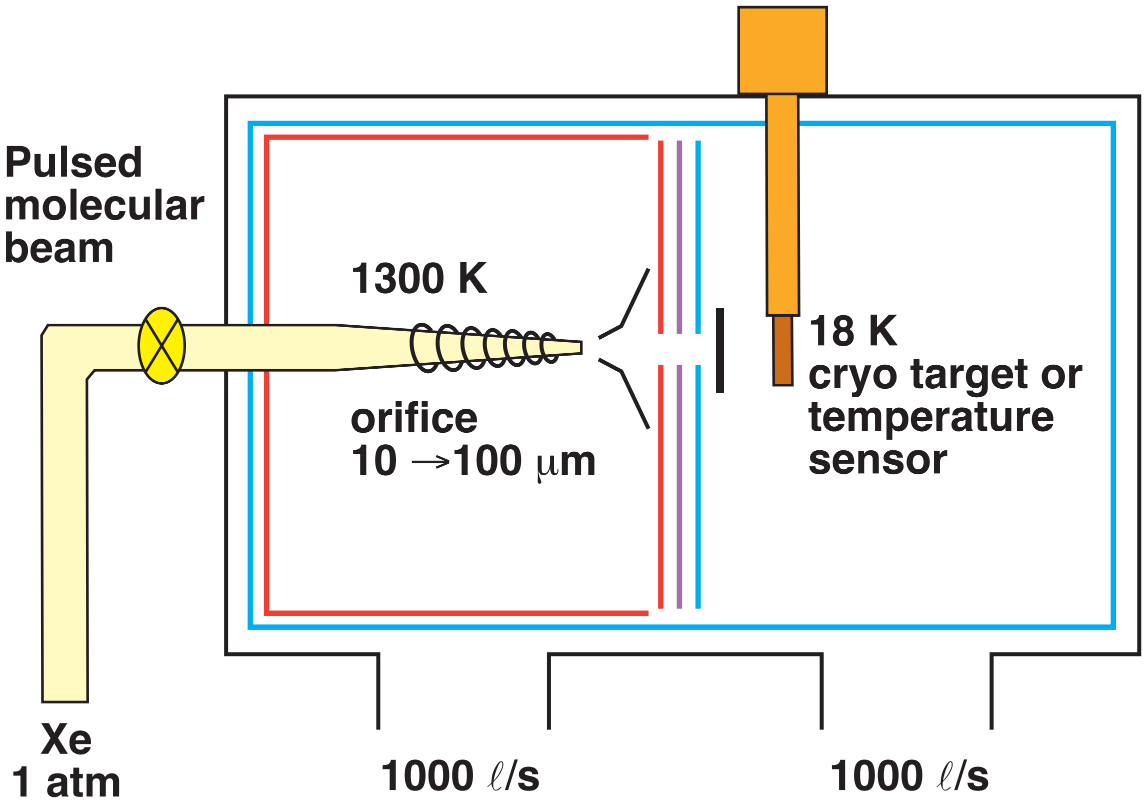
Goal:

1. Generate a molecular beam of hot Xe atoms
2. How does a cryogenic target respond to the flux?

Status:

1. Scale the problem correctly—currently
2. Engineering design

Equipment concept and expected performance



Pulsed molecular beam

1300 K

orifice
10 → 100 μm

18 K
cryo target or temperature sensor

Xe
1 atm

1000 ℓ/s

1000 ℓ/s

100-μm diam spot

Flux

10^{23} to 10^{25} $\dfrac{\text{atm}}{\text{m}^2 \cdot \text{s}}$
(1/1000 of IFE)

10^{17} to 10^{19} $\dfrac{\text{atm}}{\text{s}}$

T gas ~ 900 K

Currently: (a) Monte Carlo calculation to confirm molecular beam estimates (downstream of nozzle).
(b) heat load calculation

T1919

Summary

1. High-quality ice layers have been demonstrated
2. Potential cause of roughness variation in a target identified—engineering solution planned
3. Ice becomes rougher only $>$ 1 K below the triple point—primarily low modes (1, 2, and 3), may be mitigated by a slow cooling rate (0.5 mK/min)—need more statistics
4. Designing a molecular beam nozzle to measure IFE-scaled gas-heating loads on cryogenic targets