Target Injection Studies

David Harding, Mariana Bobeica,
and Roger Gram
University of Rochester
Laboratory for Laser Energetics

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Overview

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- Present an experimental design for generating high-velocity, hot Xe atoms and measuring the effect of these atoms on D_2 ice.
- Discuss the design required to achieve Xe gas velocities of 100 to 400 m/s and temperatures up to 3000°C.
- Discuss a technique to measure and spatially resolve the relative composition of solid, liquid, and gas phases *inside* a surrogate target—central to quantifying the effect of the impinging hot gas.
- Demonstrate improved optical transmission through a foam/ice and foam/liquid target with large pore (0.25 μm) dimensions and using IR illumination.

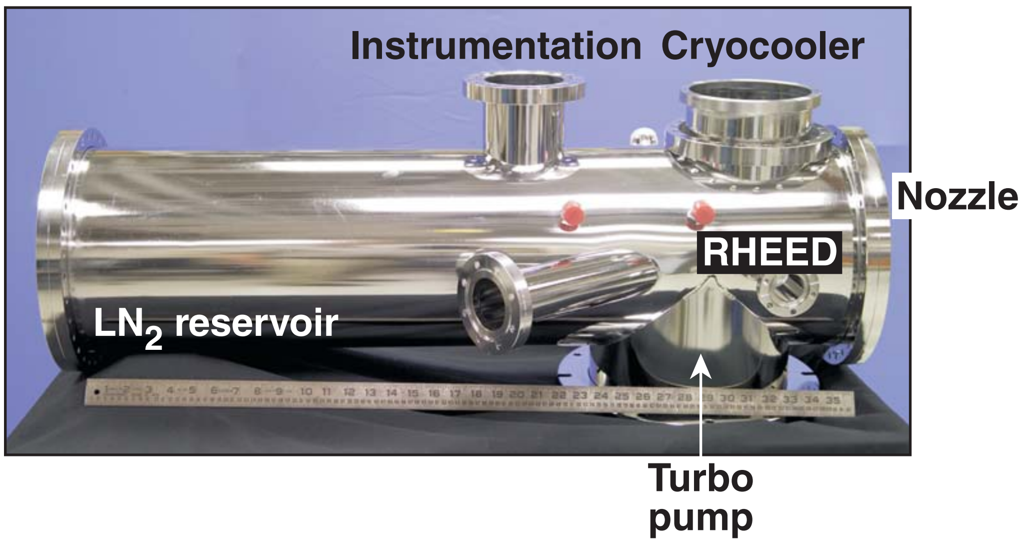
Experimental design

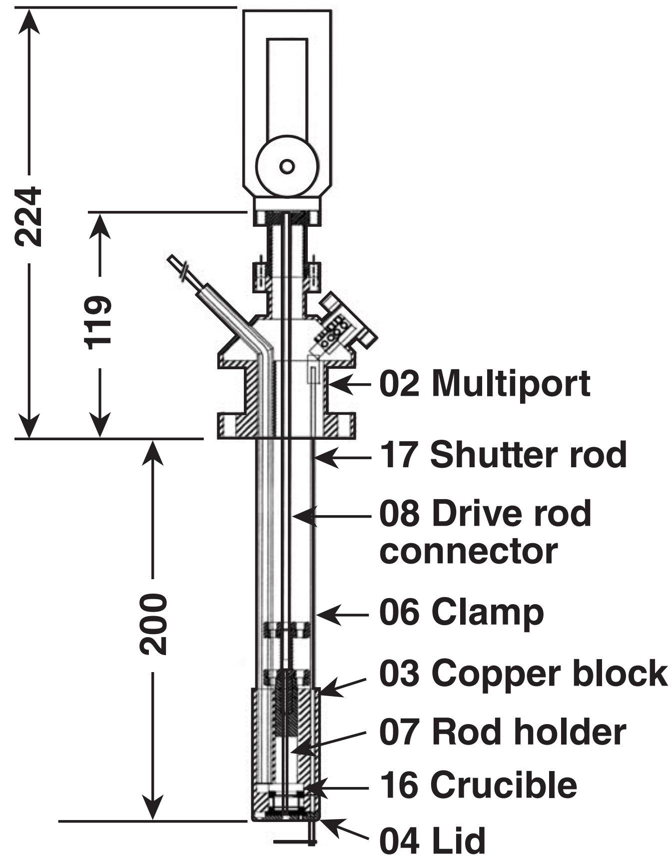
Concept:

- Vacuum chamber with:
  - high pumping speed (2400 l/min),
  - built-in LN shrouds
  - a 2-mm-diam × 1-mm-cylindrical surrogate target, and
  - a 40-W low-vibration cold head.
- Modified "atom cracker" provides high-velocity, high-temperature Xe atoms.
  - Use Monte Carlo calculations to obtain the desired gas temperature and velocity.
- Monitor the ice to measure the solid/liquid/gas ratio at discrete positions
  - Quantify heat-flux propagating through the ice/foam.
- Monitor the target's surface with RHEED to determine the rate of solid Xe accumulation.
  - To correlate Xe growth on the Al surface with mass, heat flux to the surface, and heat flow through the ice.

Experimental design (cont.)

- 1-m × 30-cm-diam vacuum vessel with integral LN tank and a 40 W (at 20 K) low-vibration cryostat





- The Xe source is a tungsten nozzle, (0.5-mm diam) e-beam heated (<4000 K) with baffles, and can be biased to produce Xe ions.

T1956

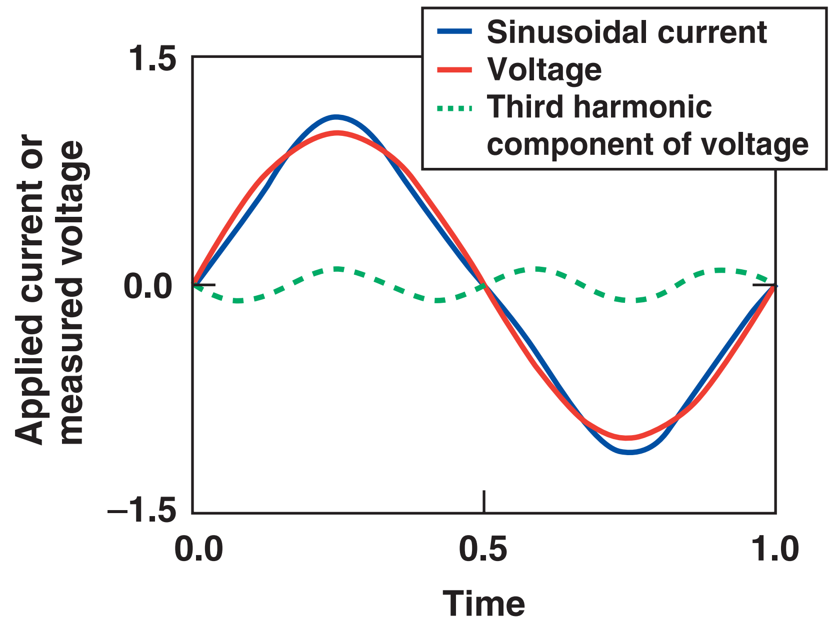
Diagnostics: heat flux and Xe condensation

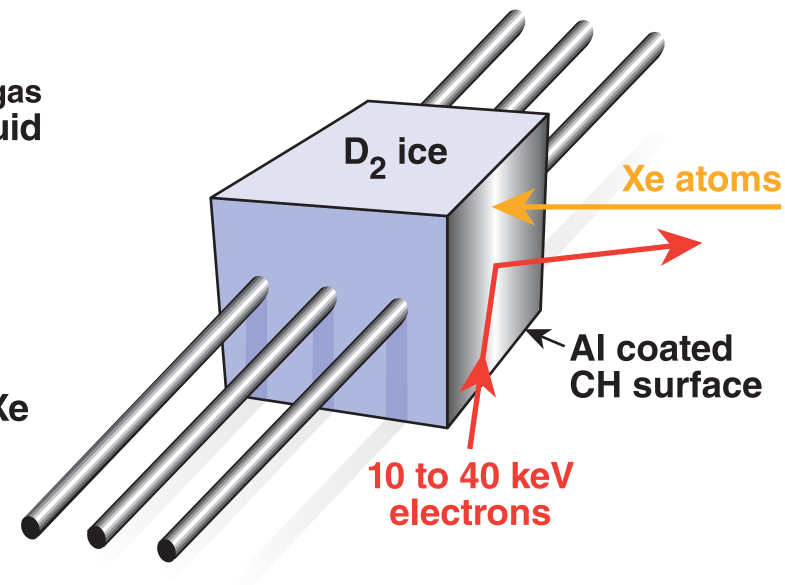
- ***Heat flux*** uses a 3ω measurement of thermal conduction to determine D_2 phase.
  - Pt-wire: 15-µm diam × 1.3 cm
  - Drive with a pure sine wave ($V_{1\omega}$ ~ 1 mV; 0.85 to 85 Hz; 15 mA_{rms})
  - Produces a ΔT that depends on the thermal diffusivity of the fluid contacting the wire.
  - Also, ΔT produces a resistance fluctuation

    $$\{(dR/dT)[1-\cos(2\omega t)]/2\Delta T\}$$

    that creates a 3ω frequency, that is measured with phase-sensitive detection where

    $$\Delta T = (v_{3\omega}/v_{1\omega})\,4R\,(dT/dR).$$
  - The large difference between the k_{liq}, k_{solid}, k_{gas} should allow the rate of conversion of ice to liquid and gas be resolved.
  - The H_{fusion}, $H_{sublimation}$ and the rate of phase change yields the heat flux.
- ***Sticking coefficient*** uses RHEED (reflected high-energy electron diffraction) to measure the rate of Xe film growth on the target's metal overcoat.





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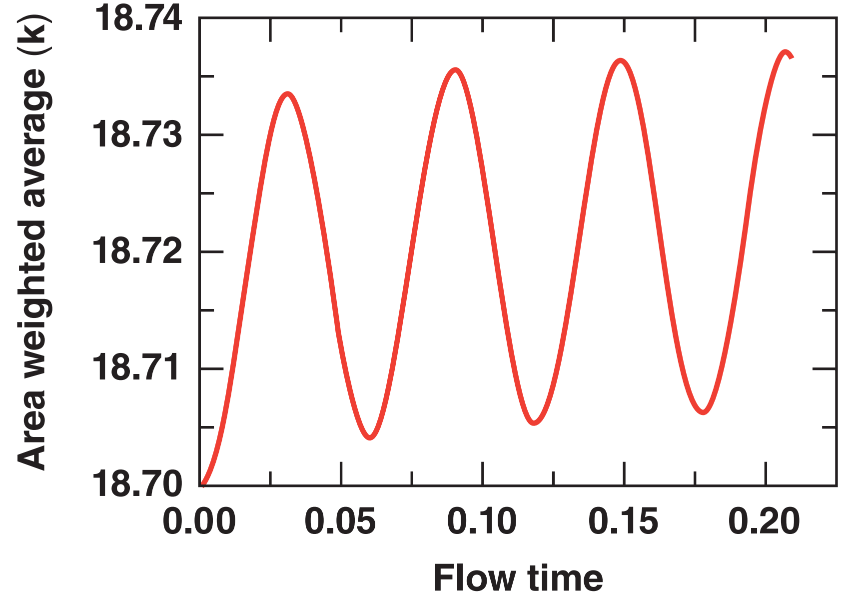
The change in resistance of the Pt wire depends on the gas/liquid/solid ratio; the sensitivity of this technique is being addressed

- For the same initial conditions (74 mW, 8.5 Hz) ΔT in the Pt wire was 50, 29, and 350 mK for the solid, liquid, and gas, respectively.

- This equates to the following thermal conductivities:
  - Liquid: k = 220 mW/m-K
  - Solid: k = 150 mW/m-K
  - Gas: k = 23 mW/m-K

Calculated ΔT for $V_{1\omega}$ = 1.2 V, 8.5 Hz, k_{liquid} = 220W/m-K ($V_{3\omega}$ = 0.00015 mV)



- Issues: k ice is low, possibly due to thin-film boiling and the contact area between the wire and ice—need to minimize the time required for 3ω measurement.

Expanding the hot, stagnant gas through a nozzle converts a high gas temperature into a high stream velocity

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- Goal: Determine the gas density, temperature, and nozzle dimensions that yield
  - the desired heat flux to the target
  - (1) above with the desired 100- to 400-m/s stream velocity and 2000+°C temperature.

Approach: use Monte Carlo simulations and confirm with analytical calculations.

IFE-relevant heat flux: 10,000–50,000 W/m^2

For comparison: $Q_{rad}^{OMEGA} \sim 200\ W/m^2$

A simple nozzle will give acceptable gas velocities and temperatures at the target when spaced 1.5 mm away, or higher velocities and lower temperatures at 1-cm separation

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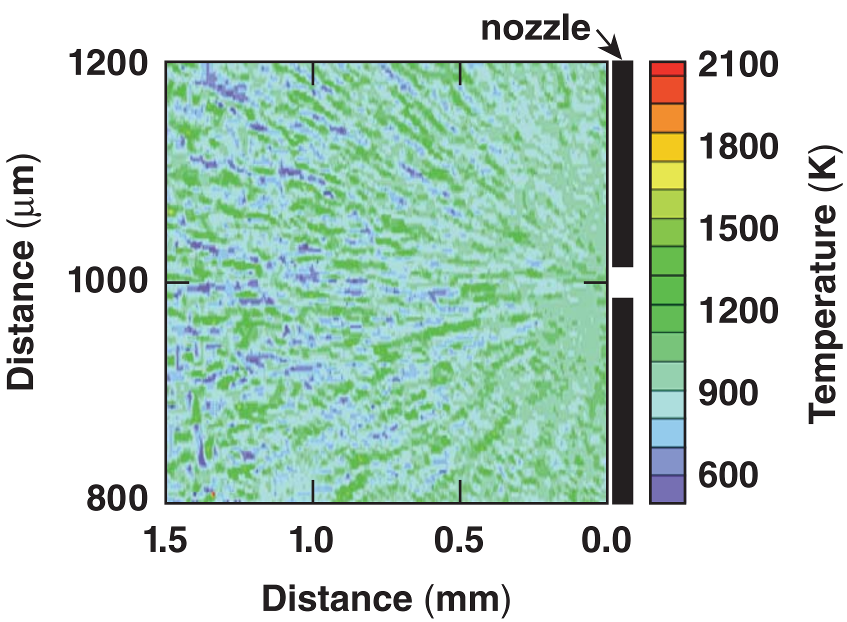
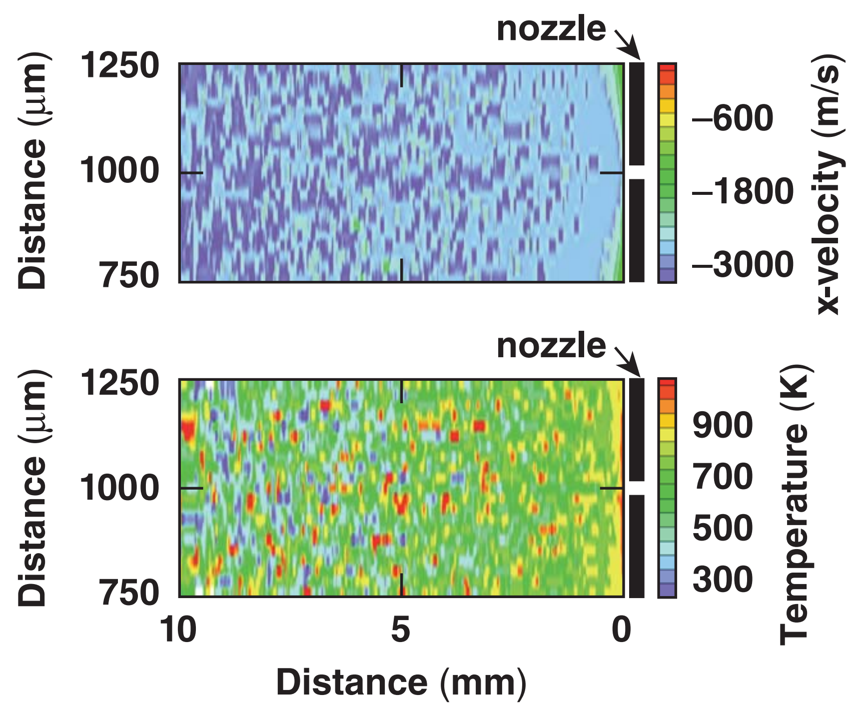
For a 20-µm diam × 500-µm length nozzle at 2000K

Gas temperature 1.5 mm from the nozzle drops by 1000°C



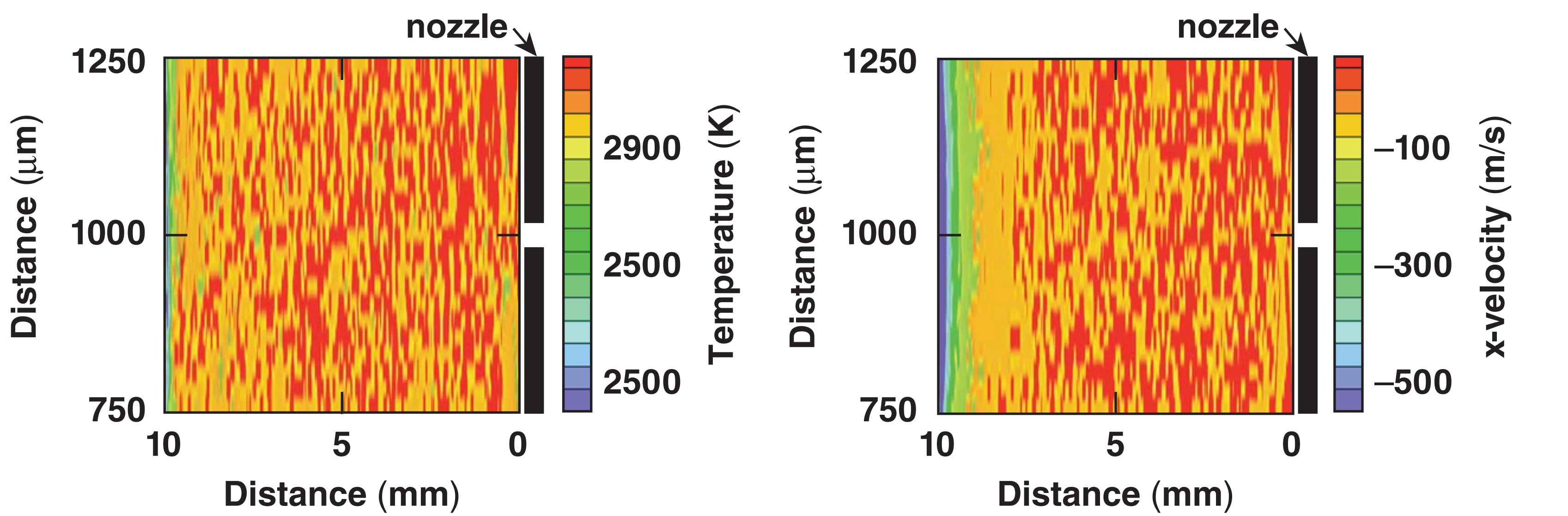
Gas properties 1 cm from the nozzle: ~600 K and 2200 m/s



T1960

A complex nozzle will achieve the desired velocity and temperature Xe atoms at the target's surface

- **Requires expanding a supersonic Xe jet into stagnant gas at the desired temperature**



The Xe atom flux to the surface is representative of the IFE chamber environment, so the effect of the appropriate sticking and accomodation coefficients will be included.

Parametric comparison of the nozzle's dimensions, the gas pressure and temperature, and the resulting heat and mass flux at the target

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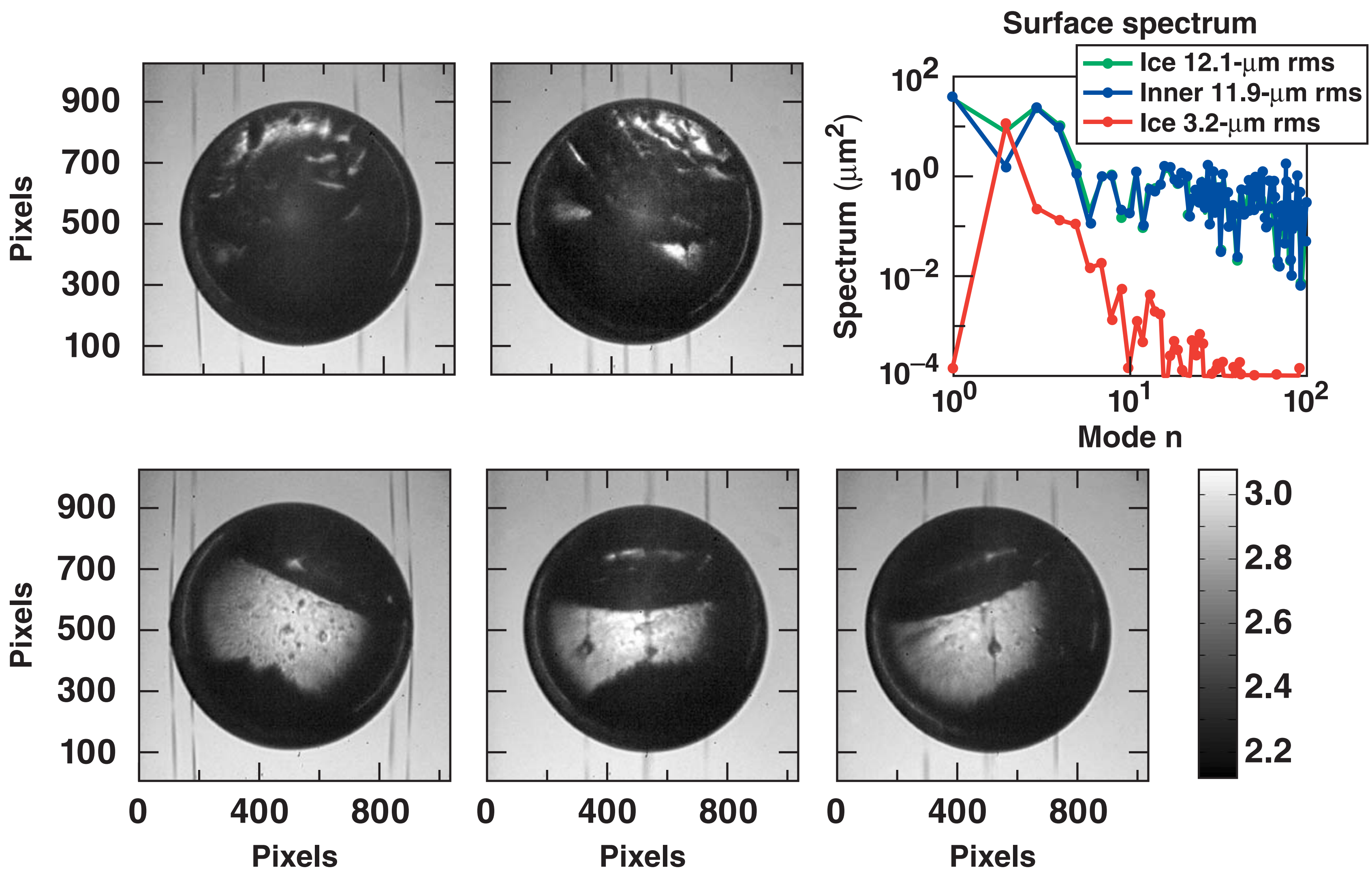
Nozzle dimension (length/diam)	Nozzle pressure @ 300 K	Atom flux (atom/m^2)	Maximum heat flux (W/m^2)	⟨v⟩ m/s	⟨T⟩ K
25	0.06 torr	4×10^{21} @ 4 mm	350±50 @ 4 mm	1800±300 @ 4 mm	1200±40 @ 4 mm
	6 torr	5×10^{23} @ 4 mm	50,000±5000 @ 4 mm	2300±300 @ 4 mm	800±200 @ 4 mm
		2×10^{23} @ 1 cm	16,000±3000 @ 1 cm	3000 @1 cm	700 @1 cm
5	6 torr	6×10^{21} @ 1 cm	50,000±10,000 @ 1 cm	1800 @ 1 cm	900 @ 1 cm
5 Complex nozzle	0.006 torr	1×10^{21} @ 1 cm	90,000± 10,000 @ 1 cm	400±150 @1 cm	2700±200 @ 1 cm
660	0.043	1×10^{20} @ 1 mm	1×10^{23} @ 1 mm	600±200 @ 1 mm	150±50 @1 mm

A wide range of heat and mass fluxes at the target are achieveable.

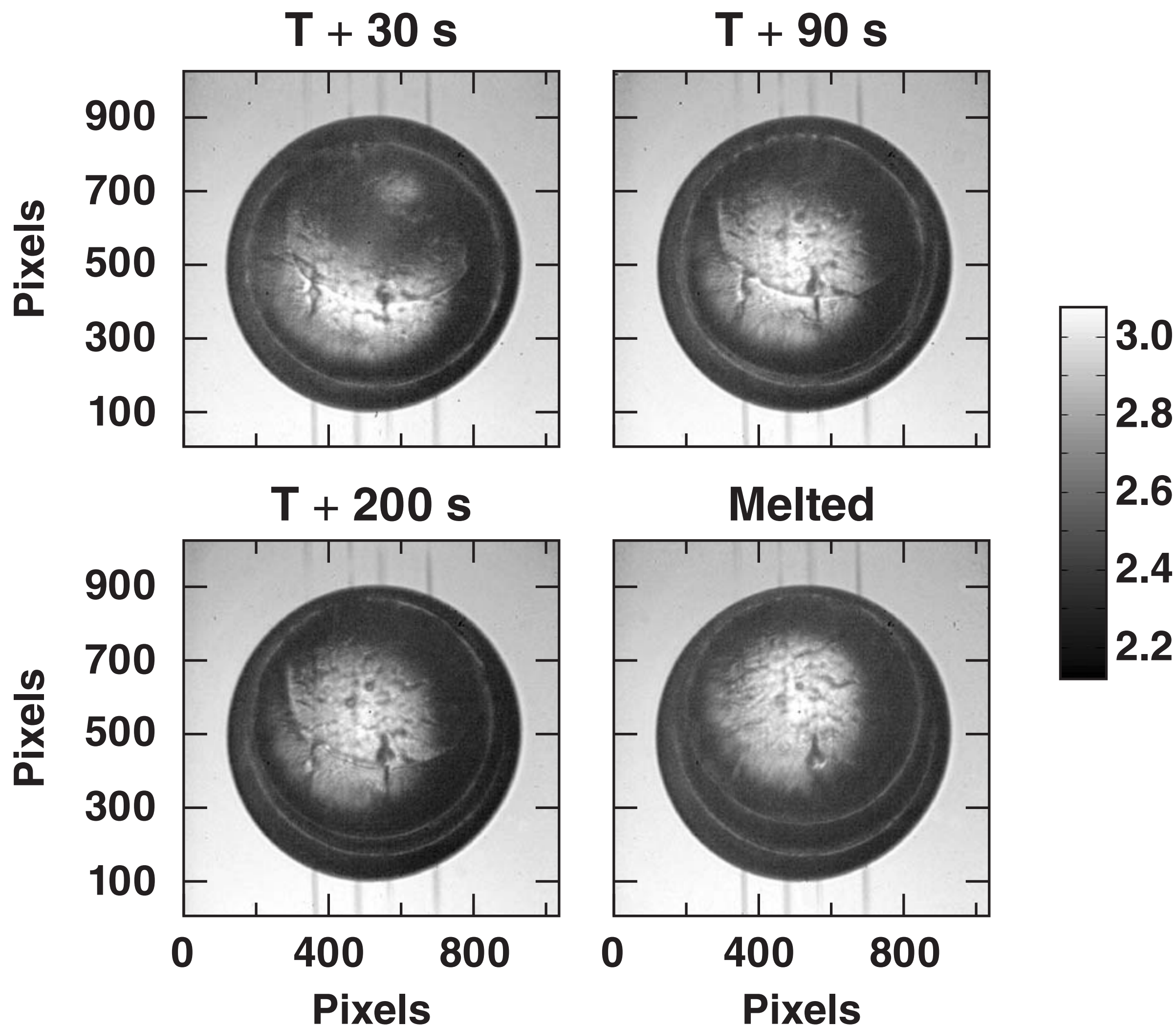
T1962

Large pore foams (0.25 μm) *and* IR illumination (950 nm) allowed the inner surface to be observed



T1963

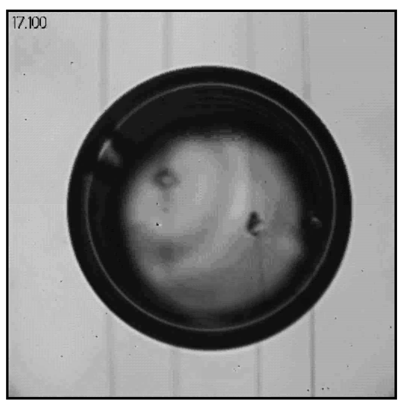
Melting the ice in a foam target revealed clearly defined brightbands



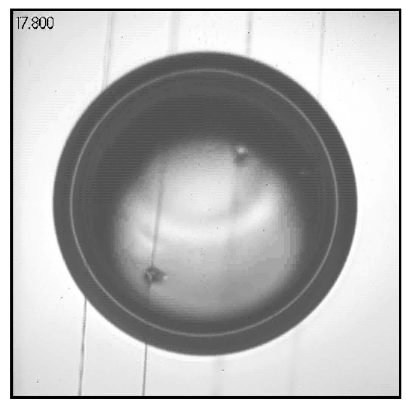
T1964

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



Initial rms = 3.6 μm
Final rms = 3.7 μm



Initial rms = 2.1 μm
Final rms = 1.7 μm

- Both targets below were cooled at a rate of 0.02 K/20 min.

T1965

Summary

- An experimental design that delivers representative heat and mass fluxes to a cryogenic target has been developed.
  - The concept allows a known Xe flux to the target to be correlated with the rate the ice melts and the rate Xe accumulates on the surface.
- The major capital equipment (except the RHEED system) has been purchased and partially received.
- During the next six months, the equipment will be assembled and the design of the gas nozzle refined.
- It is possible to observe a brightband through a larger pore (200- to 500-nm) foam using IR illumination.