Cryogenic Thermal Control Coatings An Overview

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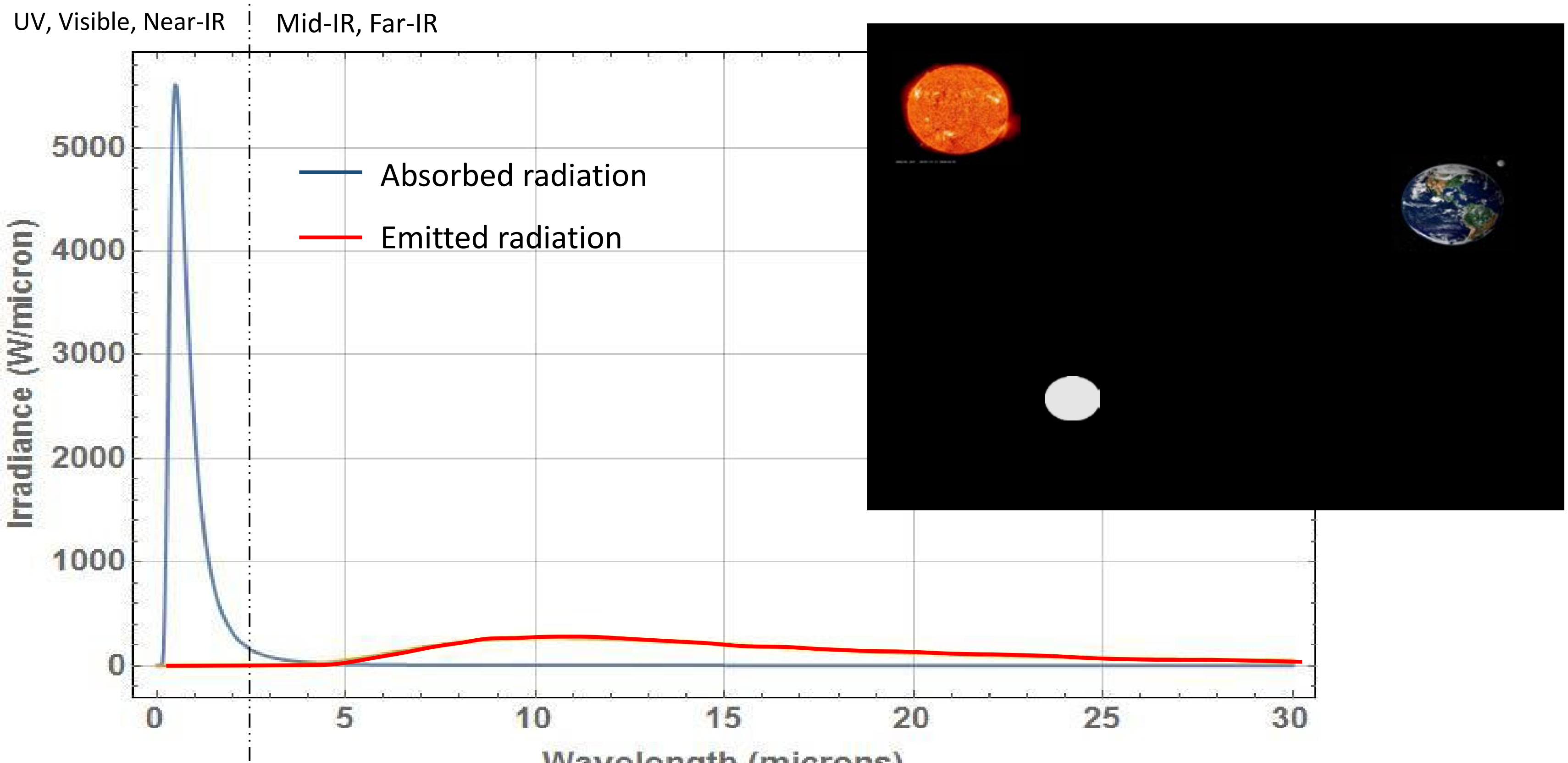
Presentation Outline

- Concepts and Goals
- Partners/Funding Sources
- Game Changing Development work
- Other work
- Publication/Patents

A Body in Space

A black body (perfect emitter and absorber) in space absorbs UV, Visible, and Near-IR radiation and emits long-wavelength radiation resulting in an equilibrium temperature (1 AU from the sun) of 280 K



If we can create a coating that reflects, instead of absorbs, the shorter wavelengths, and still emits in the longer wavelengths, how much can the equilibrium temperature of a body in space drop?

A Body in Space

In equilibrium, an object radiates (R) the same power it absorbs (B), so R=B where;

Stefan-Boltzmann Law: $R = \sigma e A T T^4$

sigma = Stefan-Boltzmann constant
e = emissivity
A_T = total area of radiating body
T = temperature

AND
(solar heat source only): $B = pIACS$

p = percentage of available power absorbed
I = Irradiant power of the Sun
A_{CS}= cross sectional area of the absorbing body

For a sphere, the total area (radiating surface = 4 π r^2) is 4 times the cross sectional area (absorbing surface = π r^2), so a factor of 1/4 replaces A_{CS}/A_T.

Solving for T:

$$T = \sqrt[4]{\frac{pI}{4\sigma e}}$$

Substituting:
I = 1366 W/m^2 (at 1 AU – Irradiance decreases as distance from the sun increases)
sigma = 5.67×10^{-8} $W/(m^2\ K^4)$
e = 0.9 (value based on emissivity data of other similar substances and is consistent with test data)
p = 1% (goal value)

Solving yields T = 90 K

Therefore, a spherical body in space, approximately 1 AU from the Sun, coated in a material that absorbs 1% of the suns power and has emissivity of 0.9, will come to equilibrium at 90 K (LOX temp), assuming no heat sources other than the sun.

Thermal Control Coatings

- Coatings that reflect some wavelengths and emit others are referred to as thermal control coatings
- NASA Reference Publication 1121 (1984) "Solar Absorptance and Thermal Emittance of Some Common Spacecraft Thermal-Control Coatings"

Current State of the Art

AZ-93 White Paint
Absorbs 15% Solar Spectrum*

Single layer silver based TCC
Absorbs 10% Solar Spectrum*

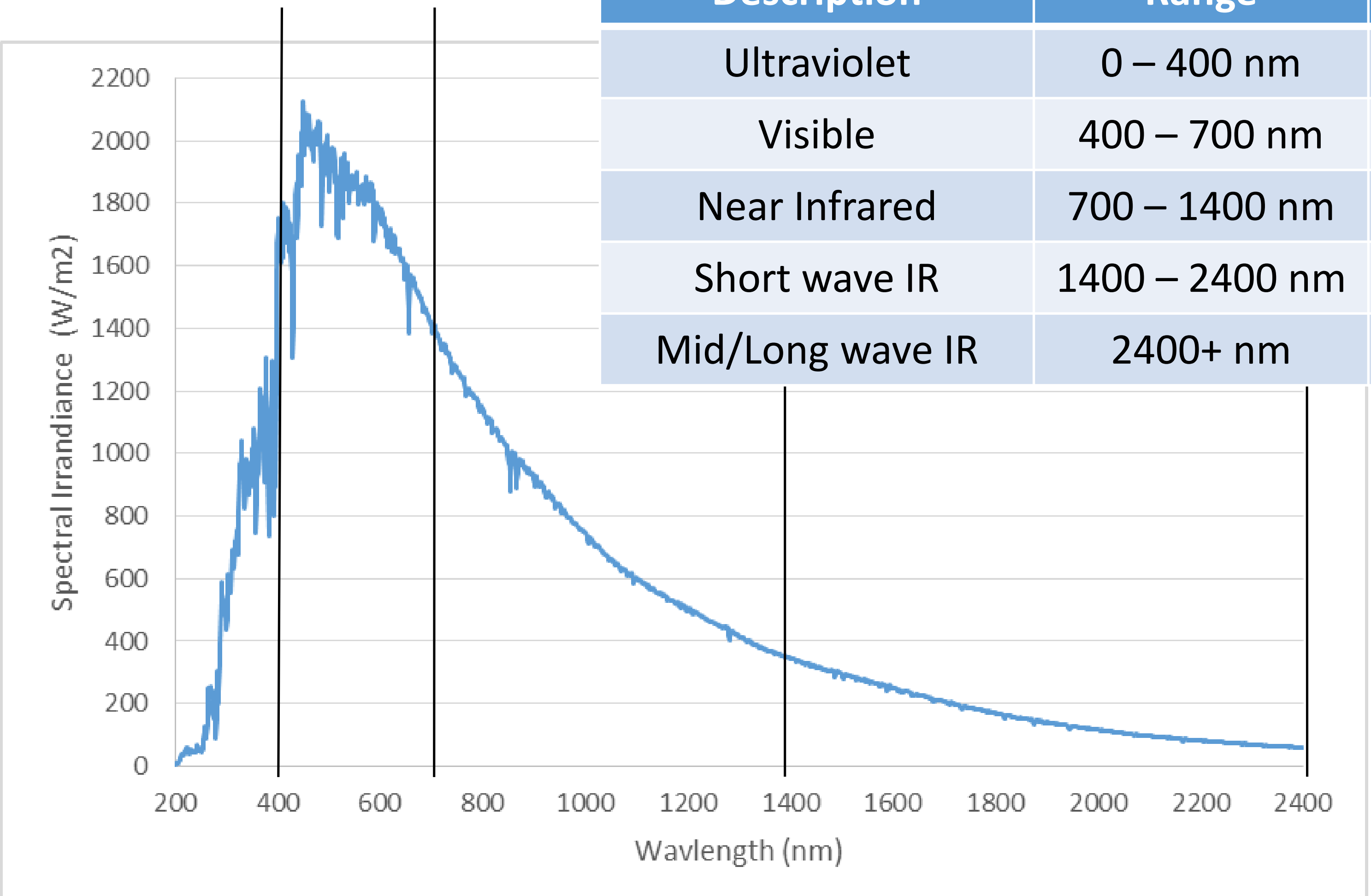
Qioptiq quartz on silver TCC
Absorbs 6% Solar Spectrum*

*Absorption numbers are based on industry standard reflectance measurements using a sprectrophotometer, with reference to NIST standard Spectralon

Solar Spectrum

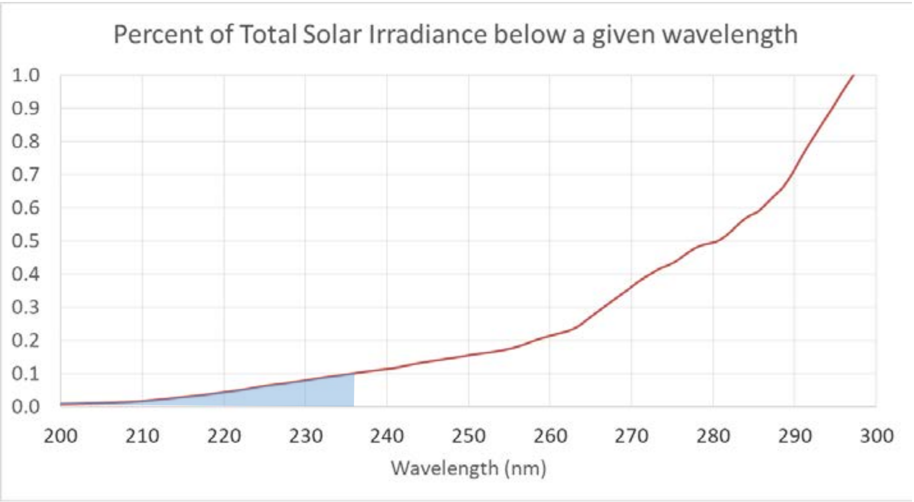
Ranges and percentages are approximate

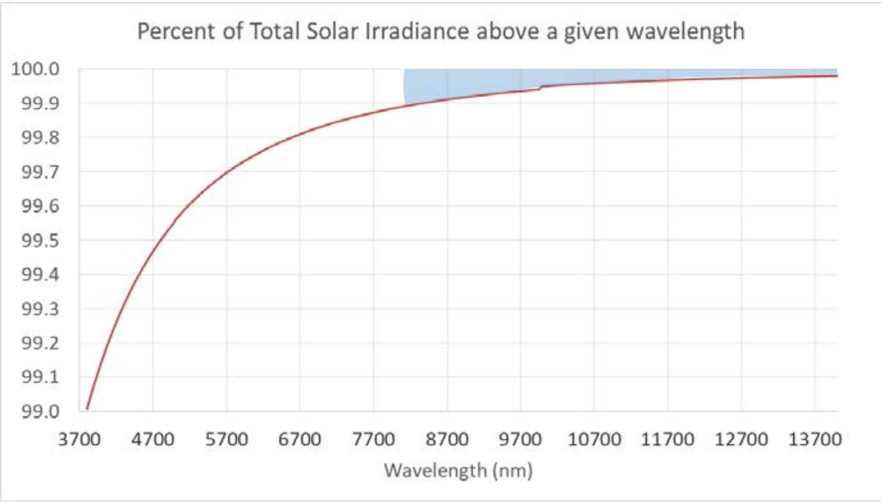
Description	Range	Solar Power
Ultraviolet	0 – 400 nm	7%
Visible	400 – 700 nm	44%
Near Infrared	700 – 1400 nm	37%
Short wave IR	1400 – 2400 nm	8%
Mid/Long wave IR	2400+ nm	4%



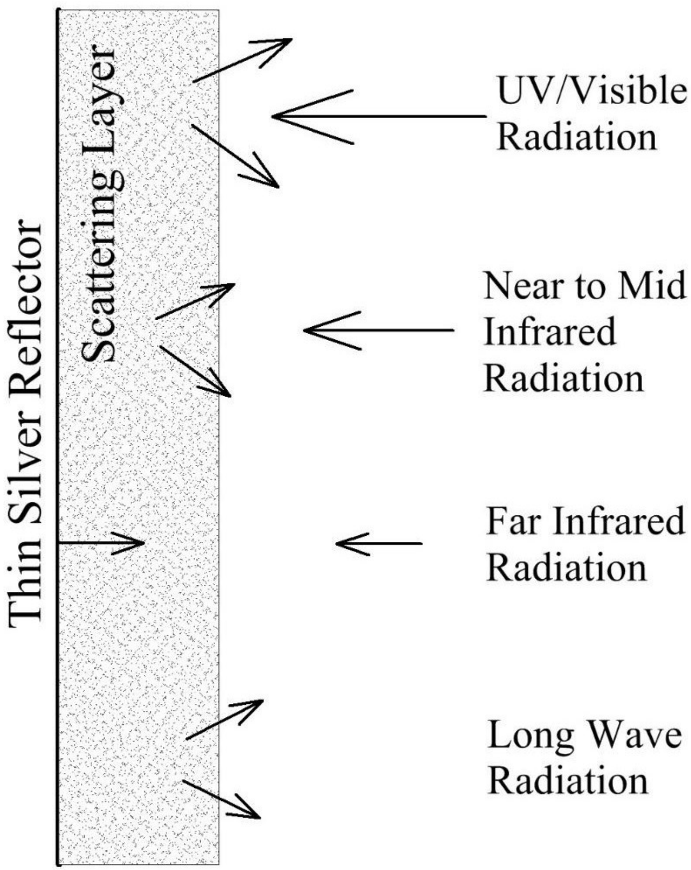
Scattering White Powder (Y_2O_3)

- Many different scattering white powders considered
- Yttrium Oxide (Y_2O_3) reflects UV above 0.235 microns through IR up to 8 microns
- This equates to 0.2% solar absorption
- If solar absorption is limited to 0.2%, the equilibrium temperature of a body in space drops to 60 K!
- Yttrium Oxide is also hydrophobic and chemically stable.





Cryogenic Thermal Control Coating



- Y2O3 scattering layer reflects UV, Visible, and Near to Mid-IR radiation
- A thin silver (or other) backing will reflect Far-IR radiation
- A metallic backing also allows for easy application
- Vapor deposition chamber 5 microns thickness

Funding Sources/Projects/Interest

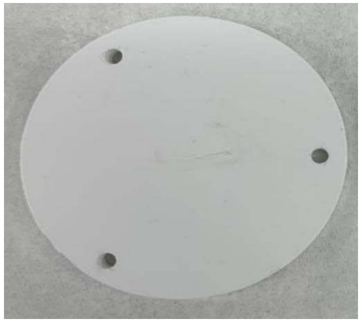
- **Game Changing Development – process development and performance testing**
- **Launch Services Program - Cube sat**
- **Materials International Space Station Experiment (MISSE) - space environment testing**
- Northrop Grumman - reflectance testing
- Blue Origin - sample testing capability
- Nuclear Thermal Propulsion – system integration
- United Launch Alliance – spray on coating development
- Launch Services Program - Superconductivity
- NASA Innovative Advanced Concepts (NIAC) – Initial concept funding and Solar Surfing

GCD Project Objectives

- **Optimization of powder sintering pressure and temperature (thermal properties & tile strength)**
- **Reflectance measurements using industry standard tools and techniques**
- **Absolute performance data using NASA designed deep-space simulator**
- Application of a metallic backing (silver preferred)
- Engagement of KSC's Thermal Protection System Facility expertise for large scale fabrication
- Atomic oxygen degradation characterization
- Electromagnetic charging characterization

Fabrication (Tile Samples)

- Compress the yttrium oxide white powder, then sinter it in an oven to make a "tile"
- Pressure used in compression and oven temperature impact tile strength and these parameters are currently being optimized



Fabrication (Spray-on Coating)

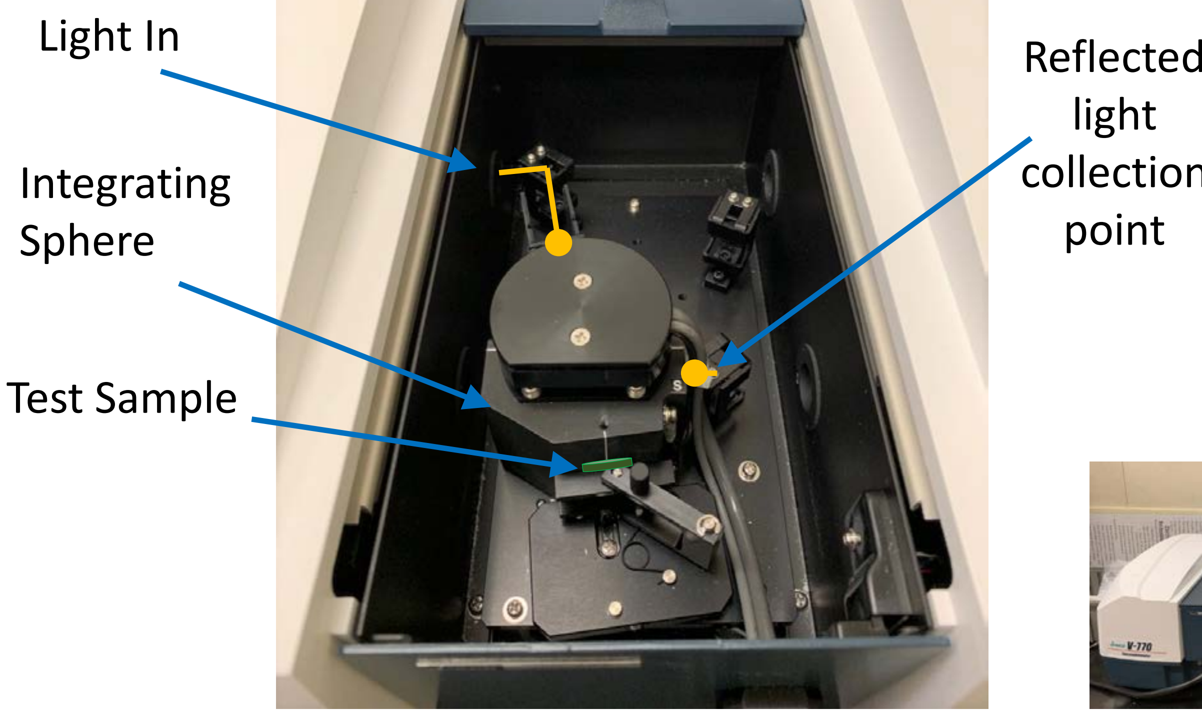
- Dissolve potassium bromide (KBr) in water
- Mix in Yttrium Oxide particles (which will not dissolve in water)
- Spray the desired surface using a paint sprayer
- After drying, the KBr forms sheets that hold the Y2O3 particles in place
- Multiple layer may be applied

This is a very similar process to making white paint, except with the use of a broadband optical material (KBr) as the binder in order to avoid UV absorption

Continuing work to enable more uniform application, increase adherence, maximize thickness, and minimize flaking

Reflectance Testing

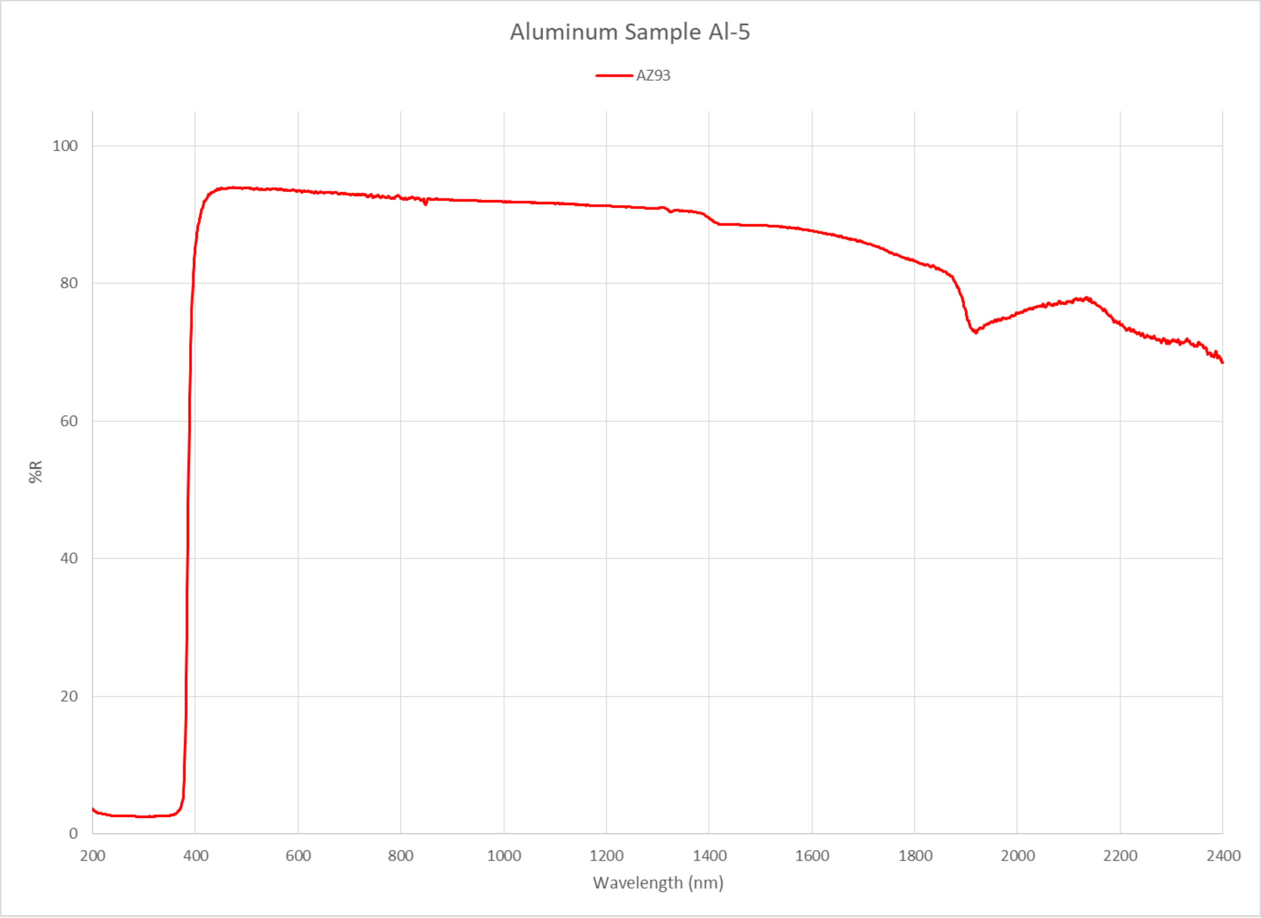
- Jasco V-770 Spectrophotometer



AZ-93 Reflectance Plot

<u>AZ-93 (white paint)</u> – Solar absorption: 15%

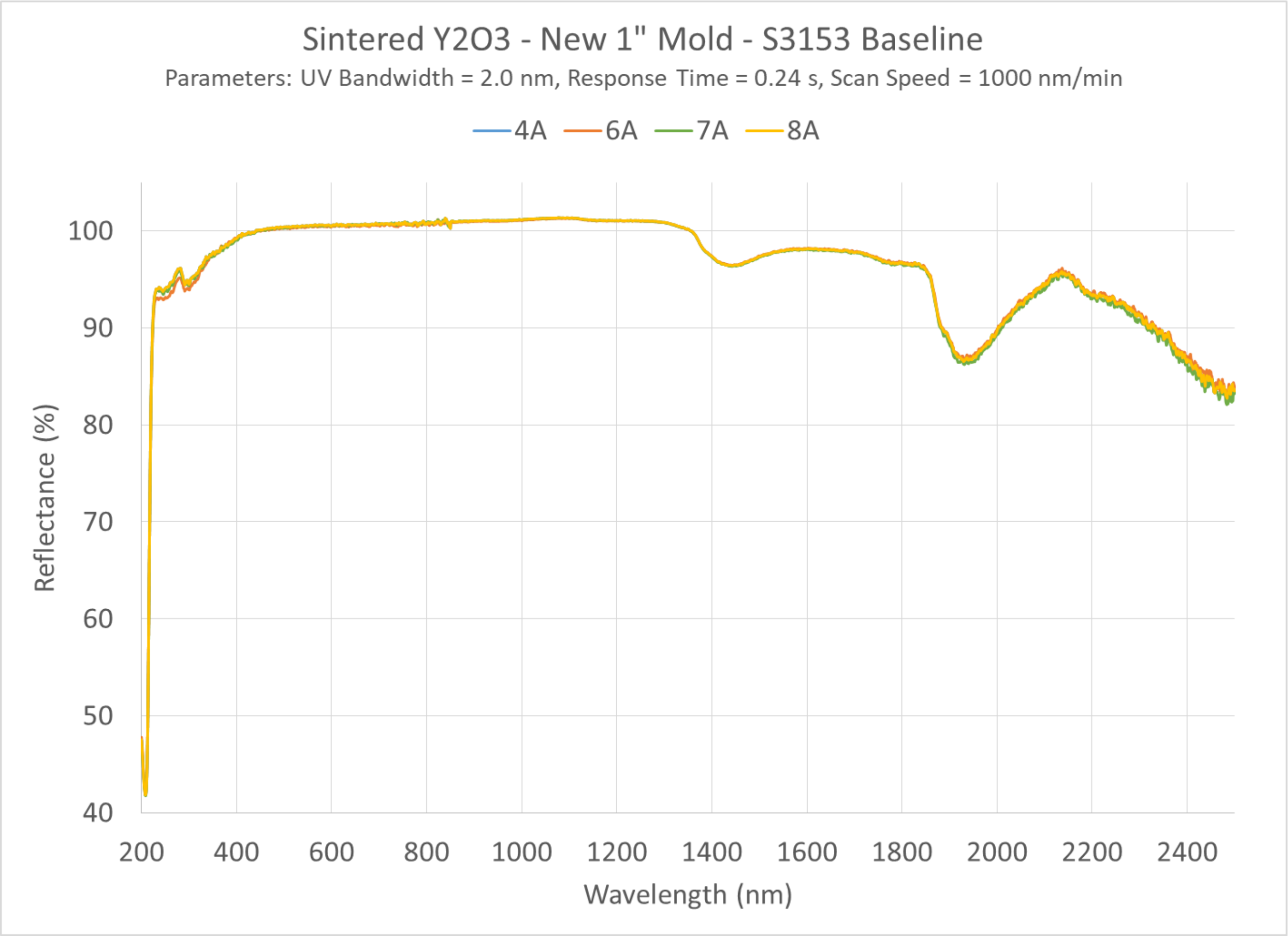
Reflectance plots like this are made measuring the material against the NIST standard reference material, Spectralon



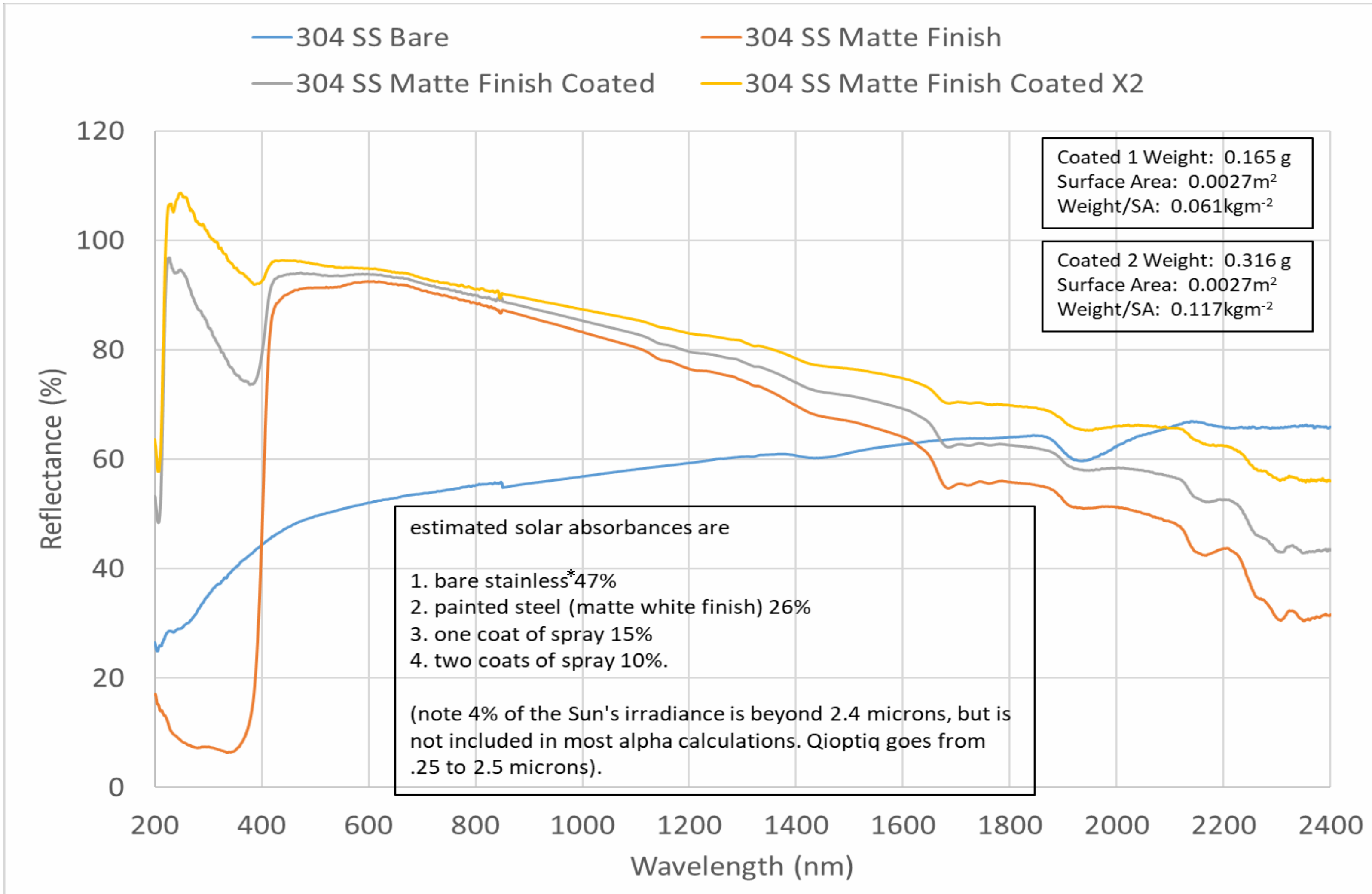
CTCC Reflectance Plot

Yttrium Oxide Tile (Y2O3) – Solar absorption: -0.004% over this range

We are not making light… the Yttrium Oxide tiles are performing better than the Spectralon reference material!



Spray-on Yttrium Oxide Reflectance Plot



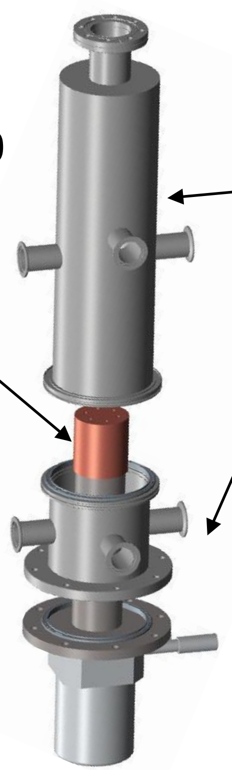
*The bare stainless surface was cleaned with solvent and lightly scuffed

Deep-Space Simulator

- Reflectance testing shows **relative** improvement over existing coatings using the industry standard testing approach
- The deep-space simulator is intended to provide an **absolute** measure of absorption
- Deep-space simulated environment testing using a vacuum chamber, cryo-cooler, and solar simulator

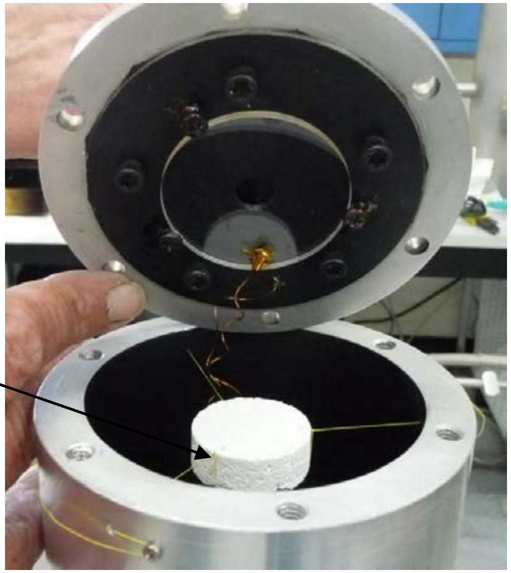
Cryomech AL230 cold head (20 K)

two-part vacuum chamber with feed-throughs



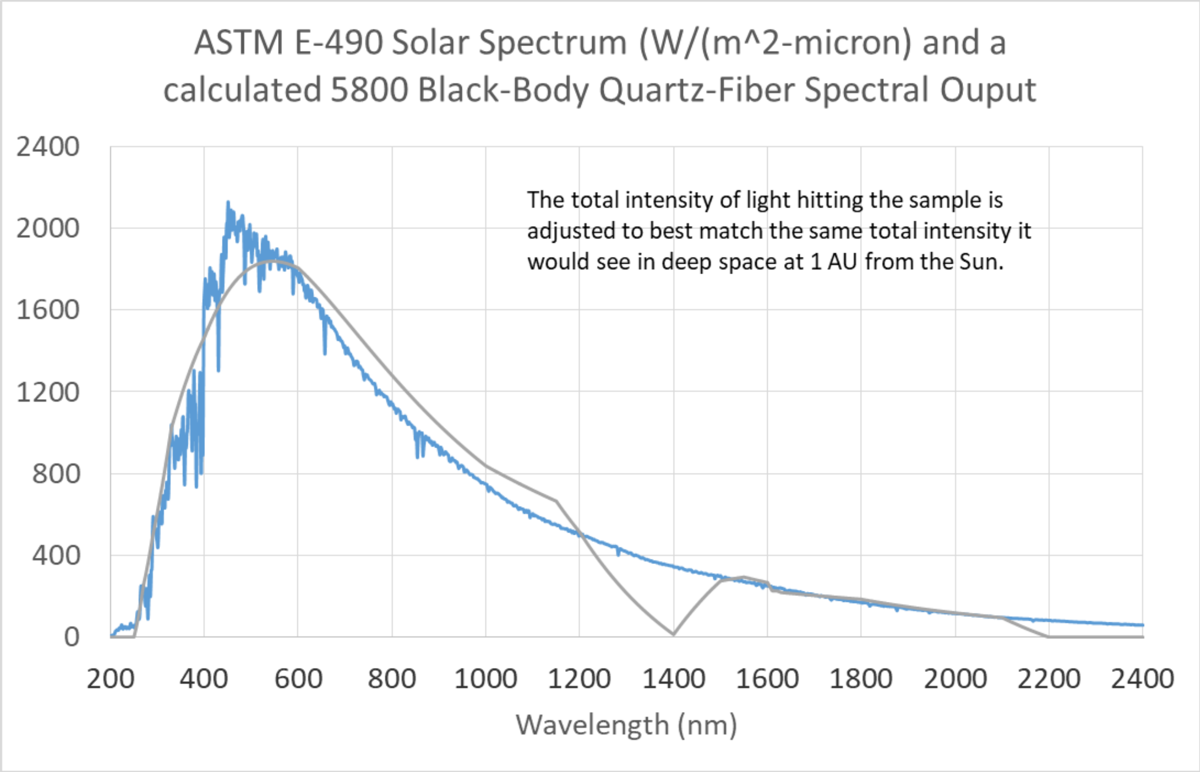
black painted test chamber, mounted to cold head

Test sample hanging from Kevlar thread



Solar Simulator

- Fiber optic quartz light source provides a good solar simulation from 255 nm to 2200 nm
- Short wave UV and long wave IR are difficult to simulate

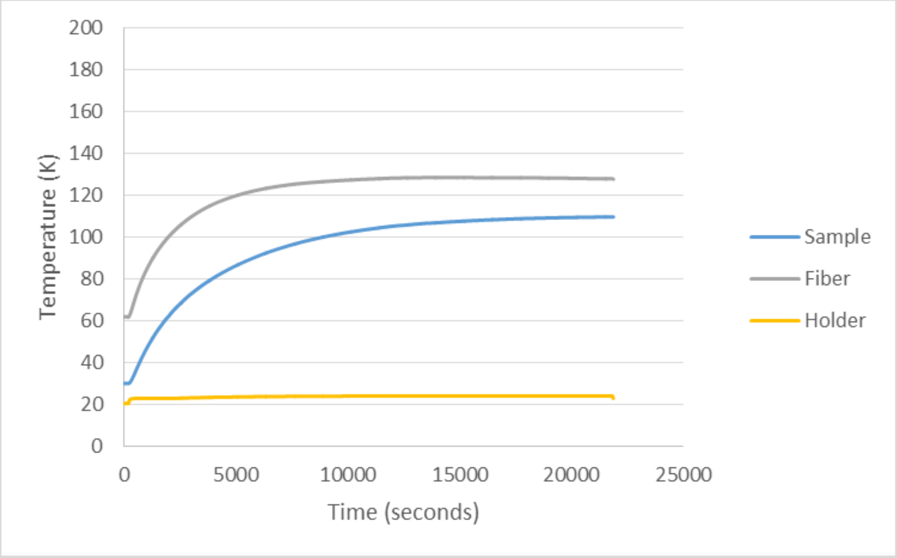


Deep-Space Simulator

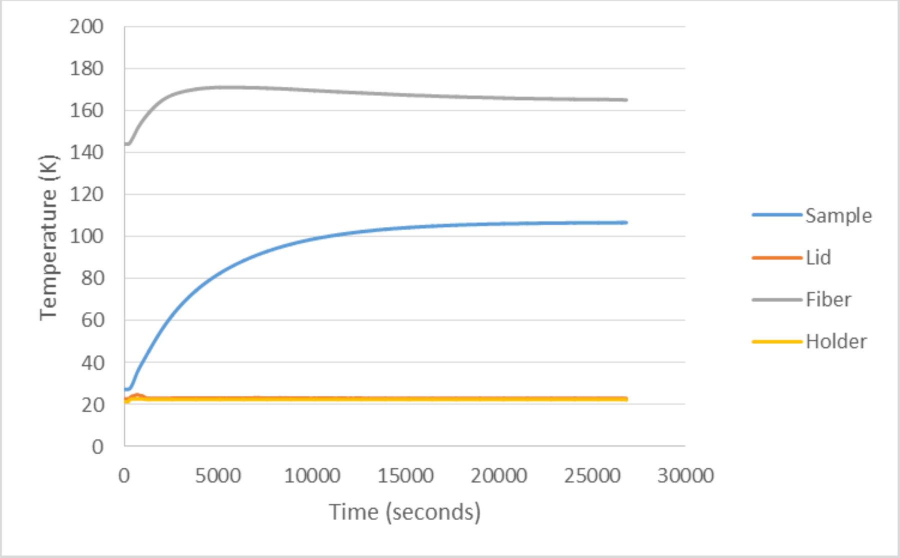
Testing (Deep-Space Simulator)

- Promising data, but refinement still needed in the test set-up
- MLI blankets have to be undone and re-wrapped for each test
- Fiber must bend to illuminate the sample, and thermally strapped to the cold head each time
- A new vacuum chamber design has recently been completed
- Multiple runs have sample temps ranging from 102 – 125 K (1.2% – 2.7% absorption)

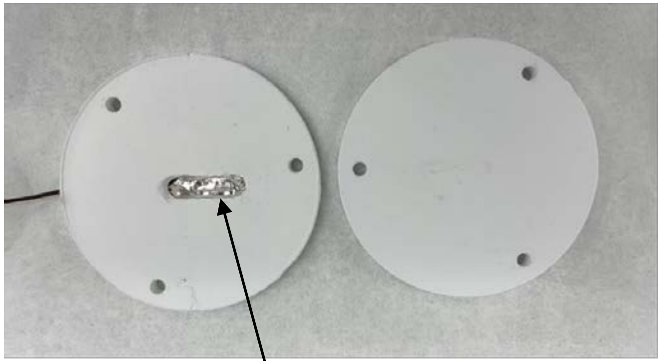
T_{max} = 110 K, corresponding to 1.6% light absorption



T_{max} = 107 K, corresponding to 1.5% light absorption



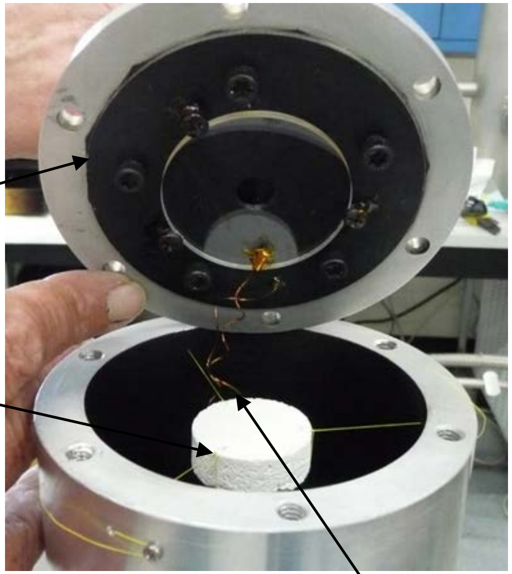
Other Heat Source Examples



Silicon Diode, barrel style, wrapped in foil

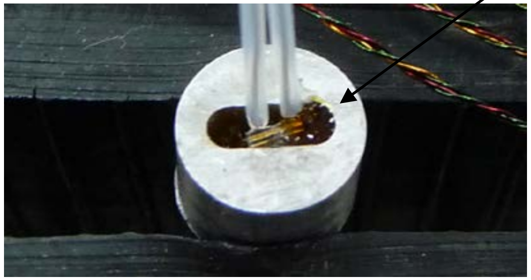
Thick layer of black coating to absorb long-wave IR

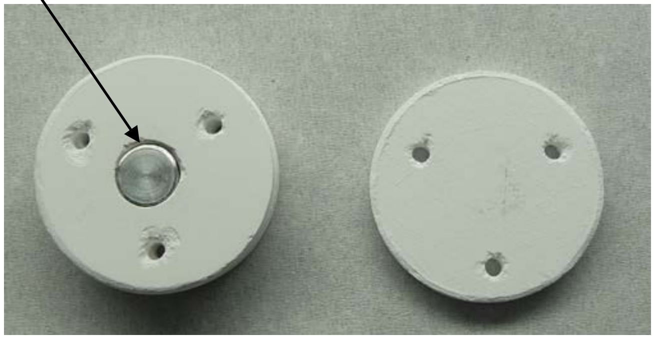
Kevlar strings



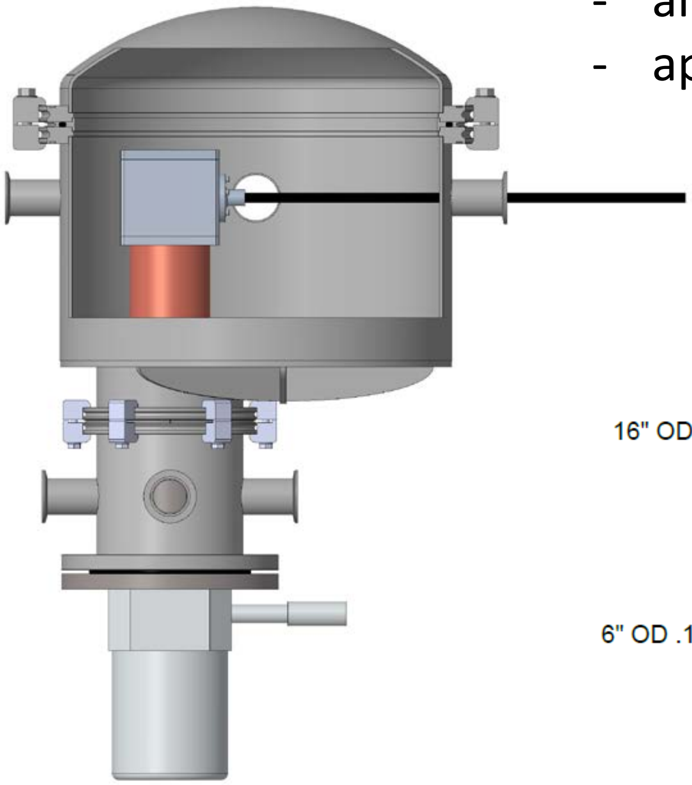
Dark temp sensor wires

Aluminum "tank" with chip style sensor varnished inside



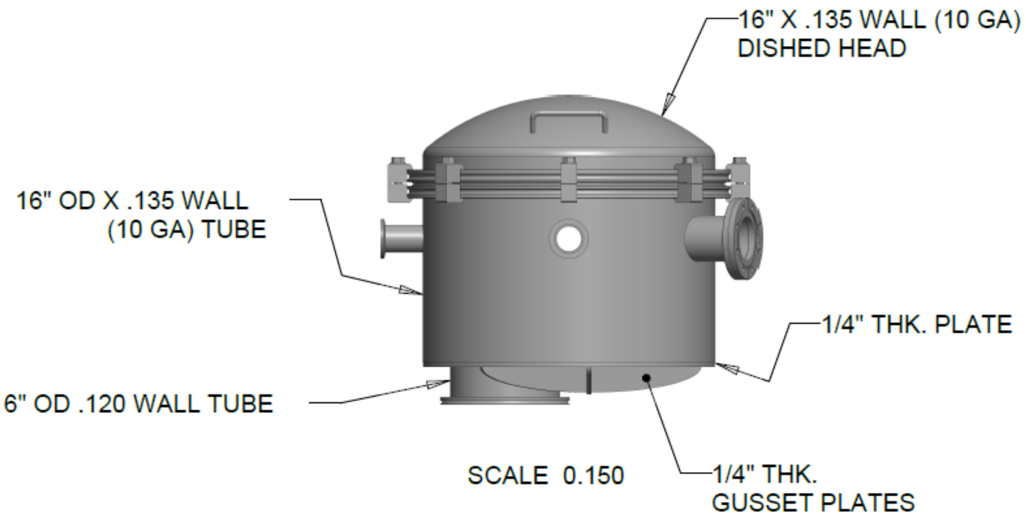


New Vacuum Chamber for KSC's Deep-Space Simulator



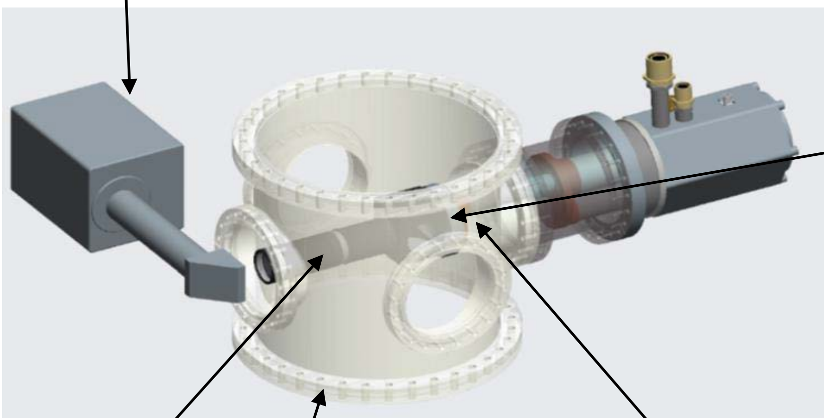
New Vacuum chamber design will:

- improve repeatability
- minimize time required between testing runs
- eliminate bends in the fiber optic cable
- allow for better chilldown of the fiber
- apply lessons learned to minimize parasitic heat leaks

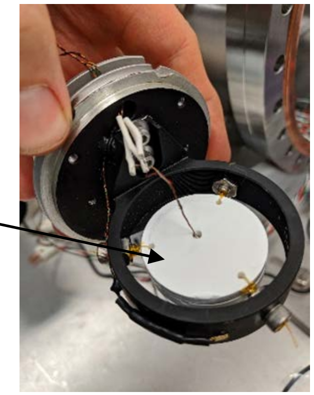


GRC's Deep-Space Simulator

Newport LCS-100 Solar Simulator



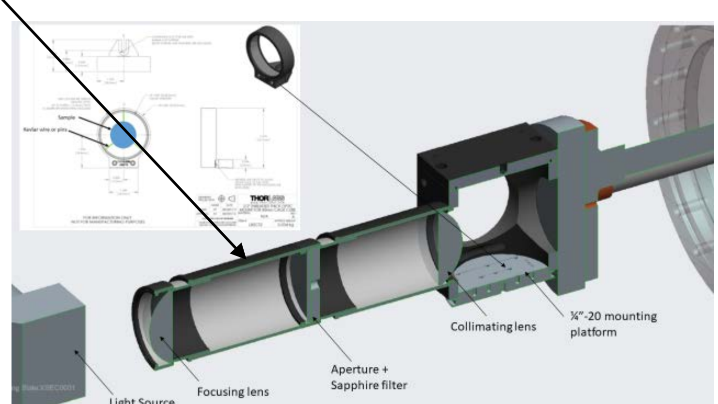
Test sample
in holder



Optical Set-up

Vacuum Chamber

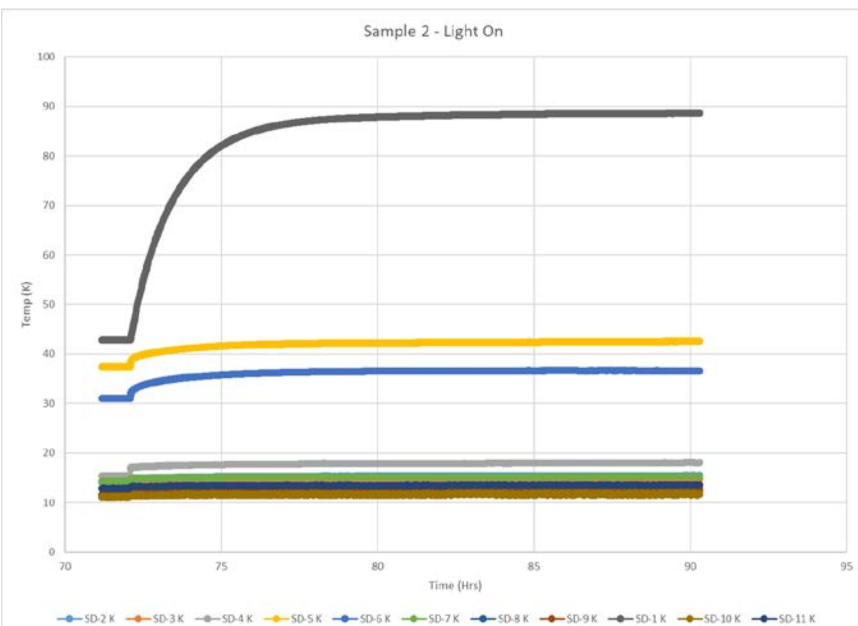
Cryomech PT805
cold head



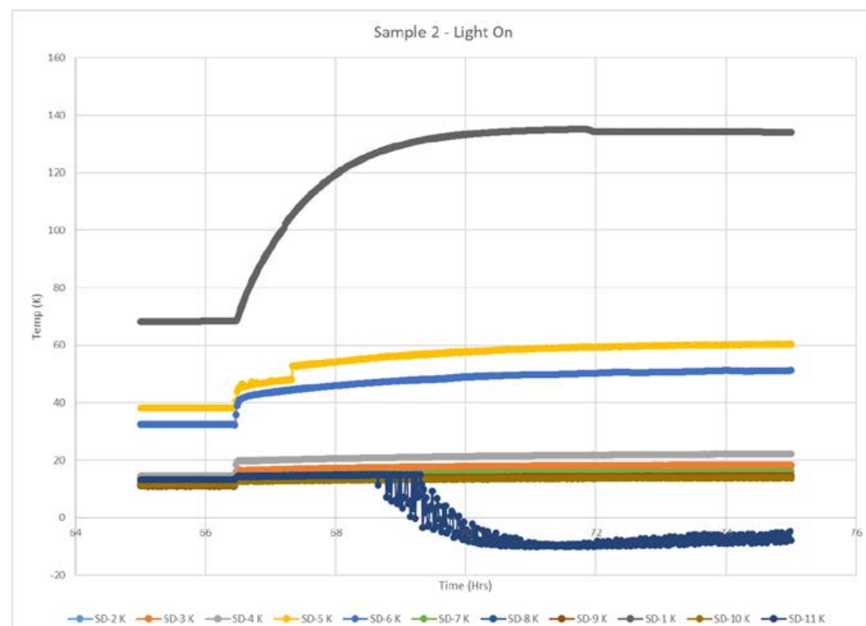
GRC's Deep-Space Simulator

- Promising data, but lacks consistency
- Changes from Run 1 to Run 2:
  - Orbital light spectrum filter decreased light intensity from 100 -180 mW/cm^2 to 85-164 mW/cm^2 (137 mW/cm^2)
  - Adjusted sample holder to increase length of Kevlar string
- Modifications to the chamber have been recently completed, testing to follow

T_{max} = 90 K, corresponding to 0.67% light absorption



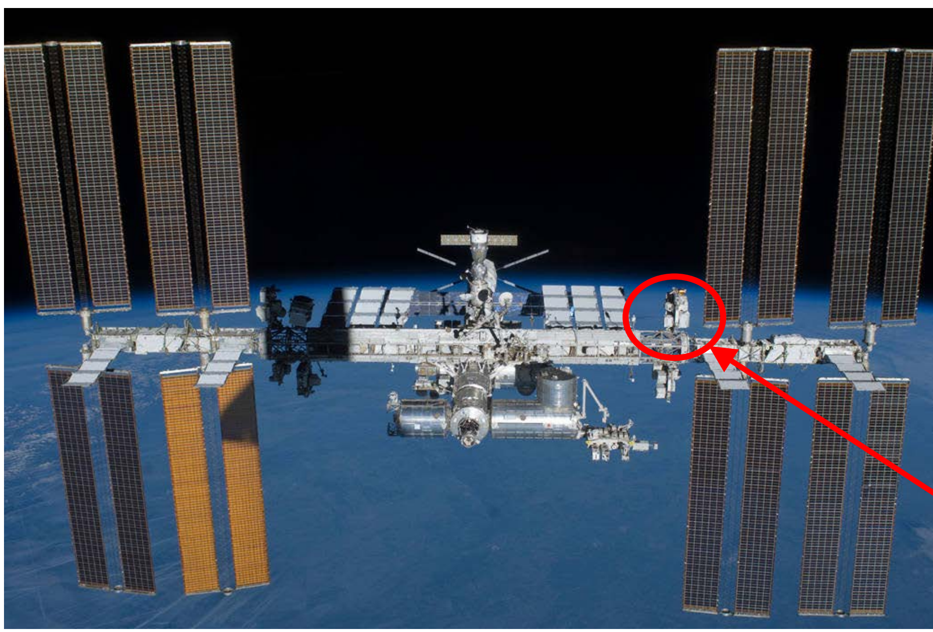
T_{max} = 135 K, corresponding to 3.8% light absorption



In-Space Environment Testing

A Y_2O_3 sample is currently flying on ISS thanks to MSFC's MISEE 11 panel (as of Feb 2019)

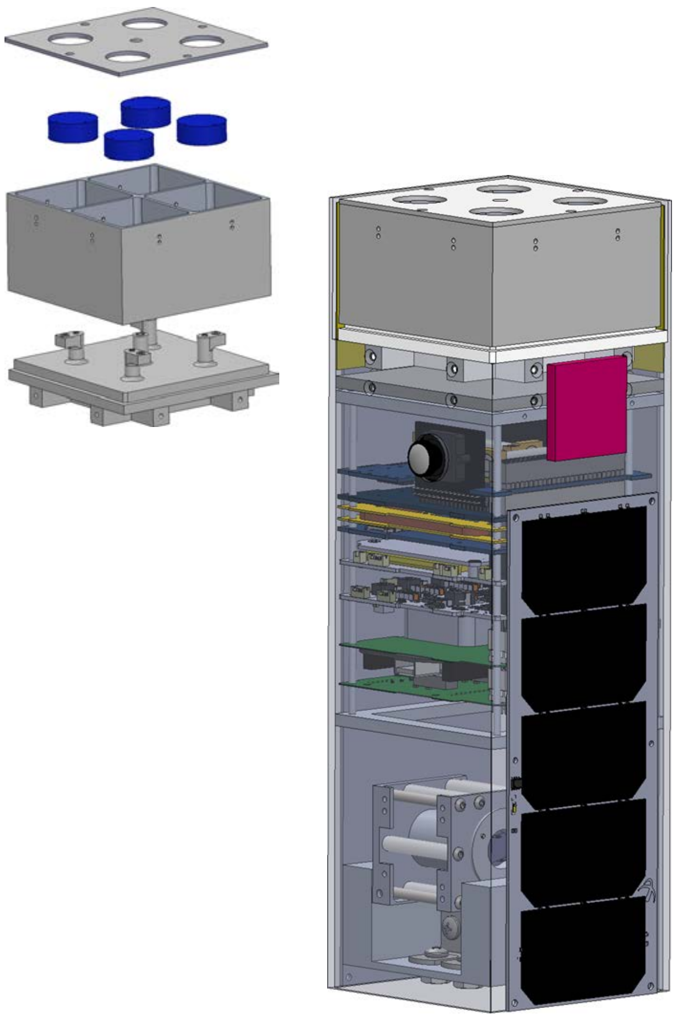
Y2O3 Sample



Location of MISEE on ISS

Cube Sat for In-space performance testing

- The Launch Services Program is developing a 3-U cube sat through the University of Florida
- The top sample holder will be thermally isolated and designed to always point away from the Earth
- It will hold 4 sample, 2 Y_2O_3 tiles and 2 Y_2O_3 tiles painted with an AZ-93 overcoat for comparisons



Patents/Papers

- Youngquist, Robert C., and Mark A. Nurge. "Cryogenic Selective Surfaces." (2016).
- Youngquist, Robert C., and Mark A. Nurge. "Achieving cryogenic temperatures in deep space using a coating." *Optics letters* 41.6 (2016): 1086-1089.
- Youngquist, Robert, et al. "Cryogenic Selective Surfaces: A Phase 2 NIAC Project: Mid-Term Continuation Review." (2017).
- Youngquist, Robert C., et al. "Cryogenic Deep Space Thermal Control Coating." *Journal of Spacecraft and Rockets* 55.3 (2018): 622-631.
- Youngquist, Robert C., and Mark A. Nurge. "Radiation reflector and emitter." U.S. Patent No. 10,273,024. 30 Apr. 2019.
- Patent application "Method of Fabrication a Rigid Radiation Reflector – filed 9/18
- Patent application "Reflective Paint for Cryogenics Applications" – filed 9/19