Continued Development of a Highly Reflective Solar Coating for Cryogenic Liquid Storage in Space

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Program

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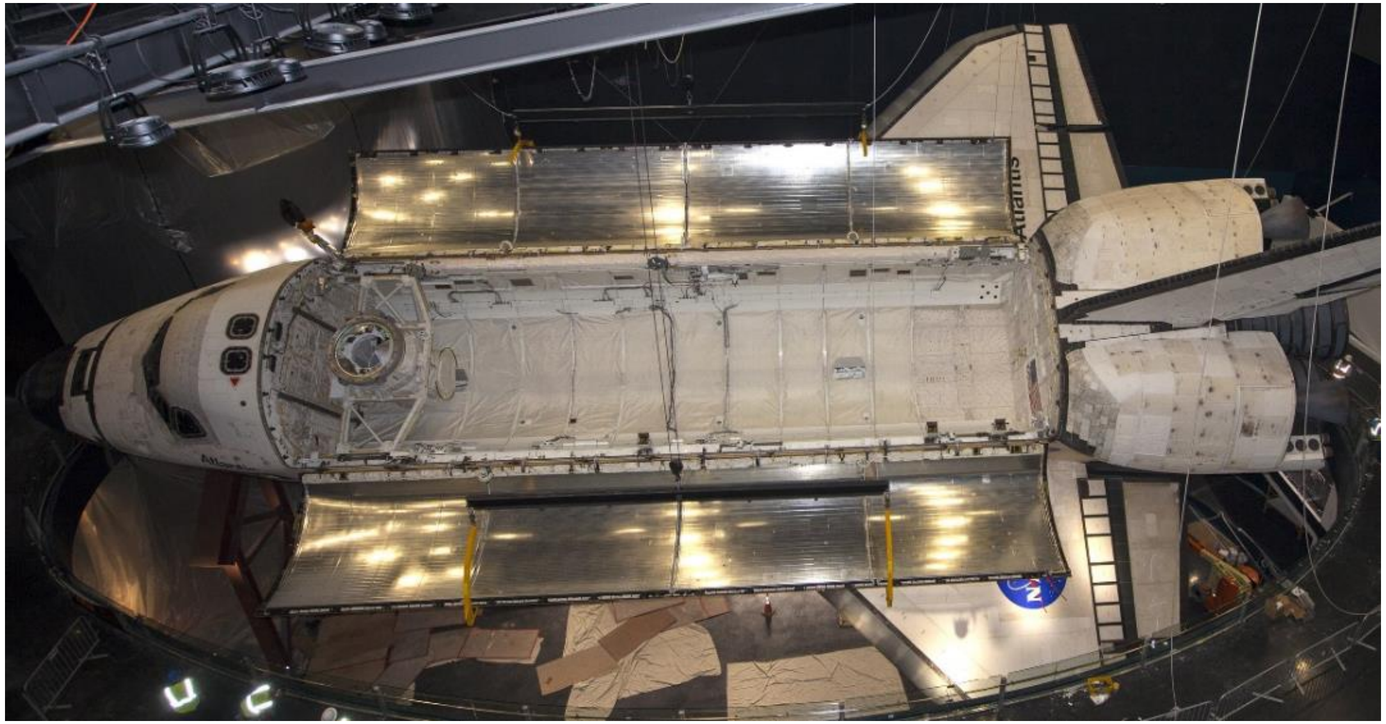
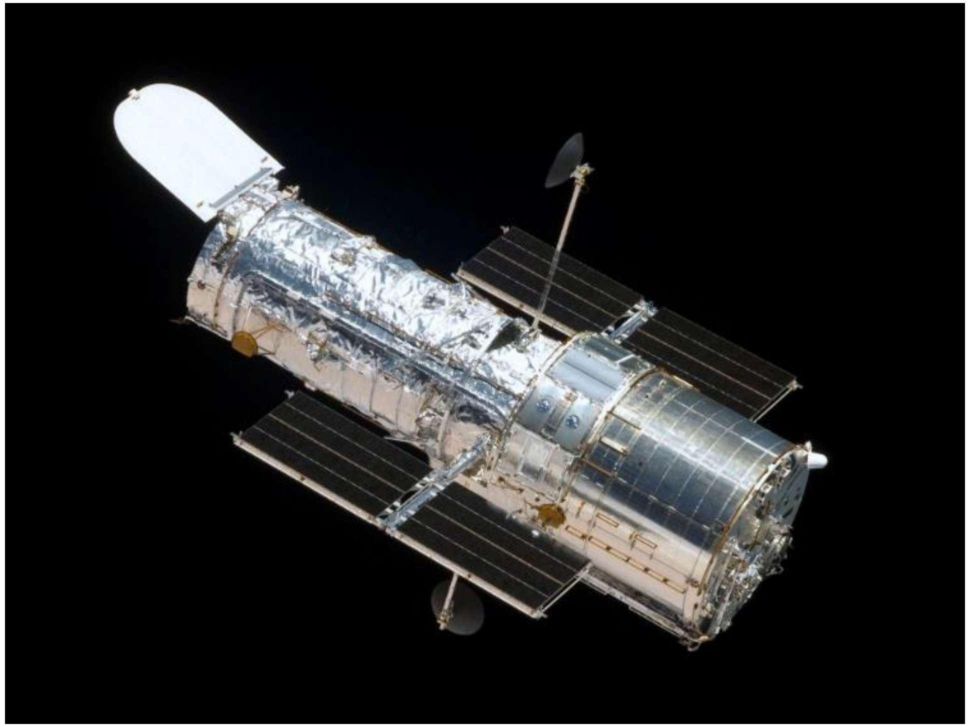
Thermal control coatings, i.e. coatings with different visible versus infrared emission, have been used on the Orbiter and Hubble Telescope to reflect sunlight, while allowing heat rejection via infrared emission.





Existing coatings are useful for maintaining a 300 K temperature range in the presence of the Sun.

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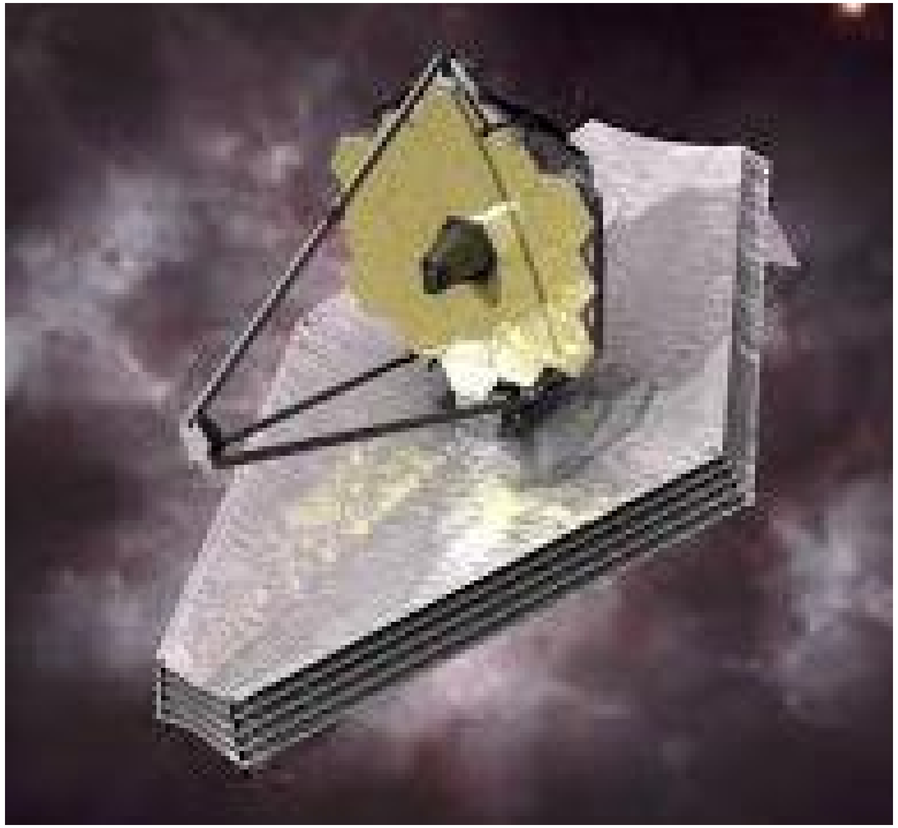

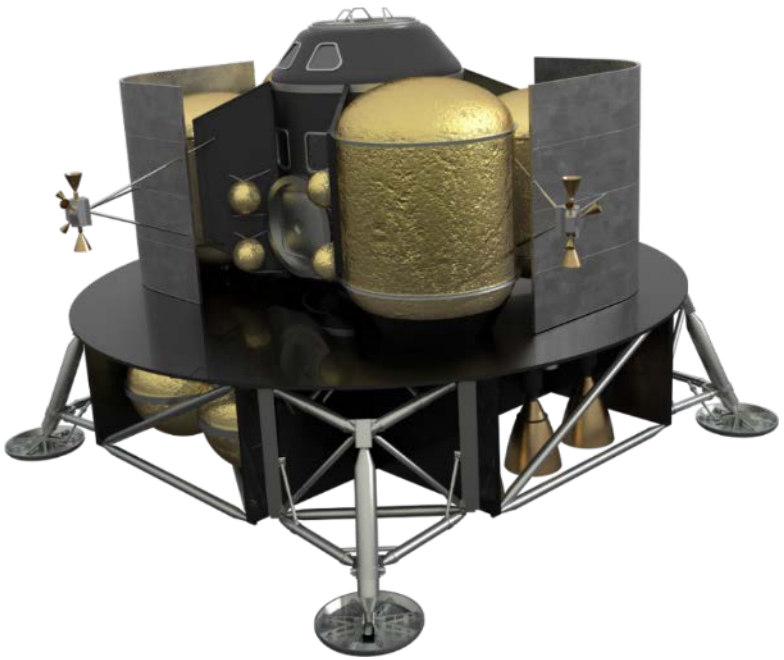

A concept image of a Mars Lander with liquid oxygen and liquid methane storage tanks.

However, existing coatings absorb at least 6% of the Sun's irradiant power, limiting the minimum temperature that can be reached to about 200 K.

NASA needs better solar reflectors. The James Webb telescope has to resort to multiple reflectors to reach cryogenic temperatures. Also, future missions will require cryogenic fuel and oxidizers, which currently cannot be maintained passively in deep space.

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In 1961 Hibbard showed that a perfect thermal control coating, one that reflects all light below a given wavelength and emits perfectly above it, can achieve cryogenic temperatures in the presence of the Sun.

In 1968, the optics community demonstrated that nearly perfect broadband reflectors can be fabricated from scatterers, e.g. powders, composed of transparent materials.

Spectralon: A NIST standard for reflectance, is composed of a pressed powder.

Titanium Dioxide Powder: 0.25 micron particles used as the basis for white paint.

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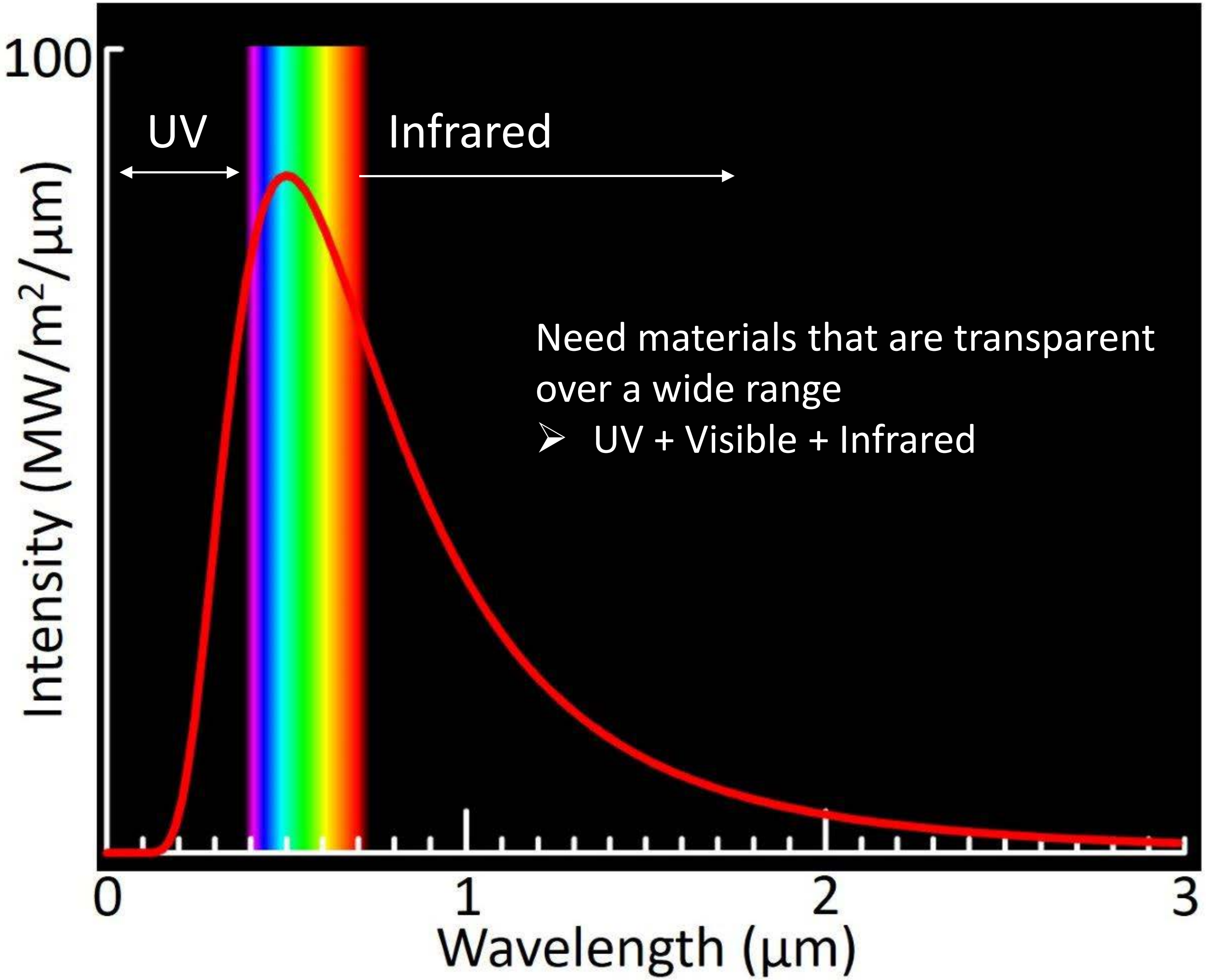

Need materials that are transparent over a wide range

- UV + Visible + Infrared

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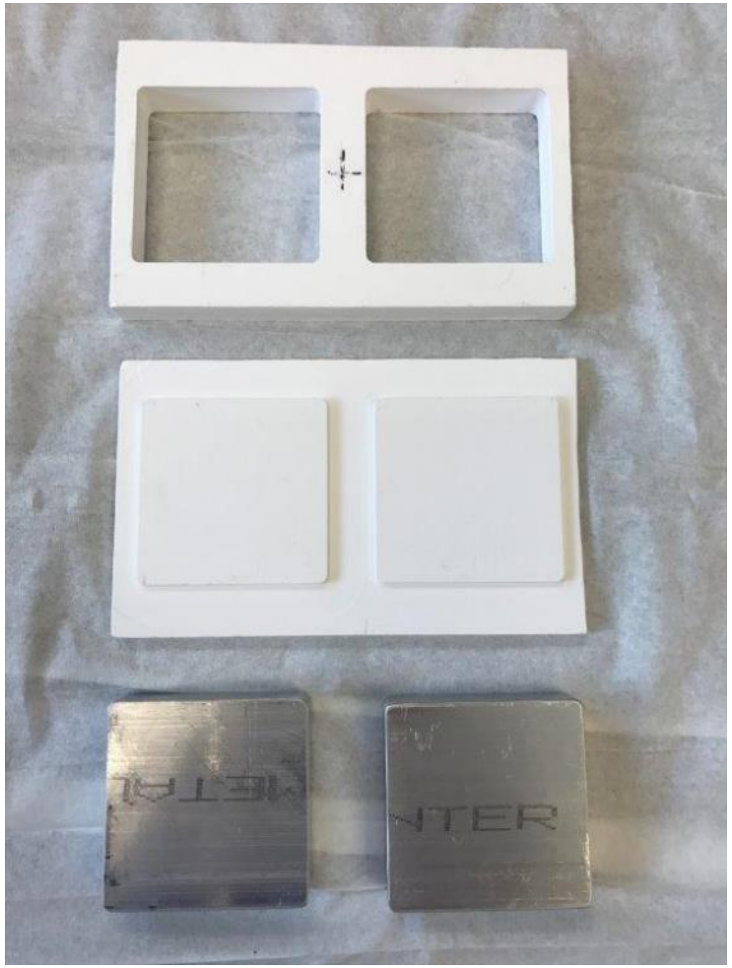

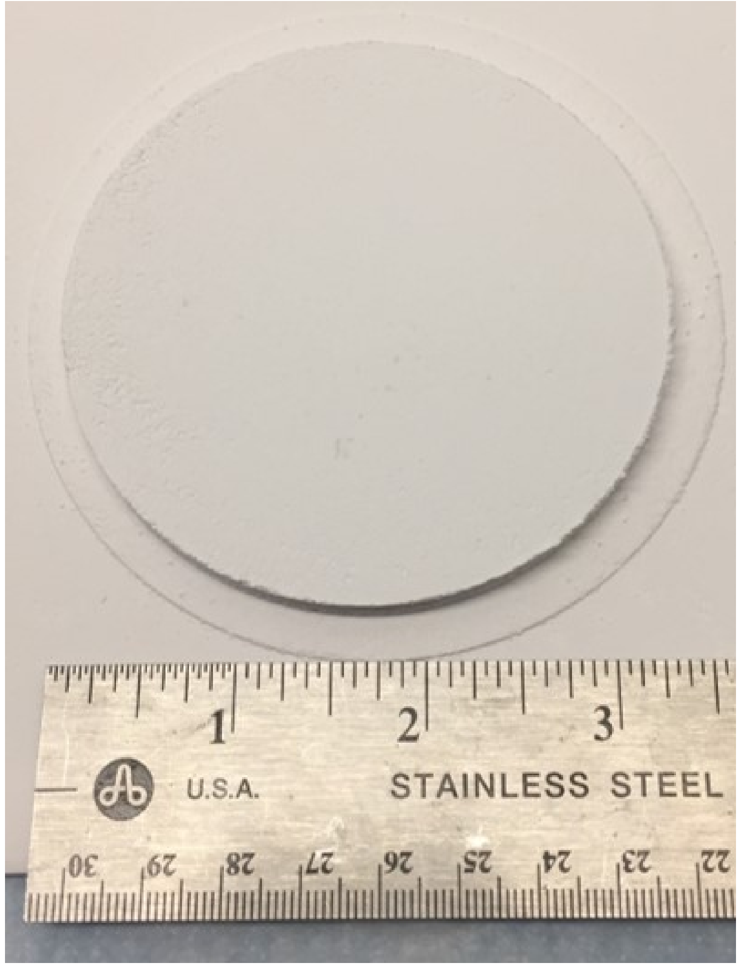

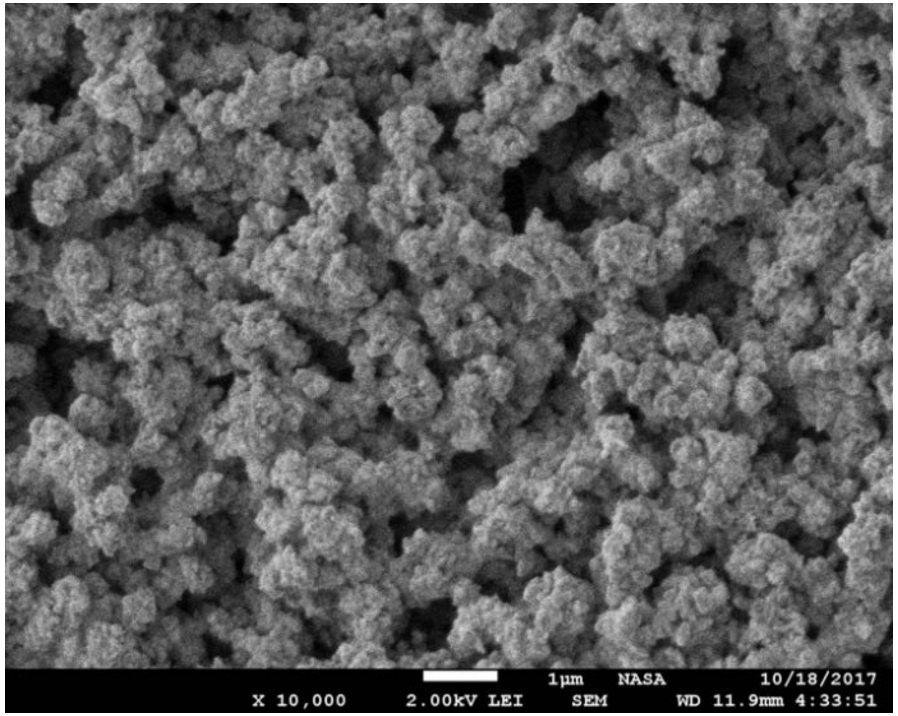

SEM photo of BaF_2 rigid coating material.

Barium fluoride (BaF_2) is transparent from 200 nm to beyond 10 microns, covering most of the Sun's spectrum. We have made reflective tiles by mixing BaF_2 powder with water, pressing the mixture in a mold, and then sintering this in an oven. The result is a bright white, rigid, material.

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Another option is yttrium oxide (Y_2O_3). This material is high index, hydrophobic, and potentially stronger than BaF_2. However, it appears to have a small UV absorption.

Fabricating coupons of Y_2O_3 requires a high pressure mold, as well as a high temperature oven due to its high melting point.

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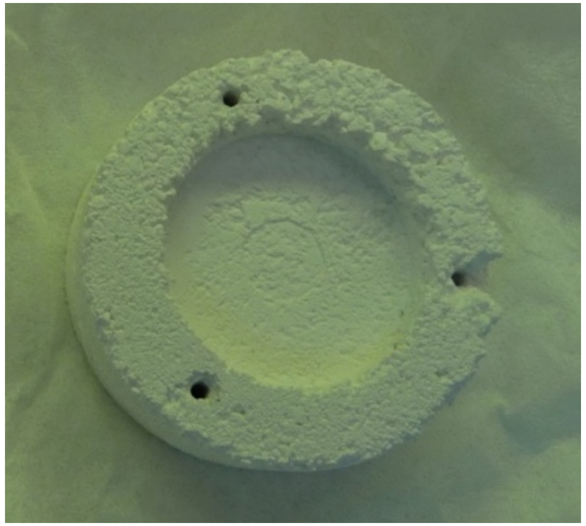
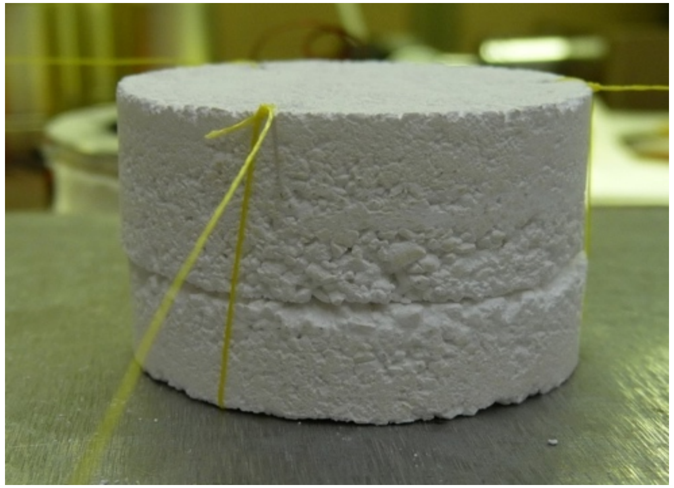
Y_2O_3 samples with temperature sensor





BaF_2 samples tied together with fine string.

So how do we test these new thermal control coatings?

Start by taking two samples, cutting out a space for a temperature sensor, and then tie the two together to enclose the sensor.

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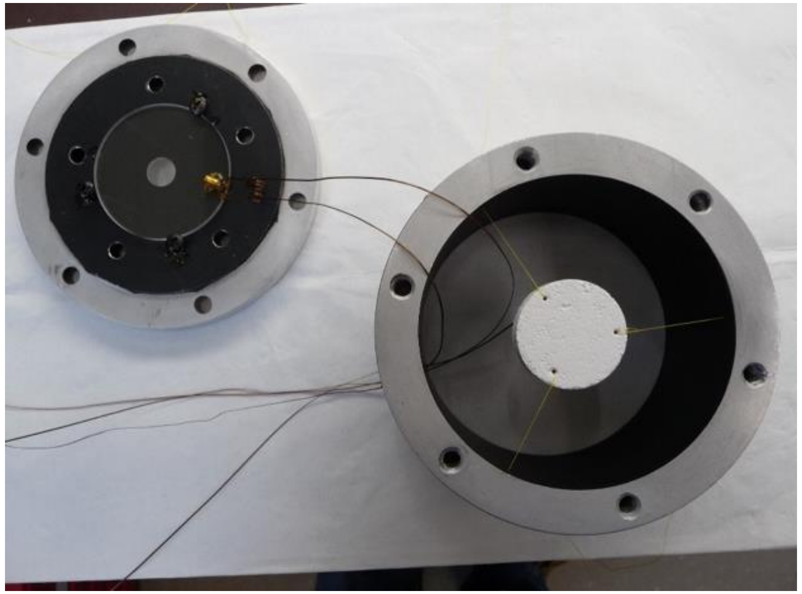
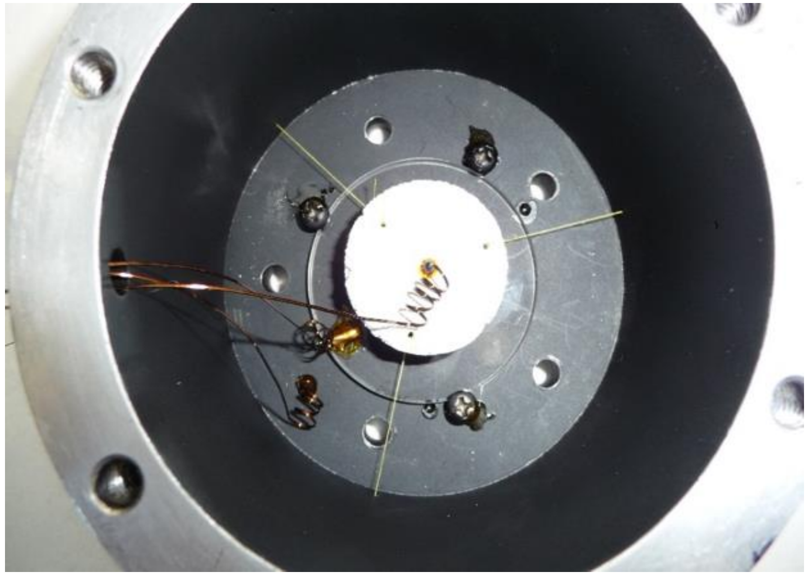
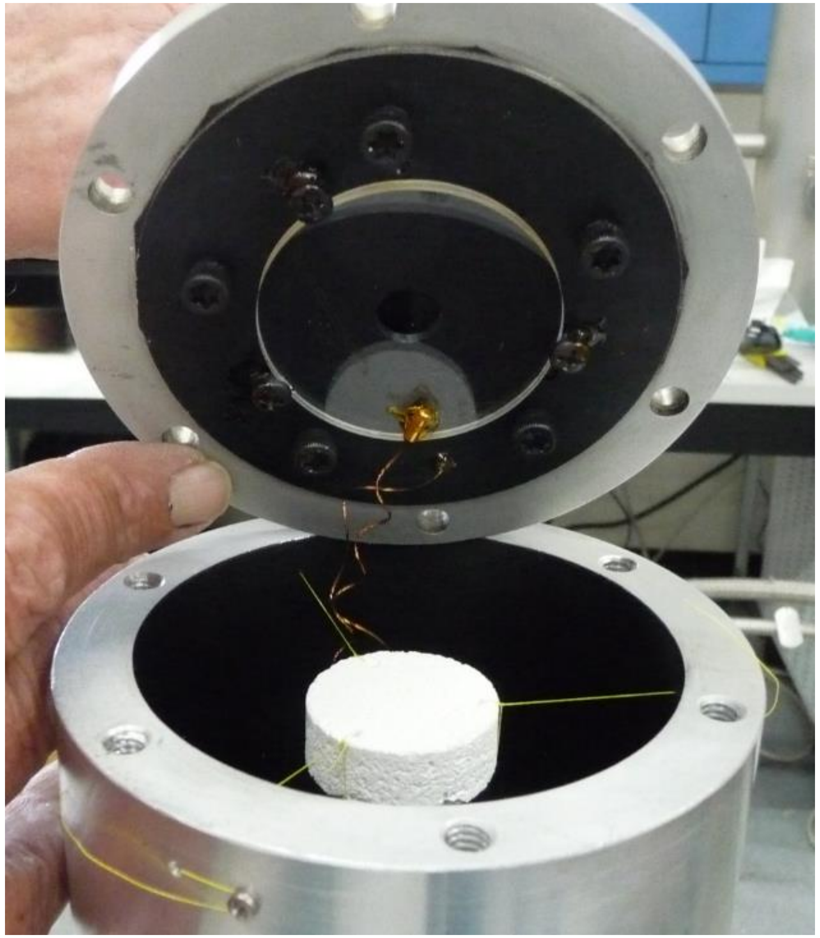
Mount the sample in a black painted chamber using the strings.



Looking down into the test chamber with the top lid set to the side.



Looking up into the chamber from the bottom. Note the temperature sensors attached to the sample, the window, and the lid.



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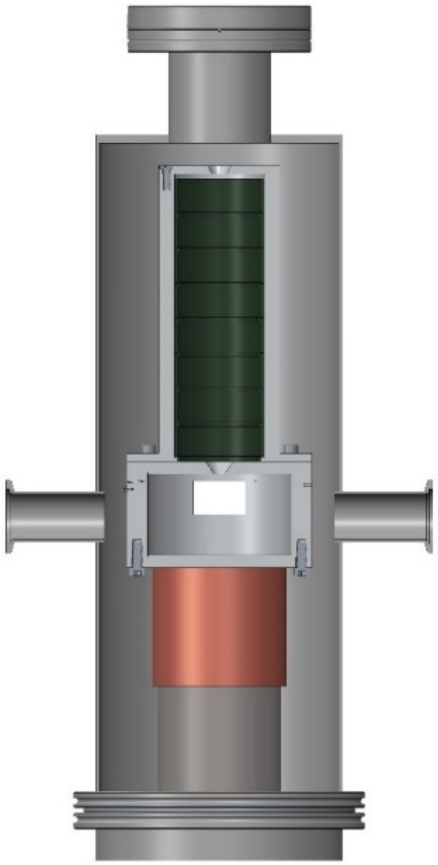

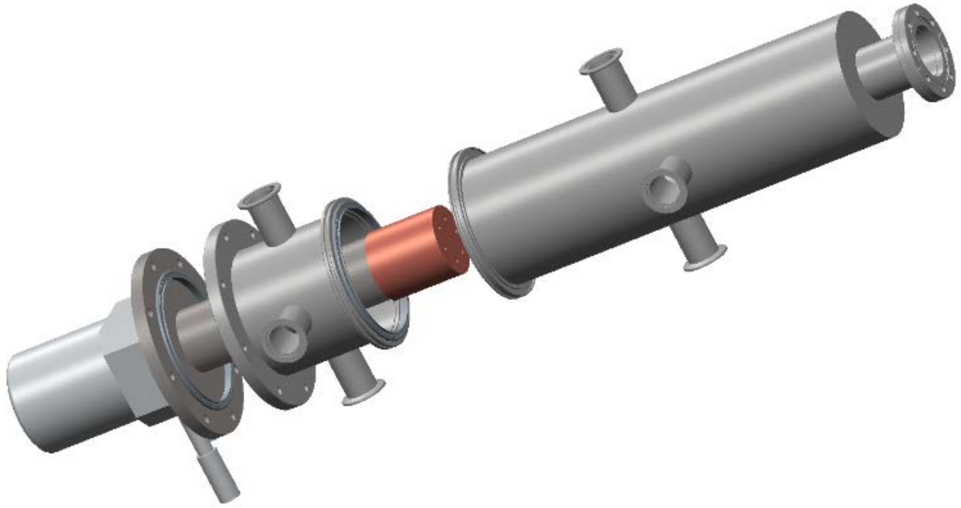

Mount the test chamber on a cryocooler and place this inside of a vacuum chamber so the sample environment is cold, dark, and evacuated; modeling deep space.

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Use a Xenon lamp to simulate the Sun's irradiant power spectrum.

Place this on top of the vacuum shroud. Light enters the vacuum through a sapphire viewport and is then relayed down onto the sample using UV fused silica optics and CaF2 windows as IR blocks.

This results in about 3.6 watts of net optical power hitting the sample.

On a 1.5 inch diameter sample this is about 2.4 times solar at 1 AU in deep space.

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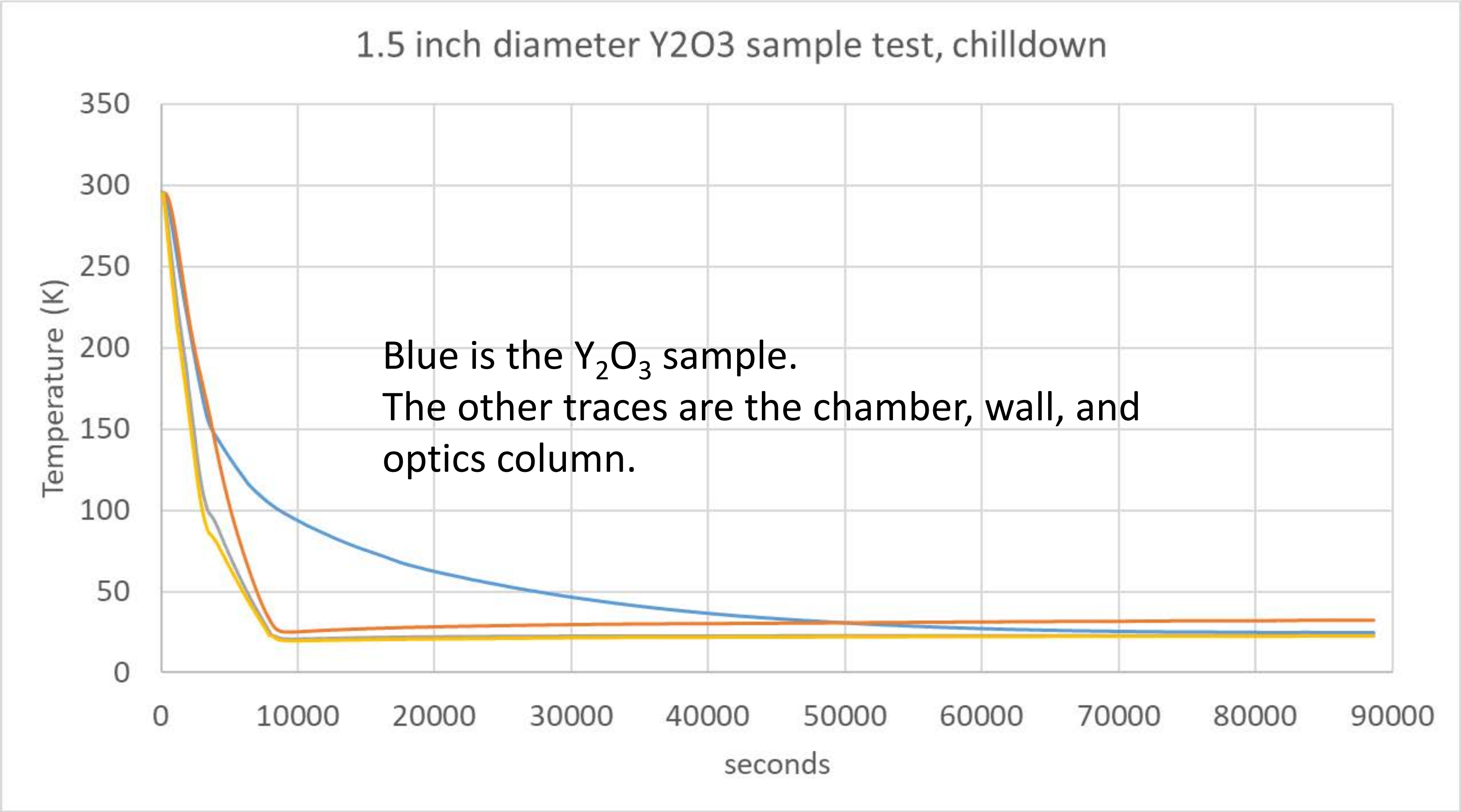

Chilldown takes about a day.

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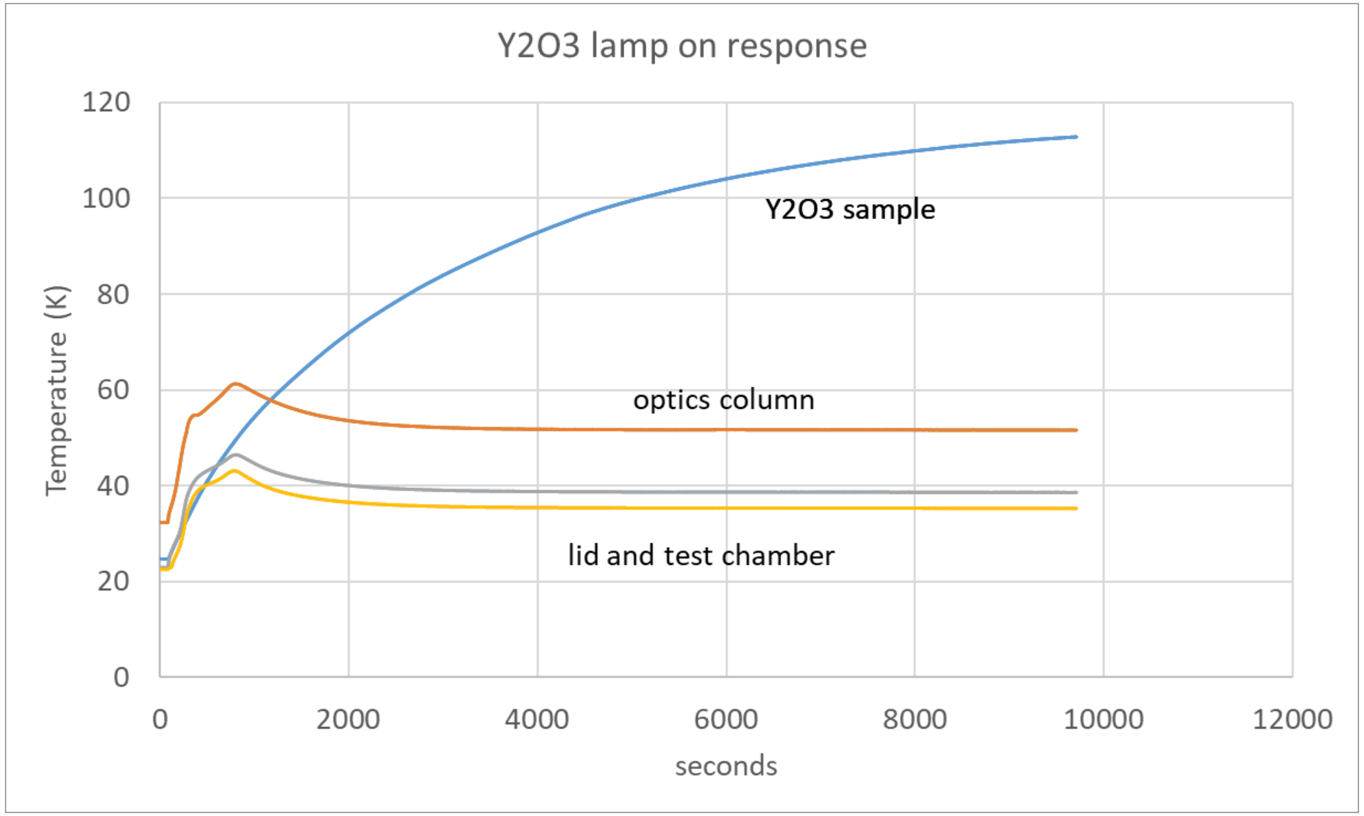

Turning on the lamp caused the sample to heat from 24.7 K to a projected 120 K.
Assuming uniform temperature; at 120 K the sample is radiating about 37 mW, about 1% of the solar simulated total power. This is much better than the state-of-the-art…..

However, note the change in the test chamber temperature, which is directly bolted to the cryo-cooler. It rose from 22.5 K to 35 K. This indicates an extra 40 watts of heat load on the cooler. We believe substantial infrared emission is making its way down the optics column and potentially skewing the results.

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We decided to remove the optics column and instead, use a UV-quartz fiber light guide to irradiate the sample with simulated solar power. The fiber guide is shown above along with a vacuum feedthrough.

The photo to the right shows the system without the upper vacuum shroud. The black polymer sheath has been removed from the fiber and replaced with copper tape to help minimize heat conduction along the fiber.

0.9 to 1.0 watt of total optical power is delivered to the sample with this system.

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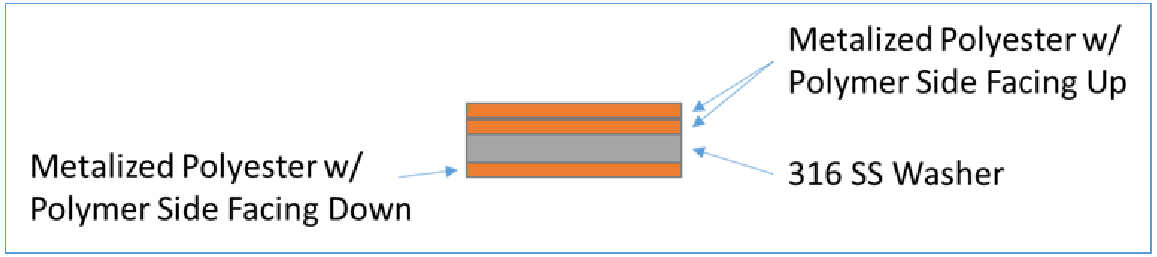
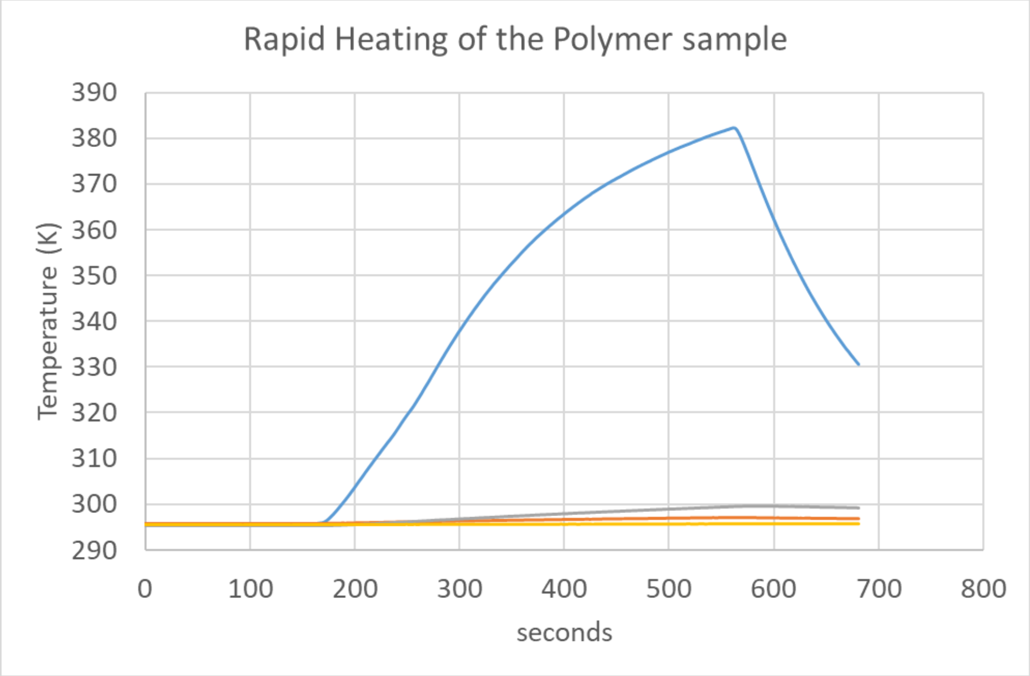
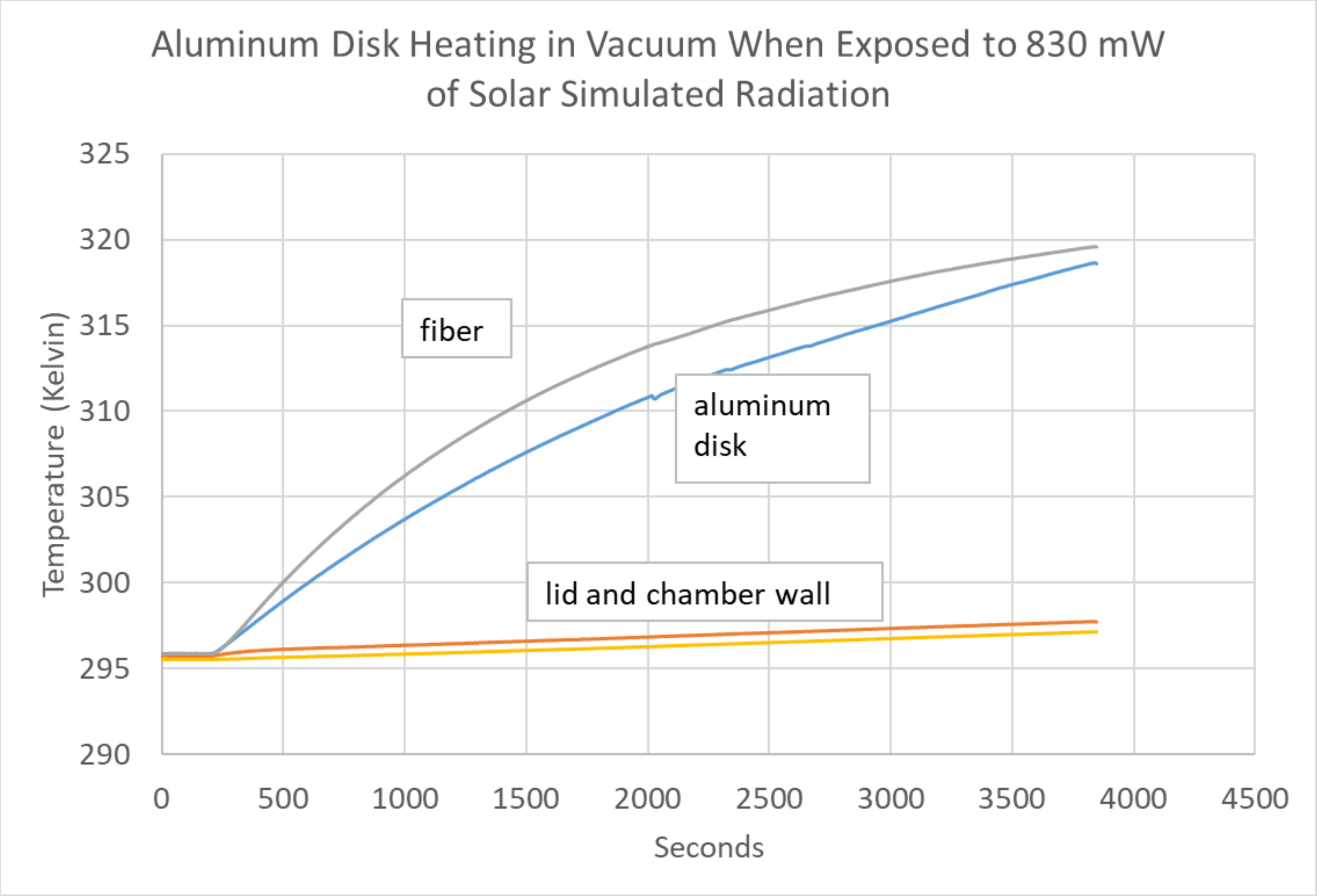




As a test, we mounted a metalized polyester sample into the test chamber. This type of material is similar to that used on the Orbiter and Hubble telescope. Under vacuum, but at room temperature, we turned on the lamp and saw a rapid rise in temperature (about 90 K in 7 minutes). We subsequently discovered we had burned the sample.



We then tested an aluminum disk, 1.5 inches in diameter and 0.25 inches in thickness. At room temperature under vacuum it increased about 0.4 degrees/minute under lamp irradiation, consistent with about 10% absorption.

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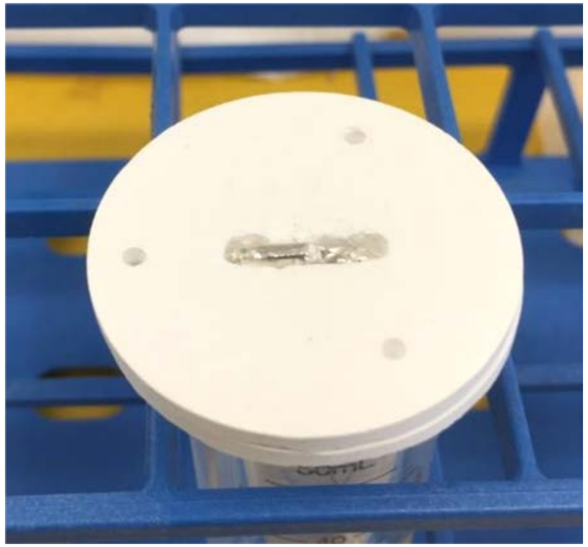

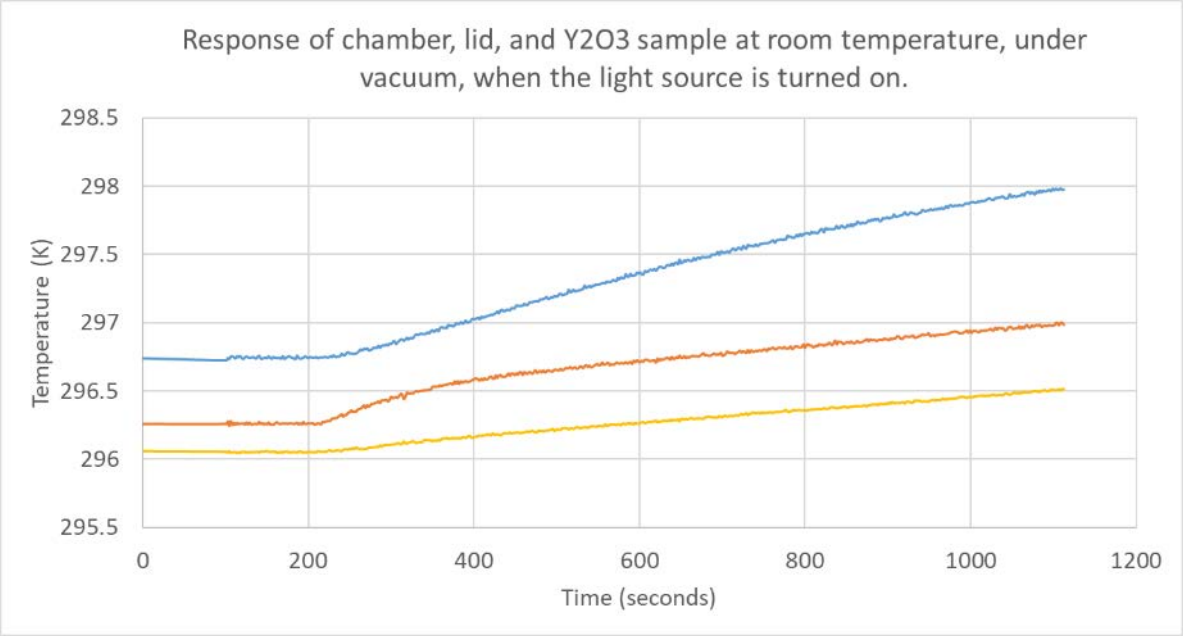

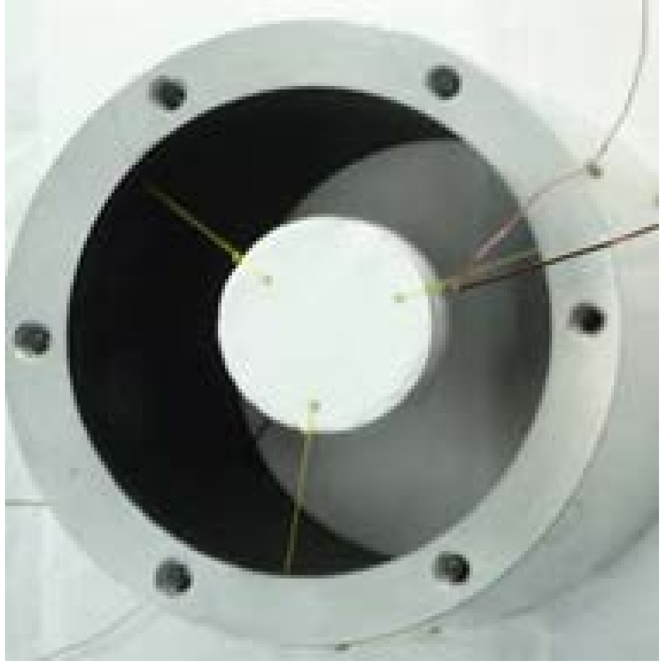

We replaced the polymer sample with a Y_2O_3 sample and repeated the vacuum, room temperature test. In this case, after about 13 minutes, we saw a rise in temperature of 1.5 K.

This is a very encouraging result, but without the cryo-cooler it is hard to tell what heating is due to absorption and what is due to heating of the surroundings. So we proceeded to run the cryogenic temperature test.

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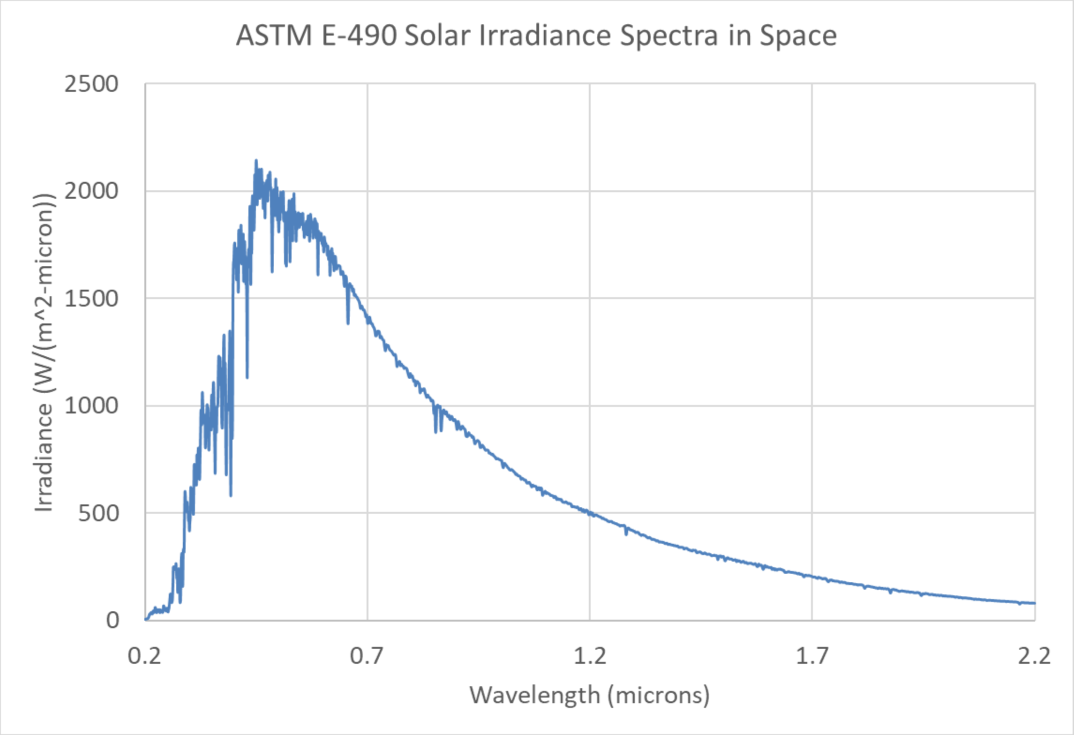

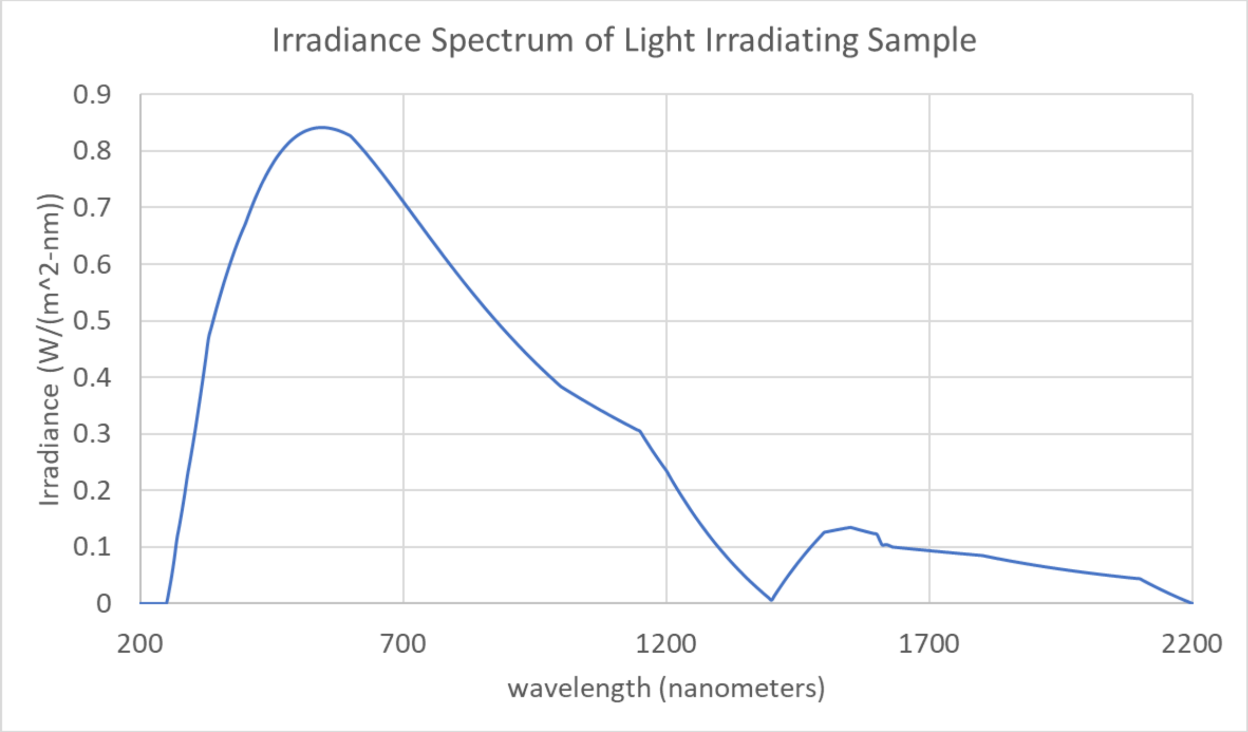

As a caveat, the light emerging from the quartz fiber is a reasonable solar match from 255 nm to about 2200 nm, but does not contain short wave UV nor long wave infrared. Fully simulating the deep space solar spectral irradiance is difficult.

Work is currently underway to design a cube sat to test the performance of this material in low-Earth orbit.

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Backup-Additional Information

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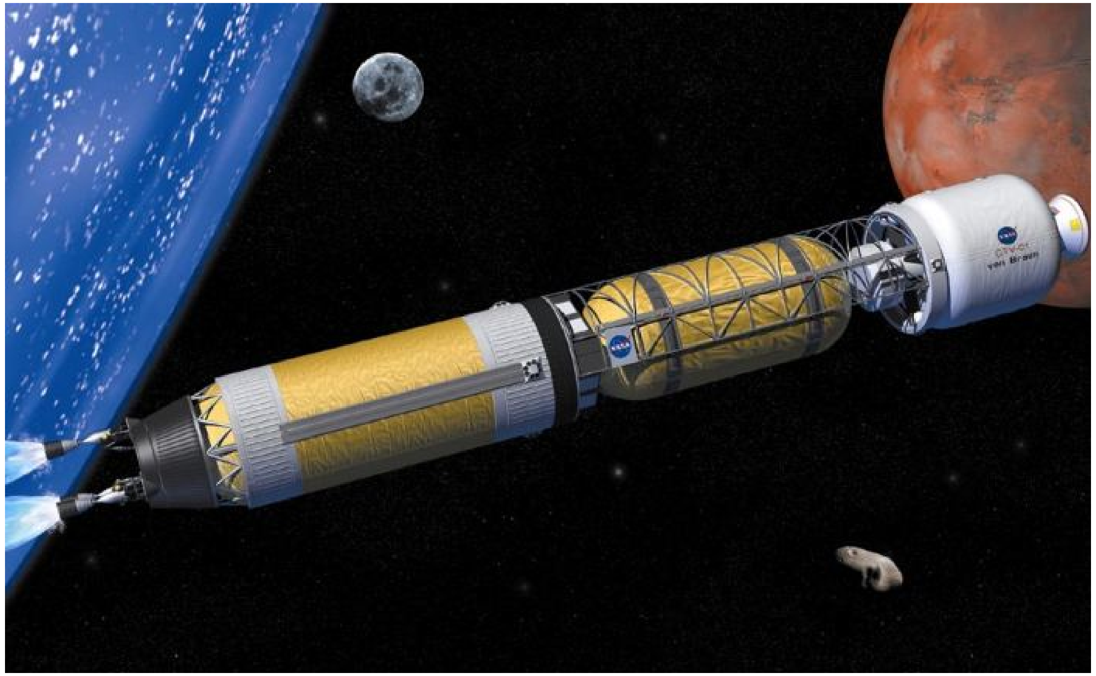

Nuclear Thermal Propulsion

Multi-layer Insulation

Nuclear Thermal Propulsion requires long duration LH2 maintenance.

We cannot reach LH2 temperatures with our coating, but we believe we can improve the performance of the multi-layer insulation they are proposing to use, lowering the heat load on the LH2 tanks.

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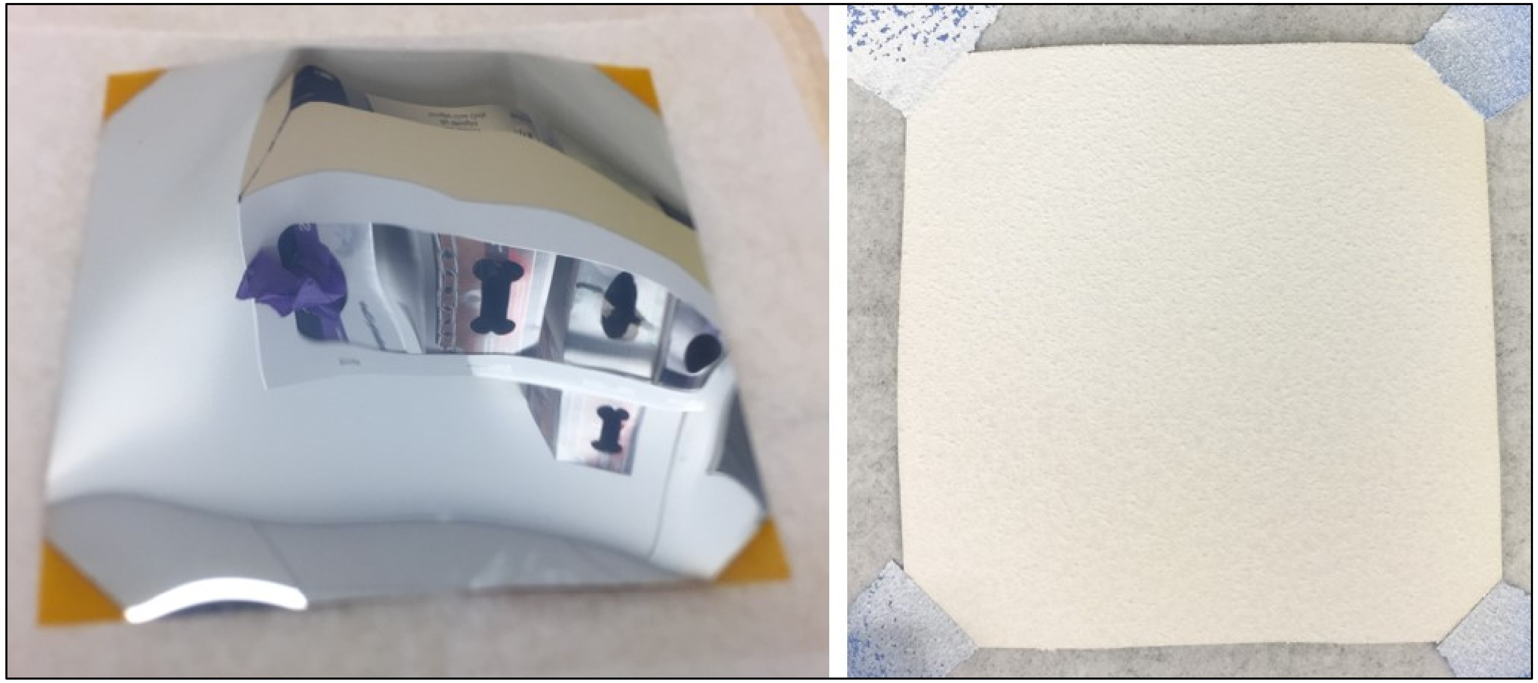


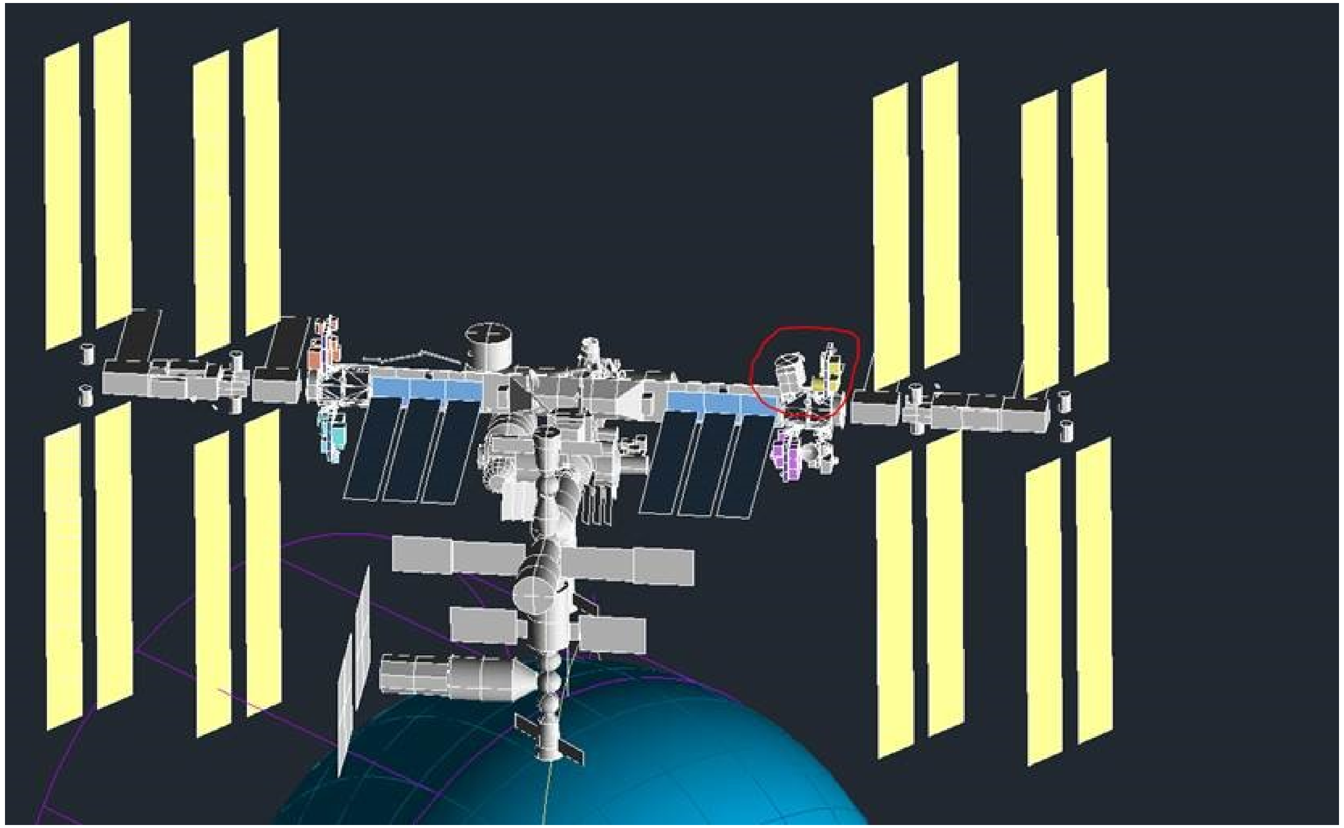
Silver coated Kapton-HN before and after being coated with our new coating.

We have developed a thin, spray on version of our coating. Y_2O_3 particles suspended in a liquid in which potassium bromide (KBr), a broad band optical material, has been dissolved. After spraying and drying the KBr comes out of solution, forming sheets that hold the Y_2O_3 particles in place.

Essentially we are copying the basis for white paint, but with broadband materials.

Our Goddard partner offered us a slot on his Space Station exposure test.

We supplied a coupon which is part of MISSE10.



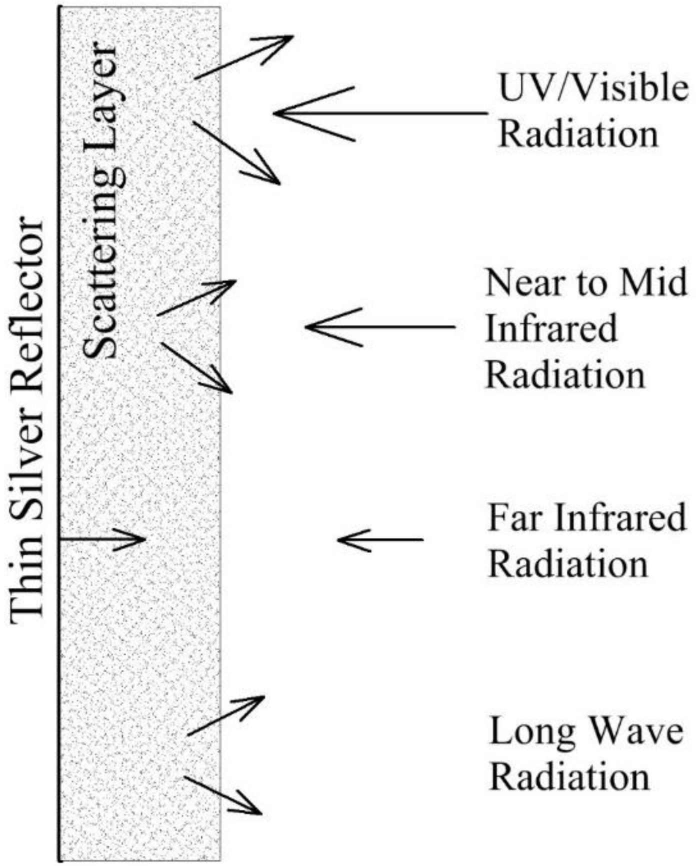
The ISS showing the location of MISSE.

We published the concept in 2016 in Optics Letters, (Youngquist and Nurge, “Achieving cryogenic temperatures in deep space using a coating” Vol. 41, No. 6, March 15, 2016).

We presented the work publically at NIAC Symposia in 2015, 2016, and 2017, have a patent, a pending patent, a provisional patent, and a second peer reviewed article as listed below.

Youngquist, Robert C., Mark A. Nurge, Wesley L. Johnson, Tracy L. Gibson, and Jan M. Surma. "Cryogenic Deep Space Thermal Control Coating." *Journal of Spacecraft and Rockets* (2017): 1-10.

Our new coating is composed of a scattering layer followed by a silver layer. The scatterer handles the UV and visible reflectance and the silver reflects mid-long wave radiation.



First, choose a material that absorbs essentially no radiation from 0.2 microns to the mid or far infrared range, e.g. MgF_2, CaF_2, BaF_2, KBr, NaCl, etc.

Second, grind this material into 200-300 nm diameter particles and make a 3-10 mm layer of this powder. This layer will scatter UV, visible, and near infrared light effectively, but not longer wave radiation.

Third, place this layer on a metallic reflector (e.g. silver) to reflect the longer wave radiation that gets through the particle layer.

The coating will emit long wave radiation beyond its transparency cut-off.