Cryogenic Selective Surfaces

A Phase 2 NIAC Project

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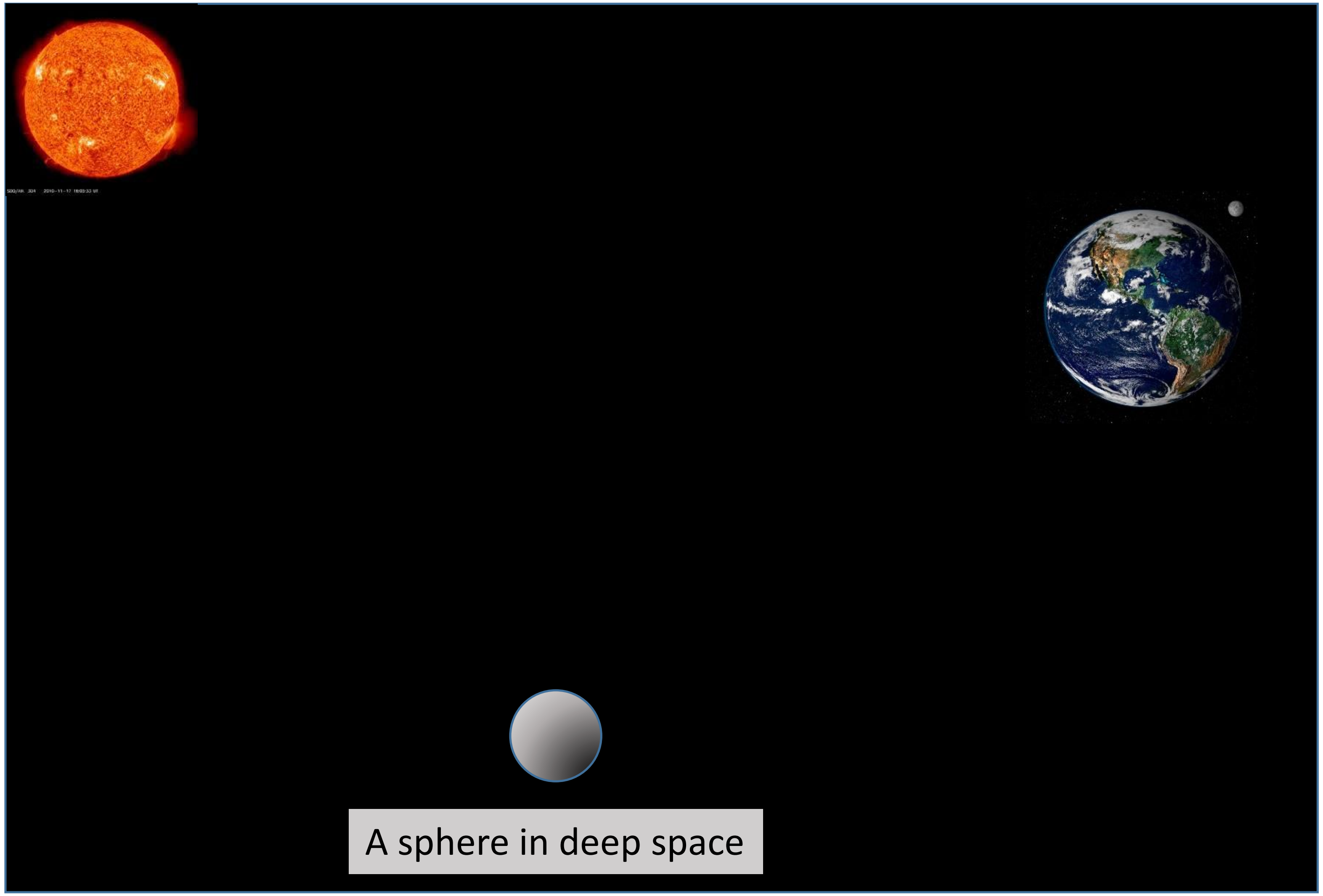
Cryogenic Selective Surfaces

NASA Innovative Advanced Concepts



If we place a sphere in deep space at 1 AU from the sun, what will its temperature be, assuming it absorbs radiation from the sun and emits infrared radiation in all directions?

Our goal is to find a way to make this sphere as cold as possible so that we can potentially store liquid oxygen or operate superconductors.

The State-of-the-Art

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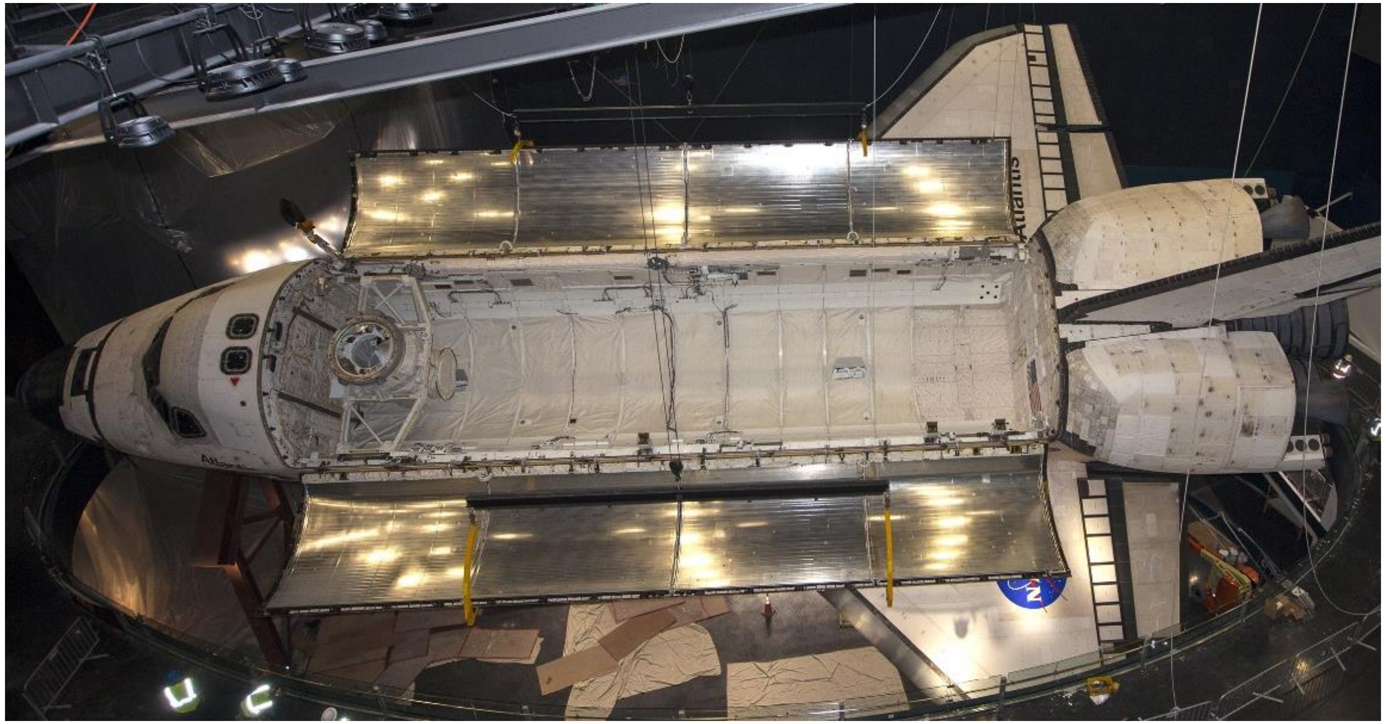
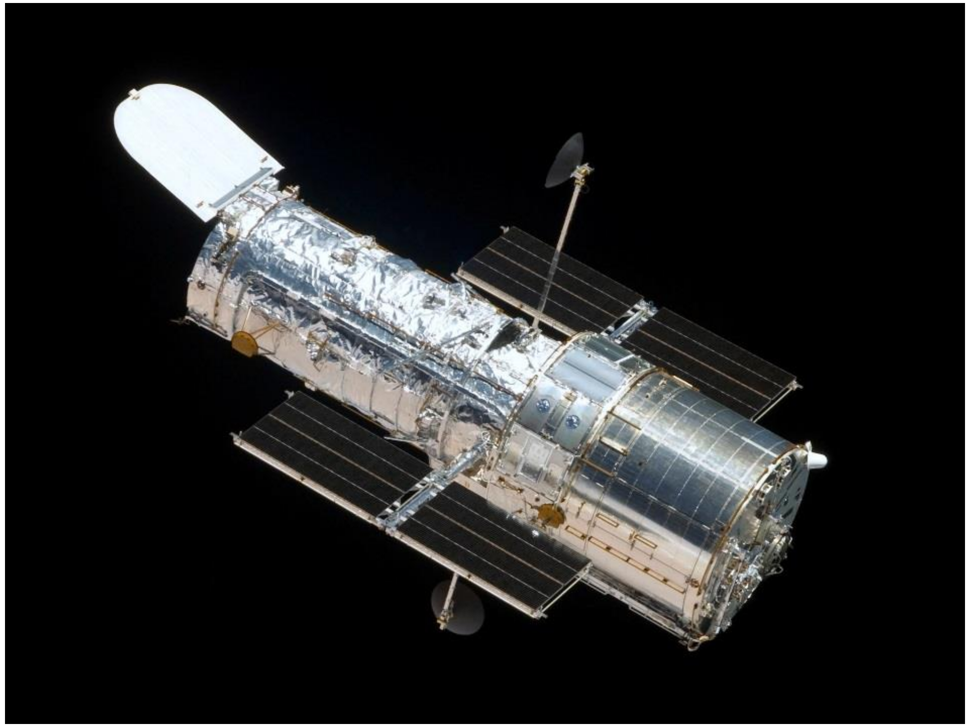
Companies such as Sheldahl sell second surface mirror sheets composed of silver on FEP (type of Teflon). These flexible reflectors/radiators have been used to remove waste heat from the Shuttle and the Hubble telescope while in the presence of the Sun.



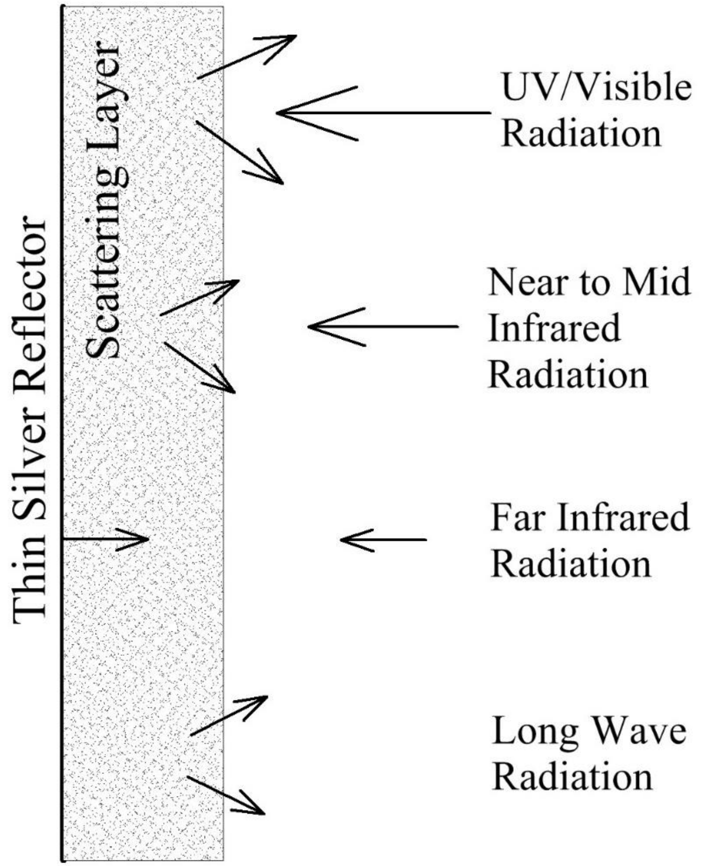


These materials absorb about 9-10% of the Sun's power and can emit with 75-80% efficiency in the infrared, but that's not good enough to reach cryogenic temperatures.

Cryogenic Selective Surfaces

Under our Phase 1 work we modelled a new coating 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.

A pressed salt disk scattering bright light.



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We modeled this new coating, published the results, and have a patent pending.

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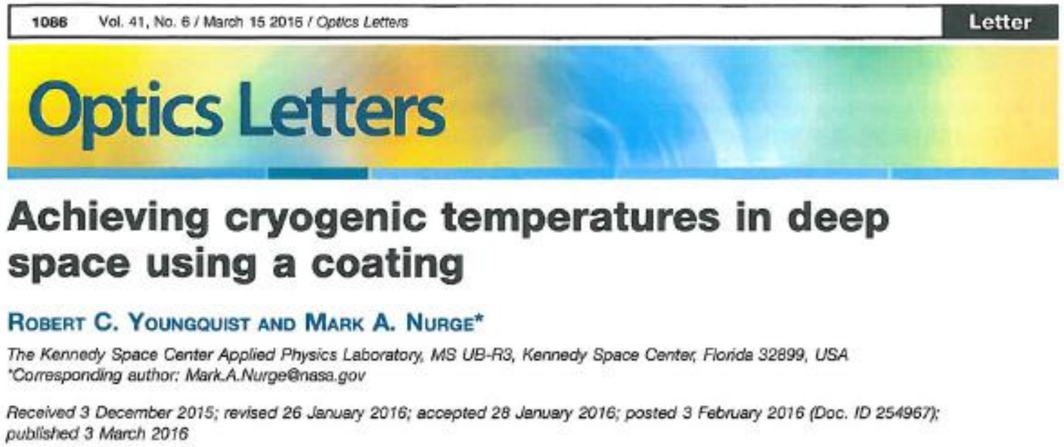
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Optics Letters

Achieving cryogenic temperatures in deep space using a coating

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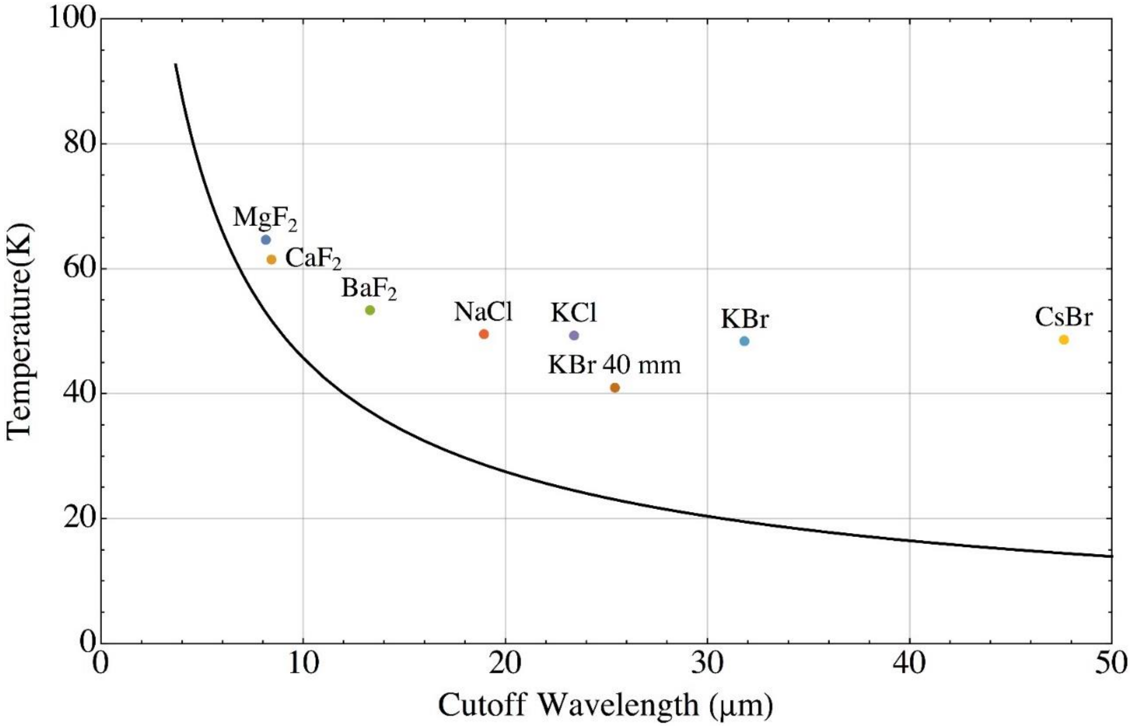
Our models show that these coatings can be constructed to absorb less than 0.1% of the Sun's illuminated power!



Predicted steady-state temperatures for a sphere coated with 5 mm of various broad transparent band materials.

The solid line is the theoretical best performance-adapted from Hibbard (1961).

Phase 2: 1st year.

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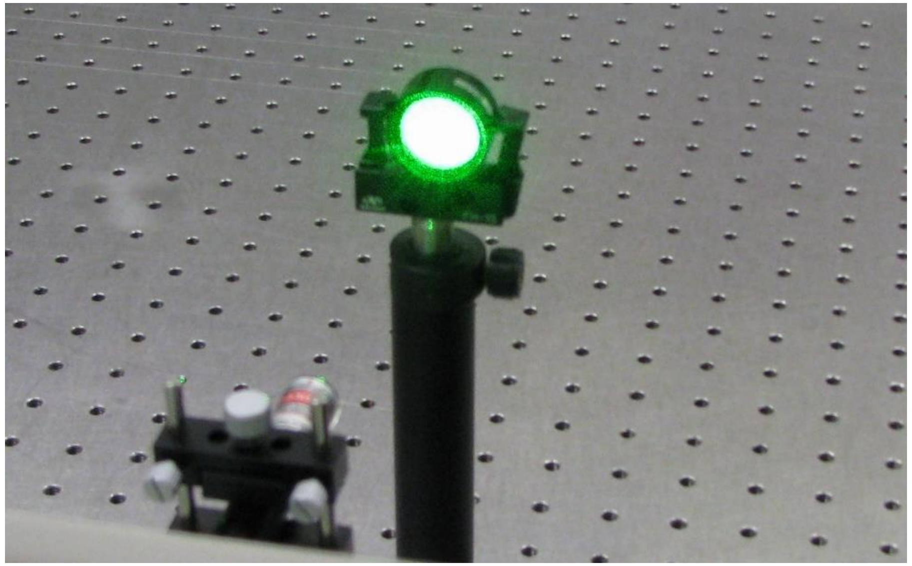
Under our Phase 2 funding we developed rigid versions of the coatings.



We take BaF_2 powder, add water to make a paste, press it into a mold, and fire it in a kiln.

Phase 2: 1st year.

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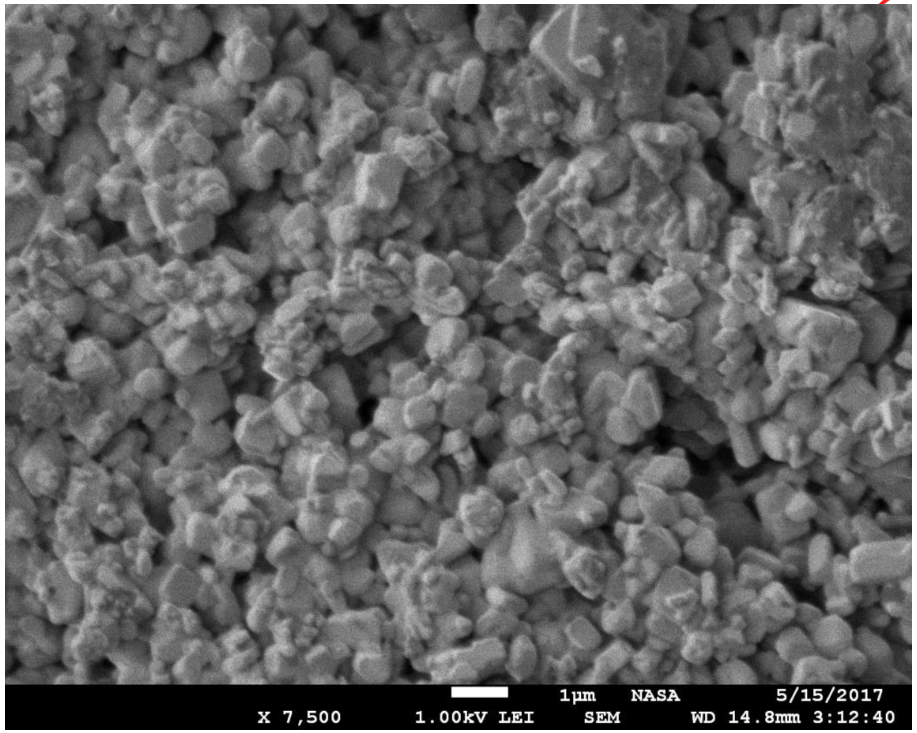
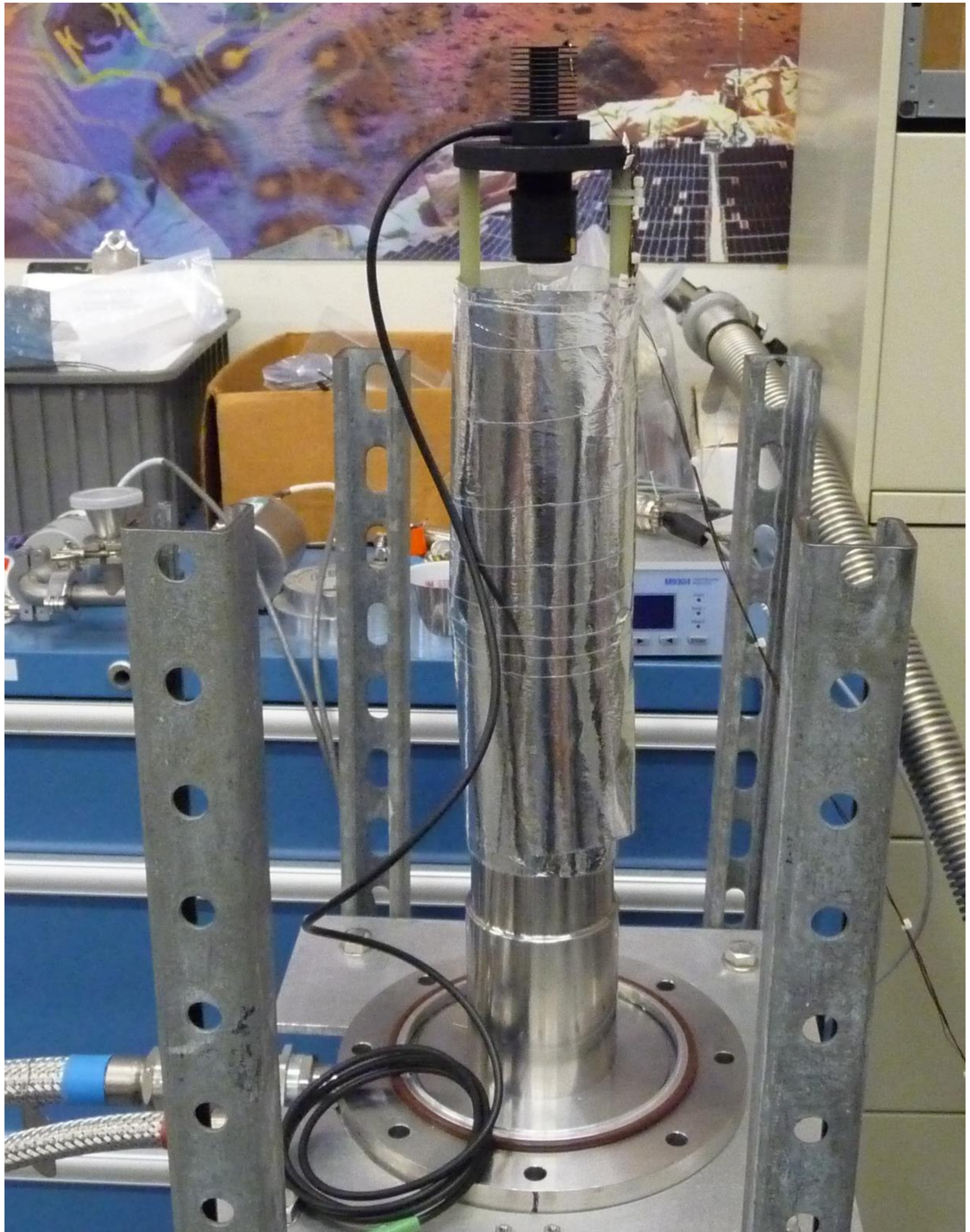


This is our best sample to date. It's more than 3 inches in diameter (87 mm), 6-7 mm in thickness.

The SEM shows the particle sizes.



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We've been testing our coatings in a cryocooler, evacuated and operating around 40 K, i.e. a simulated deep space environment.

We've used a 375 nm Ultraviolet LED as the light source, located inside of the vacuum chamber.

Phase 2: 1st year.

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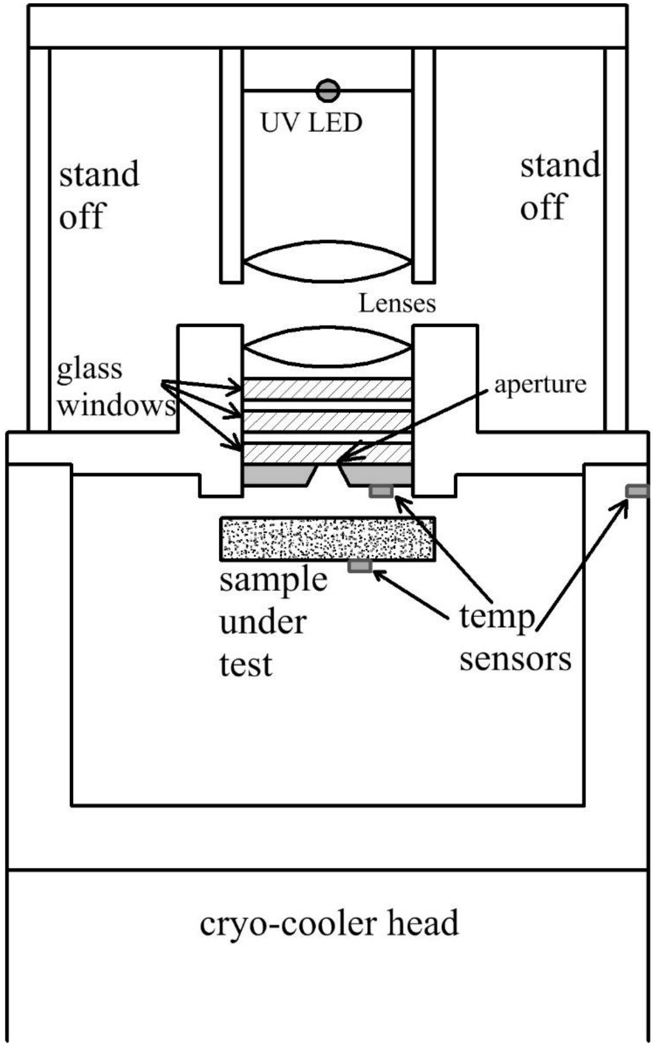

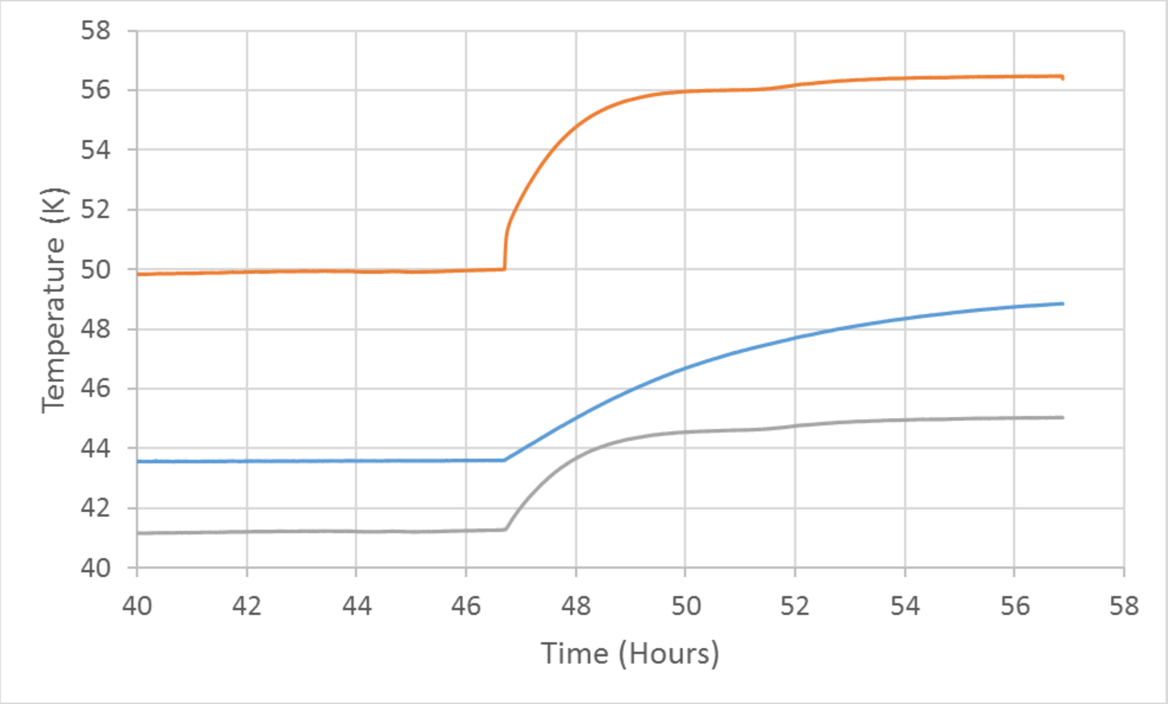

Grey is the wall temperature.

Orange is the lid temperature.

Blue is the sample temperature.

This worked well. The sample absorbed less than ¼% of the illumination. It is staying under 50 K while being illuminated with 17,000 microWatts of 375 nm radiation.

This validates the performance of the coating in a deep space environment but only for UV illumination.

Phase 2: 1st year.

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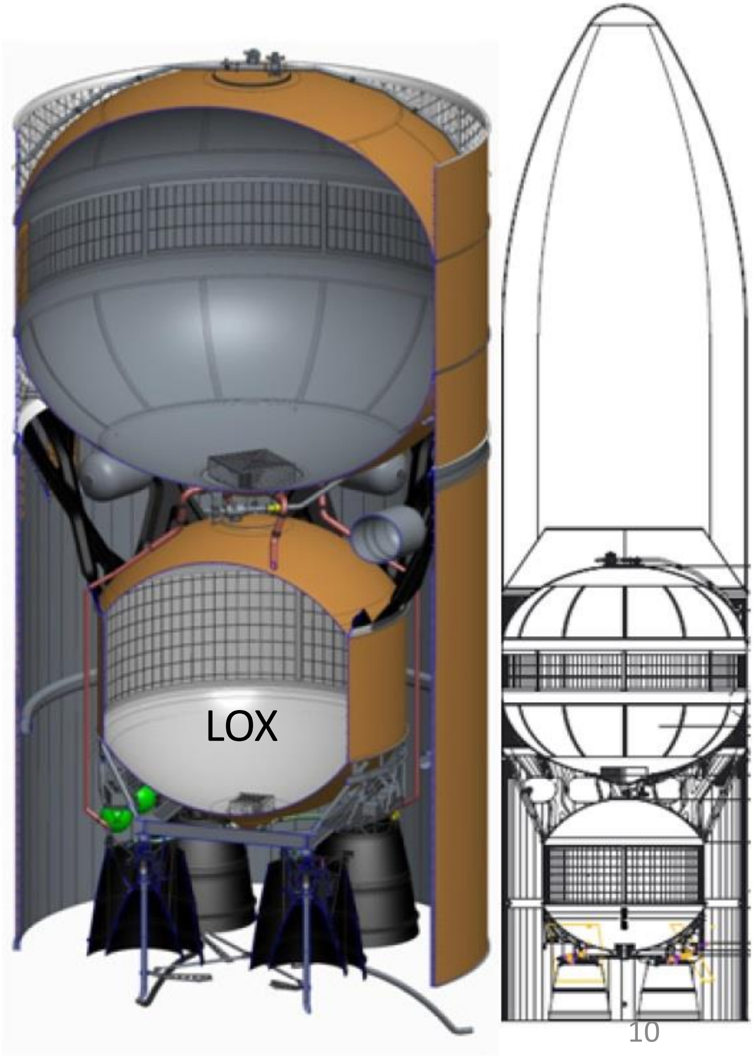
Mission Impact

NASA has a significant technology shortfall—

With the current state of the art cryogenic fluid cannot be stored in deep space without the use of cryo-coolers.

Heat reaches to the cryogenic tank via:

1. Solar illumination
2. Infrared illumination from nearby warm objects
3. Conduction along support struts.



A proposed design for a Mars vehicle with a liquid oxygen tank.

Phase 2: 1st year.

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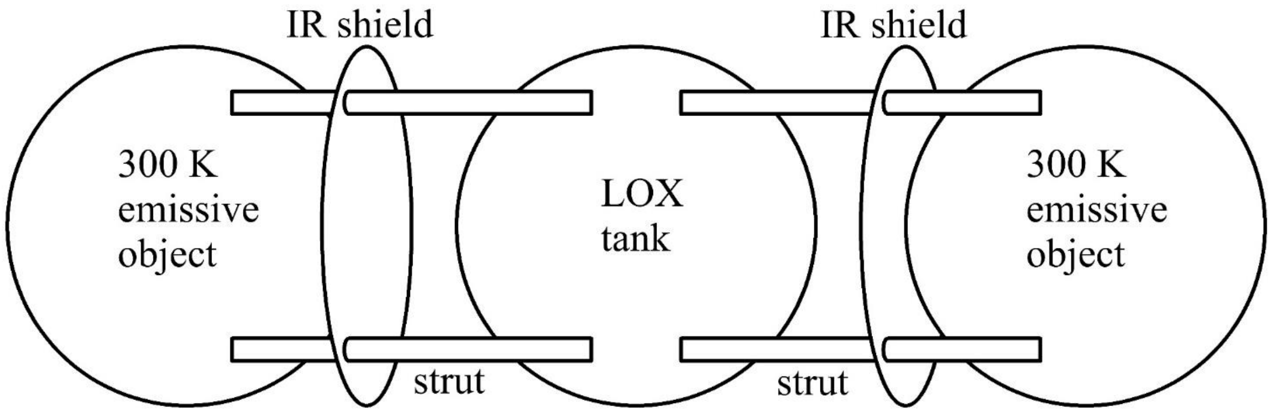

We've chosen to model a Mars vehicle as having a LOX tank located between two warm objects.

1. The tank is coated with our new selective surface minimize solar power absorption.
2. Infrared shield are proposed to minimize infrared coupling with warm spacecraft components.
3. By using low thermal conductivity struts and coating them with our new selective surface heat is radiated away rather than reaching the LOX tank.

The resulting modeling shows that LOX can be taken to Mars using shields and our new coating.

Our partner at the Glenn Research Center is assessing the impact of this on various proposed missions.

Phase 2: 2^{nd} year plans

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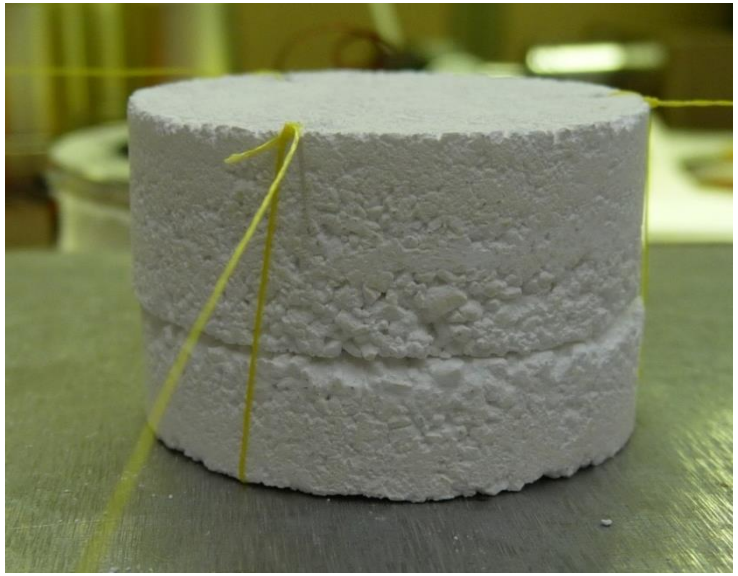
Refine the coating:

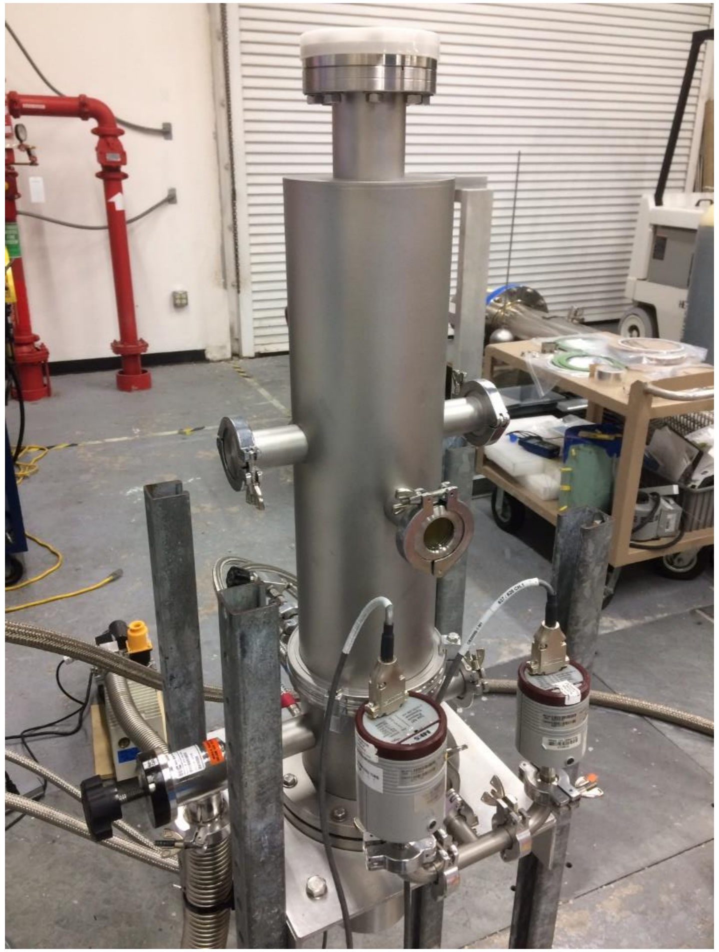
1. How do we attach it?
2. How thick should it be?
3. How strong is it?
4. Can it handle launch vibrations?
5. Can it be cold shocked?
6. How do we clean it?
7. Can it be sealed?
8. Should we introduce other broadband optical materials?
9. How do we optimize the optical performance?
10. Is the silver working properly.



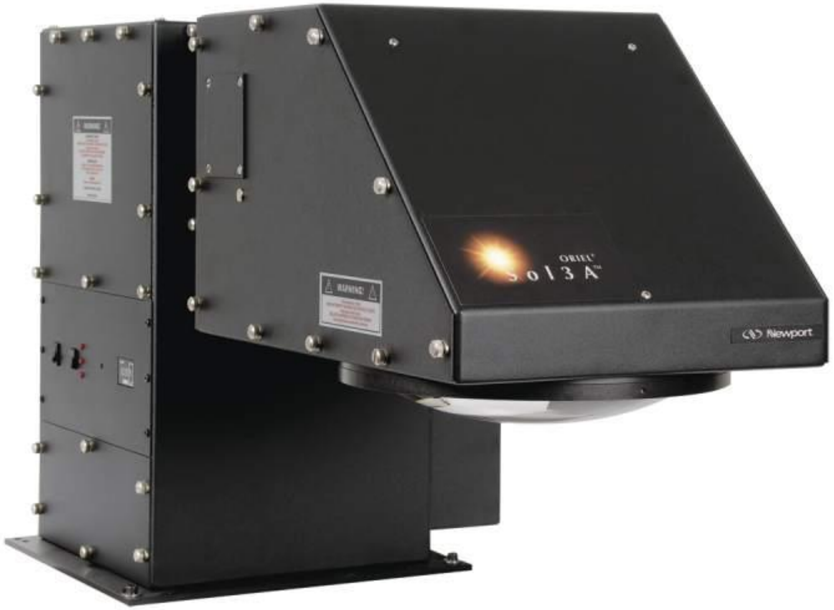
Phase 2: 2^{nd} year plans

Cryogenic Selective Surfaces

Testing with a Solar Simulator



KSC's new cryo-cooler system with sapphire window—low fidelity solar simulator testing.



Our partner at the Glenn Research Center has purchased a Newport Solar Simulator which will be mated to a cryo-cooler to allow higher fidelity testing.

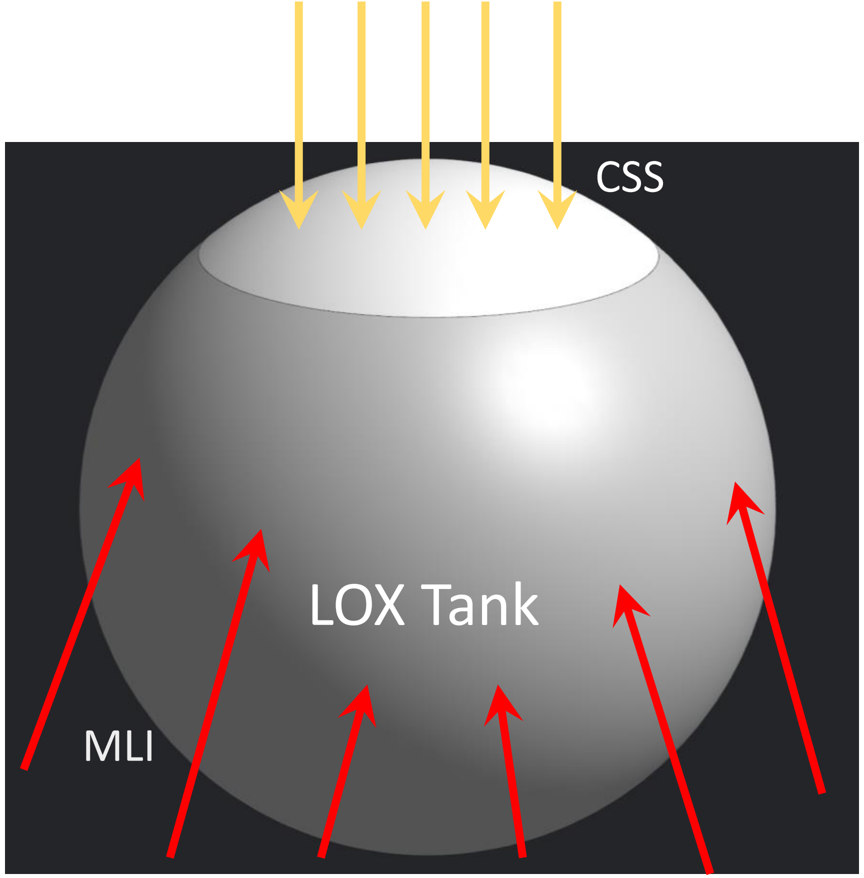
The goal is to test in the summer of 2018.

Cryogenic Selective Surfaces

New-near term Mission Impact

Maintenance of LOX in low earth orbit.

The sun illuminates the cryogenic selective surface (CSS) portion of the LOX tank.



Earth IR and Solar Albedo illuminate the multi-layer insulation (MLI) covered section of the LOX tank.

The launch service program wants to maintain LOX in low-earth orbit. Our new coating can minimize the solar heat load, but it will absorb the infrared radiation generated by the Earth.

We are considering a LOX tank with multi-layer insulation (MLI) coating the lower section and our new coating on the top.

Early analysis shows our coating may be able to radiate sufficient power to make up for the heat that gets through the MLI, allowing LOX to be maintained passively in a low earth orbit tank.

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Phase 2: 2^{nd} year plans

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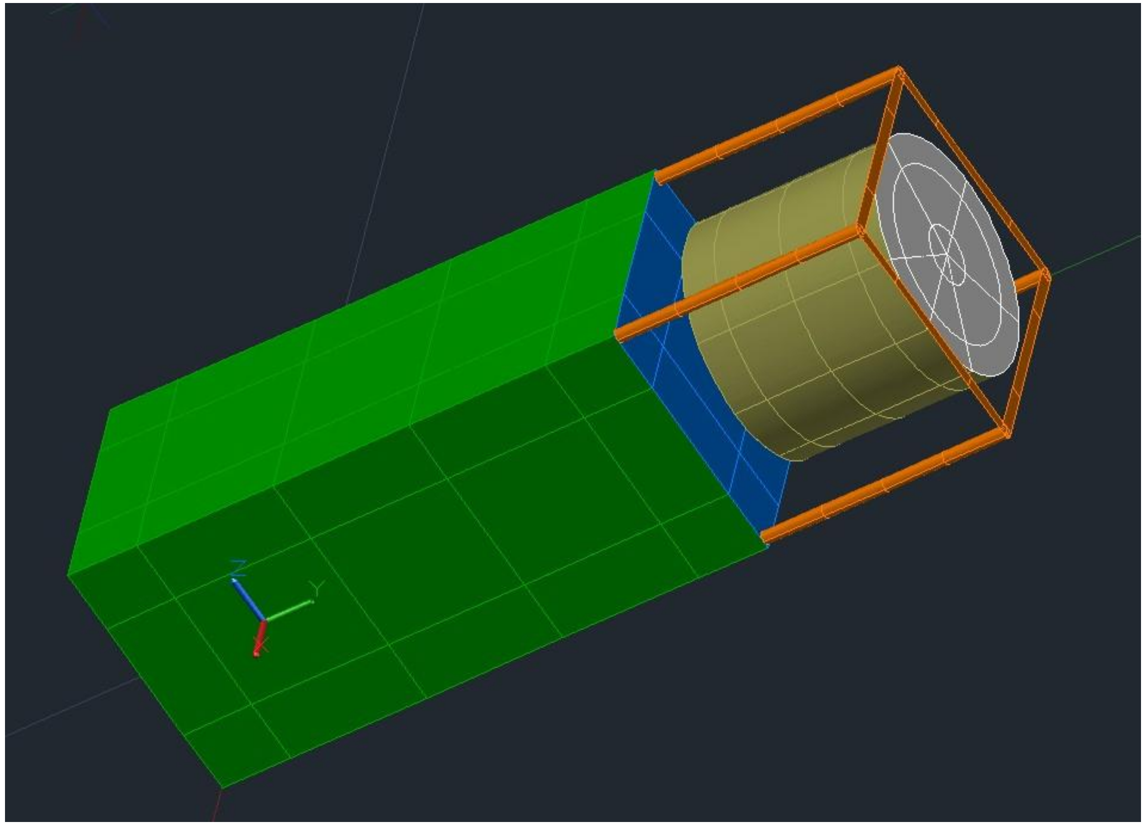
We've begun modeling a possible Cube-Sat to test the low earth orbit concept.

The Launch Service Program has agreed to fund a portion of this development.



A 3-U Cube-Sat with a cylindrical test cell in the top cube.

Beyond NIAC

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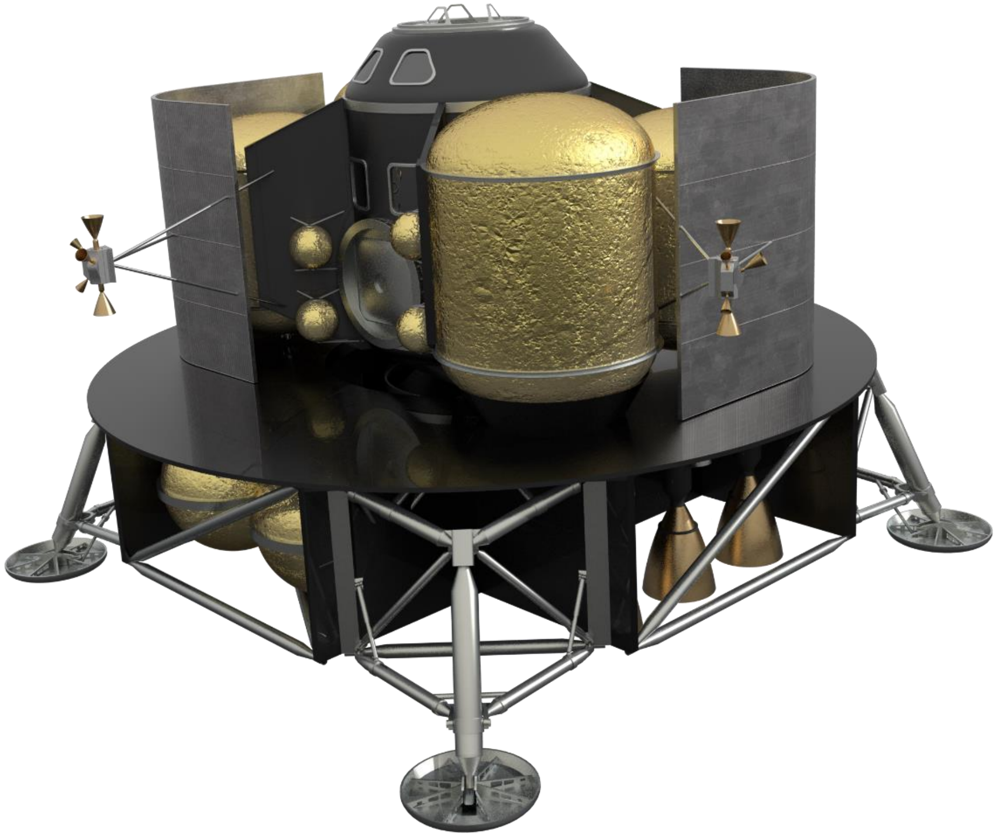
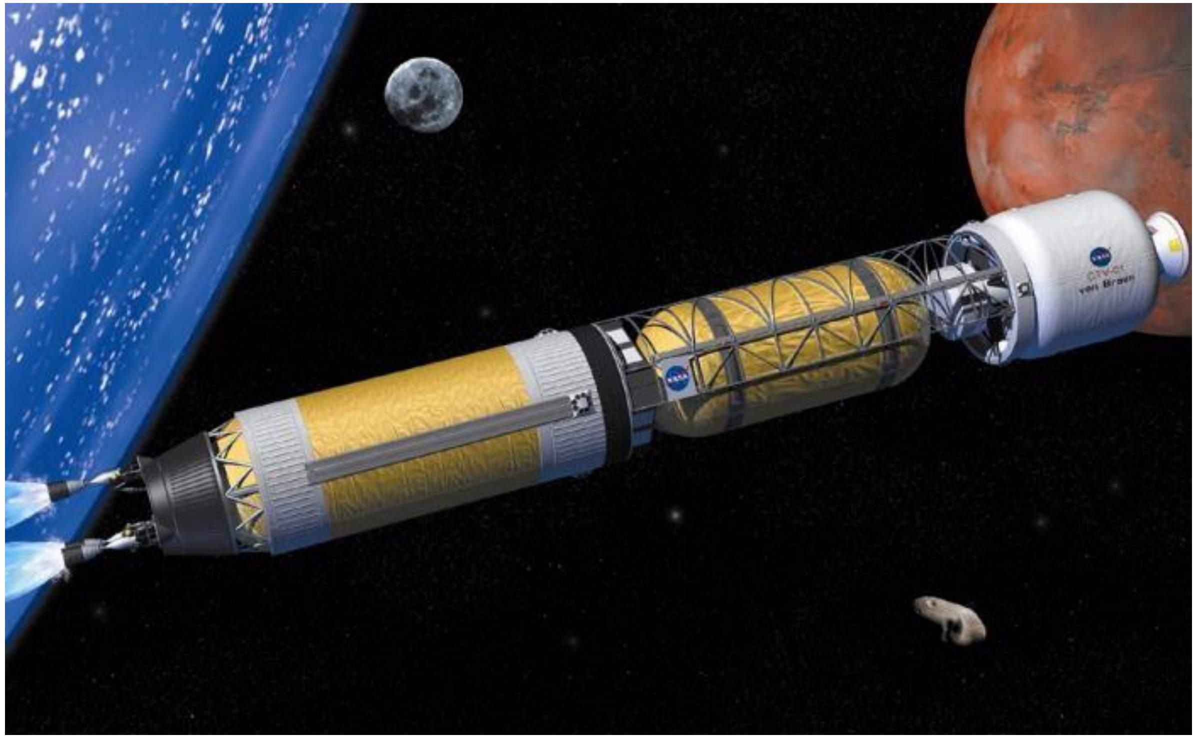


A concept image of a Mars Lander with liquid oxygen and liquid methane.   One of the liquid methane teams is current considering our coating.



Development of a liquid hydrogen based nuclear thermal rocket is underway. We have been asked to consider the impact of our new coating on the cryogenic thermal management of this vehicle.

Cryogenic Selective Surfaces

Co-funding provided by

The Kennedy Space Center

The International Space Station

The Launch Service Program

NASA's Game Changing Program

Various programs at the Glenn Research Center.

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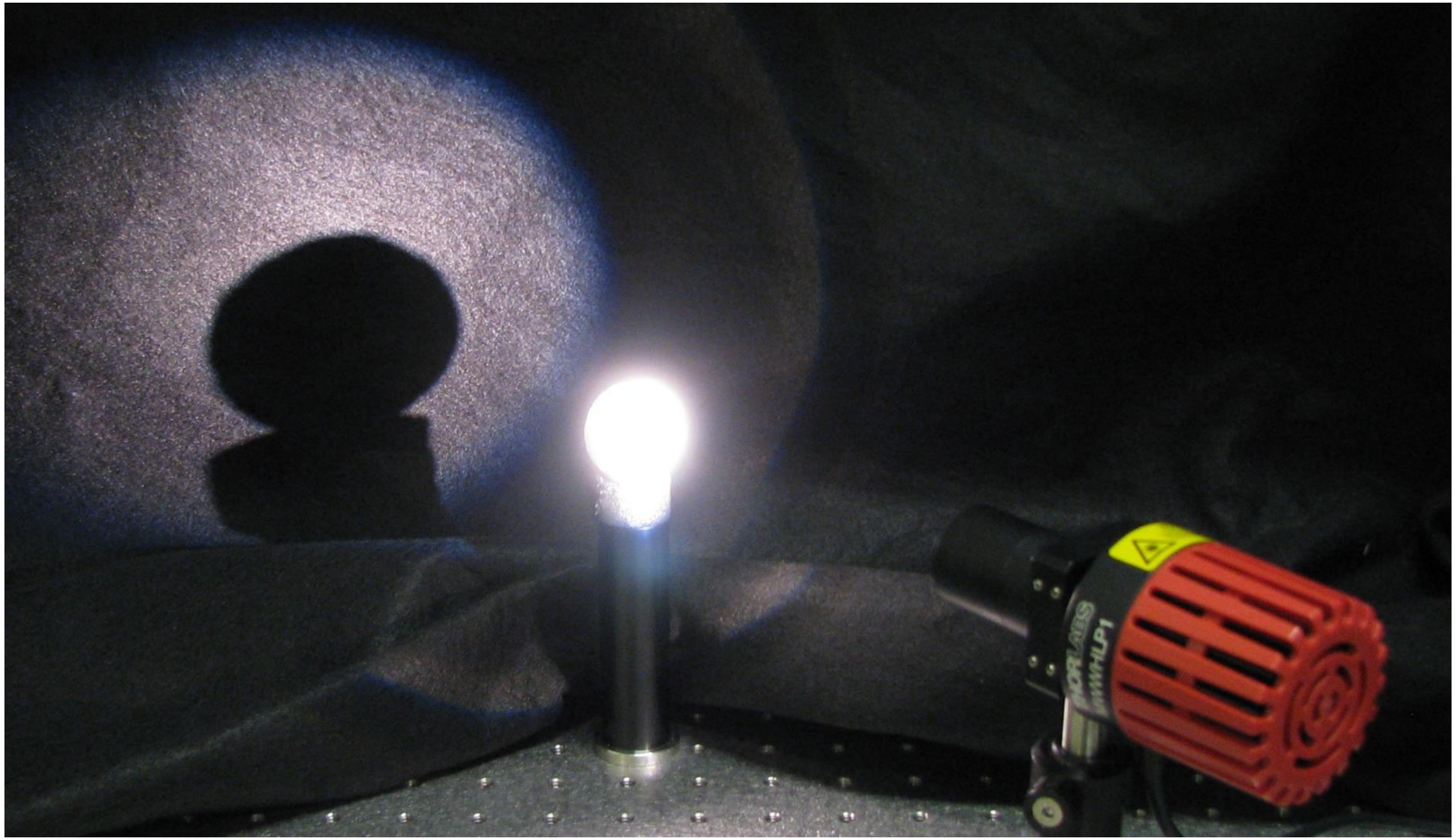
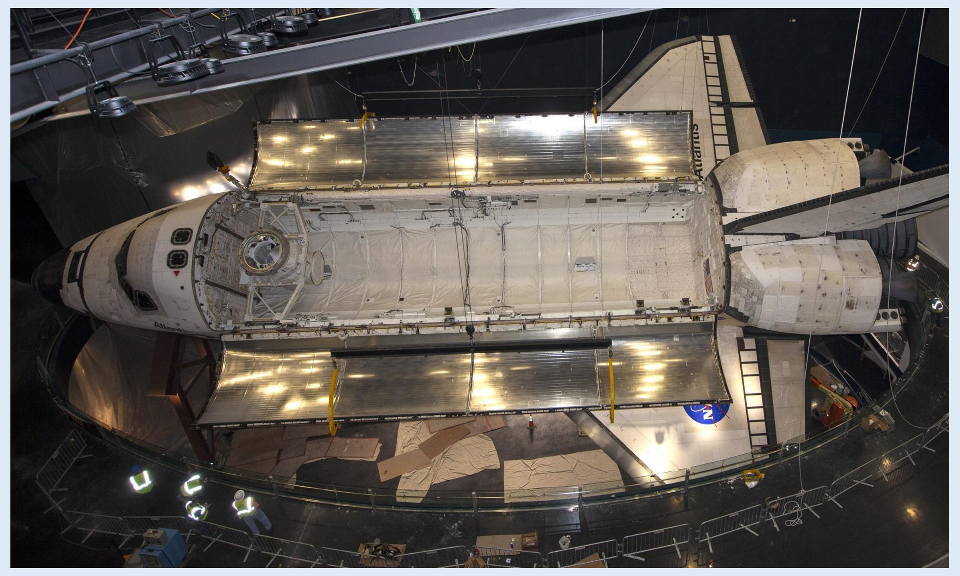
Questions?



Cryogenic Selective Surfaces

Robert C. Youngquist, Mark A. Nurge and Tracy Gibson, Kennedy Space Center, Wesley Johnson, Glenn Research Lab

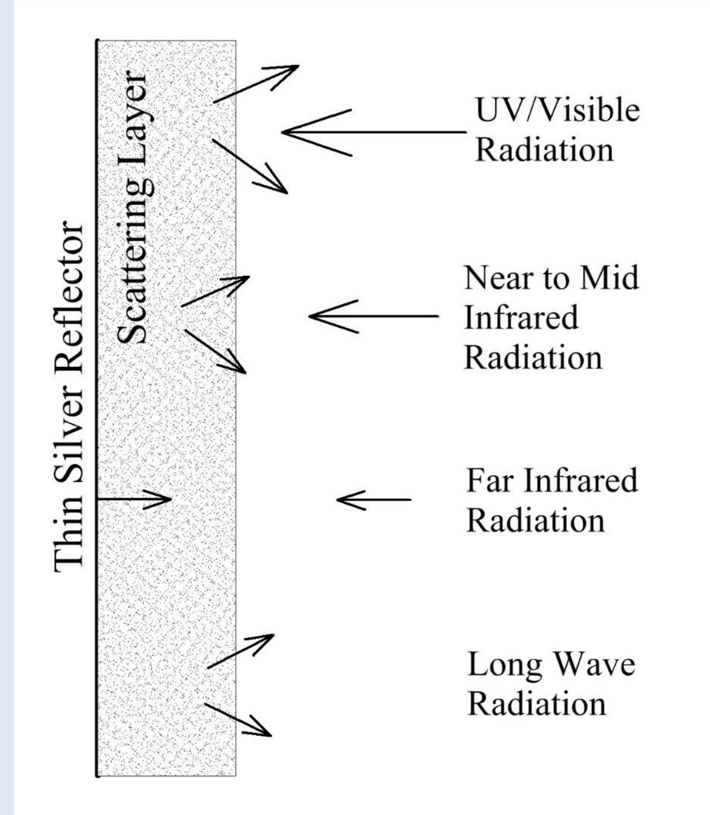
Selective Surfaces (i.e. thermal control coatings) reflect Sunlight while emitting IR energy, providing cooling.



The Payload Bay doors of the Space Shuttle Orbiter were coated with a selective surface to allow heat rejection in the presence of the sun.

But these coatings absorb 8-10% of the Sun's irradiance and cannot be used to reach cryogenic temperatures.

During our Phase 1 we proposed a new coating



First, choose a material that absorbs essentially no radiation from 0.2 microns to the mid or far infrared range, e.g. MgF2, CaF2, BaF2, KBr, NaCl, etc.

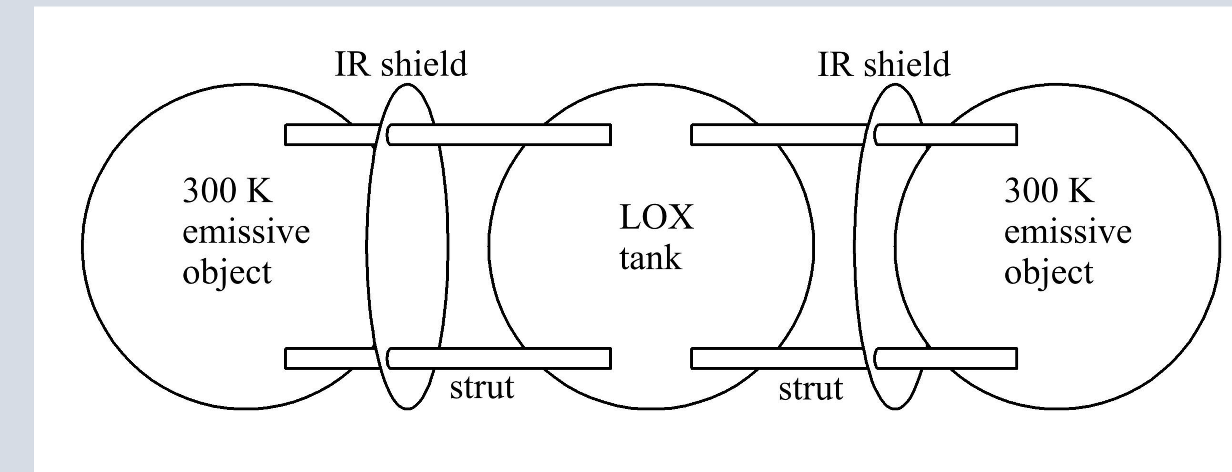
Second, grind this material into 200-300 nm diameter particles and make a 3-10 mm layer of this powder. This layer will scatter UV, visible, and near infrared light effectively, but not longer wave radiation.

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

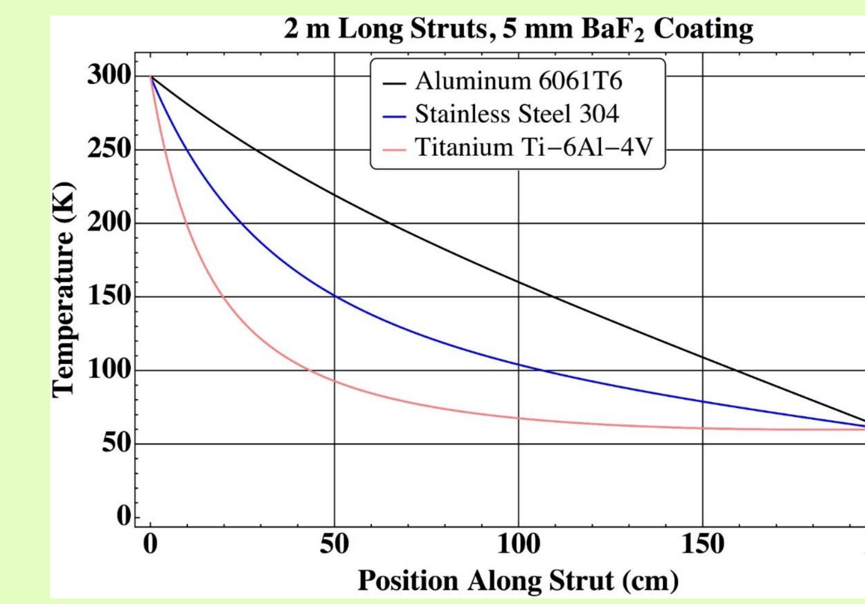
The coating will emit long wave radiation beyond its transparency cut-off.

We modeled this coating, projected that cryogenic temperatures could be reached, published our work in Optics Letters (3/16) and applied for a patent.

We showed that with this new coating we can take LOX to Mars



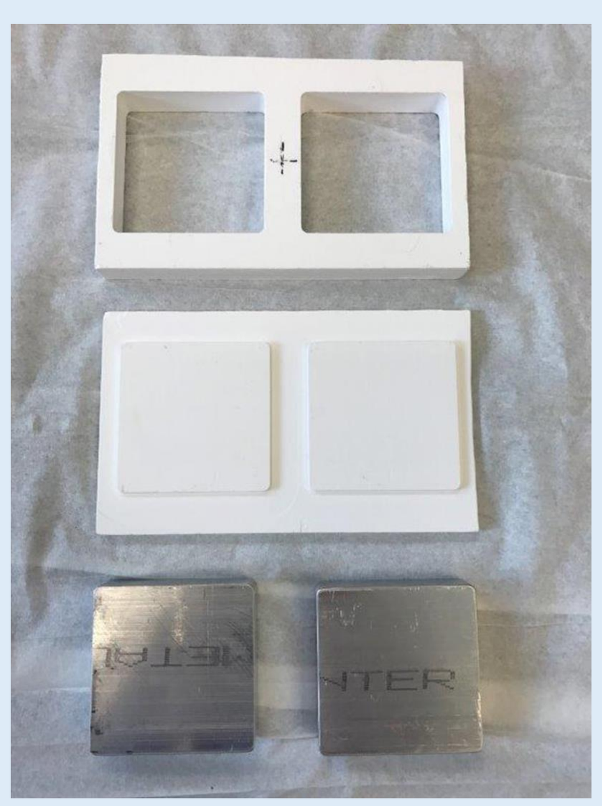
If we coat the LOX Tank with our cryogenic selective surface to minimize solar absorption, use coated struts (as shown to the right), and use IR shields composed of multi-layer insulation, the heat load will be sufficiently minimized to allow LOX storage on a trip to Mars.



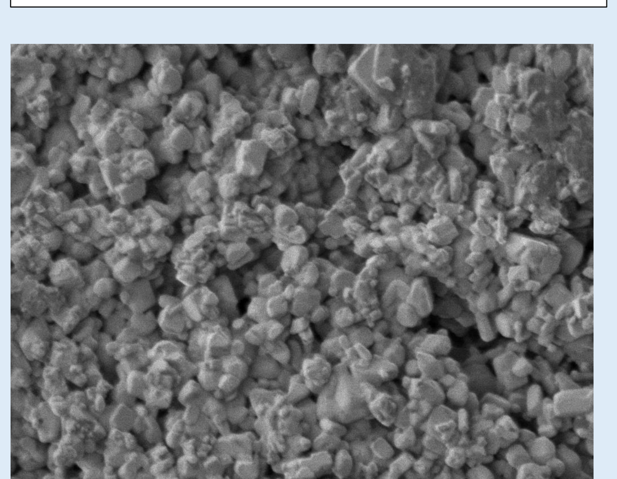
Analysis shows that coated Titanium struts chill sufficiently that no heat is conducted to the LOX tank from warm sections of the vehicle.

Hibbard (1961) showed that 40 K could be achieved with ideal materials. But real world materials are not ideal. We have found a material that is closer to the Hibbard ideal than any off-the-shelf coating.

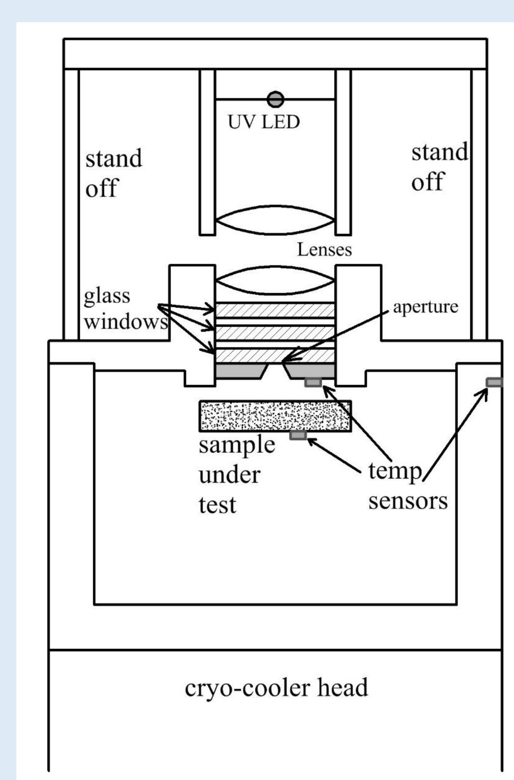
Phase 2 First Year: Rigid Material, Ultraviolet Testing

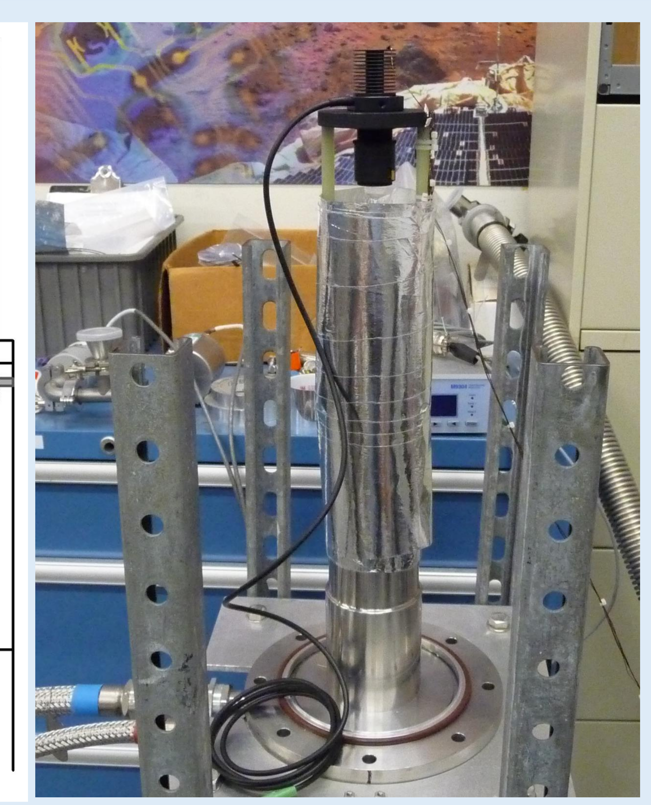


We can now make rigid coatings. Mix powder (BaF2) with water to make a paste. Mold it and sinter it to form a solid entity. The SEM image below shows that we've retained the particles needed for scattering.

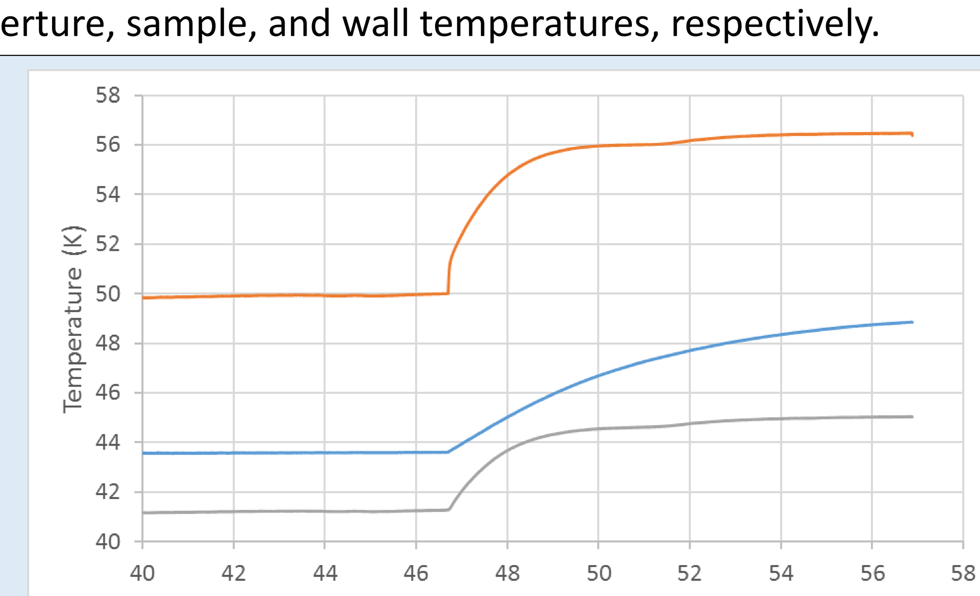


Above is a small BaF2 solid disk with mounting holes drilled into it. Below is our largest disk, measuring more than 3 inches in diameter.



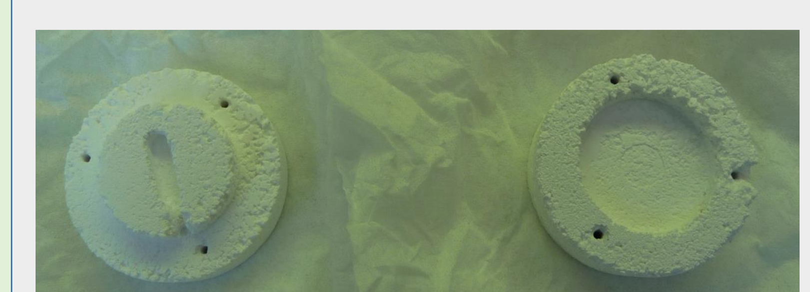


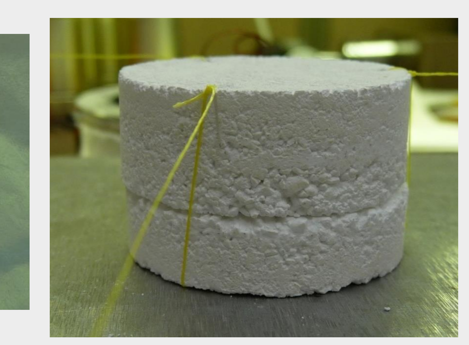
The samples are tested in a simulated deep space environment, cold and under vacuum. Looking at the plot below, turning on a 375 nm UV LED at hour 47, shows that less than 0.25% of the radiation hitting the BaF2 sample is absorbed—partially validating the concept. The orange, blue, and grey plots are the aperture, sample, and wall temperatures, respectively.



Phase 2 Second Year: Better Coatings, Solar Testing, and a New Mission

Coating Development



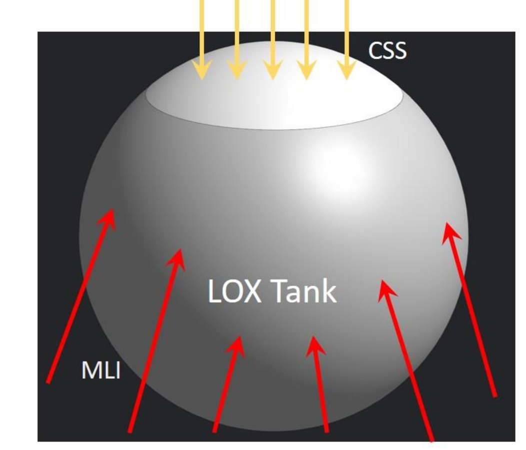


1. How do we attach it?
2. How thick should it be?
3. How strong is it?
4. Can it handle launch vibrations?
5. Can it be cold shocked?
6. How do we clean it?
7. Can it be sealed?
8. Is the silver working properly?

A New Mission

The Launch Service Program needs to maintain LOX in low-earth orbit. Analysis shows that using our coating on the top, to radiate away heat, even in sunlight, while using MLI on the bottom and sides to minimize Earth sourced radiation should allow LOX to be stored with zero boil-off.

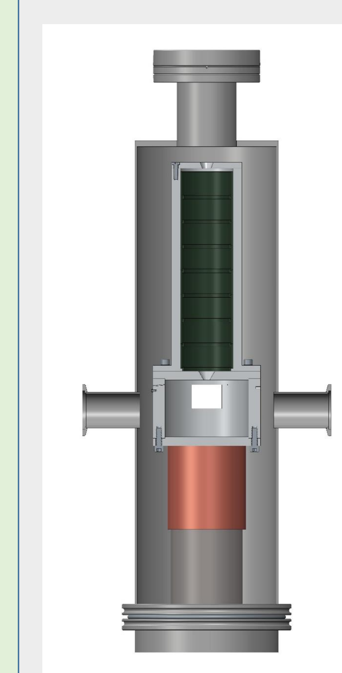
The sun illuminates the cryogenic selective surface (CSS) portion of the LOX tank.

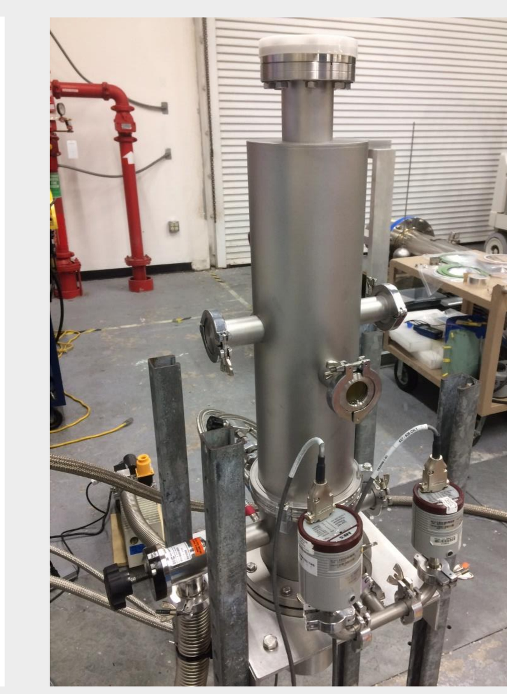


Earth IR and Solar Albedo illuminate the multi-layer insulation (MLI) covered section of the LOX tank.

We will be considering the impact of our new coating on nuclear thermal propulsion.

Solar Simulator Testing in Deep Space Conditions





We have a new cryo-cooler system that will allow an external light source. So we can do limited solar exposure tests. Glenn Research Lab will be doing higher fidelity solar exposure tests next summer with the source shown below.