Cryogenic Selective Surfaces—How Cold Can We Go?

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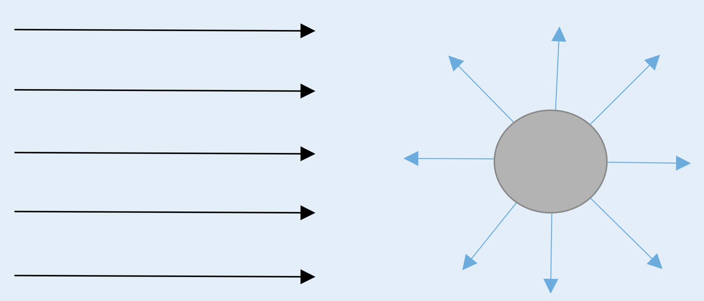
The Concept

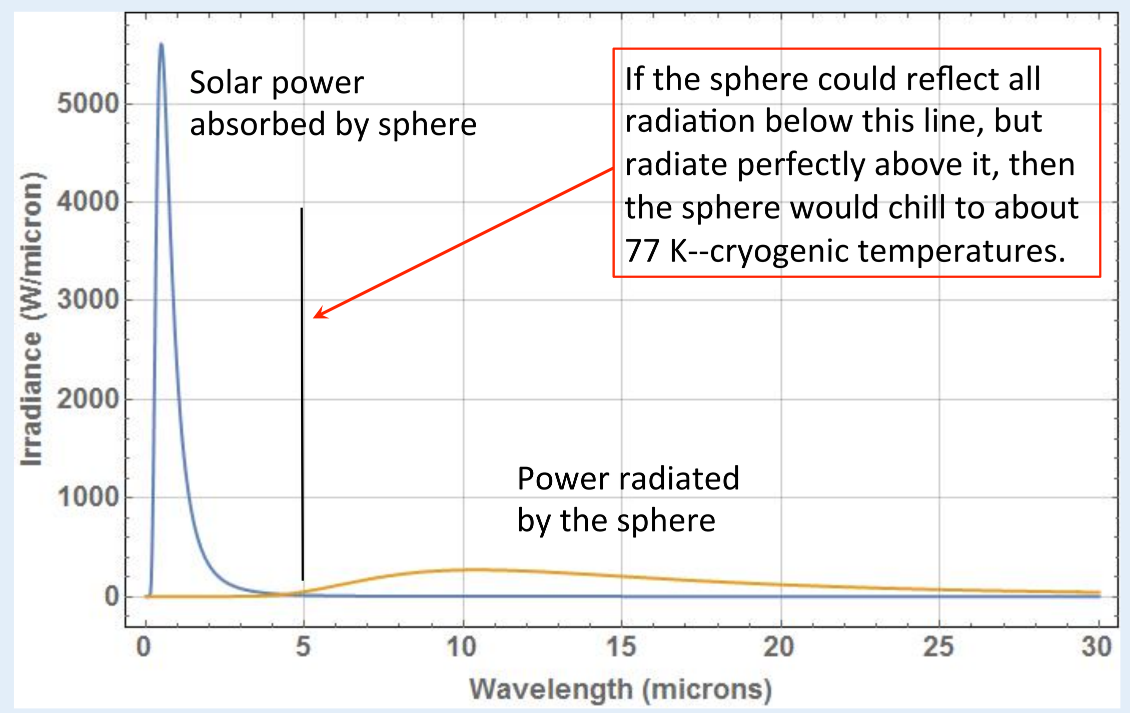


The sphere radiates infrared power.

Radiation from the sun hits the sphere.

A sphere located in deep space 1 A.U. from the sun.

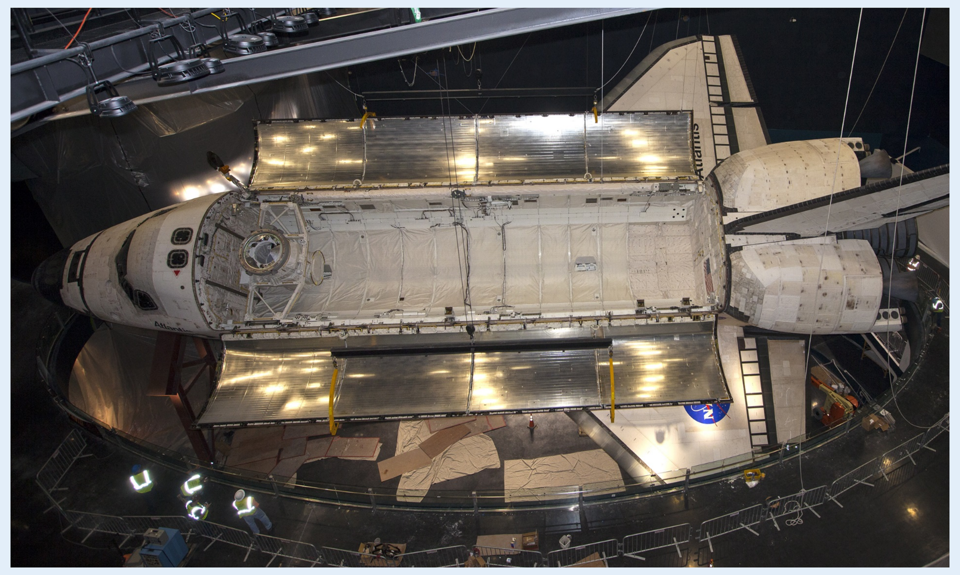
Assuming constant emissivity, the sphere will reach an equilibrium temperature of about 280 K (about 42 degrees F).



The area under the curves is equal, but the sun's irradiance is at a much shorter wavelength than the irradiance produced by the sphere.

Surfaces designed to reflect one wavelength band and absorb the other are called **Selective Surfaces**.

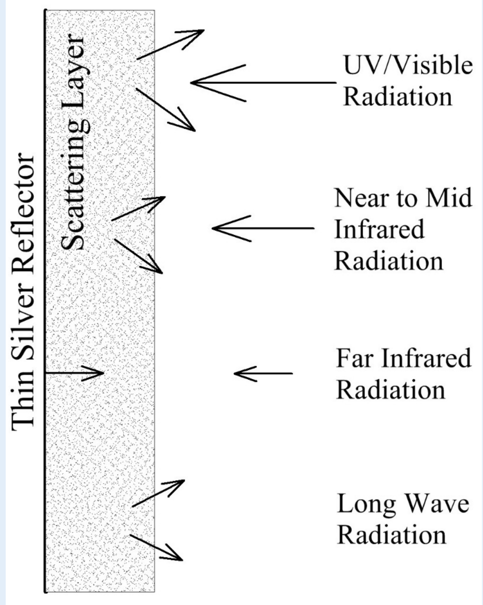
Selective Surfaces are already used in space applications, but not at cryogenic temperatures.



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.

The Hubble Space Telescope also uses a selective surface to reduce solar heating.

A New Selective Surface—"Solar White"



1st, 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.

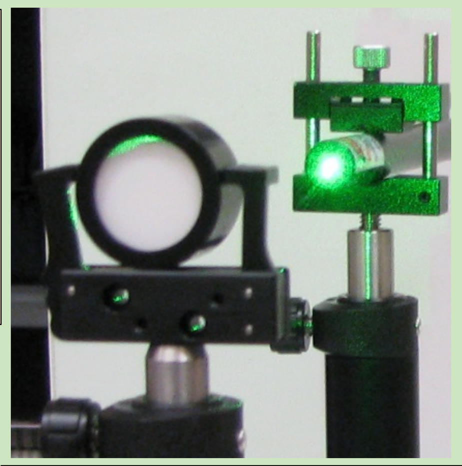
2nd, grind this material into 200-300 nm diameter particles and make a 3-10 mm layer of this powder. This layer will scatter UV, visible, and near infrared light effectively, but not longer wave radiation.

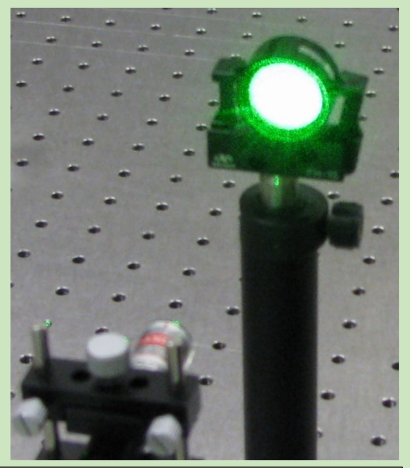
3rd, place this layer on a metallic reflector (e.g. silver) to reflect the longer wave radiation that gets through the particle layer.

4th, The coating will emit long-wave radiation beyond its transparency cut-off.

The paint industry uses TiO_2 particles to scatter visible radiation, so "items" look white.

Let's put 6 mm of TiO_2 powder into a 1 inch diameter cell and hold it in place with two glass windows, as shown below. Then launch a 5 mW laser beam at this thin layer of powder.



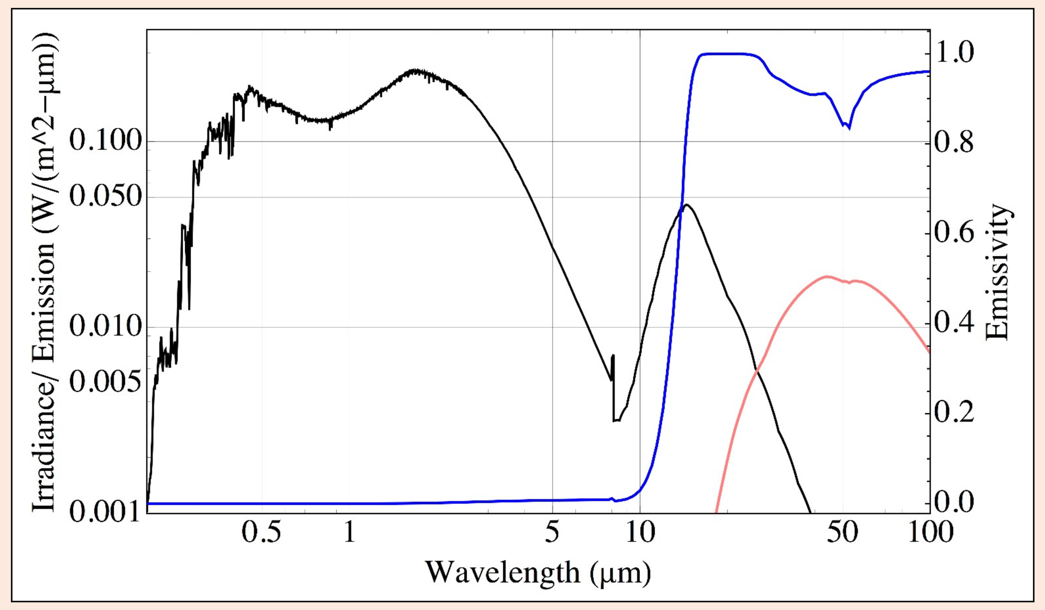


Nearly all light is reflected with no apparent transmission!

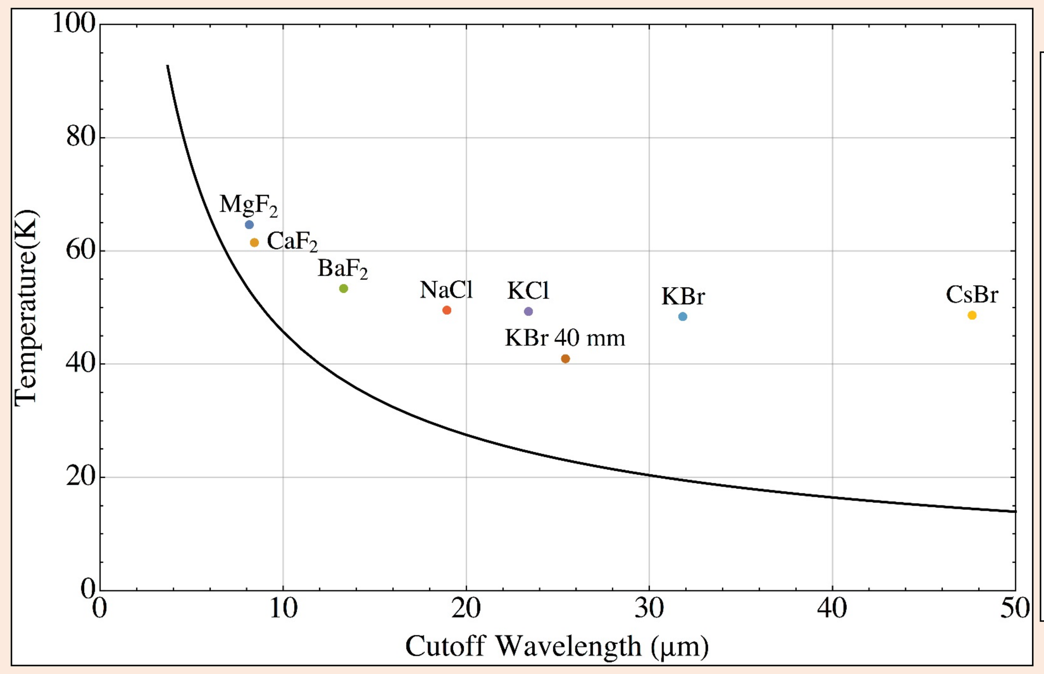
Hibbard (1961) showed that 40 K could be achieved with ideal materials. But real world materials are not ideal. The key question is, can we reach cryogenic temperatures with a realizable selective surface?

Modeling

We developed models—identical to published paint theory models—and coupled these to Mie scattering models, to predict the performance of our new coating. The plots below show the solar absorbed spectrum, the emitted power spectrum, and the emissivity for a 5 mm thick layer of BaF_2 on silver on a flat plate facing the sun, coated on both sides.



A coated 1 m radius sphere only absorbs about 3.5 Watts out of the 4300 Watts of solar power hitting it, enabling it to reach a predicted temperature of about 53 K !!



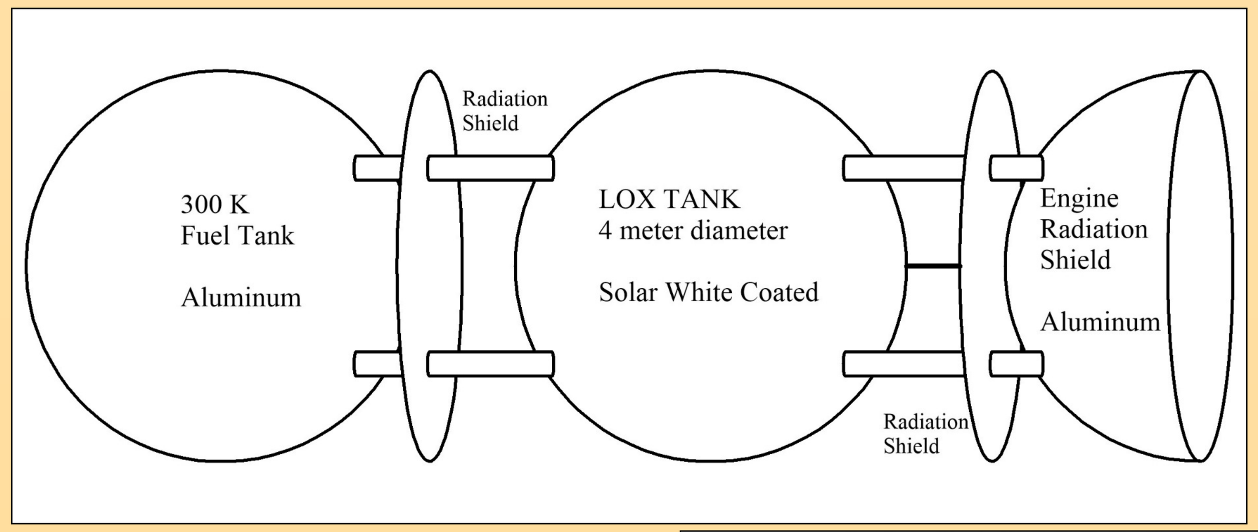
We modeled our sphere with 5 mm coatings on silver using seven broadband spectroscopy materials.

Predicted temperatures, compared to those achievable by a Hibbard selective surface are shown to the left.

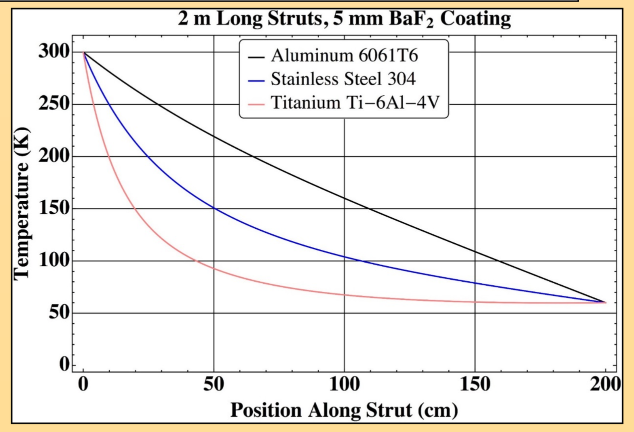
LOX to Mars

Here is a possible configuration where a LOX tank is located between a warm fuel tank and warm engine/nozzle.

Solar White does not effectively reflect long wave infrared radiation, so radiation shields are needed to block that radiation from the warm portions of the vehicle and from nearby planets, such as the Earth.



We calculate the temperature along a 2 m strut coated in Solar White in full sunlight and find that titanium struts chill sufficiently so that no heat is conducted to the LOX tank from warm vehicle items.



Power Budget with radiation shields for 5 mm BaF2 Solar White Coating

Solar Irradiance	13.5 Watts
IR Load from the shields	10 Watts
Struts	0 Watts
Fuel line	3 Watts
Total	**26.5 Watts (63 K)**

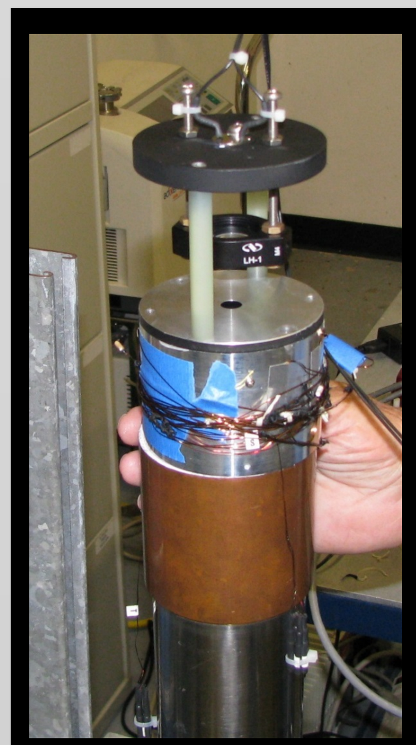
On a trip to Mars via Venus, the total heat load can rise to about 54 Watts (70 K)

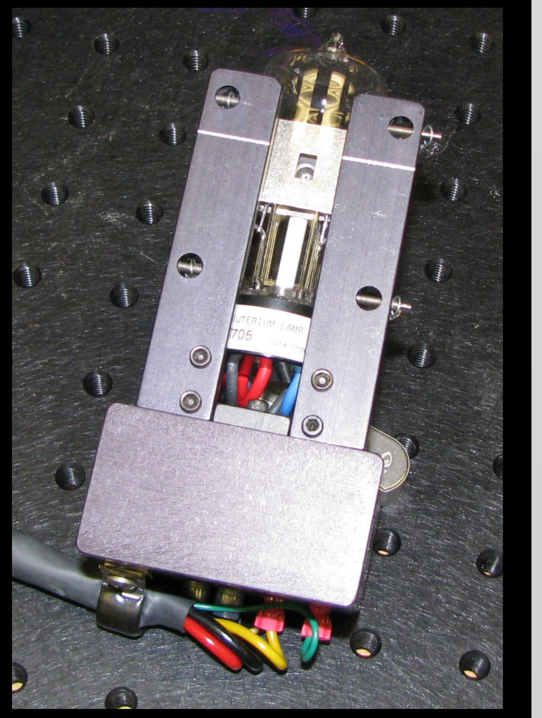
Planetary infrared radiation can raise these values, while using a thicker coating or switching to KBR can lower them.

Experiments and Plans

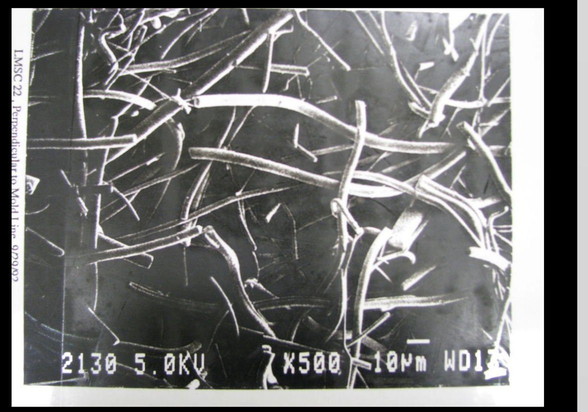
Goals:

- Test "Solar White" sufficiently so its performance can be verified.
- Construct rigid versions of the coating (not based on powders).





We started testing powders in a cryo-cooler with an infrared emitter. We plan on moving to a deuterium lamp to measure ultraviolet absorption.



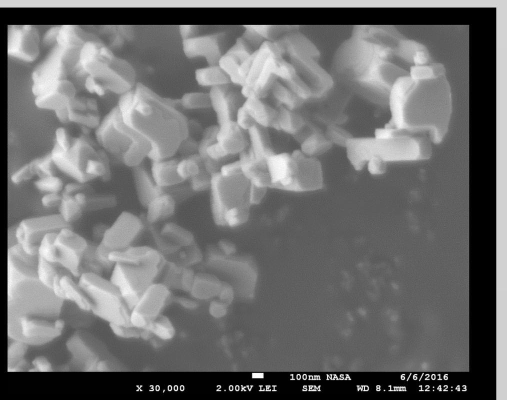
Shuttle tile material is an example of a rigid, single transparent component material. Note how white the tile appears and the corresponding SEM photo.

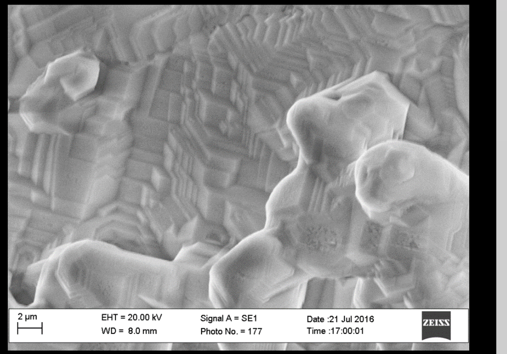
Solar White should allow cryogenic storage, superconductor operation, and the development of better thermal shields for deep space operation.

We have published our work (Optics Letters, March 2016) and have a patent application.

We have obtained co-funding from KSC and from the Launch Service Program.

We are in discussions with the Florida Institute of Technology, the International Space Station Program, the John Hopkins Applied Physics Laboratory, and STMD's Game Changing Development Program to plan the future of this work.





BaF_2 is a promising material. It can be purchased as a powder with correct particle size.

We tried sintering it to form a rigid coating, but the first attempt caused melting of the particles, as seen above.