Solar Surfing-Phase I

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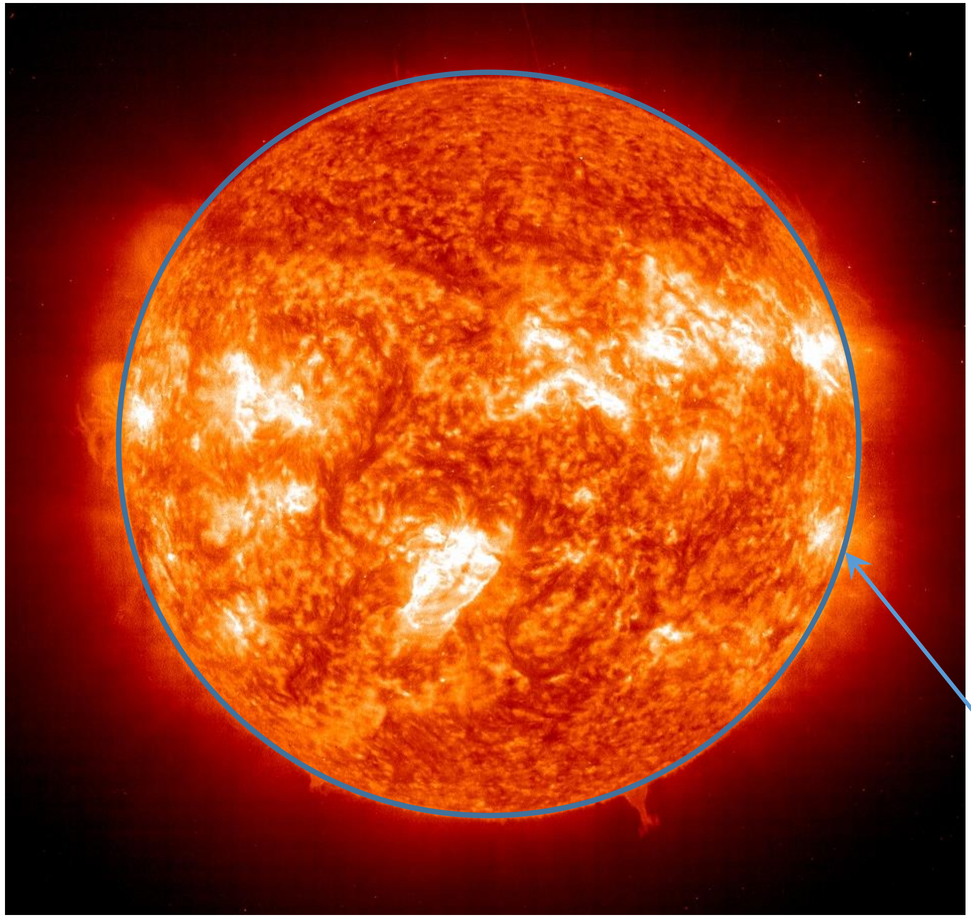
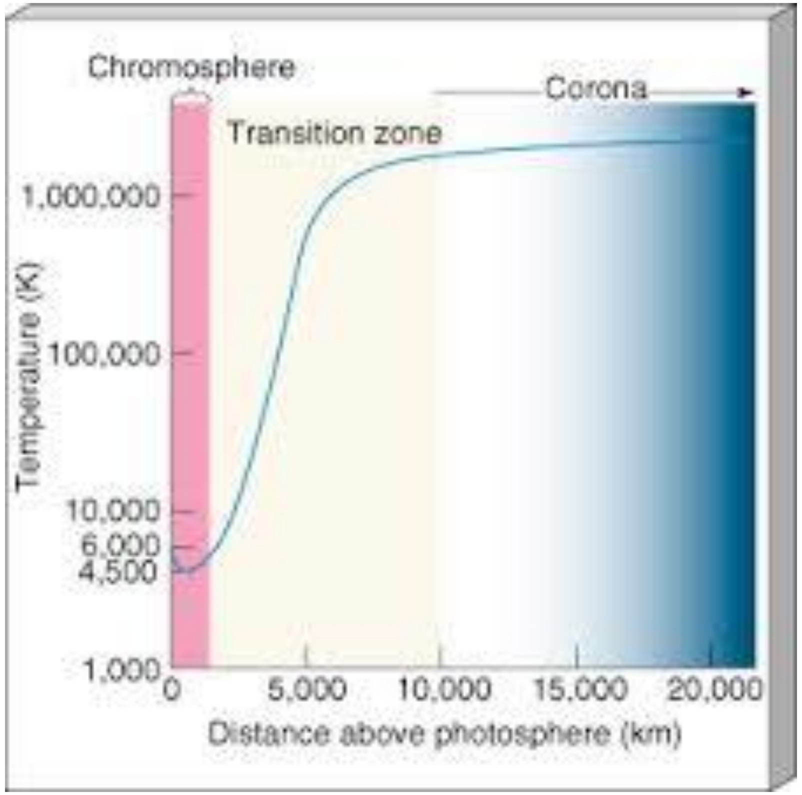
The surface of the Sun is about 6000 K, but within 10,000 km of this surface the temperature transitions to over 1,000,000 K. The cause of this temperature rise is not understood and several Solar missions have set out to explore this transition zone.



The transition zone to scale.

The radius of the Sun is about 700,000 km.



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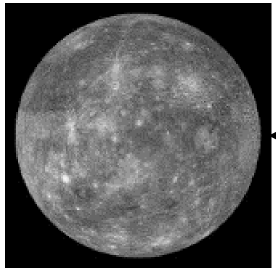
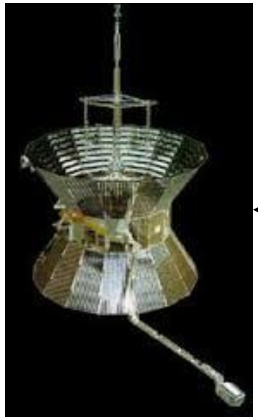
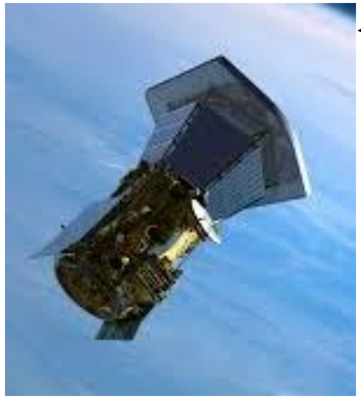
The Earth is about 214 Solar Radii from the Sun.



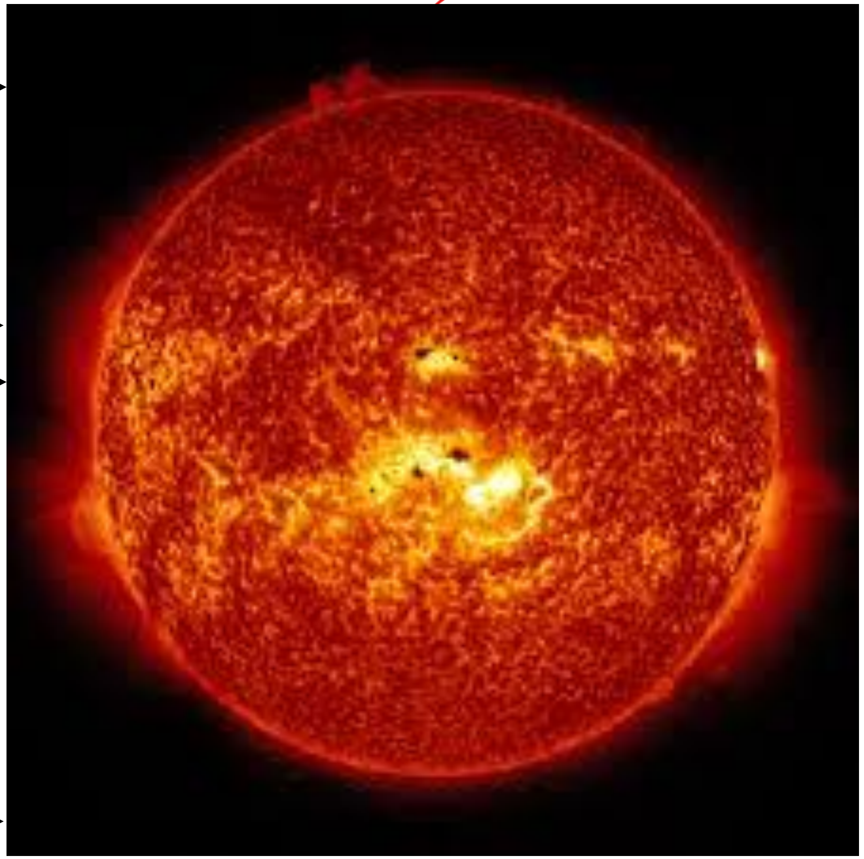
Mercury is about 100 Solar radii from the Sun.



Helios B (1976) approached the Sun to within 62 Solar radii.



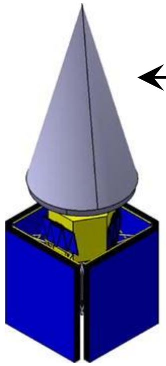
The Parker Solar Probe will reach 8.5 Solar Radii from the surface of the Sun, touching the edge of the corona!



Other Heliophysics Missions

Solar Orbiter (2018)
Solar Observatory (SOHO) (1995)
Transition Region and Coronal Explorer (TRACE) (1998)
Solar Dynamics Observatory (SDO)(2010)

PHOIBOS is an ESA proposed mission to come with 3.5 Solar Radii of the Sun.



We would like to get closer to the transition region and possibly even touch it.

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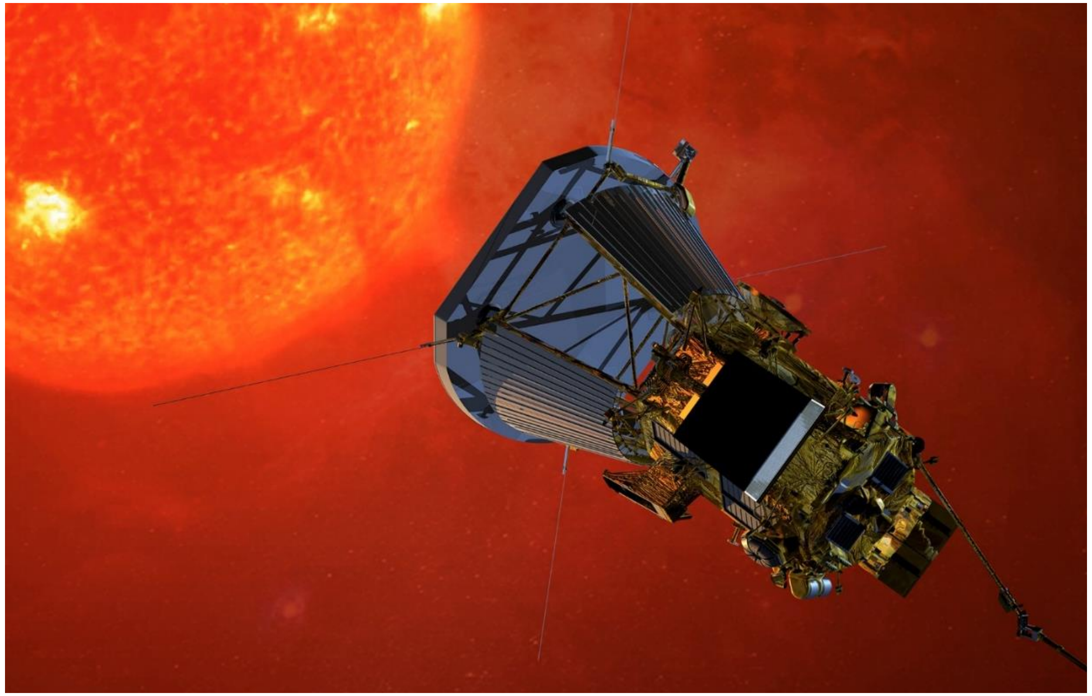
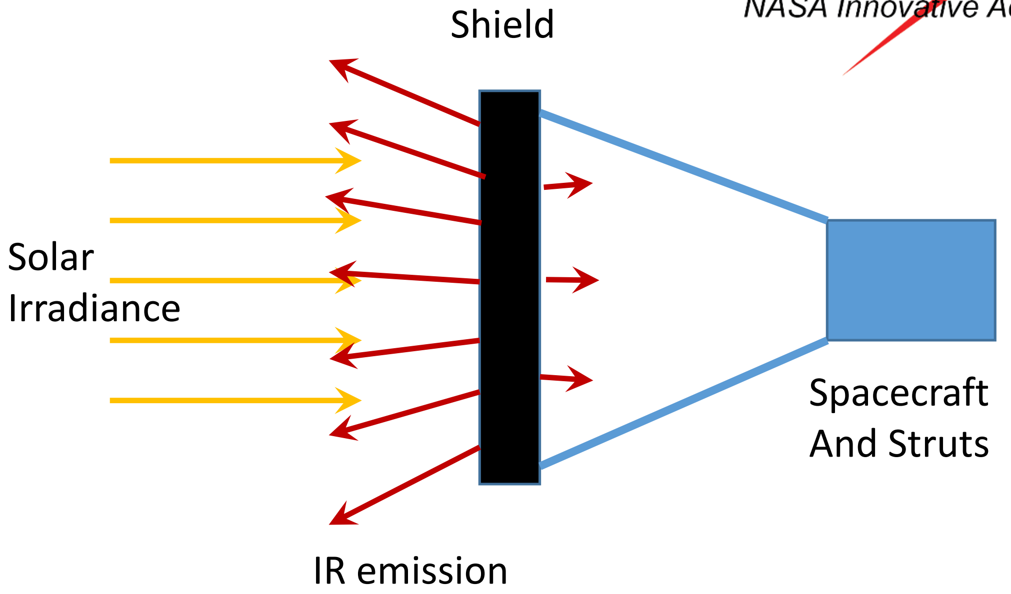
The Parker Solar Probe





The Parker Solar Probe uses a Carbon Composite solar shield with a thin ceramic white scattering layer. The result is that about 60% of the Sun's irradiance is absorbed.

The carbon composite heats to as high as 1700 K; radiating the Sun's absorbed power as infrared radiation.

Behind the carbon composite is a thick layer of carbon foam insulation and customized struts, minimizing the transmission of heat to the spacecraft.

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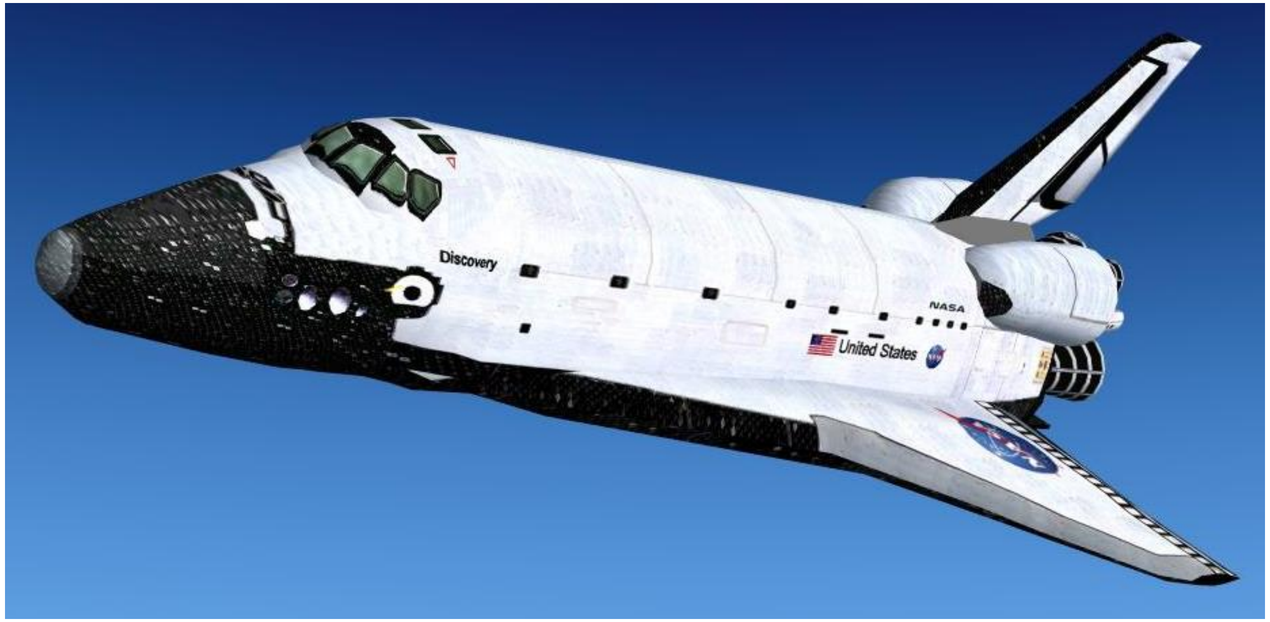
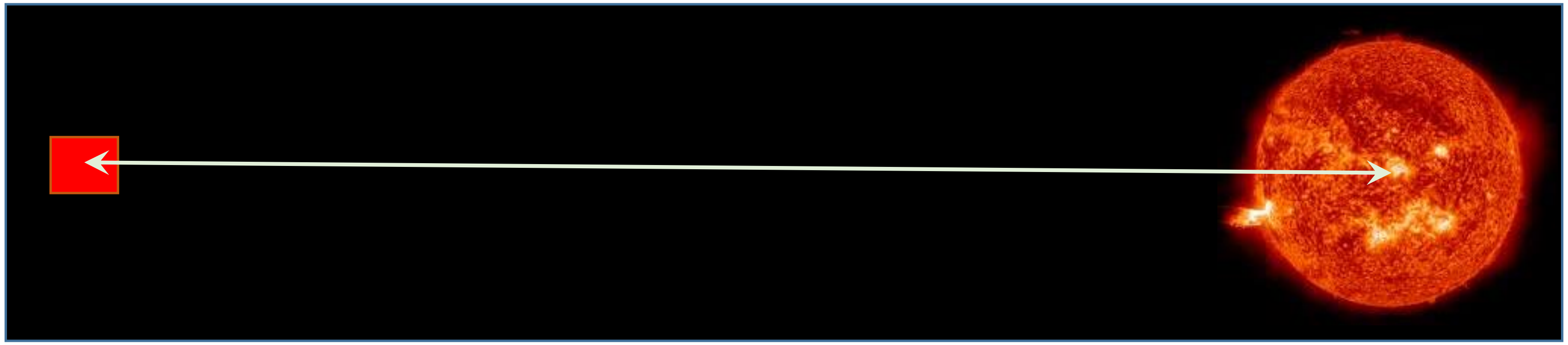


The light grey areas are reinforced carbon composite thermal protection. These reached over 1500 ^{o}C on reentry.

If we assume high temperature carbon composites can survive up to 2000 K, then approximate analysis shows the Parker Solar Probe can reach 8 solar radii from the Sun's center.

The design goal for the Parker Solar Probe is to reach 9.5 Solar Radii from the Sun's center.
At that distance it will absorb more than 350,000 Watts/m2 of the Sun's Power!!!

So how do we get closer?



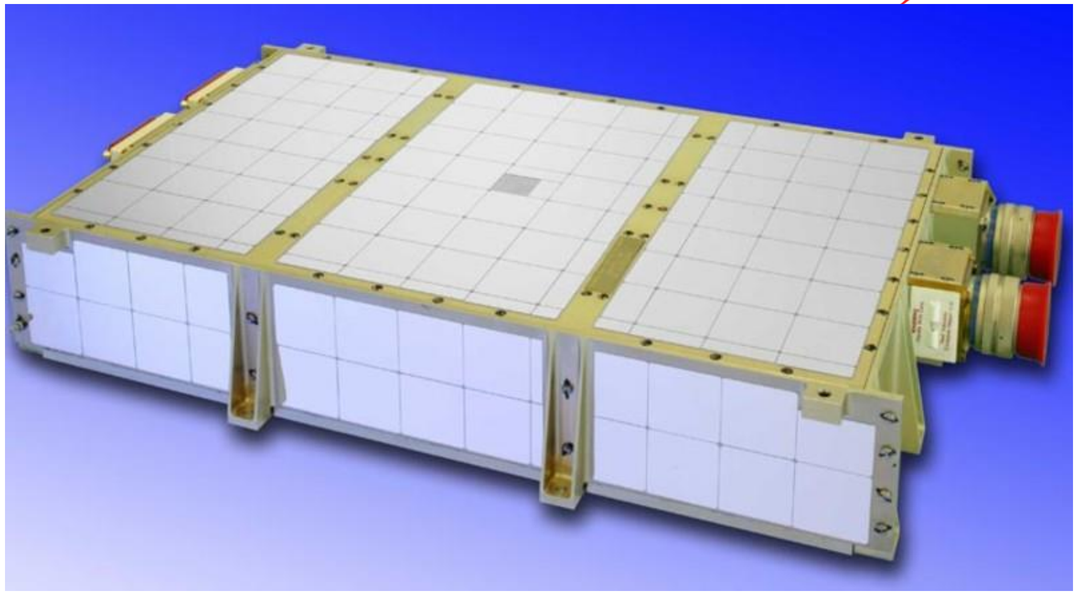
9.5 Solar Radii from the Sun.

Cryogenic Selective Surfaces

The best "optical solar reflector" absorbs 6% of the Sun's power.

This is the current state-of-the-art.

However, this is based on silver and silver absorbs substantial short wave (ultraviolet) radiation. At about 8 solar radii the silver will absorb enough energy that it will start to melt.



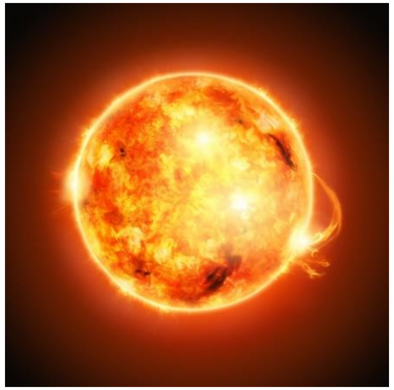
An object covered with a state-of-the-art solar reflector.

8 Solar Radii from the Sun.

Cryogenic Selective Surfaces

A better approach is to use scattering. Small, non-absorbing particles, scatter light and can be used to create white substances.

Snow, clouds, powdered sugar, white paint are all white because they are composed of small particles that do not absorb radiation and instead scatter it.



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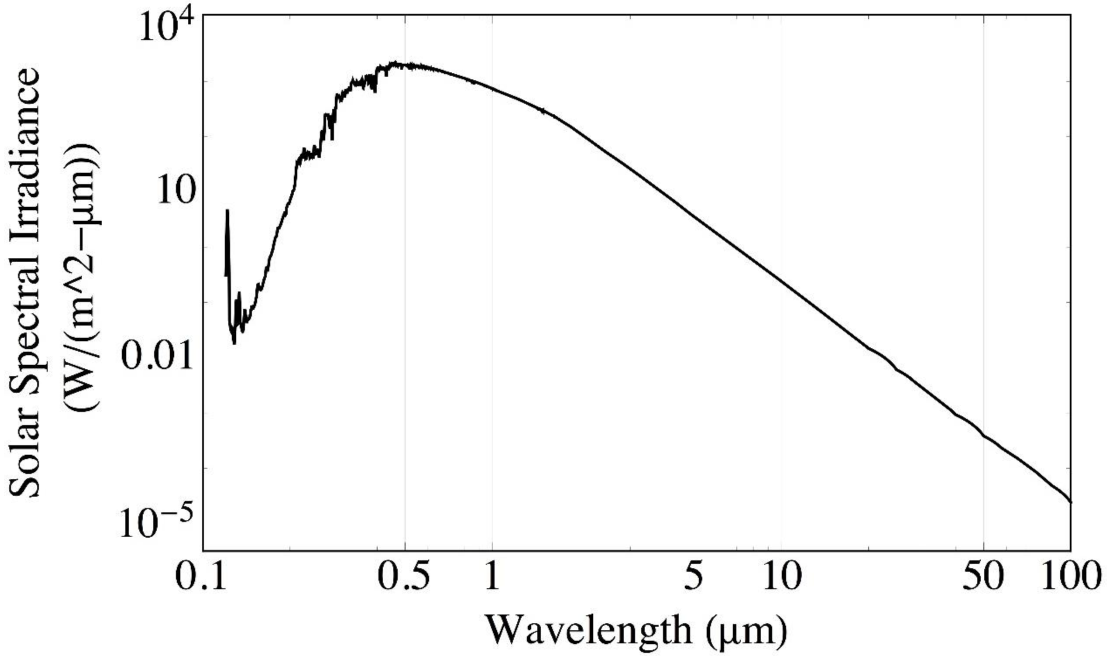
So we need a material that

1. Is transparent to as much of the Sun's spectrum as possible and
2. Can be ground into a fine powder and made into a coating.

<u>Fortunately there are several good materials:</u>

Barium Fluoride (BaF2) is transparent from 0.14-12 microns.

Potassium Bromide (KBr) is transparent from 0.21-20 microns.



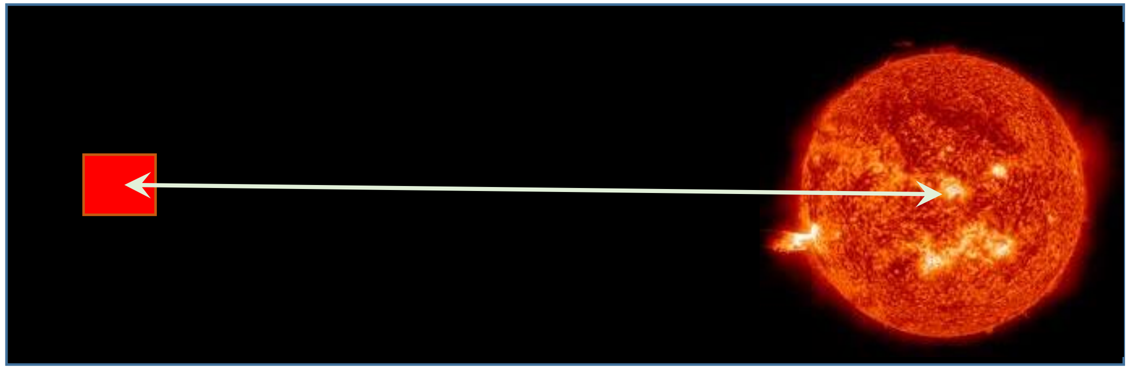
The Sun's spectrum.

Solar Surfing

Front and back surfaces of a rigid material composed of nearly pure BaF2 with a silver coating deposited on the back.

Our models indicate that a BaF2 powder based coating with a silver backing will only absorb about 0.1 % of the Sun's power.

However, even this will only allow us to reach about 5.5 solar radii from the center of the Sun a sintering temperature of about 1000 K is reached. This material cannot emit enough infrared energy to cool off.



5.5 Solar Radii from the Sun.

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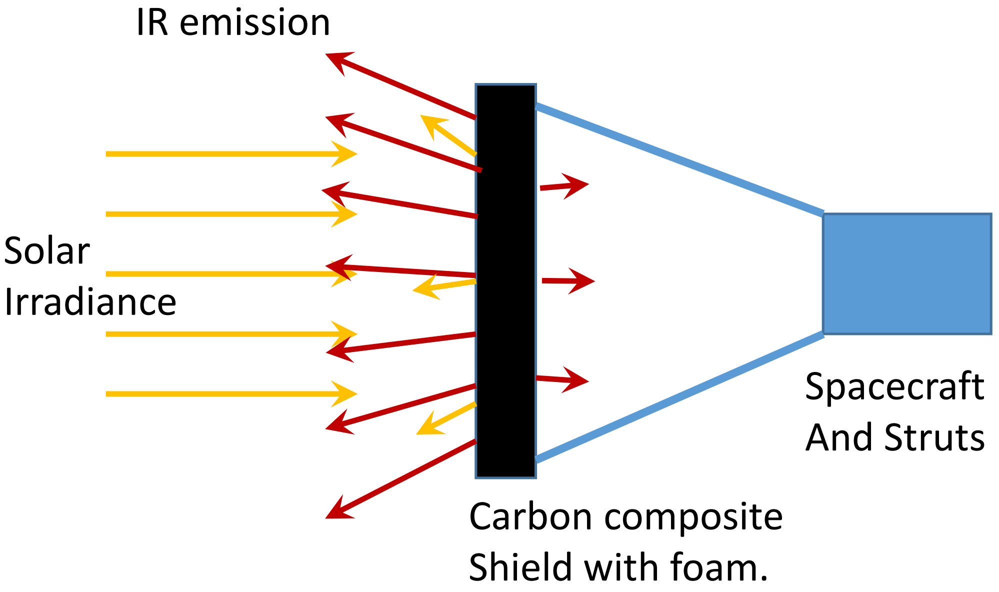
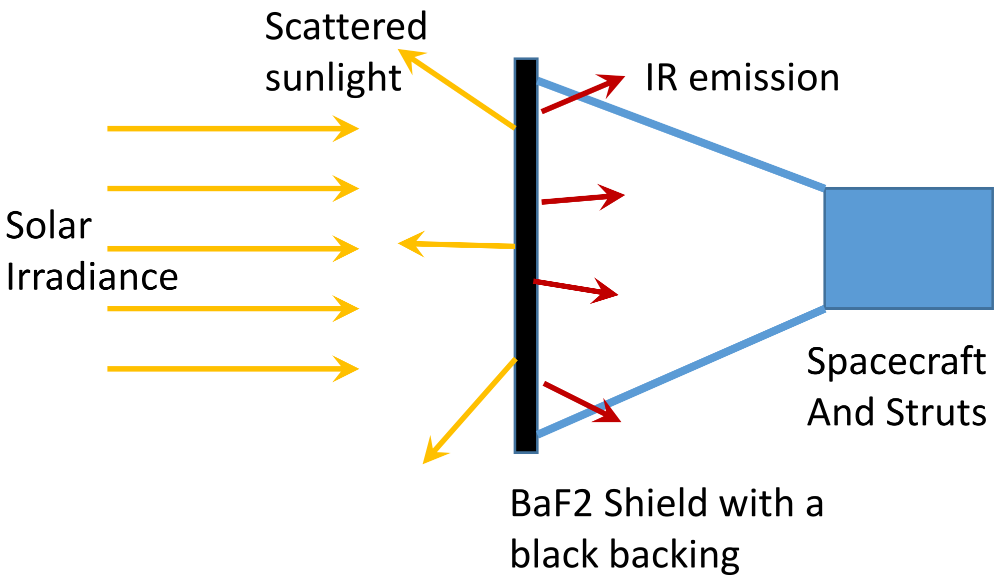
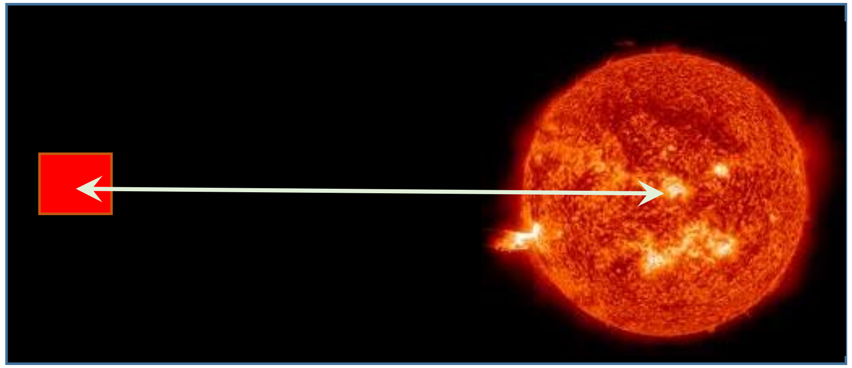


The Parker Solar Probe must protect the spacecraft from intense IR emission, so the shield emits primarily in the forward direction.



The BaF2 shield absorbs much less energy, so to a point it can radiate towards the spacecraft. At 7 Solar radii the shield's at 300 K (room temp)! But at 1 Solar radii the shield's at 950 K, which will cook the spacecraft.



4 Solar Radii from the Sun, the shield is at about 420 K.

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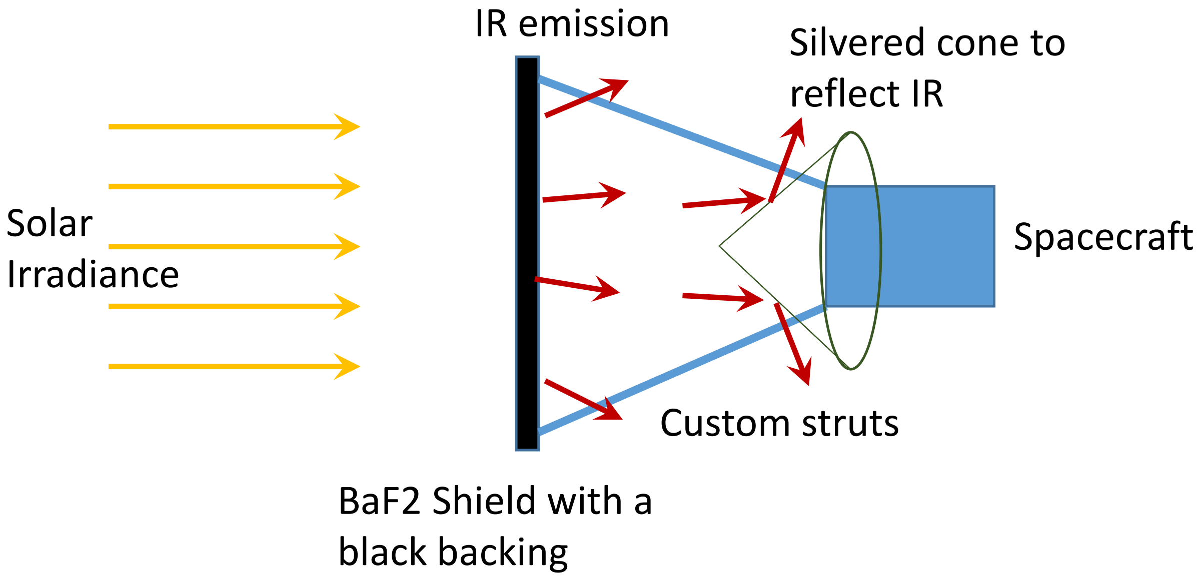
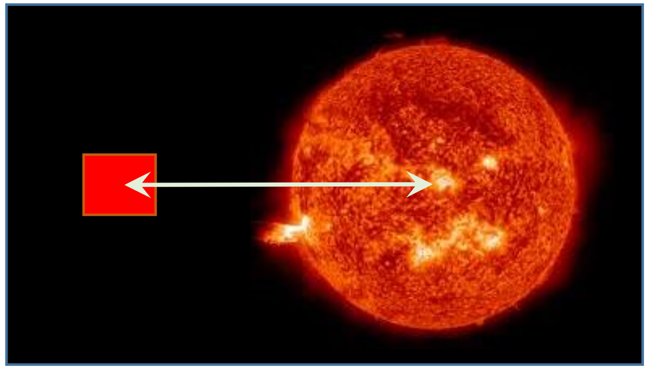


A silvered cone can be used to reflect the shield's infrared emission away from the spacecraft.

We would need low thermal conductivity struts, silvered on the inside and black on the outside to minimize heat flow to the spacecraft.

So can we get to the transition zone?



2 Solar Radii from the Sun, the shield is at about 650 K.

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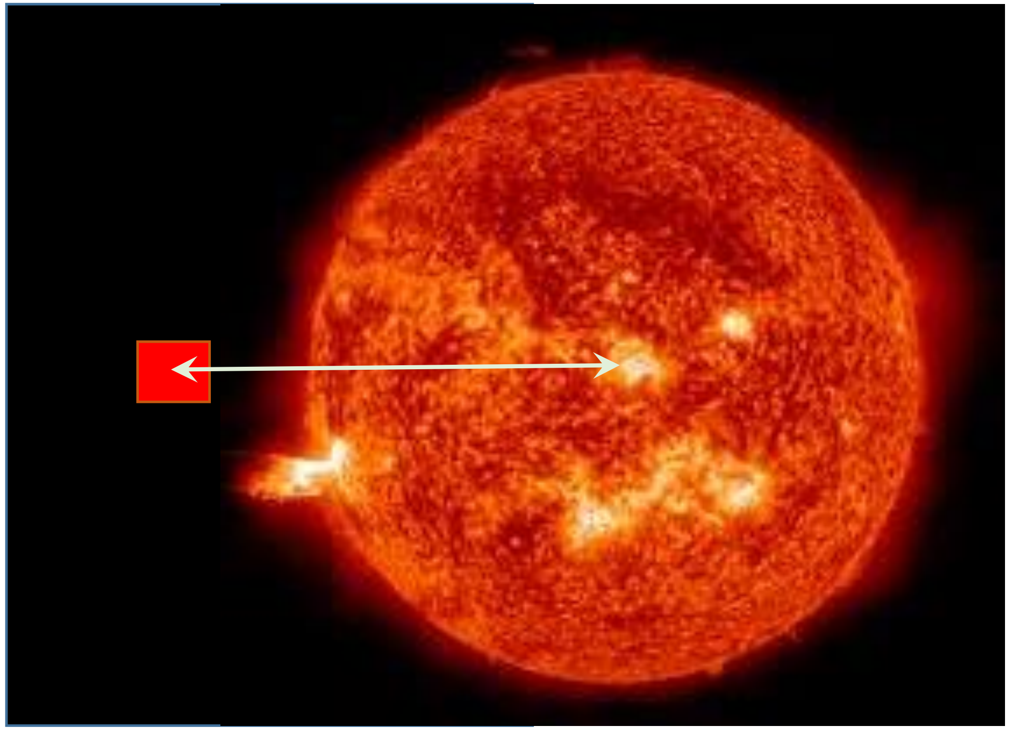
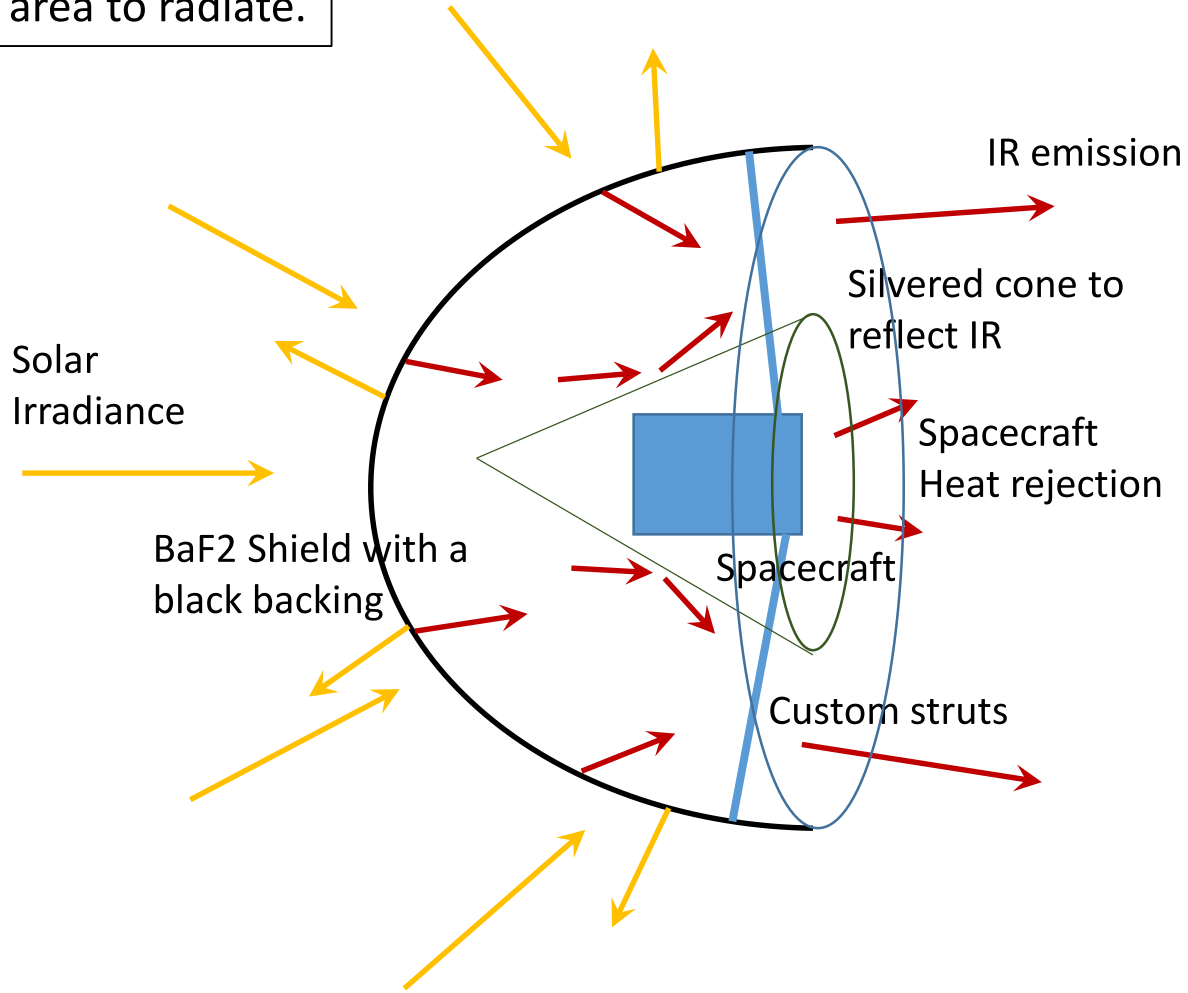
Not Yet.
In the transition zone the spacecraft will need a curved shield.

This means we capture more solar power and have less area to radiate.



1.5 Solar Radii from the Sun



Experiments

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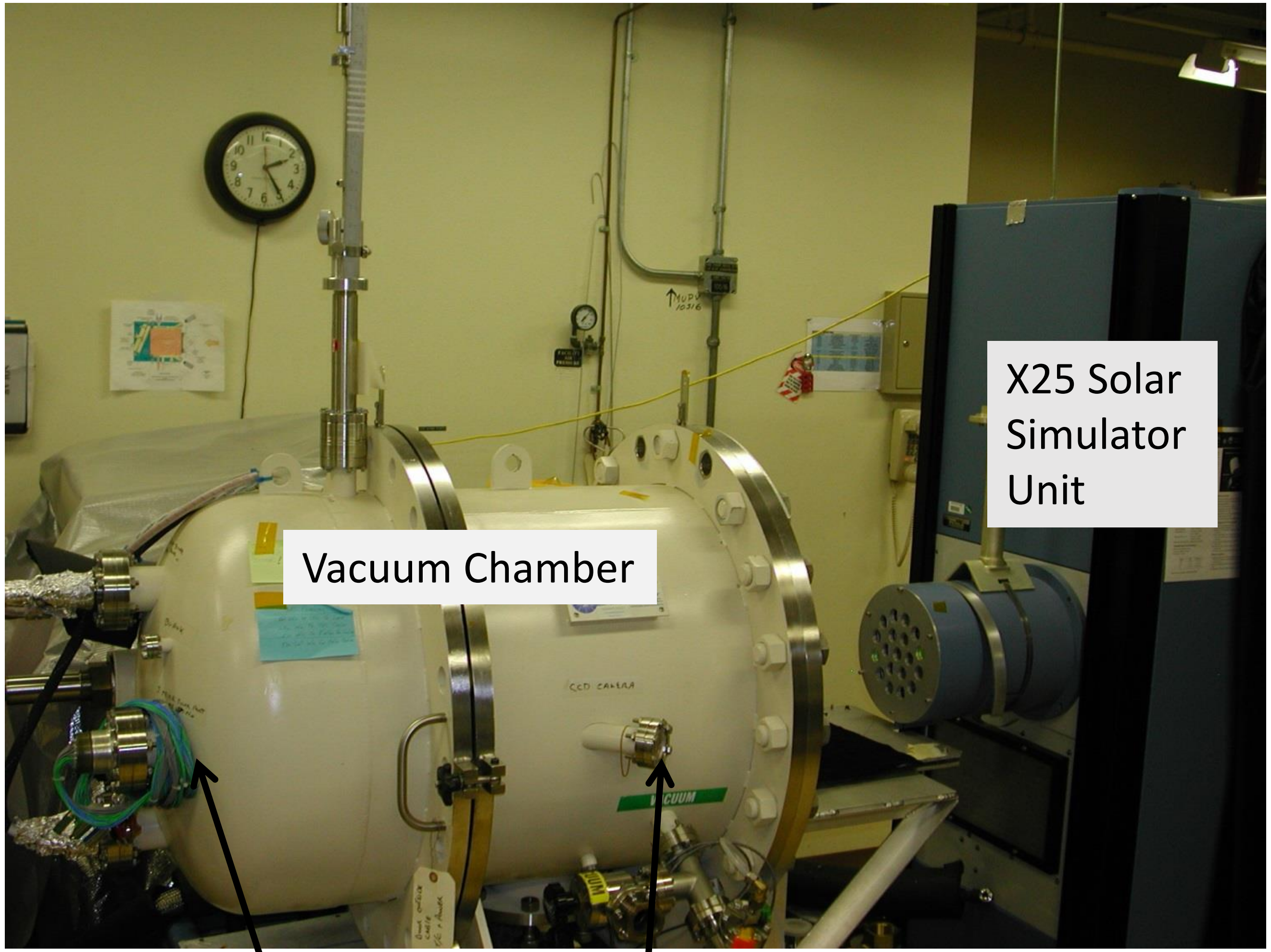


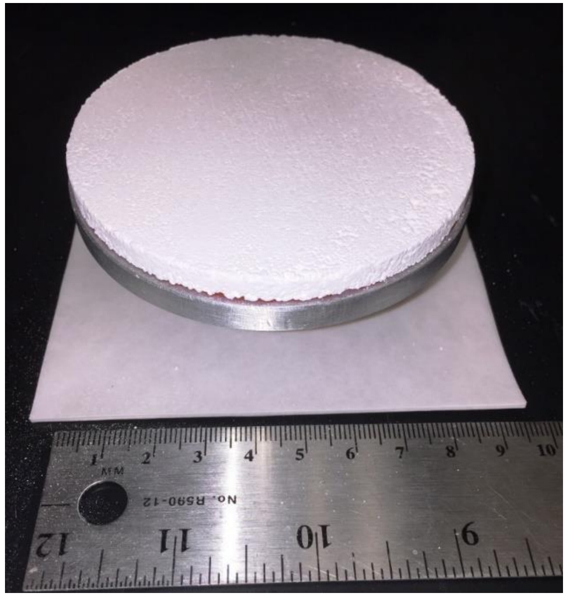
Test Article Mounting Location

Viewing Port

We had planned on testing our BaF2 coating in a high intensity solar simulator at the Johns Hopkins Univ. Applied Physics Lab, but contractual issues prevented this.

We constructed the test sample shown below.

BaF2 sample. 6.3 mm thick, 86 mm diameter, silvered, mounted with RTV to an aluminum plate.



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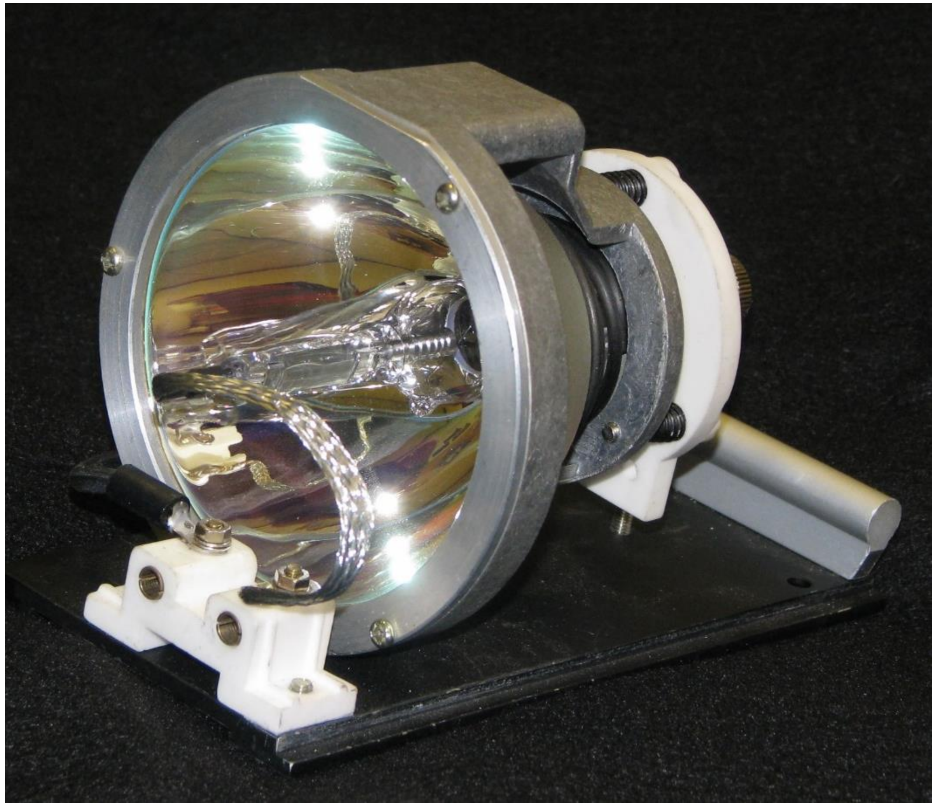

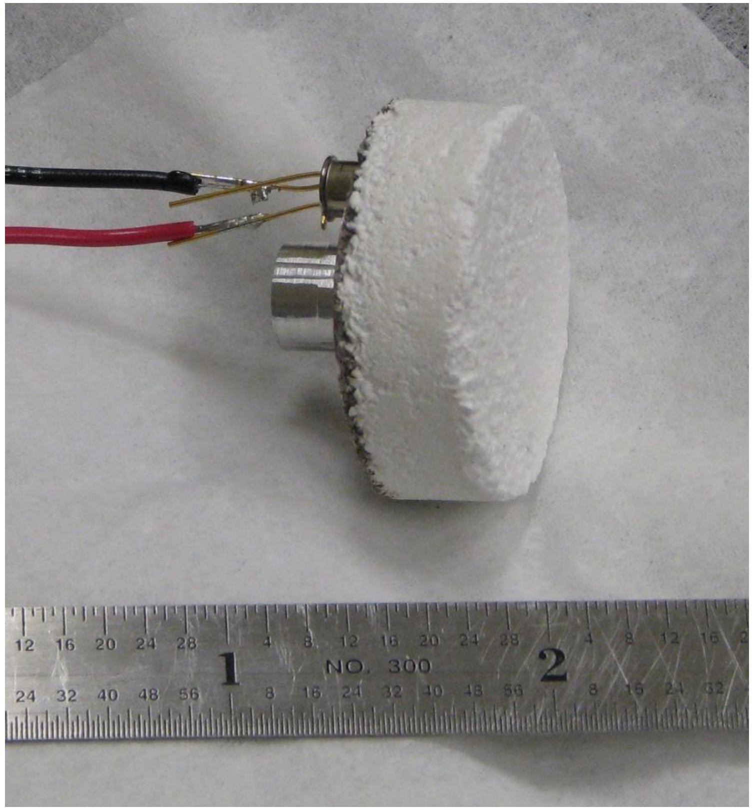

We've acquired a 250 Watt Xenon lamp (about 10 Watts of solar simulation) and will be testing a 32 mm diameter sample (about 8-9 times Solar Irradiance) this fall at KSC.

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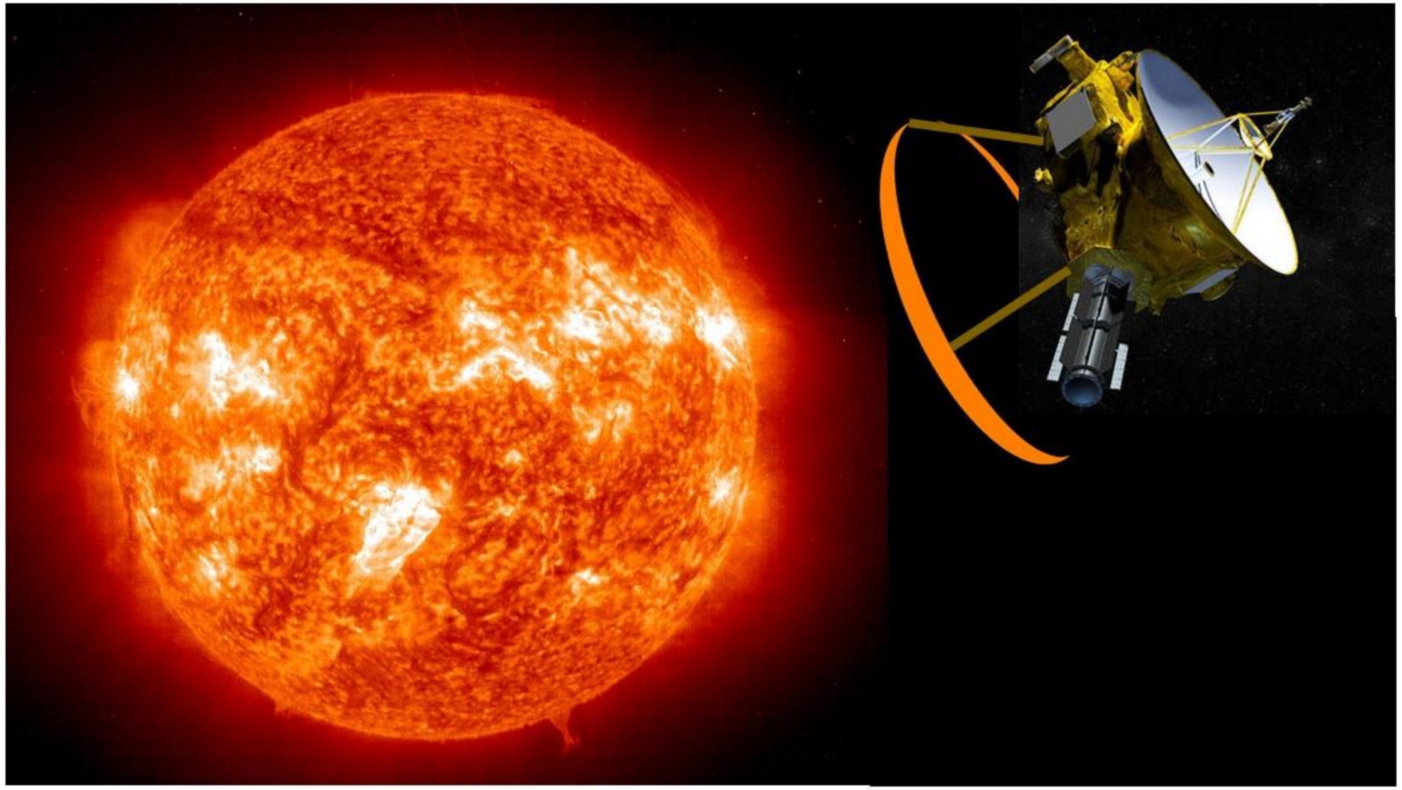
Future Work:

1. Perform high irradiance exposure testing.
2. Consider the effects of high temperature on the shield material.
3. Optimize the curved shield performance.
4. Consider transient response.
5. Consider other shield materials.



The goal is to show that there is a way to "Surf the Sun", to reach the transition zone.

Solar Surfing—How close to the Sun can we get?

Robert Youngquist and Mark Nurge, KSC, NASA; Bruce Williams, Johns Hopkins Univ. APL

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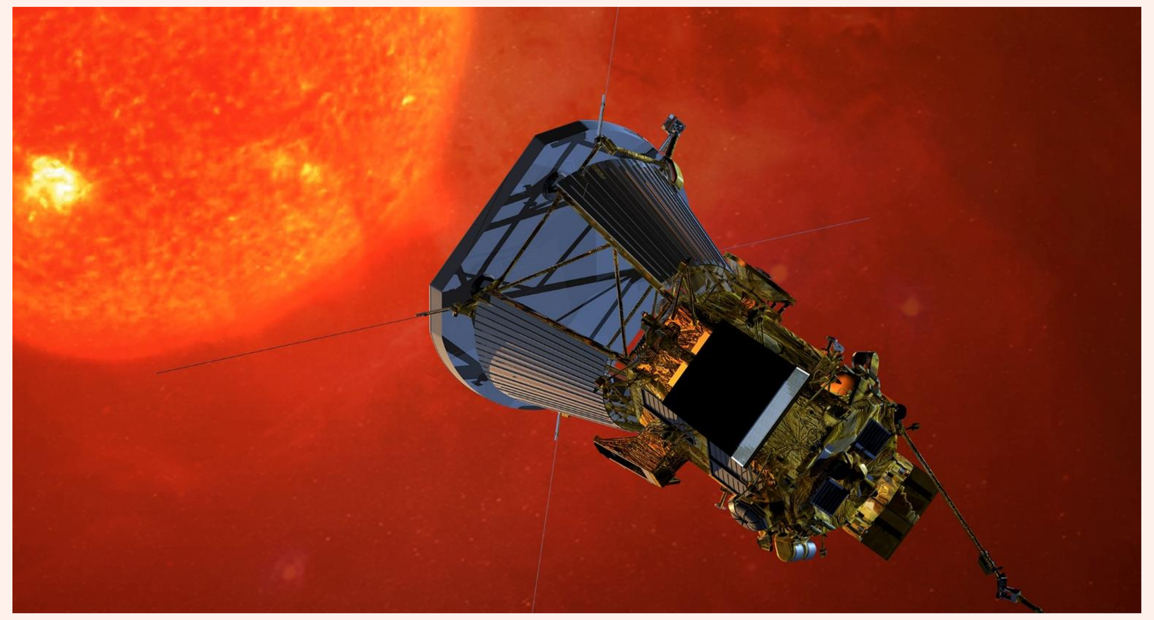
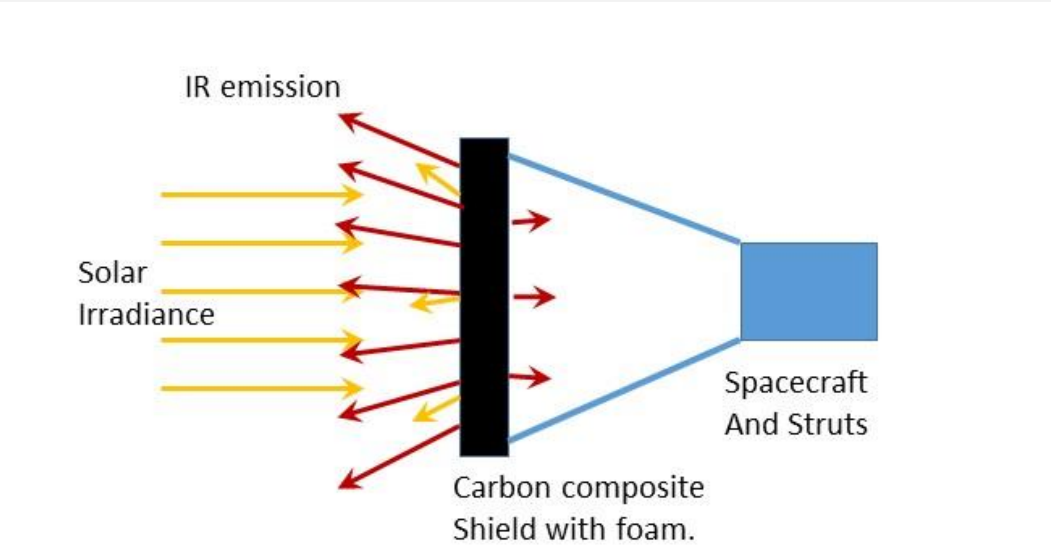
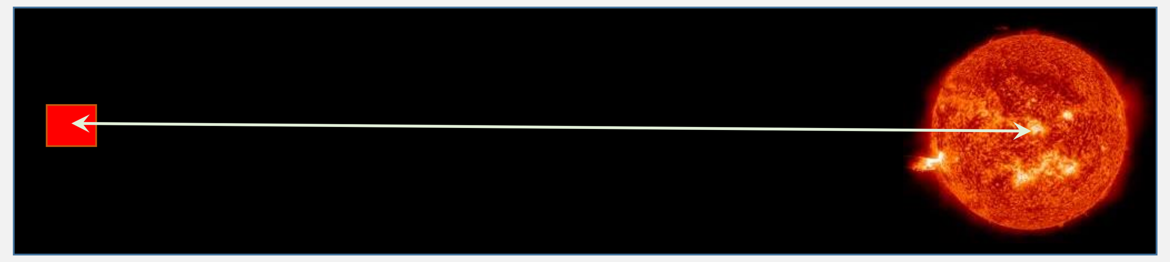


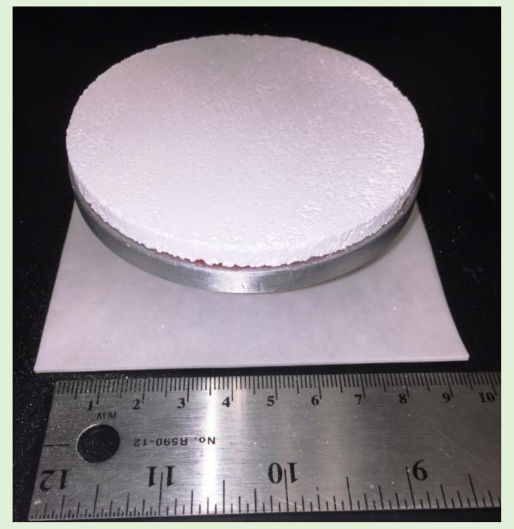
In 2018 the Solar Probe Plus will begin a mission to approach to within 9.5 Solar radii of the Sun. The Probe uses a carbon composite thick foam heat shield to protect the spacecraft.



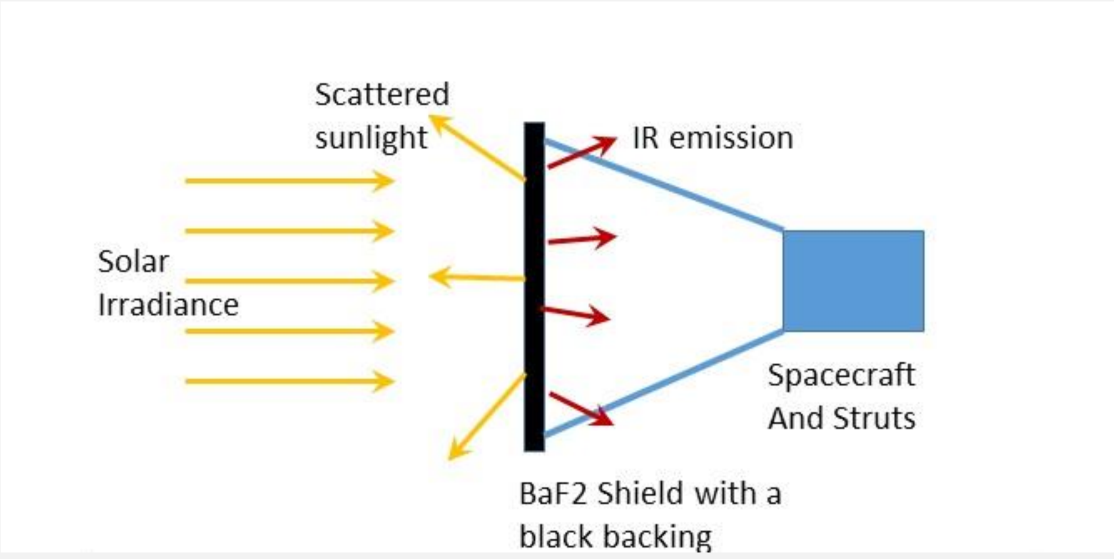
The Parker Solar Probe must protect the spacecraft from intense infrared emission (the shield can reach 1700 K), so the shield is designed to emit primarily in the forward direction.



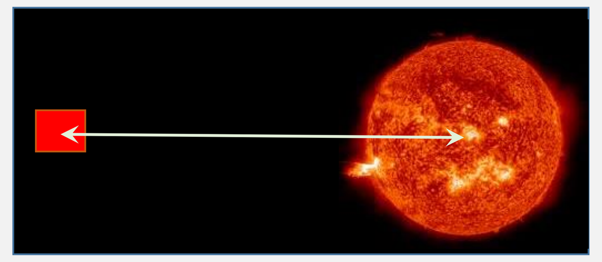
9.5 Solar Radii from the Sun.



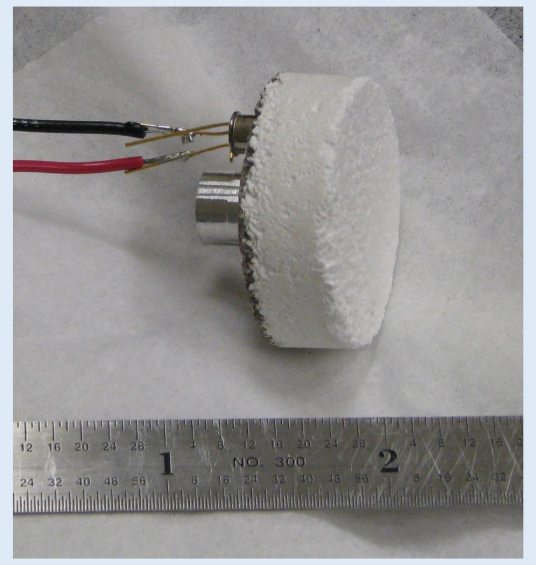
We are developing a coating that is predicted to reflect 99.9% of the Sun's radiant power. It does this using BaF_2 scattering particles and a silver backing. BaF_2 is transmissive from 0.14 – 12 microns, so it absorbs almost none of the Sun's power.

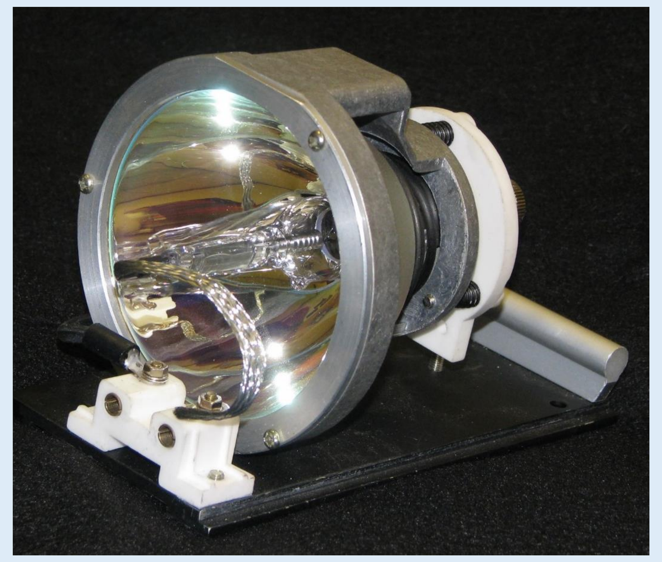


The BaF_2 shield absorbs much less energy, so to a point it can radiate towards the spacecraft. At 7 Solar radii the shield's at 300 K (room temp)! But at 1 Solar radii the shield's at 950 K, which will cook the spacecraft.

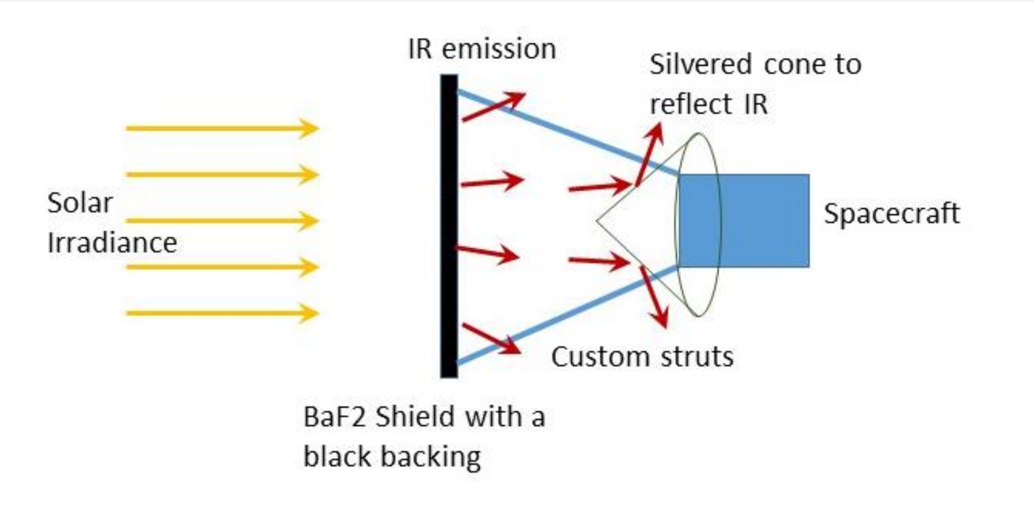


4 Solar Radii from the Sun, the shield is at about 420 K.

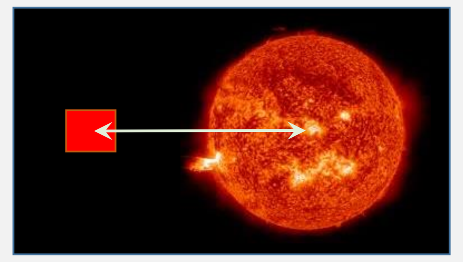




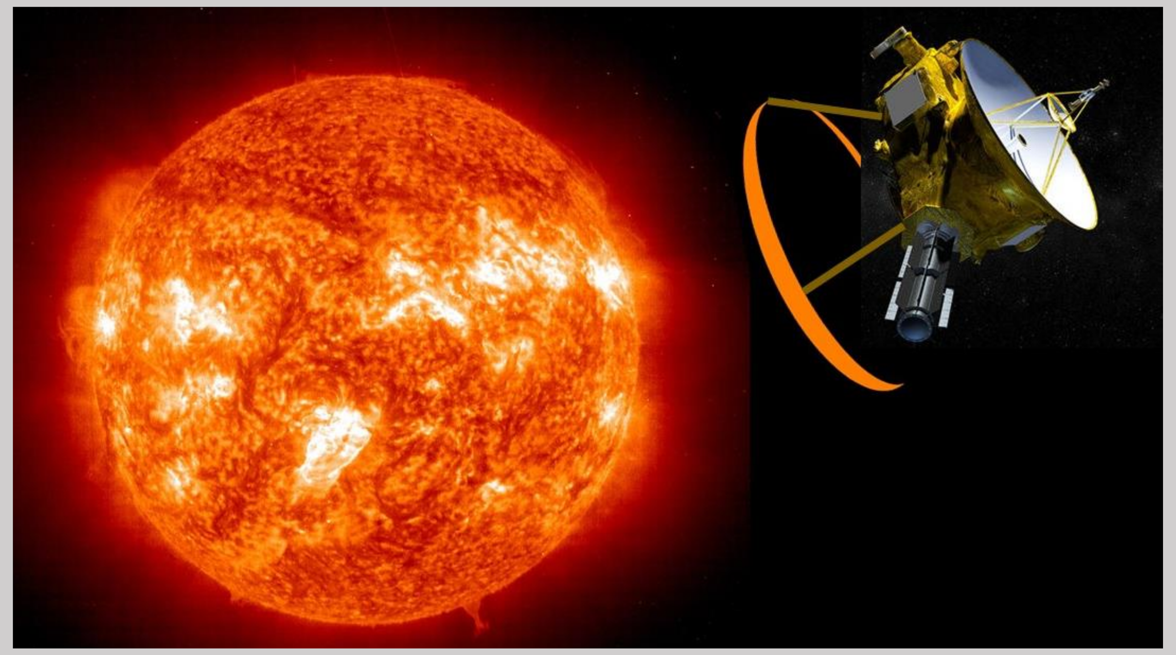
We plan to test our coatings under 8-9 times solar irradiance using the output from a 250 W Xe lamp. This testing is non-trivial in that it is prone to infrared radiation contamination from windows and lenses heated by the Xe Lamp.



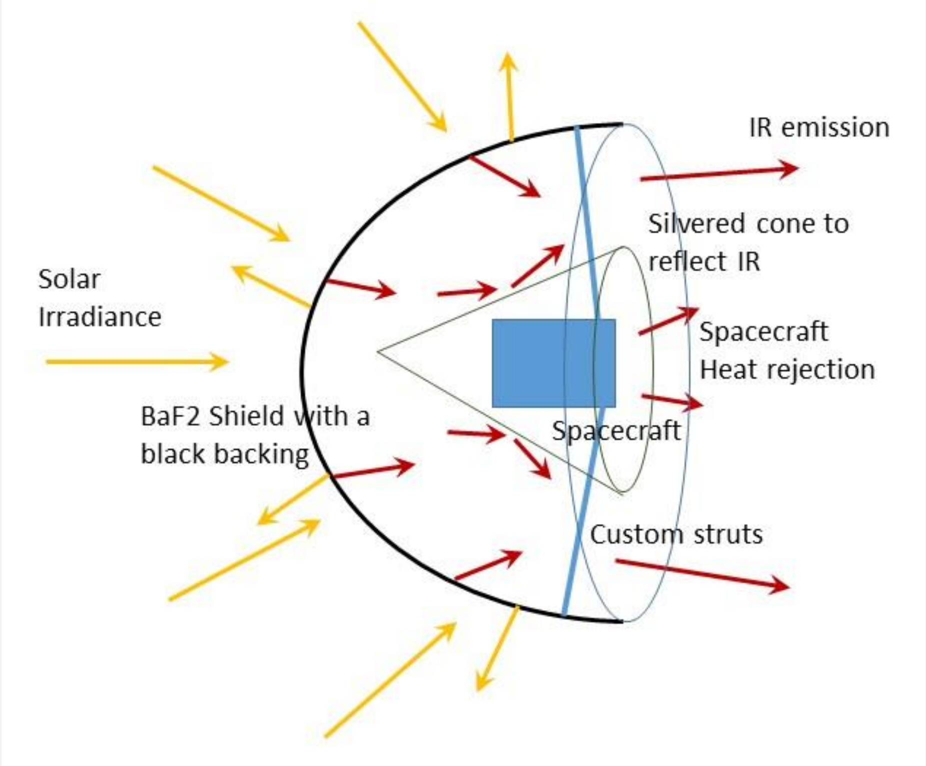
A silvered cone can be used to reflect the shield's infrared emission away from the spacecraft. This let's us get even closer to the Sun.



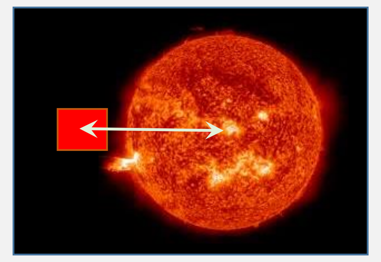
2 Solar Radii from the Sun, the shield is at about 650 K.



The goal is to see how close to the Sun we can get. Our current theory suggests we can approach the Sun's surface. This would enable measurements within the Sun's corona and help resolve the coronal heating problem.



Approaching too close to the Sun requires a curved shield, which increases Solar exposure and reduces effective infrared emission. So our current limit on approaching the Sun is about 1.5 Solar radii.



1.5 Solar Radii from the Sun is about the current limit.

Over the next few months:

- Consider the effects of high temperature on the coating (sintering).
- Consider the orbital trajectory and take exposure time into account.
- Consider other shield materials.
- Consider long term coating degradation.
- Analyze the curved shield and optimize the performance.
- Perform high irradiance exposure testing.