Absorptivity and Emissivity Measurement Error Characterization of Protective Methods for Optical Property Instruments

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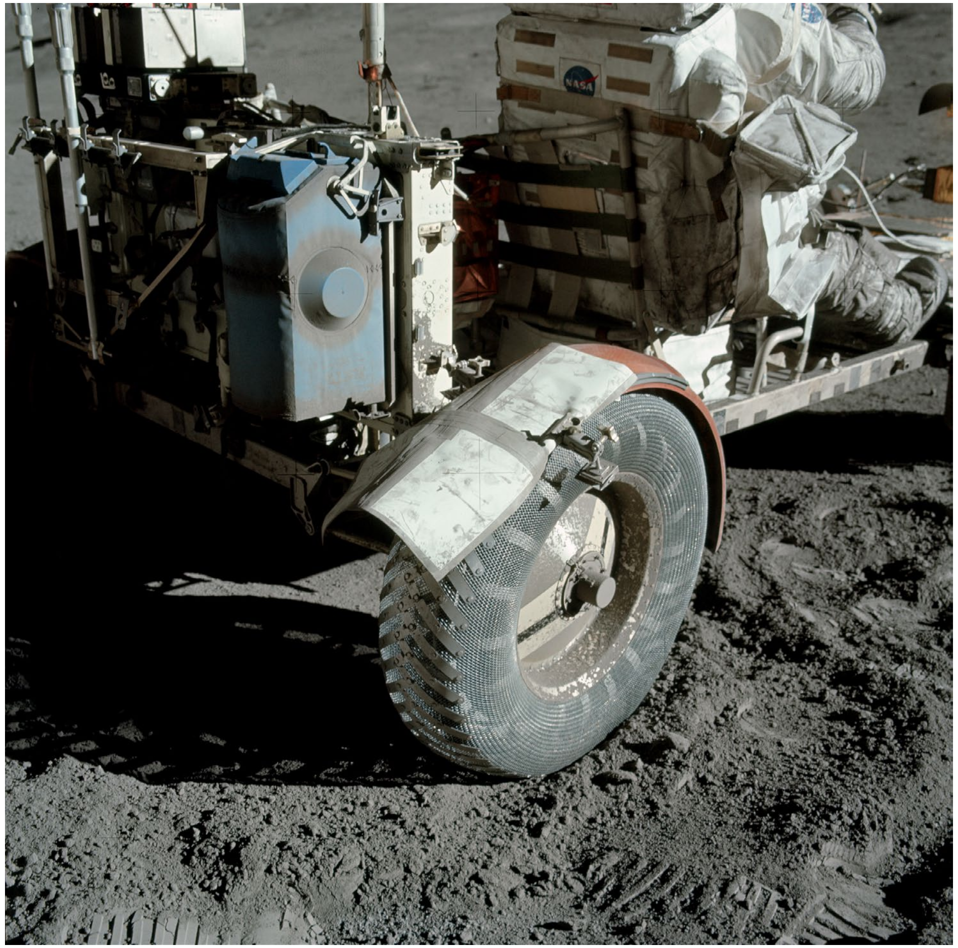
Introduction

- Design, analysis, and testing for lunar missions must account for the effects of lunar dust, particularly in thermal systems.
  - Primarily regarding diminished optical properties.
- Optical properties used in thermal analysis are critical in system design.
- Determining the optical properties of dusty surfaces is a challenge, as instruments require a light seal onto the test surface, but the inlets are open to the air and extremely sensitive to contaminates.

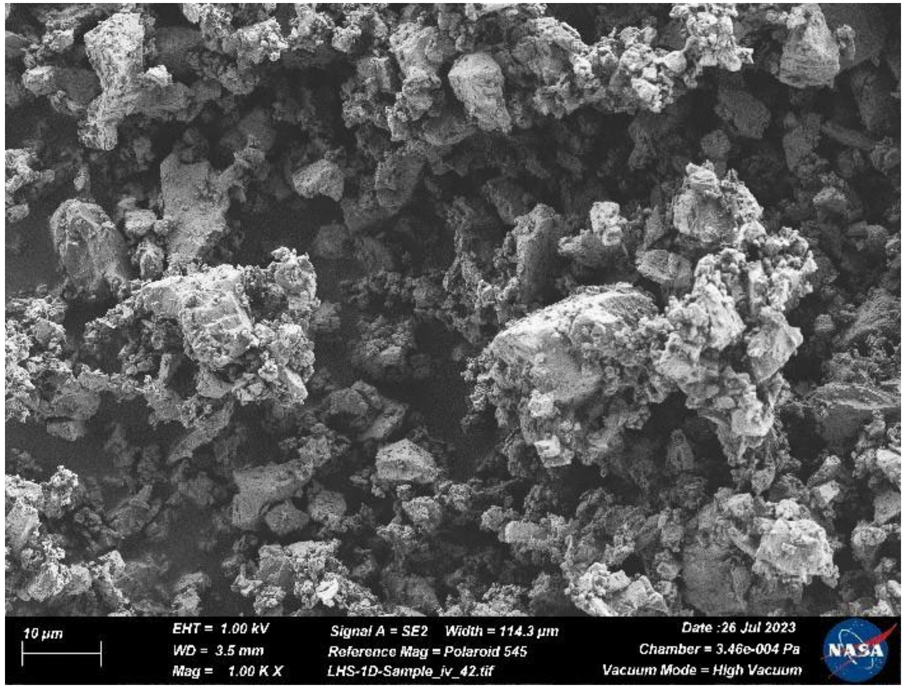


[1]

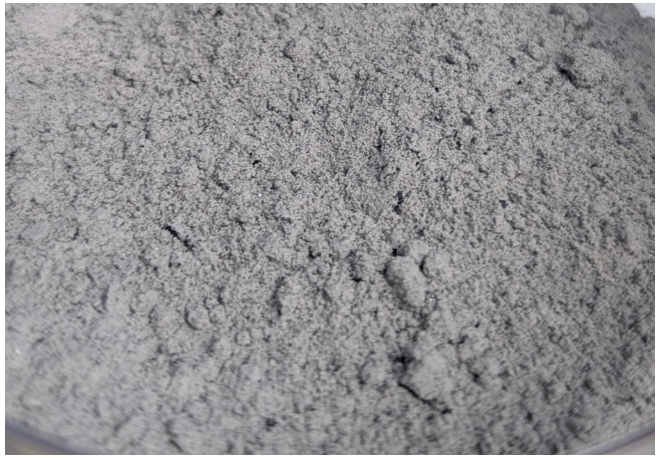
How do we determine dust optical properties without contaminating optical property instruments?

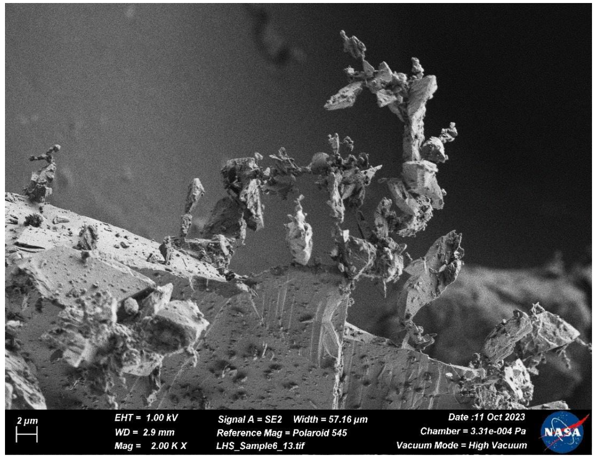
Background

- A recent study discovered that low-density lunar simulants do not distribute evenly onto surface but instead form “fairy castles”[2].
  - The results of this study do not align with the linear Rule of Mixtures assumption that is historically how analysts approximated dust coverage.
- The gaps in the dust may affect overall surface optical properties.
- Compressing the dust structures while taking measurements may produce inaccurate optical properties.



[2]





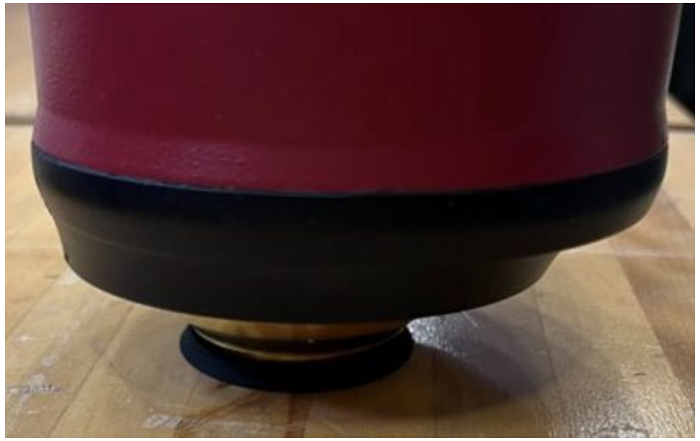
DEPOT + Protective Materials

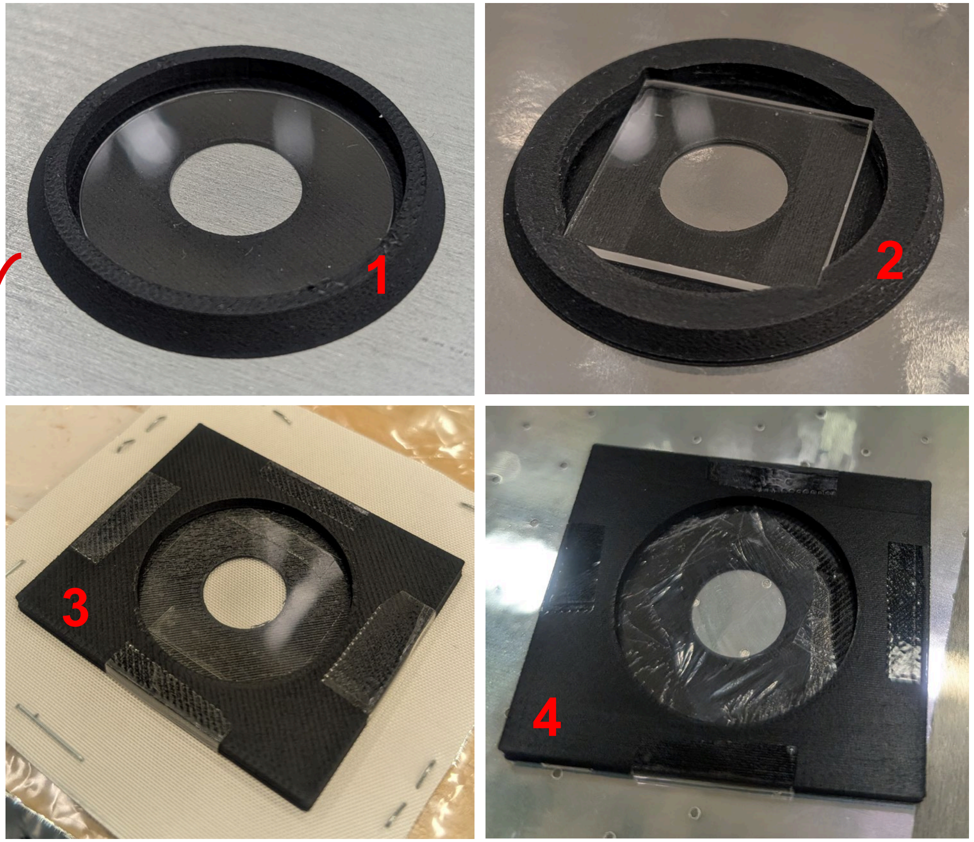
DEPOT:

Dust Experiment Protector for Optical Tools

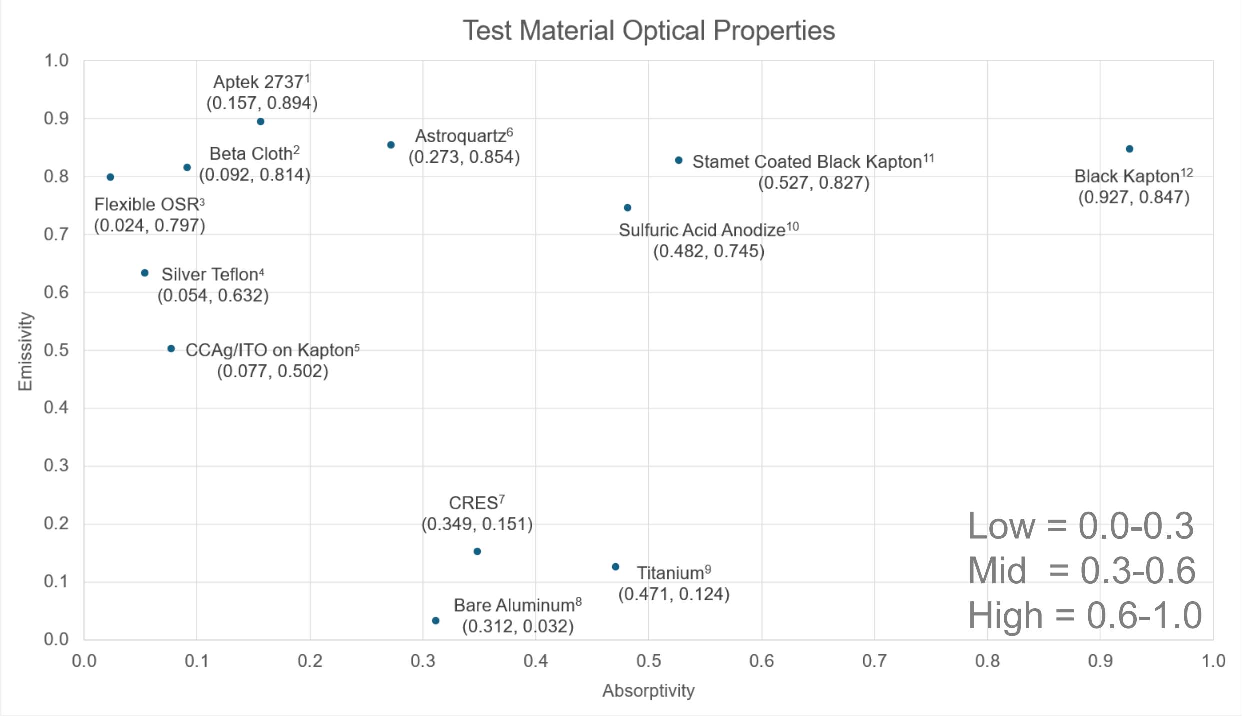
- Optical instruments need an adapter to protect the open sensor inlet.
- Three main purposes:
    1. Preserve dust structures (center)
    2. House protective material (middle)
    3. Provide light seal (sides)

1. Sapphire Glass
2. Borosilicate Glass
3. Acetate Film
4. Polyethylene Film



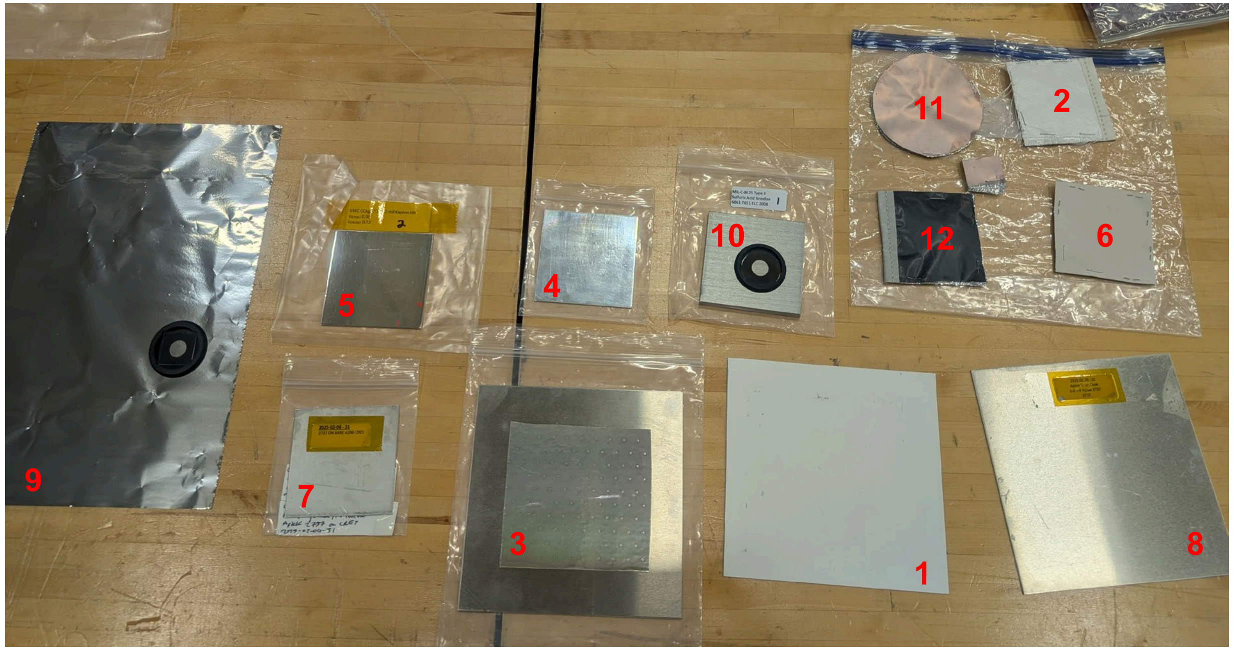


Test Materials and Methodology



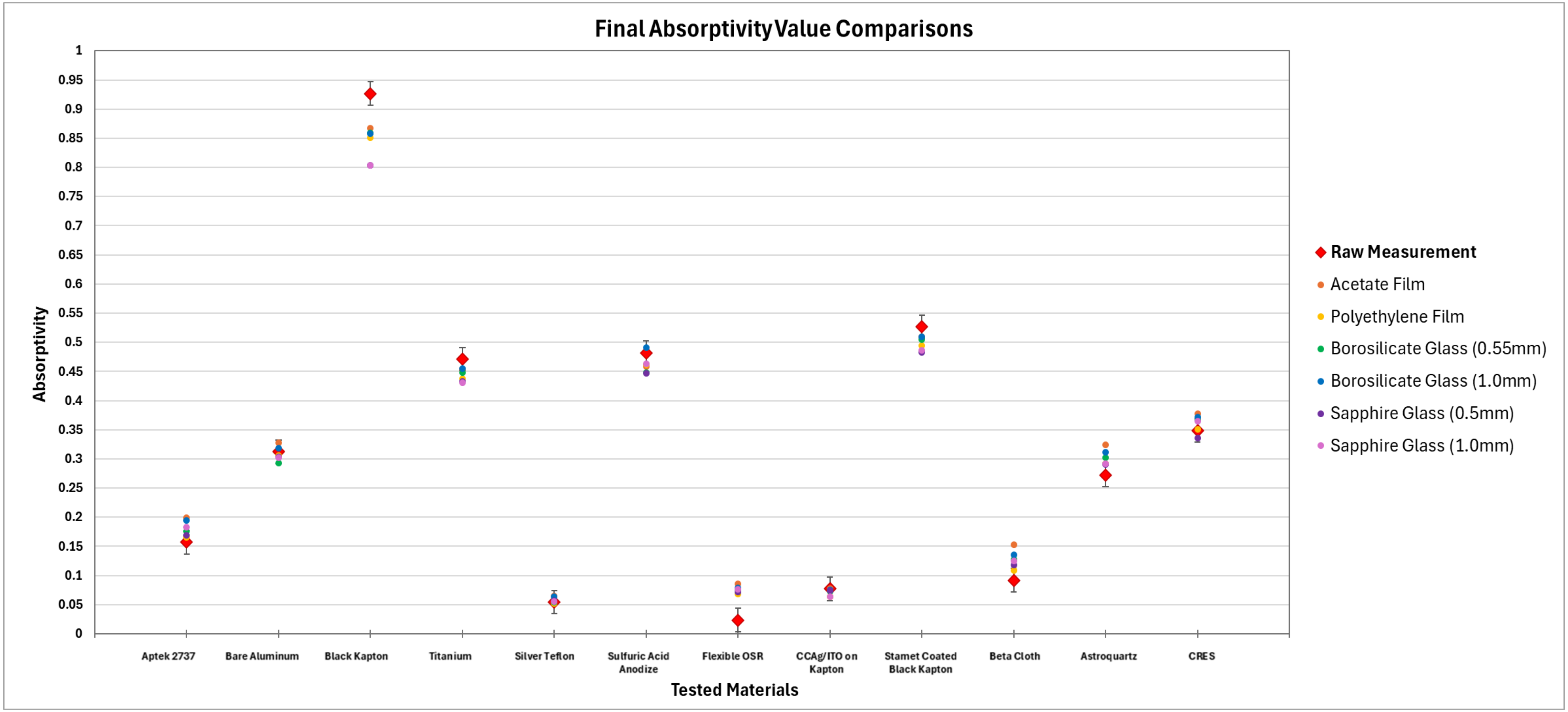
Optical properties of 12 common space materials demonstrate performance across a range of absorptivity and emissivity values.

1. Aptek 2737
2. Beta Cloth
3. Flexible Optical Solar Reflector (OSR)
4. Silver Teflon on Aluminum
5. Composite Coating Silver with Indium Tin Oxide (ITO) on Kapton HN
6. Astroquartz
7. Corrosion Resistant Stainless Steel (CRES)
8. Bare Aluminum
9. Bare Titanium
10. Sulfuric Acid Anodized Aluminum
11. Stamet Coated Black Kapton
12. Black Kapton

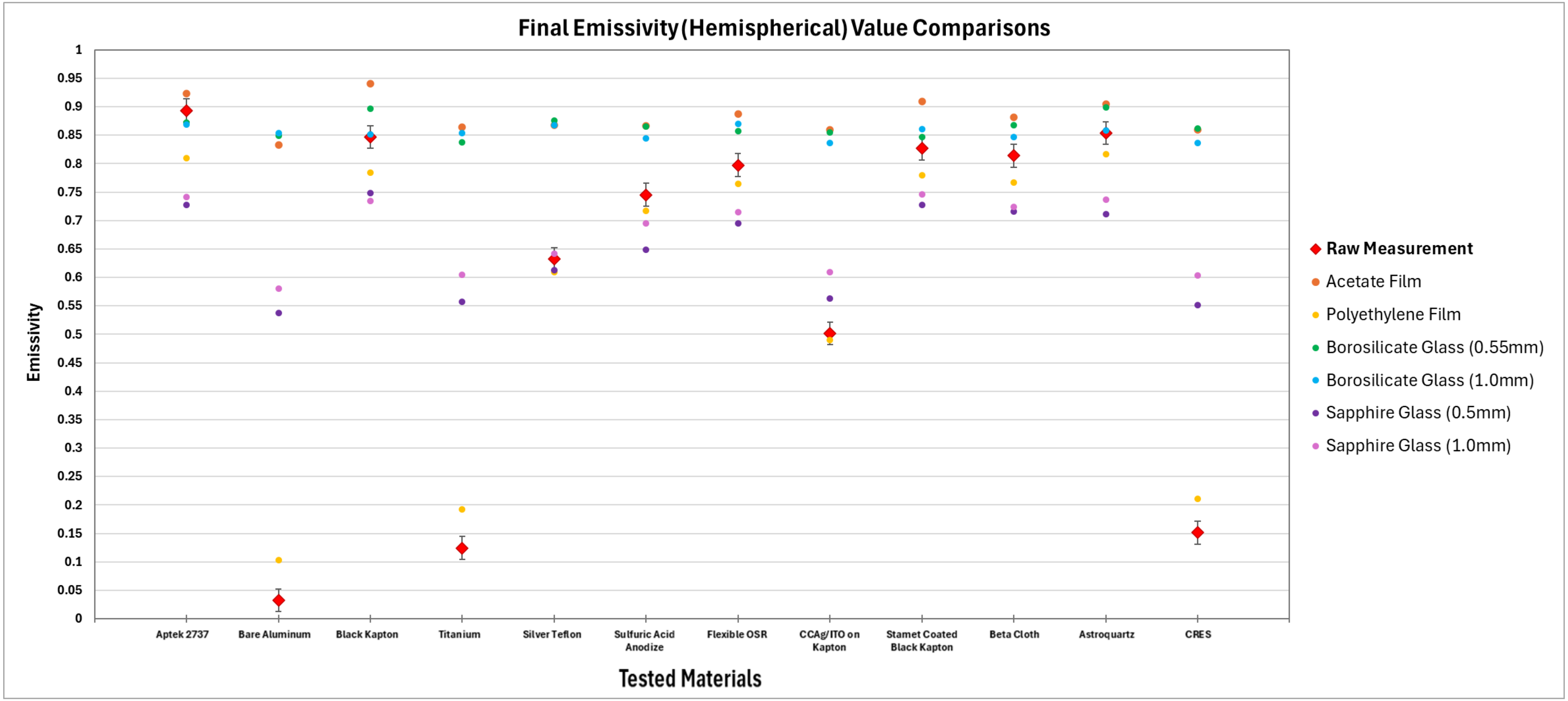


- Three measurements for absorptivity and emissivity were taken for each material, both *with* and *without* the protective materials and DEPOT.
- The wavelengths and final reported values were compared between raw and protected measurements.

Results - Absorptivity



Results – Emissivity (Hemispherical)



Observed Data Trends

Diffuse Materials

Low α materials ↑ in the specular wavelengths and ↓ in the total reflectivity wavelengths, but final α values ↑.
Mid to high α materials saw an ↑ in both wavelengths but a ↓ in final α values.

For ε, low α materials ↓ in the lower end of the 20° and 60° wavelength values and ↑ on the upper end.
For mid/high α materials, no specific trend could be identified.
No final ε trends could be identified.

Many materials favored the films for α, but instead favored the borosilicate glass for ε.

Slightly Specular Materials

These materials generally ↑ in the specular wavelengths and ↓ in the total reflectivity wavelengths, but results are varied.
Final α values have no defined trend.

For ε, the 20° and 60° wavelengths show a consistent ↓.
However, the final hemispherical ε value always ↑.

There was a high variability between the lowest-error protective materials, with some materials favoring the films and some favoring the glasses.

Specular Materials

These materials saw ↓ in specular wavelength values and ↑ total reflectivity wavelength values. Final α values did not significantly change.

For ε, both the 20° and 60° wavelengths consistently ↓. Final ε values showed no definite trends.

The overall best protective material for α and ε was the Polyethylene film.

Absorptivity Wavelengths (nm)
335-380
400-540
480-600
590-720
700-1100
1000-1700
1700-2500

Emissivity Wavelengths (μm)
1.5-2.0
2.0-3.5
3.0-4.0
4.0-5.0
5.0-10.5
10.5-21.0

Conclusions and Forward Work

- In conclusion, each protective material performs differently depending on the test material's absorptivity, emissivity, and specular properties. **No one protective material is the best for all test materials.**
  - Contributing factors could be that the protective materials may be better in the visible spectrum vs the IR spectrum, that they may be slightly shiny, or that they have varying thicknesses.
- However, protection for optical property sensors is *necessary* to measure dust. This study characterized the final error for a wide array of materials so that future testing can utilize the DEPOT with protective materials to preserve dust structures and the cleanliness of the instruments.
  - **A detailed flowchart can be found in the backup slides to select the best material depending on use case.**
- Future testing will take top performing protective materials with their corresponding test material and evaluate those materials with lunar dust.
  - These efforts can help with model correlation and provide more accurate optical properties for thermal models of dust covered surfaces

THANK YOU!

Questions?

Special thanks to Thomas Slusser and Lisa Erickson

Backup Slides with Detailed Material Info

1. **Identify if the material is specular or diffuse by the value of the R_specular wavelength values.**
   a) Navigate to Slide 12 for diffuse materials, Slide # for slightly specular materials, or Slide # for highly specular materials
2. **Identify is your material has low/medium/high absorptivity and emissivity, and choose the subsequent slide called out on the title slide**
   a) If there is more than one slide called out, navigate to the material that most closely aligns with yours
3. **The final slide outlines the material error comparisons and recommends a protective material for absorptivity measurements and emissivity measurements**
   a) Choose the protective material that best aligns with your testing

Testing a Diffuse Material?

Low absorptivity?
High emissivity?
Go to Slides 13,14,15

Mid absorptivity?
High emissivity?
Go to Slides 16,17

High absorptivity?
High emissivity?
Go to Slide 18

Currently no data for low or mid emissivity

Aptek 2737

100% diffuse, low absorptivity, high emissivity coating

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.157	0.199	27.0%	0.166	5.52%	0.176	11.9%	0.194	23.57%	0.169	7.64%	0.183	16.6%
Emissivity												
0.894	0.923	3.32%	0.810	-9.36%	0.872	-2.39%	0.869	-2.76%	0.728	-18.6%	0.742	-17.0%

For absorptivity, PE film is recommended along with a 5.5% decrease to the final α value

For emissivity, borosilicate glass is recommended along with a 2.4-2.8% increase to the final ε value, depending on the thickness of the pane

(Acetate or PE film can also be used with their respective error addition/decrease)

Beta Cloth

100% diffuse, low absorptivity, high emissivity fabric

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.092	0.153	65.9%	0.109	18.1%	0.128	38.8%	0.136	47.46%	0.118	27.9%	0.125	36.2%
Emissivity												
0.814	0.881	8.27%	0.767	-5.73%	0.867	6.55%	0.847	4.10%	0.716	-12.04%	0.724	-11.10%

For absorptivity, PE film is recommended along with a 18% decrease to the final α value

For emissivity, borosilicate glass is recommended along with a 4.0-6.5% decrease to the final ε value, depending on the thickness of the pane

(Acetate or PE film can also be used with their respective error addition/decrease)

Astroquartz

100% diffuse, low absorptivity, high emissivity fabric

Absorptivity													
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.273	0.325	19.1%	0.292	7.21%	0.302	10.9%	0.311	14.2%	0.291	6.72%	0.292	7.09%
Emissivity												
0.854	0.905	6.05%	0.817	-4.33%	0.899	5.31%	0.858	0.51%	0.711	-16.7%	0.737	-13.6%

For absorptivity, sapphire glass is recommended along with a 6.7-7.0% decrease to the final α value (PE film can also be used for lower cost)

For emissivity, borosilicate glass is recommended along with a 0.5-5.3% decrease to the final ε value, depending on the thickness of the pane

(Acetate or PE film can also be used with their respective error addition/decrease)

Sulfuric Acid Anodize Coating

100% diffuse, mid-range absorptivity, high emissivity coating

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.482	0.459	-4.84%	0.462	-4.15%	0.448	-6.98%	0.491	1.80%	0.447	-7.33%	0.463	-3.94%
Emissivity												
0.745	0.867	16.3%	0.717	-3.8%	0.865	16.1%	0.844	13.3%	0.649	-12.9%	0.695	-6.7%

For absorptivity, borosilicate glass is recommended along with a 1.8% decrease to the final α value (though all materials are viable)

For emissivity, PE film is recommended along with a 3.8% increase to the final ε value (sapphire glass can also be used)

Stamet Coated Black Kapton Film

Mostly diffuse, mid-range absorptivity, high emissivity film

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.527	0.509	-3.42%	0.494	-6.26%	0.505	-4.24%	0.509	-3.42%	0.483	-8.29%	0.487	-7.65%
Emissivity												
0.827	0.910	10.0%	0.780	-5.7%	0.846	2.4%	0.861	4.2%	0.727	-12.0%	0.746	-9.8%

For absorptivity, borosilicate glass is recommended along with a 3.4-4.2% increase to the final α value, depending on thickness. (though all materials are viable)

For emissivity, borosilicate glass is recommended along with a 2.4-4.2% decrease to the final ε value, depending on thickness. (PE film is also a viable option)

Black Kapton Film

100% diffuse, high absorptivity, high emissivity film

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.927	0.867	-6.47%	0.851	-8.20%	0.859	-7.30%	0.858	-7.37%	0.803	-13.3%	0.804	-13.2%
Emissivity												
0.847	0.941	11.1%	0.784	-7.4%	0.897	5.9%	0.851	0.5%	0.749	-11.6%	0.735	-13.3%

For absorptivity, acetate film is recommended along with a 6.5% increase to the final α value.
(PE film and borosilicate glass are also viable options)

For emissivity, 1.0mm borosilicate glass is recommended along with a 0.5% decrease to the final ε value.

(Thinner borosilicate glass or PE film are also viable options)

Testing a Slightly Specular Material?

Mid absorptivity?

Low emissivity?

Go to Slides 20,21,22

Currently no data for low/high absorptivity or mid/high emissivity

Bare Aluminum

Slight specularity, mid-range absorptivity, low emissivity metal

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.312	0.327	4.8%	0.305	-2.24%	0.293	-6.08%	0.319	2.03%	0.303	-2.88%	0.302	-3.31%
Emissivity												
0.032	0.833	2475%	0.103	220%	0.850	2528%	0.853	2539%	0.537	1562%	0.581	1696%

For absorptivity, borosilicate glass is recommended along with a 2.0% <u>decrease</u> to the final α value (all materials are viable options, and PE film is a close second)

For emissivity, PE film is recommended along with a 220% <u>decrease</u> to the final ε value (Other materials are not recommended due to high error)

Bare Titanium

Slight specularity, mid-range absorptivity, low emissivity metal

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.471	0.454	-3.54%	0.438	-7.08%	0.448	-4.81%	0.455	-3.40%	0.433	-8.14%	0.430	-8.63%
Emissivity												
0.124	0.865	595%	0.192	55%	0.838	574%	0.853	586%	0.558	349%	0.605	387%

For absorptivity, borosilicate glass is recommended along with a 3.4-4.8% increase to the final α value (all materials are viable options, and acetate film is a close second)

For emissivity, PE film is recommended along with a 55% decrease to the final ε value (Other materials are not recommended due to high error)

Corrosion-Resistant Stainless Steel

Slight specularity, mid-range absorptivity, low emissivity metal

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.349	0.377	8.02%	0.351	0.67%	0.367	5.25%	0.372	6.59%	0.336	-3.63%	0.365	4.58%
Emissivity												
0.151	0.860	468%	0.210	39%	0.862	469%	0.837	453%	0.552	265%	0.603	299%

For absorptivity, PE film is recommended along with a 0.7% decrease to the final α value (all materials are viable options)

For emissivity, PE film is recommended along with a 40% decrease to the final ε value (Other materials are not recommended due to high error)

Testing a Highly Specular Material?

Low absorptivity?
Mid emissivity?
Go to Slide 24

Low absorptivity?
High emissivity?
Go to Slides 25,26

Currently no data for mid/high absorptivity or low emissivity

CCAg/ITO on Kapton HN

Highly diffuse, low absorptivity, mid-range emissivity coating

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.077	0.078	0.86%	0.063	-18.1%	0.073	-6.03%	0.076	-2.16%	0.074	-4.31%	0.064	-17.7%
Emissivity												
0.502	0.860	71.4%	0.490	-2.3%	0.855	70.4%	0.836	66.6%	0.563	12.2%	0.609	21.4%

For absorptivity, acetate film is recommended along with a 1.0% decrease to the final α value.

For emissivity, PE film is recommended along with a 2.3% increase to the final ε value.

Silver Teflon

Highly diffuse, low absorptivity, high emissivity coating

Absorptivity												
Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
0.054	0.065	20.2%	0.052	-3.68%	0.054	0.00%	0.064	17.18%	0.057	5.52%	0.055	1.84%
Emissivity												
0.632	0.868	37.2%	0.609	-3.6%	0.876	38.6%	0.868	37.2%	0.613	-3.1%	0.642	1.5%

For absorptivity, 0.55mm borosilicate film is recommended.

For emissivity, sapphire glass is recommended along with a 1.5% decrease to the final ε value. (Alternatively, PE film can be used to reduce cost)

Flexible OSR

Highly diffuse, low absorptivity, high emissivity material

Raw Measurement	Acetate Film		Polyethylene Film		Borosilicate Glass (0.55mm)		Borosilicate Glass (1.0mm)		Sapphire Glass (0.5mm)		Sapphire Glass (1.0mm)	
Absorptivity												
0.024	0.086	263%	0.069	190%	0.075	218%	0.079	235%	0.072	204%	0.076	221%
Emissivity												
0.797	0.887	11.2%	0.765	-4.1%	0.857	7.5%	0.870	9.1%	0.695	-12.8%	0.715	-10.3%

For absorptivity, PE film is recommended along with a 190% <u>decrease</u> to the final α value.
(Other materials are not recommended due to high error)

For emissivity, PE film is recommended along with a 4.0% <u>increase</u> to the final ε value.

References

[1]Apollo 17 image archives, Link: http://www.nasa.gov/wp-content/uploads/static/history/alsj/a17/AS17-137-20979HR.jpg

[2]Quick, E., Kurwitz, C., Hurlbert, K., Suess, L., “Determination of Percent Area Coverage of Lunar Simulant on a Surface and Observations of Fairy Castle Structures,” AIAA Aviation Forum and Ascend, Jul 2024. https://arc.aiaa.org/doi/10.2514/6.2024-4864