# Lunar Dust and Dust Mitigation Testing


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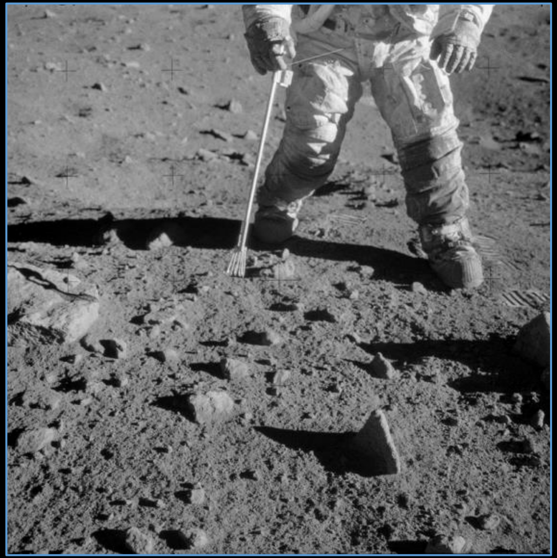
# Lunar Dust Issues During Apollo

"We must have had more than a hundred hours suited work with the same equipment, and the wear was not as bad on the training suits as it is on these flight suits in just the eight hours we were out" – Pete Conrad –Apollo 12 –from the Apollo 12 Technical Crew Debriefing, December 1, 1969



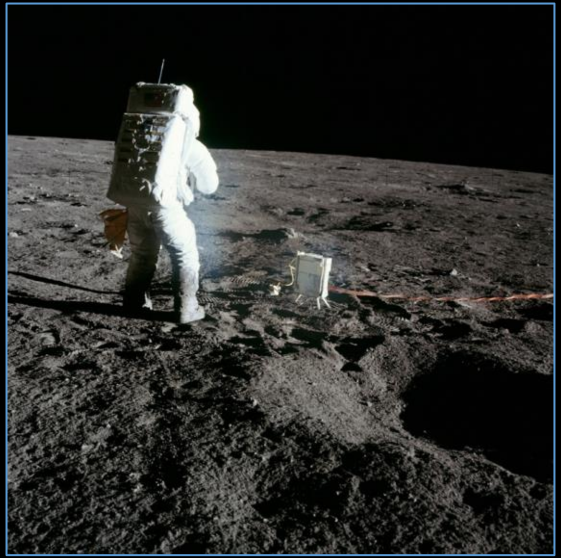


Image on the left is of Pete Conrad's suit on the lunar surface during an Apollo 12 EVA, showing dust accumulation on gloves, lower legs and boots, center image is a photo of Alan Bean taken by Pete Conrad, the blue haze in the center was on multiple images and attributed to dust on the camera lens, image on the right is of the TV mirror on Surveyor III after Pete Conrad wiped the surface with a gloved finger (area in circle). - *Photos courtesy of NASA Apollo 12 Image Library*

# Primary Effects of Dust on Extra-Vehicular Activity (EVA) Systems Based on Apollo Mission Logs

- Vision Obscuration
- False Instrument Readings
- Coating and Contamination
- Loss of Traction
- Clogging of Mechanisms
- Abrasion
- Thermal Control Problems
- Seal Failures
- Inhalation and Irritation

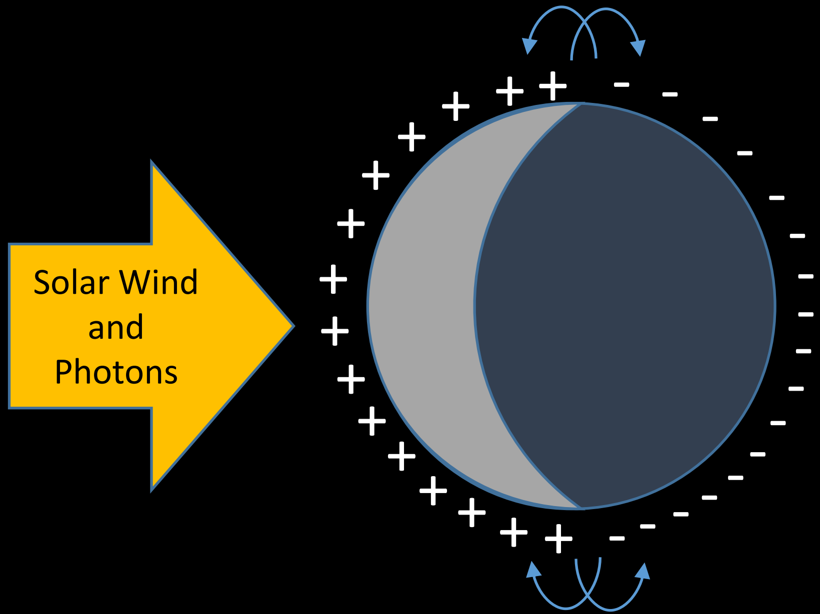
Gene Cernan Covered in Lunar Dust
NASA Apollo Image Library

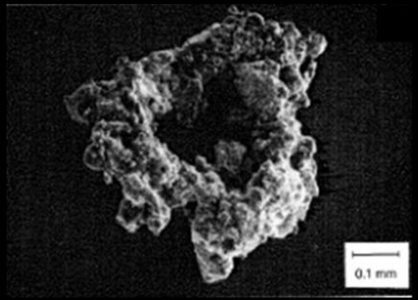
Gaier, J.R. “The Effects of Lunar Dust on EVA Systems During the Apollo Missions”, NASA TM-2005-213610/Rev1, (2005)

# Lunar Dust Adhesion and Wear

Image from Clementine Spacecraft-NASA

## Electrostatic



SEM Image of Lunar Soil Agglutinate
NASA S87-38112

## Triboelectric

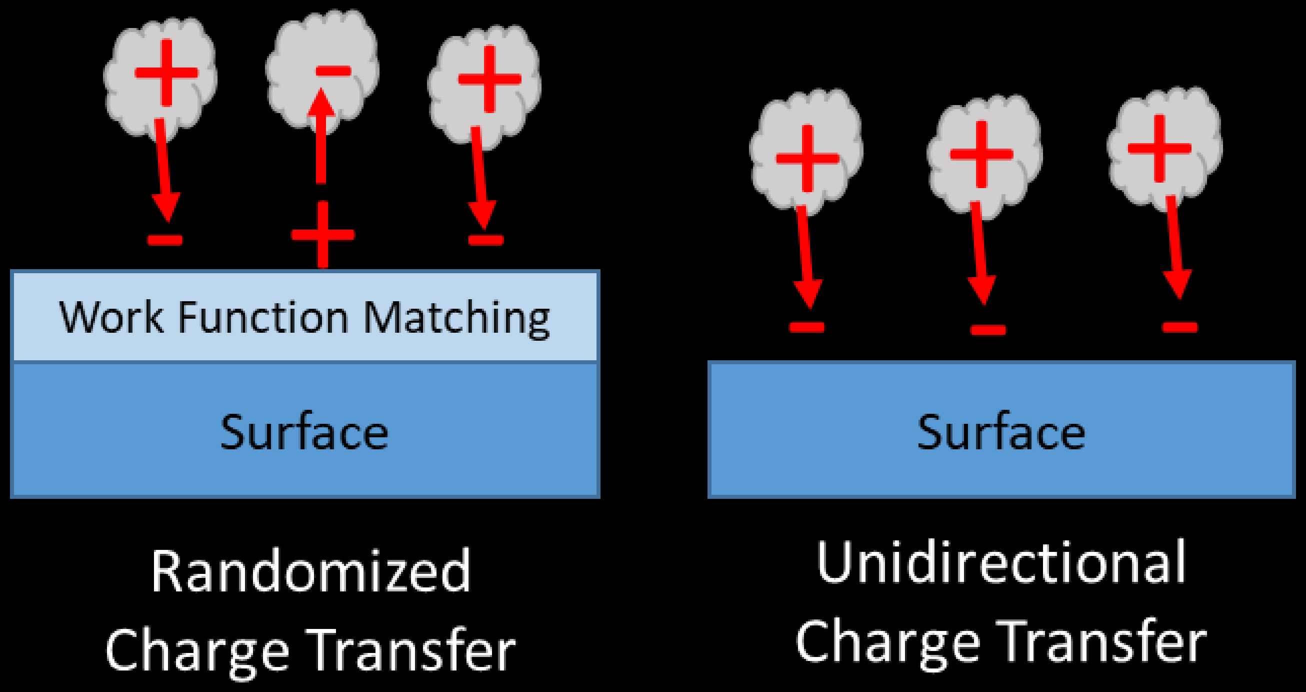
Apollo 12 Image Library-NASA

A portion of the leg of Harrison Schmitt's Apollo 17 Pressure Garment Assembly –NASA from Gaier 2009

# Some of the Dust Mitigation Techniques Being Studied

- Passive
  - Low Energy Surface Coatings
  - Work Function Matching Coatings
  - Textured Surfaces
  - Non-Woven Fabrics
- Active
  - Electrodynamic Dust Shield
  - Dust Lofting
  - Electrostatic Repulsion/Attraction

# Work Function Matching Coatings for Passive Dust Mitigation



# Ground Testing of Dust Mitigation Concepts

- Determine the environment and failure mode
- Determine the lunar simulant to use
- Determine the testing technique

- NASA-STD-1008: Classifications and Requirements for Testing Systems and Hardware to be Exposed to Dust in Planetary Environments: 2021-08-21_nasa-std-1008-approved.pdf

- Database of Simulants: Colorado School of Mines, https://simulantdb.com

# Ground Testing of Dust Mitigation Concepts

Ground Testing:

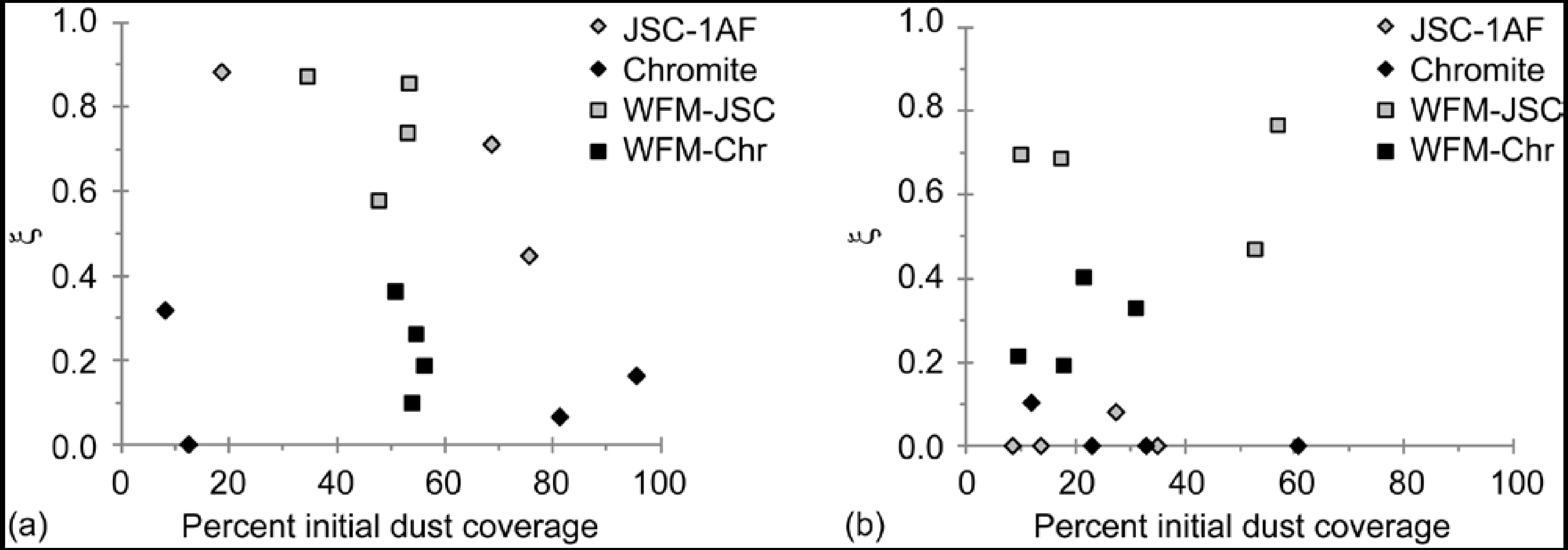
- Simulant (JSC-1AF, LHT-1…) sifted onto surfaces in vacuum (<1e-6 Torr) after bakeout at 200 °C for several hours
- Non-adhering simulant removed by nitrogen jet

Lunar Dust Adhesion Belljar

Sample pair under nitrogen jets after dusting, prior to nitrogen jet

Sample pair after exposure to nitrogen jet

# Effectiveness of Work Function Matching Coatings in Removal of Lunar Simulant Using a Regulated Puff of Nitrogen Gas




Dust removal efficiency, ξ, calculated for pristine and workfunction matching coated (a) AZ93 and (b) AxFEP using JSC1-AF and Chromite simulants for dusting. (From Gaier, J.R., Waters, D.L., Misconin, R.M., Banks, B.A and Crowder, M. "Evaluation of Surface Modification as a Lunar Dust Mitigation Strategy for Thermal Control Surfaces" NASA/TM—2011-217230.)

# Flight Testing of Work Function Matching Coating on Lunar Surface

- Commercial Lunar Payload Services (CLPS) Lander 19-D
- Destination Mare Crisium (Basaltic plain on the moon's near side)
- Carrier: Firefly, Blue Ghost Lander
- Mission Launch: 2024
- Experiments: Aegis Aerospace, Regolith Adherence Characterization (RAC); Honeybee Robotics, Planet Vac


Moon Image: NASA/Goddard Space Flight Center/Arizona State University, 2017

# Matching the Chemistry of Mare Crisium

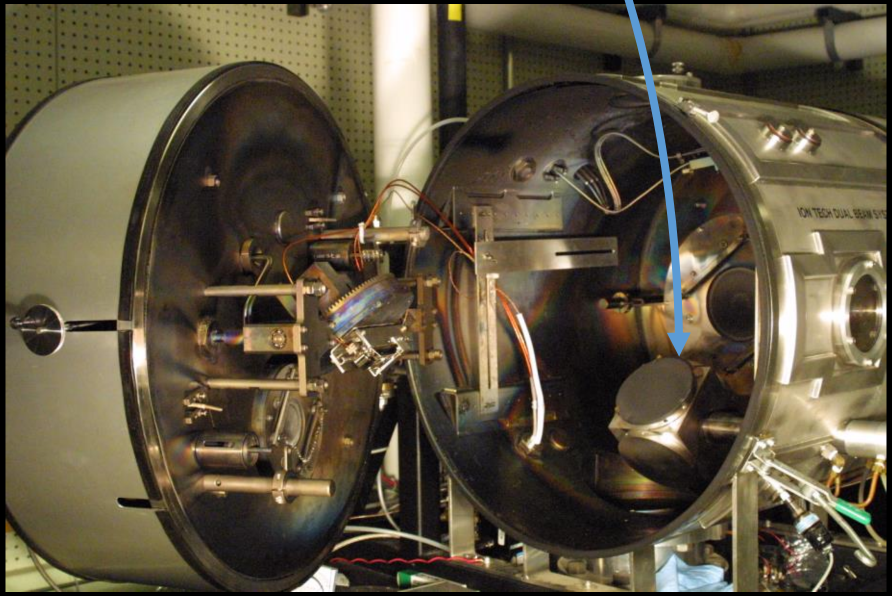
| | JSC-1 Simulant[1] | Basalt from Luna 24 Landing at Mare Crisium[2] |
|---|---|---|
| $SiO_2$ | 47.71 | 44.6-46.6 |
| $TiO_2$ | 1.59 | 0.8-1.14 |
| $Al_2O_3$ | 15.02 ppm | 11.9-12.9 |
| $Cr_2O_3$ | 0.04 | 0.08-0.35 |
| FeO | 7.35 | 17.4-18.1 |
| MnO | 0.18 | 0.2-0.26 |
| MgO | 9.01 | 6.2-6.8 |
| CaO | 10.42 | 12.7-13.7 |
| $Na_2O$ | 2.70 ppm | 0.02-0.31 |
| $K_2O$ | 0.82 | 0.03-0.04 |
| $P_2O_5$ | 0.66 | 0-0.04 |
| BaO | ---- | 0-0.07 |

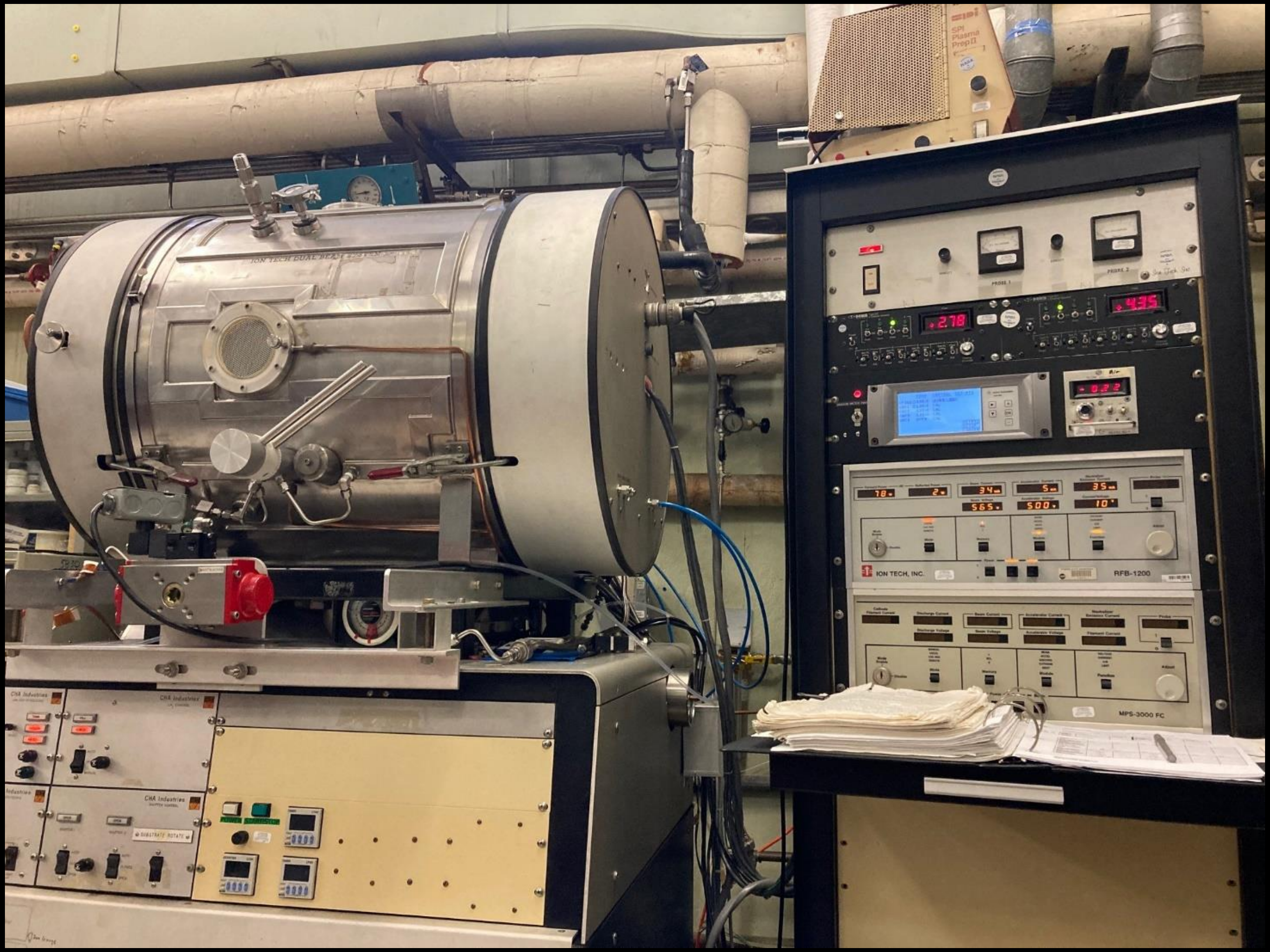
[1]Mc Kay, D.S. et al., JSC-1: A New Lunar Soil Simulant: Engineering, Construction, and Operations in Space IV American Society of Civil Engineers, pp. 857-866, 1994

[2]Ryder, G., et al., Basalts From Mare Crisium, Center for Astrophysics, Cambridge, Mass., U.S.A., 1977.

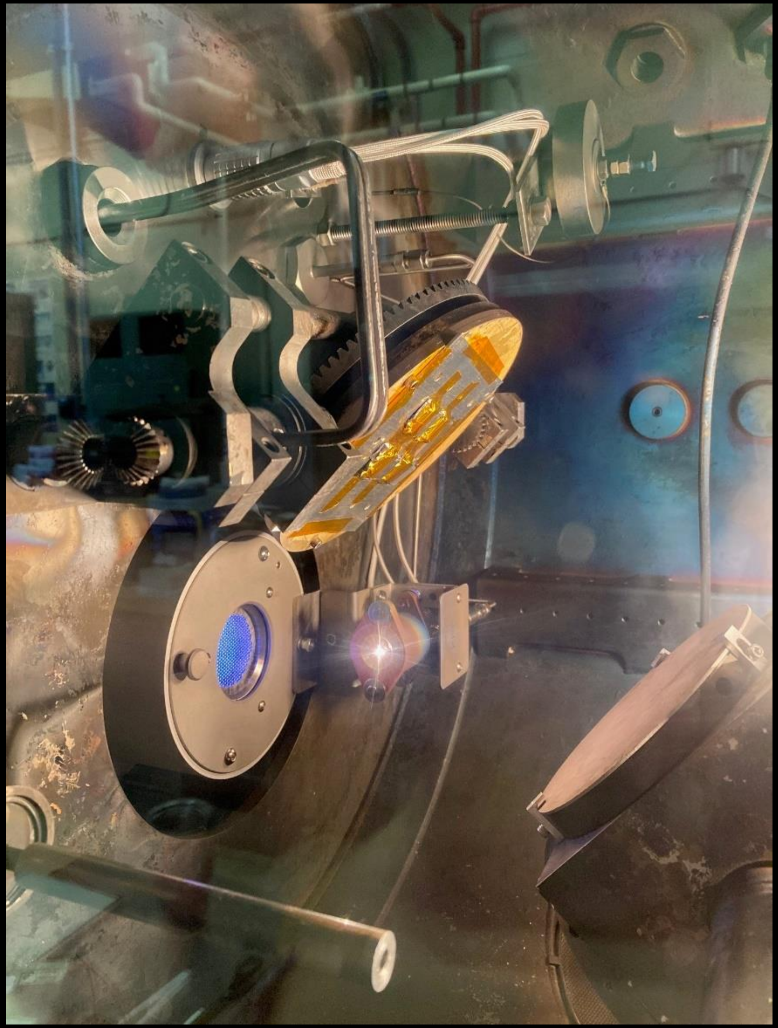
# Work Function Matching Coating Preparation

Sputter target made from simulant with chemistry closest to Mare Crisium





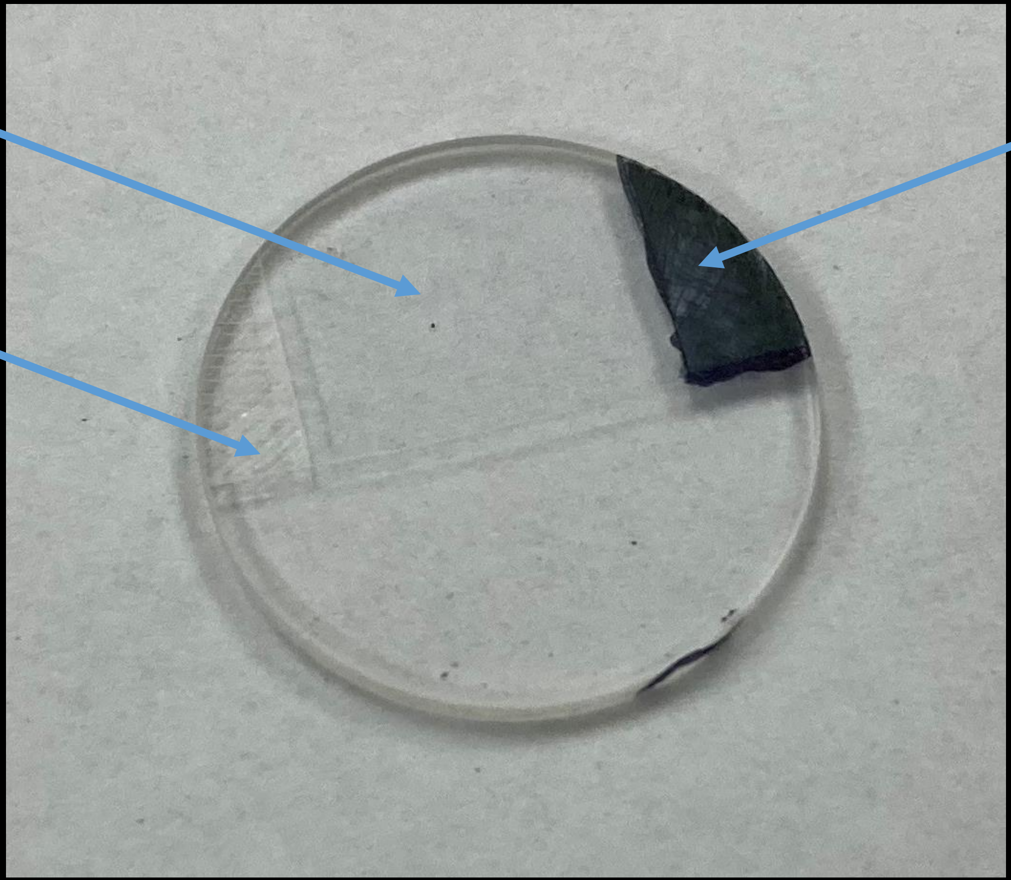
# Work Function Matching Coating Preparation



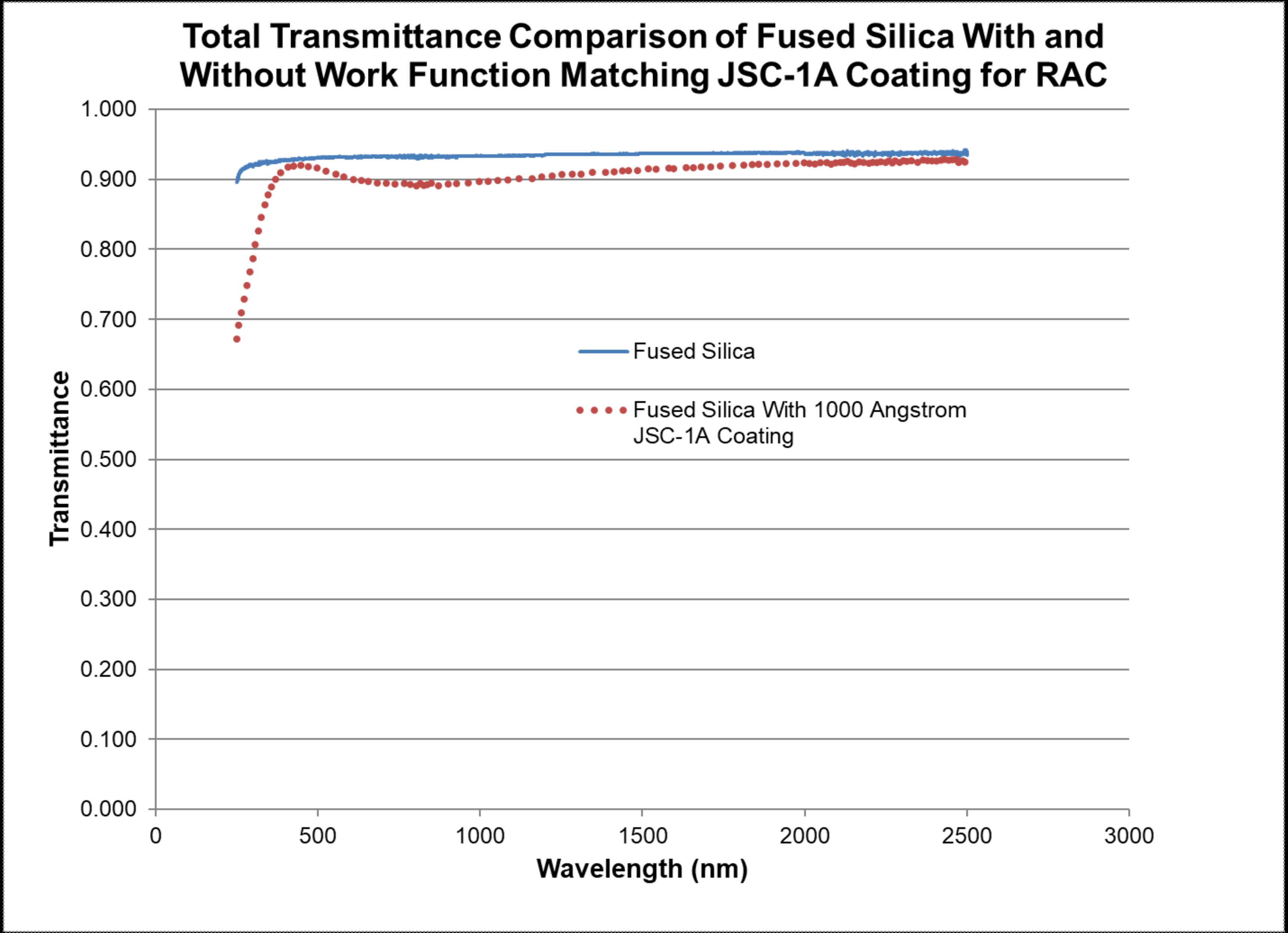
# Work Function Matching Coating on Upper Marked Half of Fused Silica Disk for RAC

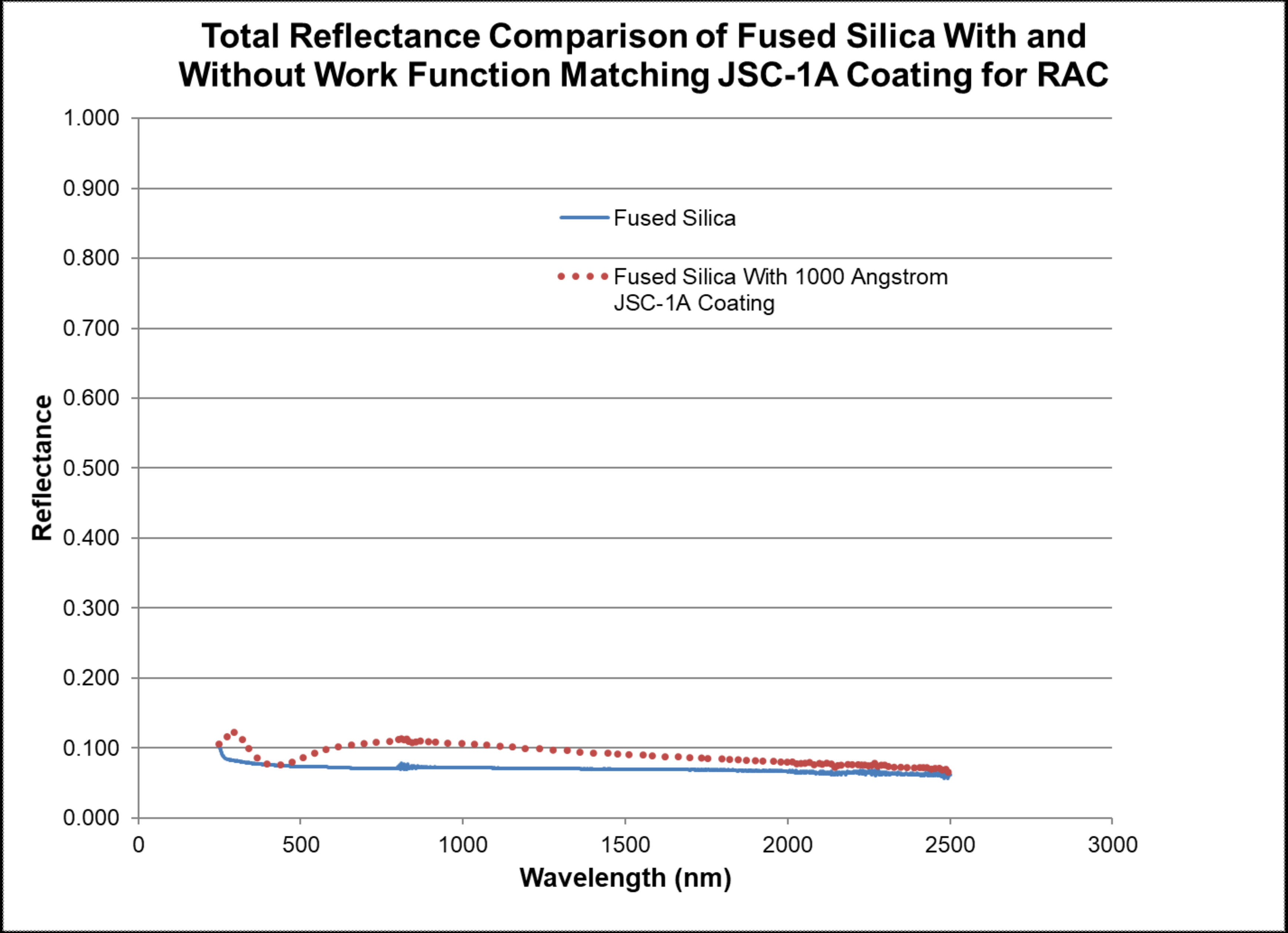
Work Function Matching Coating (1000 Å) on Top Half

Section of Fused Silica with Hash Marks Applied by Diamond Scribe Prior to Work Function Matching Coating (to distinguish coated and uncoated halves in camera images when on the lunar surface)

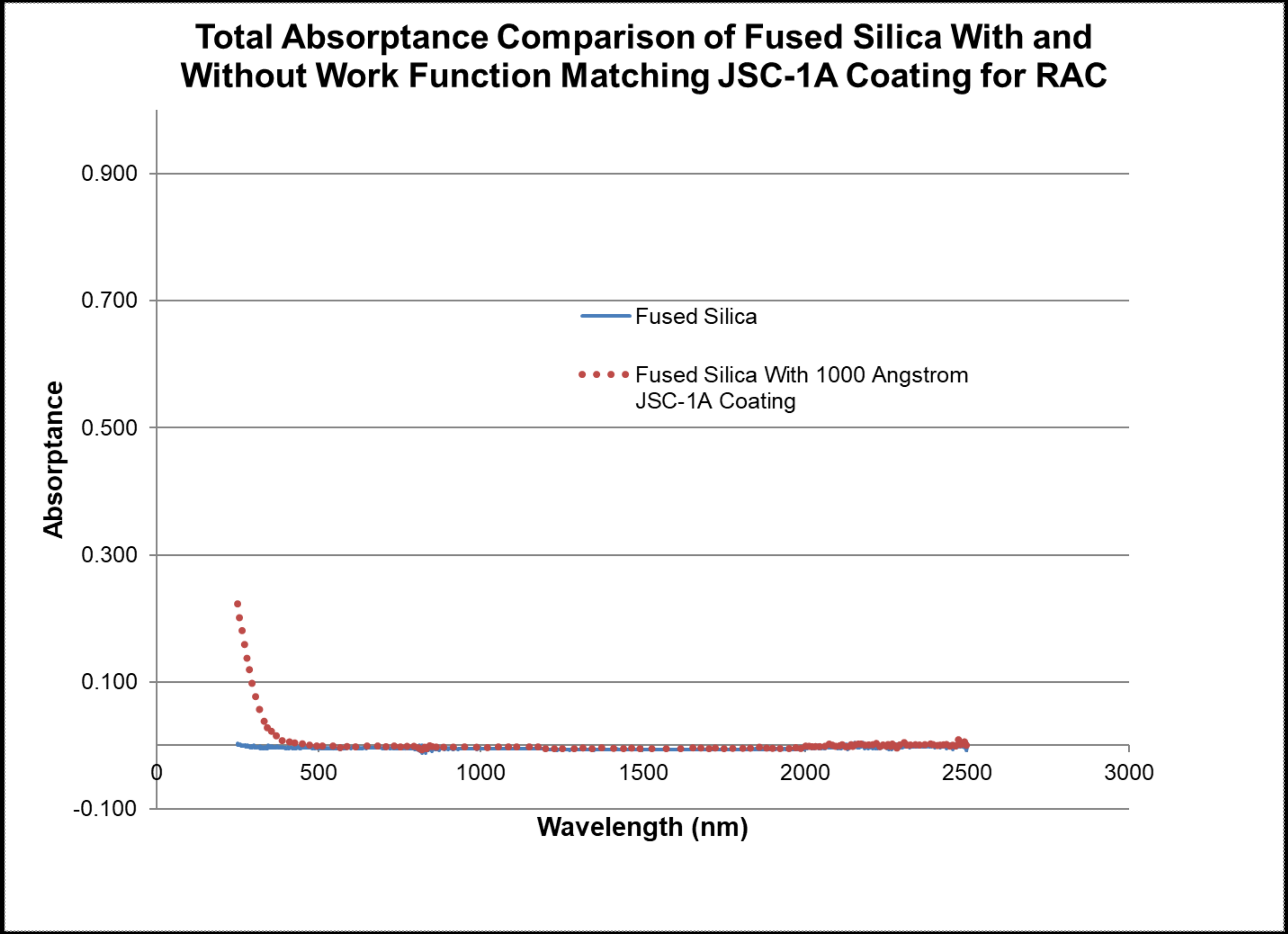


Section of Fused Silica with Hash Marks Applied by Diamond Scribe then Overcoated with Black Ink Prior to Work Function Matching Coating (to distinguish coated and uncoated halves in camera images when on the lunar surface)


Total Transmittance Comparison of Fused Silica With and Without Work Function Matching JSC-1A Coating for RAC
Transmittance
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
500
1000
1500
2000
2500
3000
Wavelength (nm)
Fused Silica
Fused Silica With 1000 Angstrom JSC-1A Coating



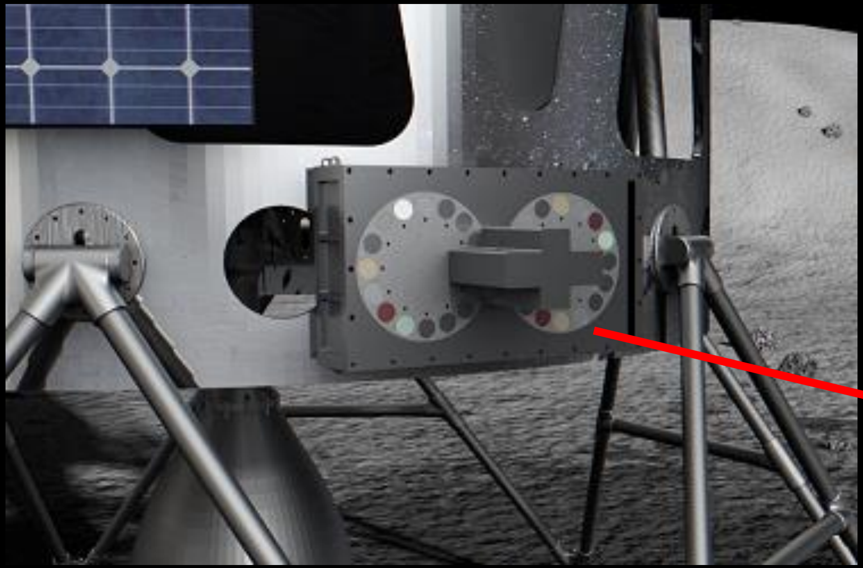
Total Reflectance Comparison of Fused Silica With and Without Work Function Matching JSC-1A Coating for RAC
Reflectance
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Fused Silica
Fused Silica With 1000 Angstrom JSC-1A Coating
0
500
1000
1500
2000
2500
3000
Wavelength (nm)


Total Absorptance Comparison of Fused Silica With and Without Work Function Matching JSC-1A Coating for RAC
Absorptance
0.900
0.700
0.500
0.300
0.100
-0.100
0
500
1000
1500
2000
2500
3000
Wavelength (nm)
Fused Silica
Fused Silica With 1000 Angstrom JSC-1A Coating

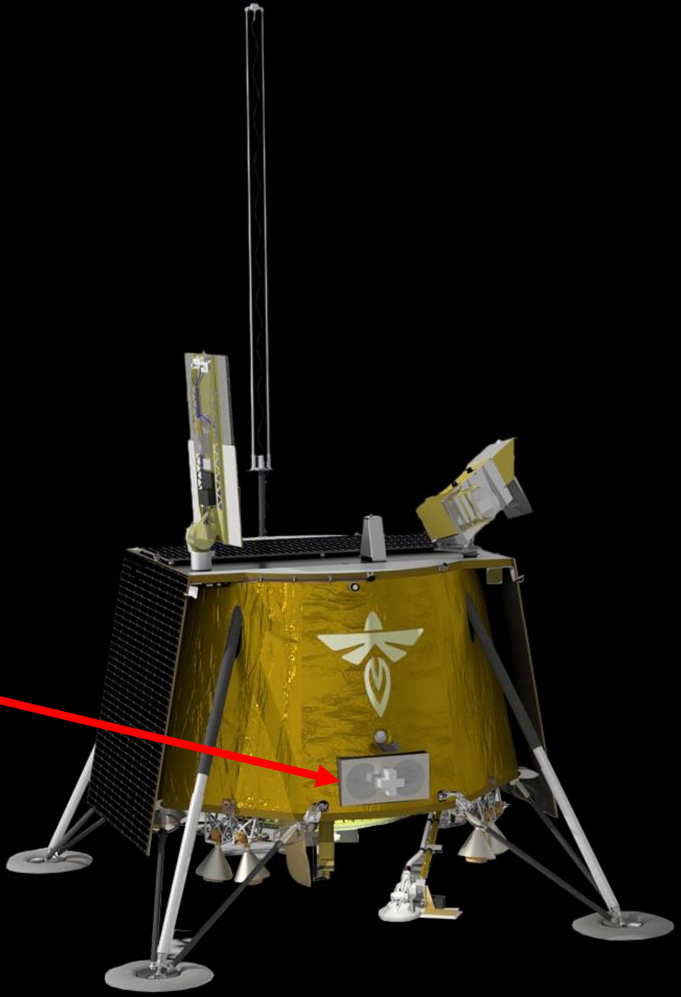
# Commercial Lunar Payload Services Flight Test

Two identical flight and backup samples were delivered to Aegis Aerospace for integration into the Regolith Adherence Characterization (RAC) experiment. This experiment is being integrated for launch to Mare Crisium on the Firefly Blue Ghost Lander in 2024.

## RAC Experiment

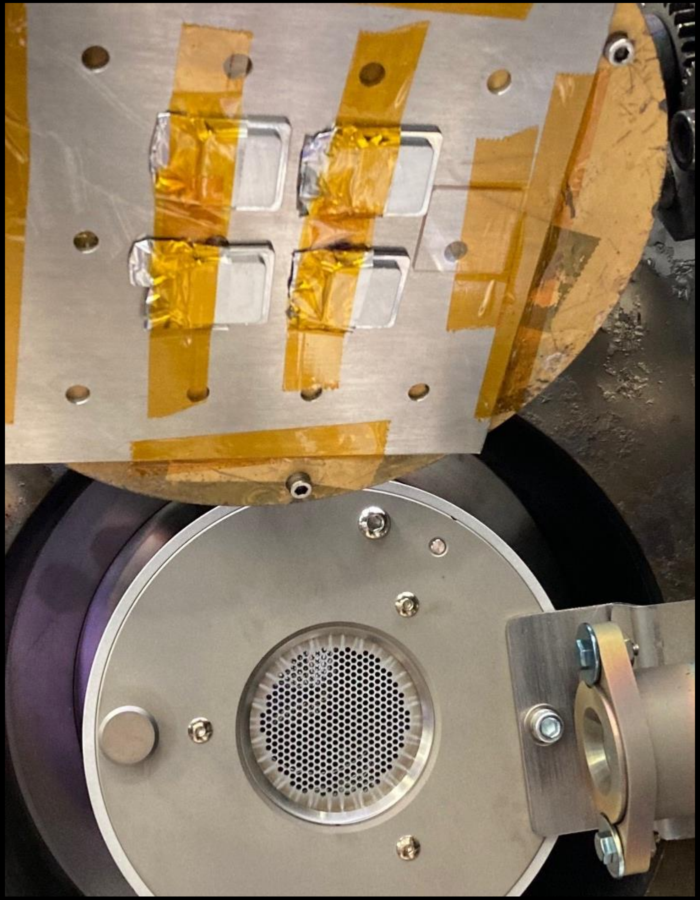


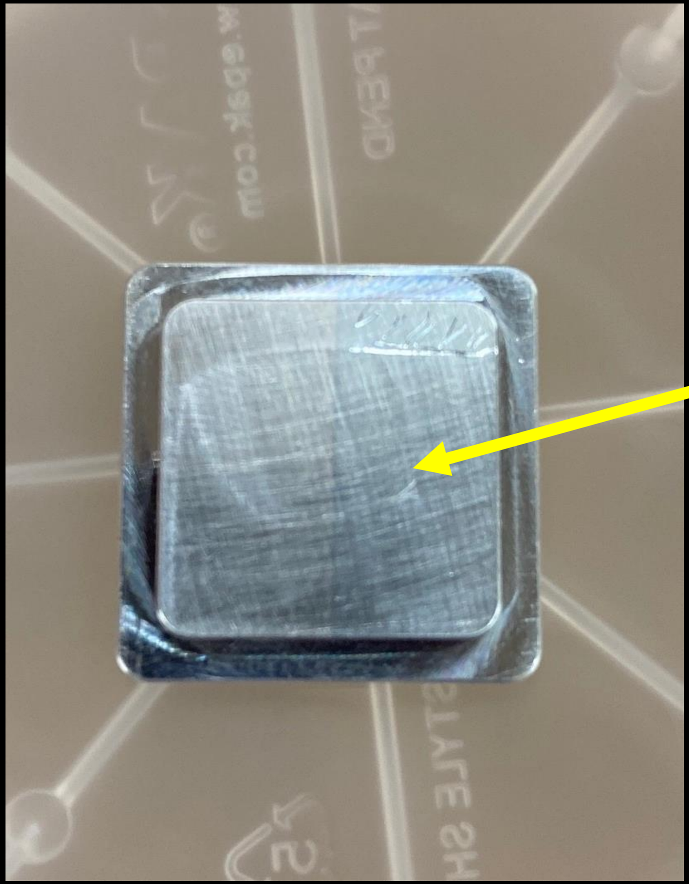
Aegis Aerospace (formerly Alpha Space) : [NASA Selects Alpha Space for Lunar Payload – News and Events]



Firefly Aerospace: https://firefly.com/lunar-lander/

# Work Function Matching Coating Deposition on Samples for Honeybee Robotics' Planet Vac





Work Function Matching Coating (1000 Å) on the Right Half

# Summary

- Lunar dust affected EVA systems on Apollo Missions
- Lunar dust is difficult to remove from surfaces
- Dust mitigation techniques are being developed
- Techniques are being tested in ground based systems using lunar simulants
- Flight testing is the next step to both verifying performance and tailoring ground based testing systems to be closer to the actual environment

Thanks to the Space Technology Mission Directorate's Lunar Surface Innovation Initiative, Game Changing Development Program, Dust Mitigation Demonstration Project for their support

And

Dr. James Gaier, NASA GRC, retired, for his expert advice and mentorship