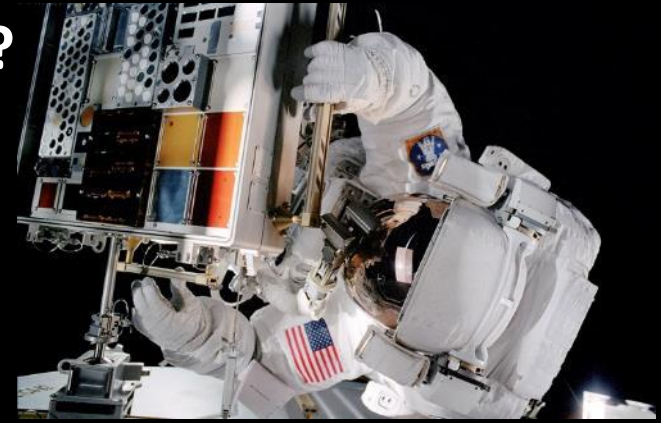


Vantablack® S-VIS/S-IR Optical Properties & Space Qualification Test Data



Why Use Vantablack S-VIS/S-IR Coatings In Your Flight Instruments?

- Improved stray light control in baffle systems leading to:
 - Direct reduction in baffle weight, complexity and size whilst maintaining or improving performance
 - UV - >FIR performance provides exceptional stray light artefact reduction in lens assemblies
- High performance blackbodies for IR sensing
 - Very high emissivity and spectrally flat from NIR to FIR provides superior performance across a wide spectral range
 - Simplified design potential reduces flight mass and cost



Coating Risk Mitigation

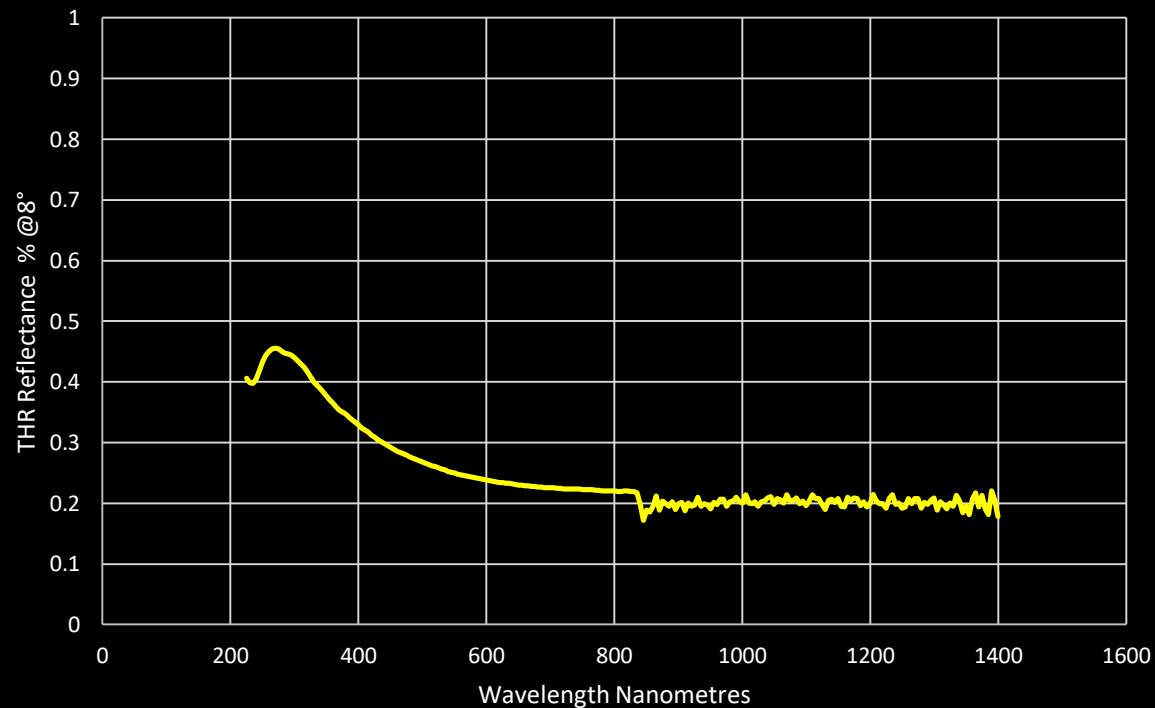
- 4 years performance in low earth orbit
- Qualified by Prime and tier 1 - 2 instrument builders for baffles and black bodies
- UV resistance: Exhibits no degradation unlike polymer-based alternatives
- Radiation resistance: resistant to breakdown and particulate generation under high radiation doses
- Shock resistance: resistant to launch shock and staging
- ATOX: optical properties remain consistent throughout mission life
- Outgassing: easily passes ASTM E-595 standards
- Test data: repeated and confirmed by relevant third parties



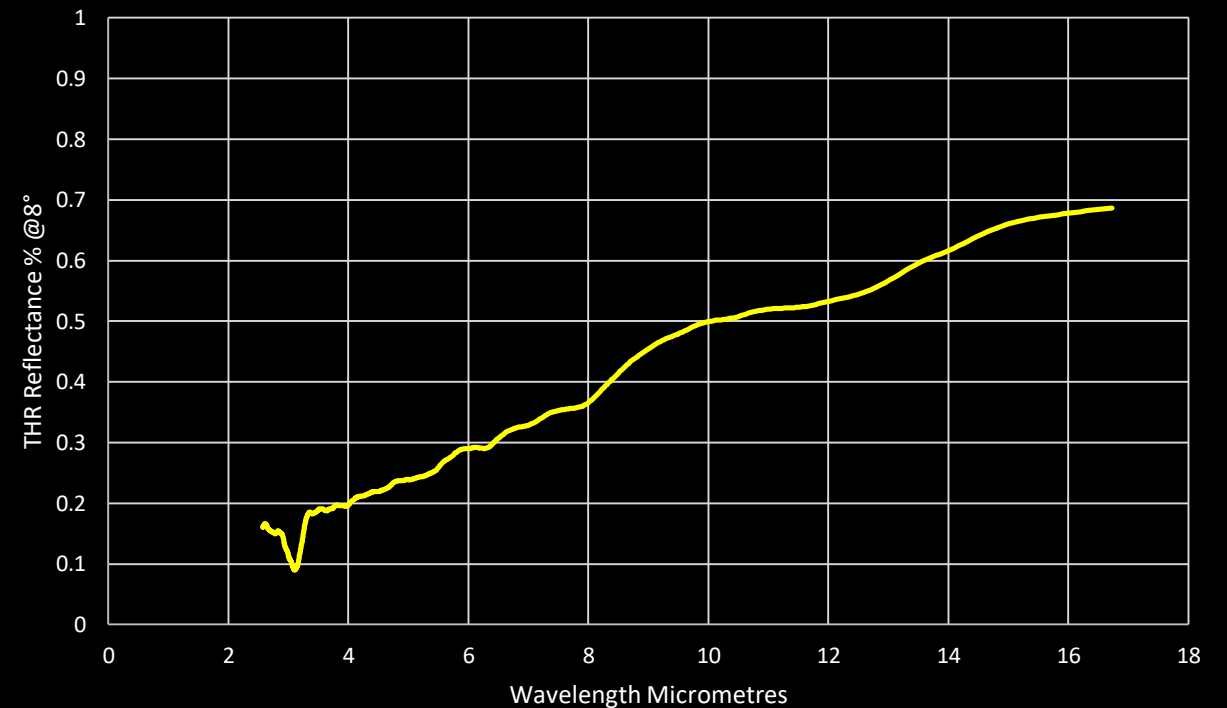
Vantablack S-VIS: Total Hemispherical Reflectance

- Reflectivity: Optically superior to all other available black coatings across a very wide spectral range

Vantablack S-VIS: UV-NIR THR



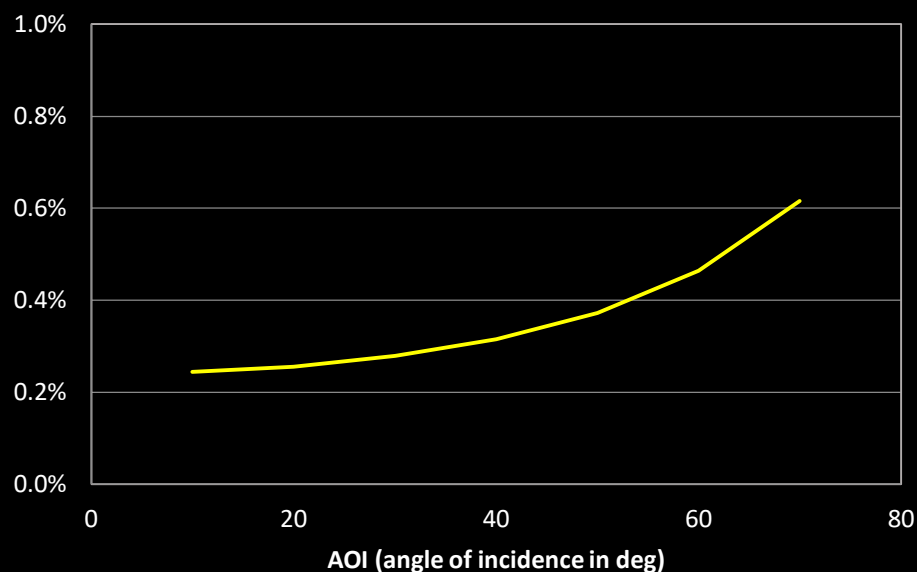
Vantablack S-VIS: IR THR



Vantablack S-VIS BRDF & TIS Chart: Visible Spectrum

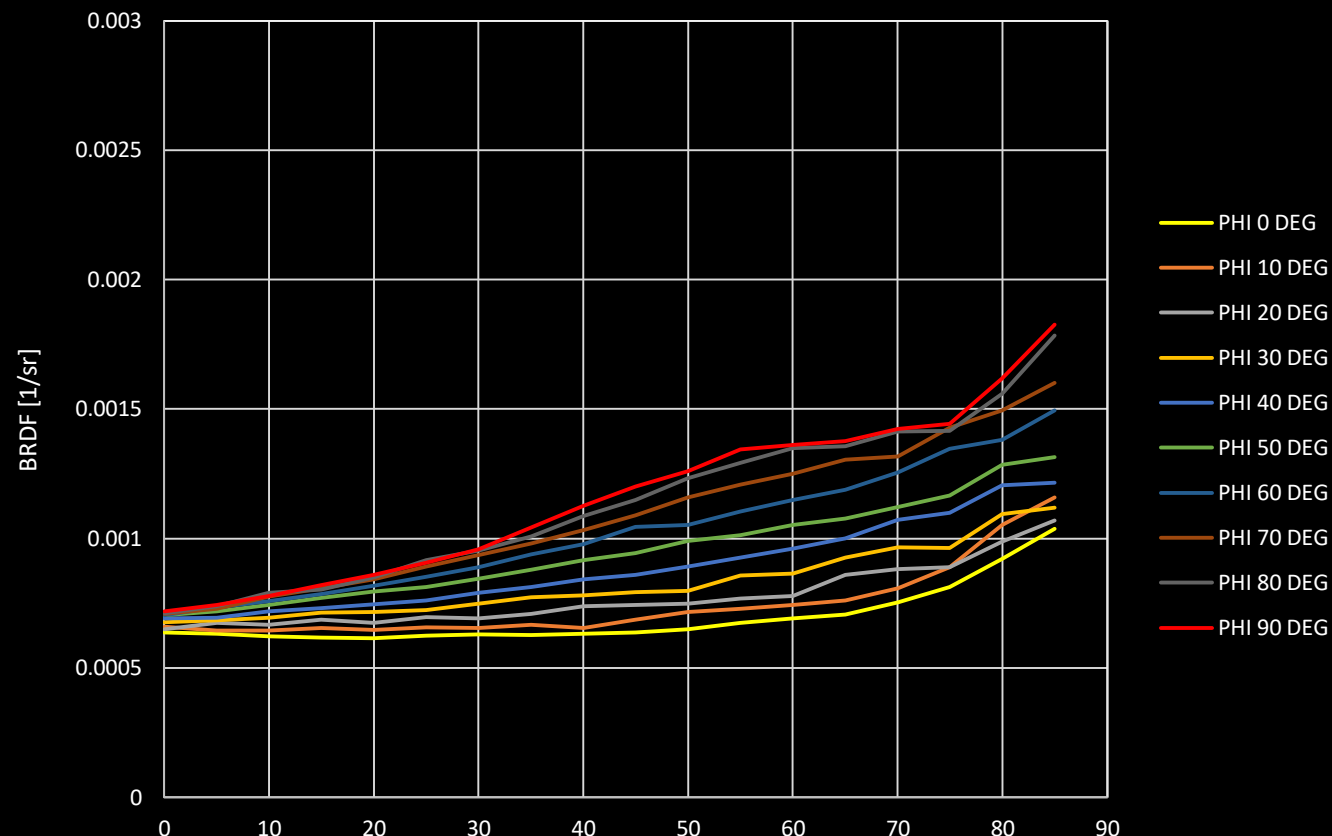
- BRDF: unlike other coatings, Vantablack retains its performance from all viewing angles

TIS Reflectivity; 400nm – 800nm



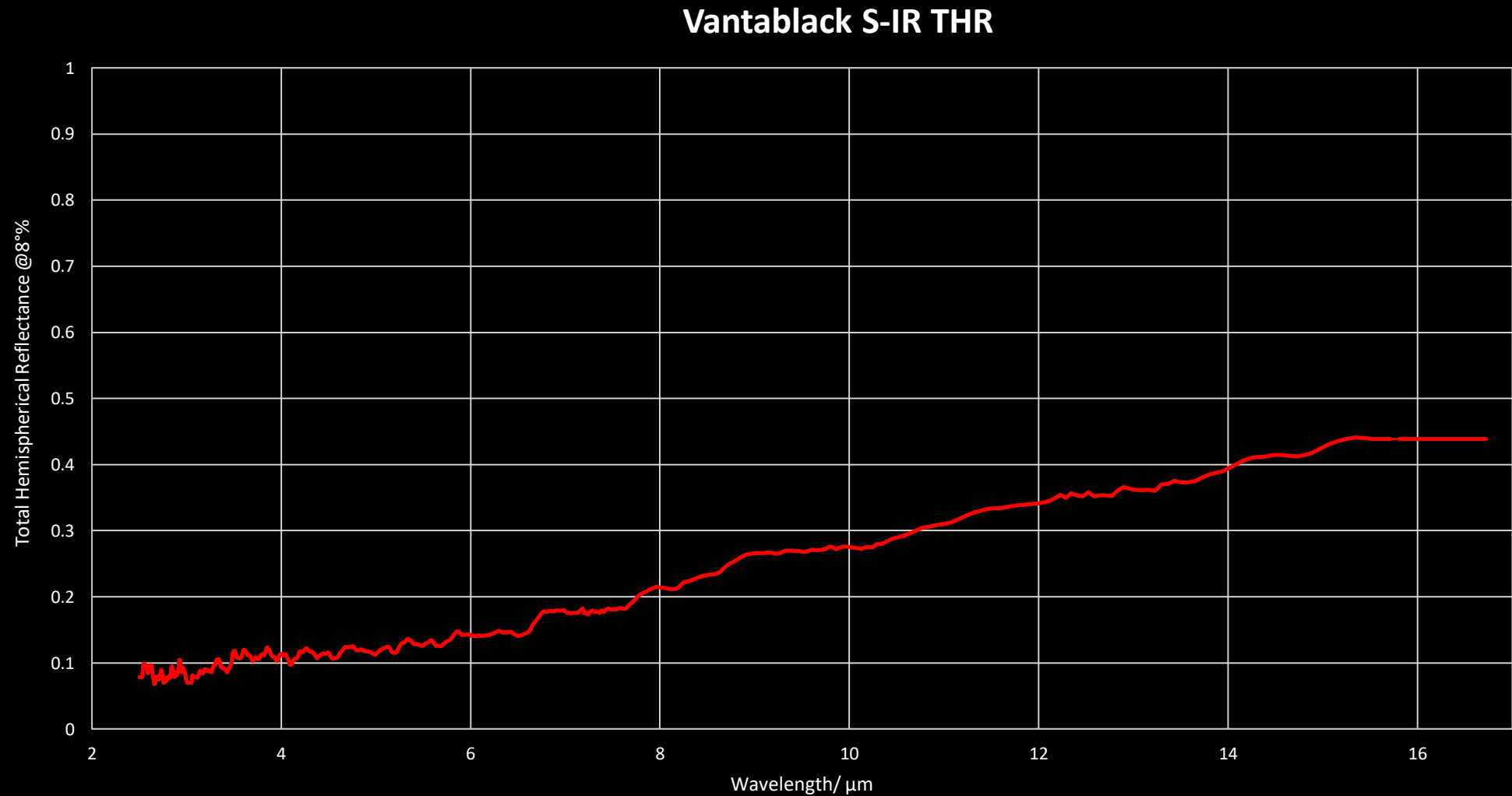
Wavelength: 400nm – 800nm Optowhite source
Incident Zenith Angle: 50.0
Polarizers: Yes – Angle 0°

Visible Spectrum BRDF Theta = 50 degree AOI



Vantablack S-IR: Total Hemispherical Reflectance NIR to LWIR

Typical performance

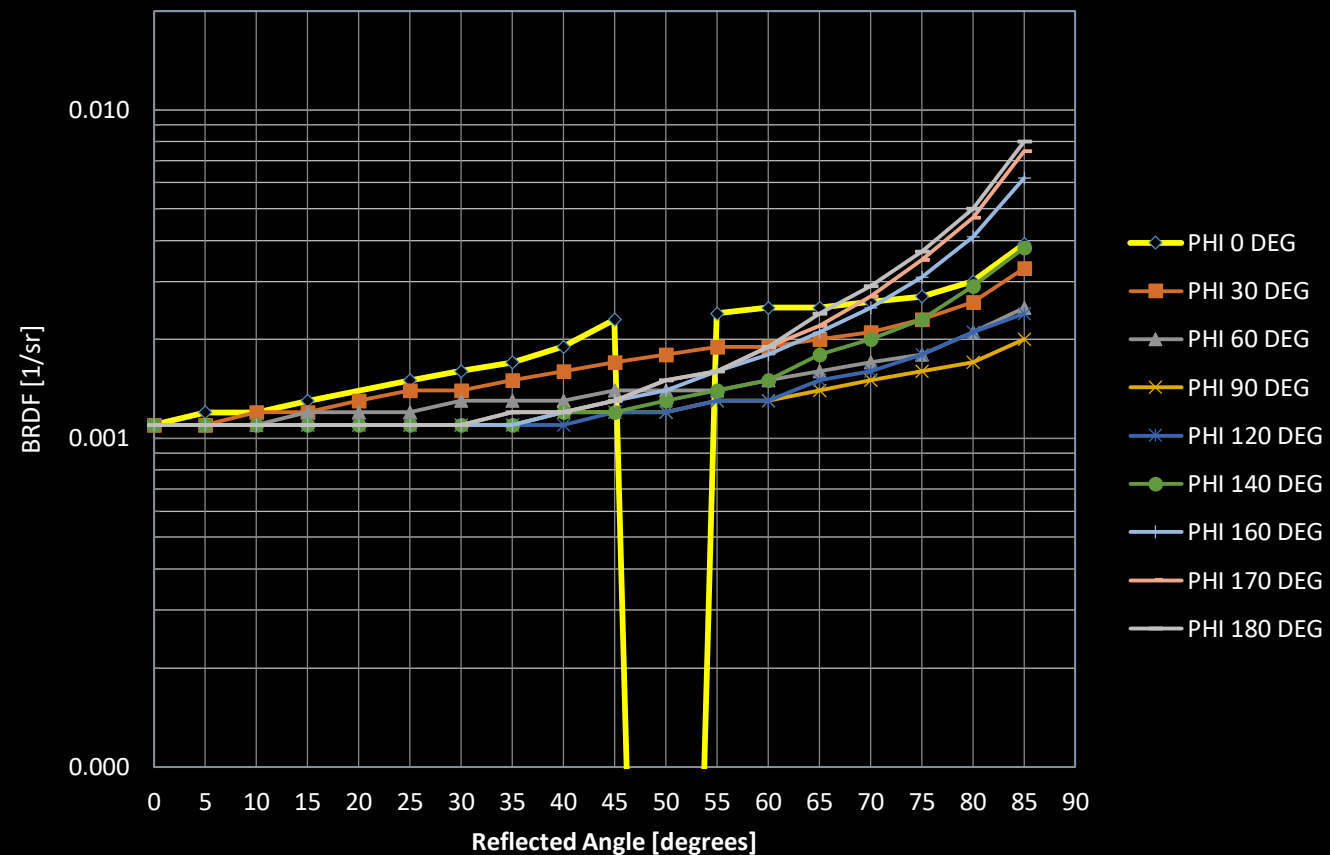
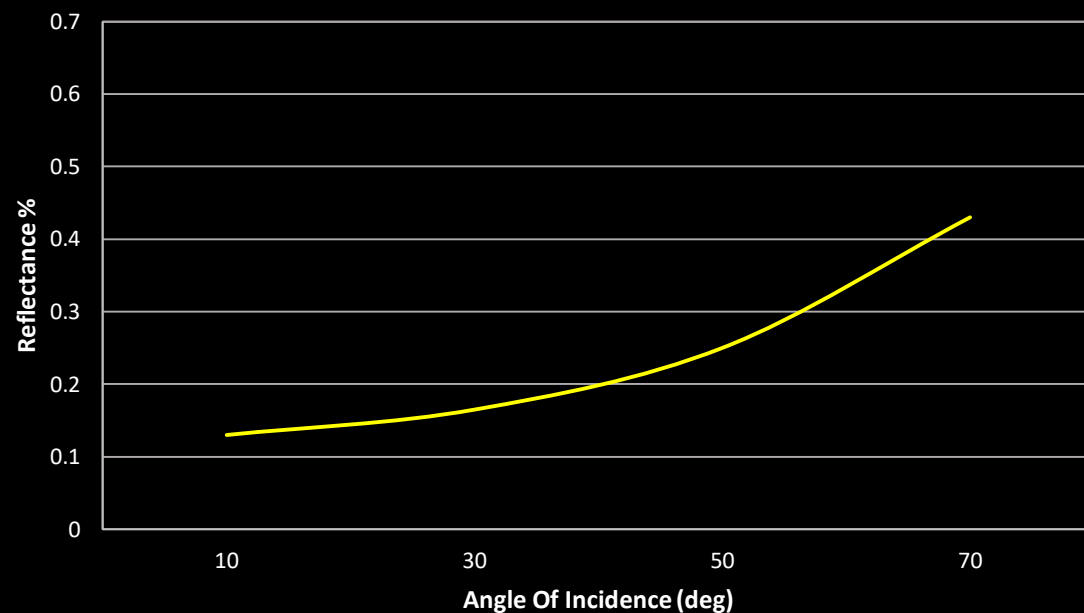


Vantablack S-VIS: MID Infrared BRDF & ADR Charts

MWIR BRDF

Theta = 50 degree AOI; CWL = 4 micron

Angle Dependent MWIR Reflectance - S-VIS
3-5um unpolarized



Sample Number: GT0102

Sample Description: VBS-2538

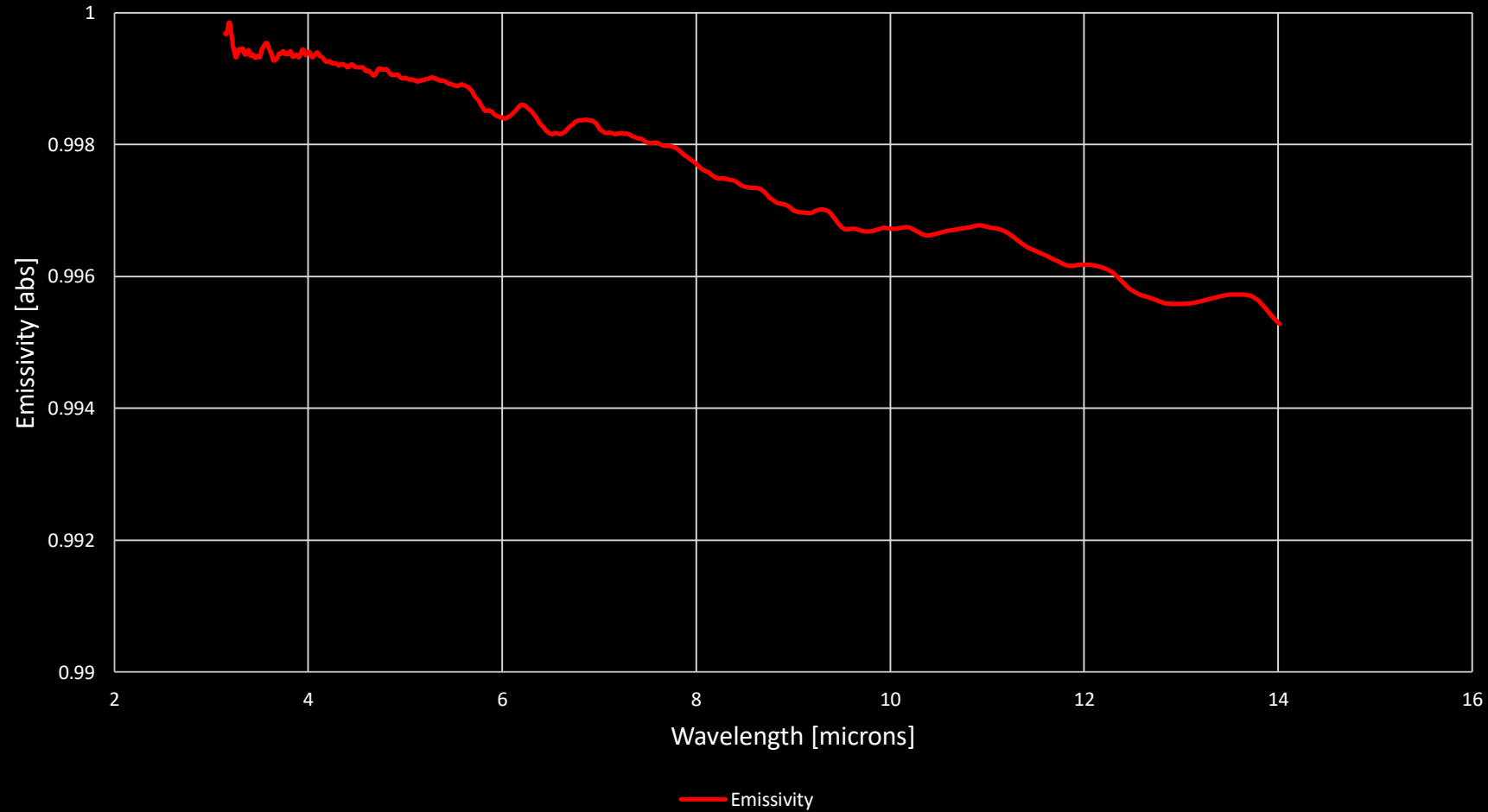
Wavelength: 4.000 CWL (3-5 bandpass)

Incident Zenith Angle: 50.0; HDR = 0.0047

Vantablack S-IR: Infrared Emissivity

Infrared Effective Emissivity of Vantablack S-IR Bonded Coating

AOI = 7 deg; 293 K; Random Polarization



Space Qualification Trials Vantablack S-VIS/S-IR Coatings



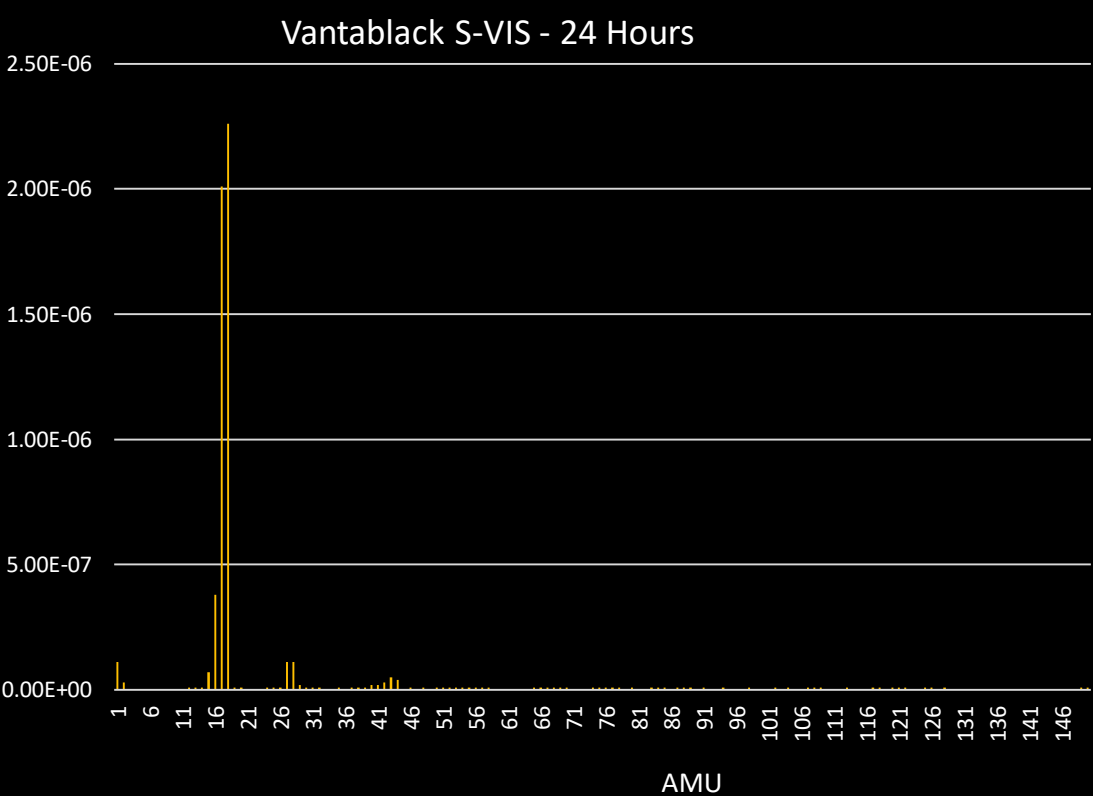
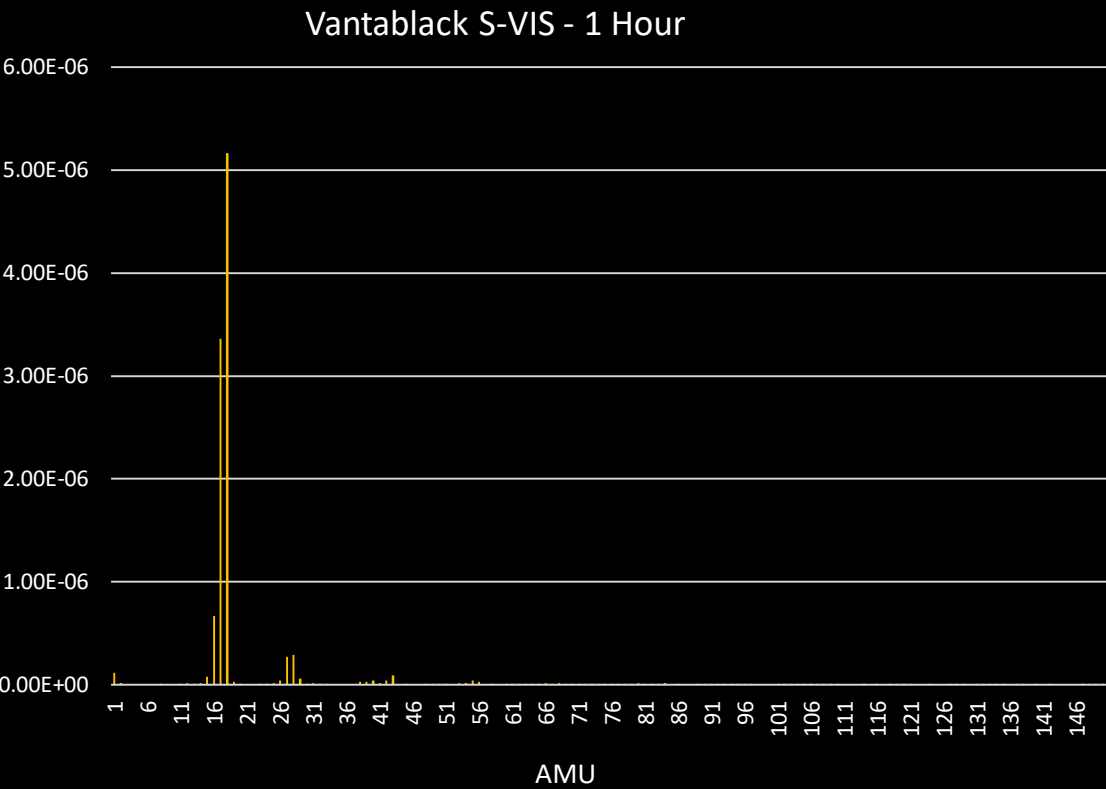
Vantablack S-VIS: Outgassing Data - ECSS-Q-ST-70-02C (ASTM E-595)

Sample	TML %	CVCM %	RML %
Crucible 1	0.495	0	0
Crucible 2	0.512	0.007	0
Crucible 3	0.474	0.003	0
Crucible 4	0.496	0	0

Raw data from crucibles

Cell ref	Contents	Mass of Crucible	Mass of crucible and sample	Mass of crucible and sample after run	Total Mass Loss	Mass of mirror	Mass of mirror after run	CVCM %*	Crucible and sample after conditioning	Recovered mass loss %*
1	E	34.077	34.077	34.075	0	955.932	955.936	0	34.076	0
2	S	35.205	94.208	93.916	0.495	811.47	811.46	-0.017	94.378	-0.288
3	V	0	0	0	0	911.892	911.908	0	0	0
4	V	0	0	0	0	909.914	909.906	0	0	0
5	V	0	0	0	0	880.602	880.569	0	0	0
6	S	34.019	92.172	91.874	0.512	866.812	866.816	0.007	92.324	-0.261
7	S	32.118	90.813	90.535	0.474	966.524	966.526	0.003	90.985	-0.293
8	V	0	0	0	0	976.26	976.266	0	0	0
9	E	33.464	33.464	33.464	0	1029.82	1029.83	0	0	0
10	S	32.419	63.249	63.096	0.496	960.552	960.548	0	63.309	-0.195
11	V	0	0	0	0	967.752	967.742	0	0	0
12	V	0	0	0	0	930.708	930.696	0	0	0

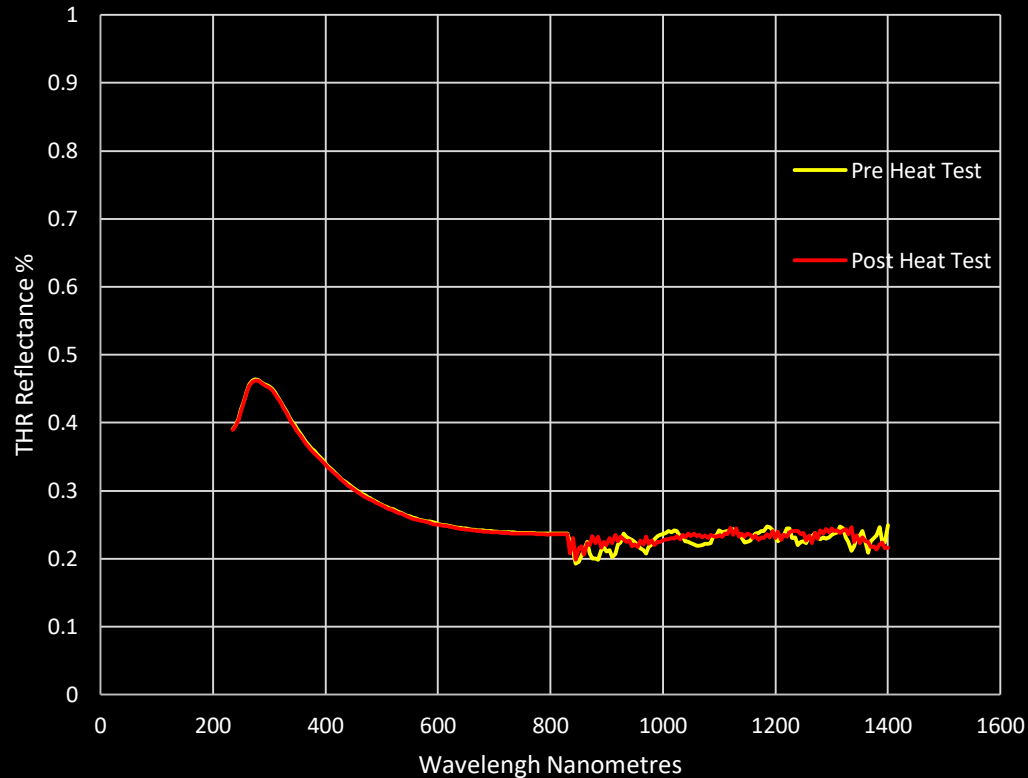
Vantablack S-VIS: RGA Data – 125°C



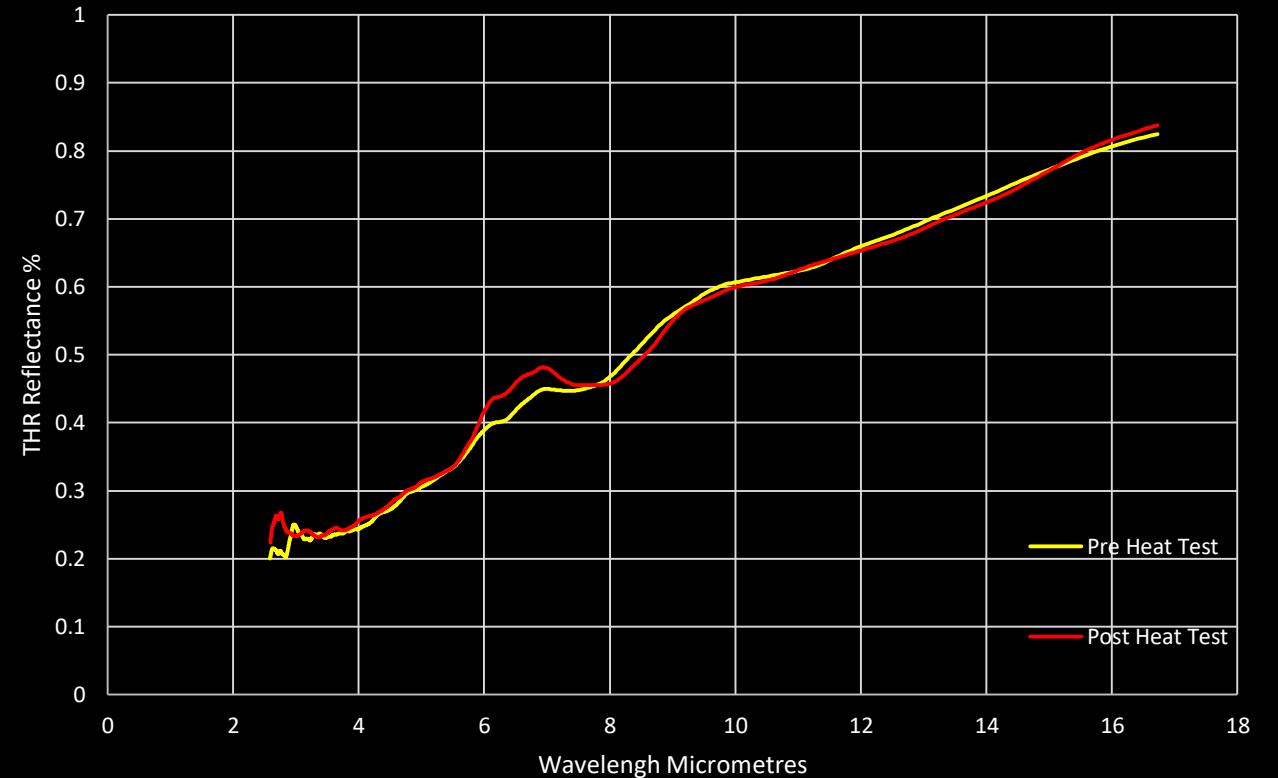
Vantablack S-VIS: Atmospheric Thermal Soak

The coupon is heated to 200°C in air on a hot plate at 50% RH and held for 4 hours to test for delamination or a change in optical properties. The cycle is repeated 5 times and then the sample is re-measured.

Heat test UV/Vis



Heat test IR



Variation is within the uncertainty of the spectrometers

Vantablack S-VIS: Radiation Resistance

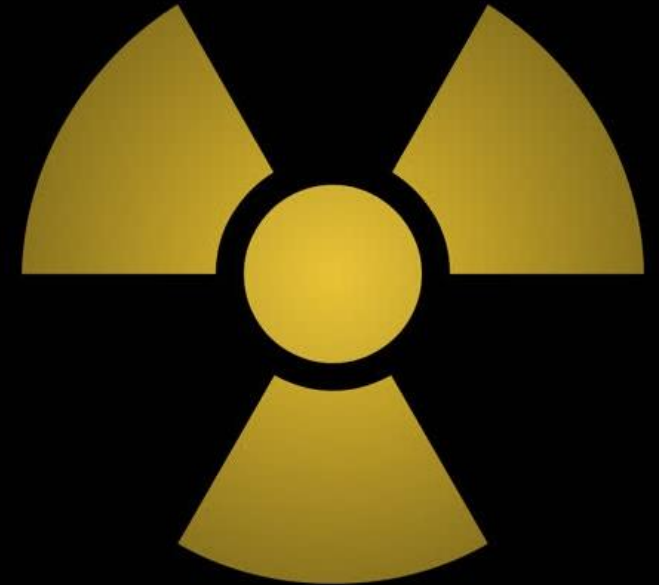
Typical performance (third party qualification test)

Samples: 6061-T6 Aluminium substrates coated with Vantablack S-IR

- Multiple substrates exposed to a dose of 2Mrad gamma and proton radiation

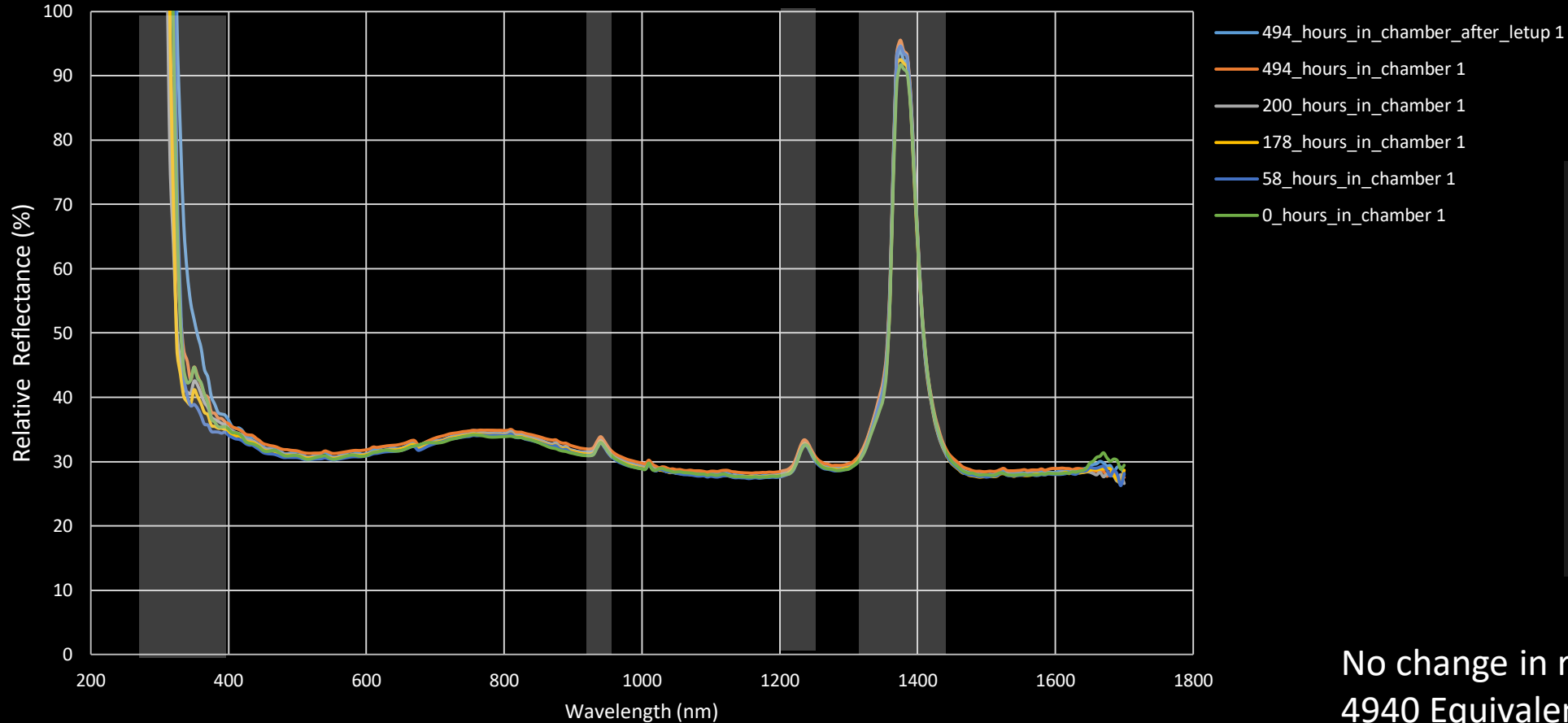
Result:

- Optical properties unchanged
- No particulates generated
- No change in optical properties after elevated humidity trials



Vantablack S-VIS: (VUV) Vacuum UV Exposure

VUV Reflectance Spectra - ESH 4940 Hrs



Wavelength range: 115nm – 700nm

Sources: Deuterium and Xenon

Acceleration Factor: 10

Substrate Temperature: 180°C



No change in reflectance after
4940 Equivalent Solar Hours
(ESH)

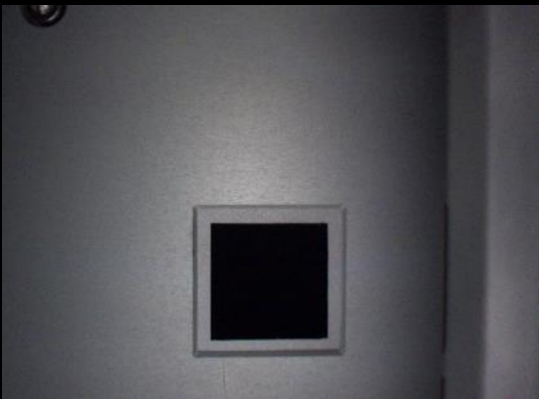
 Bands denote measurement instrument
artefacts from spectrometer light pipe

Vantablack S-VIS: Atomic Oxygen (ATOX)

- 4 years LEO orbit data from externally mounted dual star-trackers
 - 550km equatorial orbit
 - Launch date: 16 Dec 2015
 - PSLV-C29 launcher of ISRO from SDSC
 - No optical degradation in star-tracker performance after 4 years LEO exposure

On going LEO ATOX trials:

- ISS MISSE-10 Bonded Vantablack S-VIS in ram and wake positions
- ISS MISSE- 11 Bonded Vantablack S-VIS in ram and wake positions
- ISS MISSE-12 Bonded Vantablack S-IR and CX2 in ram and wake positions



MISSE-11 Ram Nov 19
Image in shadow



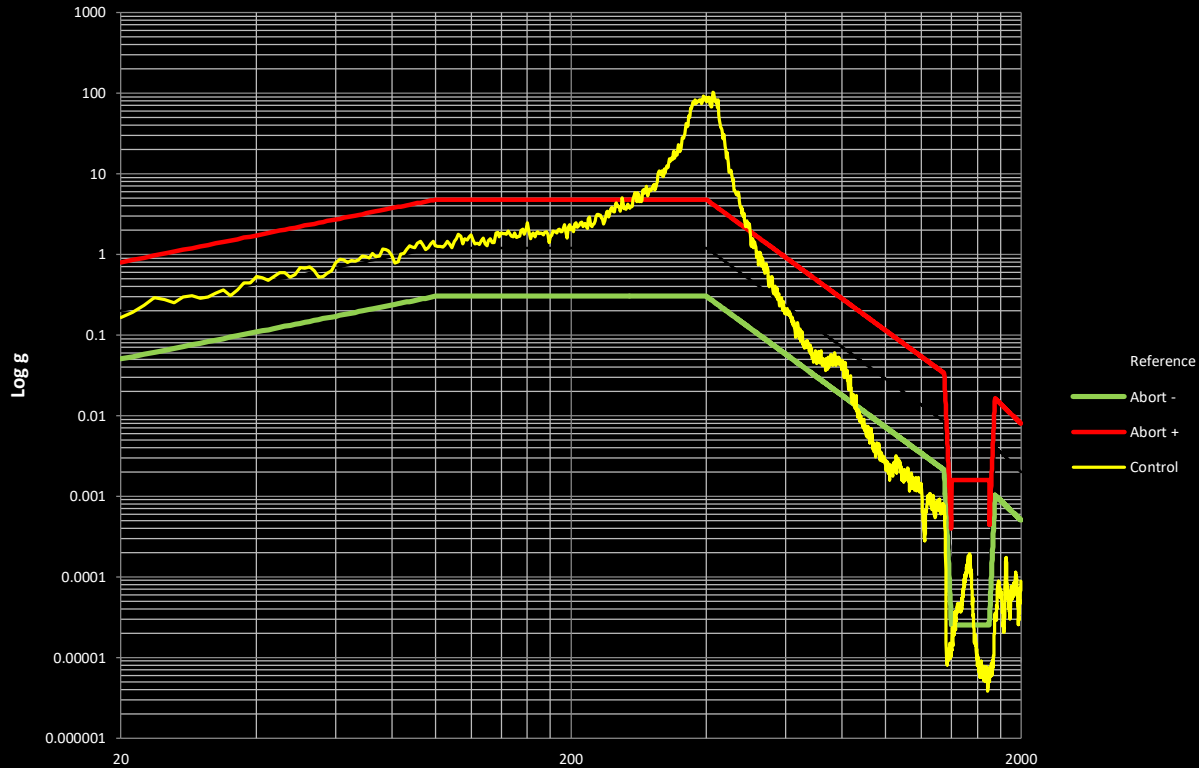
MISSE-10 Ram Nov 19
Image in direct sunlight

No detectable deterioration
in optical properties, and
QCM is not detecting
unexpected mass loss

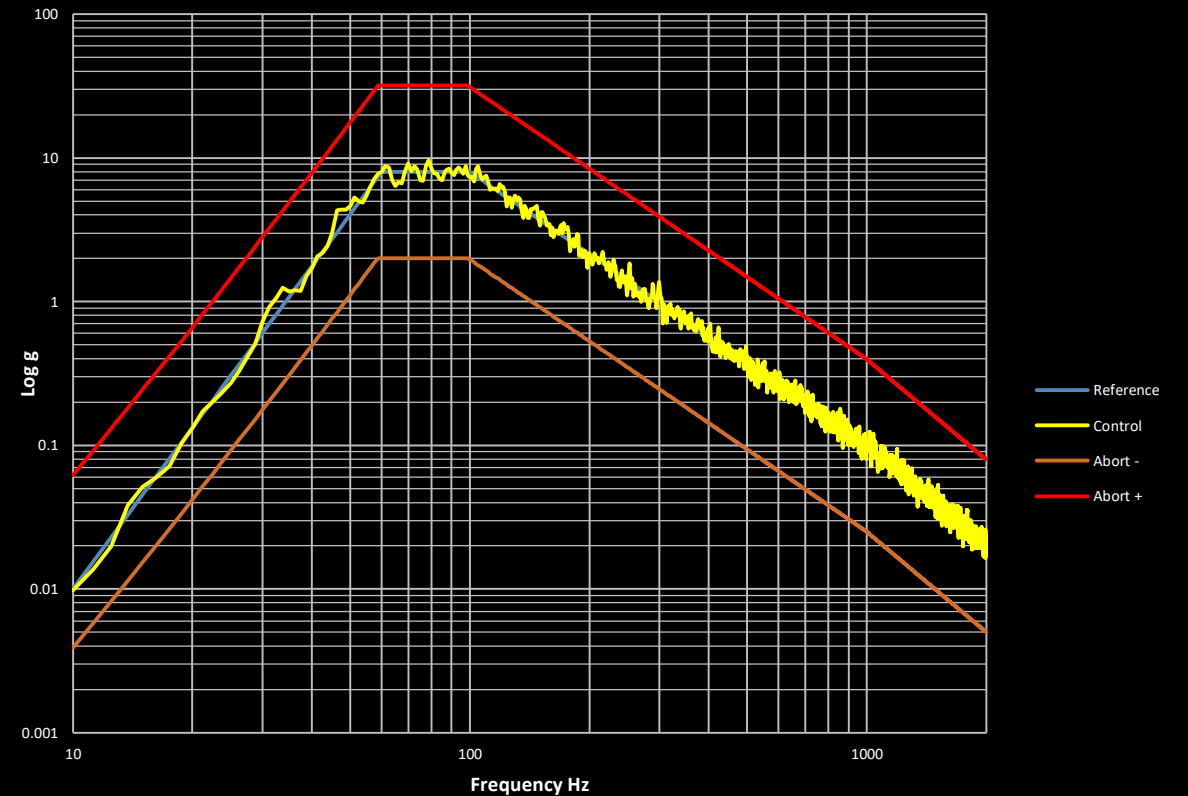
Vantablack S-VIS: Example Vibe PFO Test

- The following profiles are run 4 times for 5 minutes with an inspection for PFO after the first and fourth runs

Vibration Profile 1

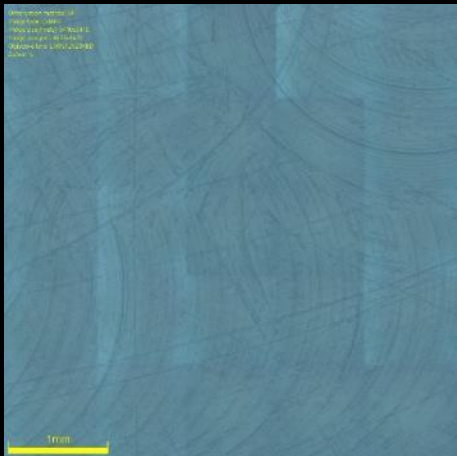


Vibration Profile 2

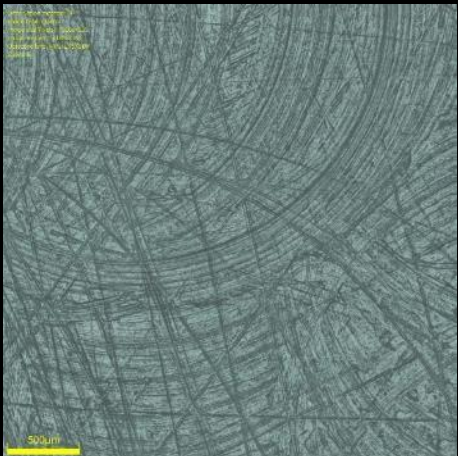


Vantablack S-VIS: Vibration PFO Test – Run 4 Result

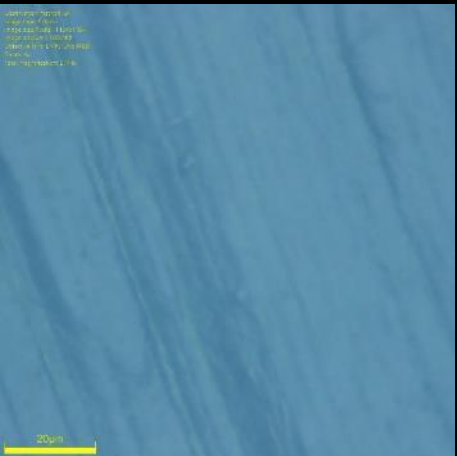
Microscope images of the PTFE capture plate after run four



Wide area -
1000µm scale

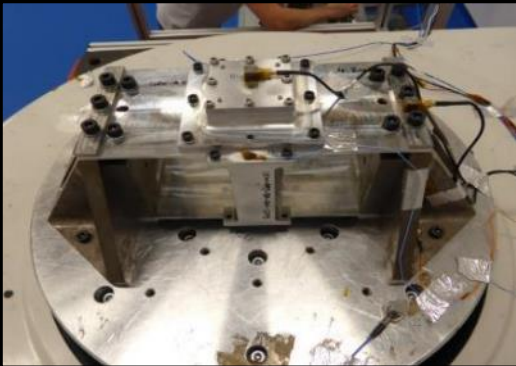


Central location –
500µm Scale

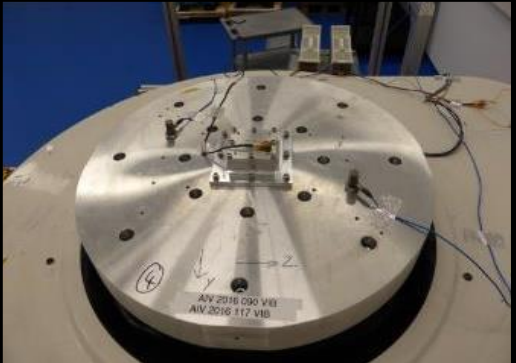


Central location –
high mag 20µm scale

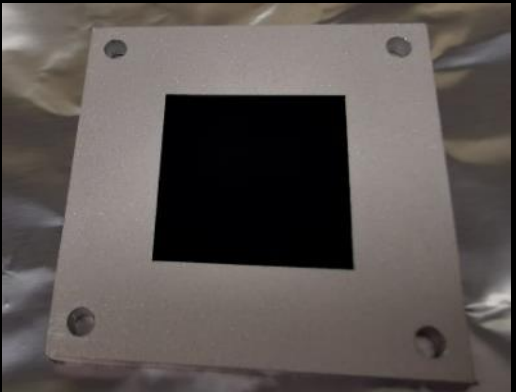
Coating Type	Number of particulates found and size range				
	25-50µm	15-25µm	5-15µm	1-5µm	Total Particle Count
Vantablack S-VIS	0	0	0	0	0
Vantablack S-IR	0	0	0	1	1
Control	0	0	0	0	0



Resonance mount – Vibe profile 1



Standard mount – Vibe profile 2



Standard 6061-T6 Test Coupon

Acronyms Used In This Presentation

- THR Total Hemispherical Reflectance in %
- UV Ultraviolet (spectrum)
- VIS Visible (spectrum)
- MIR Mid Infrared (spectrum)
- NIR Near Infrared (spectrum)
- VUV Vacuum Ultraviolet
- TIS Total Integrated Scatter %
- BRDF Bidirectional Reflectance Distribution Function
- AOI Angle of Incidence
- PFO Particle fallout
- TML Total Mass Loss
- CVCVM Collected Volatile Condensable Matter
- RML Recovered Mass Loss

- RGA Residual Gas Analyser
- ITAR International Traffic in Arms Regulations
- TVAC Thermal Vacuum
- ATOX Atomic Oxygen



Performance Data

- Raw data is available for input into your stray light modelling systems
- The company maintains a comprehensive range of test systems that can be made available for customer qualification
- Please contact enquiries@surreynanosystems.com for additional information or to have someone call you to discuss your application

VANTABLACK

Where Vision Makes the Difference