

Spacecraft materials degradation under a space-simulated low Earth orbit (LEO) environment

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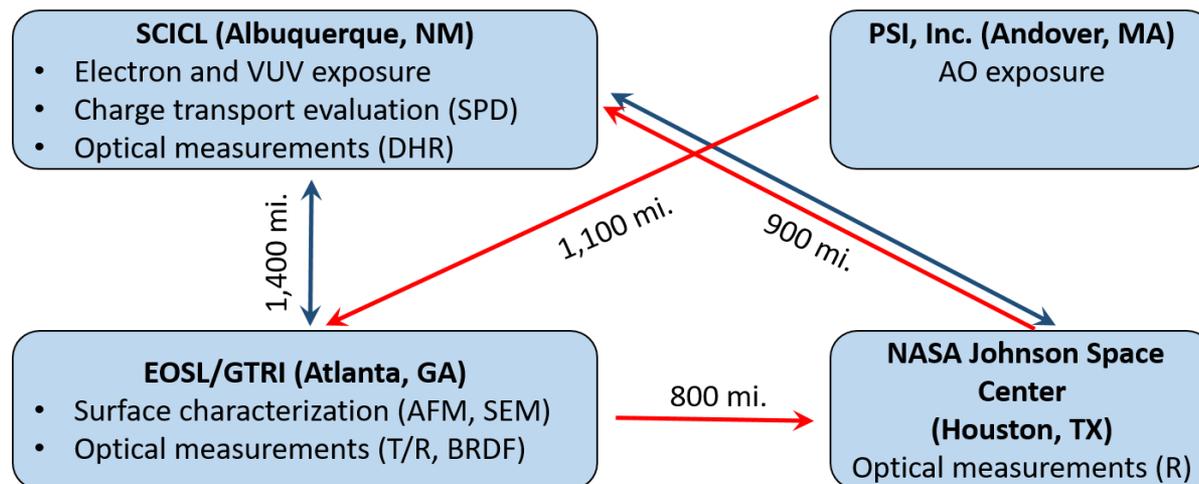
Elena Plis
Senior Research Engineer
elena.plis@gtri.gatech.edu

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Motivation

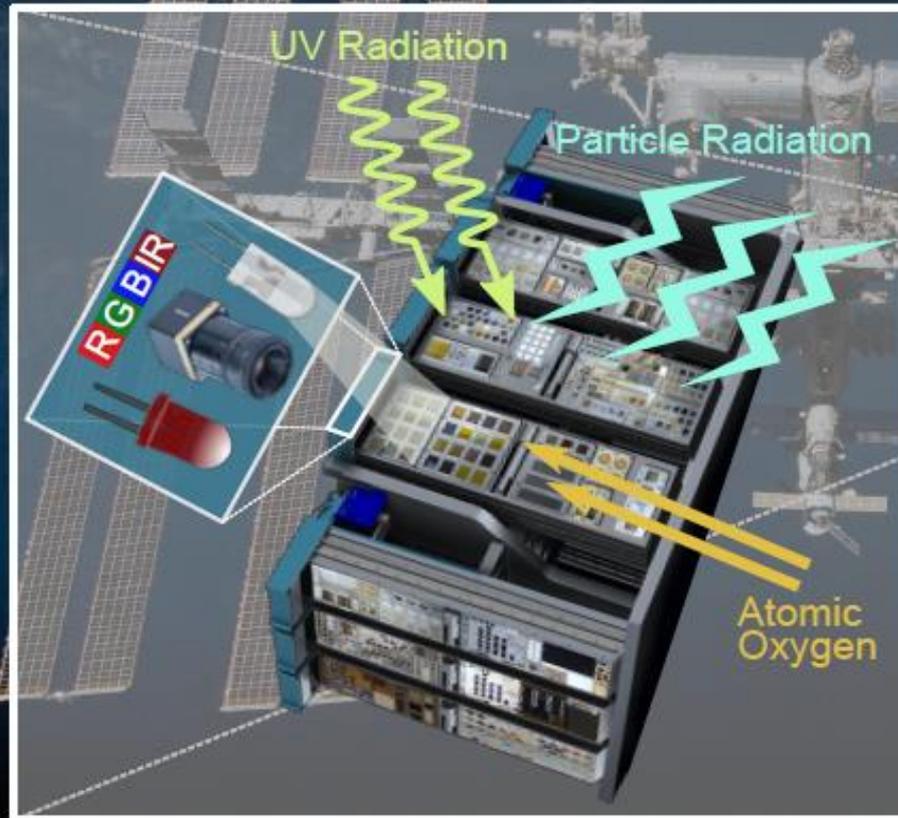
Thorough characterization of physical and chemical changes of heritage and novel spacecraft materials under true space exposure and ground-based space-simulated weather is important

- Establishing correlation factors between true space exposure and accelerate space weather experiments
- Enabling accurate prediction of on-orbit material performance based on laboratory-based testing
- Supporting material identification for space situational awareness

Materials International Space Station Experiment (MISSE) Flight Facility (MISSE-FF) is a perfect testbed to generate benchmark data for the efficiency validation of ground-based space weather simulation experiments

Materials International Space Station Experiment (MISSE) Flight Facility (MISSE-FF)

- Samples on ram, wake, zenith faces
- Unique damage occurs on each face
- White and IR LEDs illuminate samples
- Camera records RGB and IR color data
- Comparison of orbital data with ground tests allows identification of damage pathways

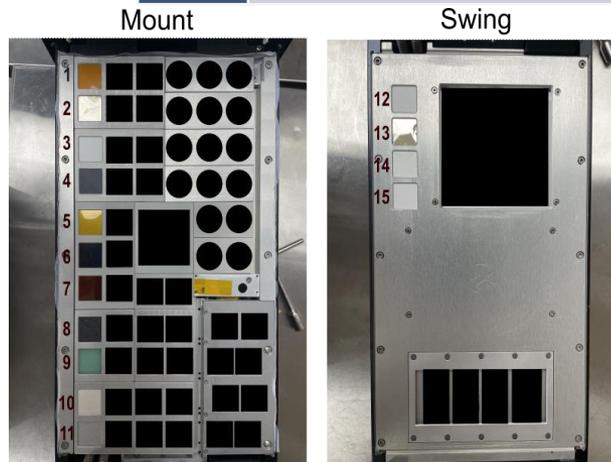


ISS images by courtesy of www.nasa.gov

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MISSE-16 Mission Overview

	Material	Type
1	Kapton® CR	PI/ PMDA
2	Kapton® CS	
3	Kapton® WS	
4	Kapton® XC	
5	Kapton® TF	
6	DR9	
7	Kapton® HN	
8	Economyplate™ Carbon Fiber	CFRP
9	G-10/FR4 Glass Epoxy	GFRP
10	Zenite®	LCP
11	Melinex® 454	PET
12	Mylar® M021	
13	CORIN®XLS	POSS
14	Thermalbright®N	
15	Alumina	Alum. Oxide



Powered Hinge
Drive Assembly

Underdeck
Volume

Swing Side
Mount Side

Photo/image credit: Aegis Aerospace

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MISSE-16 Mission Overview

- Proposal submitted to ISS NL on May 2020
- Launched from Kennedy Space Center on July 15th, 2022
- Docked on Harmony Forward (Node 2 Forward) on July 16th, 2022
- First data are taken on August 16th, 2022



Photo credit: NASA

News Articles

Launch <https://spacenews.com/spacex-launches-cargo-dragon-mission-to-iss/>

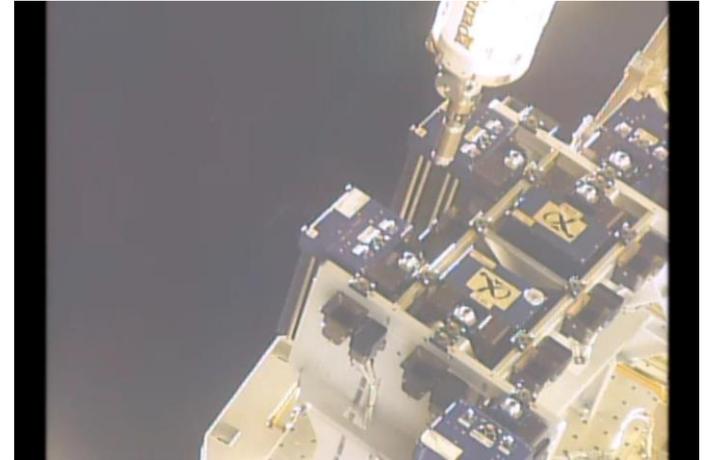
Docking <https://spaceflightnow.com/2022/07/16/spacex-crs-25-iss-docking/>

MISSE-16 Mission Overview

MISSE-16 Science Carriers (MSCs) were installed on the MISSE-FF on 31 July - 2 August 2022 with support from the Canada Space Agency ISS Robotic Systems Team



MISSE-16 Ram 3 MSC on the ROBO arm



MISSE-16 Zenith 3 MSC install



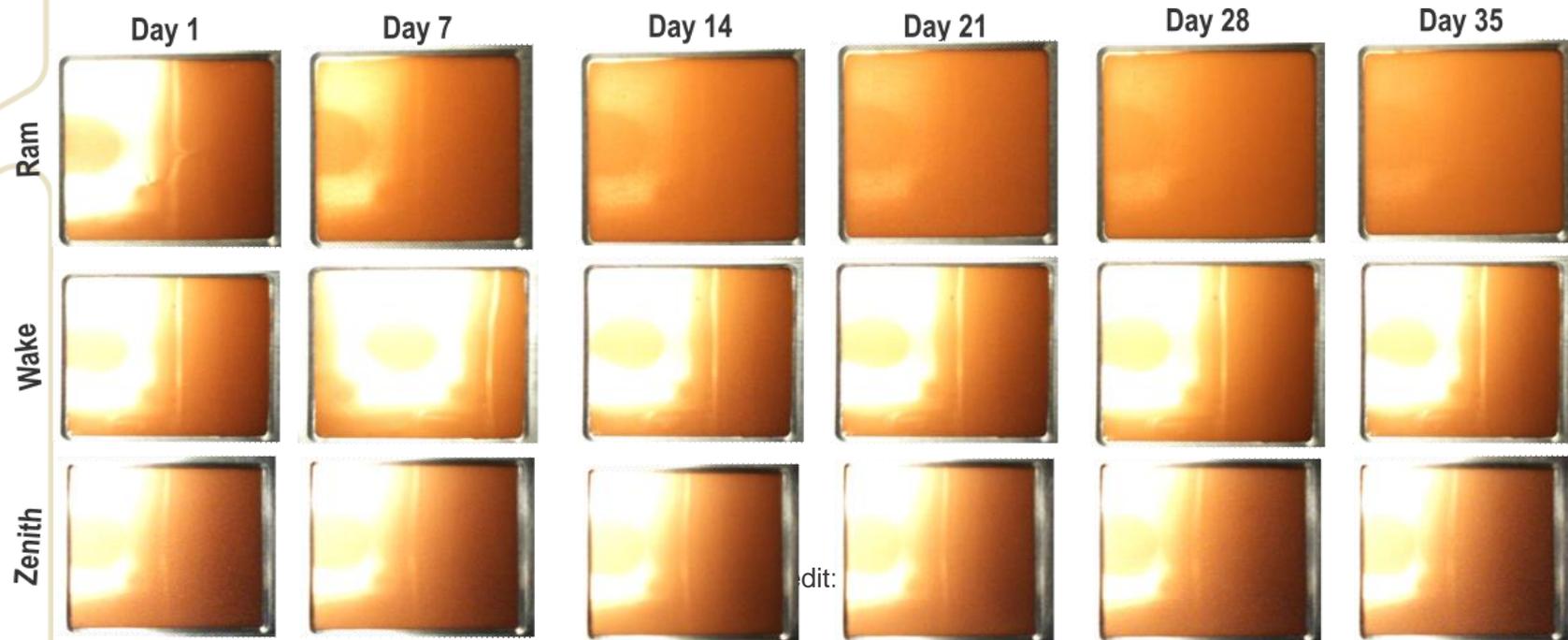
MISSE-16 Zenith 2 install

Photo credit: NASA

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Representative Orbital Data



Kapton® CR evolution on Ram, Wake, and Zenith faces of ISS

“Spectral material characterization using reflectance spectra extracted from RGB/IR color images” by Dr. Jainisha Shah

Photo/image credit: Aegis Aerospace

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Weathering Facilities

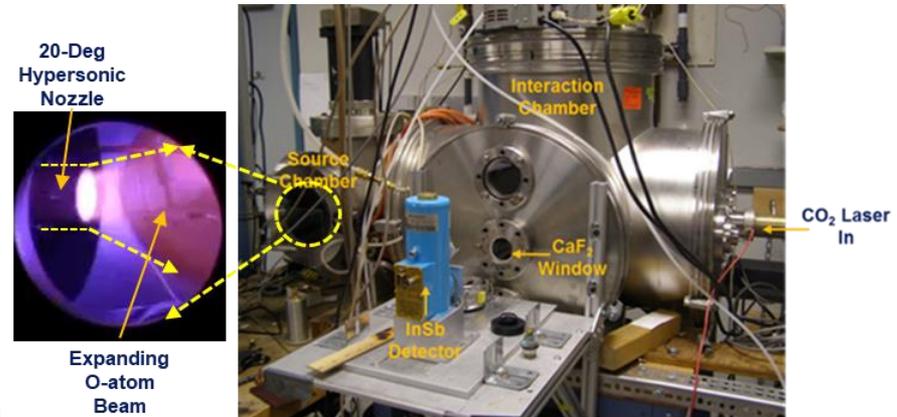
Electron and VUV Exposure



Image credit: AFRL

- Materials may be irradiated with high-energy electrons (up to 100 keV) and/or exposed to VUV particles
- *In situ* directional hemispherical reflectance (DHR), surface potential decay (SPD), and Fourier-Transform Infrared (FTIR) spectral measurements capabilities

AO Exposure



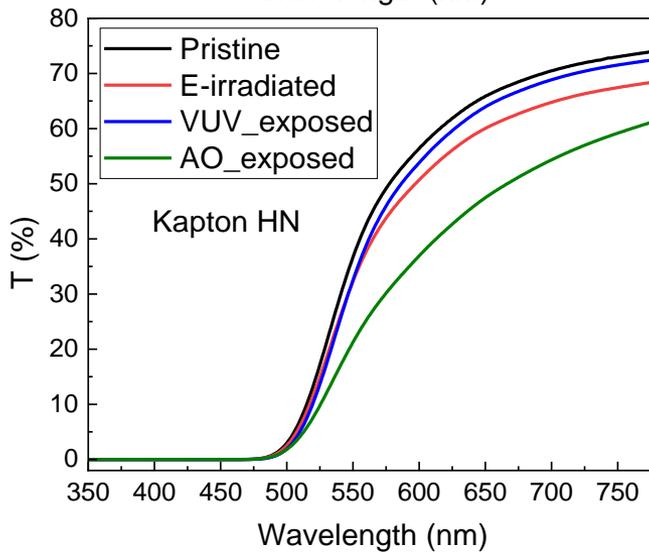
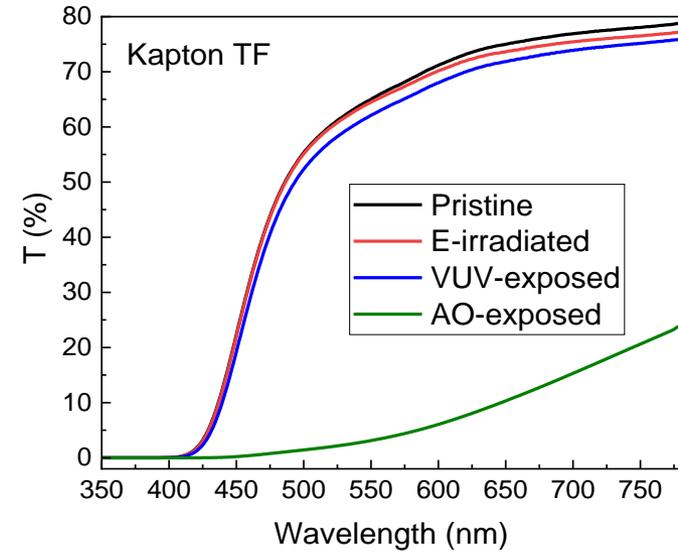
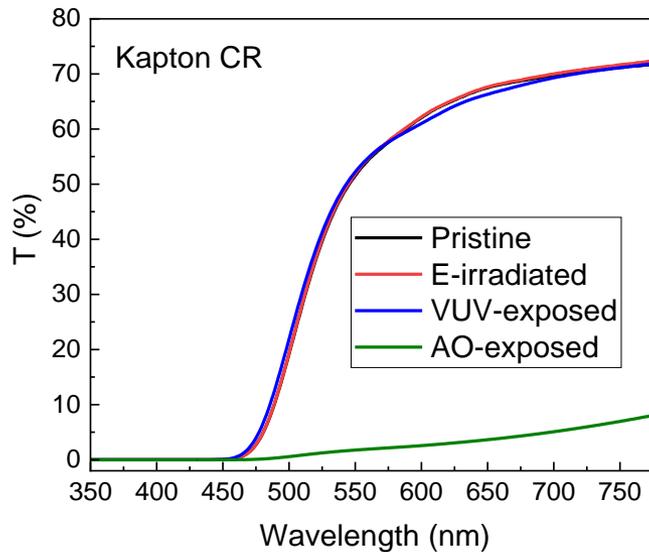
U.S. Patent 4,894,511, Foreign Patent
Image credit: PSI

- Targeted peak fluence of 2×10^{20} O/cm²
- 8 km/s O-atom beam generated in high vacuum chamber with pulsed laser discharge
- AO beam is a neutral atom beam with a ~1% O⁺ ion content

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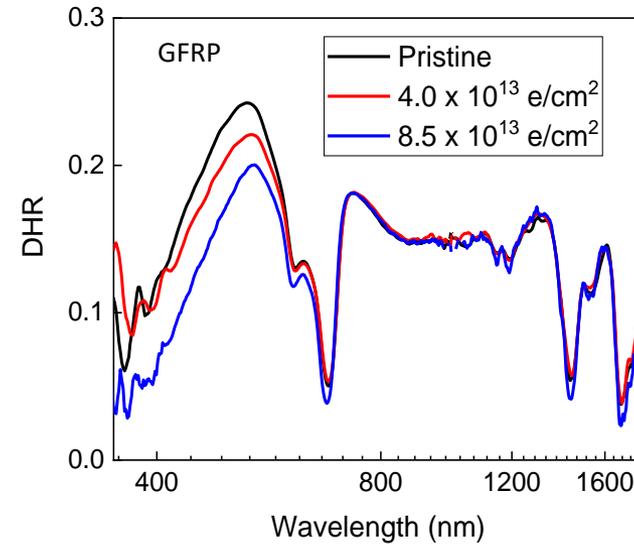
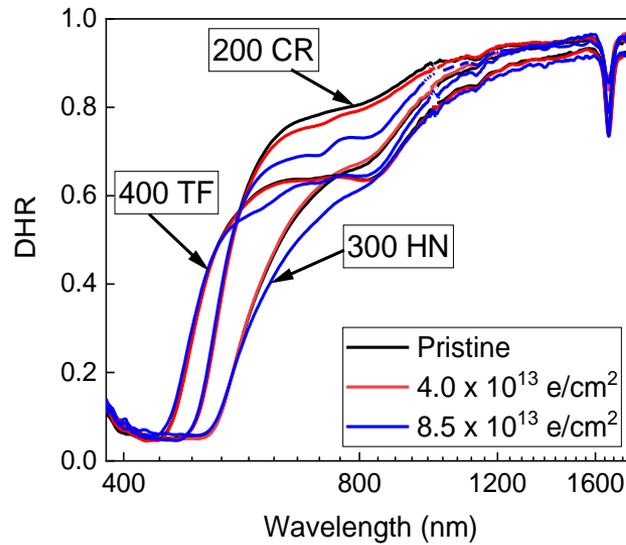
Optical Properties

UV/Vis Transmission Measurements



AO exposure has the most effect on the optical properties of studied materials

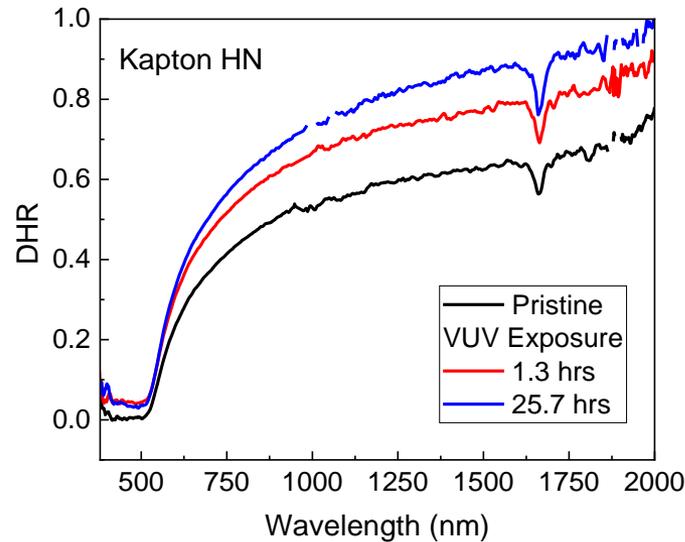
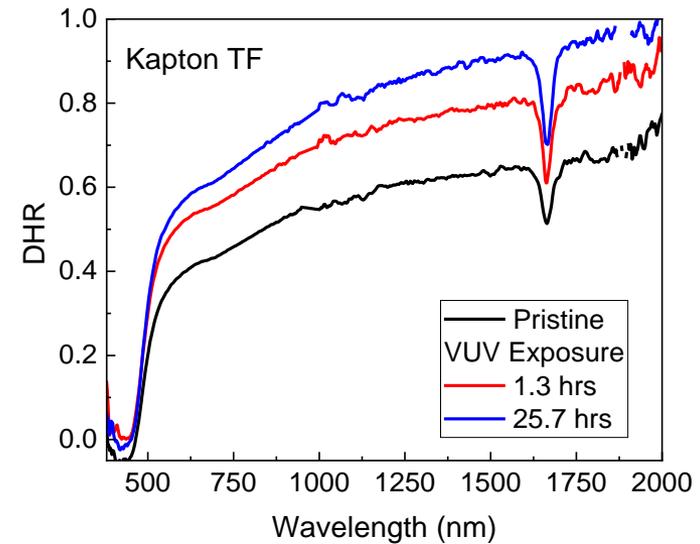
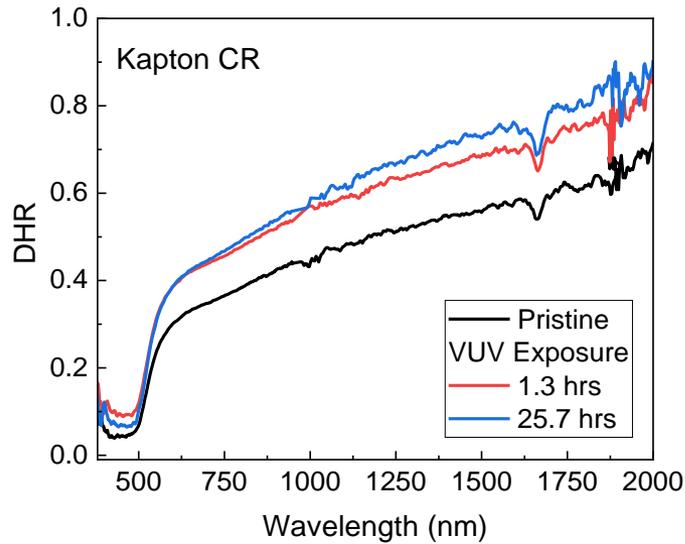
Materials irradiated with high-energy electrons



Increased exposure to high-energy electrons causes degradation of their reflectance

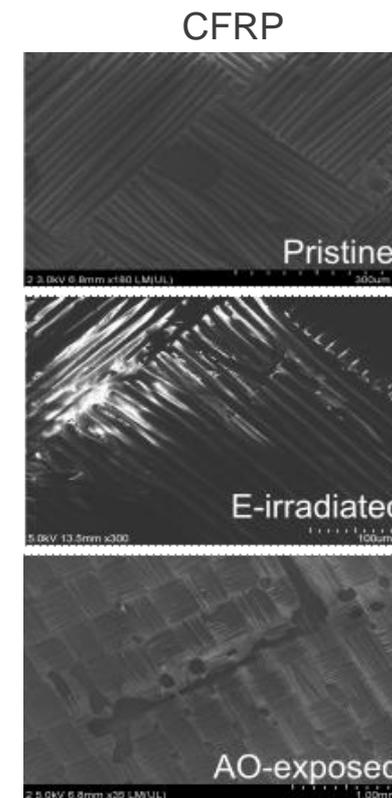
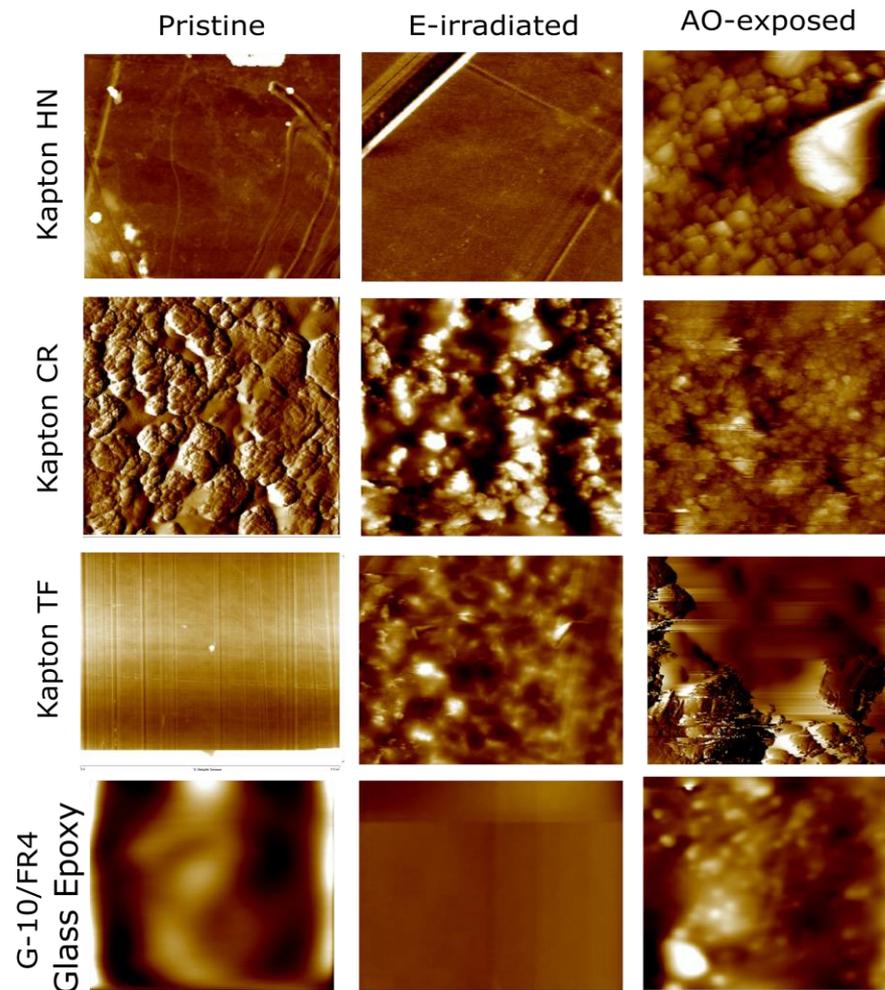
DHR Measurements

VUV-exposed materials



The reflectance of studied materials from the Kapton family increases with prolonged VUV exposure

Surface Morphology



AO exposure has the most effect on the surface morphology of studied materials

Surface roughness of materials exposed to simulated space weather

Material	Surface roughness R_a (nm)		
	Pristine	E-irradiated	AO-exposed
Kapton® CR	26.7	25.6	62.9
Kapton® TF	5.5	12.3	136.3
Kapton®HN	11.4	2.5	91.0
GFRP	12.2	4.6	218.0

Mass loss and the relative erosion rate of AO-irradiated materials

Material	Mass loss (mg)	Erosion rate
Kapton® CR	0.84	0.18
Kapton® TF	9.16	1.19
Kapton® HN	7.76	1.57
CFRP	8.10	1.71
GFRP	4.00	1.10

Charge Transport Properties

Volume resistivity of materials exposed to the simulated space-weather conditions measured using the ASTM D257 method

Material	Volume resistivity $\rho \times 10^{18}$ ($\Omega\text{-cm}$)		Volume resistivity $\rho \times 10^{15}$ ($\Omega\text{-cm}$)	
	Pristine	E-irradiated	Pristine	AO-exposed
Kapton® CR	13	0.008	5.2	6.5
Kapton® TF	3.6	0.07	13	32
Kapton® HN	5.6	0.09	2.7	3.6
CFRP	2.4×10^{-8}	1.4×10^{-9}	2.7×10^{-8}	2.7×10^{-8}
GFRP	420	0.01	12	12

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Summary

- The ultimate goal is to provide a detailed assessment of the material properties of novel and heritage spacecraft materials under a simulated space weather environment to compare with measurements during true space conditions
- Results of ground-based experiments will be compared with *in situ* measurements during true LEO space exposure
- High electron, AO, and VUV exposure experiments were performed sequentially on 15 MISSE-16 materials
- Subset of 5 samples is the focus of the presented research
- Overall, electron irradiation has the least damaging effect on the studied samples. VUV exposure increases the reflectance of studied materials, whereas AO exposure affects their morphology

Thank you!