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Evaluation of the Mechanical Properties of Innovative Spacecraft Materials under a LEO – Simulated Atomic Oxygen Environment

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Advanced Space, Aerospace, and Terrestrial Systems

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Motivation

We endeavor to understand the physical and chemical transformations of spacecraft materials under actual space exposure and simulated space weather

Image credit: ISS NL

- Deriving correlation coefficients between space exposure and accelerated space weather simulations
- Facilitating precise predictions of on-orbit material performance through laboratory testing
- Enhancing material identification for space situational awareness

The MISSE Flight Facility (MISSE-FF) is an ideal testbed for generating benchmark data to validate the efficiency of ground-based space weather simulations

Previous Work – MISSE-16

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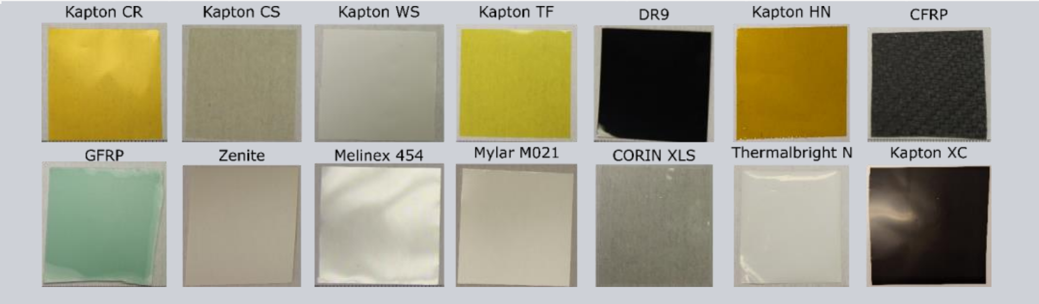
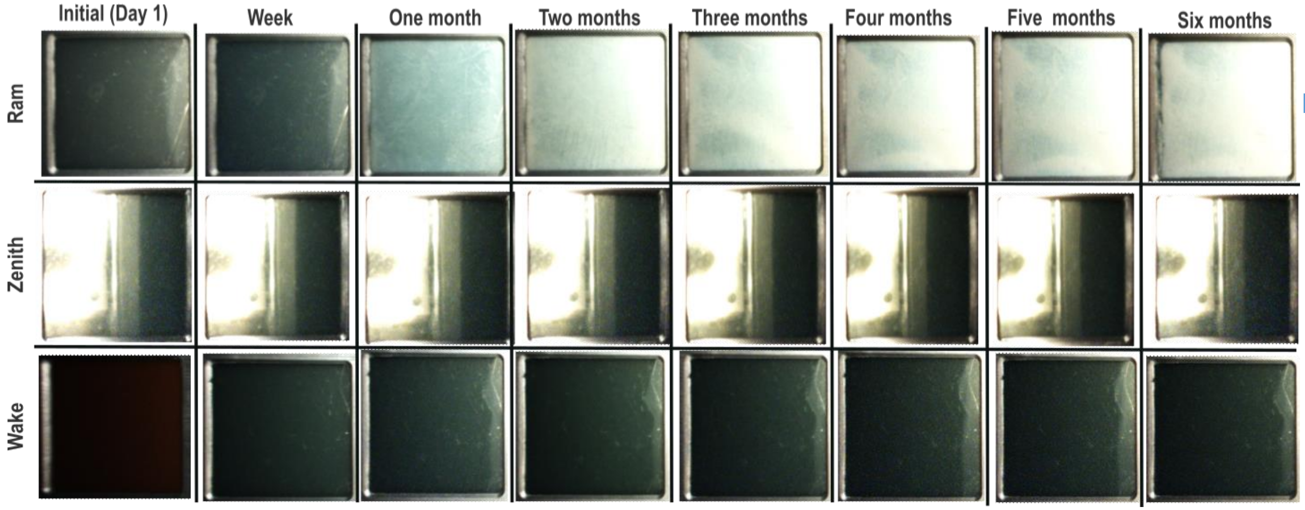
- Launched on July 2022
- Payload returned on May 2023
- Identical sample sets were installed on the Wake, Ram, and Zenith faces of ISS
- RGB and IR images of each sample were taken for the first 7 days, weekly for the next two months, and monthly for the remaining duration of the mission

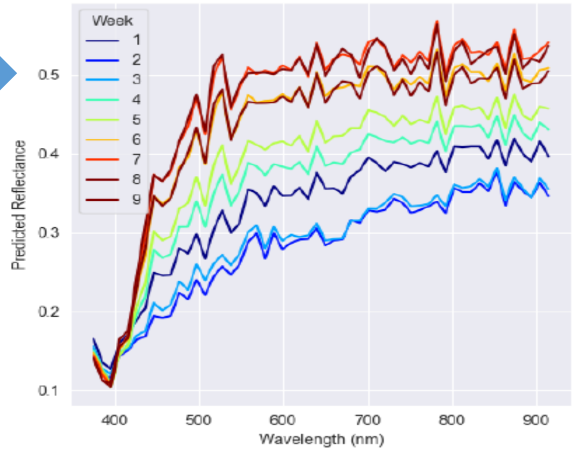
Material State	Characterization technique								
	Optical				Surface		Charge transport		Chemical
	DHR	T	R	BRDF	AFM	SEM	SPD	ASTM	FTIR
Pristine									
E-irradiated									
AO-exposed									
VUV-exposed									
ISS - Flown									



Sequential exposure of every material to LEO space weather components

Representative Orbital Data





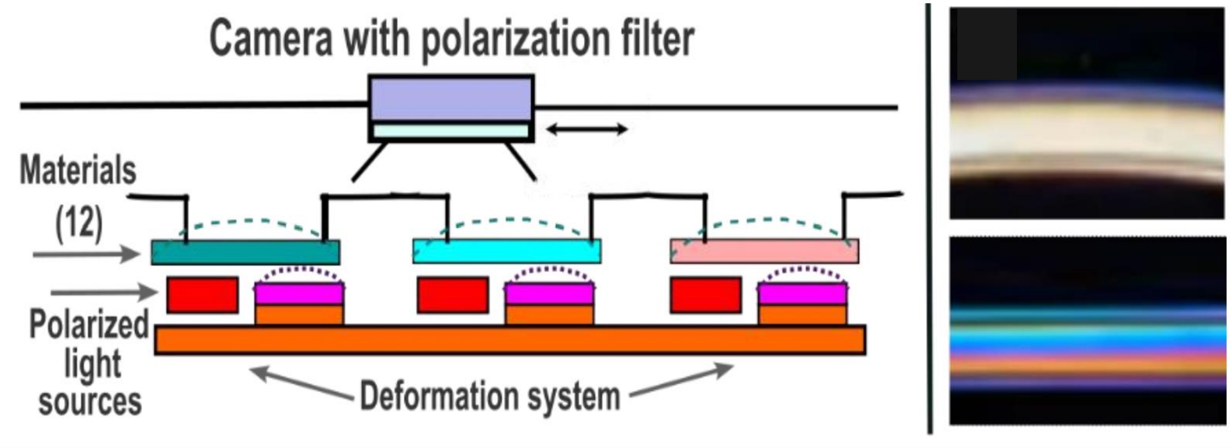
Kapton CS

Photo/image credit: Aegis Aerospace

MISSE-22 in a Nutshell

MISSE-16 focused on changes in optical properties in orbit, but how are the mechanical properties evolving?

Stress-induced birefringence: Disordered materials (polymers) can become birefringent under mechanical strain due to the alignment of constituent polymer chains

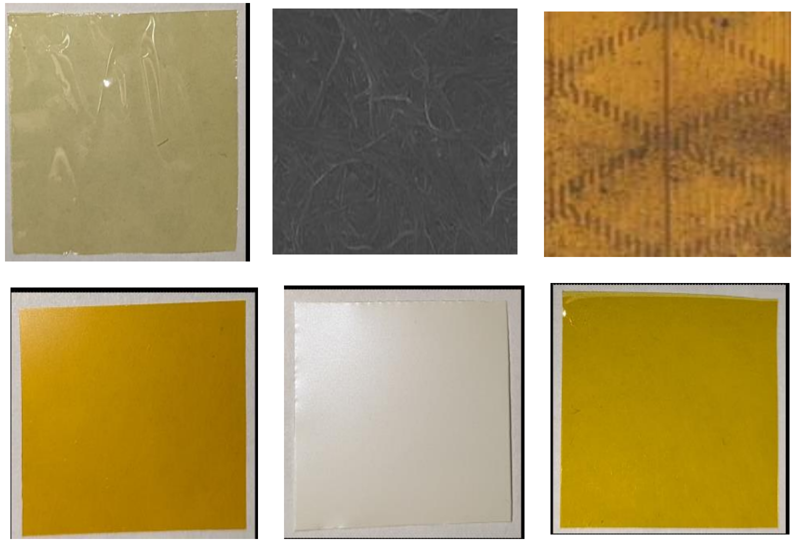


Educational Partner	Commercialization Partner
UTEP	DuPont, HFR
Proposed Project GTRI, SCICL/AFRL	
Data Dissemination Partner	**Implementation Partner**
SatAC/AFRL, NASA	Aegis Aerospace

Photoelastic colors can indicate both the magnitude and direction of stress

MISSE-22 Material Candidates

Kevlar EXO | Densified CNT | BEDS

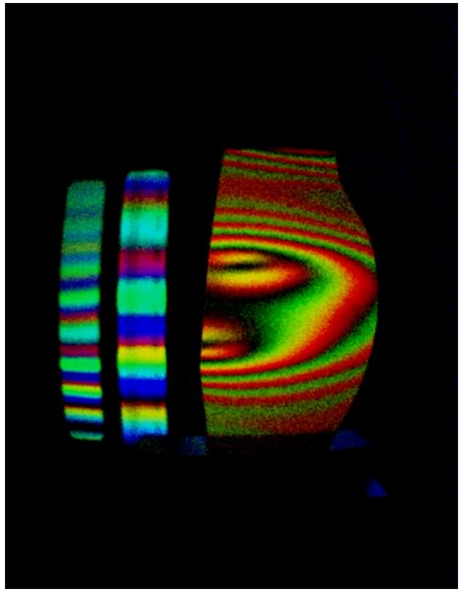


Kapton MT | Kapton WS/ITO | Kapton CR

+

24 other novel materials

- Innovative and potentially significant for the spacecraft industry
- Resilient to atomic oxygen (AO)
- Flexible
- Birefringent



Expected deformation-induced color pattern

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Space Weathering Facilities

AFRL

AO Exposure at PSI using FAST Source

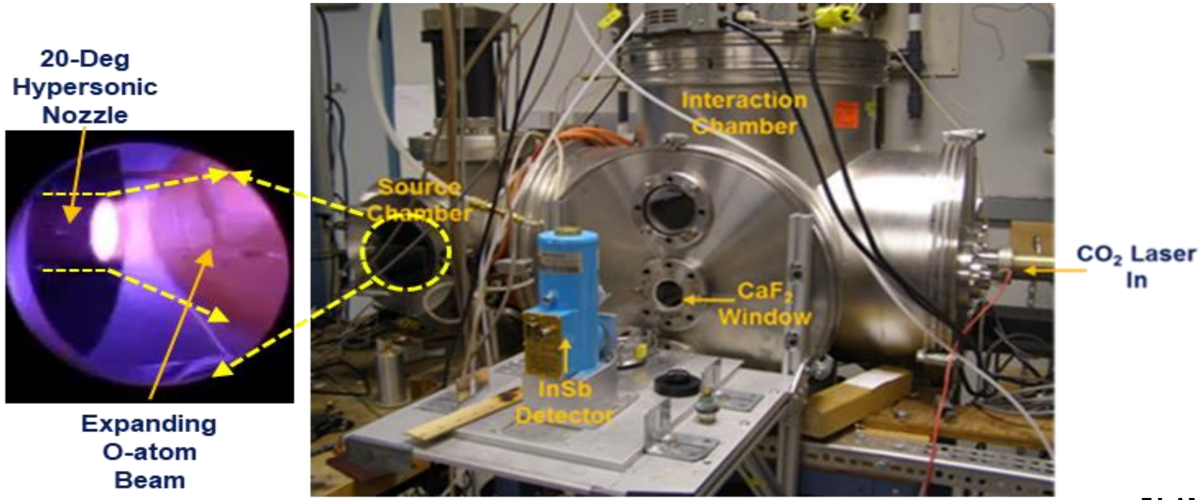


Image credit: PSI

- Targeted peak fluence of 2 x 10^{20} O/cm^2
- 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

JUMBO Space-simulation Chamber at SCICL/AFRL

- High-energy (up to 100 keV) electrons and/or VUV particles exposure
- *In situ* directional hemispherical reflectance (DHR), surface potential decay (SPD), and Fourier-Transform Infrared (FTRI) measurements

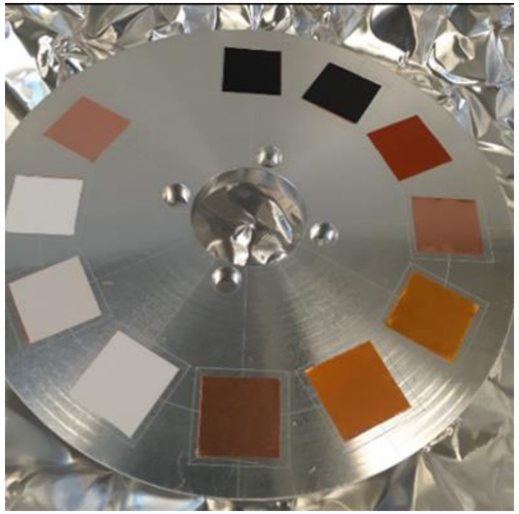


Image credit: AFRL

Experimental Set Up

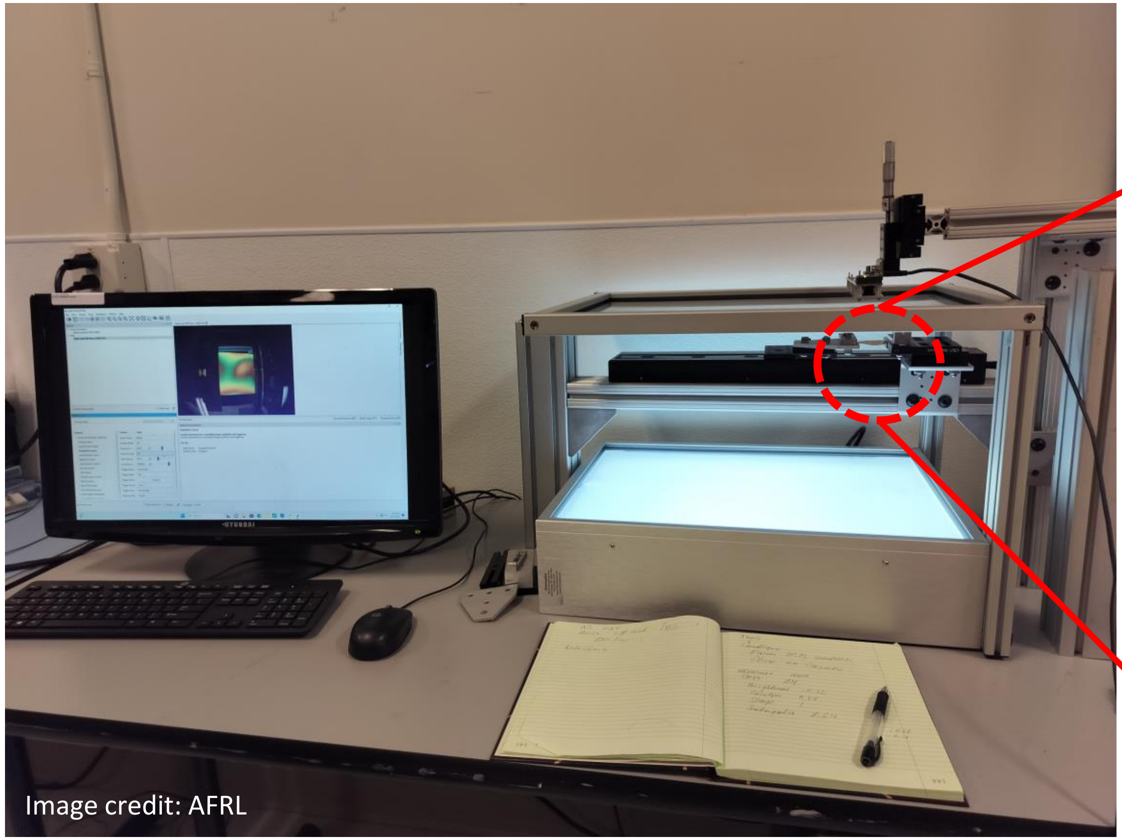


Image credit: AFRL

- Deformation is defined by the electrical stage position

Laboratory prototype based on commercial (Strain Optics) Polariscope

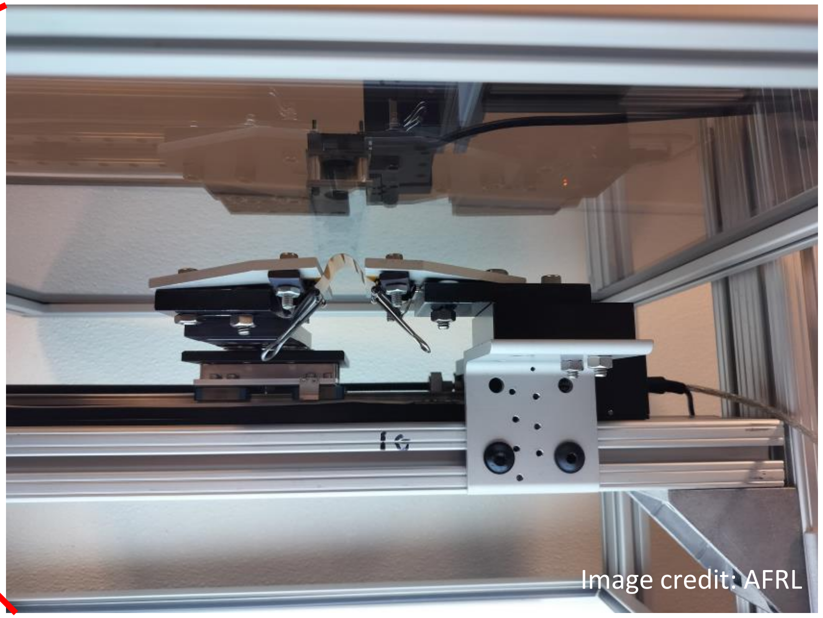
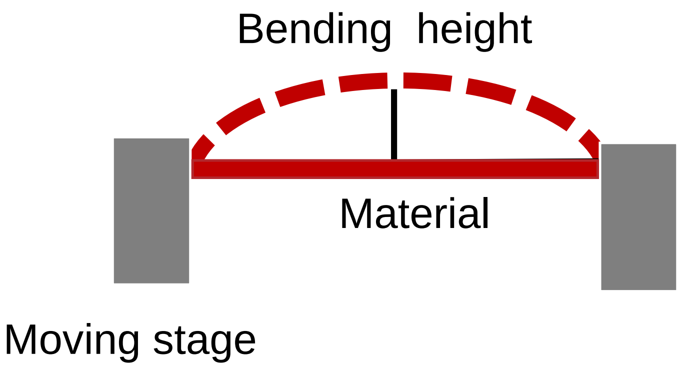


Image credit: AFRL



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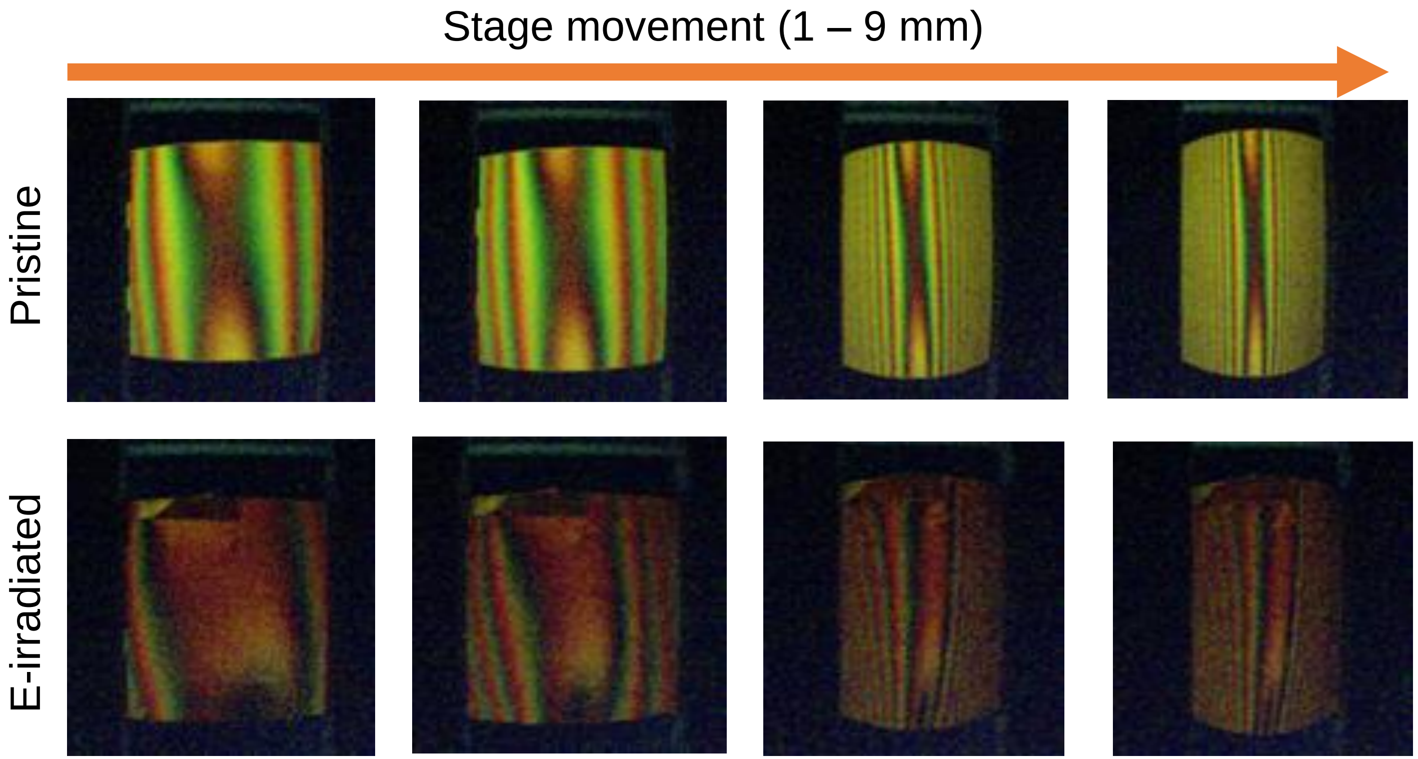
Measurements of Pristine and Degraded Materials

3 mil Kapton® HN

- Investigate stress-induced pattern of colors in Kapton® HN
- Compare pristine and electron-irradiated materials



- Stress – induced colors distribution is different in electron-irradiated materials
- Intensity and number of fringes is changed

Measurements of Pristine and Degraded Materials

Stage movement

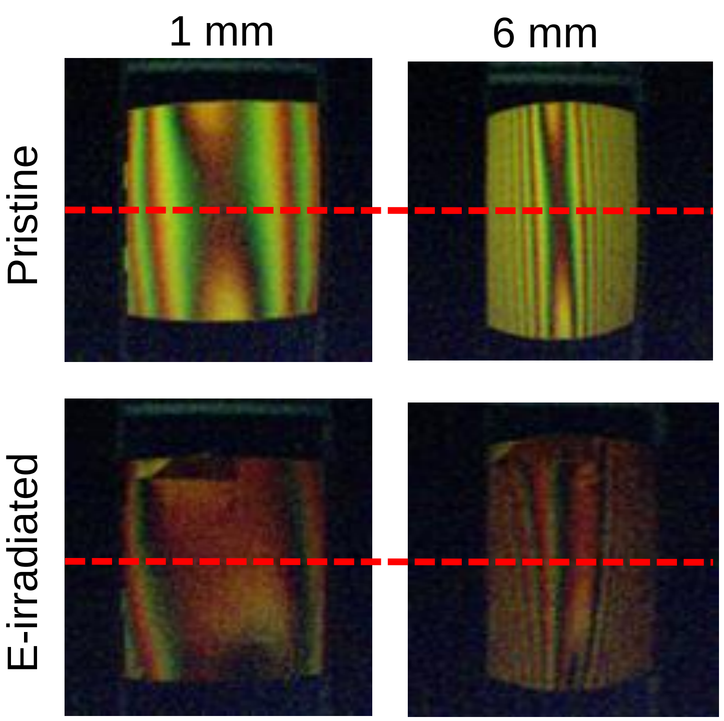
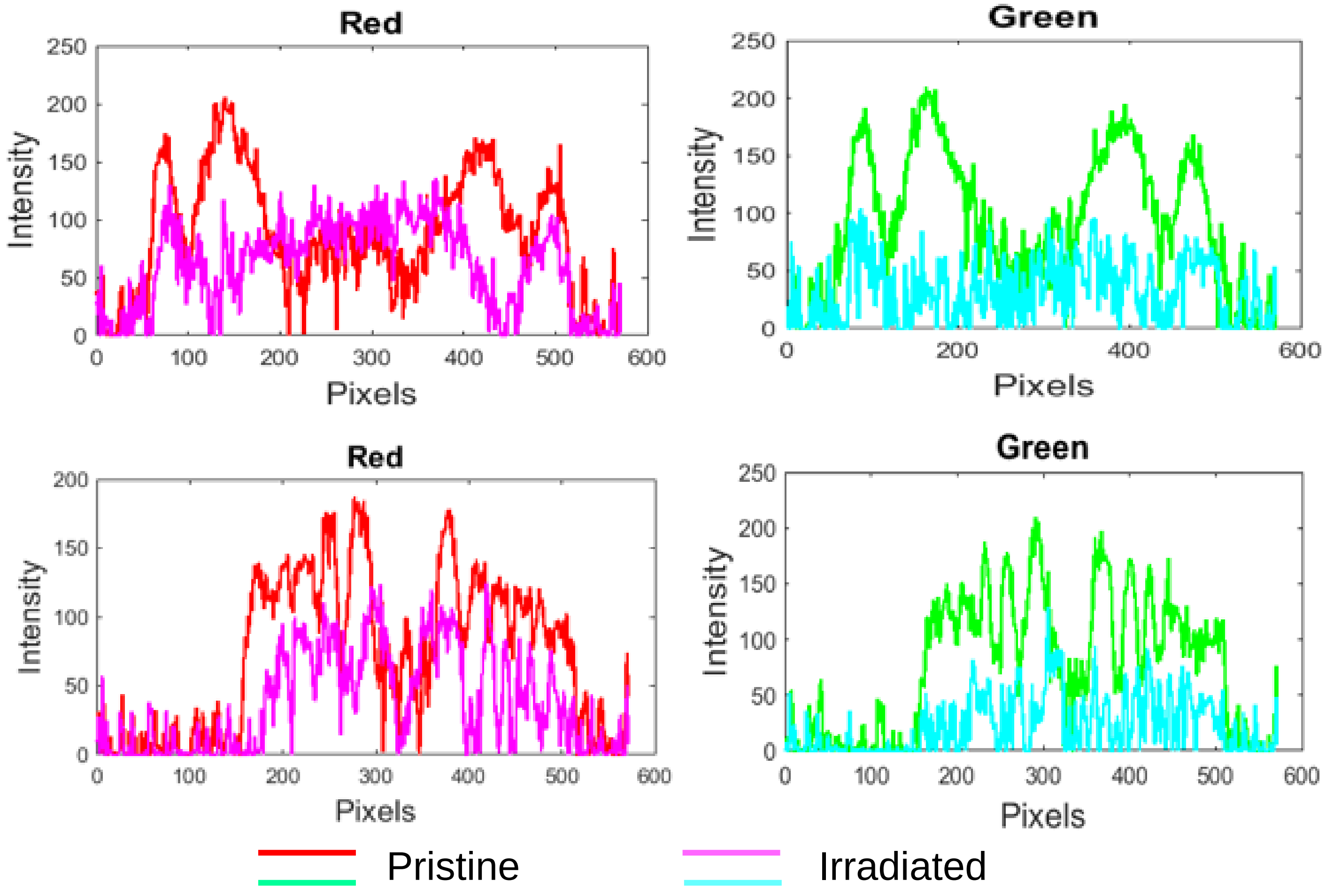
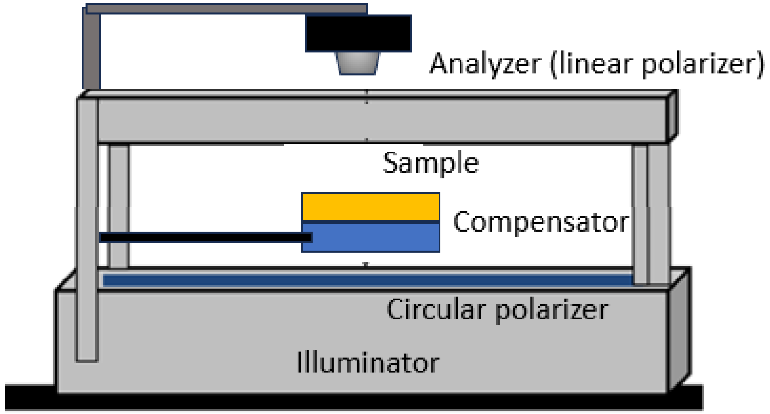


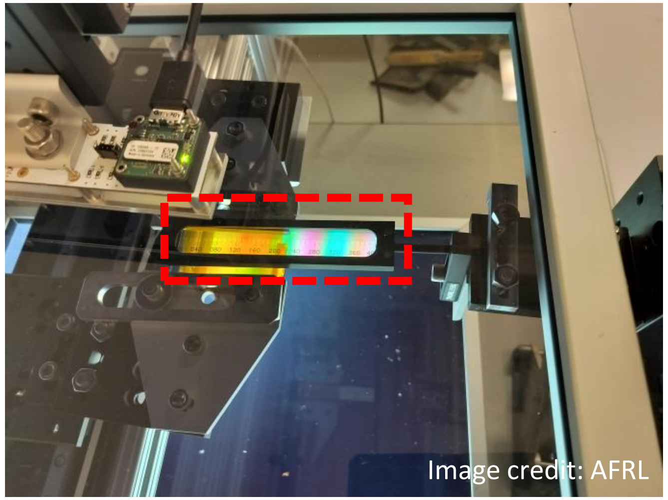
Image crosscuts at Red and Green camera channels



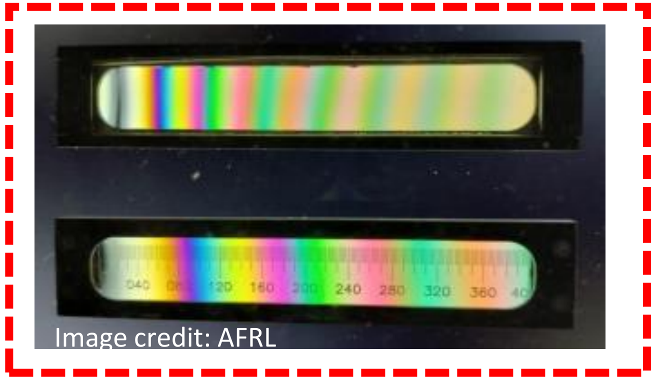
Quantitative Stress Analysis

The proposed setup schematic for quantitative stress analysis





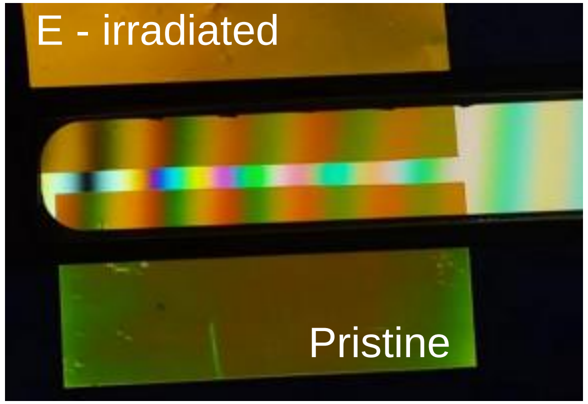
LW-100 compensator manufactured by Strain Optics



$$Stress = \frac{R}{t * Cb}$$

R - Retardation (nm)
t − Thickness (mm)
Cb – Stress - optic coefficient (B)

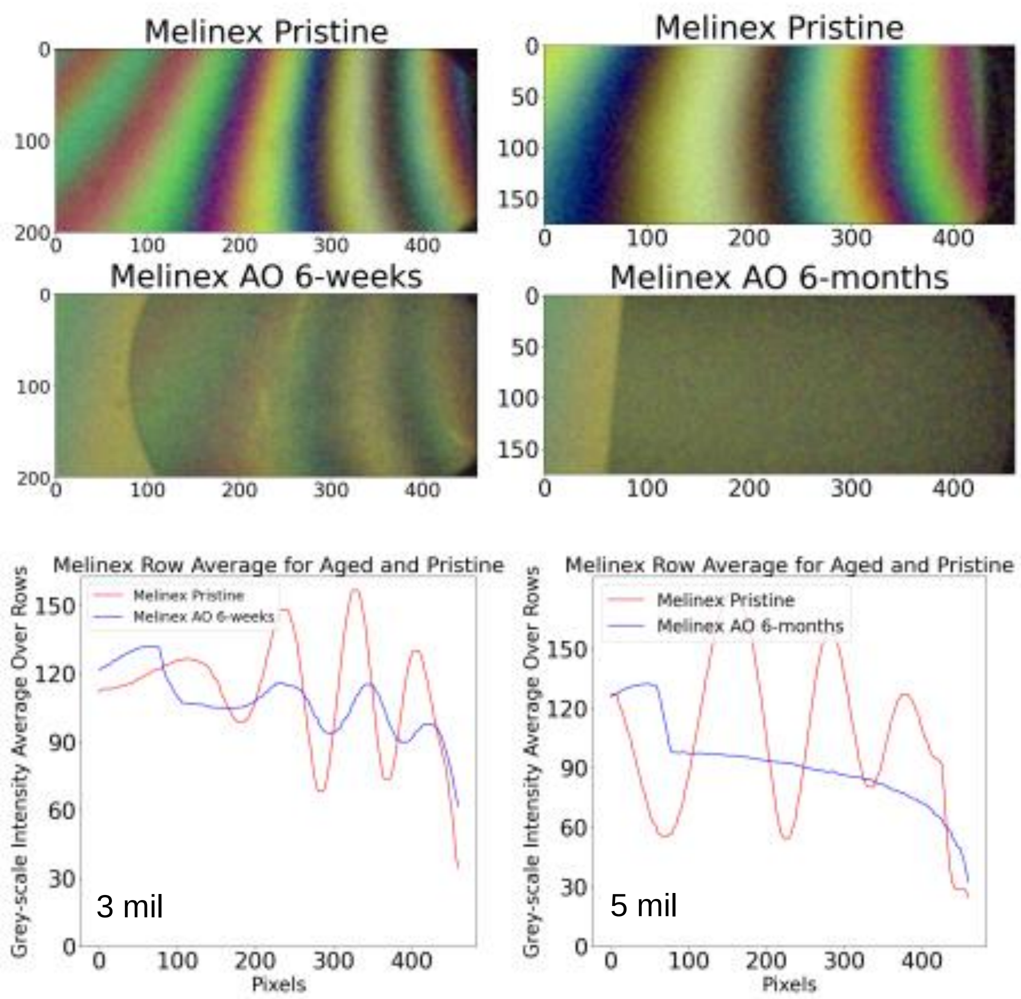
Representative measurements



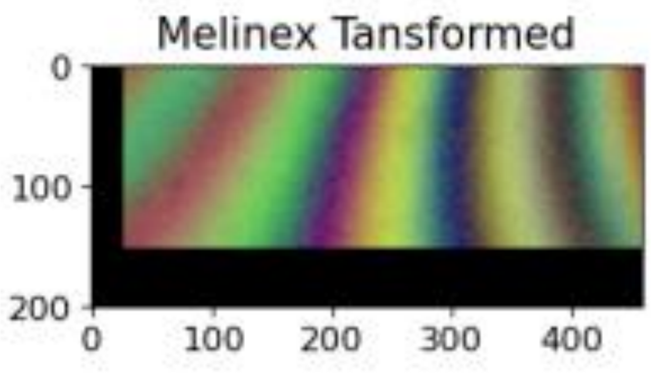
3 mil Kapton® HN

Quantitative Stress Analysis (Cont'd)

Measurements of Melinex® film with 3 mil and 5 mil thickness



- Determine the variation in retardation
- Employ an affine transformation
- Linearly morph pristine image to degraded image



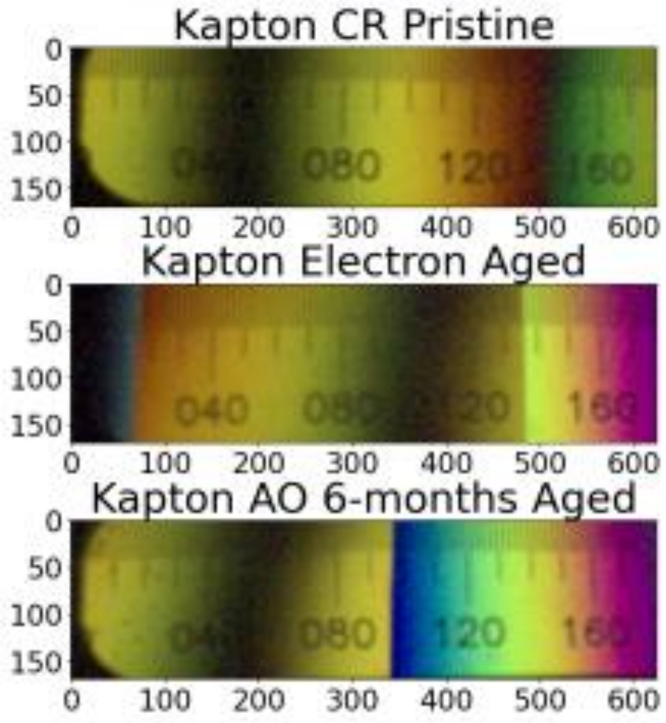
Quantitative Stress Analysis (Cont'd)

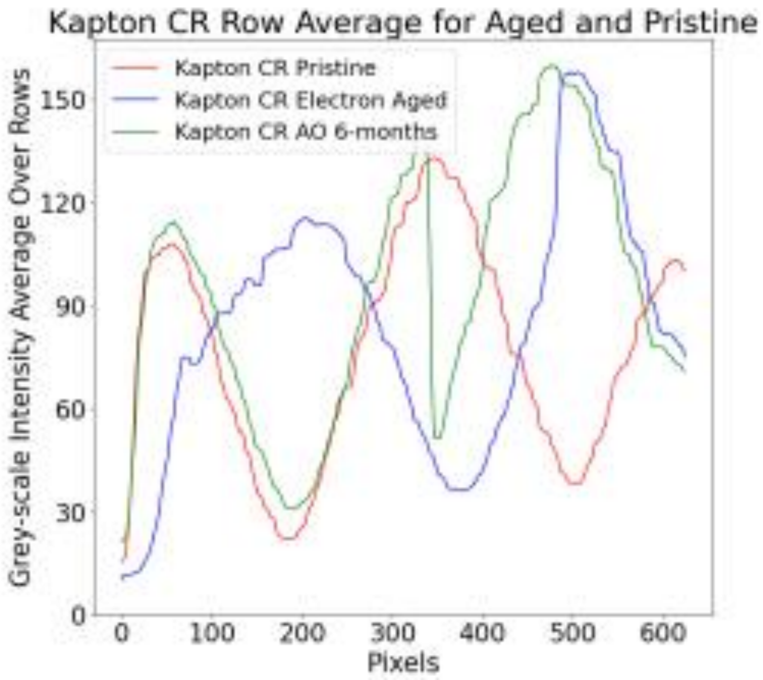
Material	Thickness (mil)	Condition	Retardation (nm)	Stress (MPa)
Melinex® 453	5	Pristine	4.4	10.1
Melinex® 453	5	6 weeks of LEO-equivalent AO exposure	4.3	10.0
Melinex® 453	3	Pristine	4.0	15.6
Melinex® 453	3	6 months of LEO-equivalent AO exposure	N/A	N/A

- The brightness and contrast of images of the irradiated materials have diminished
- The difference in retardation between pristine Melinex® and Melinex® exposed to AO for 6 weeks is ~30 nm, with a corresponding stress difference of 0.1 Mpa
- No fringes are present in the Melinex® after 6 months of AO irradiation

Quantitative Stress Analysis (Cont'd)

Measurements of 2 mil Kapton® CR using LW-100 compensator





Quantitative Stress Analysis (Cont’d)

Material	Thickness (mil)	Condition	Retardation (nm)	Stress (MPa)
Kapton® CR	2	Pristine	276.0	4.5
Kapton® CR	2	Electron-irradiated	557.0	9.3
Kapton® CR	2	6 weeks of LEO-equivalent AO exposure	254.0	4.7

- Compared to electron-irradiated material, Kapton® CR did not change significantly after 6 weeks of LEO-equivalent AO exposure
- The retardation of the electron-irradiated sample changed by 281 nm, with a respective stress change of 5.2 MPa

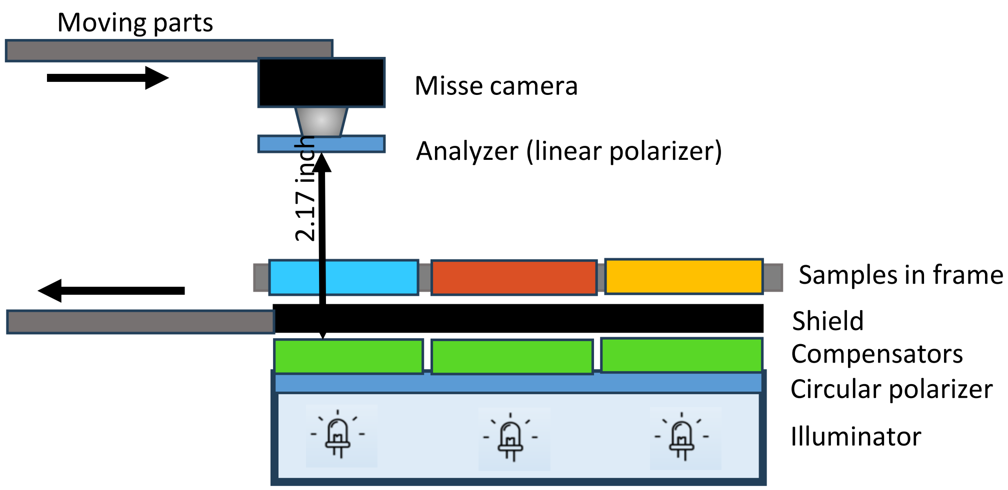
Conclusions and Future Work

Conclusions

- We successfully demonstrated a proof of concept for evaluating stress changes in polymer materials using photoelasticity measurements
- We tested candidate samples for the MISSE-22 mission from various chemical families
- The photoelasticity method revealed that Kapton® CR exhibits superior resilience to both electron and AO exposure, indicating its suitability as a robust candidate for long-term space missions

Future Work

- Comparison of the photoelasticity measurement results with those from other damage evaluation methods (DHR, AFM, and Raman spectroscopy)
- Simulate images of radiation-damaged materials and compare them with experimental results
- Develop a polariscope setup for the MISSE-22 experiment



Considered MISSE-22 Setup

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QUESTIONS?