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Screening Tests for Ultra-Light Alternatives to Space Coverglass for Solar Arrays

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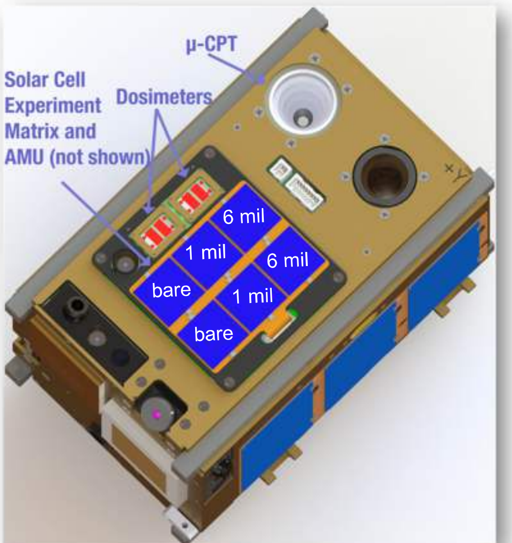
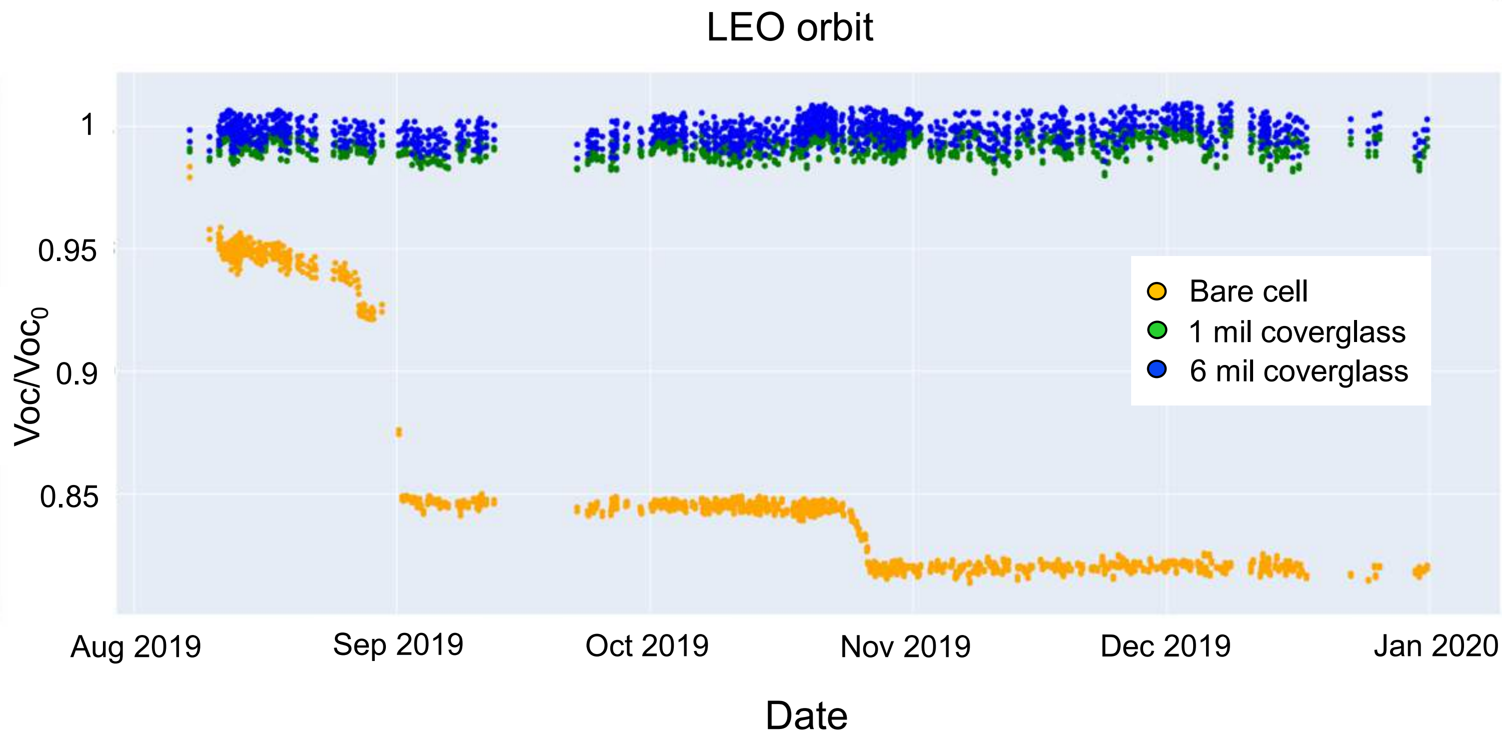
Space Power Workshop
21-23 April, 2026

Motivation: How much shielding is necessary?



2x 1.5U CubeSat mission



"Applying CubeSat-scale low resource on-orbit instrumentation to Root-Cause Analysis of Anomalous Solar Array Degradation" Jann Grovogui, Justin Lee, Don Walker, Christina Wade, David Hinkley, Catherine Venturini, Garrett Kinum, Colin Mann, Ariel Berman, William Crain, Can Nguyen, Victor Chin, J. Bernard Blake, Presentation at the Space Power Workshop 2023 OTR 2023-00602

New opportunities for alternative solar cell shielding materials

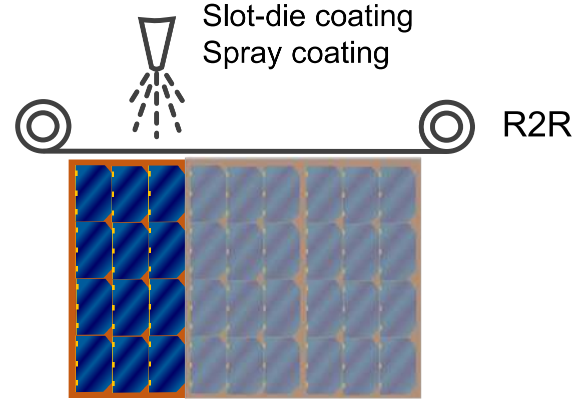
Space coverglass

- Shielding for the solar cells ✓
- Robust with long heritage ✓
- Protection against AO ✓
- Protection against micrometeoroids and space debris ✓
- Protects the adhesive against VUV ✓
- High emissivity → reduces solar cell operating temperature ✓

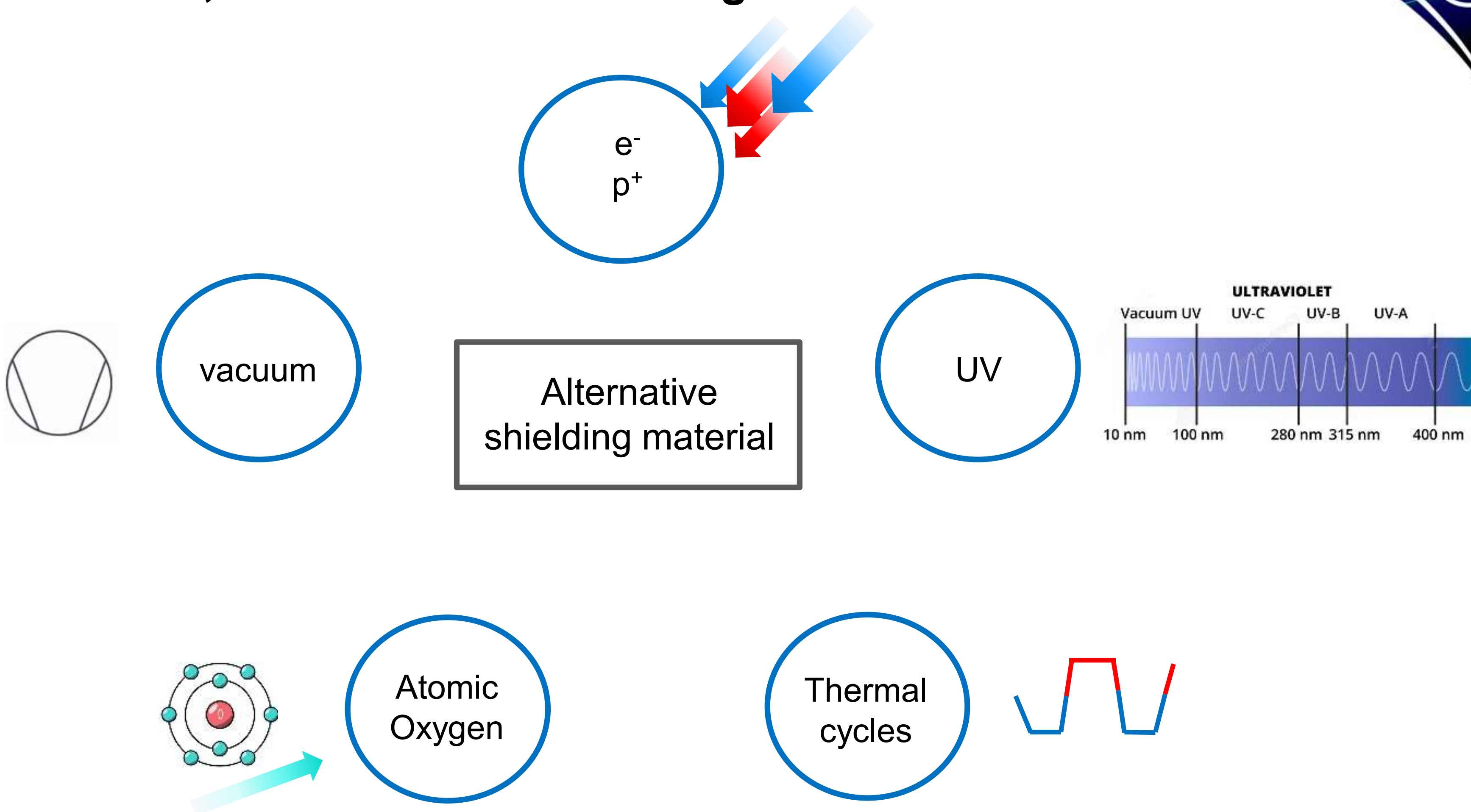
- Limits the flexibility and weight ✗
- Low throughput ✗
- High attrition rate ✗

Alternative shielding

- Compatible with high volume, high speed and low-cost manufacturing techniques
- Compatible with large area solar array coverage
- High transmission
- Low degradation in space



Space environment, how do we do screening tests?



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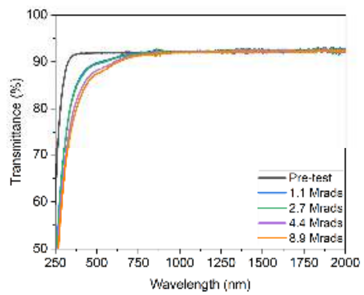
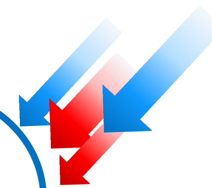
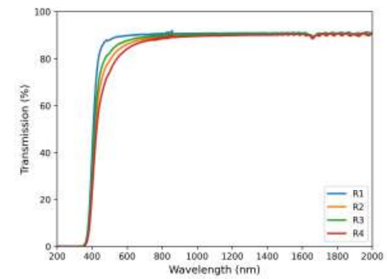




e$^-$
p$^+$



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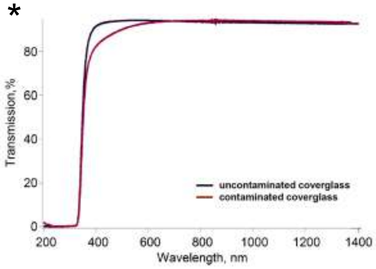
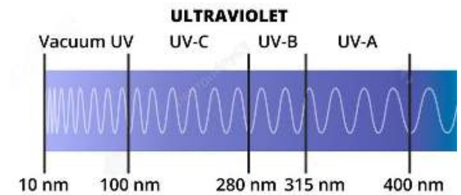
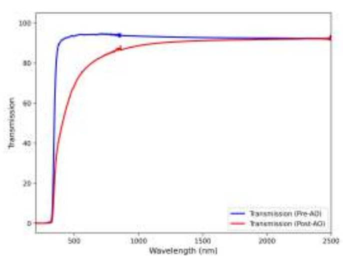


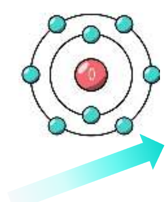
vacuum

Alternative shielding material

UV

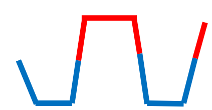






Atomic Oxygen

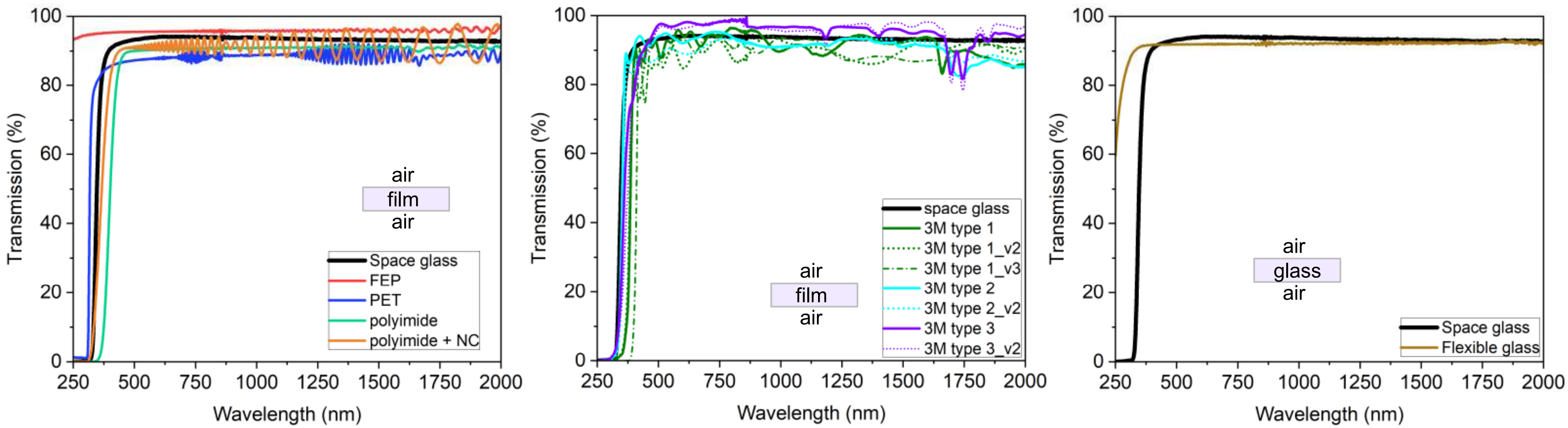
Thermal cycles



* Figure taken from : D. Liu *et al.*, "Effects of contamination on solar cell coverglass," *2010 35th IEEE Photovoltaic Specialists Conference*, Honolulu, HI, USA, 2010, pp. 002563-002568

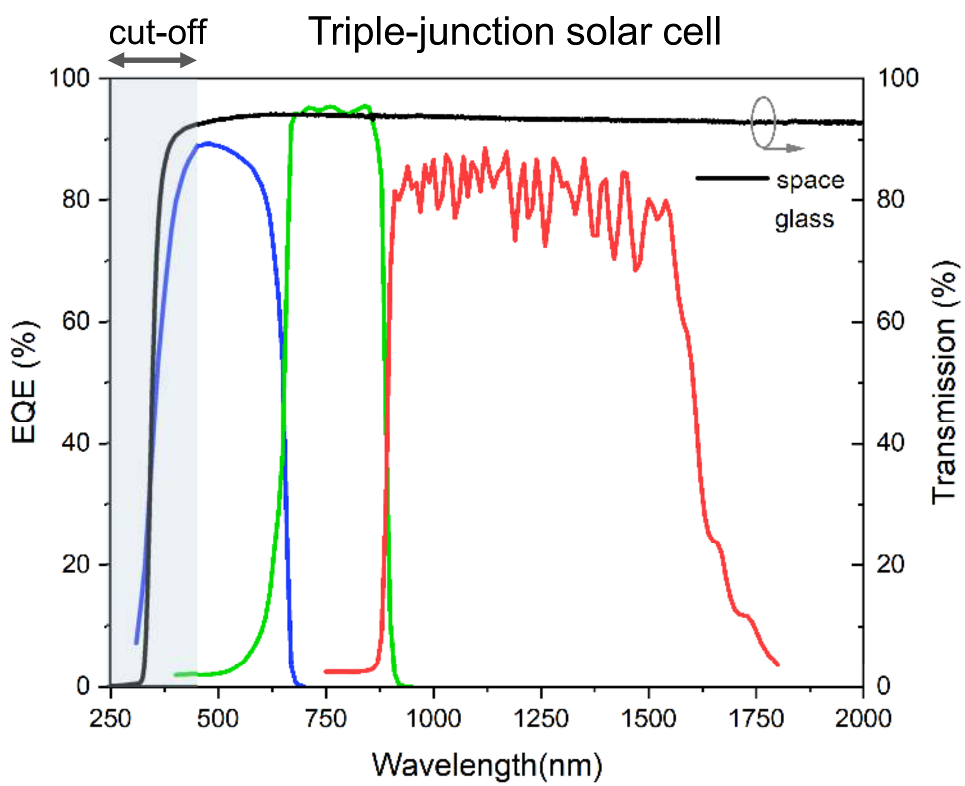
Screening of alternative shielding materials

- Commercially available films
  - ✓ FEP
  - ✓ PET
  - ✓ Polyimide (PI)
  - ✓ Polyimide with nanocomposite (PI with NC) (AO resistant)
- 3M films under development (AO resistant)
  - ✓ 3M type 1
  - ✓ 3M type 2
  - ✓ 3M type 3
- Glasses
  - ✓ Corning® Willow® (terrestrial)
  - ✓ Space glass (MgF_2 ARC)



Cut-off wavelength impacts the Jsc of the solar cell (mainly in MJSC) and the UV degradation of the adhesive (if any)

Impact of the transmission spectrum on the solar cell performance



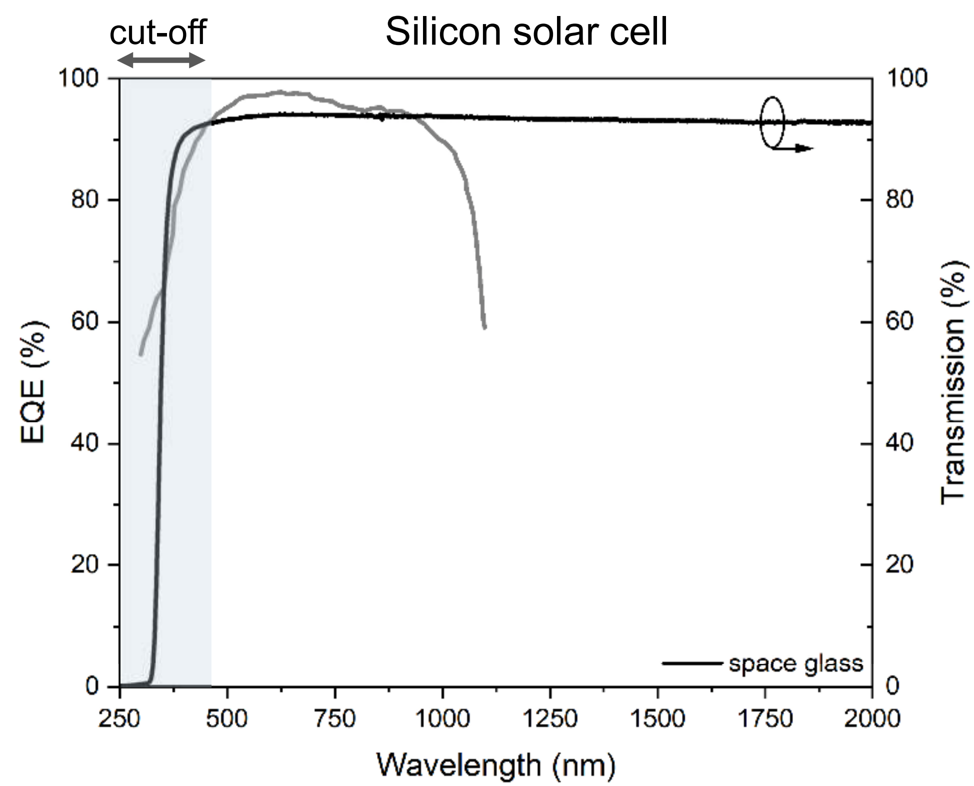
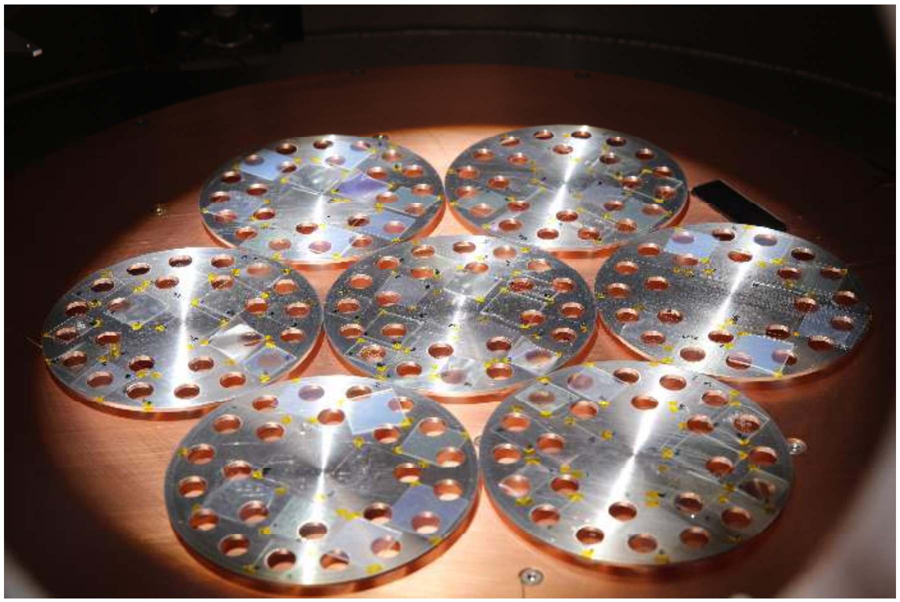


Figure adapted from "Comparative study of commercial crystalline solar cells" Ajit Singh et al. Results in Optics, Volume 11, May 2023, 100379

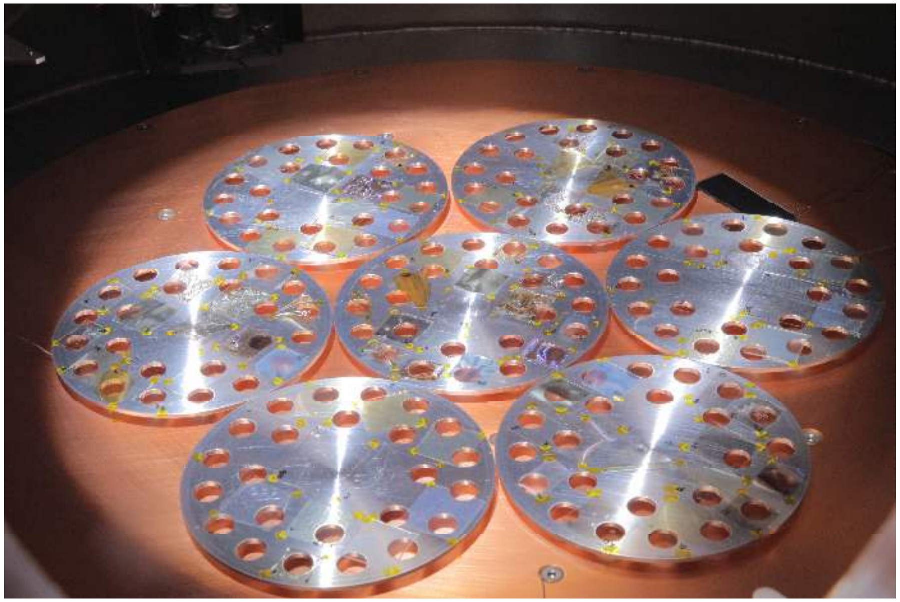
Images authored by Aerospace

Space environment: VUV screening test

Before



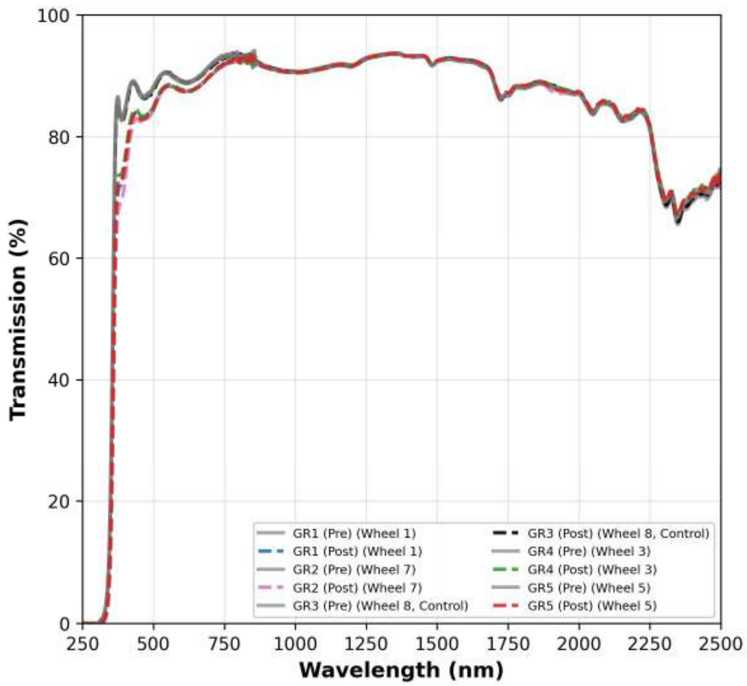
After a max of ~2000 ESH



- Integrated intensity ~3.5 suns for the vacuum UV (115 nm to 180 nm, from NIST calibration) and ~2.7 suns for the broadband UV (200 nm to 400 nm, from measured radiometric data)
- Baseline vacuum in the chamber is 8.6x10-9 Torr
- Spatially non-uniform illumination/temperature, with samples of the same type placed in different wheels

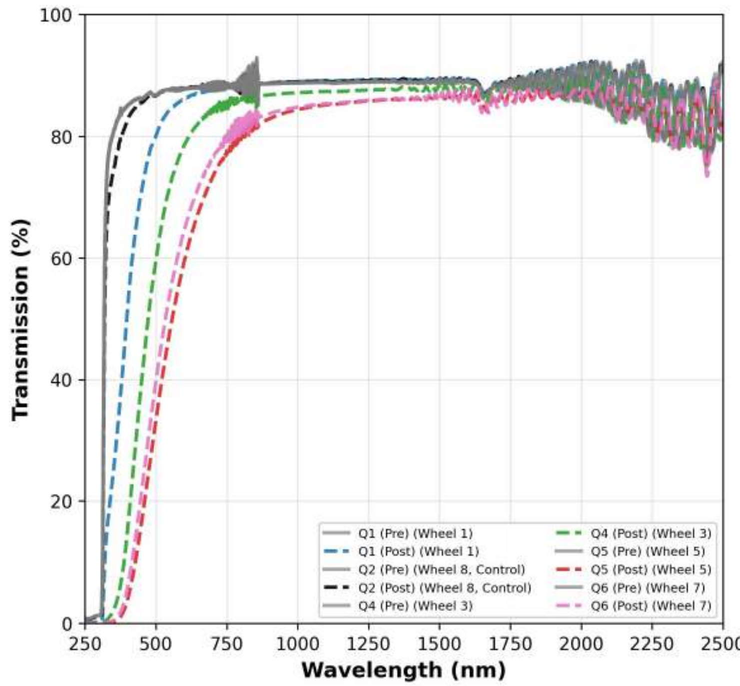
Space environment: VUV screening test

3M type 2_v2

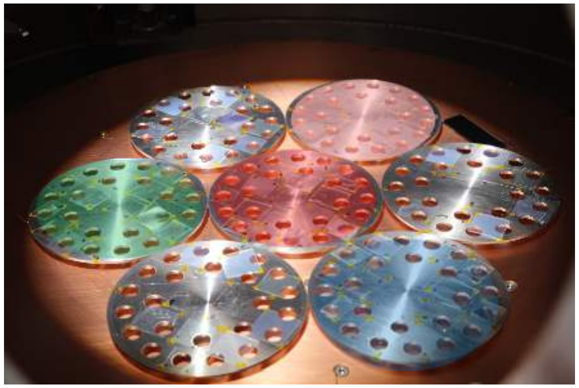


Uniform degradation

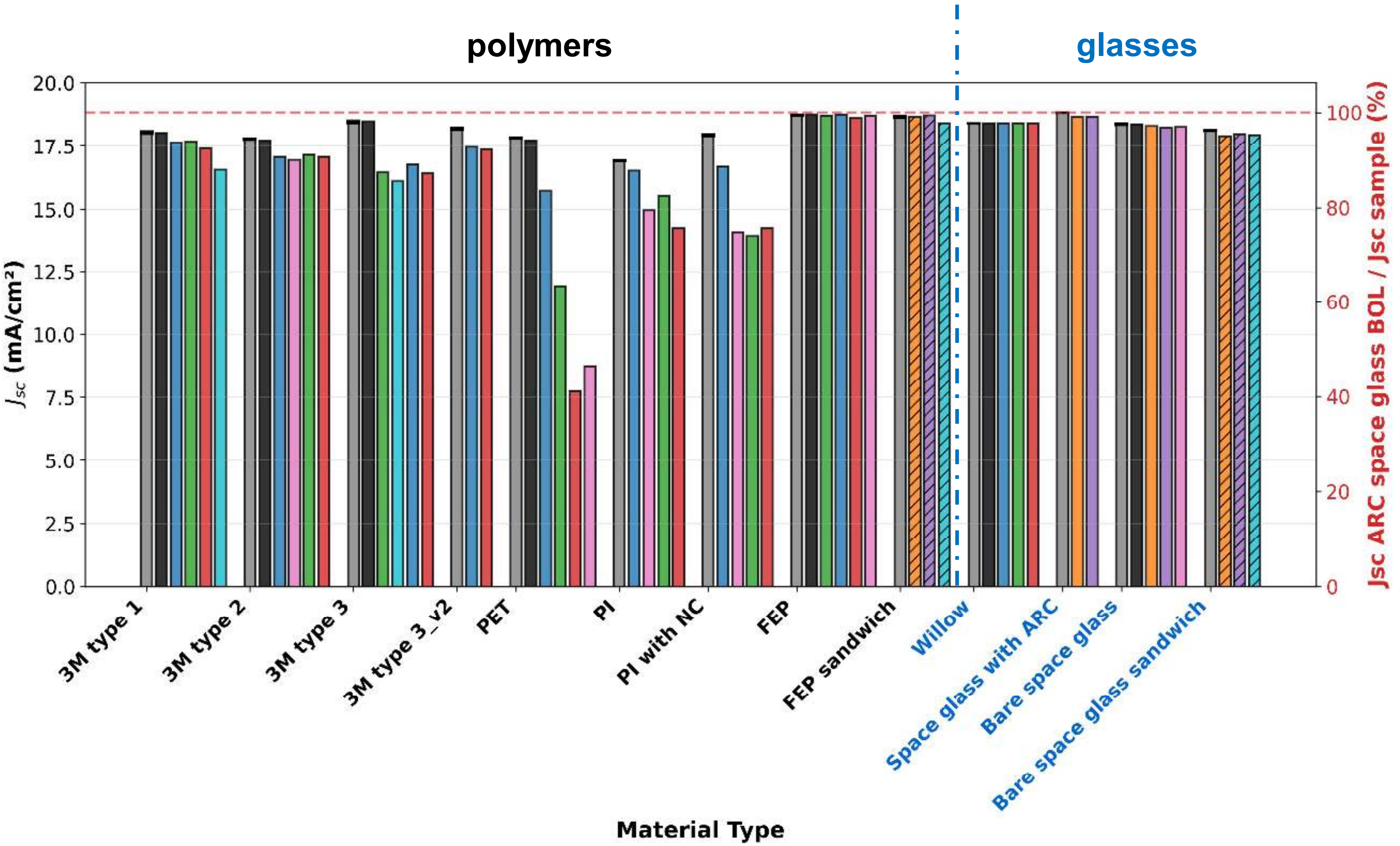
PET

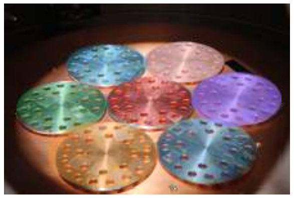


Location dependent degradation



Space environment: VUV screening test, 3J solar cells





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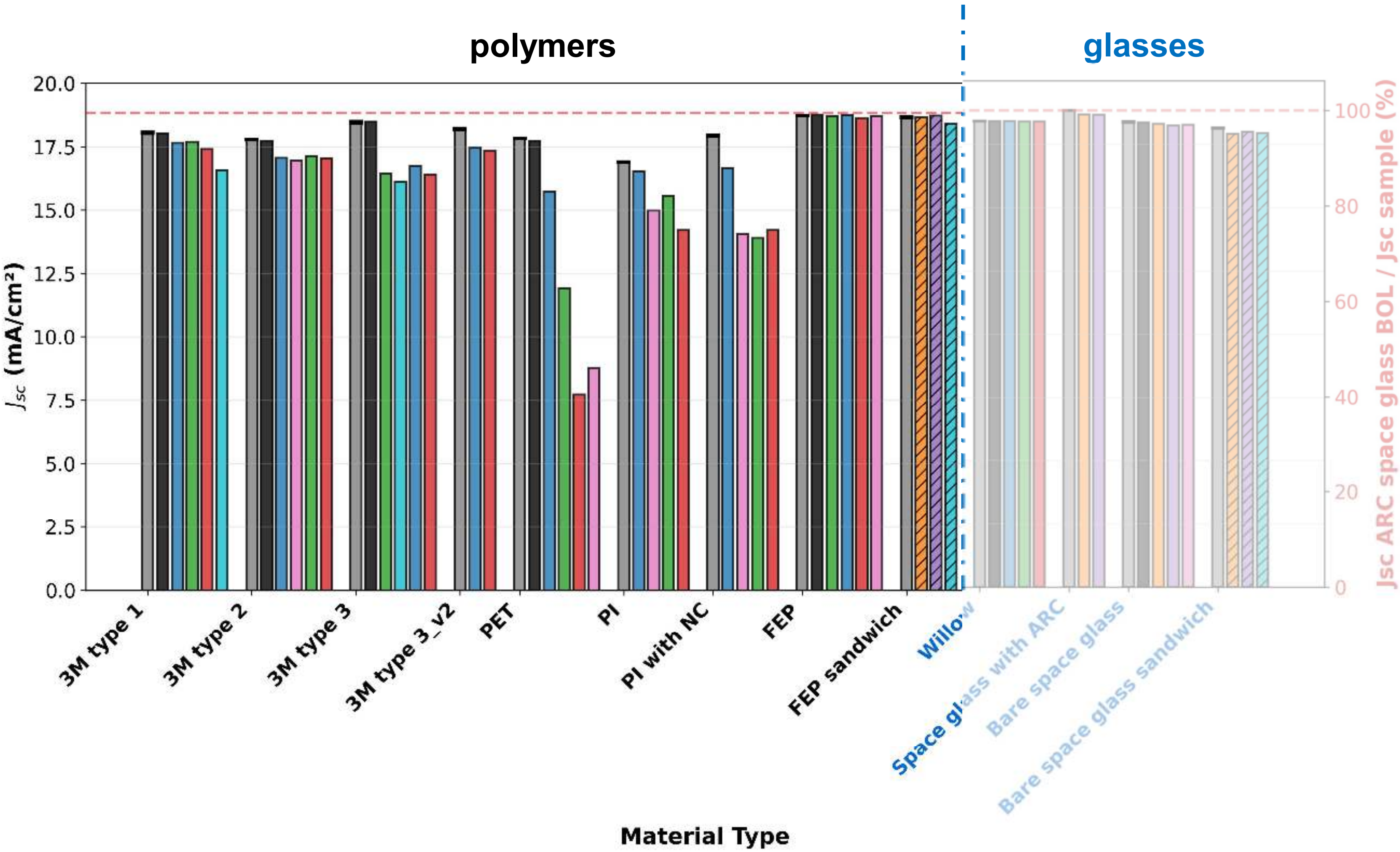

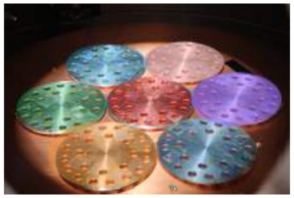

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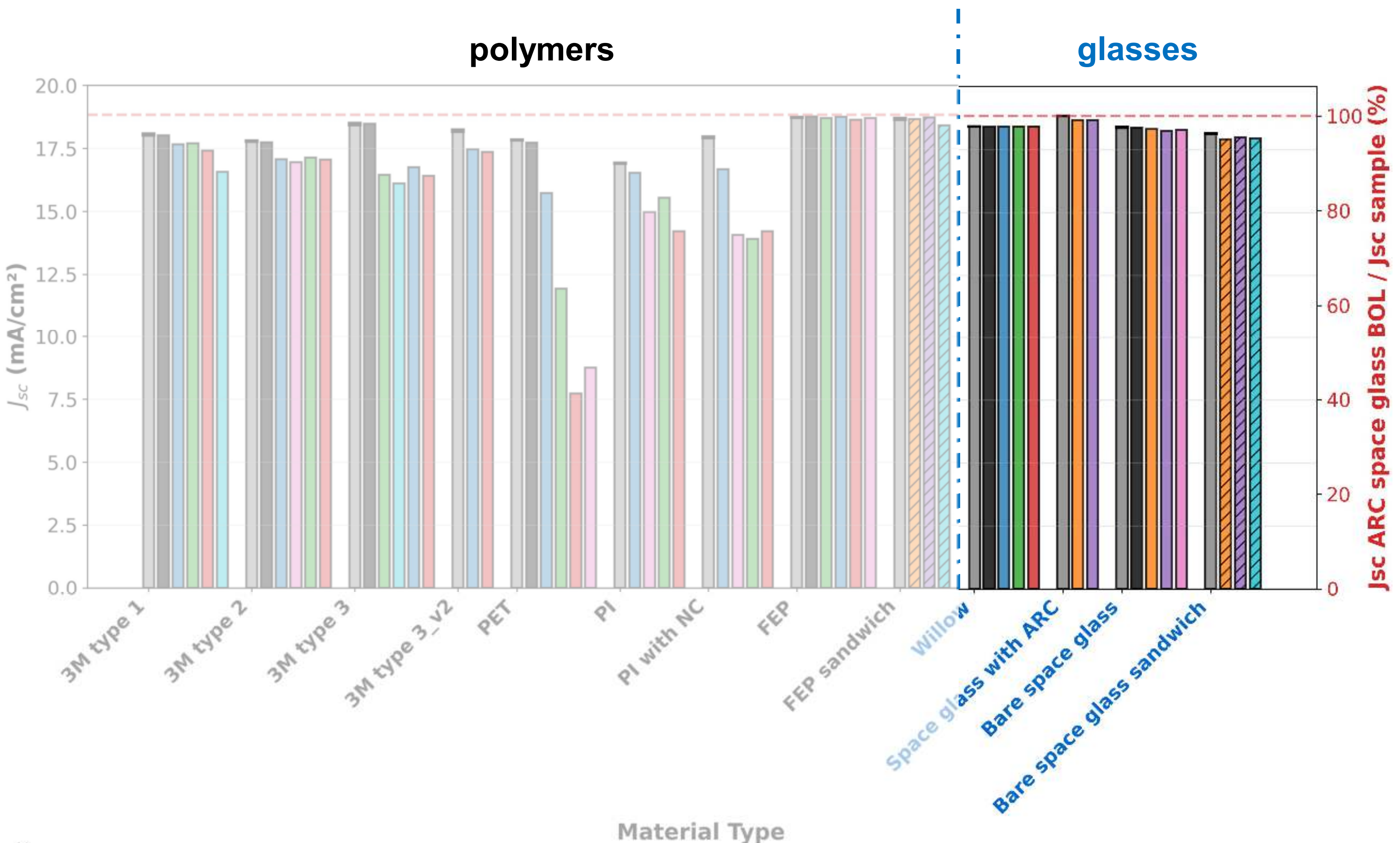

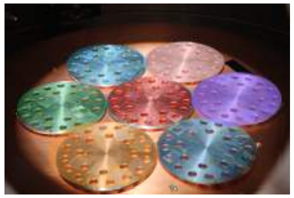

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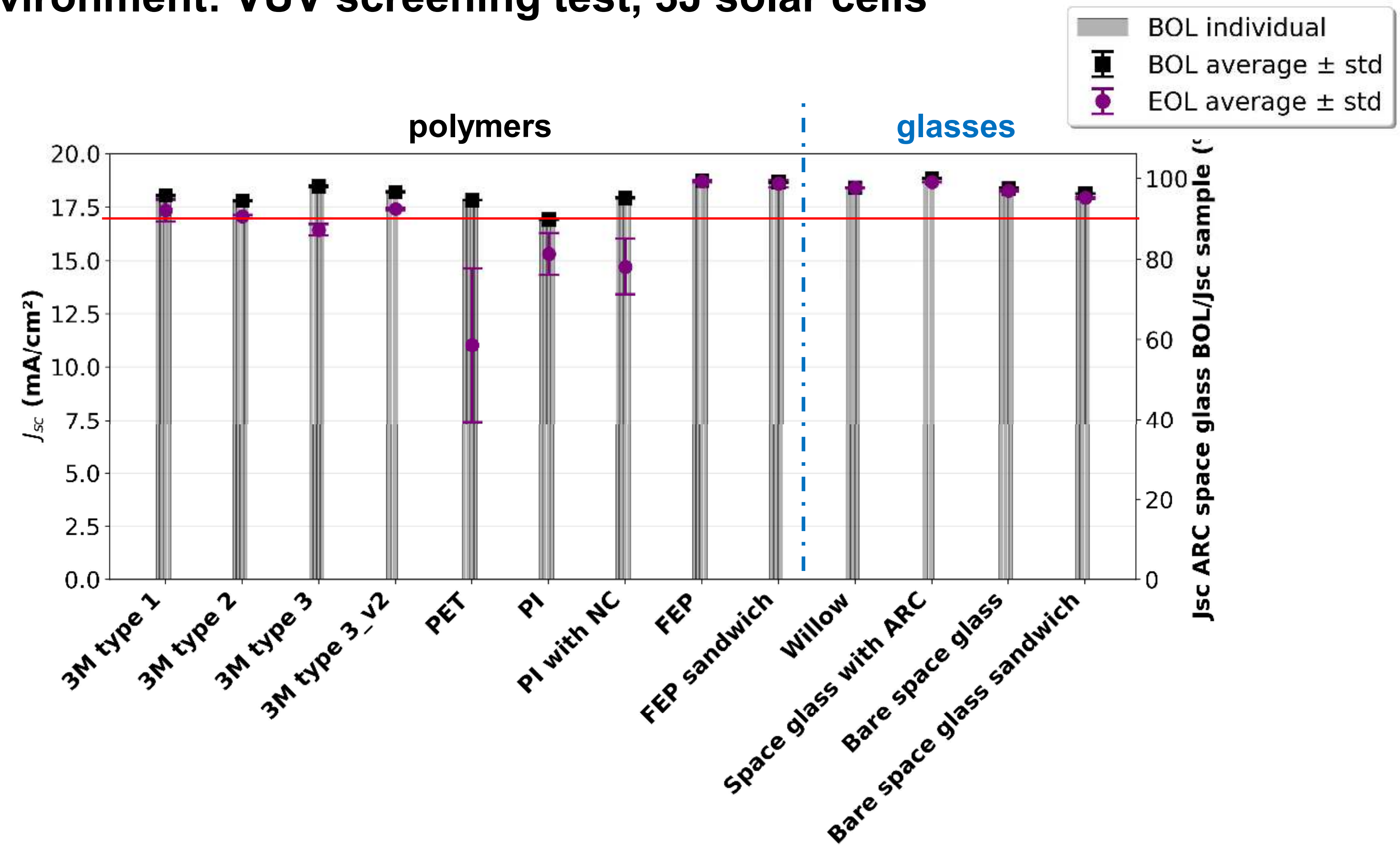
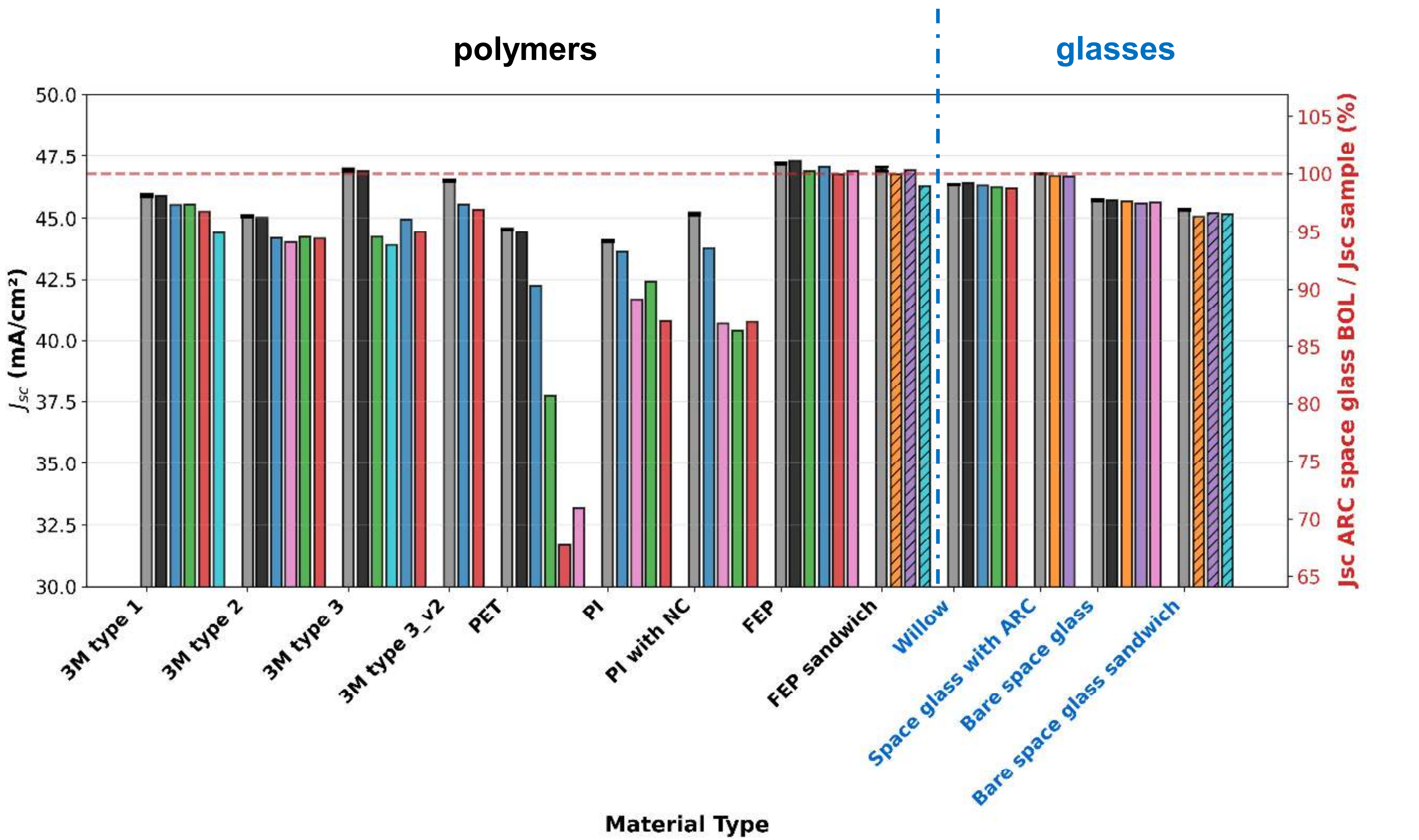
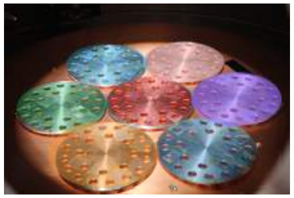
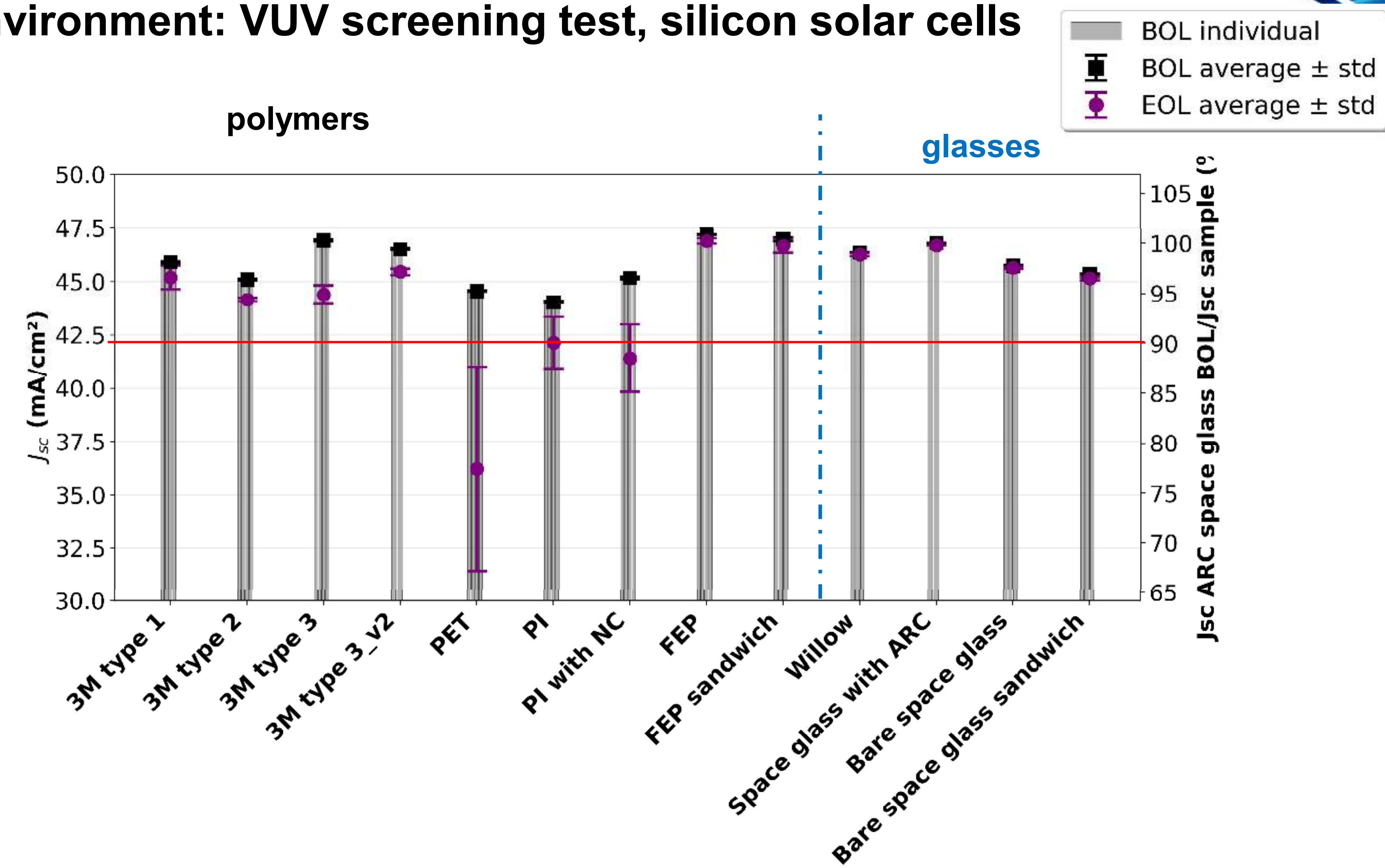


Space environment: VUV screening test, silicon solar cells





Space environment: VUV screening test, silicon solar cells



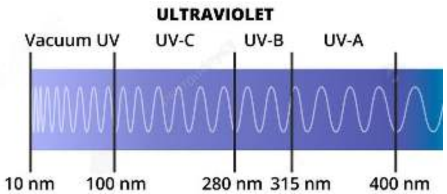
Space environment, how do we do screening tests?

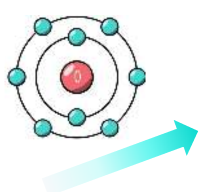
e^-
p^+

vacuum

Alternative shielding material

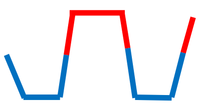
UV



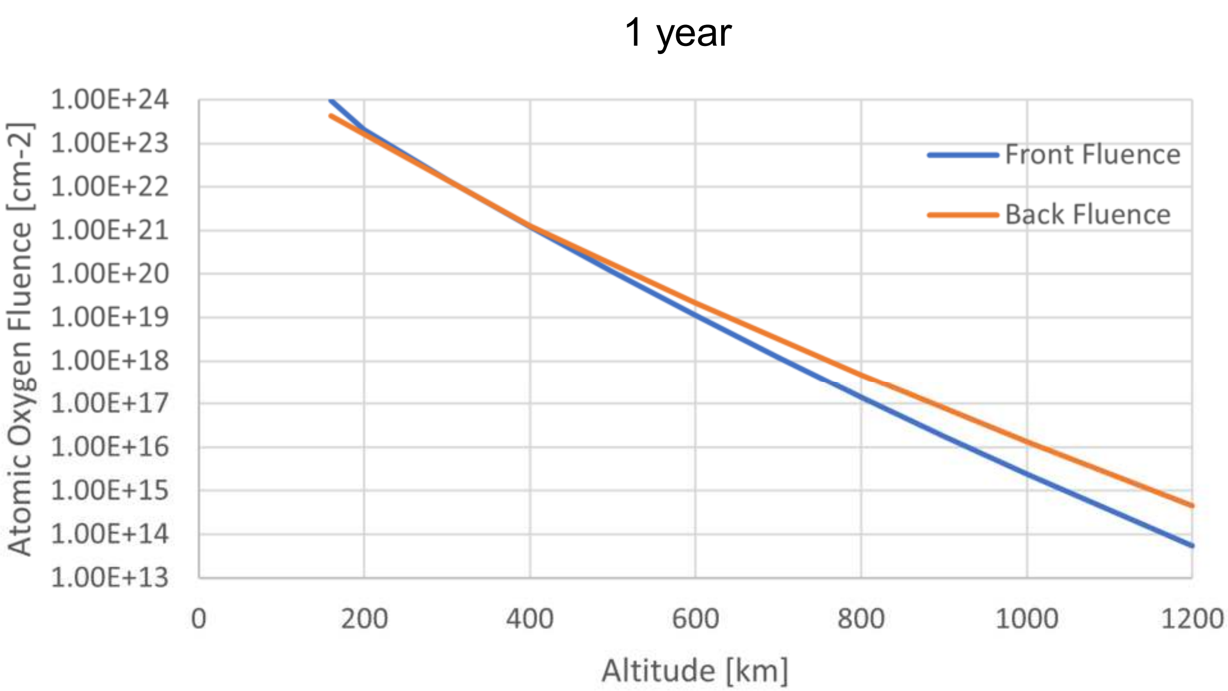


Atomic Oxygen

Thermal cycles



Space environment: Atomic Oxygen

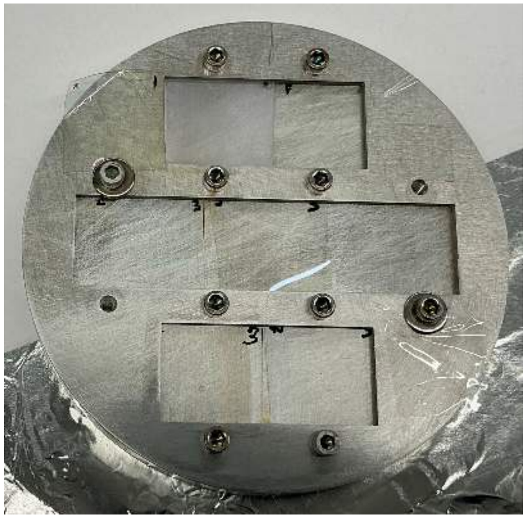


University of Nebraska
Electron cycloton resonance
AO **5 eV $2 \cdot 10^{21}$, $1.7 \cdot 10^{22}$,**
$3.5 \cdot 10^{22}$ particles/cm^2

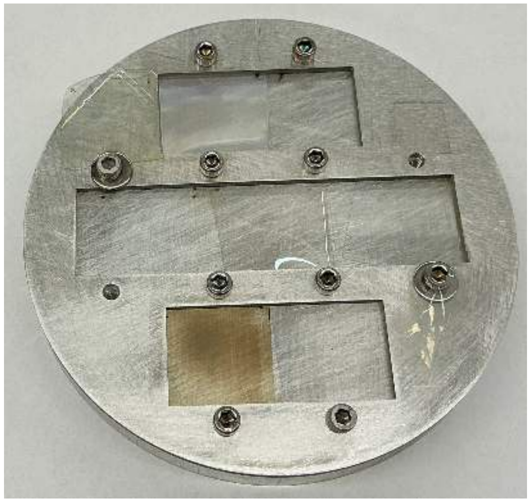
Protection against AO is critical in LEO orbits

Space environment: Atomic Oxygen, University of Nebraska set-up

Before



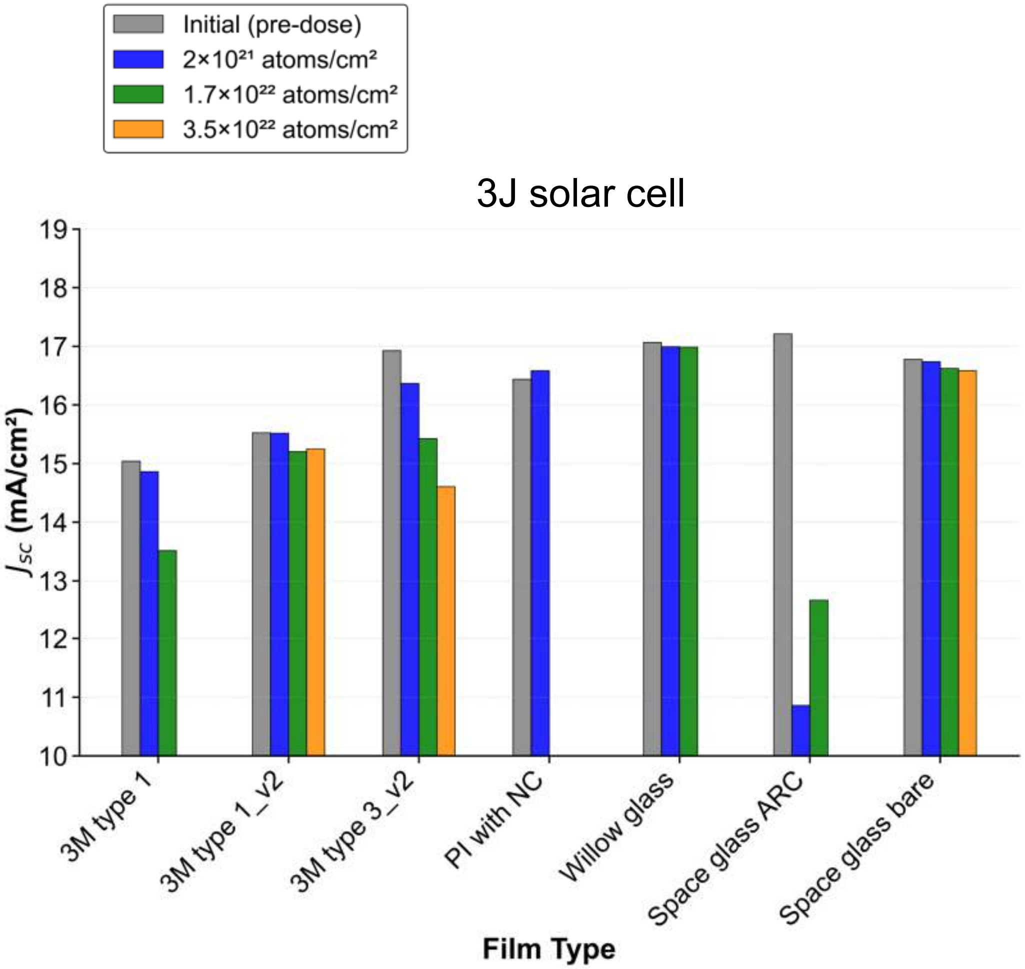
After $2 \cdot 10^{21}$ AO/cm^2

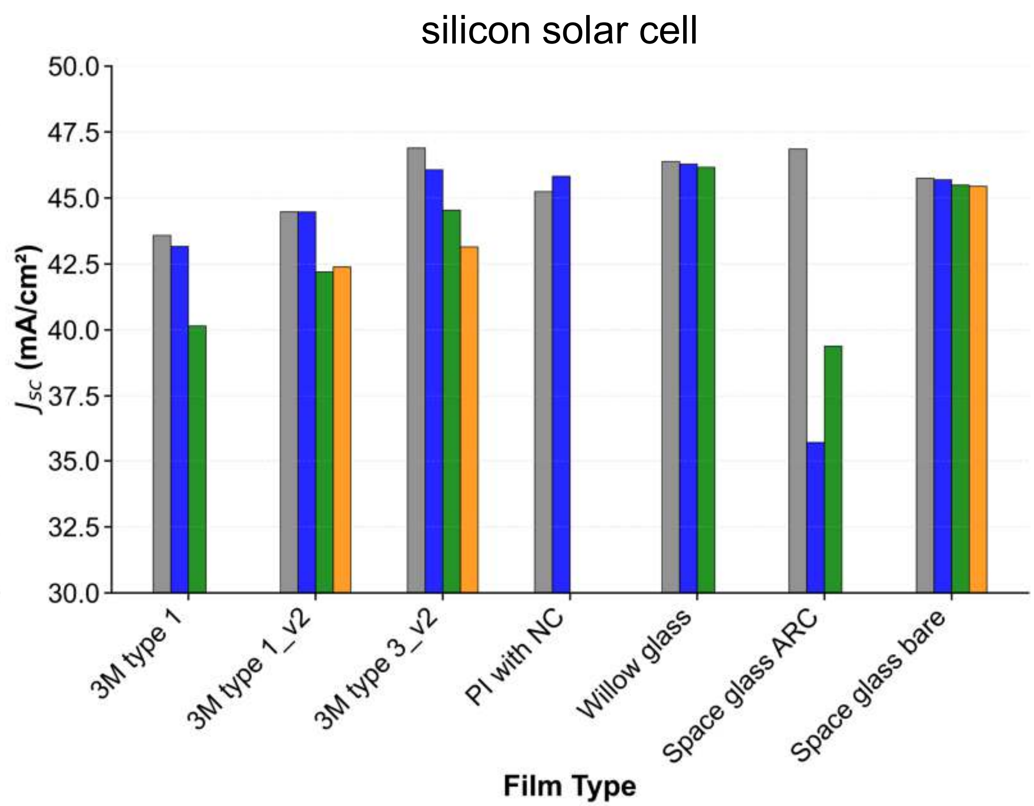


- AO testing was performed in a 1000-watt, axial magnetic field, electron cyclotron resonance (ECR) plasma system
- The flux and energy were determined using four-point probe measurements of a silver film and the Kapton erosion rate, respectively
- The flux was 2×10^{16}/cm$^2\cdot$s, and the energy of the atomic oxygen was 3–5 eV over a 3-inch diameter area
- A piece of quartz at a 45^{o} angle was used to absorb the VUV light produced in the oxygen plasma

Space environment: Atomic Oxygen

Sample	$2 \cdot 10^{21}$ AO/cm2
PET	✗
PI	✗
FEP	✗





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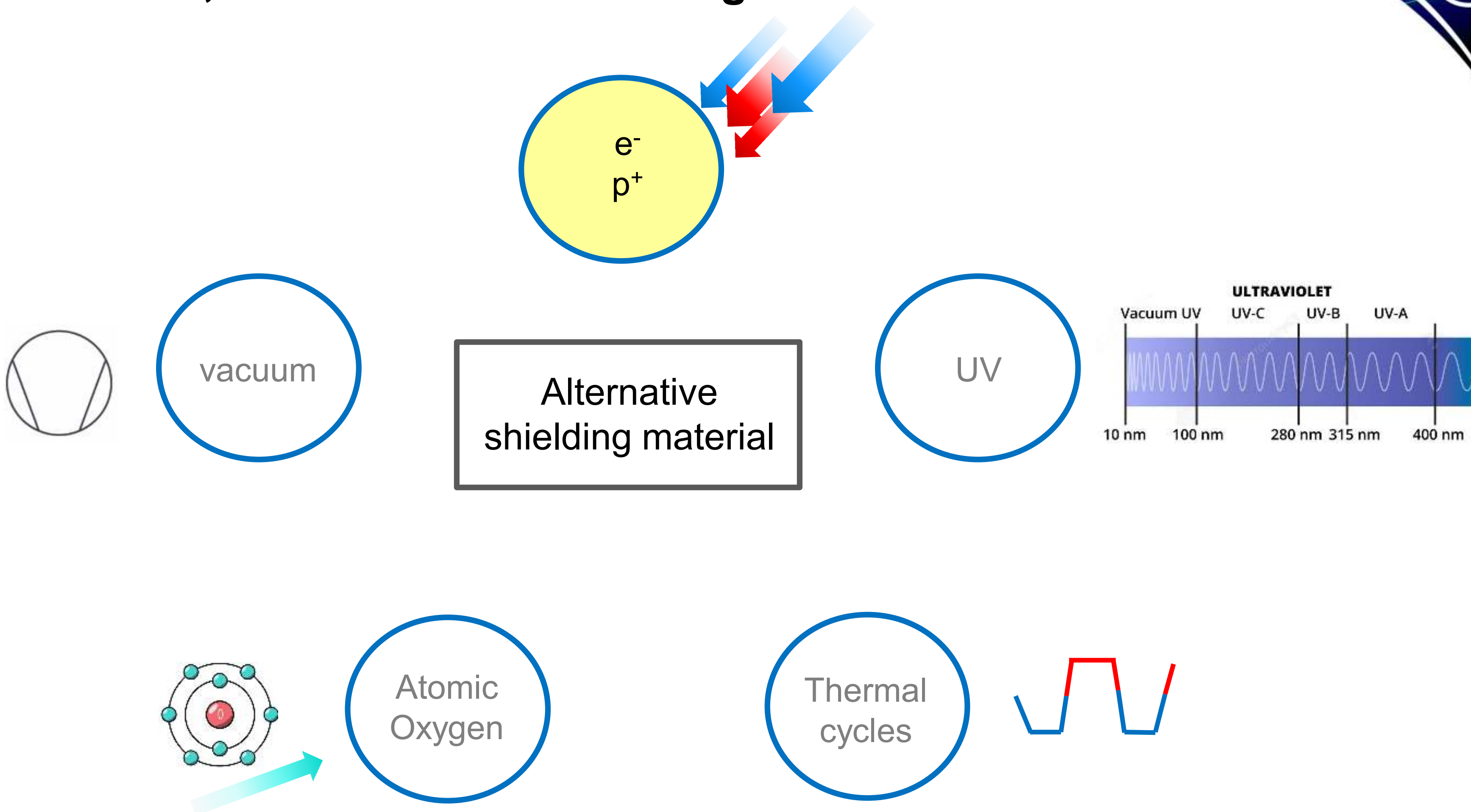
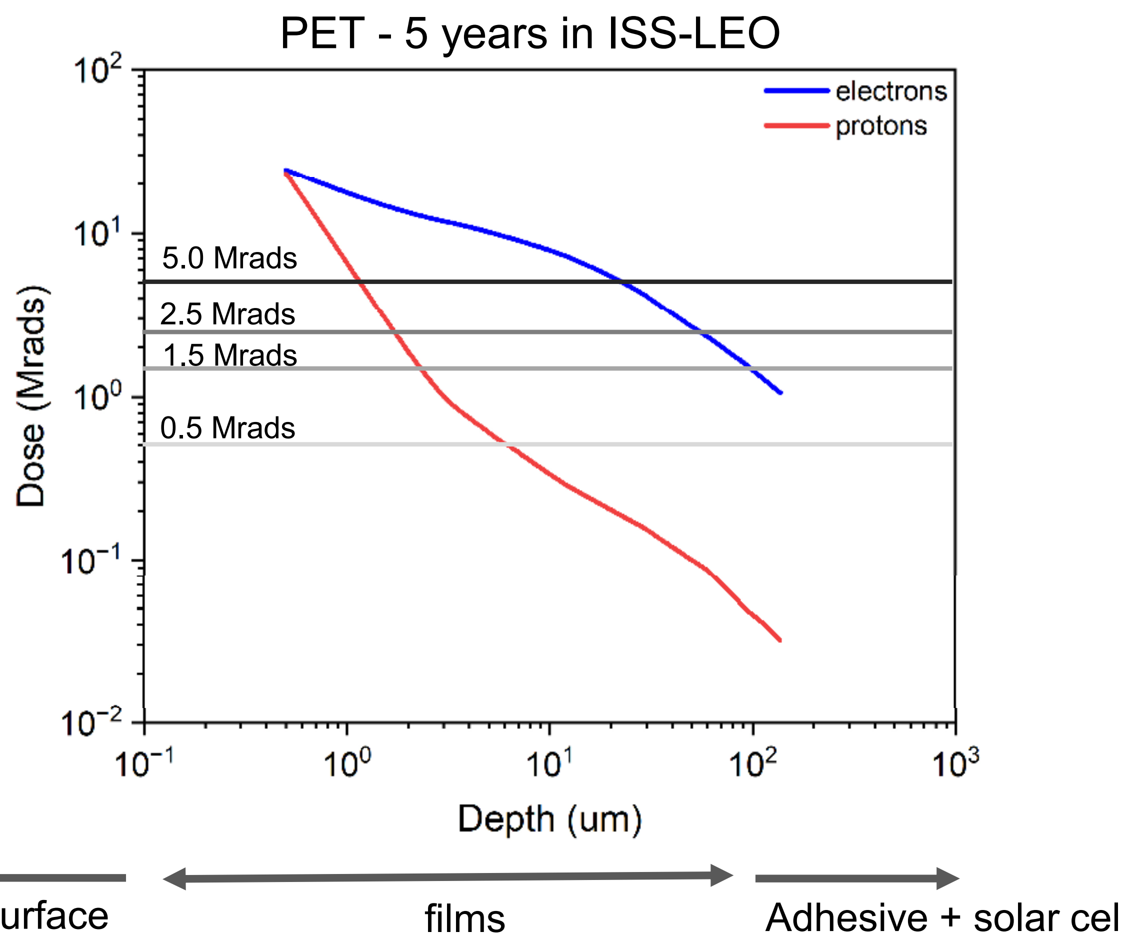


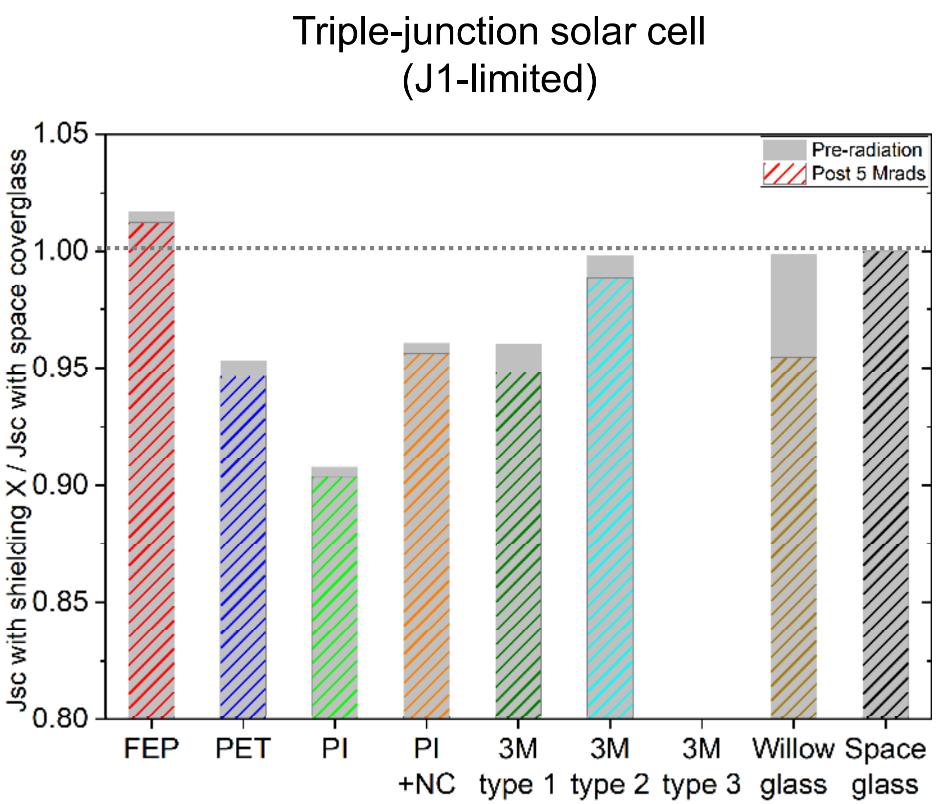
Space environment: gamma testing

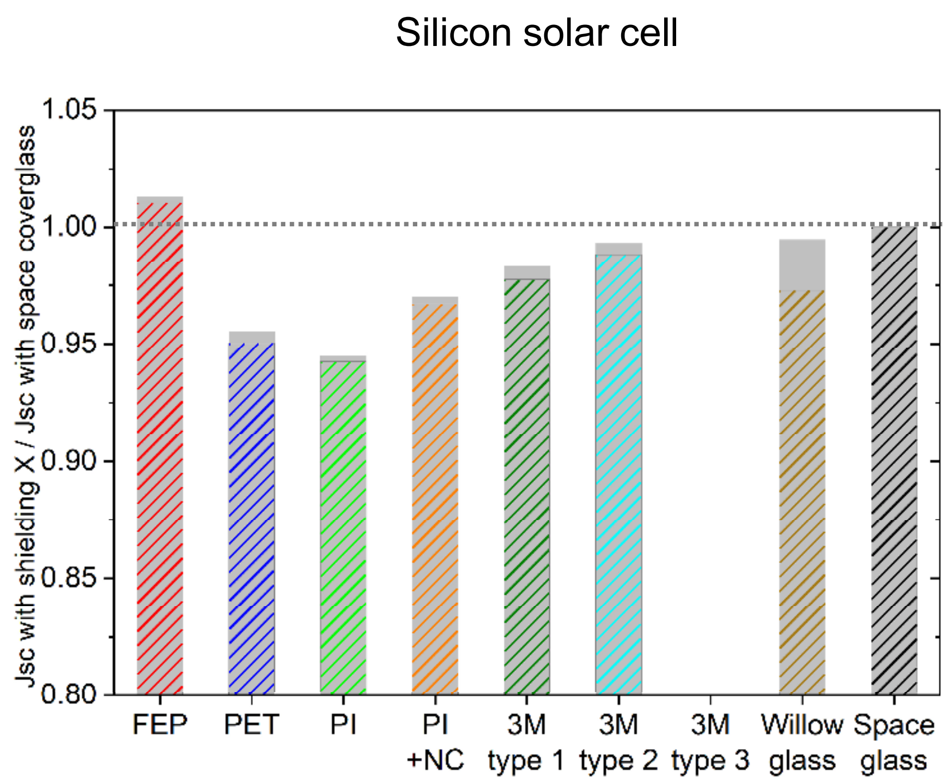
Images authored by Aerospace

Gamma testing: Co-60 radiator



Space environment: gamma testing





Conclusions and future work

- Standard space coverglass is a bottleneck: low-throughput, high-cost manufacturing
- Evaluated alternatives for high-volume, high-speed production: polymer films and flexible glasses
- Single junction solar cells (silicon) show lower sensitivity to optical darkening vs. multi-junction cells

VUV Exposure Results:

- Polymer degradation varies significantly under VUV
- Severe intensity/temperature impact on the degradation of some polymers
- Top performers: FEP (100%), 3M type 3_v2 (93%), 3M type 2 (91%) relative to space glass with ARC
- Longer time testing needed to evaluate the EOL performance

Atomic Oxygen (AO) Testing:

- AO protection is mission-critical in LEO
- AO-resistant polymers show promising durability under AO
- Bare glass without coating remains the most robust choice for AO environments
- Coatings can have significant impact under AO (as shown with MgF_2)

Radiation Testing (5 Mrad):

- Most polymer films showed minimal degradation
- Terrestrial glass can be more sensitive to radiation than polymer films

Promising candidates:

- 3M type 1_v2 for LEO environments
- FEP for orbits without AO orbits
- Willow glass for low-radiation environments

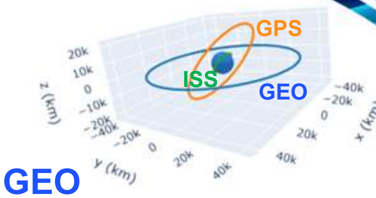
Future work

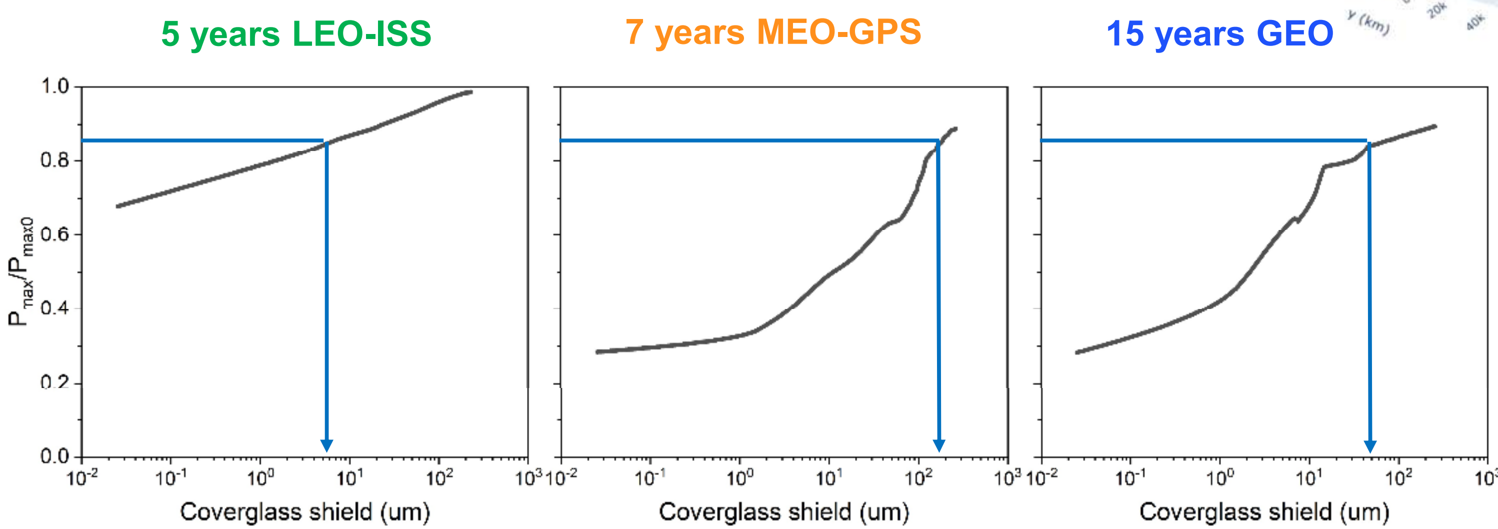
- Evaluate synergistic effects (combined VUV, AO, radiation, thermal)

Thank you

Additional slides

Shielding requirements

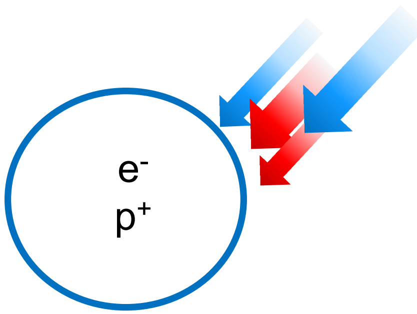




85 % remaining power at EOL

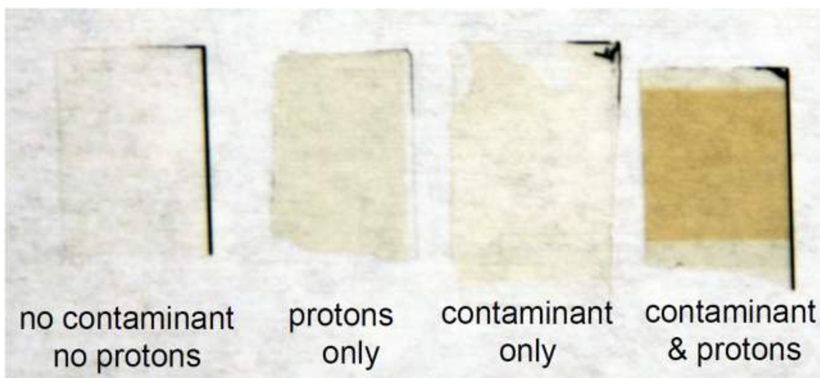
	Coverglass (2.2 g/cm^3)	Polyimide (1.5 g/cm^3)
5 years LEO-ISS	7 µm	10 µm
7 years MEO-GPS	178 µm	258 µm
15 years GEO	51 µm	72 µm

Space environment, how do we do screening tests? What about synergetic effects?

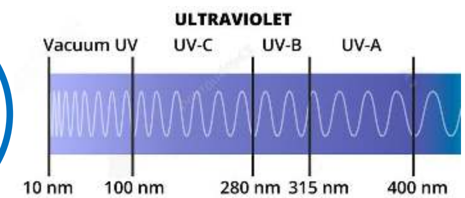


vacuum

*



UV



* Figure taken from: D. L. Liu *et al.*, "Synergistic effects of contamination and low energy space protons on solar cell current output," *2011 37th IEEE Photovoltaic Specialists Conference*, Seattle, WA, USA, 2011, pp. 001595-001600

Space environment: Outgassing

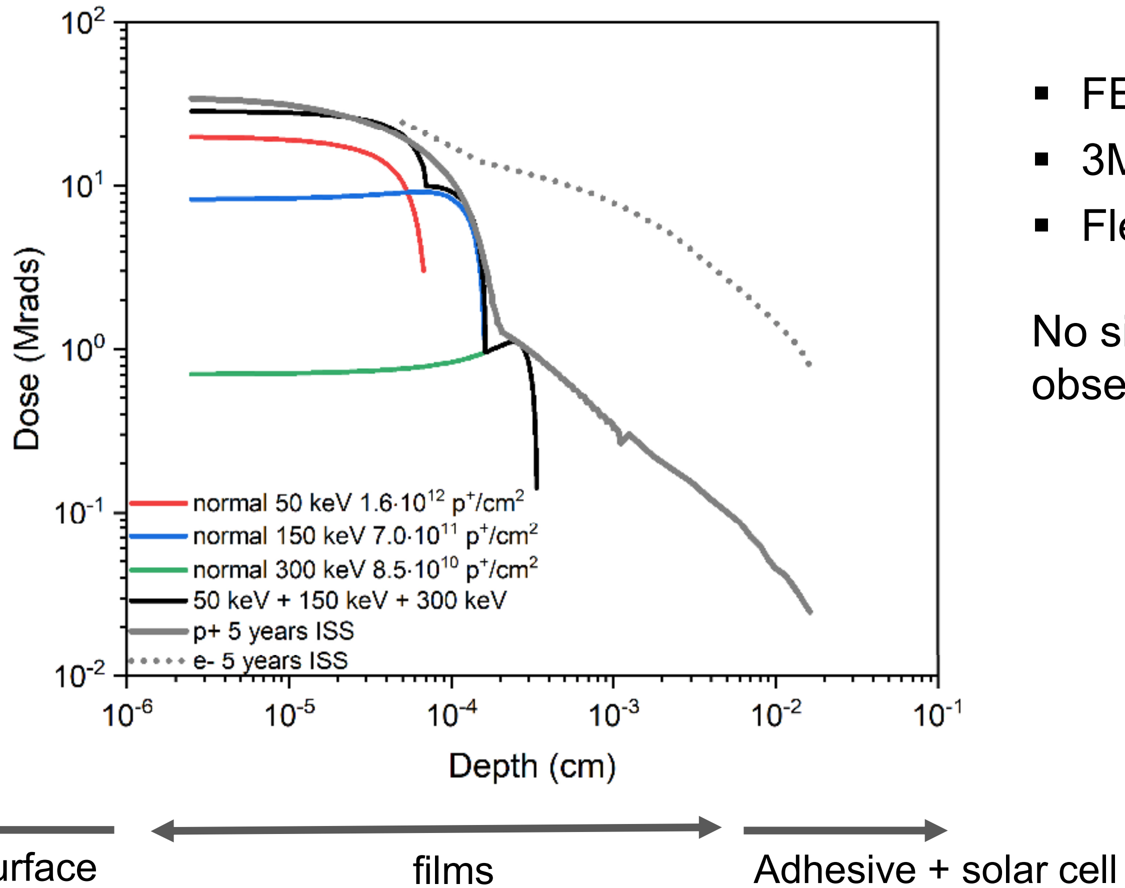
Test duration (h)	24
Sample temperature (°C)	125
Collector temperature (°C)	25
Chamber pressure (Torr)	$\leq 5 \times 10^{-5}$

Material	%TML, average	%CVCM, average	%WVR, average
3M type 1	0.275 ± 0.004	0.002 ± 0.007*	0.140 ± 0.005
3M type 2	0.998 ± 0.284	0.035 ± 0.013*	0.408 ± 0.004
FEP	0.023 ± 0.022	0.004 ± 0.004	0.014 ± 0.006
PET	0.217 ± 0.032	0.008 ± 0.010	0.144 ± 0.021
Polyimide	6.024 ± 0.567	0.007 ± 0.005	0.239 ± 0.013

* Significant haze observed on at least one collector foil

Space environment: high energy p^+

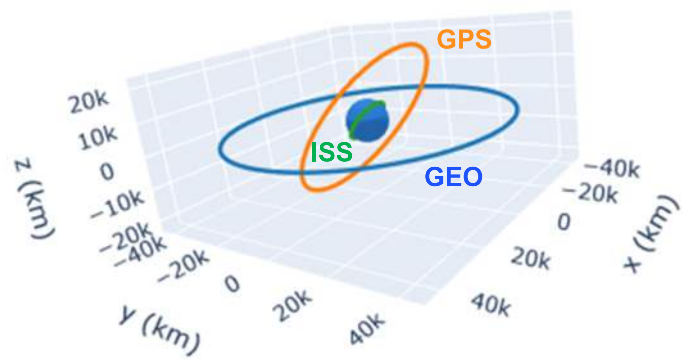
PET - 5 years in ISS-LEO



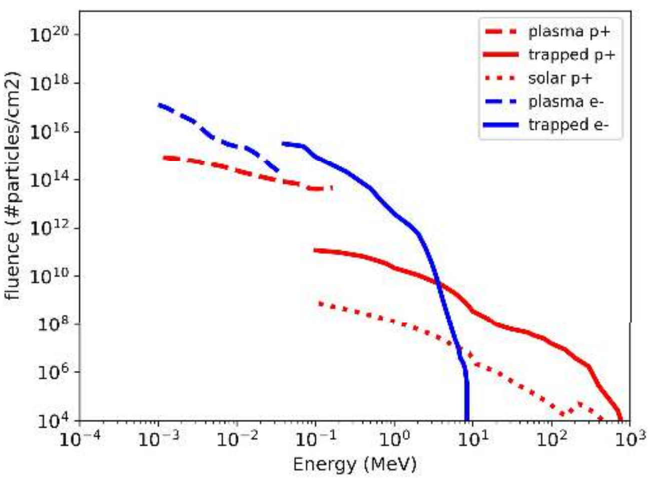
- FEP, PET, PI, PI +NC
- 3M_B
- Flexible glass and space glass

No significant degradation observed in any of the samples

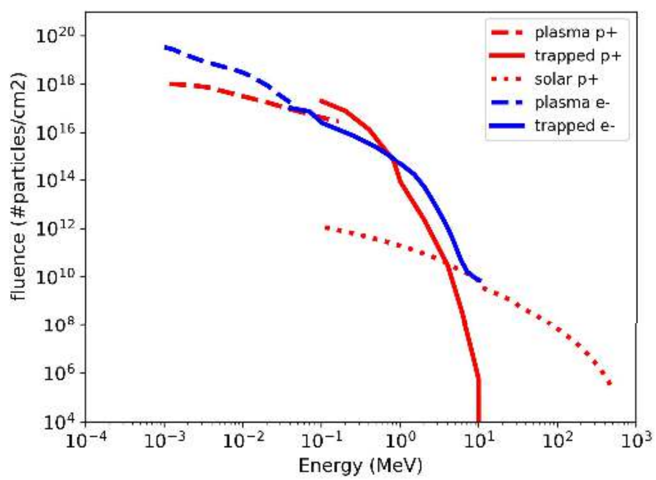
Space environment in different orbits



5 years LEO-ISS



7 years MEO-GPS



15 years GEO