Testing of Novel, Lightweight Radiation Shields for GaAs Solar Cells in Prolonged Space Environment Exposure

Space Power Workshop, April 21st, 2026

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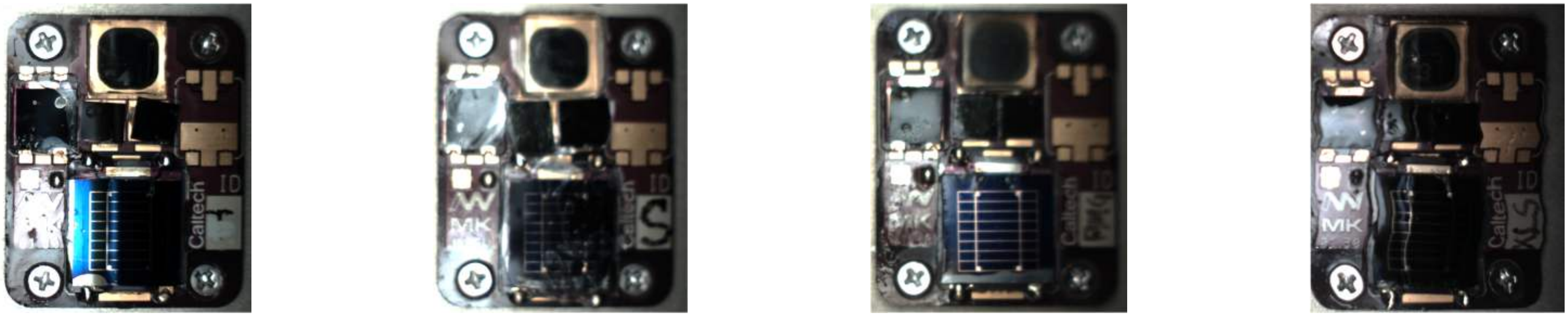
[2]Angstrom Designs, Inc



Space Solar Power Project (SSPP):

- SSPP is an ultralight, space-based solar power array meant to collect energy from sunlight and transmit it back to earth through radio-frequency power from GEO

- Basic technoeconomic analysis[2] dictates requirements for solar cells to sell energy for $5¢/\mathrm{kWhr}$
    - Lightweight (< 50 $^{\mathrm{g}}/_{\mathrm{m}^2}$)
    - Efficient (> 20%)
    - Radiation hard (15 years at GEO)
    - Cost-effective (<$1/W)

To date, no commercially available cell meets the full suite of these design requirements[2]

Space solar power constellation [1]

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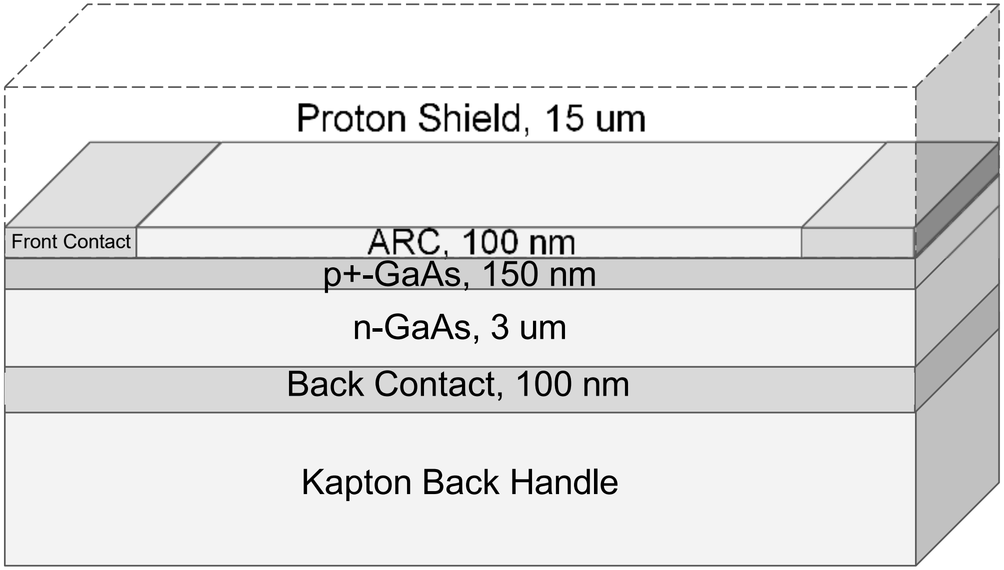
[1] Caltech press release

[2] Mizrahi, O. S., et al. (2025). Space solar power generation: A viable system proposal and technoeconomic analysis. *Joule*, *9*(6).https://doi.org/10.1016/j.joule.2025.101928

Inexpensive, Lightweight, Efficient Cell Design

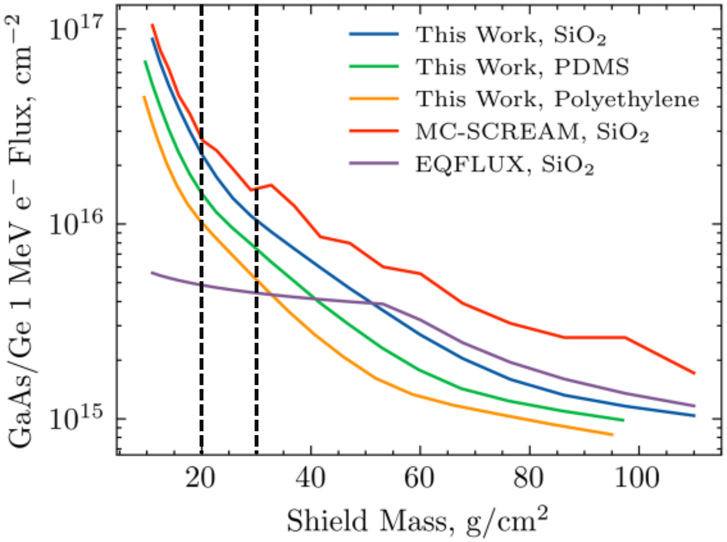
- To meet the demands of the SSPP platform, our team has chosen is to **avoid** the cost-prohibitive expense of **epitaxy** in cell fabrication and to **avoid heavy shielding**
- We have pursued the development of a **thin-film (spalled), diffusion-doped** p+/n GaAs device, with **thermally annealed**, long minority carrier lifetime performances
- Currently, the SSPP **bulk** cell design demonstrates at *15.5% efficiency*



Proposed design for GaAs-based SSPP cells

Radiation Shield Requirements for SSPP Solar Cells

- Thick enough to mitigate protons
  - Limit proton flux to 10^{16} 1 MeV cm^{-2} flux
  - **20-30 g/m^2** of organic or inorganic required[1]
- Survives harsh ultraviolet radiation
  - Ultraviolet radiation can break chemical bonds and darken transparent materials such as normal glass
- Survives atomic oxygen
  - Plasma oxidation of polymers
  - Erosion/degradation of unshielded electronics
- Survives thousands of thermal cycling
  - Avoids delamination events within cell
  - Avoids fatigue build up from coefficient of thermal expansion mismatches



Simulated radiation penetration flux of varying shield compositions and masses from incident GEO proton radiation environment[1]

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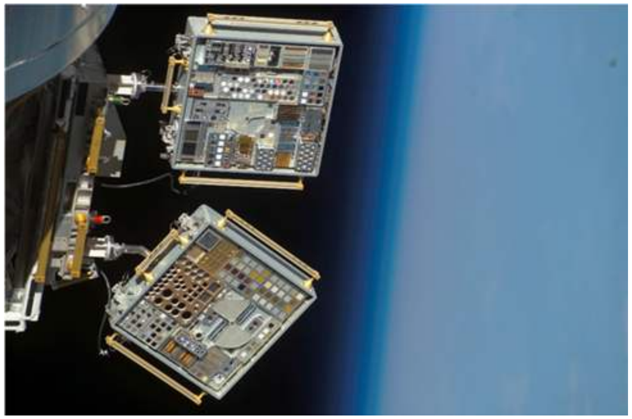
[1] Jahelka, P. R., Kelzenberg, M. D., & Atwater, H. A. (2025). Simulating Proton Transmission Through Thin Radiation Shields for Space Based Solar Power. *Conference Record of the IEEE Photovoltaic Specialists Conference*, 1643–1645. https://doi.org/10.1109/PVSC59419.2025.11133144

Orbital Electronics Lab (OEL) on the International Space Station

- OEL adds cell IV and temperature measurement to the Materials International Space Station Experiment (MISSE)
  - OEL leverages Aerospace Measurement Unit technology (AMU) developed by Colin Mann and Don Walker
- Six months hosted on the ISS with LEO environmental conditions
  - IV curve per cell every 10 seconds
    - > 6,000,000 IV curves from this flight
  - 3,000 thermal cycles
  - UV radiation damage
  - Some particle radiation (less than SSPP)
  - Atomic oxygen exposure (higher than SSPP)
- Samples are recovered for post-flight experimental comparison
- Four GaAs solar cells with different shields will have constant simultaneous measurements
- MISSE and ISS telemetry can give sun pointing and sun angle data

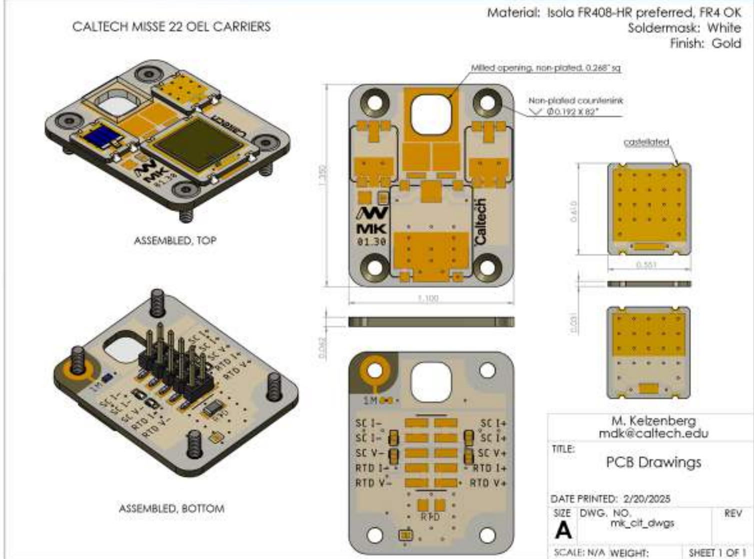


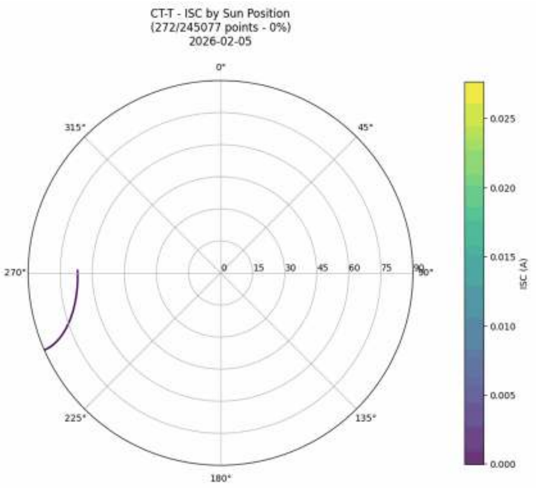
MISSE experiments aboard the ISS[1]

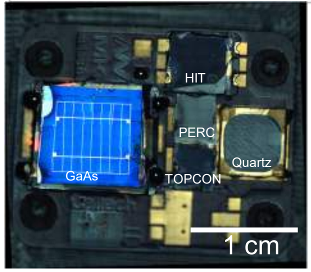
[1] https://www1.grc.nasa.gov/space/iss-research/misse/

Orbital Electronics Lab (OEL) on MISSE

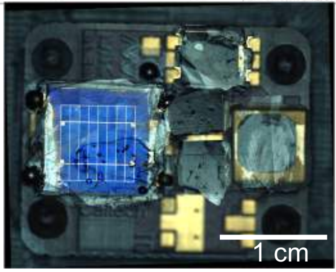
- Partnered with Angstrom Designs to send four PCBs with different shields
  - Traditional space cover glass encapsulation
  - Spalled space cover glass encapsulation
  - Pseudomorphic glass encapsulation
  - Corin XLS encapsulation
- Each PCB carried:
  - 12 x 12 mm area for interposed and instrumented GaAs
  - 6 x 6mm interposed and non-instrumented photovoltaic cells used for HIT silicon solar cells
  - Two 4.5 x 4.5mm pads used to carry PERC and Topcon solar cells
  - 7 x 7mm window for quartz standard transmission test to isolate degradation comparisons
- Polar plots show the short-circuit current as a function of the sun-incidence vector
- Polar plots are used to filter away low-confidence, high sun angle, or anomalous data (spacecraft or orbital maneuvers)



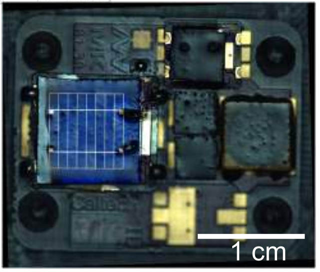




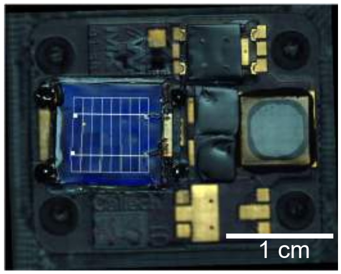
Traditional space cover glass encapsulated solar cells



Spalled space cover glass encapsulated solar cells



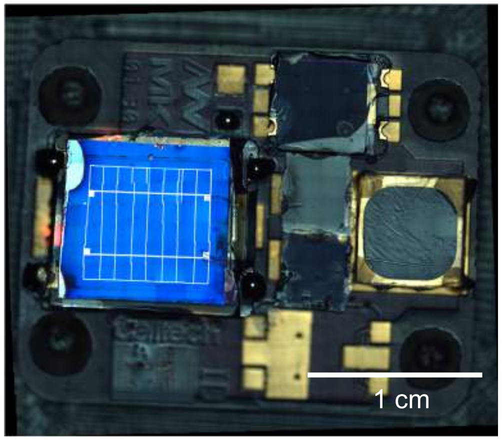
Pseudomorphic glass encapsulated solar cells

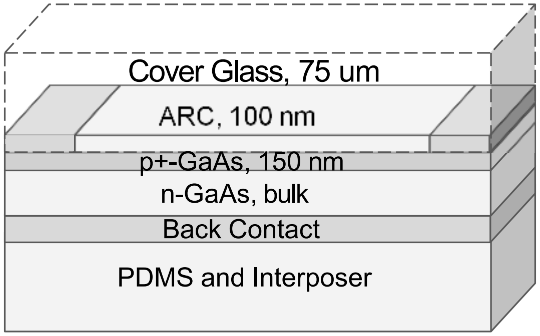


Corin XLS encapsulated solar cells

Traditional Space Cover Glass Encapsulation

- 75 µm thick bulk space grade glass
  - Semi flexible due to relative thinness
  - Weighs ~ **200** $\mathbf{{}^{g}/_{m^2}}$
  - Ceria coped to avoid glass yellowing
- DC 93-500 PDMS space grade adhesive between glass and solar cell
- **Standard technique** for space solar cell encapsulation
- Difference in Fill Factor from pre-flight IV is likely due to solar spectrum differences*




Cover Glass, 75 um

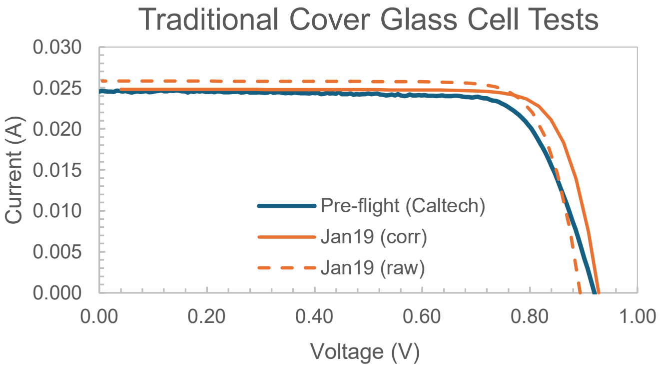
ARC, 100 nm

p+-GaAs, 150 nm

n-GaAs, bulk

Back Contact

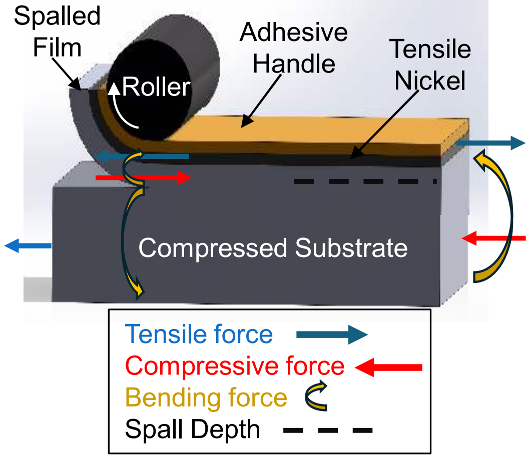
PDMS and Interposer



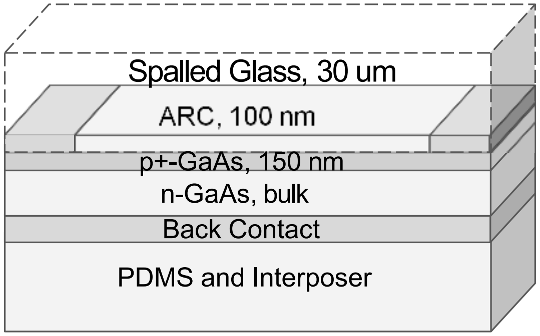
Traditional (43.9°C)	Pre-flight	19-Jan	Change (%)
V_{oc} (mV)	920	928	0.90%
I_{sc} (mA)	24.6	24.8	1.08%
FF (%)	76.5	81.4	6.41%

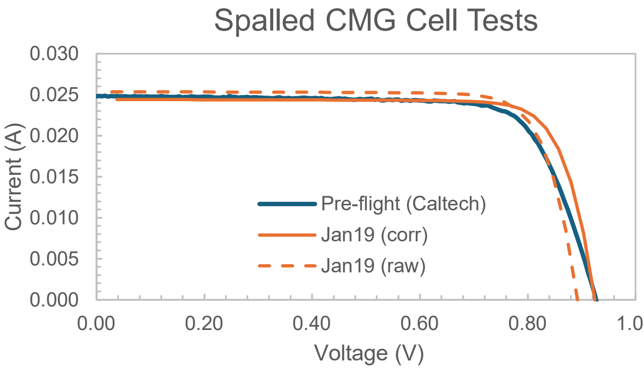
Spalled Cover Glass Encapsulation

- **30 µm thick** spalled space grade glass
    - Thin film of glass is achieved using spalled exfoliation with stressed nickel layer to remove **continuous, thin layer of cover glass**
    - Weighs ~ **75** $^{\mathbf{g}}/_{\mathbf{m^2}}$
    - Ceria coped to avoid glass yellowing
    - **2 µm thick films** were obtained
- DC 93-500 PDMS space grade adhesive
- **Traditional material with novel thinning**



Adapted from Hutchinson, J. W., and Z. Suo. *Advances in Applied Mechanics* 29.C (1991): 63–191.





Spalled (41.9°C)	Pre-flight	19-Jan	Change (%)
V_{oc} (mV)	927	925	-0.22%
I_{sc} (mA)	24.8	24.4	-1.60%
FF (%)	75.7	81.1	7.13%

Pseudomorphic Glass (PMG) Encapsulation

- **30 µm thick silica/PDMS composites**
  - DC 93-500 PDMS and 5 µm quartz microspheres mixed composite
  - Atomic oxygen erodes exposed PDMS until a stacked layer of **silica protects the surface**
  - **Weighs ~ 50** $^{g}/_{m^{2}}$
- Developed originally at the **Air Force Research Laboratory** with unknown usage history[1]

MISSE PMG sample preparation

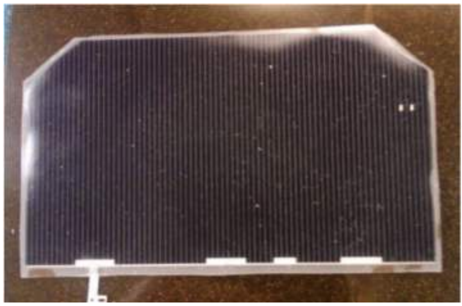
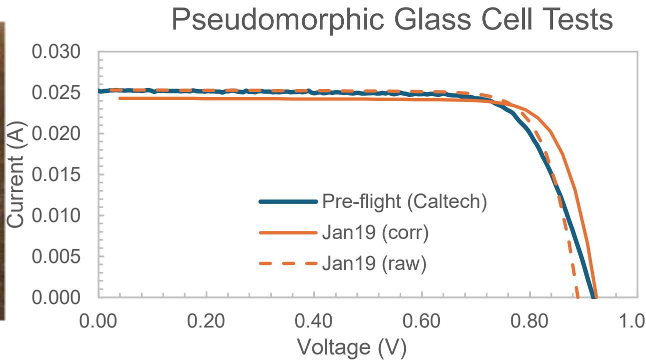
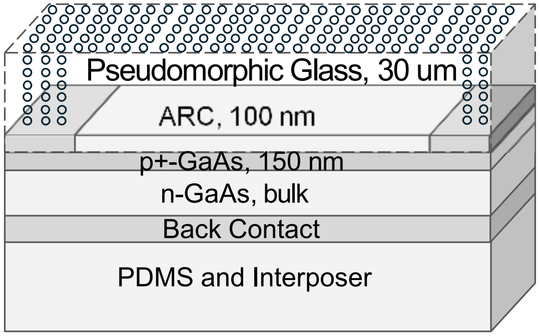


Image of Spectrolab ITJ cell covered with fused silica PMG[1]



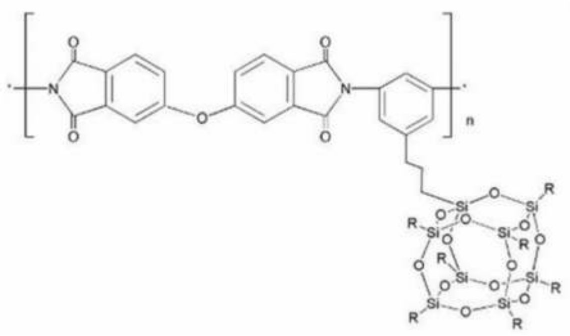


PMG (43.4°C)	Pre-flight	19-Jan	Change (%)
V_{oc} (mV)	918	924	0.67%
I_{sc} (mA)	25.2	24.3	-3.66%
FF (%)	75.4	80.8	7.10%

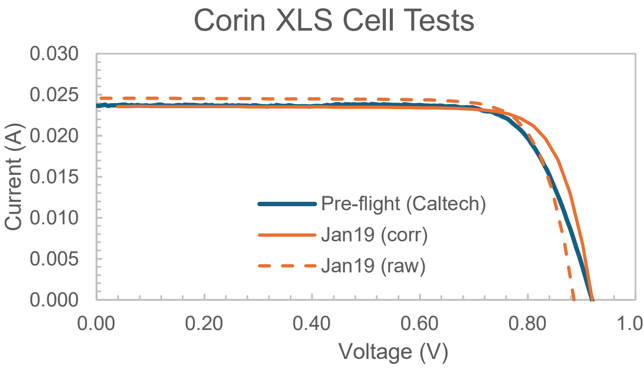
[1] Wilt, D., Howard, A., Snyder, N., Sahlstrom, T., Heersema, N. A., Nathan, L., Ohshima, T., Sato, S., & Imaizumi, M. (2011). *Pseudomorphic Glass to Enable High Efficiency Space Photovoltaic Devices*. IEEE.

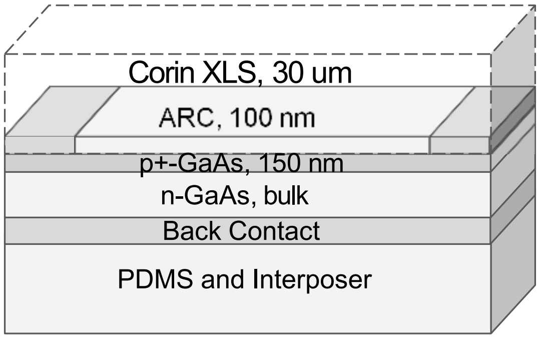
Corin XLS Encapsulation

- **30 μm thick** polyimide resin with fluorine and Silsesquioxane functionalization[1]
  - Fluorine stays stable
  - Silsesquioxane decomposes into silica in atomic oxygen which **improves atomic oxygen resistance**
  - **Weighs ~ 40 $^{g}/_{m^2}$**
- **Proven history on MISSE[1]** including success with solar cell devices



Chemical structure of Corin XLS[1]





XLS (43.6°C)	Pre-flight	19-Jan	Change (%)
V_{oc} (mV)	919	920	0.07%
I_{sc} (mA)	23.7	23.6	-0.42%
FF (%)	77.4	80.3	3.76%

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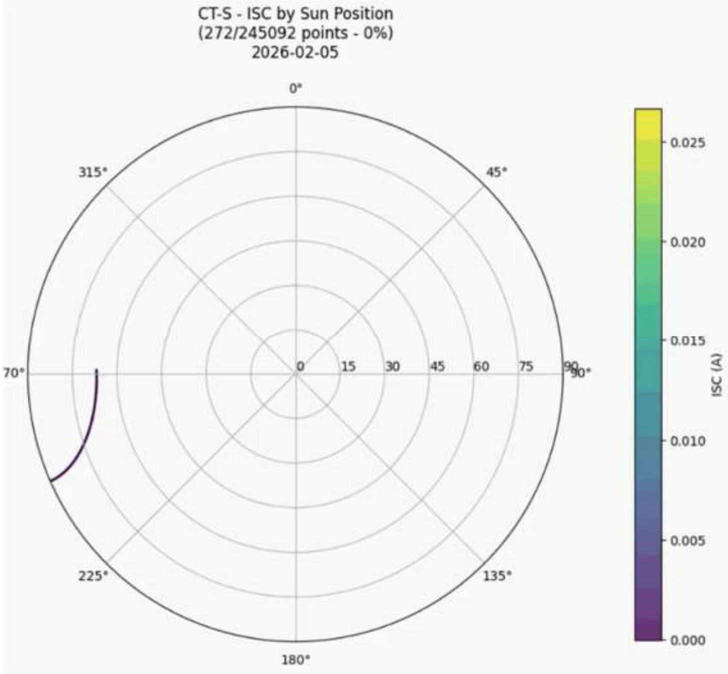
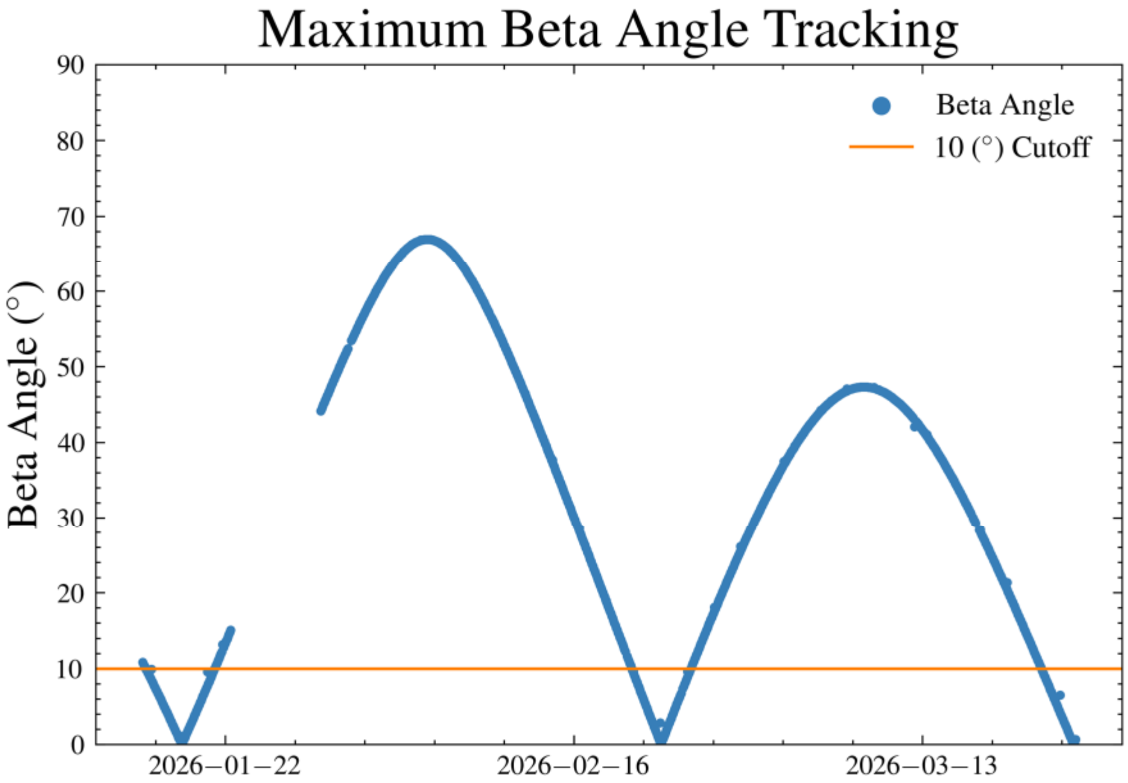
[1] Finckenor, M. M., Rodman, L., & Farmer, B. (2015). *Analysis of Fluorinated Polyimides Flown on the Materials International Space Station Experiment*.

Sun Angle Tracking and Data Selection



Stable and maximal cell current readings within 10° of center

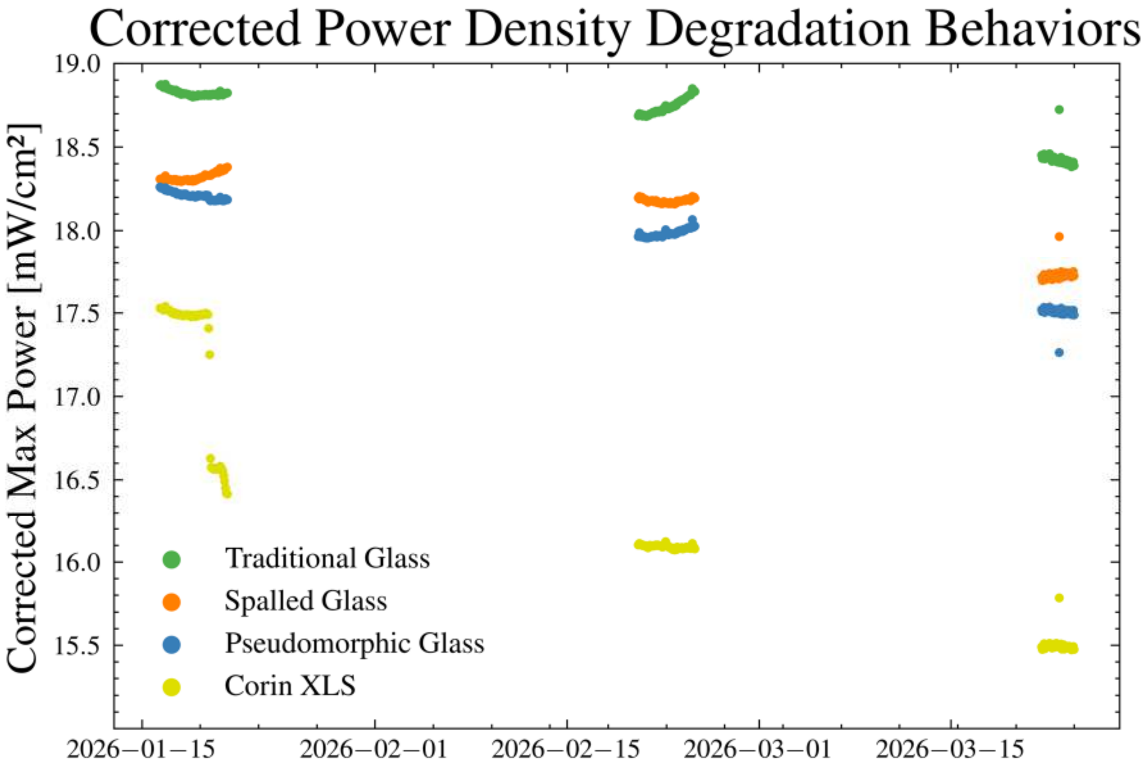


Normalized Power Density Degradation Behaviors

Coating	Power Loss [mW/cm^2]	Power Loss %	Mass [g/m^2]
Traditional	0.48	2.5%	200
Spalled	0.59	3.2%	75
PMG	0.77	4.2%	50
Corin XLS*	1.05	6.3%	40

*Comparison post January 19th

- Spalled glass and PMG were close to the degradation of traditional glass
- Corin XLS device experienced an anomaly on January 19th, 2026
- Power density normalized by sun angle for delivered current density and temperature for voltage and fill factor

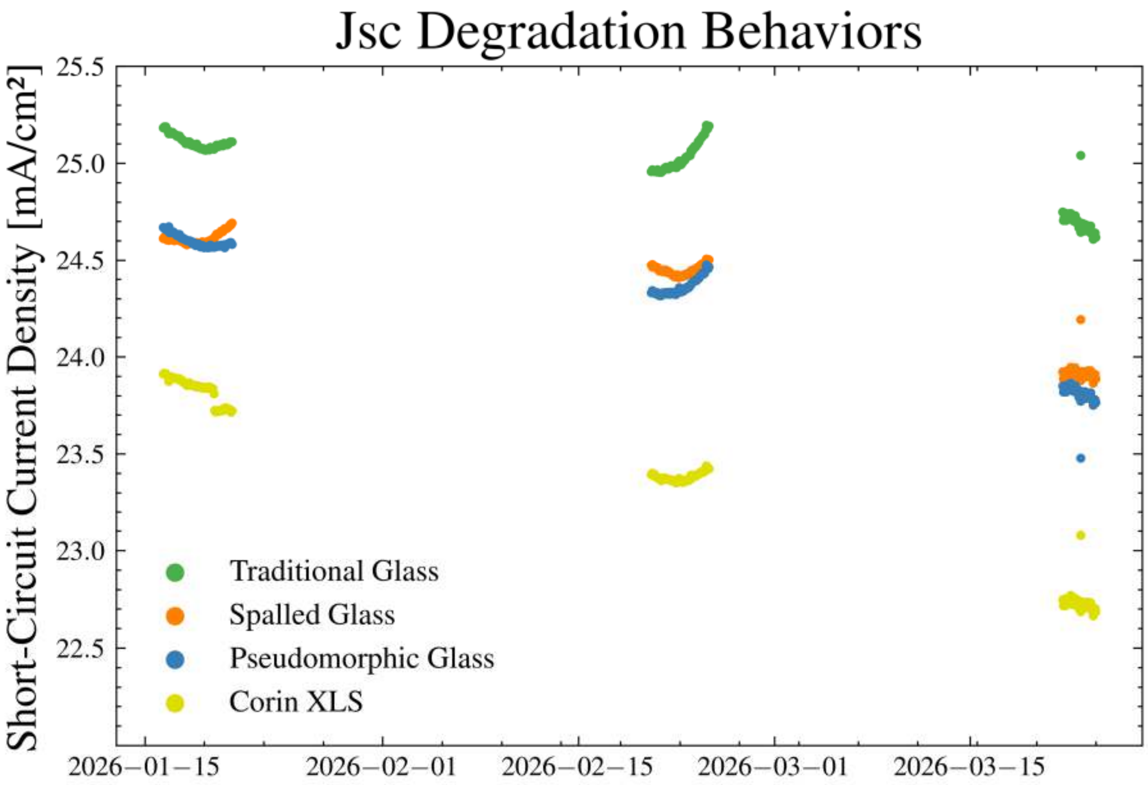


Short-Circuit Current Density Degradation

Coating	J_{sc} Loss [mA/cm^2]	J_{sc} loss %	Mass [g/m^2]
Traditional	0.56	2.2%	200
Spalled	0.72	2.9%	75
PMG	0.91	3.7%	50
Corin XLS*	1.04	4.4%	40

*Comparison post January 19th

- J_{sc} corrected by sun angle
- Traditionally encapsulated glass provided the best protection, but spalled glass was similarly resilient

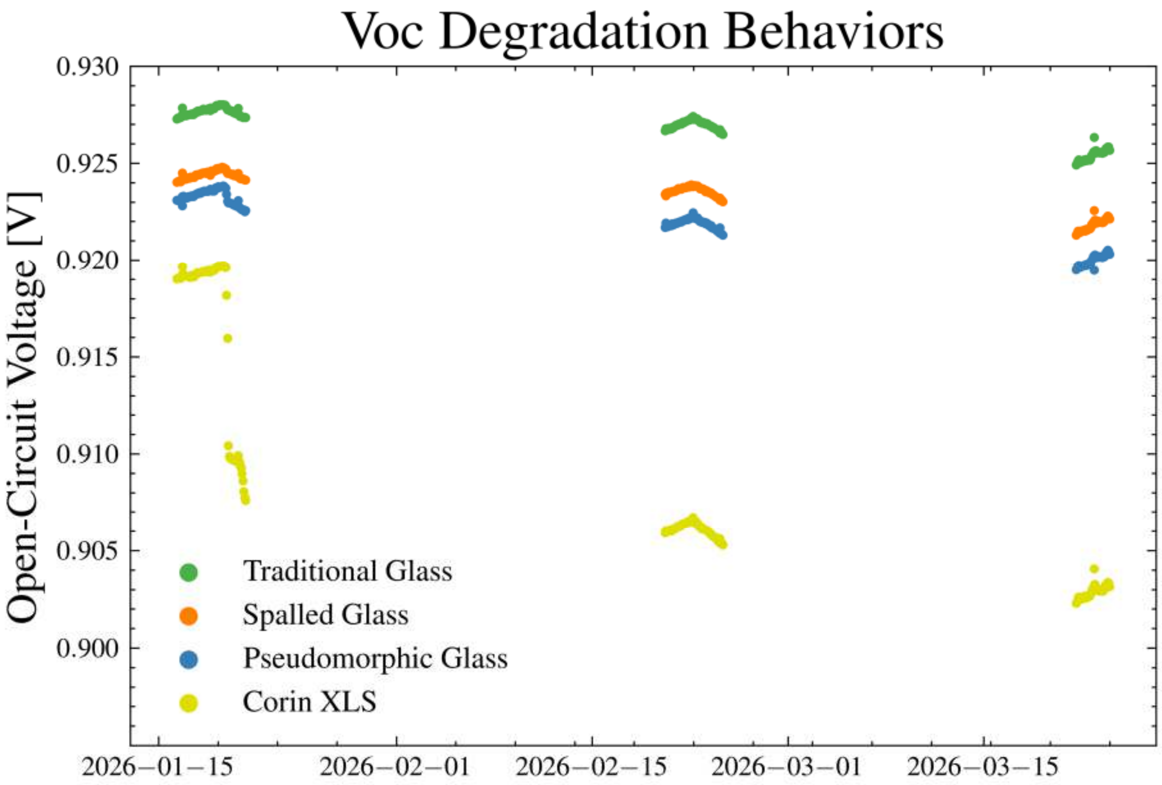


Open-Circuit Voltage Degradation

Coating	V_{oc} loss [mV]	V_{oc} loss %	Mass [g/m^2]
Traditional	1.6	0.17%	200
Spalled	1.9	0.21%	75
PMG	2.8	0.30%	50
Corin XLS*	5.8	0.64%	40

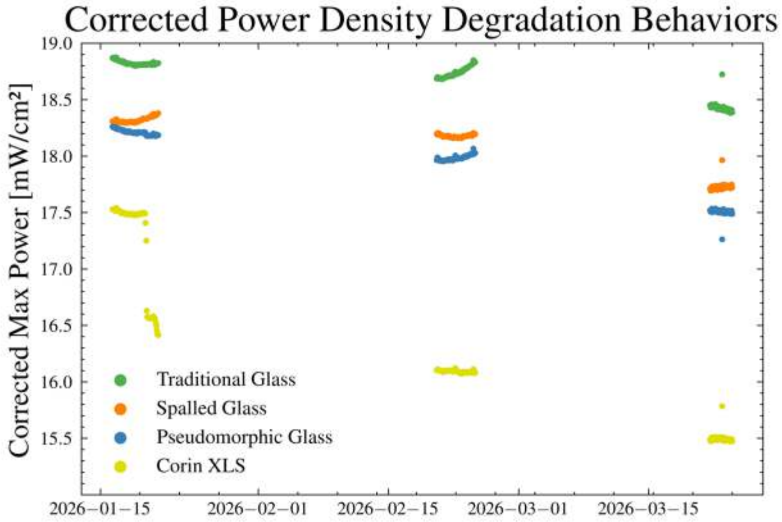
*Comparison post January 19th

- V_{oc} corrected by temperature
- Traditional, spalled, and PMG protected devices experienced similar, small degradations



Conclusions and Next Steps

- We tested three alternative, light weight, proton shield encapsulants for space photovoltaic devices in flight:
  1. **Spalled space cover glass for direct replacement of traditional cover glass with comparable performance**
  2. Pseudomorphic glass for a **novel, sprayable, flexible encapsulant**
  3. Corin XLS for proven commercial availability and history
- **Demonstrated the first flight using spalled glass encapsulation and extensive data of non-epitaxy GaAs cells in space**
- Preliminary data show that **spalled cover glass and PMG protect similarly to bulk cover glass with a fraction of the mass**
- Calibrated degradation rates and failure mechanisms will be reported upon sample retrieval
  - Origins of the sudden device performance drops in Corin XLS device
  - Transmission data comparisons between post mission with pre mission measurements



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*Comparison post January 19th

Acknowledgements and Team Members

Caltech SSPP/MISSE Team

- Principle Investigator: Professor Harry A. Atwater
- Staff Scientists: Dr. Philip Jahelka and Dr. Michael Kezlenberg
- Graduate Students: Elsie Loukiantchenko and Susana Torres-Londono

Members of A-team holding MISSE samples

Angstrom Designs, Inc

- Scott Ireton, VP Engineering
- Casey Hare, CTO
- Brady Gin, Computer Engineer

ÅNGSTROM DESIGNS

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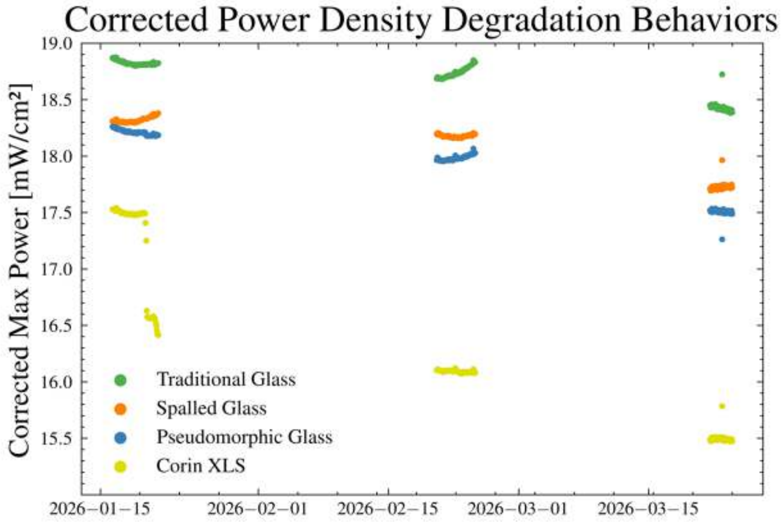

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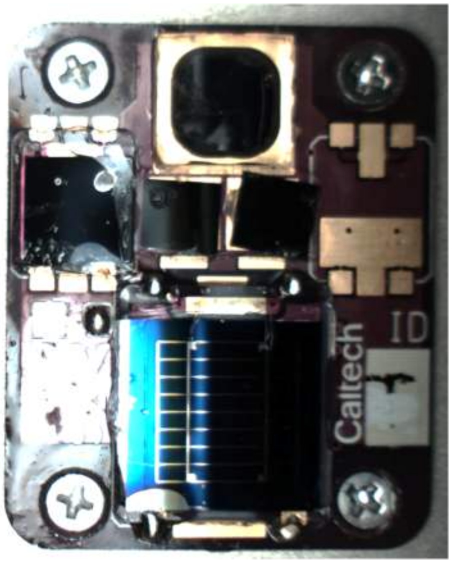
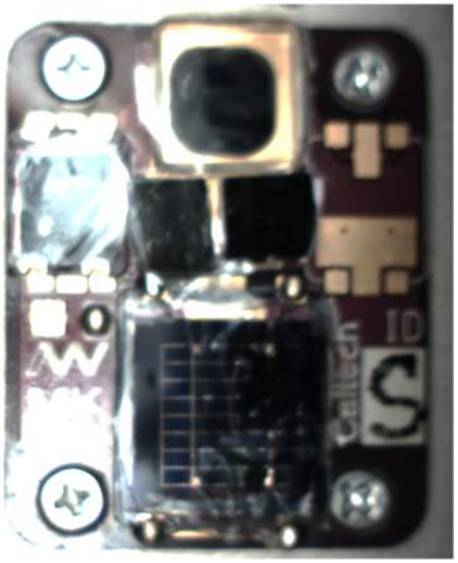
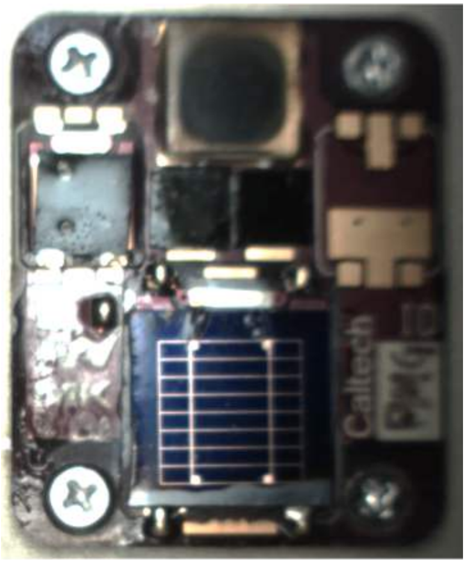
January 21st, 2026 Devices in Space



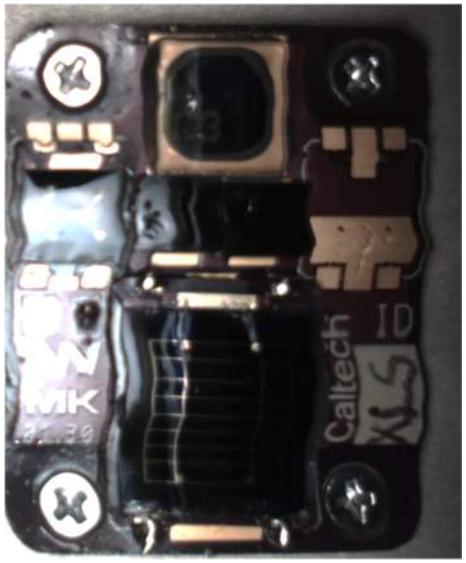
Traditional space cover glass encapsulated solar cells



Spalled space cover glass encapsulated solar cells



Pseudomorphic glass encapsulated solar cells



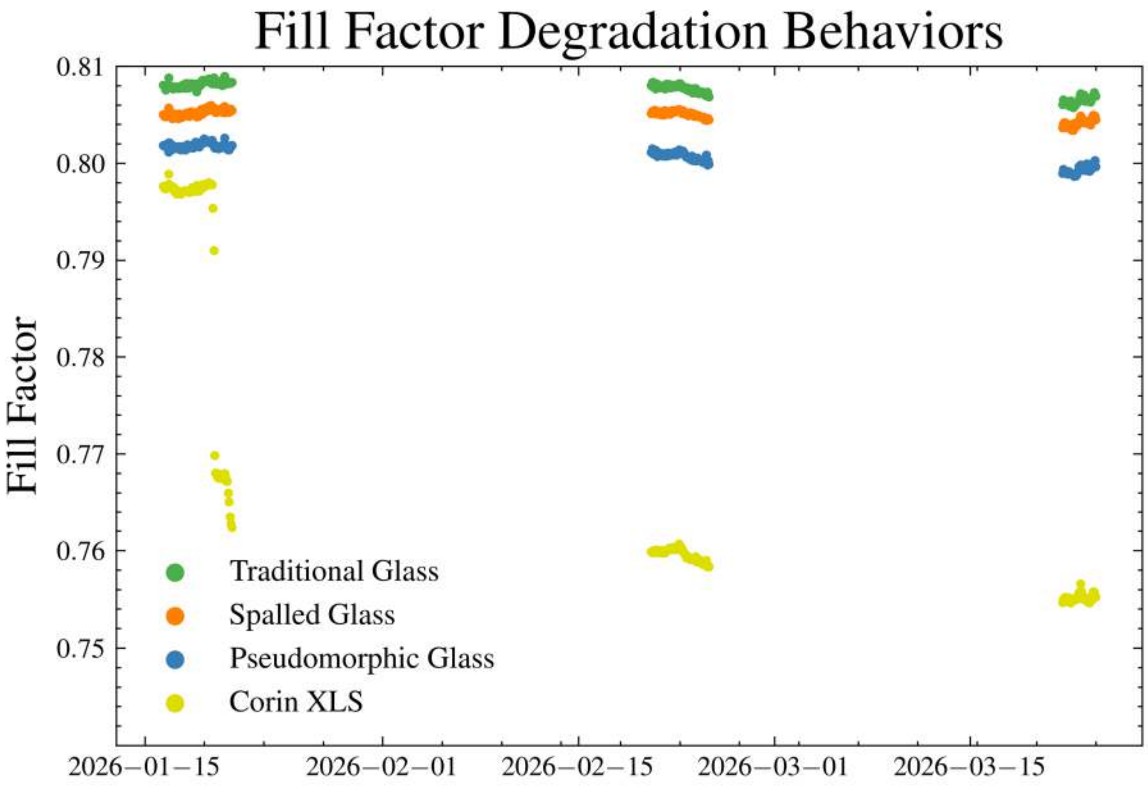
Corin XLS encapsulated solar cells

Fill Factor Degradation

Device	Fill Factor Loss %	Mass [g/m²]
Traditional	0.1%	200
Spalled	0.1%	75
PMG	0.2%	50
Corin XLS*	1.4%	40

*Comparison post January 19th

- Traditional and spalled glass encapsulation had near identical Fill Factor losses
- Only Corin XLS had a significant drop in Fill Factor performance



Extracting Temperature Coefficients from OEL Data

- Temperature coefficients can be calculated using orbital data
  - TempCo methods are a work in progress

ISC Temperature Coefficient (α_{ISC})

α_ISC (mA/°C)	0.0477
95% CI (± mA/°C)	0.0003
Slope (A/°C)	4.7670e-05
Intercept (A)	2.1757e-02
R²	0.984476
Std Error	1.7266e-07

VOC Temperature Coefficient (β_{VOC})

β_VOC (mV/°C)	-1.8224
95% CI (± mV/°C)	0.0069
Slope (V/°C)	-1.8224e-03
Intercept (V)	9.6515e-01
R²	0.995485
Std Error	3.5399e-06