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Characterizing UV Degradation of Silicone in Solar Cells: Lessons Learned from the Parker Solar Probe and the Game Changing Development for Extreme Environments Solar Power Programs

Matthew J Schurman, newForge Technologies, matt@newforgetechnologies.com
Richard A Stall, newForge Technologies, rick@newforgetechnologies.com
Andrew Gerger, Applied Physics Lab, Andrew.Gerger@jhuapl.edu

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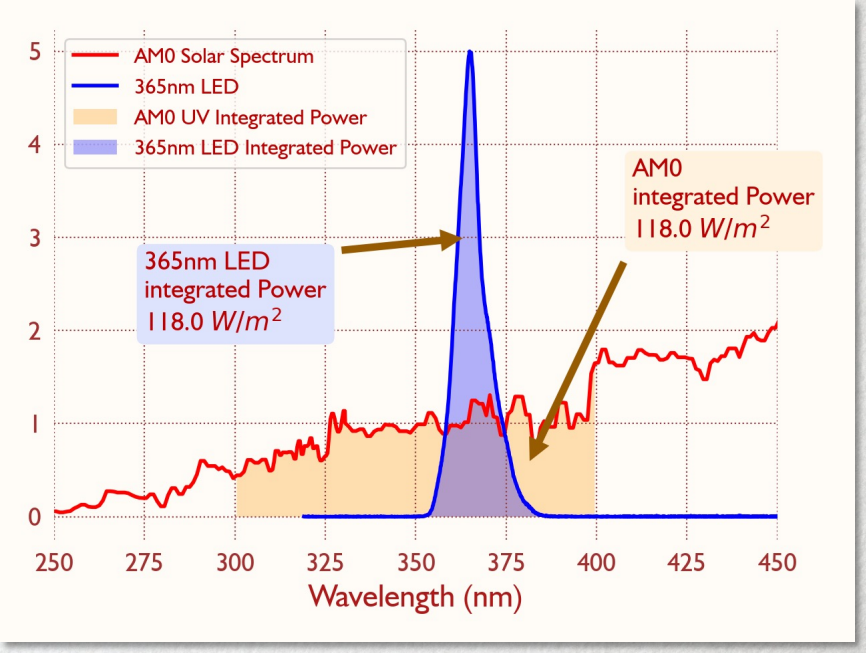
Summary of our Work

- newForge has been studying the UV degradation of silicones (both transparent and opaque) used in space based, solar cell and panel assembly for over 8 years.
- This work was initially done in conjunction with the Applied Physics Lab (APL) in support of the Parker Solar Probe (PSP) program.
- Further work has been done in support of the Transformational Array (TFA) Program to advance solar concentrator systems for spacecraft.
- Our work has focused on optical transparency loss, contamination and outgassing, and the mitigation of these effects.

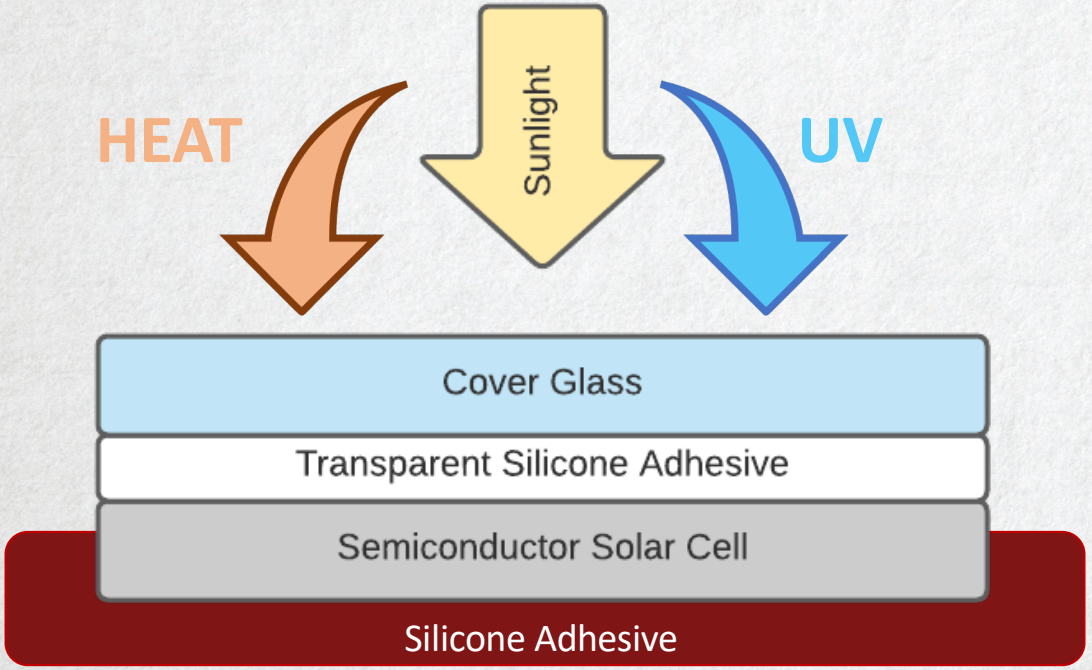
A Unique Approach to UV Degradation Studies

- Typically, UV degradation studies are done using lamp based sources for short (< 1,000 hour) durations
- Lamps are expensive, short lived (< 400 hours), and drift in intensity and wavelength over time
- newForge uses Light Emitting Diodes (LEDs), which have long life (> 10,000 hours) and low drift
- newForge has conducted numerous studies that have lasted for over 5,000 hours on flight solar cells using fully automated vacuum systems



A Summary of UV Degradation of Silicones

Solar Cell CIC (Coverglass InterConnected cell)



As the temperature and UV intensity rises, the rate of degradation increases!

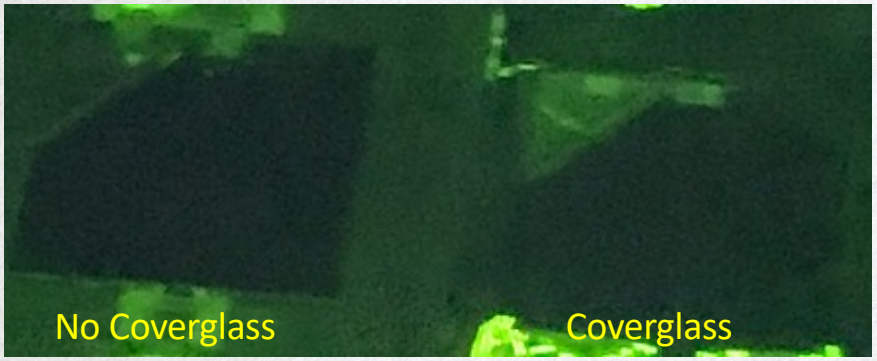
UV Degradation of Silicone

- Silicones decompose when subjected to **UV** and **HEAT**
- Decomposing silicones **outgas** and (in the case of transparent silicones) become less transparent
- Optical losses due to silicone darkening are **more significant** than is broadly assumed*

*S. W. Gelb, L. J. Goldhammer, and D. X. Kerola, In-Orbit Performance of Hughes HS 376 Solar Arrays, Proceedings of the 18th IEEE Photovoltaics Specialist Conference, Las Vegas, 1985, pp. 362-367.

The Visual Evidence of Silicone Degradation

Sample Prior to Exposure

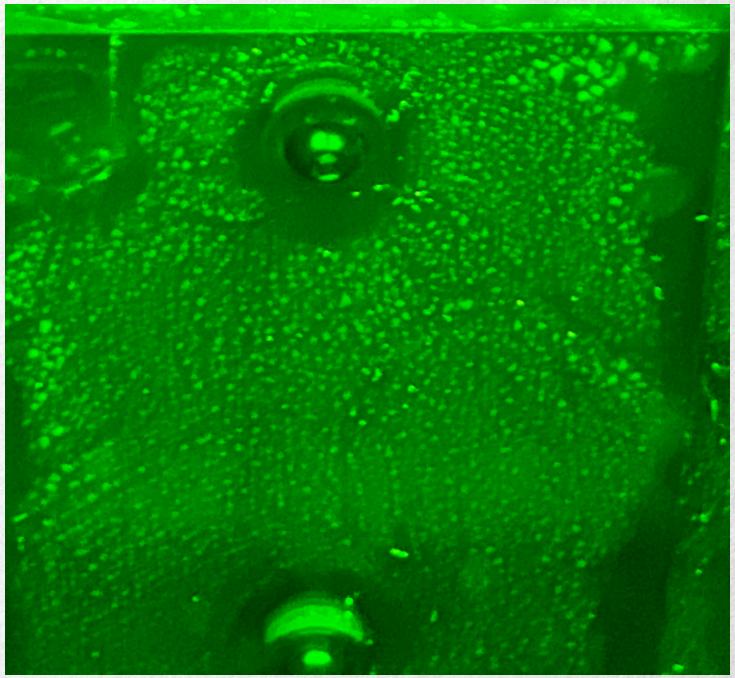


Sample Post Exposure

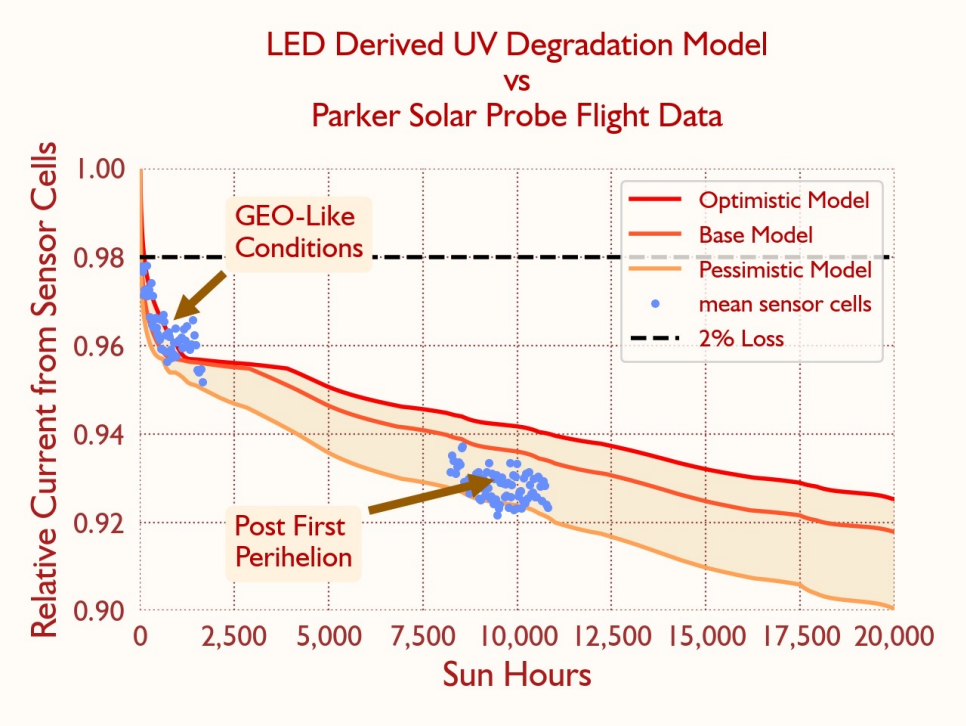
- The photos above, taken with 365 nm light on the CICs and with a narrow band filter at 570 nm on the camera, show the strong yellow-green fluorescence on heavily degraded CICs
- The center "CIC" has no coverglass and no transparent silicone adhesive.

Adsorbed Outgas Products (AOP)

- **Adsorbed Outgas Products (AOP),** evolved from silicone degradation under UV exposure, condensed on a cold surface
- The AOP begin to fluoresce under UV shortly after deposition, indicating that **these materials ALSO decompose under UV**
- Optical losses of these AOPs on reflective surfaces are **HIGH**



Observed Optical Losses



- Early studies by other groups indicated losses to follow an exponential decay that self terminates ~ 2%
- newForge test data AND **PSP Flight DATA** CLEARLY shows **this is NOT the case**.
- Most studies end after a few hundred hours and do not have the stability of our LED-based instrumentation and **miss the longer-term** degradation
- Optical losses are **HIGHER** for **SHORTER** Wavelengths

Summary of the UV Degradation Problem

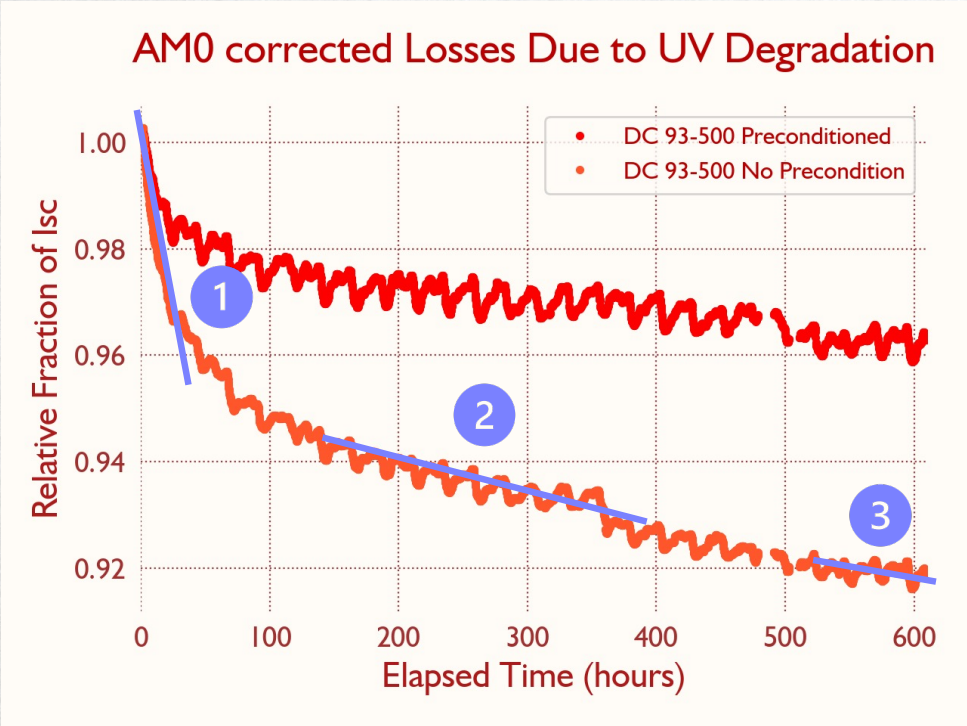
- Silicones decompose when exposed to UV light.
- **HIGHER** temperature and UV intensity lead to **FASTER** degradation.
- As silicones degrade, they outgas, and these outgas products in turn will degrade under UV exposure.
- Transparent silicones lose transparency as the silicone degrades under UV exposure.

Preconditioning of Silicones

History Dependence of Degradation Rates

- During our initial studies of DC 93-500, we observed a wide range of UV degradation rates and outgassing rates for the **same temperature and UV Intensity.**
- Closer study of the data revealed that the degradation rate is ALSO dependent on what **prior exposure** the sample received.
- By varying the initial exposure conditions of the silicone, we could **INCREASE** or **DECREASE** the long term degradation rates of the silicone by an **up to a factor of 3**.

Anatomy of Silicone UV Degradation Rates



Exposure conditions:

- ~ 1 AM0 UV Equivalent suns
- CICs held at 75^0 C

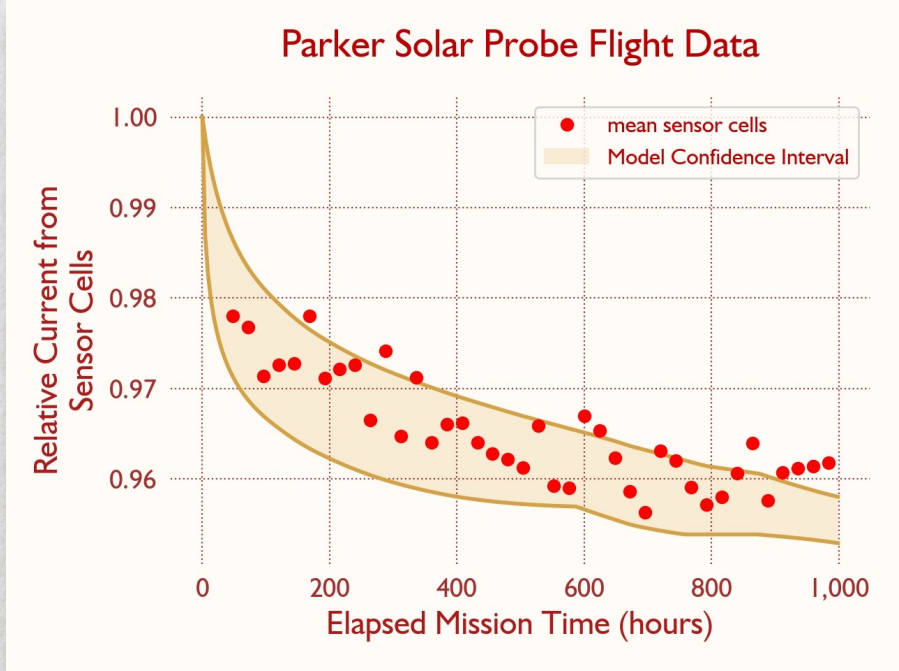
1. Initial fast optical loss
2. Loss begins to slow
3. Loss continues to slow

Can we reduce the long-term degradation rate?

Preconditioning Silicones

- newForge has developed a method to precondition **CURED** silicone to **REDUCE** the outgassing and the **LONG TERM** optical loss
- Preconditioning requires:
  - High Temperatures (> 100°C)
  - UV intensity ~1 UV-equivalent suns
  - Vacuum (< 10^{-5} torr)
  - Exposure time

Performance is Confirmed via the PSP Flight data



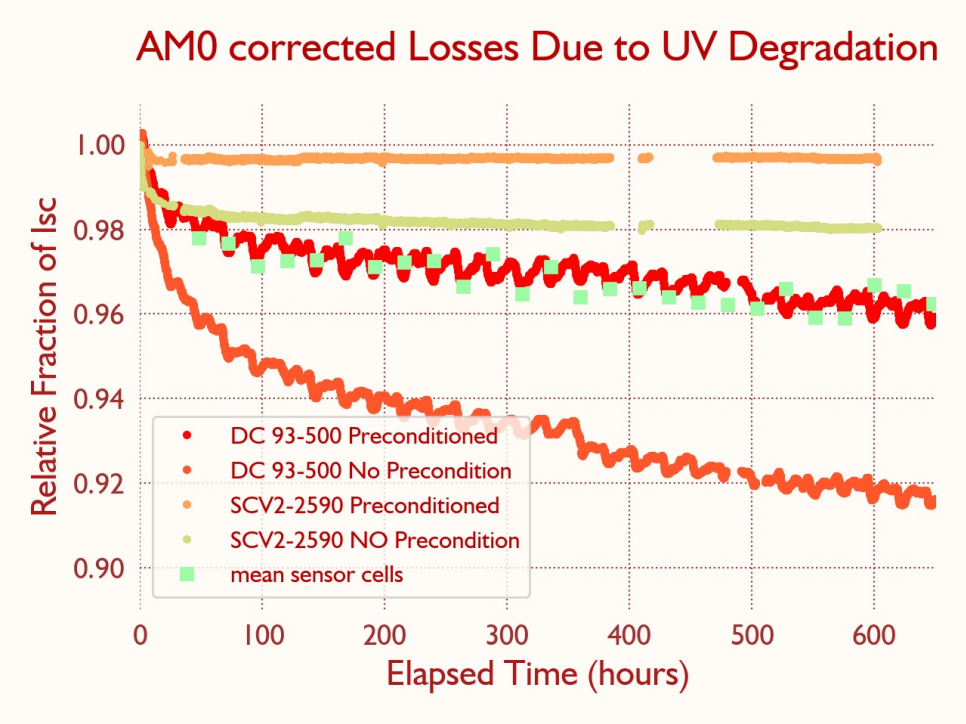
- Data from the initial 1,000 hours of the PSP while under **GEO-like conditions**
- Both PSP Panels were pre-conditioned using **newForge techniques and equipment**
- Model was derived from newForge database of degradation rates and used by APL to **adjust the mission flight** to, and around, the sun
- **Even with preconditioning, silicone transparency degrades more than 2%**

Transformational Array and SCV2-2590

Transformational Array Program (TFA)

- Project funded by NASA and led by APL to use concentrators on space PV panels for use in flying to the outer planets
- TFA concentrators use the latest multi-junction solar cells from SolAero, combined with reflective concentrators
- The transparent silicone chosen was NUSIL **SCV2-2590.**
- newForge studied the outgassing and transparency loss under UV exposure

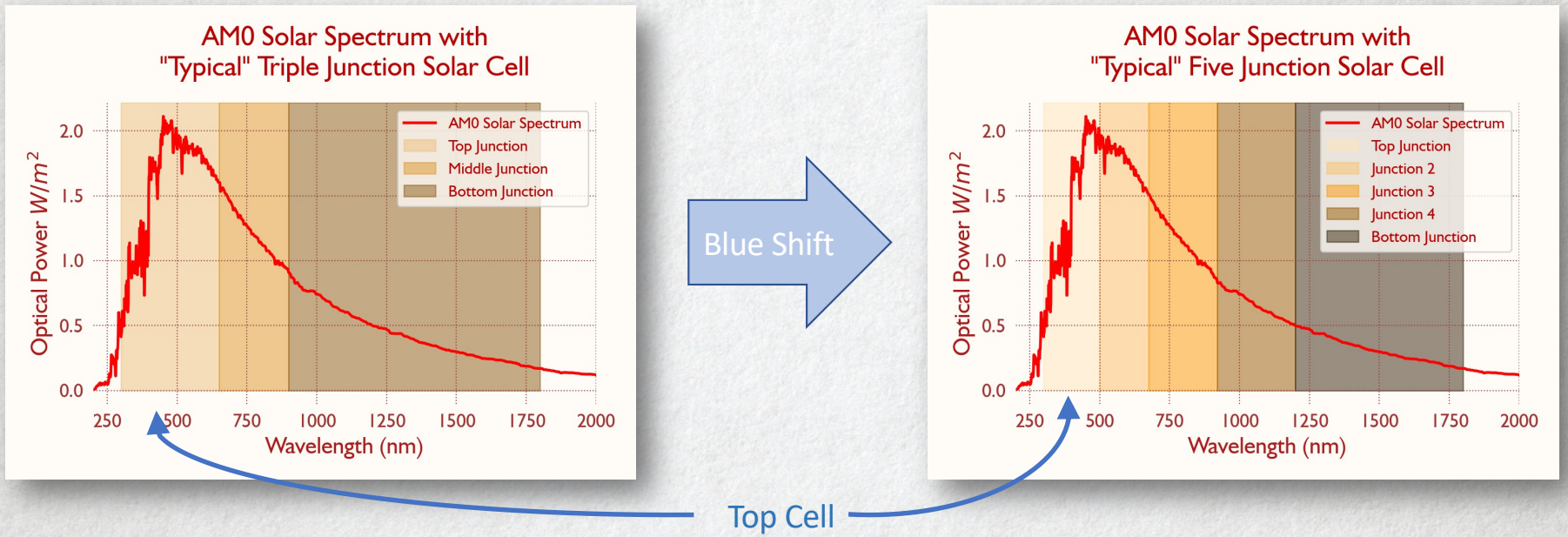
SCV2-2590 vs DC-93500



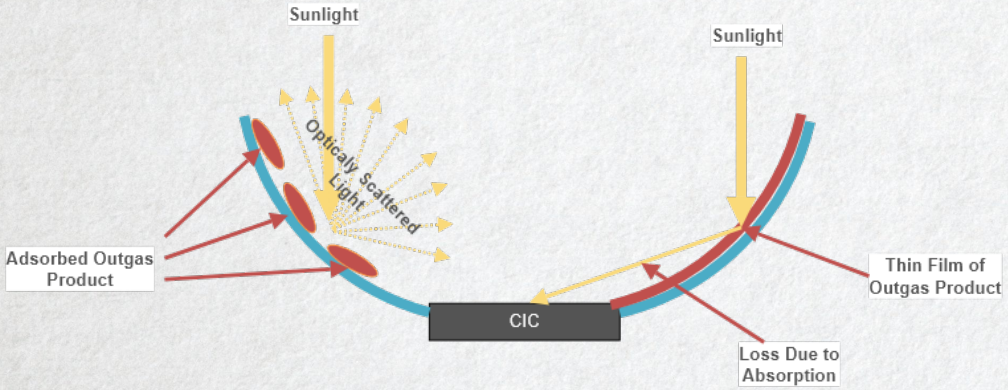
- Solid Lines are **newForge lab data**
- Green squares are **flight data** from the Parker Solar Probe during its initial flight under GEO-like conditions
- **SCV2 was preconditioned under different conditions than DC 93-500**

Why UV Degradation of Silicones is a BIGGER problem Going Forward

Advanced Cells are More Sensitive to UV Degradation



Big Losses for Concentrators



- Higher CIC Temperature and UV intensity, with cold mirrors of concentrator, will drive **higher degradation**
- AOP from **ALL silicones** will deposit on cold mirrors
- Both **SCATTERING** and **ABSORPTION** losses from the AOP on the mirror will reduce system power

Summary

- The optical loss of transparent silicones due to UV degradation can **vary considerably** depending on the **type of silicone** used.
- Preconditioning of all silicones can significantly improve the **long term optical losses** AND the **outgassing** of the silicone degradation products.
- Next generation 4+ junction solar cells and concentrator systems are **more sensitive** to UV degradation of silicone than 3J solar cells