Path Dependent Power Degradation via UV Exposure for the Parker Solar Probe

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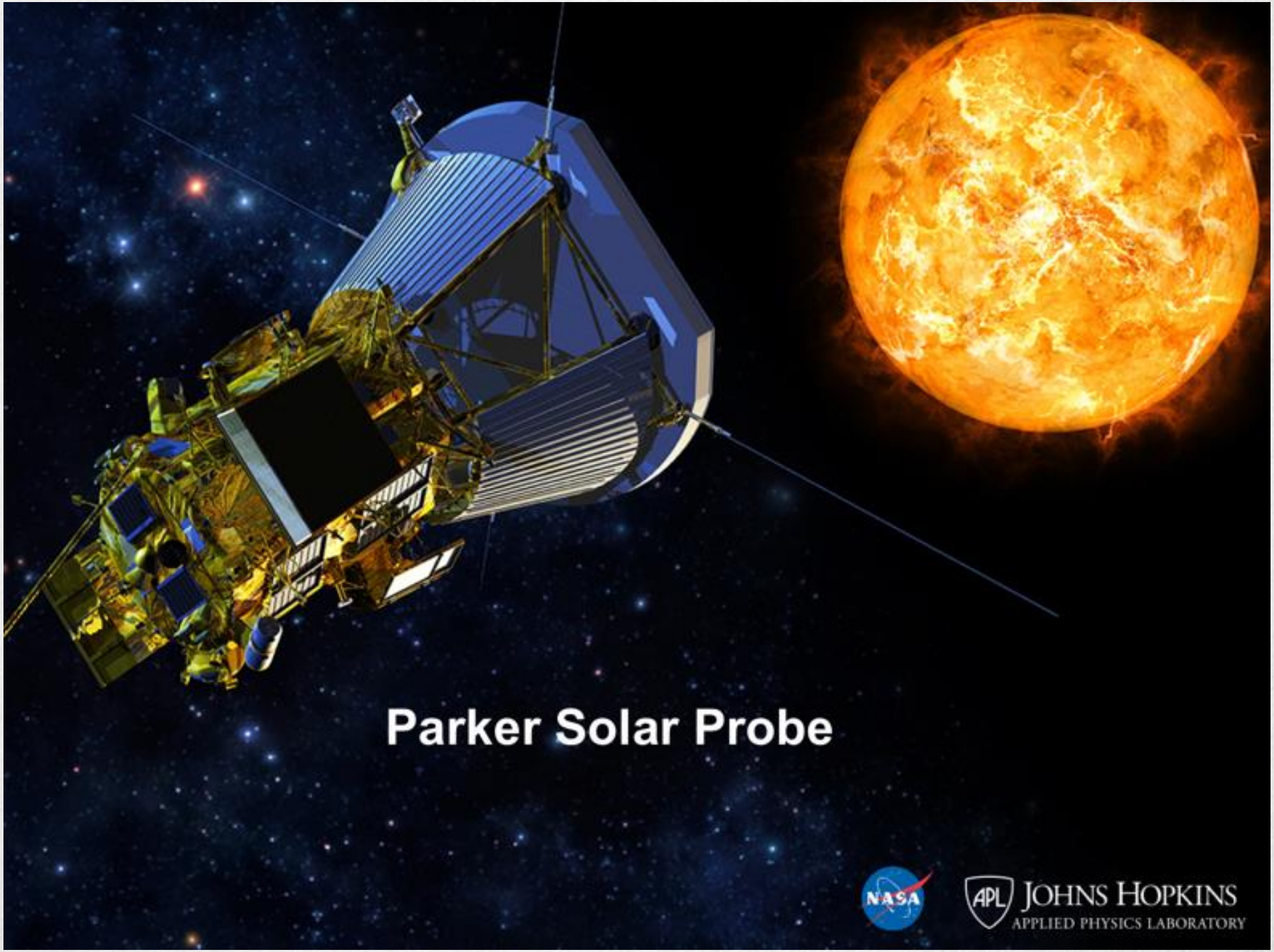
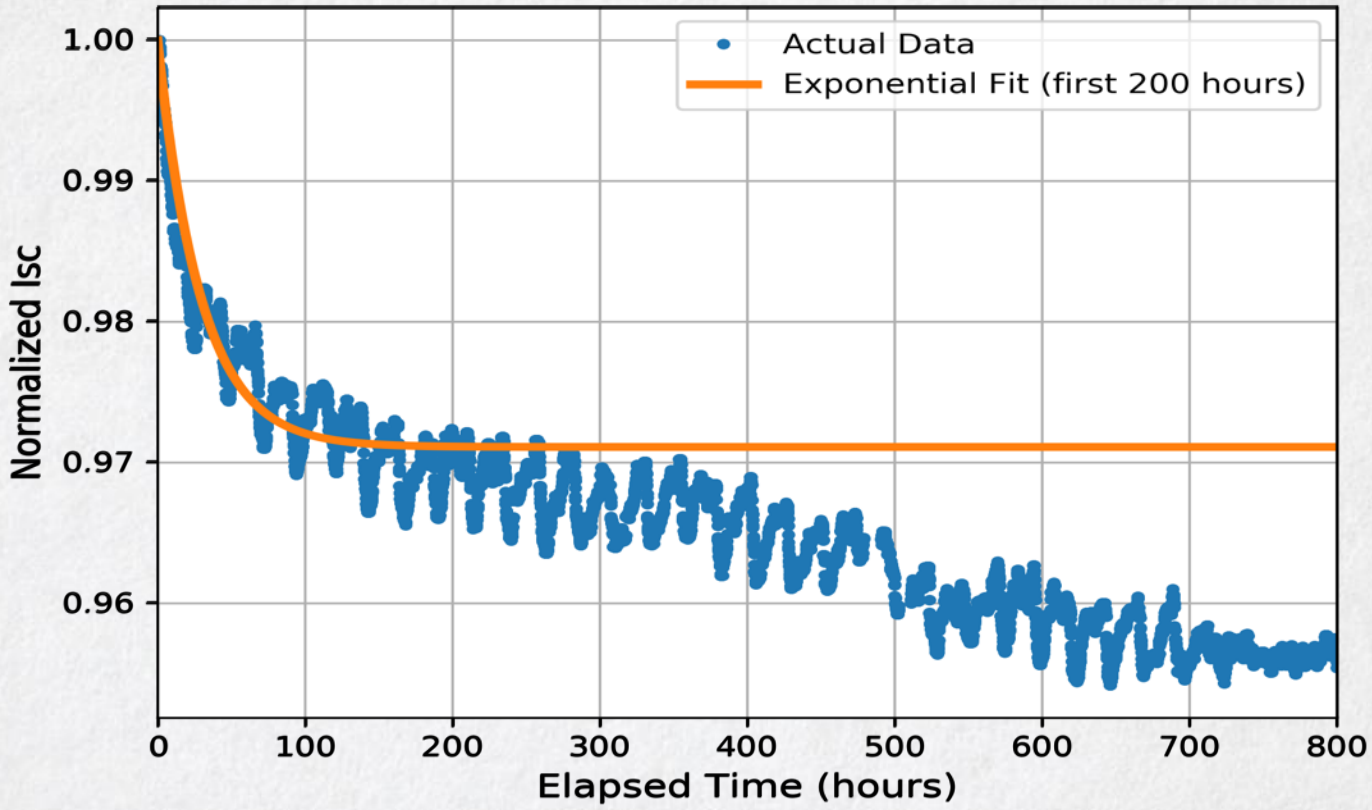

Parker Solar Probe
NASA
APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

UV Degradation of Space Solar Cells: A historical view

- UV light will degrade the transparency of the silicones used to attach the coverglass to the semiconductor cell
  - The coverglass also degrades but to a lesser extent
- An often referenced publication (Goldhammer et al, 1976) asserts that UV degradation is small (~2%) and saturates after low solar exposures (~500 sun-hours)
  - "Results from an ultraviolet irradiation ground test performed at Hughes Aircraft Company 18) indicate that damage from ultraviolet rays is nearly saturated after 400 to 500 sun hours"
  - "After 60 days in orbit (-400 sun hours), it appears that for conventionally covered cells the ultraviolet irradiation degrades current by approximately 2 percent."
- But High Intensity/High Temperature missions such as Messenger have shown anomalously high degradation levels, from unknown sources.

UV Degradation of Space Solar Cells: A historical view



- A good exponential fit to the first 200 hours can be made that shows a ~2% degradation at infinity
- HOWEVER, the degradation continues after the first 2%, albeit at a slower rate

UV degradation using narrow band LED light sources

UV LEDs degrade the CICs

- For the SPP cells and coverglasses, the degrading force of 50 W m^{-2} of 365 nm is equivalent to the degrading force of 1 sun AM0
- ~20 Watts m^{-2} of the AM0 spectrum is within the ~15 nm wide spectrum of the 365 nm LEDs.
- Wavelengths in the AM0 spectrum outside the spectral band of the 365 nm LEDs cause degradation, as we have measured in our work
  - This raises the 1 UV sun equivalent estimate to 50W m^{-2}
  - Comparisons with our work with broadband Xenon lamps confirm the validity of this estimate.

LEDs drive all three junctions

UV LEDs drive top junction of the CICs

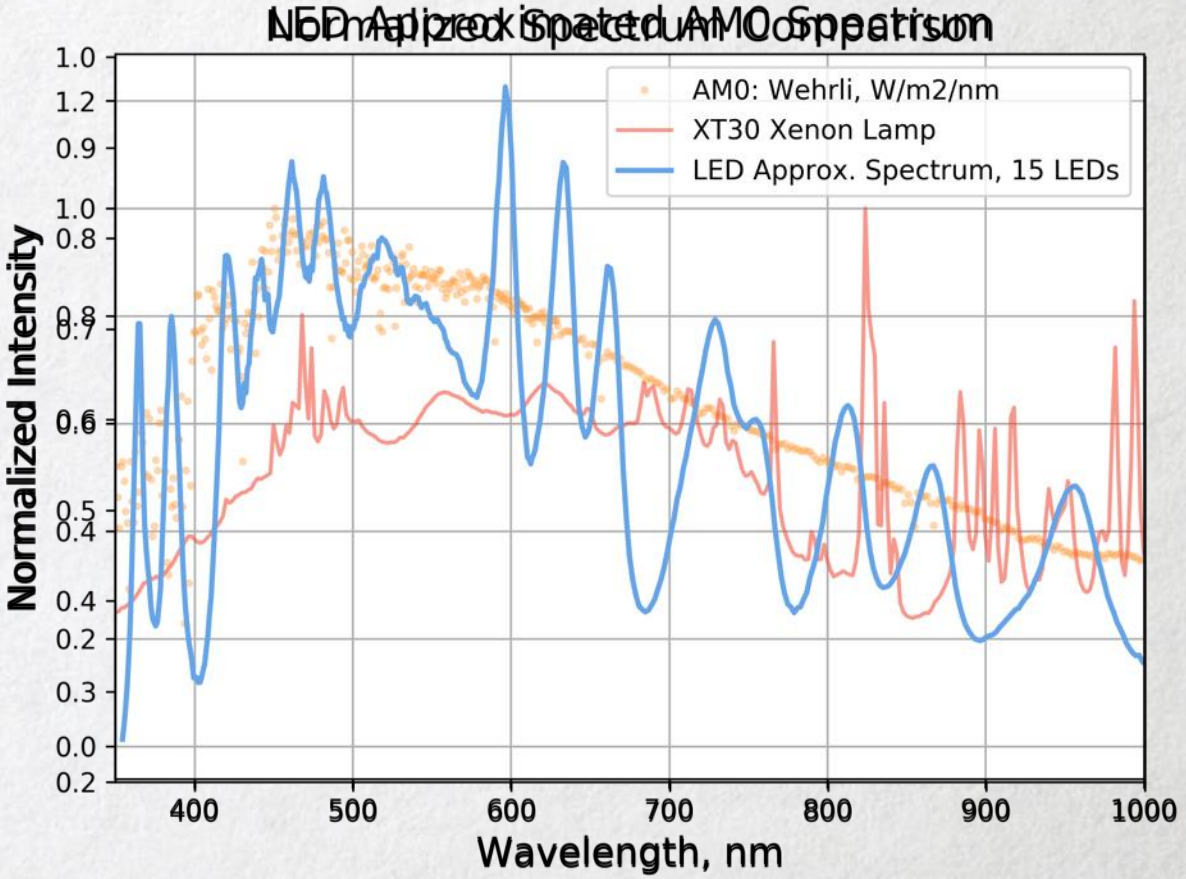
- In addition, Infrared LEDs of 850 nm and 940 nm wavelengths drive the middle and bottom junctions of standard Triple Junction SolAero ZTJ Cells.
- Current versus voltage characterizations are taken frequently during the UV exposure to track the degradation in the Isc of the top cell of the driven CICs
- Measurements on the transmission of UV degraded CICs vs ”fresh”, unexposed CICs are used to relate the degradation in the 365 nm driven CIC Isc to the degradation of Isc of CICs under an AM0 spectrum

LED Based Solar Cell Testing: Introduction

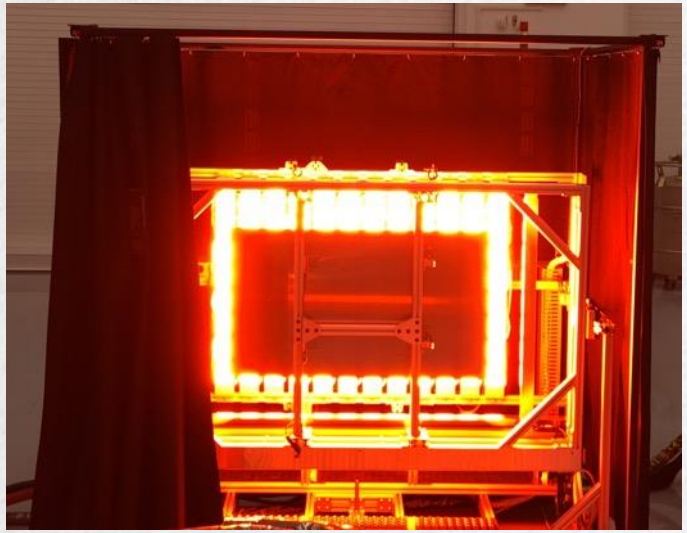
Advantages of Using LEDs Over Lamps for Solar Cell Testing

1. Very high stability of intensity and spectrum
2. Very long lifetime of the optical source (> 25,000 hours typical)
3. Adjustable spectrum
4. Adjustable intensity pattern
5. Lower power requirements
6. Tailorable illumination area from very small to very large (few cm^2 to several m^2)

The use of only 3 wavelengths in this work minimizes sample heating and helps isolate the signal of the silicone degradation effect



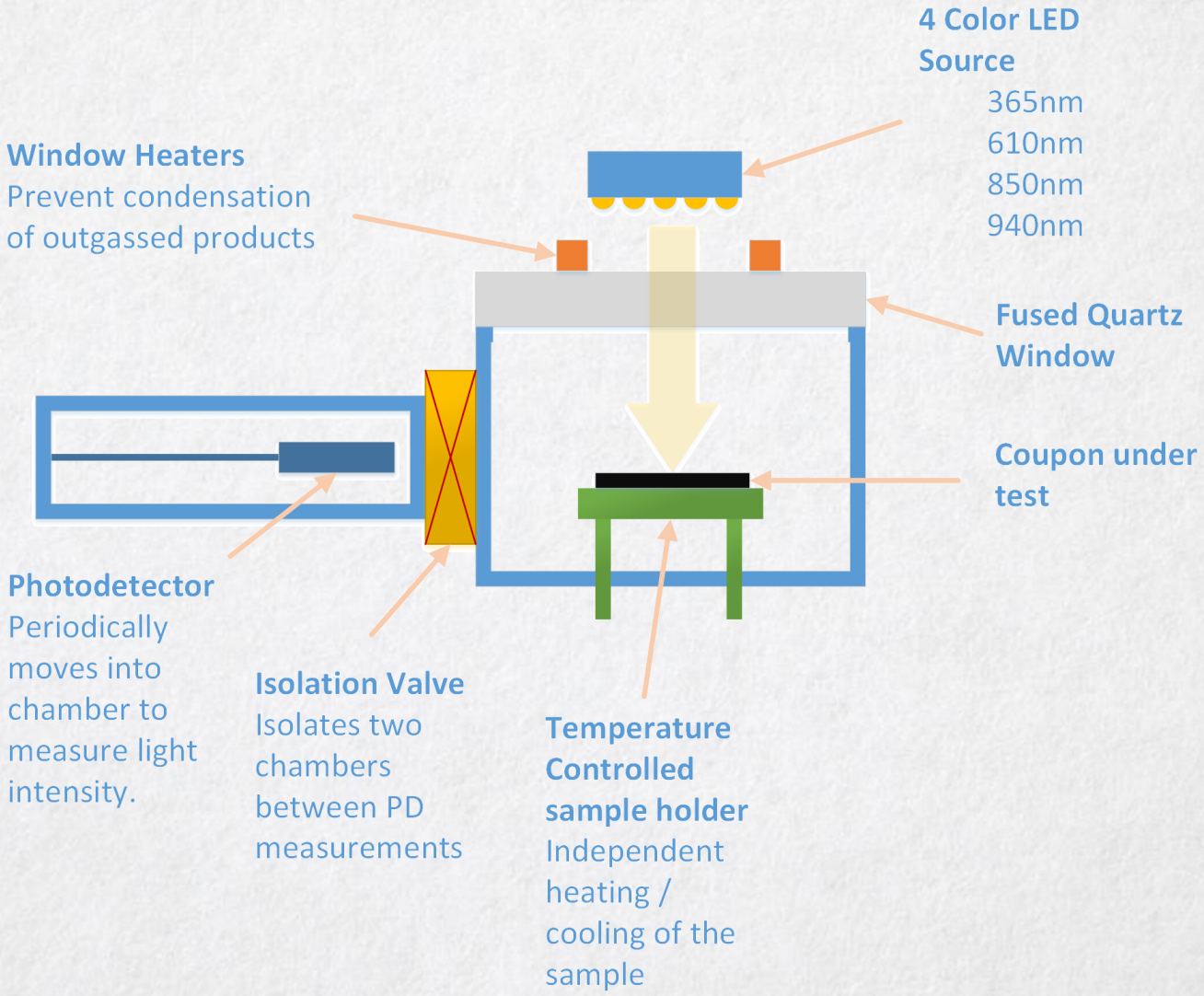
LED Solar Simulators



Full Wing LED Solar Simulator

Single String Simulator

UV System Schematic



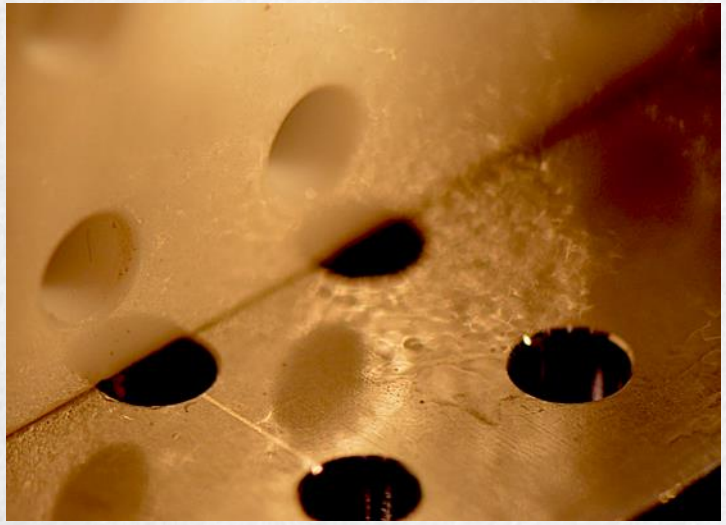
Experimental Procedure

- Coupons were placed in vacuum system and one of the cells was covered by aluminum to protect it from the UV
- Coupon was then "preconditioned" by bringing the temperature up to 140 °C with 1 UV equivalent suns (UVES) of 365nm light for ~120 hours
- Preconditioning gave an initial reduction of Isc of ~2% for the uncovered cell
- The aluminum cover was then removed from the protected cell and the coupon exposed at 1 UVES at 60 °C which are the initial conditions planned for the Parker Solar Probe

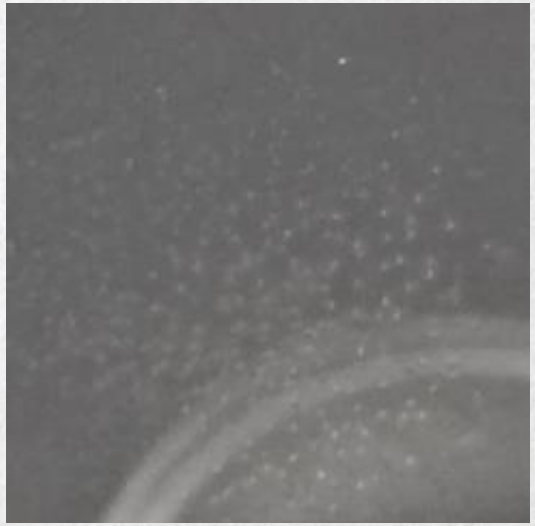
Observations from the UV Degradation of Solar Cells

CICs will outgas silicone oils during Degradation

- Oil outgassed from the full wing panel, condensed on fitting
- Outgassing occurred while wing was undergoing UV pre-treatment
- Outgassing appears NOT to be a large component of observed degradation due to it not re-depositing on the CICs.



- For a cold glass viewport, silicone oil degassing from the CICs will condense on the viewport inside the UV chamber.
- The photo below of a viewport, taken with a light to highlight the clear oil, shows droplets of silicone oils.

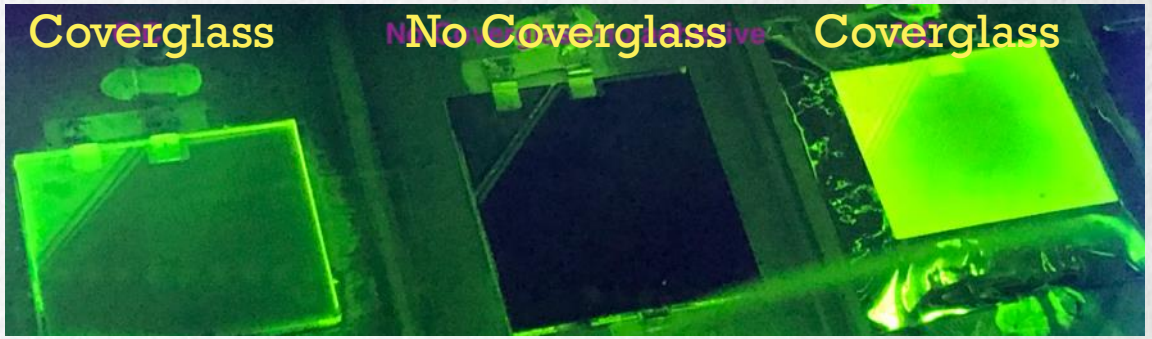


A Note About Oil Outgassing

- Even though outgassing was observed during the test, it is believed not to be a large factor in the degradation of high temperature or other arrays
- This is because the outgassing product travels away from the array and little deposits back on the array

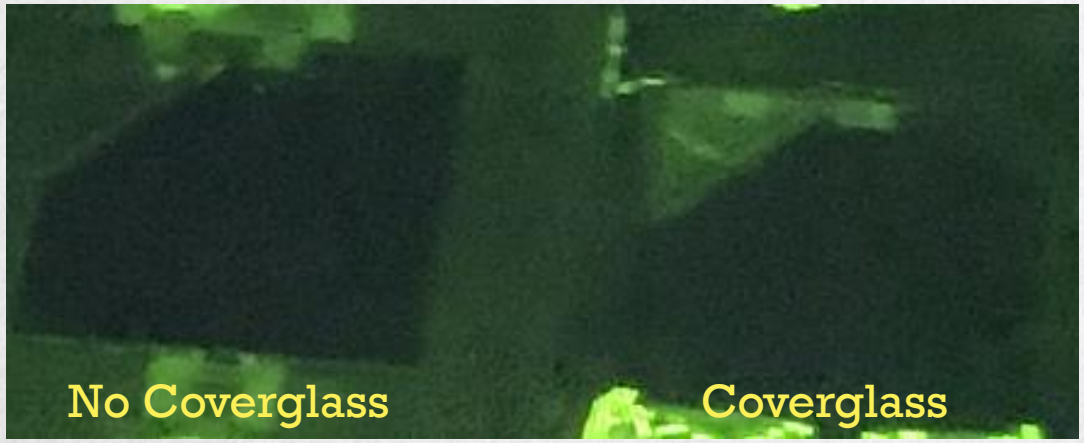
Transparent silicones fluoresce yellow-green under UV when they begin to degrade

- The photos below, 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.

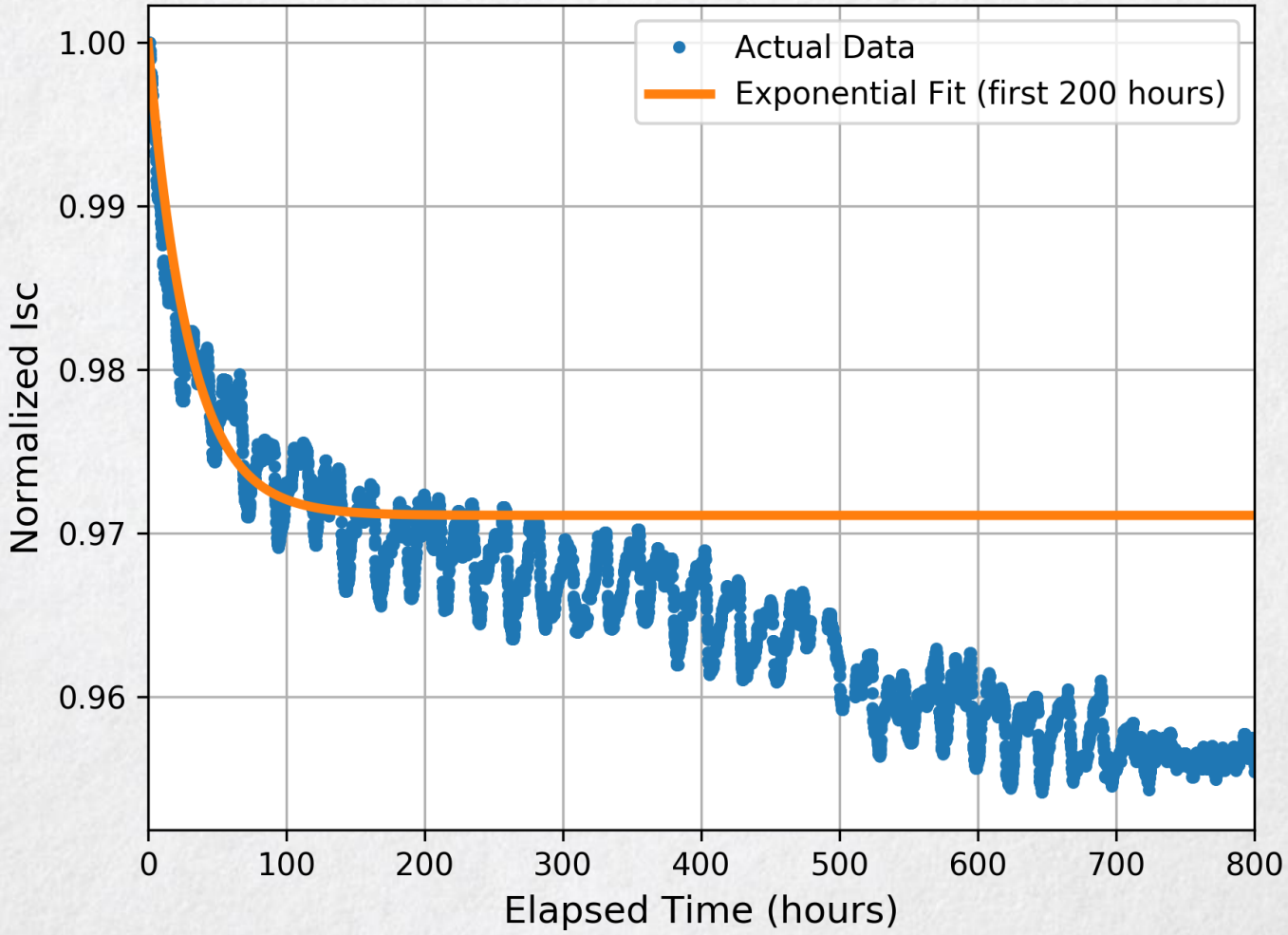


Sample Post Exposure

Sample Prior to Exposure

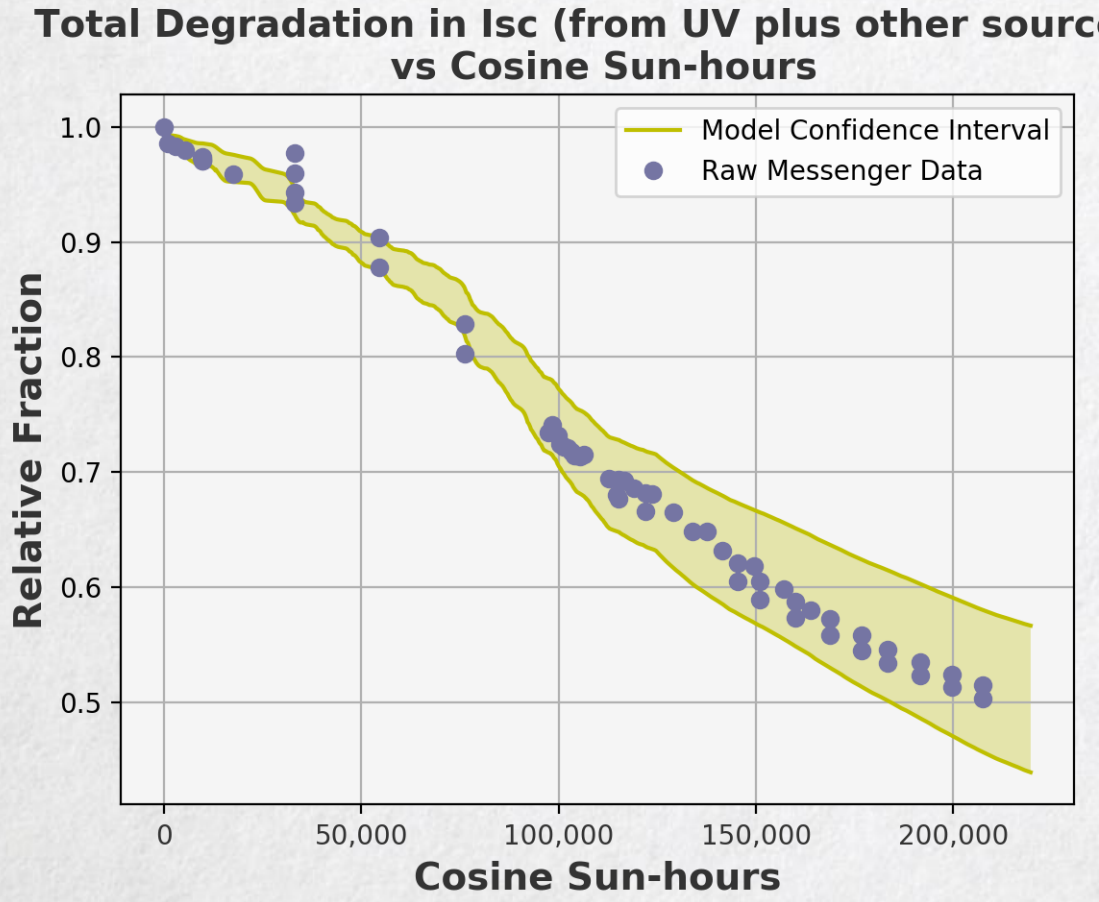


Degradation of Isc Goes Far Beyond 2%



Modeling of MESSENGER

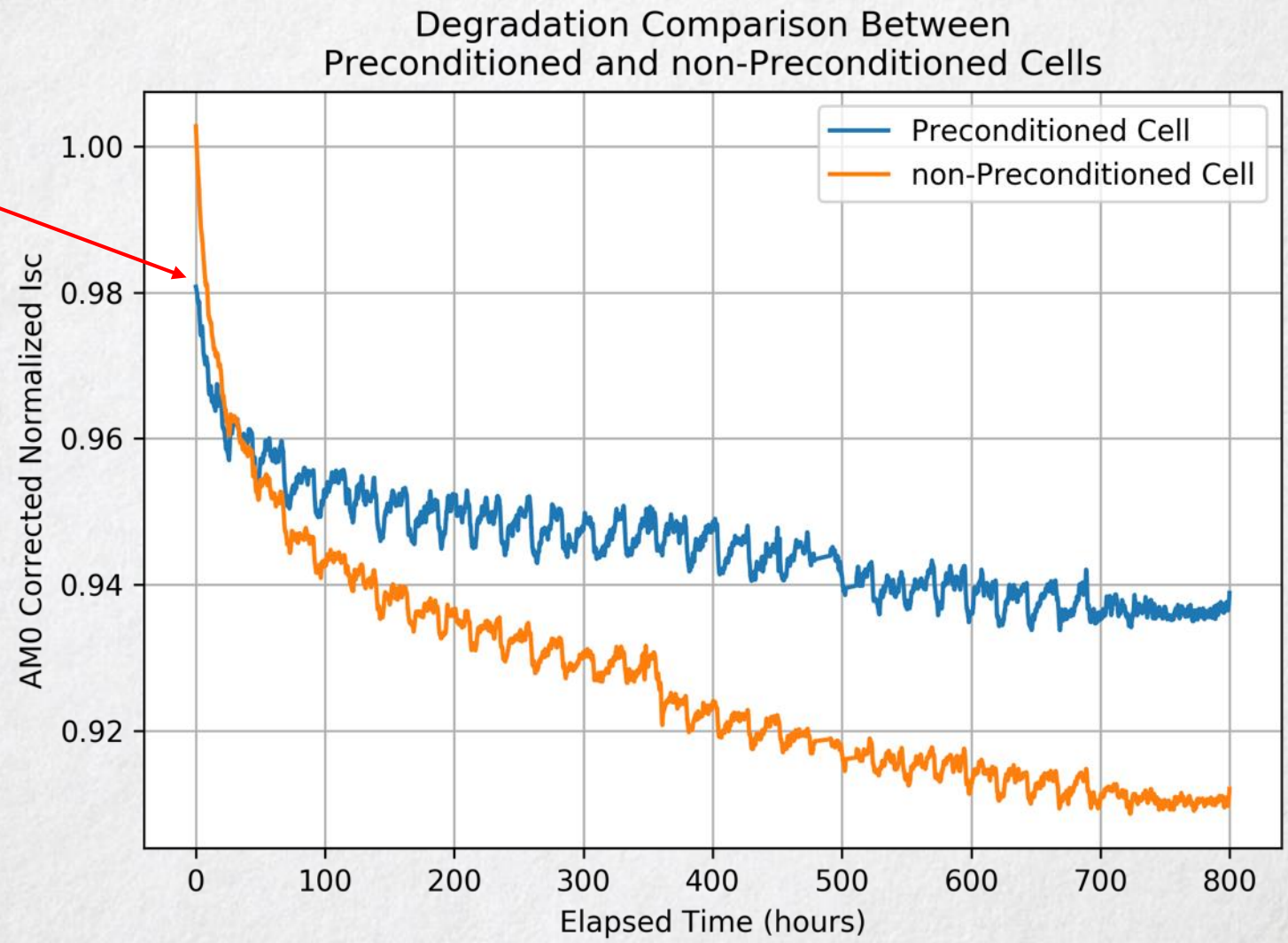
Using the compiled database of exposures completed on Parker Solar Probe Cells, a model of MESSENGER's degradation was developed and compared to the observed Messenger data for Messenger's 10 year mission.



MESSENGER and all the arrays that we know about that operated at high irradiance and high temperature all experienced large anomalous degradation. As a result of these tests, we believe this is due to the darkening of the cell to cover adhesive.

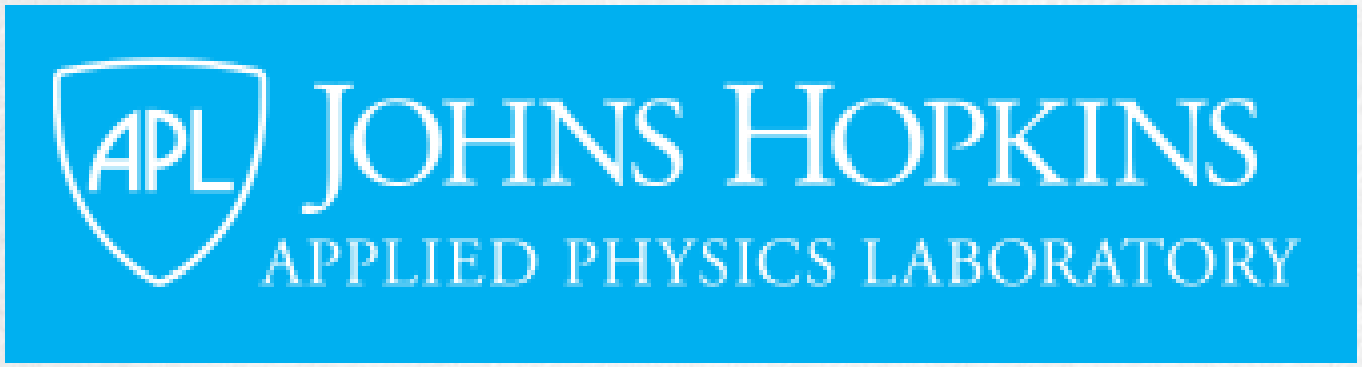
Path Dependence of Degradation Rate

Initial Lower value due to preconditioning



Conclusions

- Silicone degrades and loses transparency under UV illumination beyond the 2% observed in earlier work
- The degradation can be easily observed using LED based solar simulators with illumination wavelengths tailored to the various junction bandgaps
- The relationship between degradation at 365nm and the AM0 spectrum has been established enabling modeling of cell performance in space
- The database of conditions (temperature, irradiance, time) developed during this program enabled the modeling of the large degradation observed in the Messenger spacecraft
- This work explains the large anomalous degradation that many high temperature, high irradiance arrays have experienced.



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