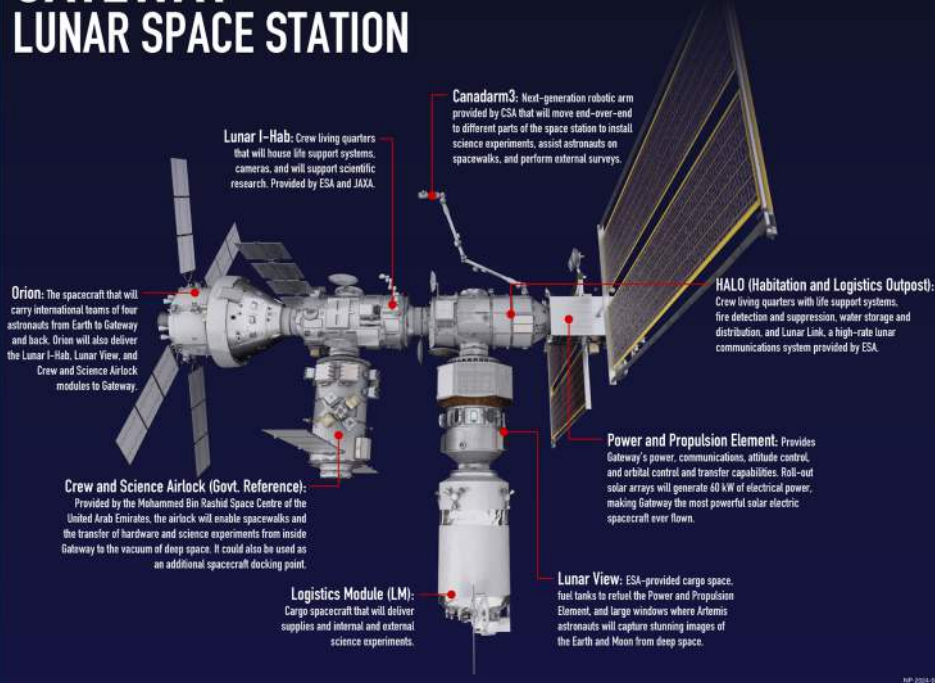


PLEDSS TESTING FOR LUNAR ROLLOUT SOLAR ARRAY

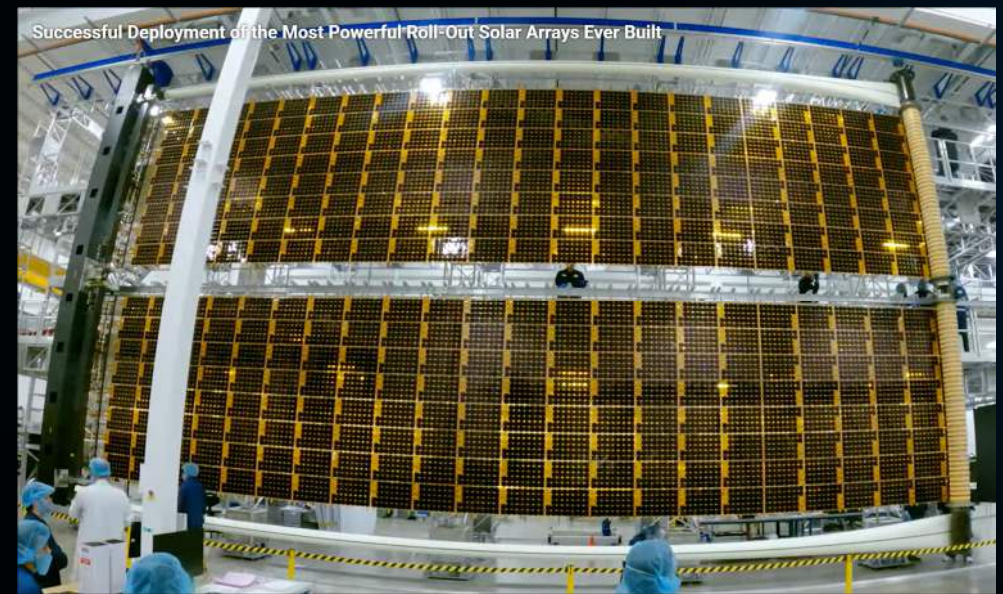
Intuitive Machines: Kate Psyk, Bao Hoang
Angstrom Designs: Casey Hare, Scott Ireton, Andrew Schwab
NASA: Brandon Klefman, Nicolas Carbone, Jeremiah McNatt
Redwire Space Systems: Nate Paszek



GATEWAY LUNAR SPACE STATION



Source: NASA



Source: Redwire YouTube Link
[Successful Deployment of the Most Powerful Roll-Out Solar Arrays Ever Built](#)

LROSA WING



~32ft

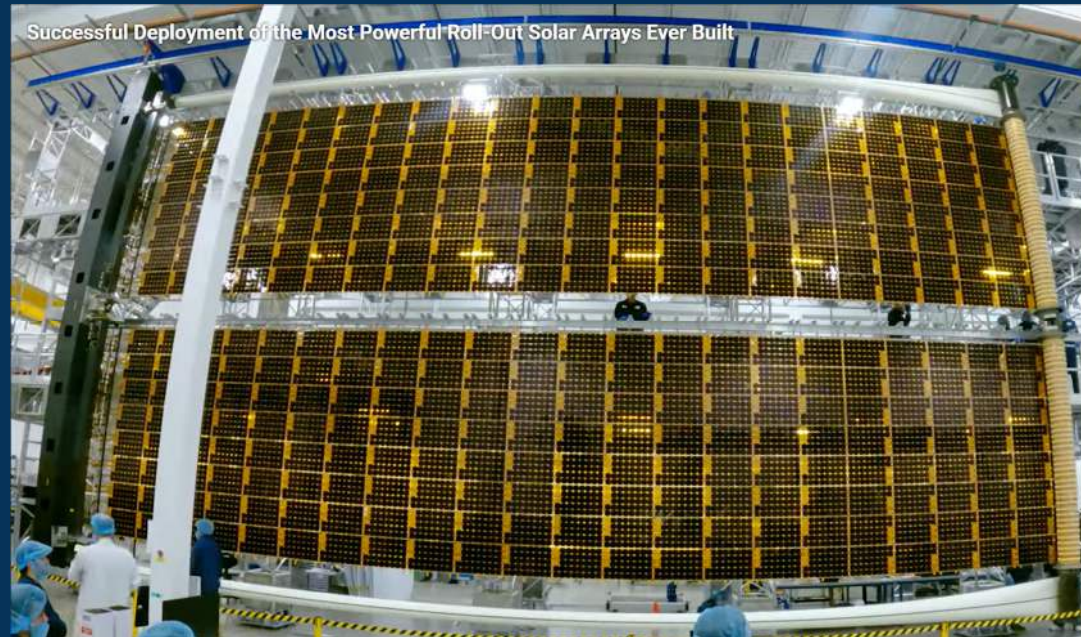
~60ft

Source: Redwire YouTube Link
[Successful Deployment of the Most Powerful Roll-Out Solar Arrays Ever Built](#)

- The two Lunar Rollout Solar Array (LROSA) Wings of the Power and Propulsion Element (PPE) are each ~32ft wide x ~60ft tall
 - Each wing is made of two roll-out blankets that support more than 14,000 solar cells per wing
- The massive size of the wing has resulted in significant ground testing challenges
 - A three-story scaffolding structure was built to support wing roll-out deployments (VDO-Vertical Deployment Offloader)
 - A programmable LED solar simulator (pLEDss) robot was built to support electrical testing
 - Success in wing level electrical testing required significant collaboration between Intuitive Machines, Redwire Space Systems, Angstrom Designs, and NASA

LROSA ELECTRICAL DESIGN

- Each of the 2x LROSA wings has two blankets of solar cells
 - Very high power capability totaling **~60kW** beginning of life
- Multiple aspect ratios of circuits
 - 2x Square aspect ratio
 - 24x Long aspect ratio



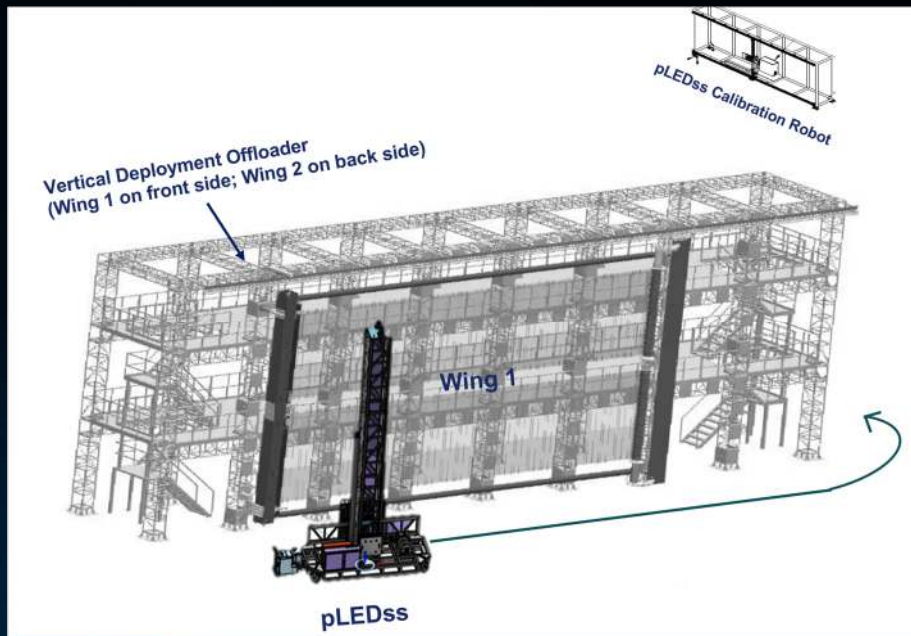
~32ft

~60ft

Source: Redwire YouTube Link
[Successful Deployment of the Most Powerful Roll-Out Solar Arrays Ever Built](#)

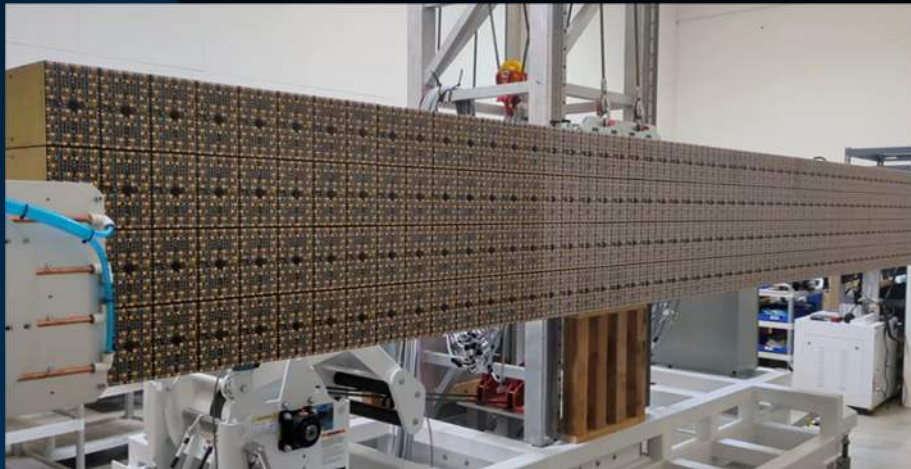
LROSA ELECTRICAL TEST PLAN DEVELOPMENT - LIMITS OF DARK IV & LAPSS TESTING

- Redwire Space Systems heritage test approach was stowed Dark IV only
 - Cost effective and relatively simple, but has known test limitations
 - See IEEE technical paper “The Importance and Limitations of Light IV and Dark IV Testing of Space Solar Arrays”
- Intuitive Machines heritage test approach was Large Area Pulse Solar Simulation (LAPSS) testing, but legacy LAPSS test equipment:
 - Not suitable for PPE’s 4junction cells
 - Test target area (illumination area) is limited to 3.5m
 - PPE circuit area is almost twice the size of the LAPSS illumination limit!
 - Requires ~9m of working distance
 - Not enough room in the building to set up this working distance!
- pLEDss addressed limitations of heritage LAPSS equipment and shortfalls of Dark IV test process

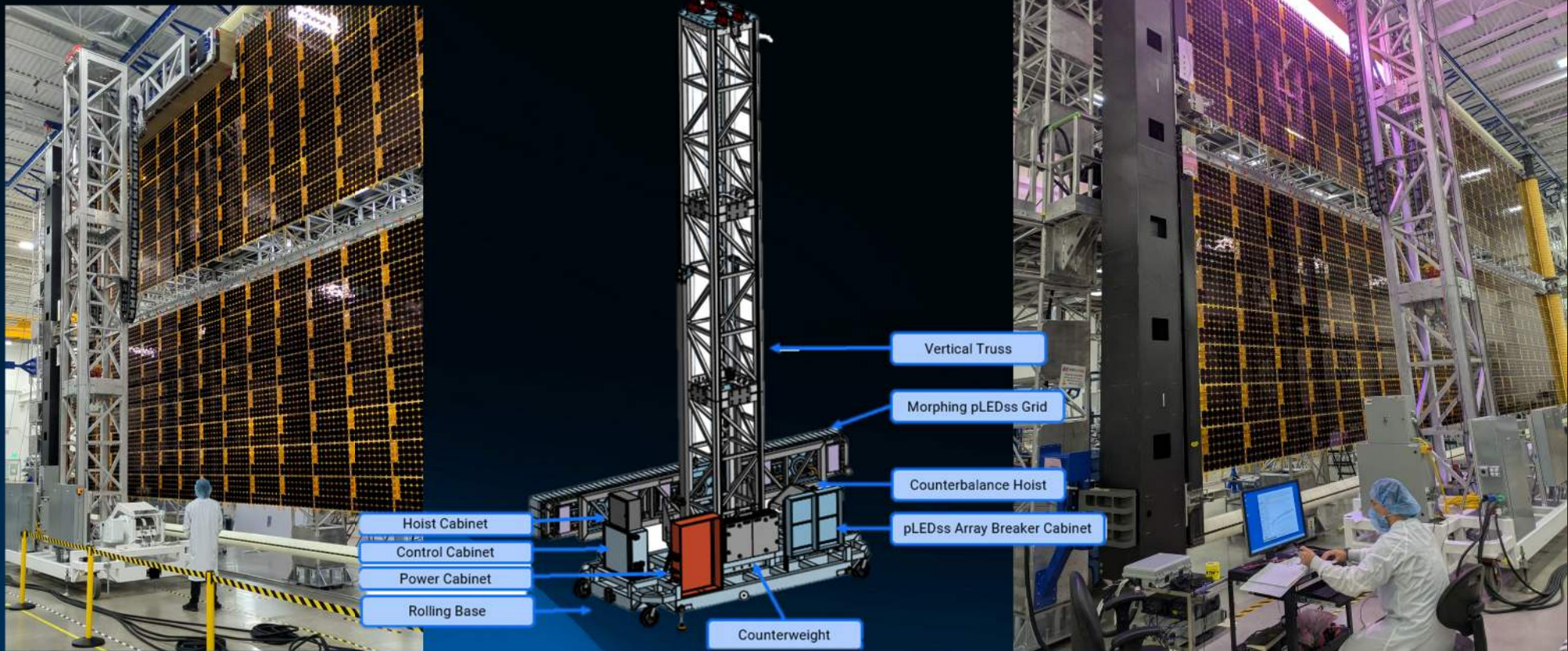


LROSA ELECTRICAL TEST PLAN DEVELOPMENT

- PPE baseline test plan developed to include Dark IV (stowed) and pLEDss (deployed)
 - pLEDss key features:
 - Suitable up to 5junction cells
 - Target test areas are configurable due to use of LED modules
 - Test working distance is small (150mm)
 - Robotic automated gantry, manual rolling cart setup, and circuit morphing enable a repeatable test setup catered to large-scale solar array wings



LROSA ELECTRICAL TEST PLAN DEVELOPMENT

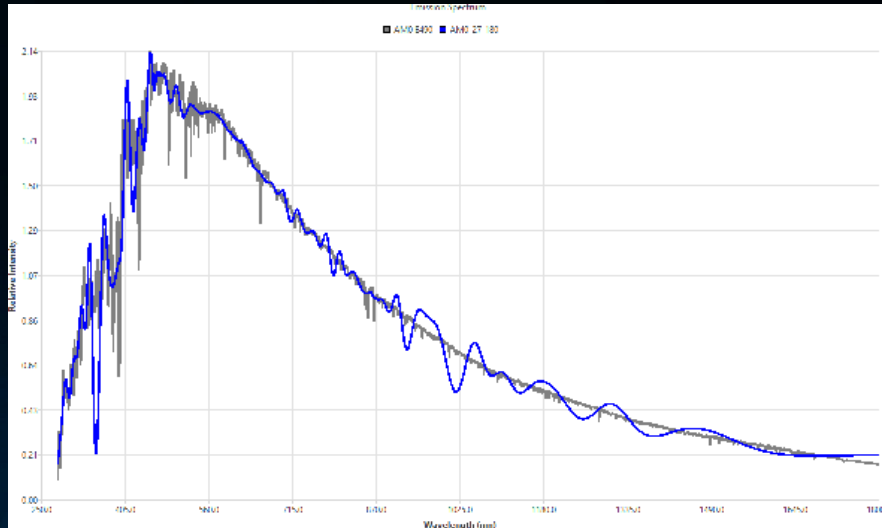


PLEDSS TEST SETUP, STAGING, AND OPERATIONS

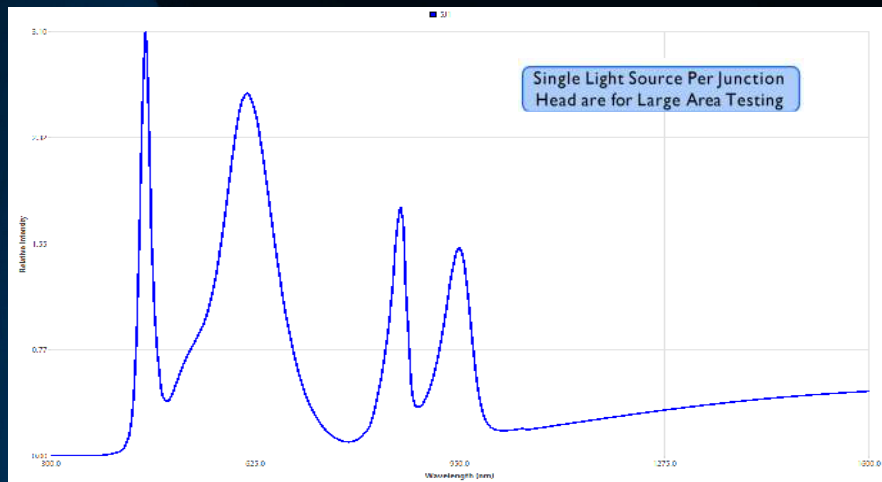
- New product development is always a challenge!
 - Developing a new product AND a new way to test that product is an even bigger challenge
- Concerns up front about how hard it would be to operate the pLEDss
 - How to “drive” it around safely in close proximity to flight hardware?
 - How to stage it and level it consistently and repeatably to ensure reliable data?
 - How to run the software?
 - How long will all of this take every time we need to test?
- After about a week’s worth of training and trial test runs with Angstrom Designs onsite, Redwire Space Systems technician team started testing on the flight wings
- Originally allocated ~15 days per wing to complete each pLEDss test event
 - pLEDss tests occur multiple times throughout our overall test campaign, so this stacked up to a significant amount of time on a tight program schedule
 - Technician team got the process down to a consistent and repeatable 5 days per wing
- Test data result output is easy to digest with automated Voc, Isc, IV, and Power curves



Spectral Match pLEDss



5J1 "discrete" pLEDss

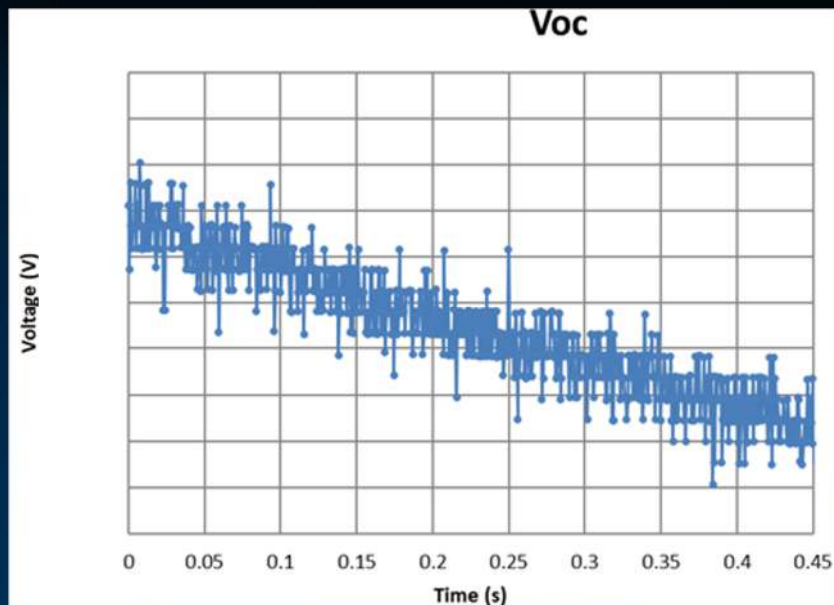


PLEDSS CAPABILITY & PPE APPLICATION

- pLEDss has different light source configurations
 - While spectrally matched pLEDss exist, PPE used a "discrete" (manufacturing optimized) LED configuration
 - Meets AIAA isotype current matching specifications (1%) for the target cell technologies
 - 5 different light source types that can measure all 3J, 4J, & 5J cells
 - Cost-effective for large area panels
 - After calibration, discrete heads produce on-orbit power levels
- pLEDss heads can be tiled to fit any illuminated area
 - A single pLEDss head is a small solar simulator
 - Many heads together can test any size array
- For PPE, pLEDss system calibrated for AM0 using Z4J standard AM0 Spectrum
 - pLEDss can accommodate a variety of spectral options
 - AM0, AM1.5, low intensity, high intensity

CELL HEATING FROM LED PULSES

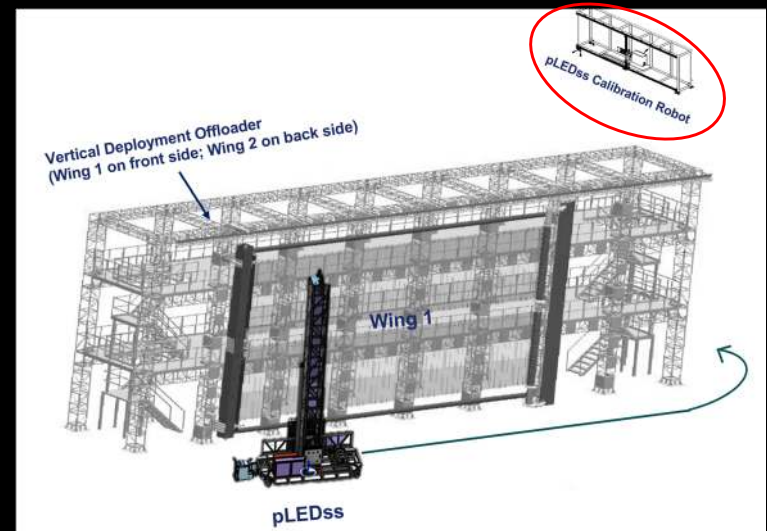
Minimal Heating During Pulses



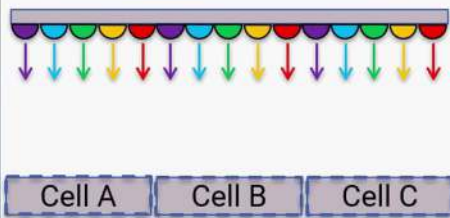
- pLEDs for PPE light pulses are ~1.0 second long
- There was concern about cell heating during the pulses
- pLEDs can measure Isc and Voc over the pulse duration
 - Voc and Isc “sweeps” were taken before and after IV sweeps
- Had heating been an issue, delta Voc could have been used to temperature correct data post testing
- Thermal analysis showed a temperature increase of ~0.5°C during pulsing
 - Heating was very consistent
- The team determined that this was small enough that no correction was needed, but data is still collected during each test event

JUNCTIONS CURRENT MEASUREMENT (JCM) CALIBRATION

- pLEDss uses the JCM calibration method
- Calibration occurred with matched isotypes of the flight cell technology
- An XY motor moves each isotype to the location of each cell on the wing
 - Calibration verifies current match, spectral, and spatial beam performance



JCM for Best Calibration



	Cell A	Cell B	Cell C
J1			
J2			
J3			
J4			
J5			

	228	229	230	231	232	233	234	235	236	237	238	239
219.5	5.017	5.018	5.019	5.020	5.021	5.022	5.023	5.024	5.025	5.026	5.027	5.028
201.5	5.235	5.236	5.237	5.238	5.239	5.240	5.241	5.242	5.243	5.244	5.245	5.246
183.5	5.453	5.454	5.455	5.456	5.457	5.458	5.459	5.460	5.461	5.462	5.463	5.464
165.5	5.671	5.672	5.673	5.674	5.675	5.676	5.677	5.678	5.679	5.680	5.681	5.682
147.5	5.889	5.890	5.891	5.892	5.893	5.894	5.895	5.896	5.897	5.898	5.899	5.900
129.5	6.107	6.108	6.109	6.110	6.111	6.112	6.113	6.114	6.115	6.116	6.117	6.118
111.5	6.325	6.326	6.327	6.328	6.329	6.330	6.331	6.332	6.333	6.334	6.335	6.336
93.5	6.543	6.544	6.545	6.546	6.547	6.548	6.549	6.550	6.551	6.552	6.553	6.554
75.5	6.761	6.762	6.763	6.764	6.765	6.766	6.767	6.768	6.769	6.770	6.771	6.772
57.5	6.979	6.980	6.981	6.982	6.983	6.984	6.985	6.986	6.987	6.988	6.989	6.990
39.5	7.197	7.198	7.199	7.200	7.201	7.202	7.203	7.204	7.205	7.206	7.207	7.208
21.5	7.415	7.416	7.417	7.418	7.419	7.420	7.421	7.422	7.423	7.424	7.425	7.426
3.5	7.633	7.634	7.635	7.636	7.637	7.638	7.639	7.640	7.641	7.642	7.643	7.644
0	7.851	7.852	7.853	7.854	7.855	7.856	7.857	7.858	7.859	7.860	7.861	7.862

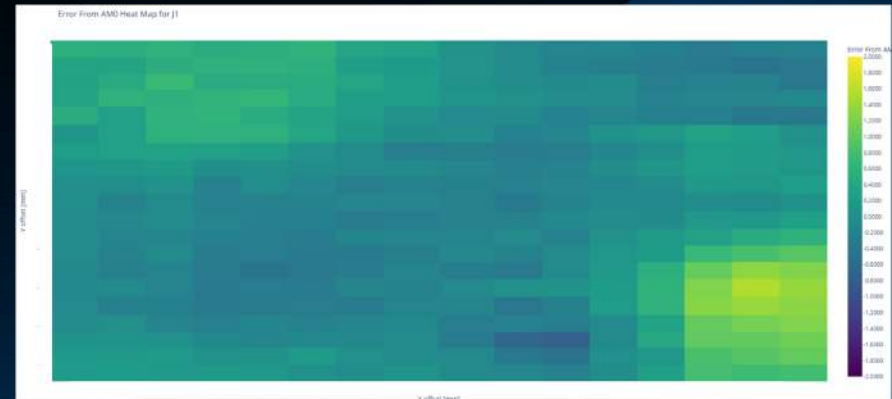
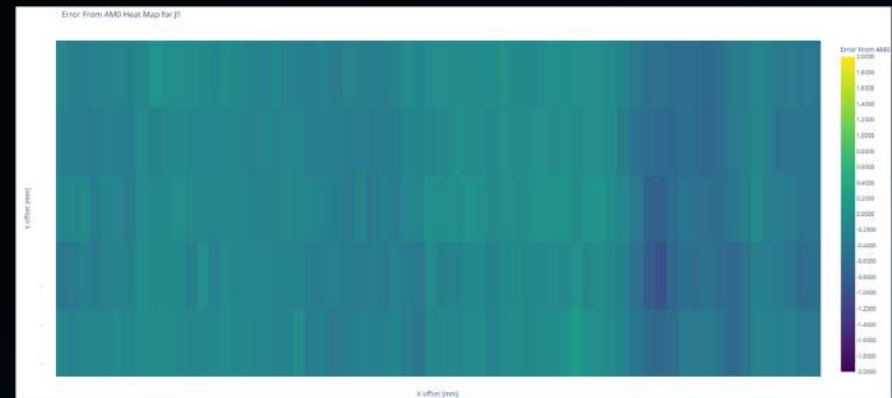
CALIBRATION RESULTS

Error exceeds expectations; very low spatial nonuniformity

Long Aspect Ratio		
Isotype	Isc SNU%	Avg AM0 Error [%]
J1	<1	<0.25%
J2	<1	<0.25%
J3	<1	<0.1%
J4	<2	<0.1%

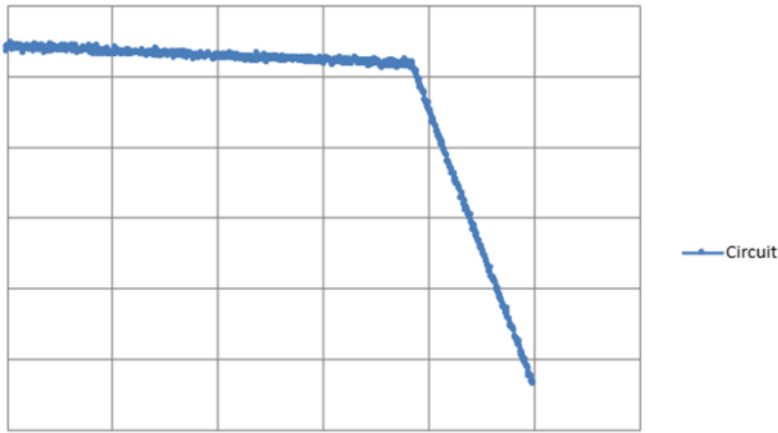
Short Aspect Ratio		
Isotype	Isc SNU%	Avg AM0 Error [%]
J1	<2	<0.1%
J2	<2	<0.25%
J3	<1	<0.25%
J4	<2	<0.5%

J1 AM0 Error - LAR

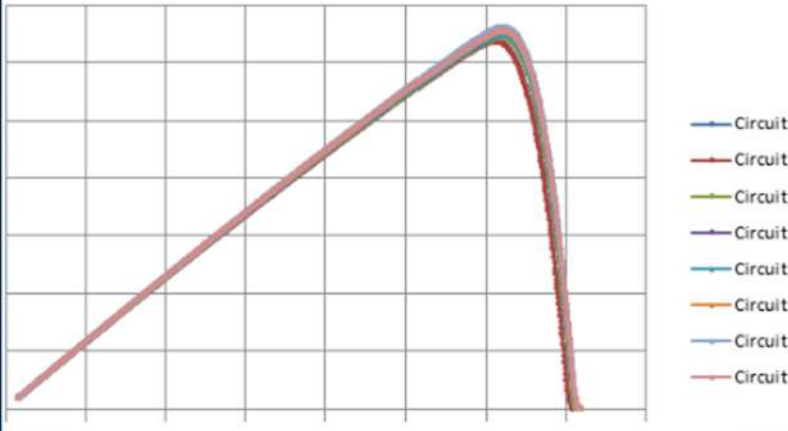


J1 AM0 Error - SAR

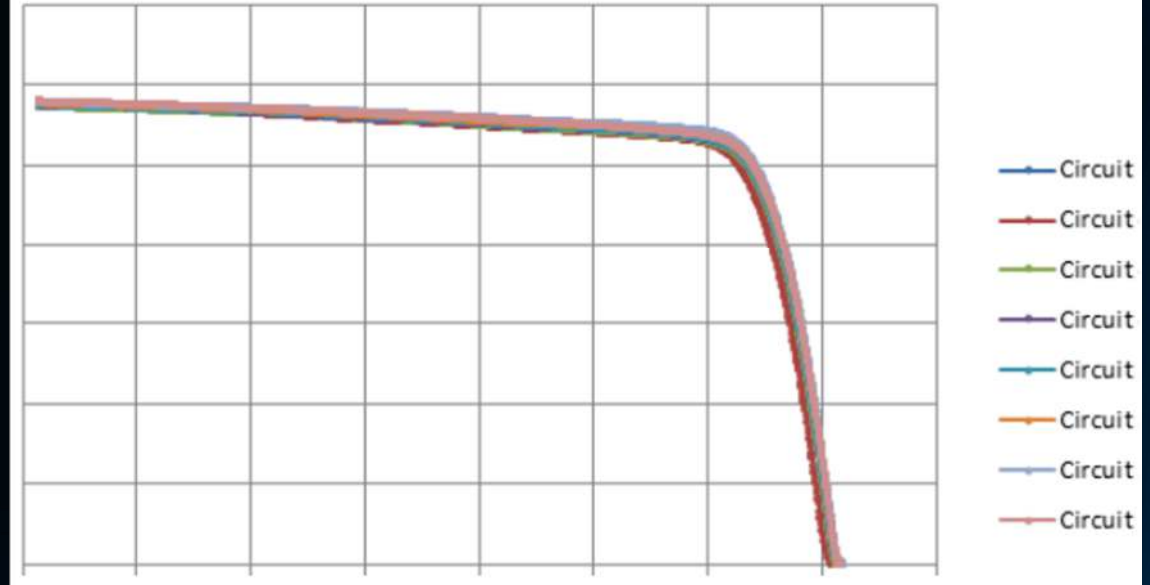
Voc



Power Curve



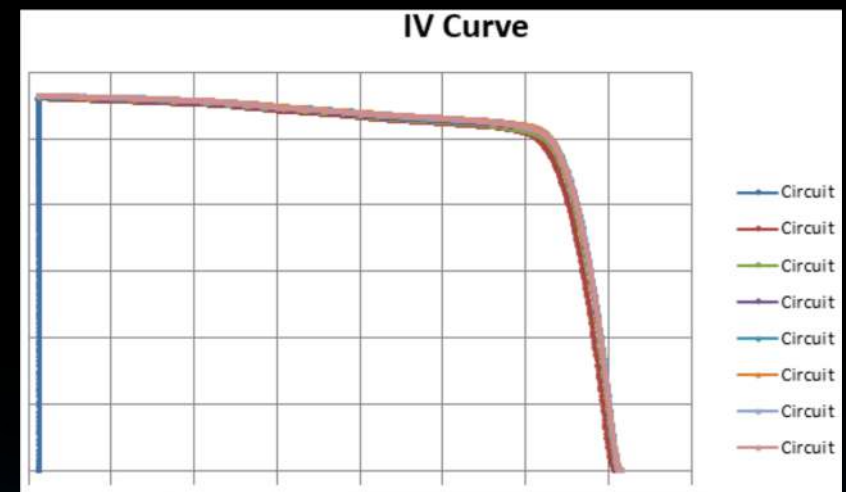
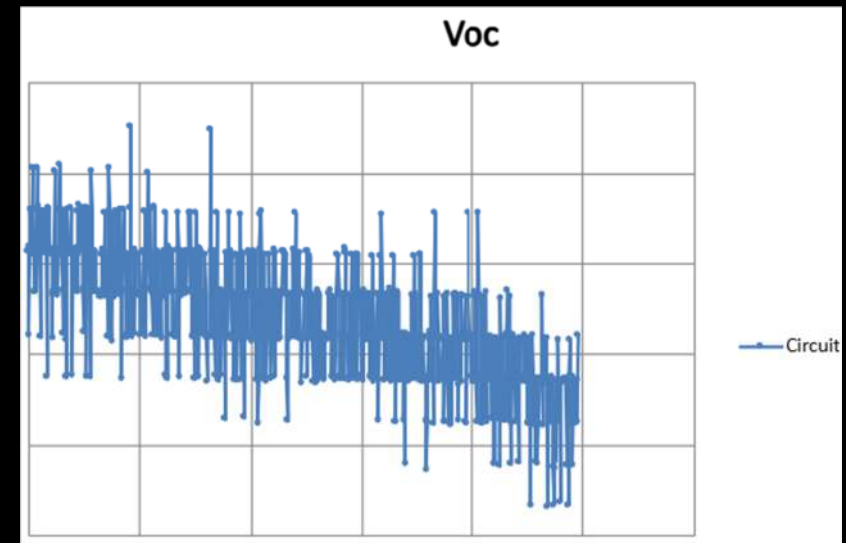
IV Curve



**PLEDSS AUTOMATICALLY
GENERATED TEST OUTPUTS**

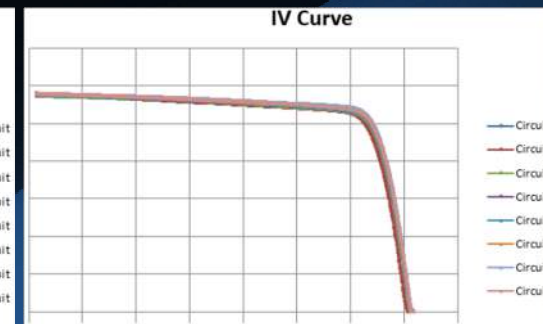
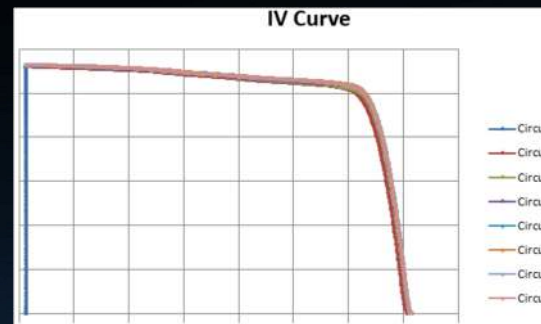
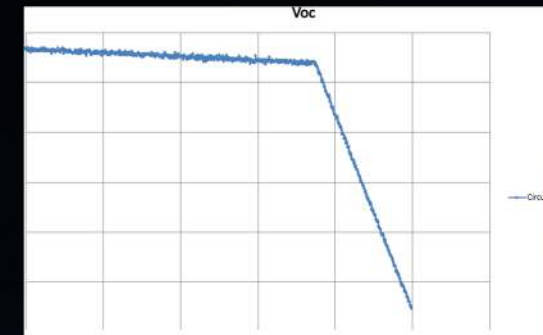
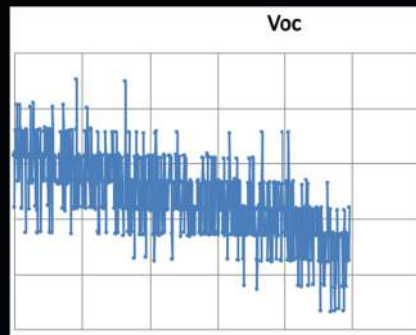
PLEDSS DETECTED LROSA MANUFACTURING ERROR

- The Voc nonconformance to the right was very easy to catch
 - Data from the pLEDss Voc test output was clearly scrambled and at too low of a voltage
 - Data from the IV curve did not generate for corresponding circuit
- Root cause investigations began with a check of the prior stowed Dark IV data that showed no issues
- Determined that root cause was an incorrectly populated connector!
 - There are multiple connectors per wing, each with several pin/sockets of different combinations (some are left intentionally unpopulated on each connector)
- ***If not for pLEDss testing, this nonconformance could have gone undetected, risking on-orbit power!***



IMPORTANCE OF TEST PLAN DEVELOPMENT

- Why didn't stowed Dark IV catch this issue?
 - Dark IV bypasses the blocking diode
 - The connectors are on the spacecraft side of blocking diode, so they were bypassed during the test
- **pLEDss is a “test like you fly” test of the end-to-end wing system**
- LROSA design has redundant power and return wiring (2x power and 2x return lines per circuit)
 - During early pLEDss development, Angstrom Designs and Intuitive Machines decided to test with a 4x wire measurement (leveraging all 4x lines)
 - This measuring technique is more accurate AND it requires all 4x wires to be installed correctly to develop IV curve
 - If there is a wiring problem, the measurement gets scrambled and allows for easy detection of nonconformances





PUBLIC & COMMERCIAL SPACE PARTNERSHIP SUCCESS

- The PPE LROSA is a wing of unprecedented size and power generation
- The pLEDss is a flexible, powerful, and efficient solar cell illumination ground test system used to ensure that the LROsAs will be a success on-orbit
- Both pLEDss and ROSA started with Small Business Innovation Research (SBIR) public funding and transitioned into commercial products that now support the NASA Lunar Gateway through the Intuitive Machines Power and Propulsion Element
 - Initial ROSA development at Redwire Space Systems (formerly DSS) began with an AFRL SBIR in 2008 and then a NASA SBIR in 2009
 - Initial pLEDss development at Angstrom Designs began with NASA SBIR funding in 2014 (following NASA STTR funding in 2013)
- ***Special thanks to the incredible collaboration of commercial and public entities that make pLEDss testing on the PPE LROSA wings possible!***