National Aeronautics and
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Pushing Boundaries
Breaking Barriers

PILS – Photovoltaic Investigation on the Lunar Surface

Jeremiah McNatt
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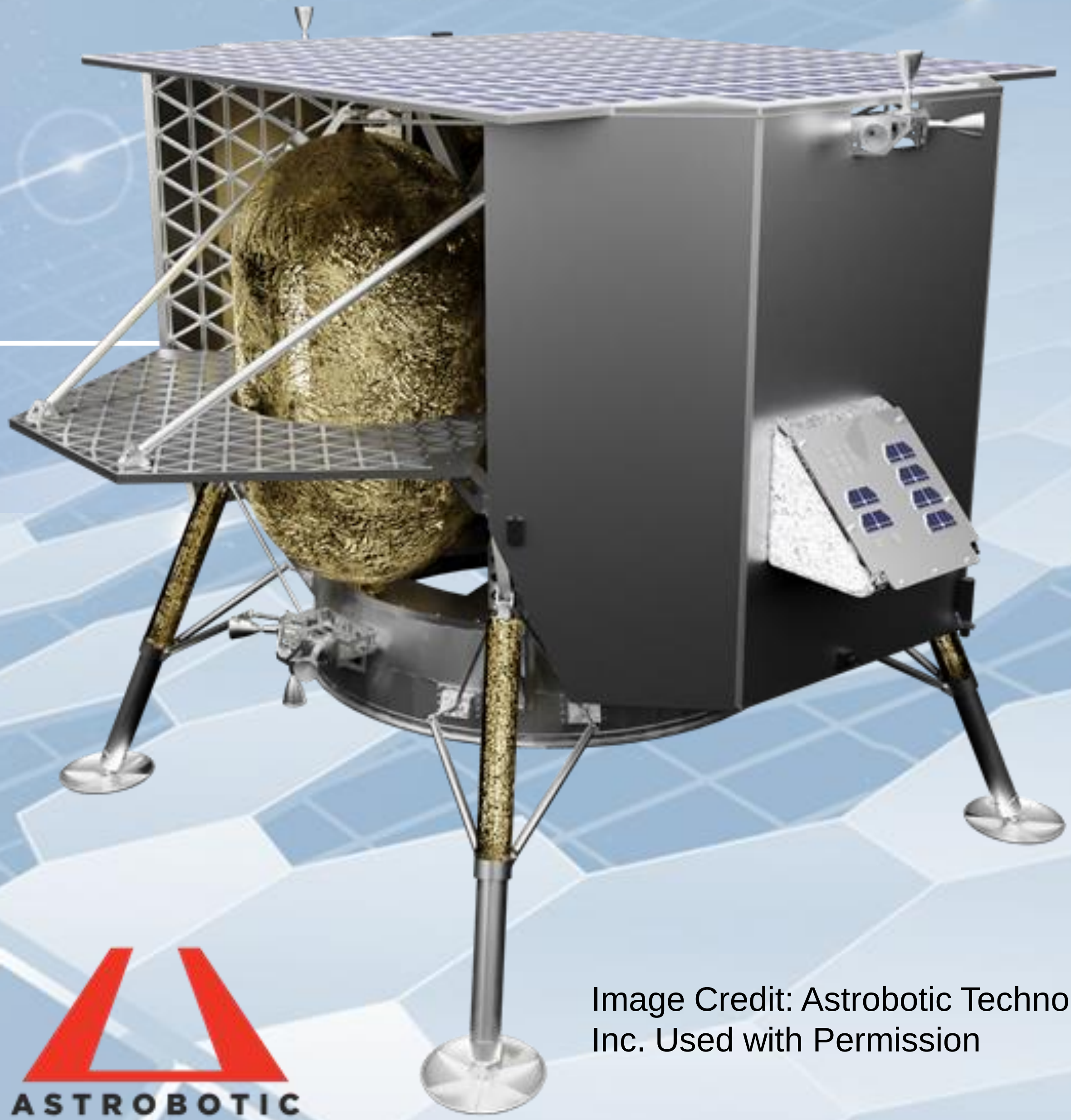

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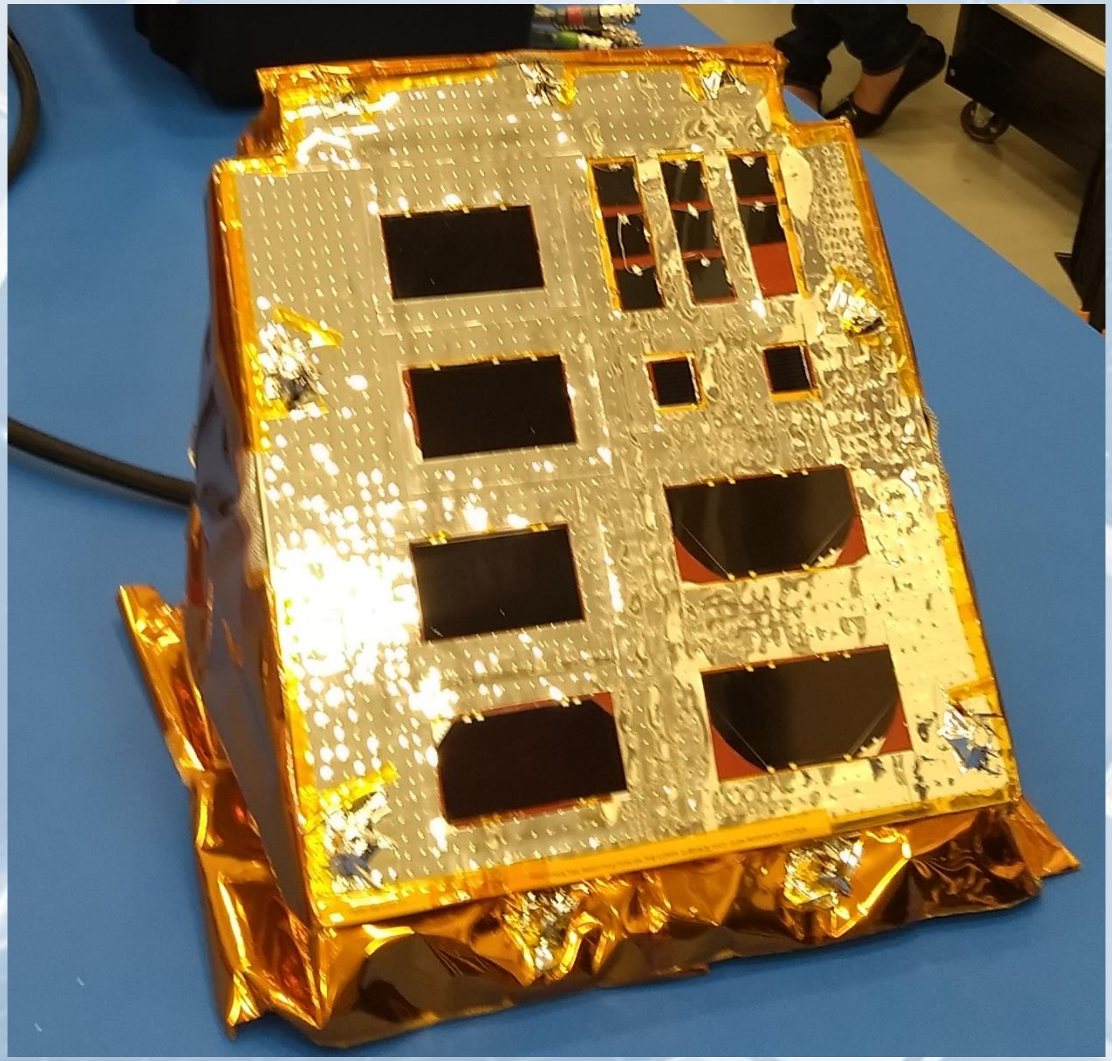
What is PILS



- Small platform testbed of state-of-the-art solar cells and surface solar array charging measurement electronics
- Designed, built and tested in-house at NASA GRC
- Will operate at Lacus Mortis on the lunar surface (approximately 45 ºN)

PILS Team

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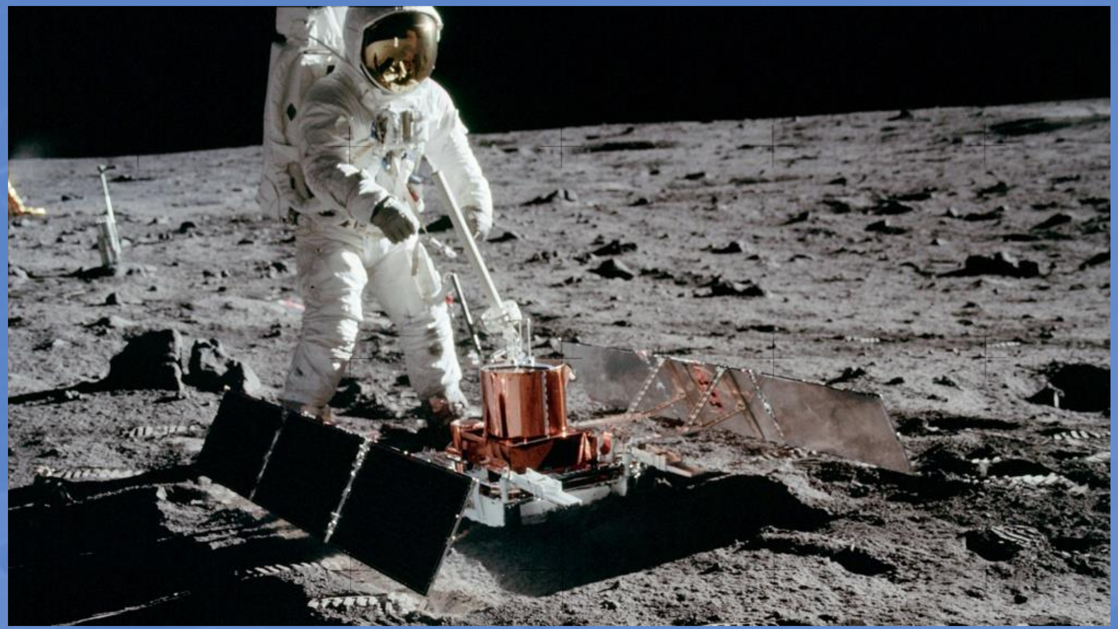
Background on PILS

- Photovoltaics and solar arrays have provided reliable power to spacecraft for over 50 years and will enable long duration missions on the lunar surface
- Solar cells have been used on the lunar surface in the past, but the technology has matured significantly
- There is still a lot unknown about the energized environment of the lunar surface and how it would impact high voltage solar arrays
- PILS team responded to a call to provide payloads to the Commercial Lunar Payload Services (CLPS) program, proposing a test-bed to measure electrical performance of state of the art and next generation solar cells, and to measure the charge build up on a small solar cell array
- Selected by Astrobotic for integration with their Peregrine Lander with a target lunar landing in ~~Fall 2021~~ 2022
- Technical Objectives:
    - Enhance existing models for future power generation systems, to shape design rules for large solar arrays on the lunar surface
    - Determine charge buildup on solar arrays and arcing hazards in the lunar environment
    - Measure plasma properties for ground-based simulation, arc threshold, and damage rate
    - Increase TRL of cells and arc detection capability



Solar arrays on the Apollo 11 Seismic Experiment

Requirements and Design Considerations

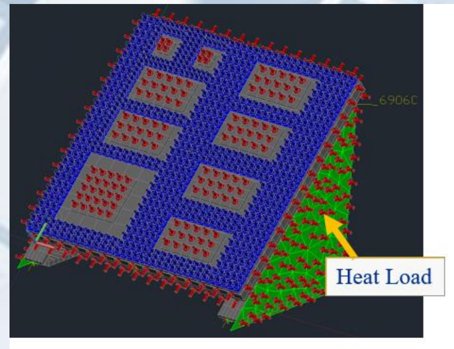
Requirements

- Proposed and accepted payload dimensions, not to exceed: 30 x 30 x 4cm (without mounting brackets)
  - Designed to be mounted flat (without brackets) and scaled in size if testing less cell technologies (adaptable for multiple lander platforms and footprints)
  - Capped mass at 4.5 kg
- Power limited to 2W for solar cell and plasma charging experiment. Additional power for on board heaters was negotiated with Astrobotic during payload design.
- Team designed platform to accommodate interfaces with the AB lander in terms of power, communication, mounting, environmental concerns

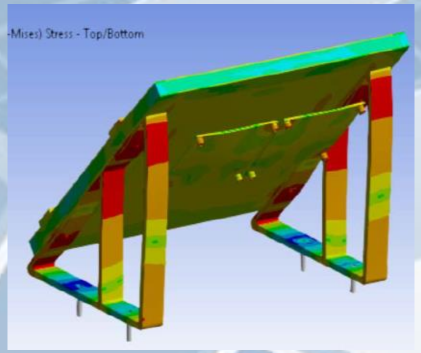
Design Considerations

- Initial concept used solar cell high altitude flight calibration holders but they added significant mass. Found a solution to use a single circuit board type top surface to mount the solar cells
- During early design the launch loads were not well known which presented a challenge to design the platform to be lightweight but still robust. Multiple iterations were considered and modeled.
- The thermal environment turned out to be our largest environmental driver. Challenge to keep the electronics warm during transit to the moon and to keep them cool while on the surface during the lunar day. Found solutions with multilayer insulation and thermal tape.
- Built scaled mock-ups of the platform to better understand interfaces and clearances


PILS Mock Up Based on Initial Concept



PILS Thermal Analysis Model

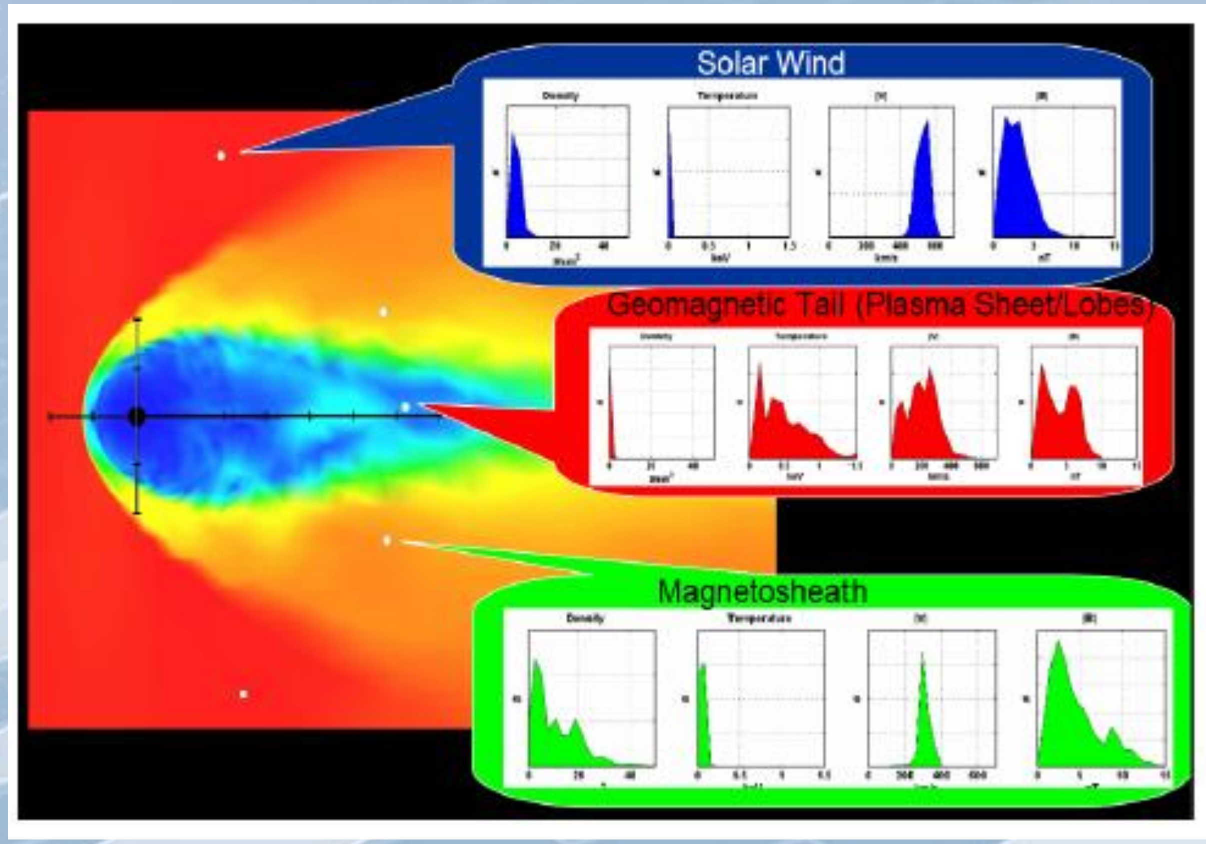

PILS Structural Analysis Model


PILS Platform Mock Up

Science Objectives

- Determine charge buildup on solar arrays in the lunar environment
  - Characterize charging phenomena on lunar surface
  - PILS uses a small array of solar cells to actively count the charge build up on the coverglass
  - Mitigate risk for future high voltage solar arrays on the moon
- Enhance existing models for future power generation systems
  - Refined & higher fidelity simulations on ground
  - Allow more accurate simulated plasma interactions
- Shape design rules for large solar arrays on the lunar surface
- Increase TRL of cells including SOA, next generation technology, and commodity grade silicon for use on future lunar surface missions

- Additionally, PILS is expected to record solar array surface charging and solar cell performance data during transit to the moon



Plasma environments the moon passes through. This illustrates a highly variable environment that also does not include secondary electron emission from the lunar surface regolith

Solar Cell Manifest

- (1) 4x8 cm SolAero ZTJ, triple junction III-V
  - Voc = 2.7V
  - Isc = 560mA
- (1) 4x8 cm SpectroLab XTJ, triple junction III-V
  - Voc = 2.6V
  - Isc = 570mA
- (2) 4x8cm SpectroLab XTE-GEO triple junction III-V
  - Voc = 2.7V
  - Isc = 400mA
- (2) 4x8cm SolAero IMM alpha 5 junction III-V
  - Voc = 4.8V
  - Isc = 400mA
- (2) 2x2cm ASU Silicon Heterojunction Intrinsic Thin Film
  - Voc = 0.62V
  - Isc = 100mA

SOA Technologies: used on many NASA missions including Mars Exploration Rovers (XTJ) and Parker Solar Probe (ZTJ) and most commercial satellites

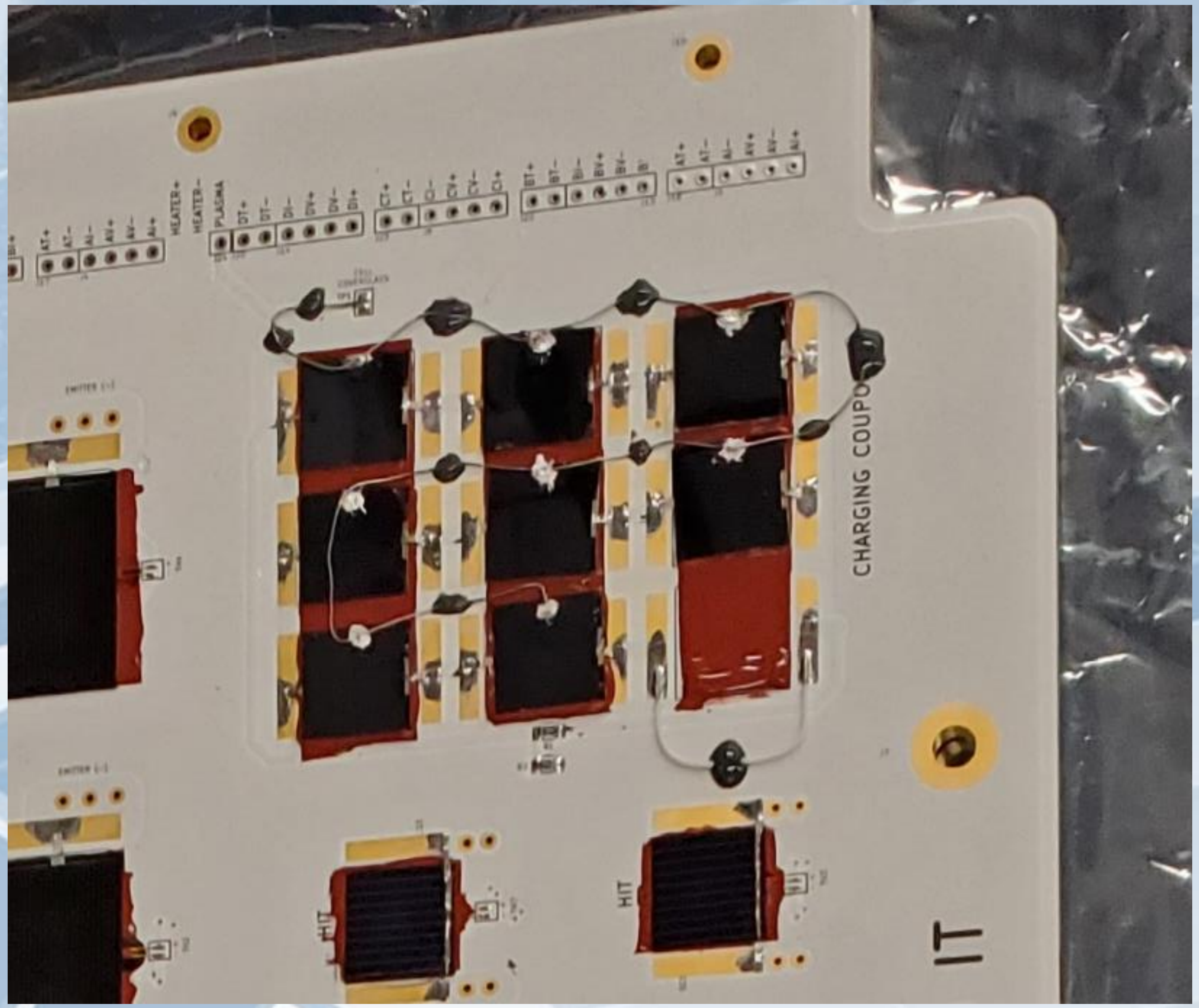
Next Generation Technologies designed to improve overall performance including higher efficiency and improved radiation resistance

Thin silicon technology that may be considered for lunar surface use due to lower cost compared to III-V technologies

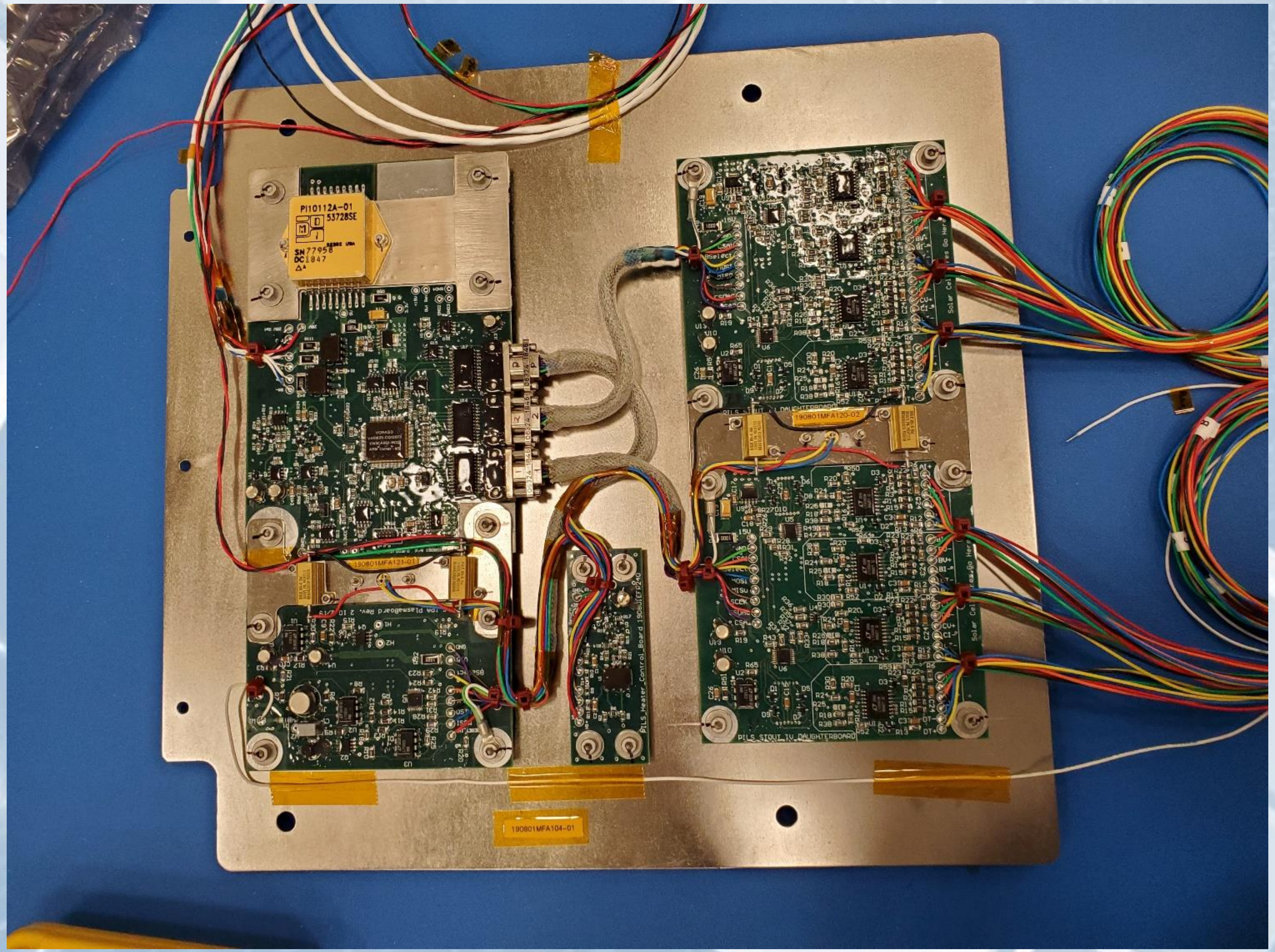
Charging coupon uses Spectrolab Ultra Triple Junction (UTJ) Technology, the predecessor to XTJ

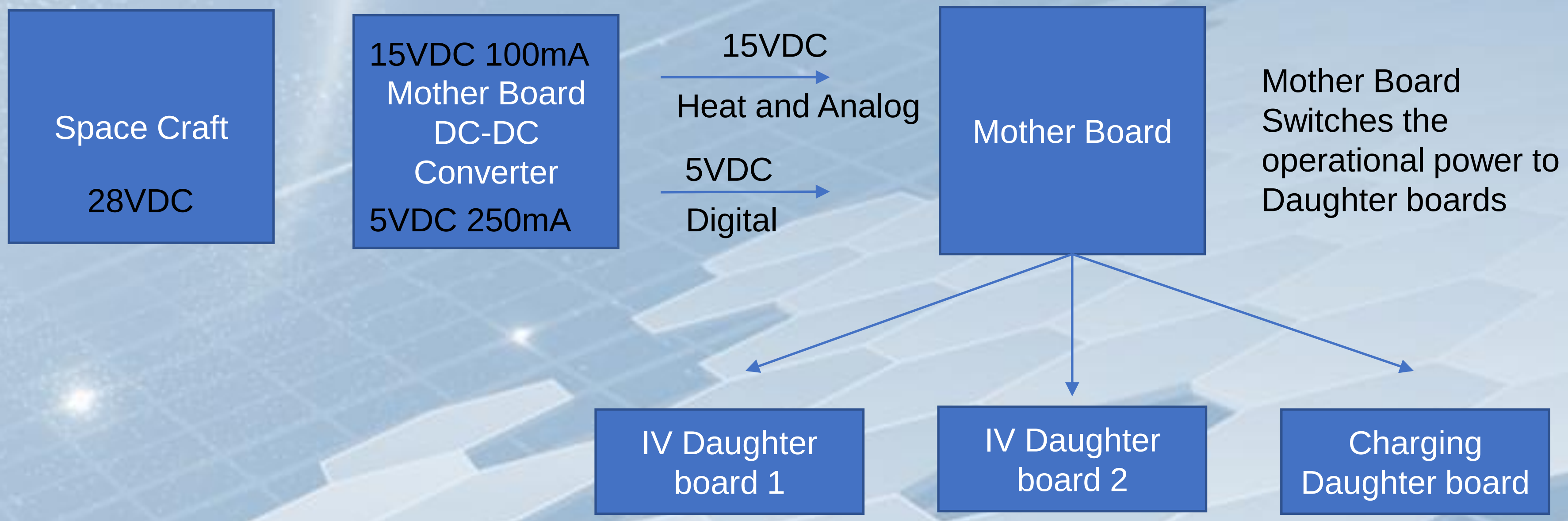
Charge Measurement Coupon

- 8, 2x2 cm UTJ solar cells strung in series and shorted through a burden resistor
- Burden resistor sets bias potential, anywhere from 0V to 18V
- Maximum current is approximately 100mA, not enough for secondary arcing under any voltage
- Solar cell coverglass is coated with <100kOhm/sq ITO to bleed charge, but the charge is isolated by high dielectric constant encapsulant
- Wires are soldered to coverglass to short all surfaces and connect to large series resistor
- Back-end of resistor is fed to monitoring measurement board

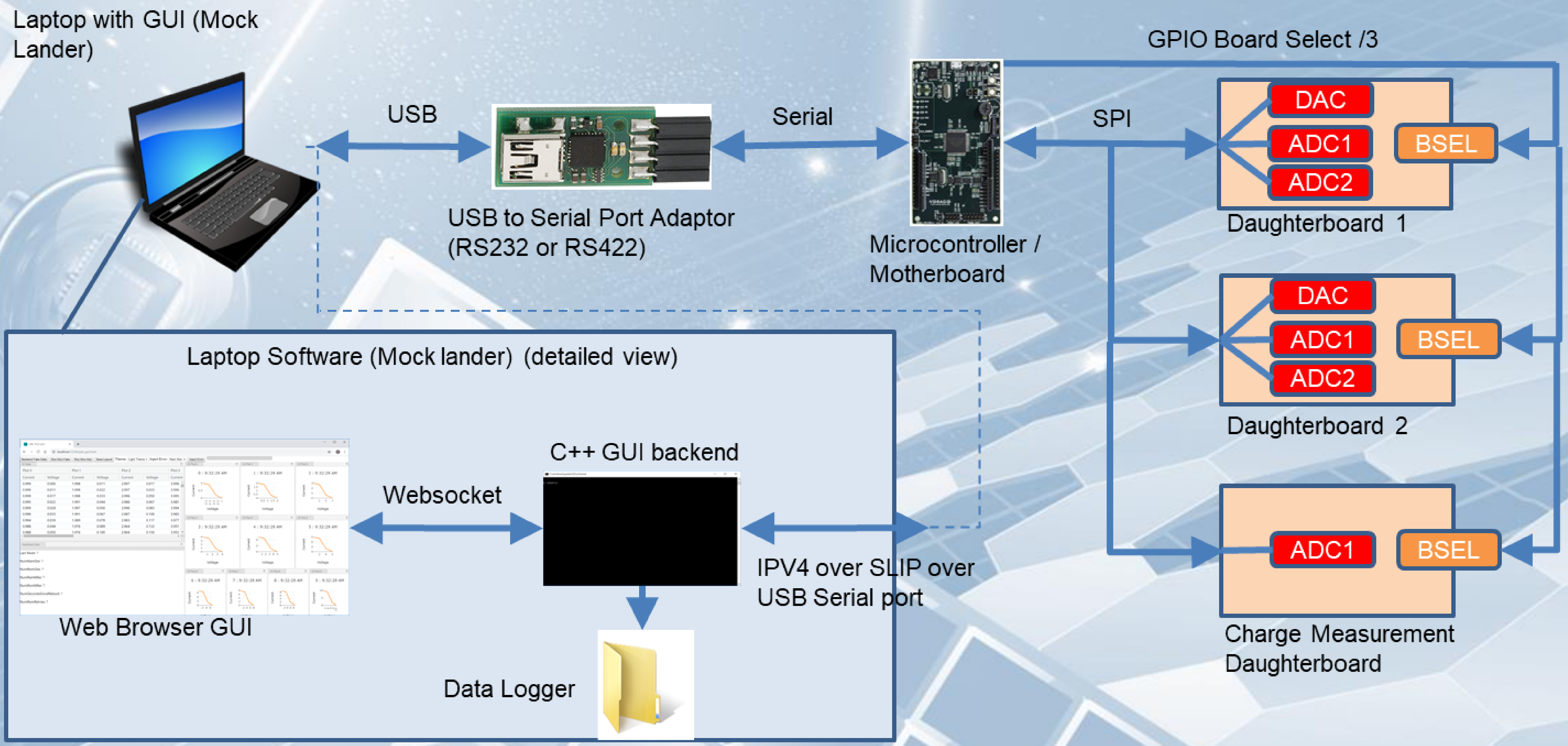


Under the Hood: Electronics



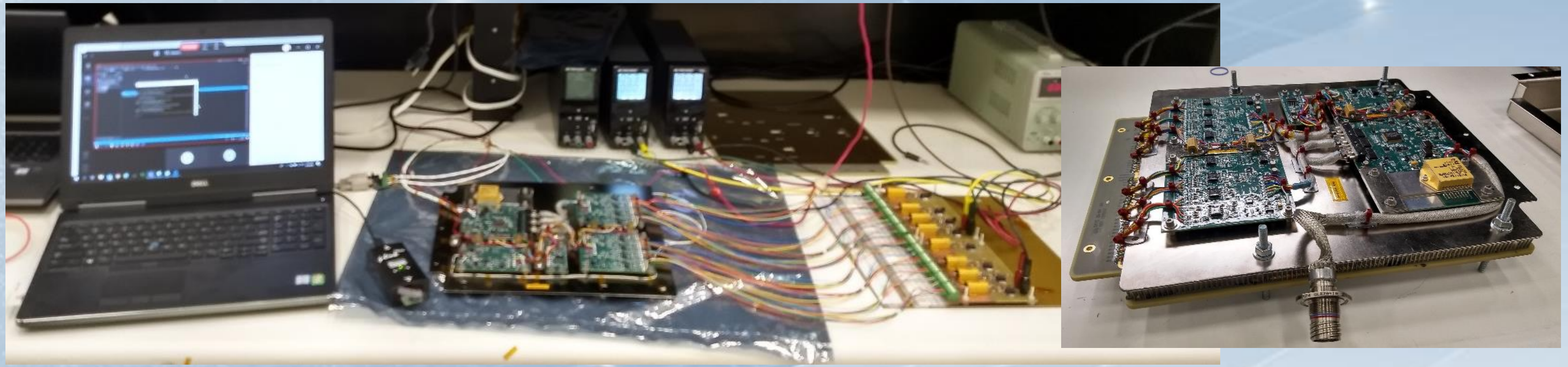


Under the Hood: Software Interface

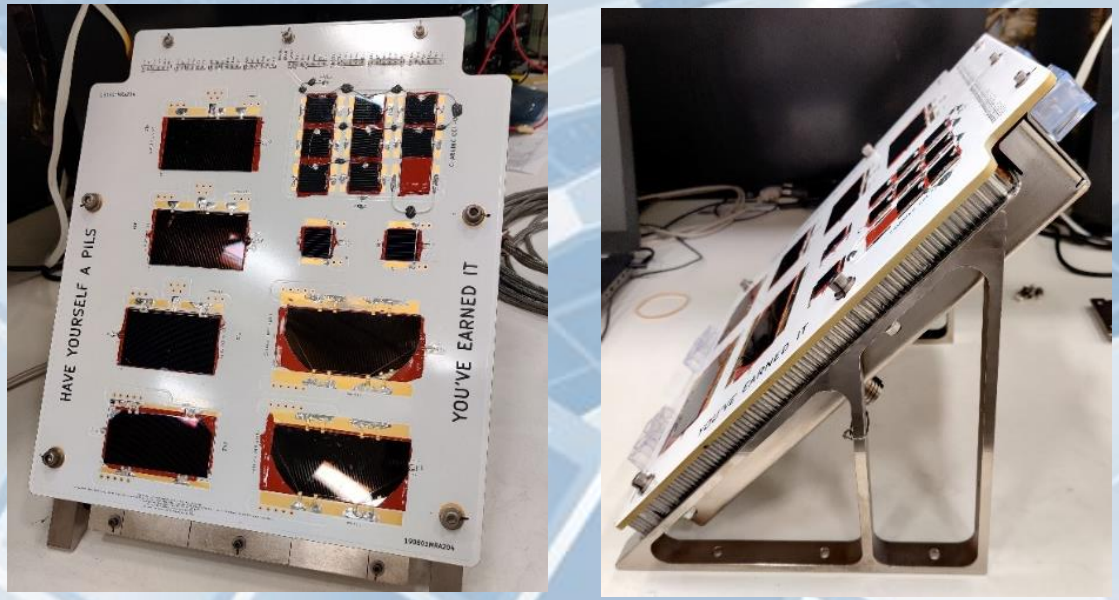


Hardware Status

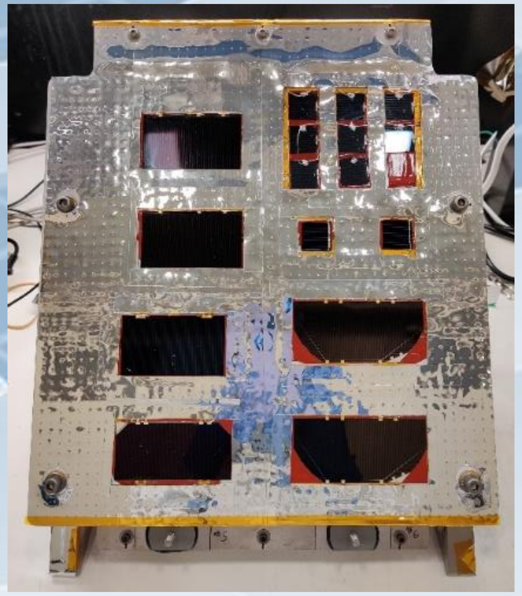
- Platform software and electronics have been tested with flight hardware
- Platform build is complete
- Platform wrapped with MLI and thermal reflective tape
- Completed Required Testing
  - Thermal Vacuum Performance (hot & cold)
  - Electromagnetic Interference Compliance
  - Vibration Structural Testing
- Payload Interface Mobile Simulator (PIMS) testing completed in Nov 2020
  - Verified compatibility with Astrobotic power and data and communication with mission control center



Software/Hardware Checkout



Assembled PILS Flight Unit



Assembled PILS Flight Unit with Thermal Tape Applied to Top Surface

Integration and Verification

- Dimensional Inspection completed Nov 17, 2020:
  - Verified dimensions of mounting holes and overall dimensions
- PILS Stored awaiting delivery to Astrobotic

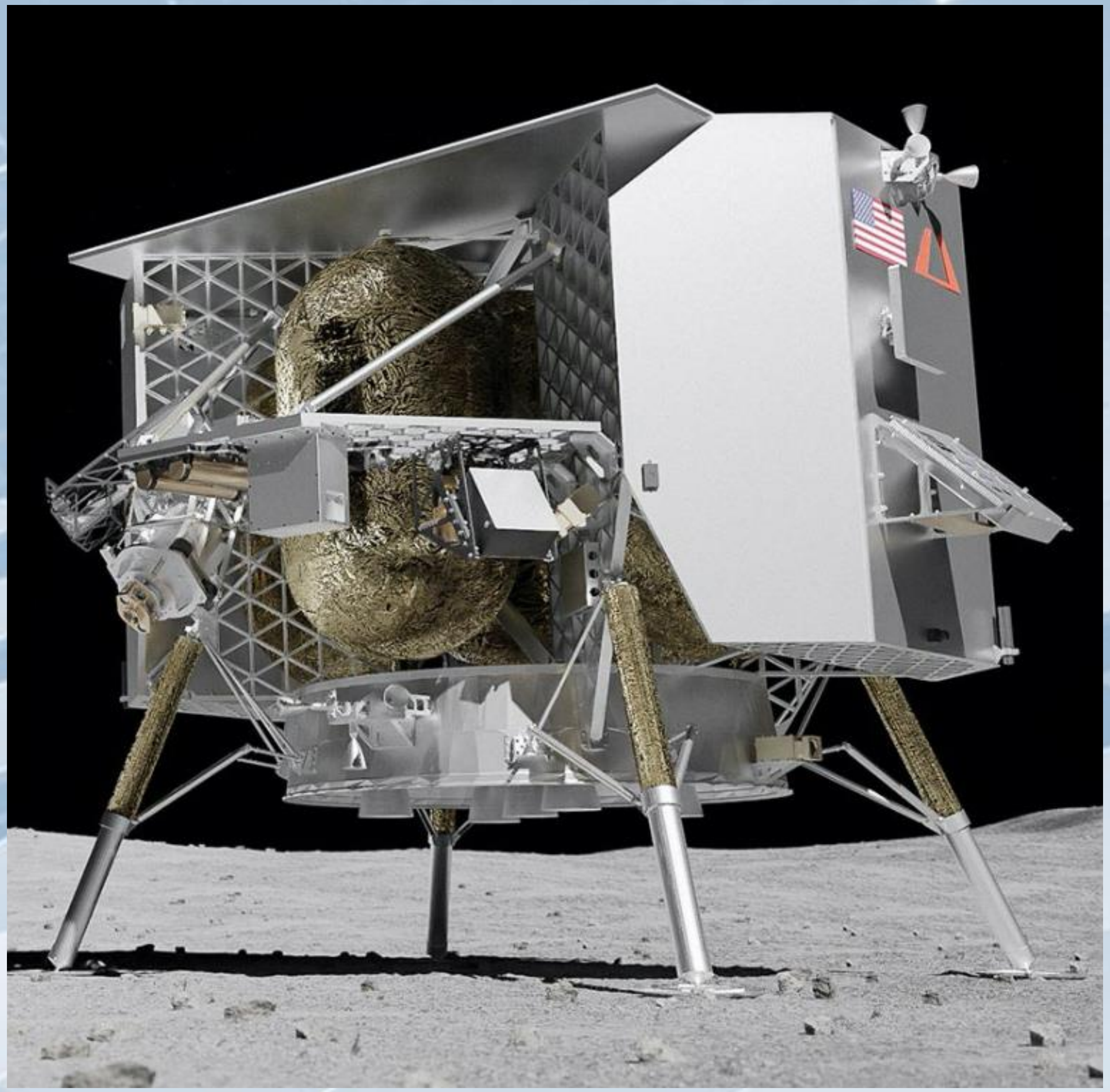
- After physical delivery to Astrobotic (late Oct 2021):
  - Interface Simulation Testing will be performed (Jan/Feb 2022)
  - Will include a test of the Astrobotic mission control center to PILS mission control center
  - Verifies nominal function and safe to integrate

- After spacecraft build complete:
  - Functional testing will re-verify payload interfaces and services are functional
  - Astrobotic will perform spacecraft level acceptance testing for mass properties, vibration, thermal vacuum, and EMI/EMC. PILS will be tested (heartbeat test minimum) post spacecraft level testing

PILS Testing with PIMS

Operations Plan

- **Pad/Launch**
  - PILS unit off during pad operations
  - Payload Mission Control Center (PMCC) staffed (options for local GRC and remote staffing); Final checks between Astrobotic mission control center (AMCC) and PMCC
- **Flight**
  - PILS will not receive power until ≥ 4 hours post stage separation
  - Expecting power during cruise to obtain baseline and cruise period payload data
- **Surface**
  - Peregrine is expected to land at lunar dawn. Payloads will be powered <6 hours after touchdown; PILS has requested surface data transmission of ≤ 6 hours
  - ~24 hour "siesta" tentatively planned by lander at solar noon
    - PILS requested operational power during this time if possible
- **End of Mission**
  - Defined by final lander shutdown at lunar night



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Conclusion and Additional Resources

- PILS is a small solar cell testbed designed for the lunar surface which includes multiple SOA and next generation solar cell technologies
- PILS will be integrated with the Astrobotic Peregrine Lander and will land at Lacus Mortis on the lunar surface in 2022
- PILS will operate for approximately 1 lunar day, collecting multiple current/voltage curves of the various solar cell technologies and measuring the build up of charge on a small solar cell array
- Data will be transmitted back to Earth through the Peregrine Lander, team expects multiple papers (PV performance, array charging, thermal control, electronics design and performance)

- https://www.nasa.gov/feature/glenn/2020/solar-power-investigation-to-launch-on-lunar-lander
- https://www.nasa.gov/feature/glenn/2021/out-of-the-shadows-lunar-solar-experiment-build-completed-despite-challenges