Photovoltaic Investigation on the Lunar Surface (PILS) & Vertical Solar Array Technology (VSAT) Project Overviews

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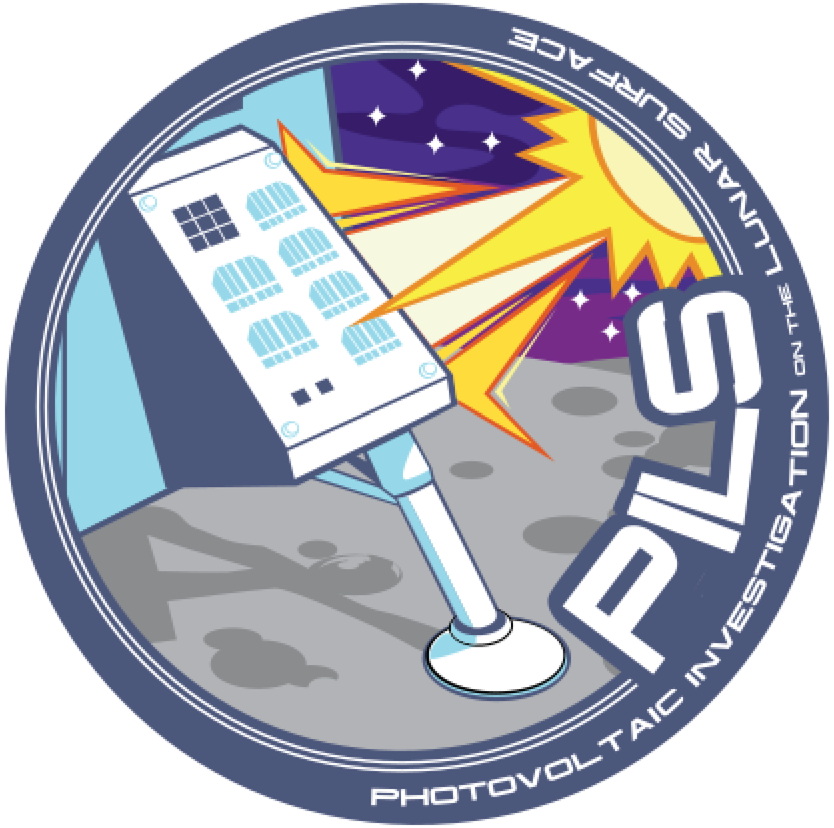
For Presentation at the NESC Electrical Power Technology Discipline Team Meeting
September 2, 2022

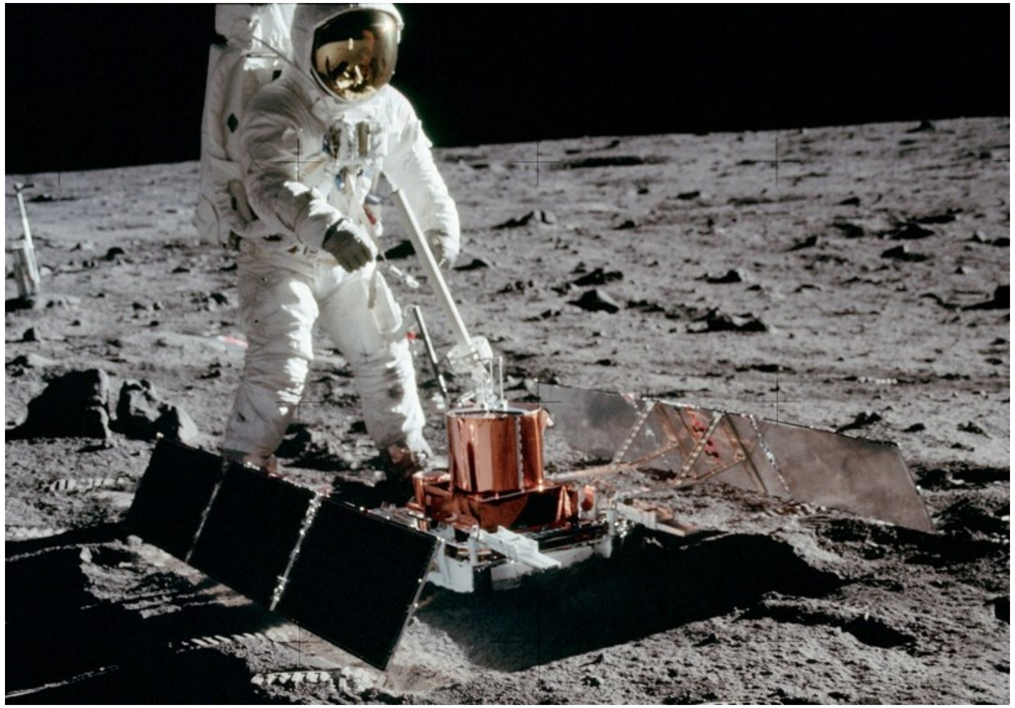
Photovoltaic Investigation on the Lunar Surface (PILS) – PV Testbed for Lunar Landers



Photovoltaic Investigation on the Lunar Surface (PILS)

Background

- 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
- The Commercial Lunar Payload Services (CLPS) program supports Artemis with commercial deliveries to perform science experiments, test technologies and demonstrate capabilities to help NASA explore the Moon and prepare for human missions
- Many of the CLPS providers plan to use photovoltaics to power their spacecraft

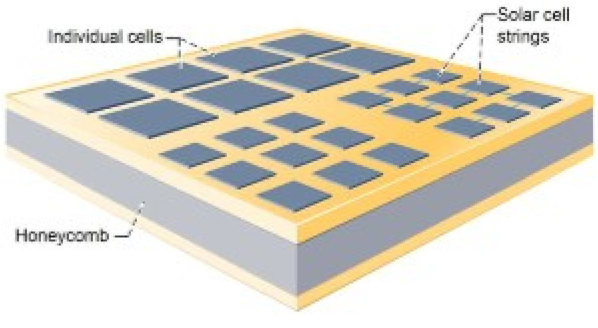


Solar arrays on the Apollo 11 Seismic Experiment

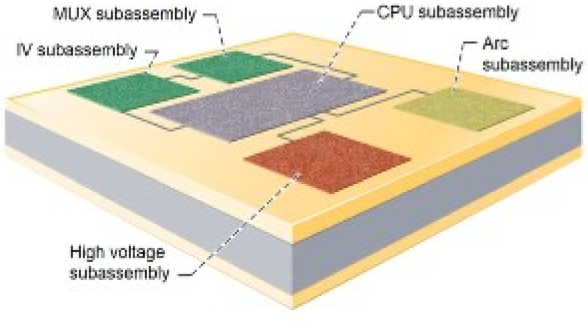
Photovoltaic Investigation on the Lunar Surface (PILS)

Background

- PILS team responded to a CLPS program call in late 2019 to provide readily available (requiring minimal tech development) payload packages for integration onto future landers
- The team proposed a photovoltaic 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
- The concept was based off a heritage Materials on the International Space Station Experiment (MISSE) solar cell flight test platform



FRONT SIDE



REAR SIDE

- Selected by Astrobotic, which will launch its Peregrine lander on a United Launch Alliance Vulcan Centaur rocket, along with 10 other NASA payloads
- Landing at Lacus Mortis for a lunar day long mission (approx. 10 Earth days)

Prior ISS Solar Cell Experiment

Lacus Mortis circled in Red

Photovoltaic Investigation on the Lunar Surface (PILS)

Mission Objectives

Technical Objectives

- Successfully deliver flight hardware to Astrobotic for integration onto the Peregrine Lander
- Do not exceed mass, power, size restraints
- Do no hard to the lander or other payloads
- Increase the TRL of solar cells and measure charge accumulation on an array of solar cells

Science Objectives

- Science objective 1: Determine performance and health checking of SOA and Next gen solar cells and terrestrial silicon cells over a lunar day. Perform I-V and temperature measurements for each cell regularly throughout mission
  - The cells are not under load (*“powered”* or *“powering anything”*) when not scanning an I-V curve
- Science objective 2: Measure the localized charging environment on a small solar array by collection of charge deposited on solar cell cover glass
  - Charging environment influenced by local neutral plasma.
- Bonus: get data in transit to the moon

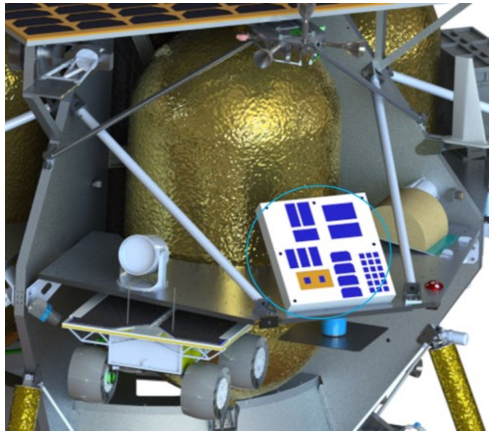
Photovoltaic Investigation on the Lunar Surface (PILS)

Design Concept and Requirements

- Dimensions: 30 x 30 x 4cm (without mounting brackets)
  - Designed to be mounted in multiple configurations (through bracketry) based on landing site and lander design
  - Capped mass at 4.5 kg
- Requires approximately 2W for solar cell and charging experiment. Designed to use additional power for heaters during cruise phase
- Team designed PILS platform to accommodate interfaces with the Peregrine lander in terms of power, communication, mounting, environmental concerns

Early rendering of Peregrine

PILS Mock Up Based on Initial Concept

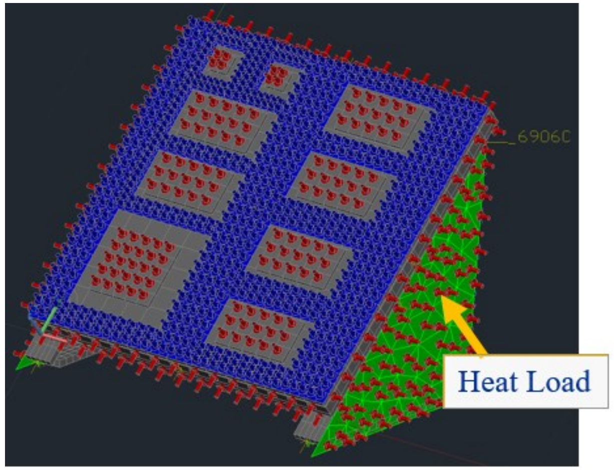


Rendering of PILS mounted on an early Peregrine design

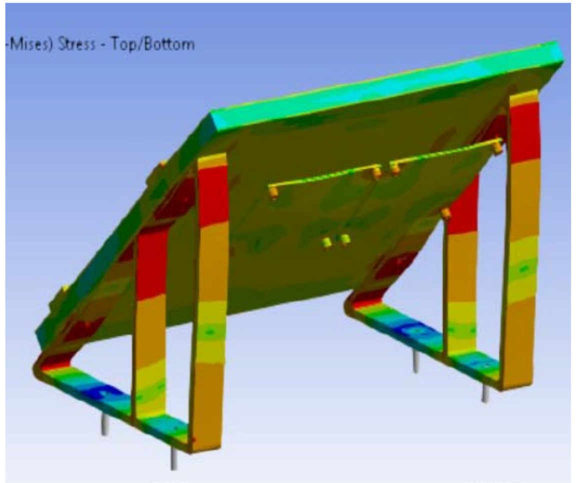
Photovoltaic Investigation on the Lunar Surface (PILS)

Design Consideration – Lessons Learned

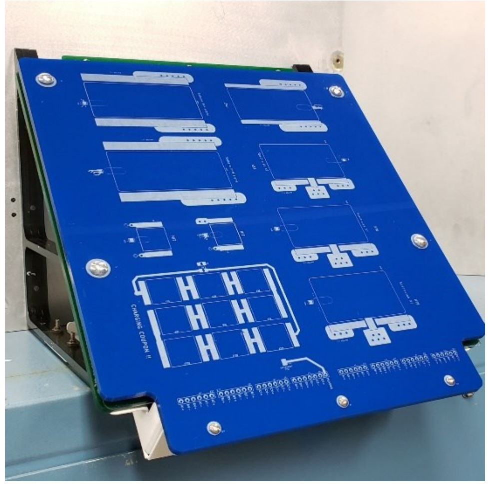
- Initial concept used solar cell high altitude flight calibration holders but they added significant mass. Found a solution to use a single circuit board type top surface to mount the solar cells
- During early design the launch loads were not well known which presented a challenge to design the platform to be lightweight but still robust. Multiple iterations were considered and modeled to get to the final design.
- 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 Thermal Analysis Model



PILS Structural Analysis Model

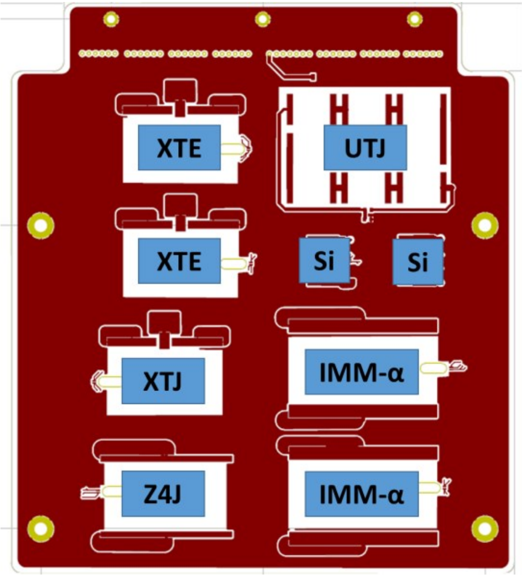


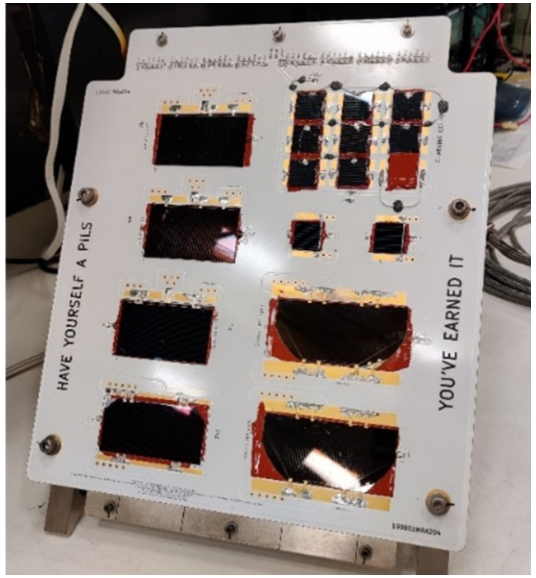
PILS Platform High Fidelity Mock Up

Photovoltaic Investigation on the Lunar Surface (PILS)

Solar Cell Manifest

- (1) 4x8 cm SolAero Z4J, triple junction III-V
- (1) 4x8 cm SpectroLab XTJ prime, triple junction III-V
- (2) 4x8 cm SpectroLab XTE-SF triple junction III-V
- (2) 4x9 cm SolAero IMM alpha 5 junction III-V
- (2) 2x2 cm ASU Silicon Heterojunction Intrinsic Thin Film (HIT)
- (8) 2x2 cm Spectrolab UTJ triple junction III-V with ITO coated connected coverglass for Surface Charge Experiment

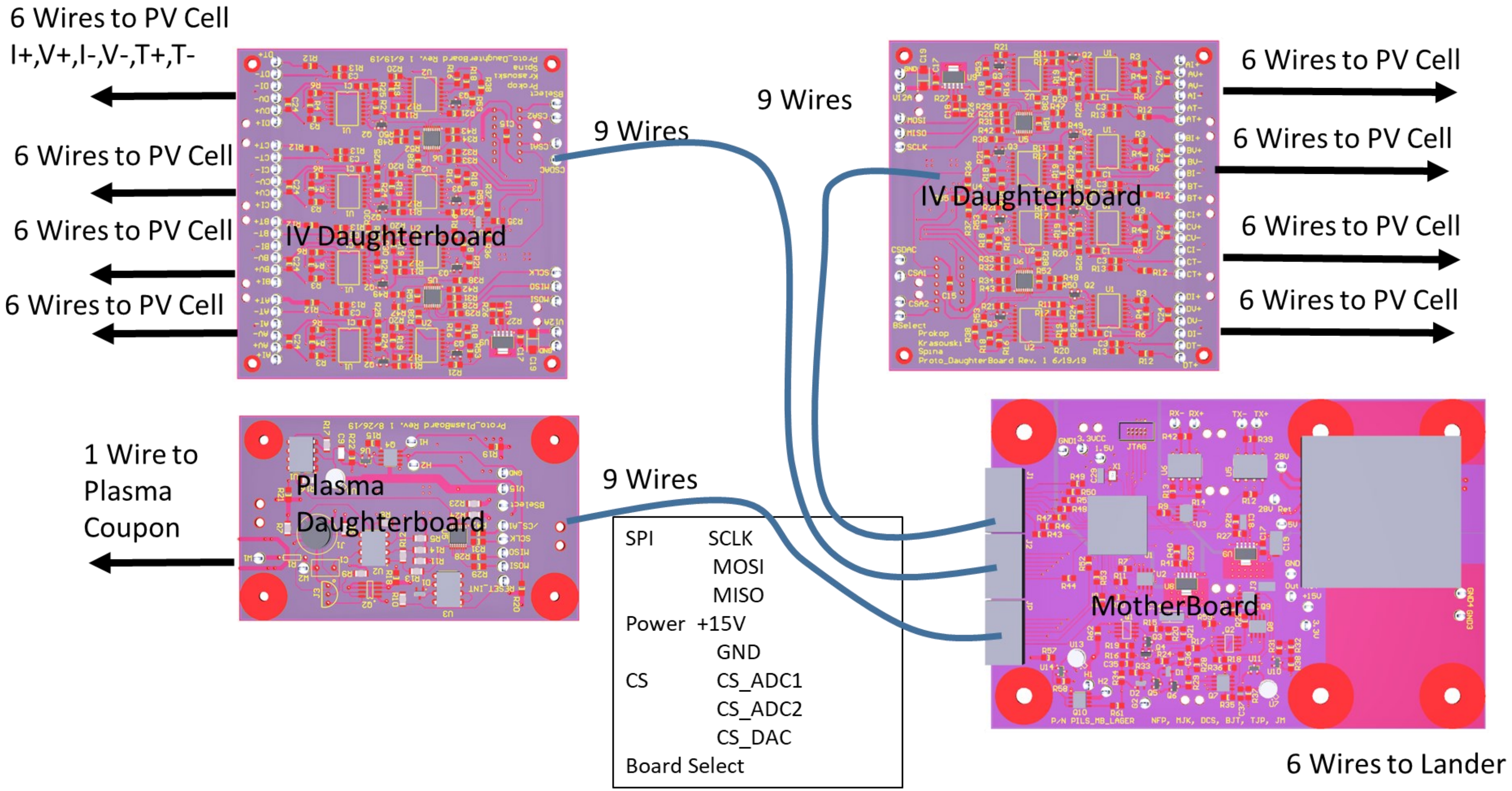




Surface Charge Experiment

- 2x2cm UTJ solar cells strung in series and shorted through a burden resistor which sets a bias potential from 0V to 18V
- Maximum current is approximately 100mA, not enough for secondary arcing under any voltage.
- Solar cell coverglass 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 to be fed to plasma monitoring measurement board

PILS Architecture



6 Wires to PV Cell
I+,V+,I-,V-,T+,T-

6 Wires to PV Cell

6 Wires to PV Cell

6 Wires to PV Cell

IV Daughterboard

9 Wires

9 Wires

IV Daughterboard

6 Wires to PV Cell

6 Wires to PV Cell

6 Wires to PV Cell

6 Wires to PV Cell

1 Wire to Plasma Coupon

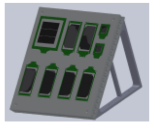
Plasma Daughterboard

9 Wires

MotherBoard

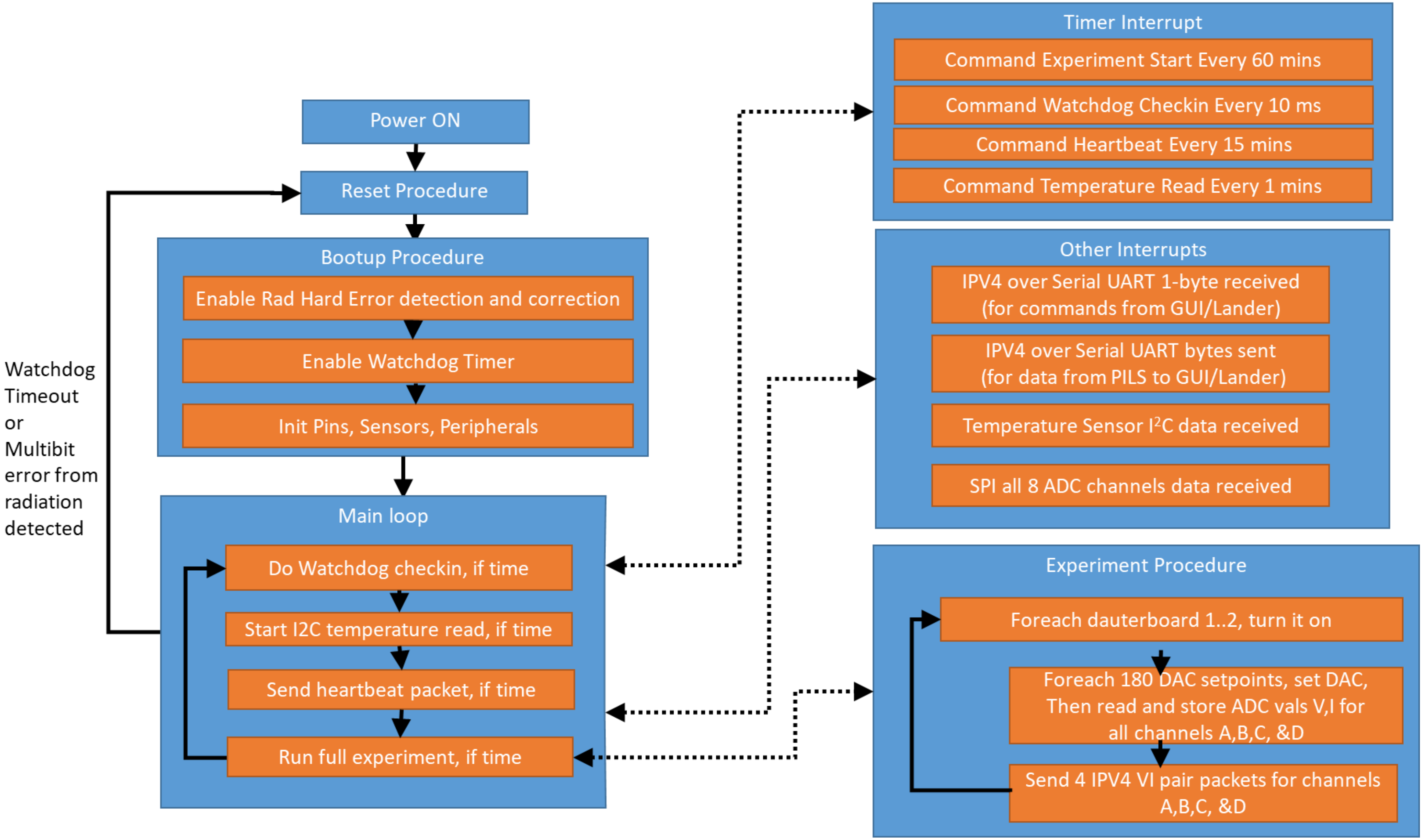
6 Wires to Lander

SPI	SCLK
	MOSI
	MISO
Power	+15V
	GND
CS	CS_ADC1
	CS_ADC2
	CS_DAC
Board Select	



PILS

PILS Software Flow



Power ON

Reset Procedure

Bootup Procedure
- Enable Rad Hard Error detection and correction
- Enable Watchdog Timer
- Init Pins, Sensors, Peripherals

Main loop
- Do Watchdog checkin, if time
- Start I2C temperature read, if time
- Send heartbeat packet, if time
- Run full experiment, if time

Watchdog Timeout or Multibit error from radiation detected

Timer Interrupt
- Command Experiment Start Every 60 mins
- Command Watchdog Checkin Every 10 ms
- Command Heartbeat Every 15 mins
- Command Temperature Read Every 1 mins

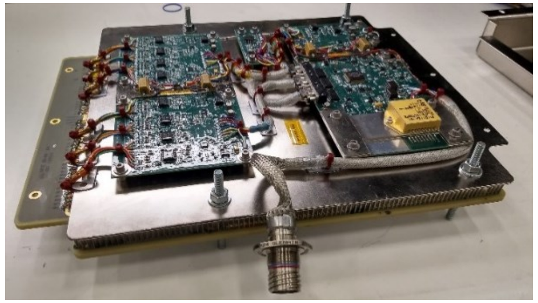
Other Interrupts
- IPV4 over Serial UART 1-byte received (for commands from GUI/Lander)
- IPV4 over Serial UART bytes sent (for data from PILS to GUI/Lander)
- Temperature Sensor I^2C data received
- SPI all 8 ADC channels data received

Experiment Procedure
- Foreach dauterboard 1..2, turn it on
- Foreach 180 DAC setpoints, set DAC, Then read and store ADC vals V,I for all channels A,B,C, &D
- Send 4 IPV4 VI pair packets for channels A,B,C, &D

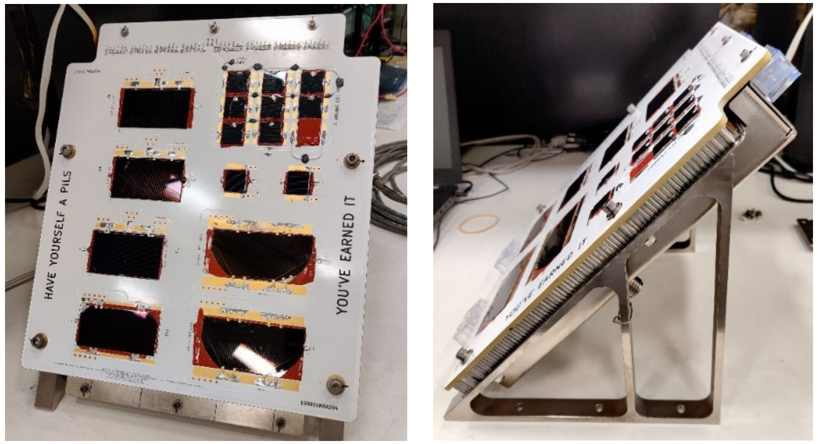
Photovoltaic Investigation on the Lunar Surface (PILS)

Finalizing Design

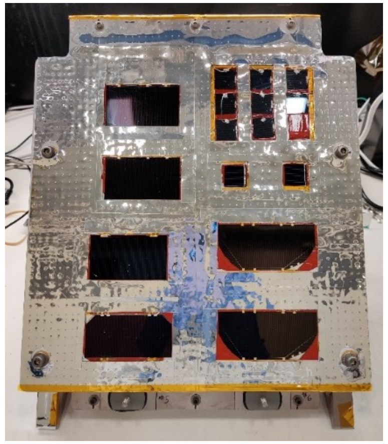
- Astrobotic made a configuration change to the lander, adding walls to two sides
- PILS was now cantilevered off the wall and exposed to additional thermal conditions from the lunar surface
- Software and hardware designs were locked, build and assembly began
- Benchtop testing with Astrobotic payload simulator occurred
- Environmental testing occurred (thermal, vibe, EMI)



Software/Hardware Checkout



Assembled PILS Flight Unit

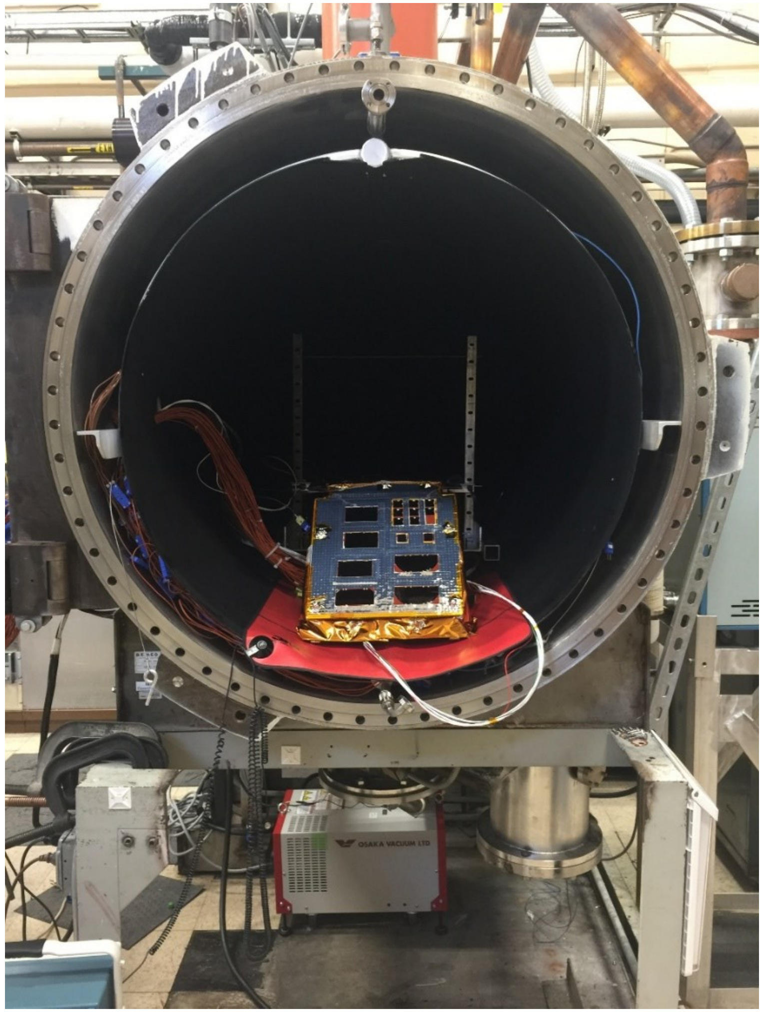


Assembled PILS Flight Unit with Thermal Tape Applied to Top Surface

Photovoltaic Investigation on the Lunar Surface (PILS)

Thermal Testing

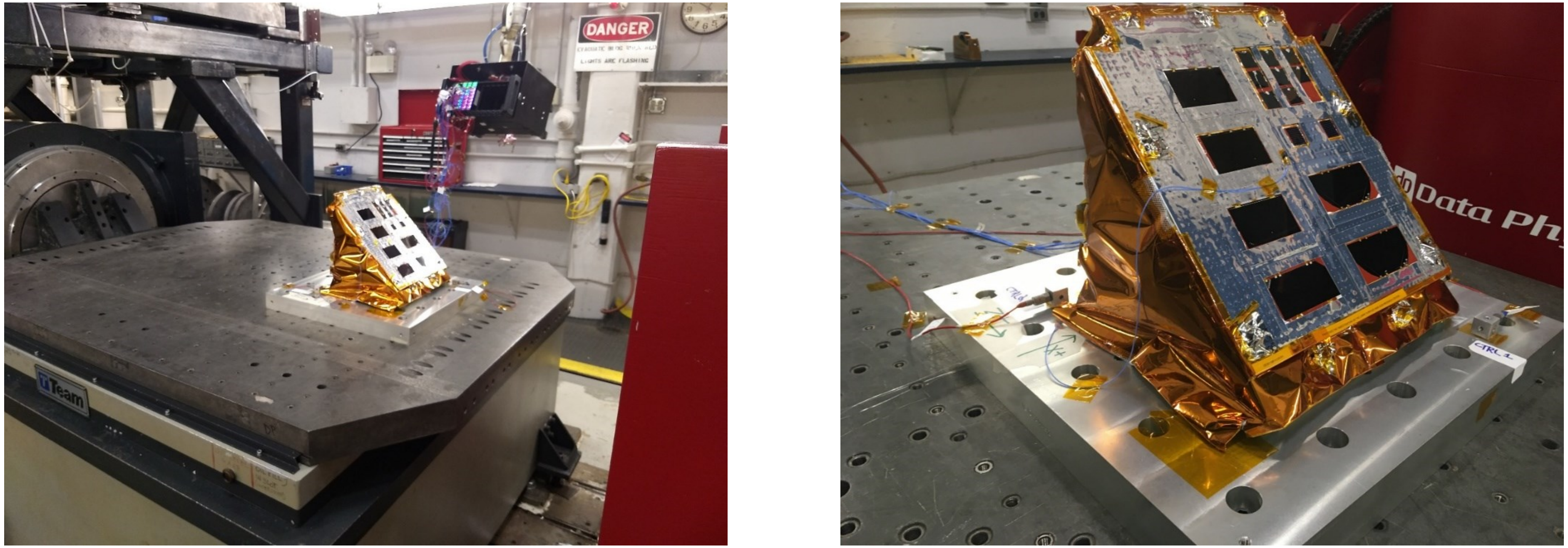
- Testing to ensure survival and operation at expected temperature extremes
  - Range from -40 C to 80 C
- Tested performance in a horizontal vacuum chamber outfitted with a liquid nitrogen cold wall.
- Platform was illuminated by a Spectrolab X25 solar simulator outside the chamber through a quartz window
- Operation was verified through 4 thermal cycles with a cold start performed during the final cycle. The platform operated successfully throughout the tests.



Photovoltaic Investigation on the Lunar Surface (PILS)

Structural/Vibe Testing

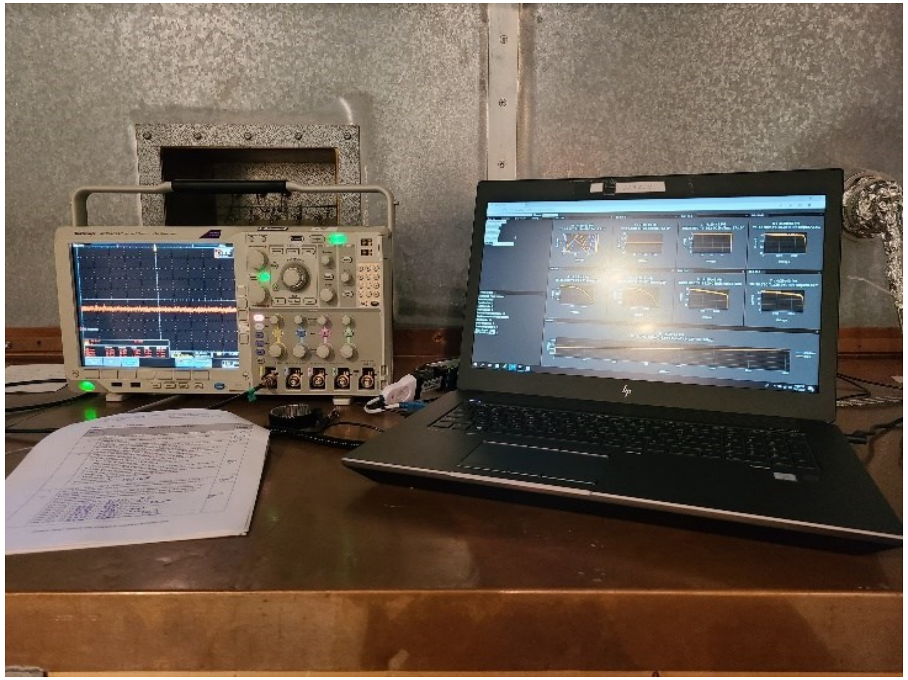
- Modal and structural analyses were performed on the platform to meet the “do no harm” requirement and to ensure that it would survive launch
- The flight hardware was tested in the GRC Structural Dynamics Laboratory under random vibe
- Functional testing was performed pre and post vibe. There was no change in performance and no damage occurred



Photovoltaic Investigation on the Lunar Surface (PILS)

Electromagnetic Interference Testing

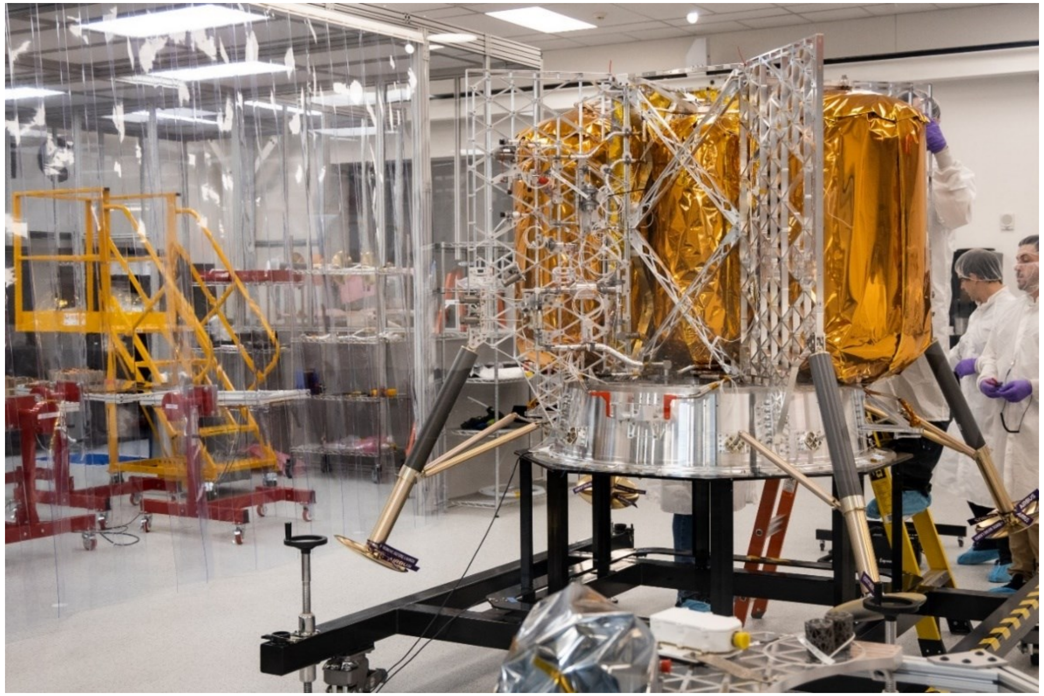
- Testing was required to ensure PILS was not susceptible to external electromagnetic signals and that it was not emitting any signals that could interfere with the lander or other payloads
- The hardware was tested following MIL-STD-461G
- Ground software for monitoring performance was ran on a computer in an isolated facility to ensure no loss in communication or data quality
- Hardware passed EMI requirements



Photovoltaic Investigation on the Lunar Surface (PILS)

Integration

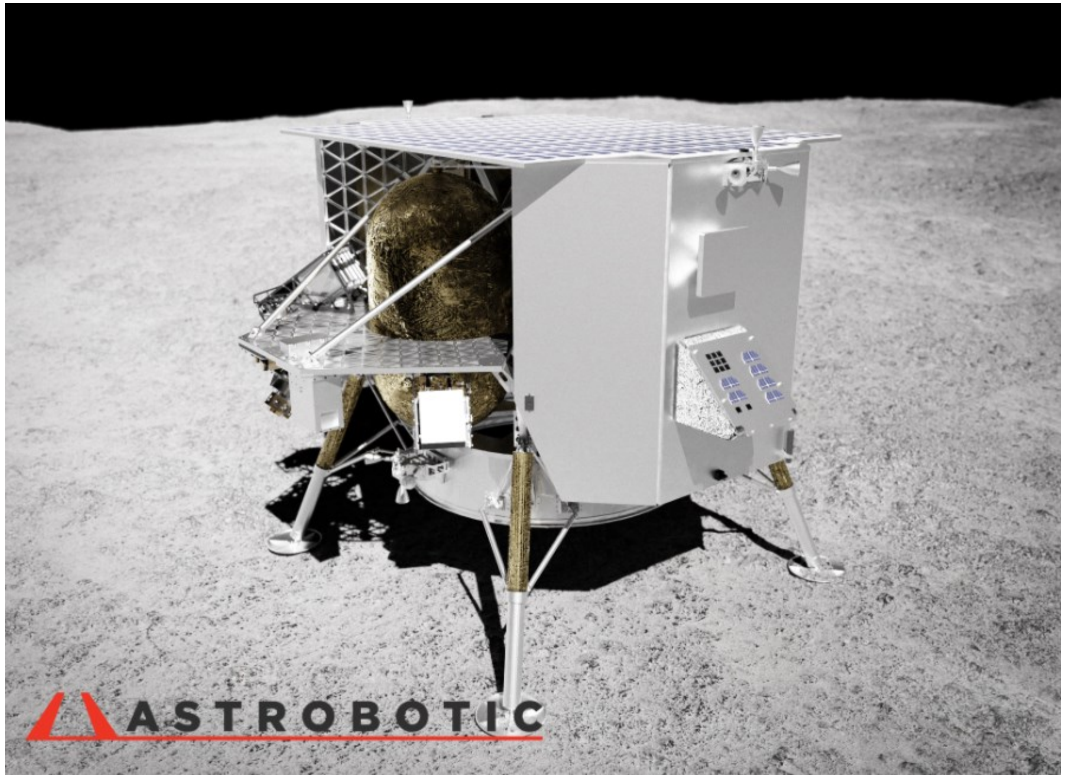
- PILS was shipped to Astrobotic in December 2021 and physically integrated onto the sidewall panel in January 2022
- Astrobotic continues to build Peregrine and the PILS panel is expected to be integrated onto lander in late August (physical and electrical integration followed by functional testing)
- Peregrine will go through environmental testing where PILS will be functionally tested after major tests



Photovoltaic Investigation on the Lunar Surface (PILS)

Next Step: To the MOON!

- Peregrine will launch on the United Launch Alliance Vulcan Centaur and head to the moon
- The PILS team will monitor hardware performance and collect data from shortly after launch through the end of the lunar surface phase of the mission
- After the mission is completed, the team will report out on performance of the hardware, the cells (I, V, temperature), and of the charge accumulation on the small array
- The team is interested in a possible PILS-2 (and beyond) at different locations on the lunar surface and with different cell technologies



Photovoltaic Investigation on the Lunar Surface (PILS)

Acknowledgements

The PILS team

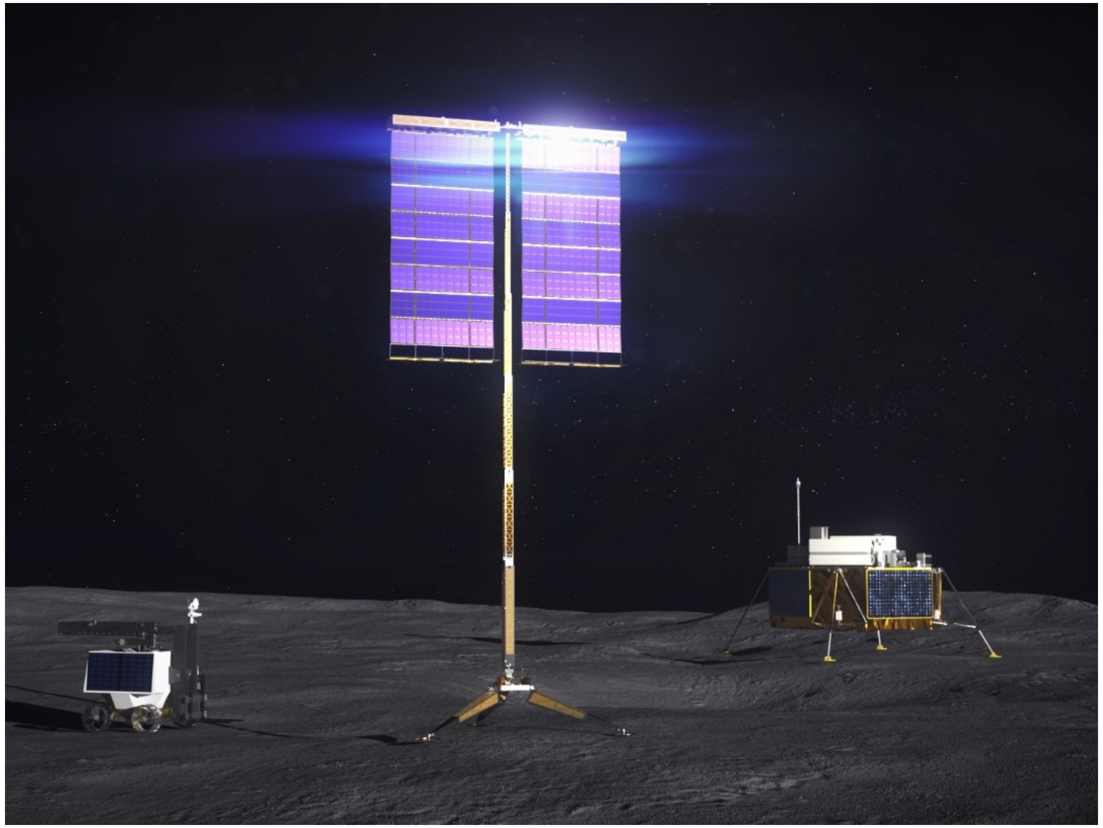
- Timothy Peshek
- Mathew Deminico
- Norman Prokop
- Michael Krasowski
- Brian Tomko
- Greeta Thaikattil
- John Heese
- Joseph Francz
- Katherine McGinnis
- Brian Morris
- Linda Nero
- Abigail Rodriquez
- Trish Seaman
- Amy Stalker
- Lowell Wolfe
- Kaiser Aquirre

- Astrobotic

- Arizona State University,
- Spectrolab
- SolAero

- NASA Science Mission Directorate CLPS Office

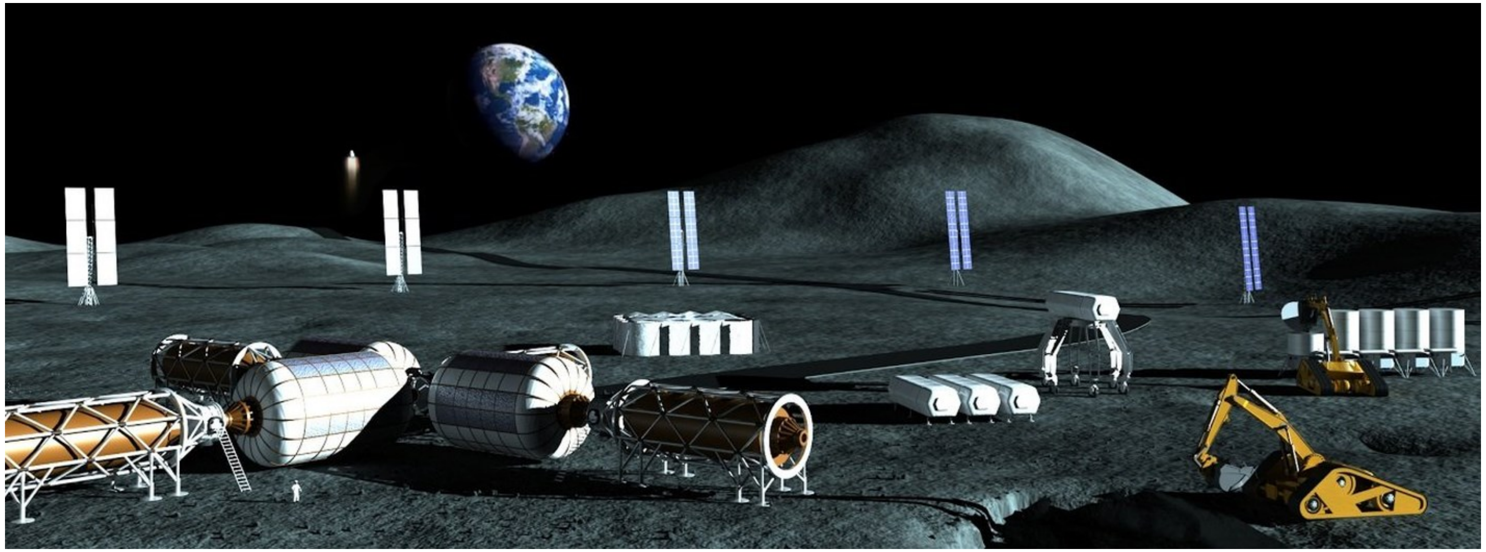
Vertical Solar Array Structures (VSAT)



Program Overview

- Vertical Solar Array Technology (VSAT) for Lunar Surface
  - NASA STMD Game Changing Development program
  - Led by NASA Langley and NASA Glenn (Richard Pappa/LaRC and AnnaMaria Pal/GRC)

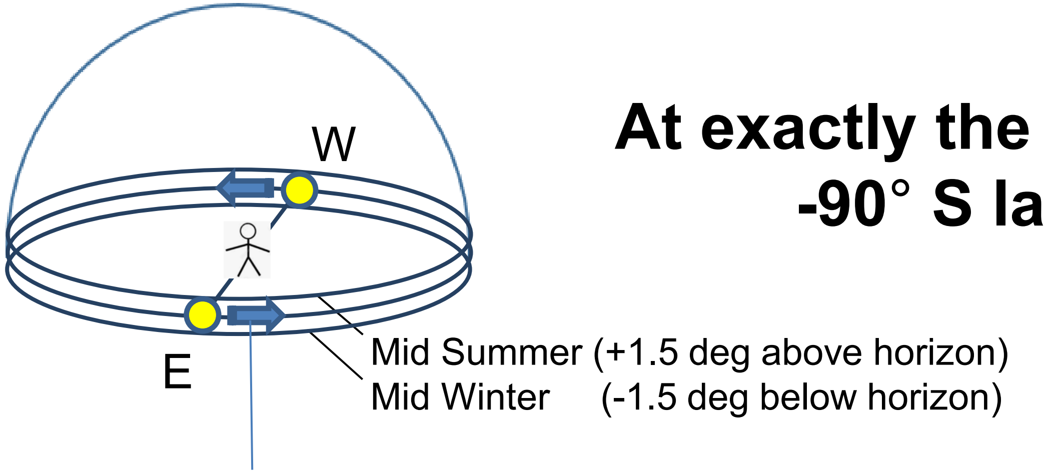
- Autonomous deployment, 10kW class systems
- 10 meter minimum height at bottom of the array
- Stable on steep terrain (adaptable to deploy vertically on slanted terrain up to 15 degrees)
- Resistant to abrasive lunar dust
- Minimized both mass and packaged volume for ease in delivery to the lunar surface



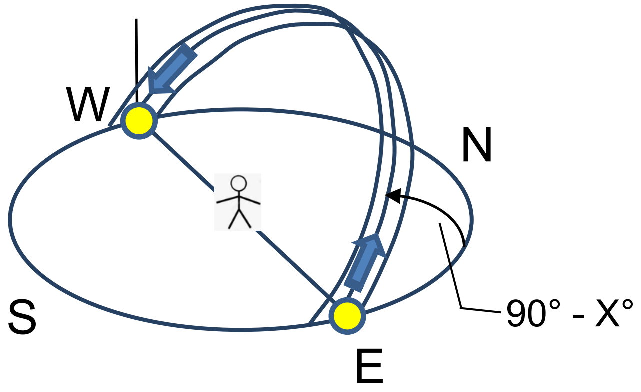
Motivation

- Lunar polar locations are of high interest for many NASA missions due to potential for ice and materials in permanently shadowed craters

- Moon’s rotation is slow, approximately 1 rotation every 29.5 Earth days
- Moon's equatorial plane is tilted by only 1.5°
- Locations exist that can have long durations of illumination with minimum shadowing (down to <100 hours) at high elevations



At exactly the South Pole, -90° S latitude

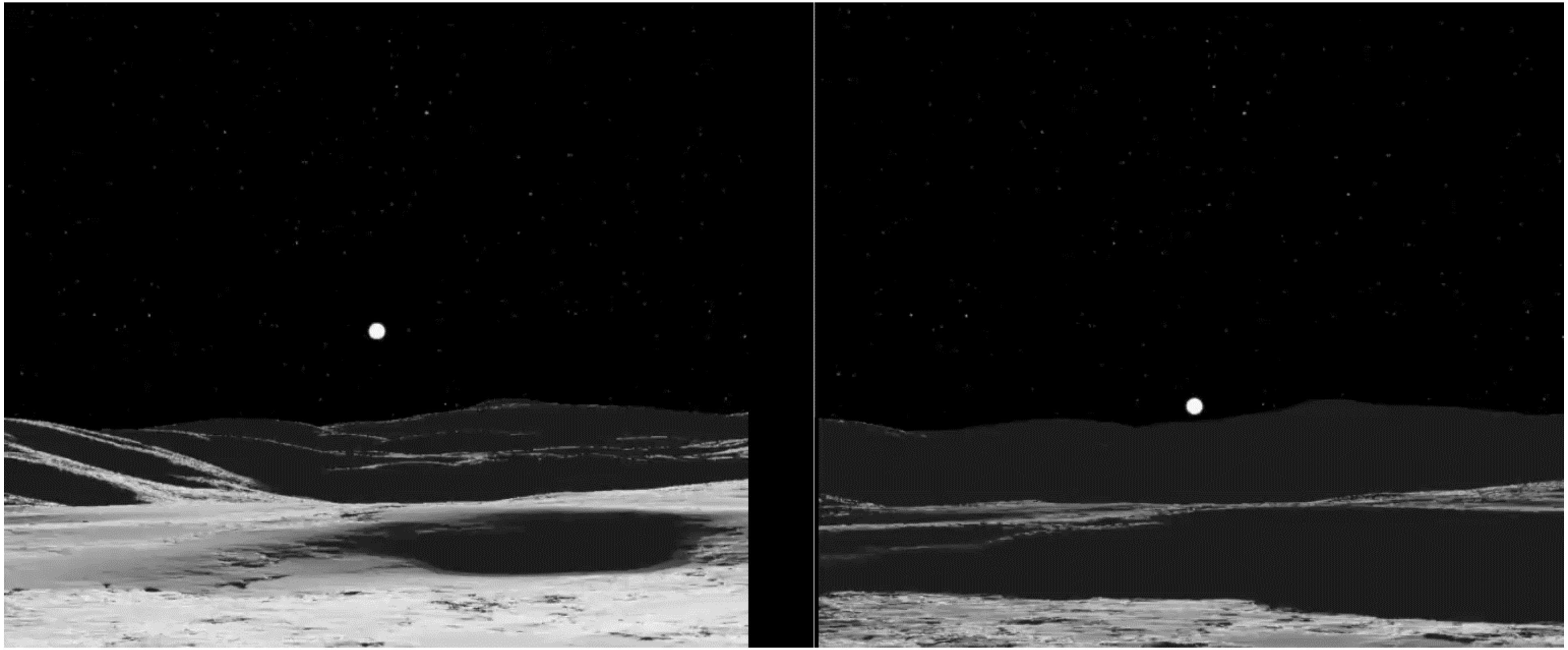


In general, at -X° S latitude, Sun paths tilt up by 90° - X°

For example, at -88° S latitude, Sun paths tilt up by 2°

Motivation

Sun Paths at an Elevated Site Near the South Pole (Movie)



At Mid-Summer **At Mid-Winter**

video shows 1 full lunar day

Provided by James Fincannon, GRC

Initial (Base) Phase

Base period contracts, valued at up to $700,000 each, awarded as 12 - month fixed price contracts to:

- Astrobotic Technology, Pittsburgh, PA
- Northrop Grumman (ATK), Goleta, CA
- Honeybee Robotics, Brooklyn, NY
- Lockheed Martin, Littleton, CO
- Maxar Technologies, Palo Alto, CA

Contracts started in Spring 2021 to further system design, perform initial testing and modeling and prepare plans for Option Phase which includes scaled hardware testing

Plan was to down select up to two companies and provide additional funding, up to $7.5 million each, to build prototypes and perform environmental testing

Option Phase

Option Phase Award was announced on August 23, 2022. https://www.nasa.gov/press-release/three-companies-to-help-nasa-advance-solar-array-technology-for-moon

3 Companies selected to go forward to build hardware for environmental testing

- Astrobotic Technology of Pittsburgh, Pennsylvania: $6.2 million
- Honeybee Robotics of Brooklyn, New York: $7 million
- Lockheed Martin of Littleton, Colorado: $6.2 million

Projects will start soon with thermal vacuum testing planned for early 2024