JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

LSIC Surface Power Telecon

May 25th, 2023

Begins at 11:03

Lunar Surface Innovation
CONSORTIUM

Dr. Matt Clement, Dr. James Mastandrea, Dr. Sean Young,
Sam Andrade, Julie Peck, Dr. Joseph Kozak, Claire Trop
Johns Hopkins Applied Physics Laboratory
Space Exploration Sector

LSIC Surface Power Facilitator POC: matt.clement@jhuapl.edu

LSIC | Agenda

- Community Updates
  - Solicitations and Awards
  - Conferences/Workshops/Telecons
    - June 7 (1PM ET): LSIC Interoperability Telecon (David LaBranche, DoD SDSFIE)
    - July 12-13: LSIC Lunar Proving Grounds Workshop
    - July 26-27: LSIC Surface Power Reliability Workshop
- LSIC Spring Meeting Summary (Sam Andrade)
- NASA VSAT Phase 2
  - **NASA**
    - Chuck Taylor (VSAT PM)
  - **Lockheed Martin**
    - Ryan Wiseman (Systems Engineering Lead and Deputy PM)
  - **Honeybee Robotics**
    - Dean Bergman (Director of Strategy and Development for Exploration Systems)
  - **Astrobotic**
    - John Landreneau (Project Manager, Lunar Surface Systems)
- Q&A

LSIC | Solicitations and Awards

Space Tech Solicitations (https://www.nasa.gov/directorates/spacetech/solicitations)

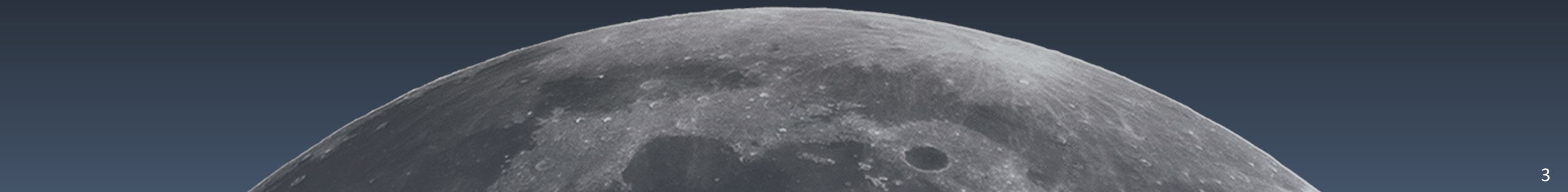
University Smallsat Technology Partnership (USTP)
Full Proposals Due: July 18, 2023

Early Stage Innovation Solicitation
SOLICITATION IS OUT!!!
NOIs Due: June 7, 2023
Proposals Due: July 6, 2023

TechFlights Solicitation
SOLICITATION IS OUT!!!
Preliminary Proposals Due: June 7, 2023
Final Proposals Due: October 4, 2023

NIAC Phase I Proposals
Solicitation release coming in June!

Space Technology Research Institutes (STRI)
Solicitation release coming in 2024!



LSIC | Upcoming Meetings and Workshops

Space Resources Roundtable (SRR)
June 2-5, Golden, CO

LSIC Interoperability Monthly Telecon
June 7, 1PM ET, Virtual

IEEE Cognitive Communications for Aerospace Applications
June 21-22, Virtual

LSIC Lunar Proving Grounds Workshop
July 12-13, HYBRID: Laurel, MD and Virtual

LSIC Surface Power Reliability Workshop
July 26-27, Virtual

More complete calendar on LSIC website, email with additional events!

LSIC | May Telecon

We hope to see you all at our next telecon, which will take place on **Thursday June 22nd, 2023 at 11:00AM ET.**

Theme: Power Requirements for Lunar Habitats

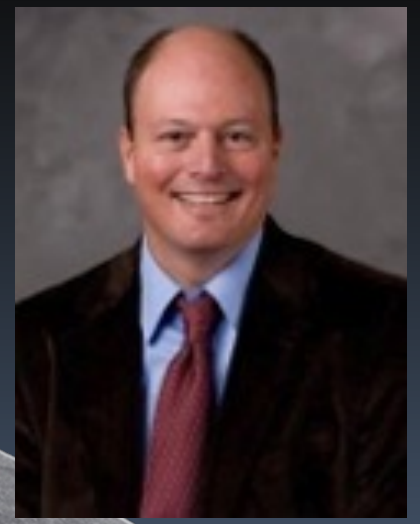
Speakers:

- **Paul Kessler (NASA LaRC)**
  NASA Surface Habitat Lead Architect
- **Ali Bazzi (UConn)**
  Resilient ExtraTerrestrial Habitats research institute (RETHi)
- **Marshall Porterfield (Purdue)**
  Professor of Agricultural and Biological Engineering

Paul Kessler

Ali Bazzi

Marshall Porterfield

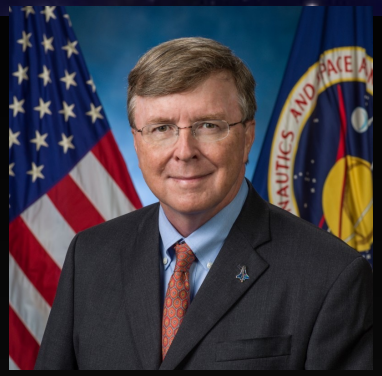


LSIC | Surface Power Reliability Workshop

- Date: July 26-27
- Time: 11:00AM – 3:30 PM ET
- Location: Virtual via Zoom
- Abstracts Due: 30 June

- ***REGISTRATION AND ABSTRACT SUBMISSION ARE OPEN***

- How do we approach reliability from the system/grid level and how should this affect the early-TRL development at the component level?



John Scott (NASA)
Principal Technologist
Power & Energy Storage

Clay Smith (APL)
ISS Probabilistic Risk Assessment Creator

David McGlone (NAVSEA)
Director
Submarine Safety Program

Joe Miller (NSF)
Antarctic Facilities Program Manager

Jim Soeder (NASA, ret.)
Senior Power Technologist (08-21)
Power Development Chief (87-08)

Roger Boyer (NASA)
Artemis Probabilistic Risk Assessment Lead

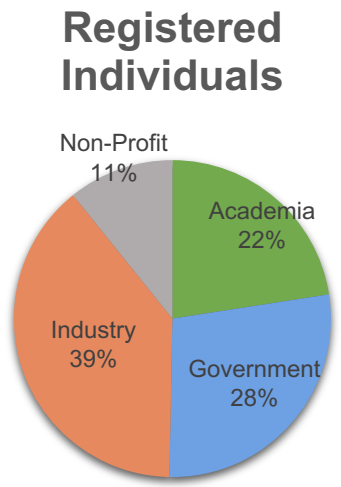
Blanca Lara (NASA)
JSC EHP Lunar Power Lead

Bill Anderson (NAVFAC)
Director of Utilities and Energy Management

LSIC | Spring Meeting, April 24th-25th, 2023

The Lunar Surface Innovation Consortium (LSIC) Spring Meeting, hosted by the Johns Hopkins Applied Physics Laboratory, provided a forum for NASA and the community to discuss NASA's Moon to Mars Architecture, as well as how government is working across agencies to support the goal of returning humans to the surface of the Moon, to stay.

Over the course of two days, over 550 individuals, representing >265 institutions attended. Half of those who attended have not worked with NASA's Space Tech before.



Key Meeting Findings

- The community is supportive of the Moon to Mars architecture, and advocates for further development of the sustainable lunar phase. NASA's transparency in their process is well-received, and the community appreciated the candor of discussion even when no definite answer was possible.
- Many international participants voiced their questions and comments, showing global interest in NASA's objectives
- Activities on the lunar surface will be critical for retiring risks and learning to live off-world, both for commercial confidence and to advance NASA exploration goals.
- Further development of the plans for transitioning infrastructure development, maintenance, and services to industry is desired.
- Continued discussion about interoperability, among industry and throughout the international community, is needed.
- Now that the architecture plans from NASA are more robust and publicly available, the audience would enjoy hearing more technical details about specific projects by members of the community.

LSIC 2023 Spring Meeting | Major Takeaways

- ✓ **Community**
  - Record-breaking attendance:
    - **Online: 200+, In-Person: 300+**
- ✓ **International Lunar Year**
- ✓ **Moon to Mars Initiative**
  - **Moon as a proving ground offers stability**
  - **Importance and relevance to other NASA efforts**
- ✓ **Commercial Lunar Payload Services (CLPS)**
  - **Block buys of landers**
  - **Expansion of services**
- ✓ **Lunar Surface Technology Research (LuSTR) Program**
- ✓ **Whole Government Engagement in Maturing Cislunar Ecosystem and Policy**
  - **International engagement for lunar operations**
- ✓ **Commercial Sector Engagement**
  - **Desirable to refine business cases and/or value propositions for terrestrial expert organizations**
- ✓ **Interoperability**
  - **Critical; clear need to establish a lunar interoperability laboratory/facility for tech assessment**
  - **Marketplace for components that meet interoperable standards**
- ✓ **Lunar Environment Considerations**
  - **ECLIPSE: *Essential Compilation of Lunar Information in Preparation of Sustained Exploration* – Coming Sept 2023!**
  - **Dust mitigation and thermal management for component and next higher assemblies**
- ✓ **Autonomy**
  - **Needs further development, such as stakeholder-wide definition and frameworks that evaluate capability autonomy levels**

LSIC 2023 Spring Meeting | White Paper Feedback

LSIC Whitepaper

The Path to an Enduring Lunar Presence

Perspectives on key enabling actions that will help our nation and the world move together toward our shared use of the lunar surface.

Access White Paper:
https://lsic.jhuapl.edu/Resources/files/The%20Path%20to%20an%20Enduring%20Lunar%20Presence.pdf

Send feedback to: LSIC-Feedback@jhuapl.edu

NASA Moon to Mars Whitepapers

Architecture Concept Review

Systems Analysis of Architecture Drivers

Why NRHO: The Artemis Orbit

Why Artemis will Focus on the Lunar South Polar Region

Gateway: The Cislunar Springboard for International and Sustainable Human Deep Space Exploration

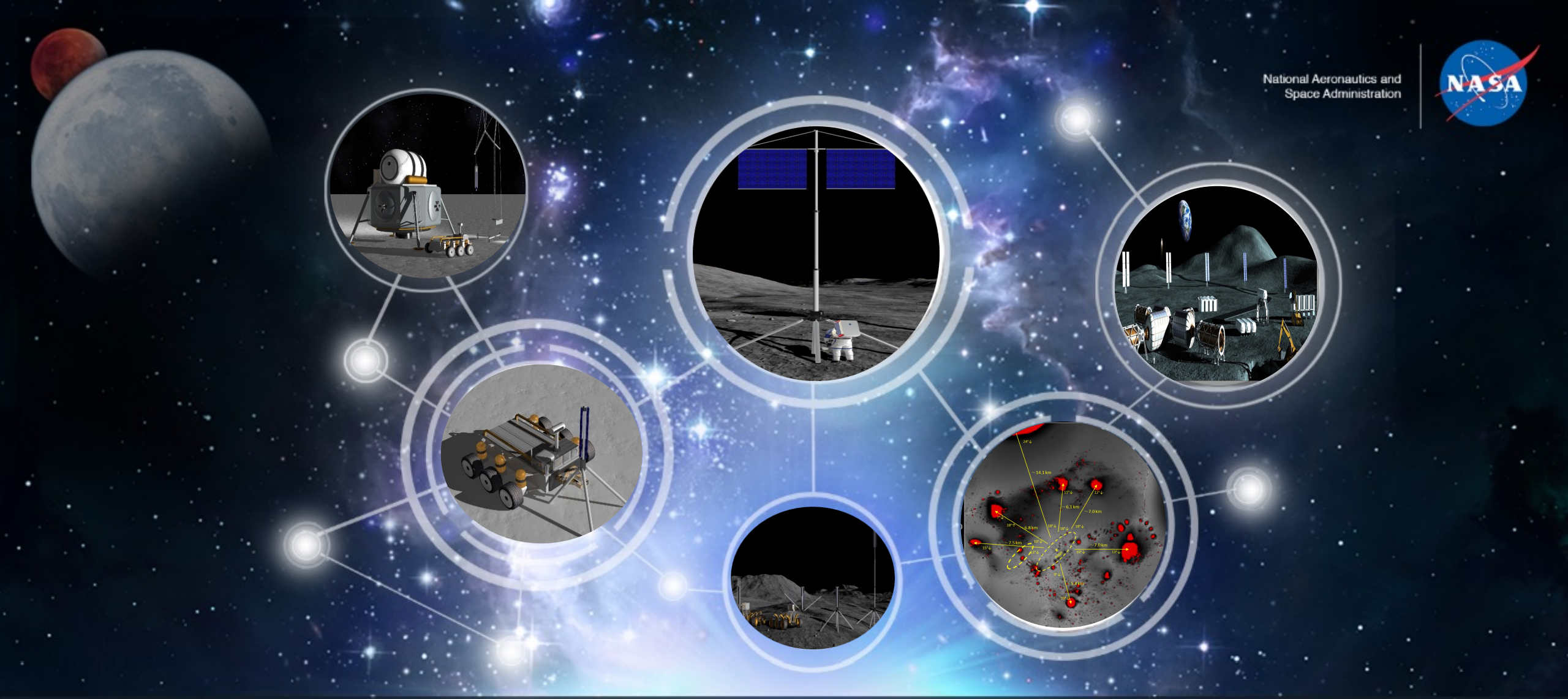
Mars-Forward Capabilities to be Tested at the Moon

Mars Transportation

Access White Papers:
https://www.nasa.gov/MoonToMarsArchitecture

LSIC | Presentation

- Speaker: Chuck Taylor
- NASA VSAT Project Manager



National Aeronautics and Space Administration

NASA

Space Technology Mission Directorate

Game Changing Development Program - Vertical Solar Array Technology Project

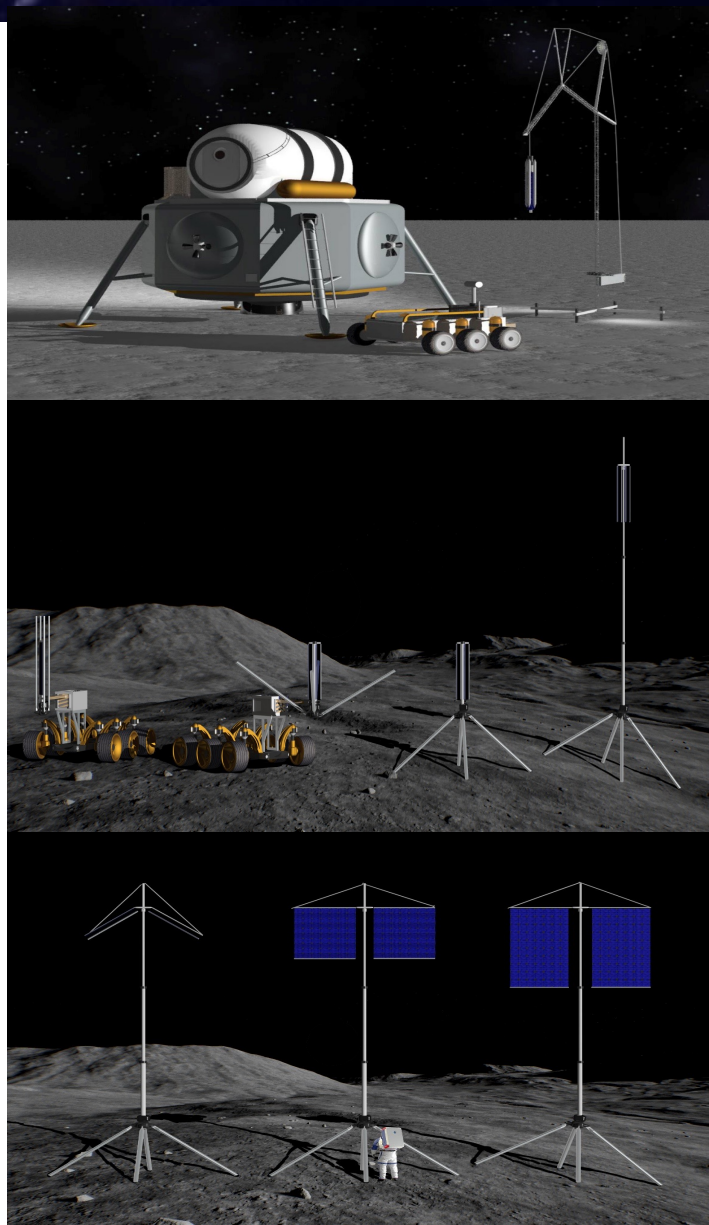
Chuck Taylor PM/Richard Pappa PI

Project Overview

The Vertical Solar Array Technology (VSAT) project is focused on the development of solar array technologies necessary for sustained presence on the lunar surface circa 2028.

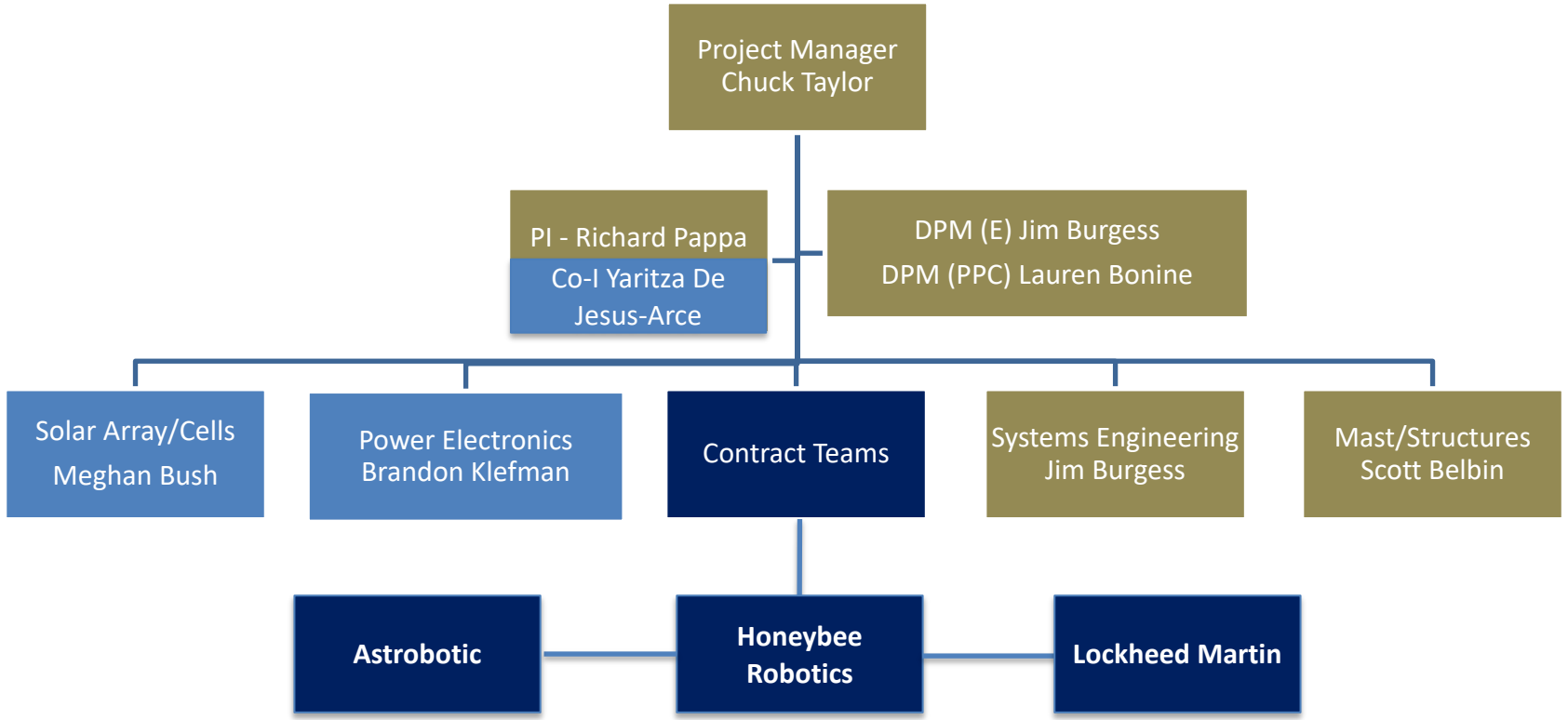
VSAT is exploring:

- **Vertical array deployment on masts of up to 10m in height on uneven terrain (15^0 slope) in order to capture continuous sun light at the lunar south pole.**
- **Mobile systems capable of autonomous deployment and redeployment as mission requires.**
- **Systems capable of providing a minimum of 10kW of power that are adaptable to future mission needs**
- **System capable of surviving illumination outages of ~96hrs**
- **Minimization of system mass and stowed volume**



Artist Conception
VSAT GRD

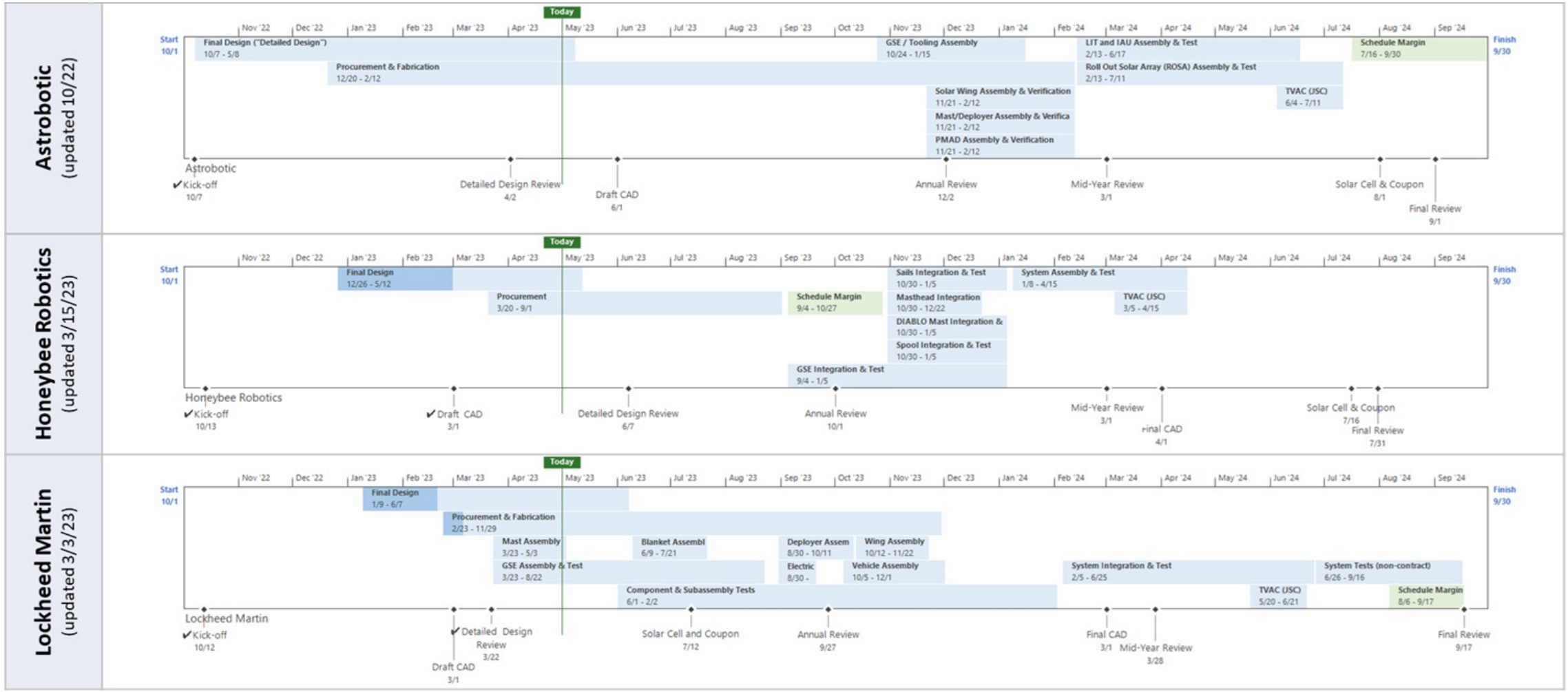
Team Members / Project Org Slide



-- LaRC

-- GRC

VSAT Schedule



Plans Forward
Transition / Infusion Plan

To Be Clear:

- **We are building Prototypes, not Flight Mission Engineering Models**
- **When we started, we didn't have launch vehicles, landing vehicles, mission requirements, or an overarching mission architecture**
- **Our purpose is to reduce risk to future flight mission**
- **Immediate infusion plan is to advertise the three selected vendor prototype efforts as possible steppingstones to both NASA and Industry efforts to put Power Architectures on the Lunar Surface**
- **Internal to STMD we will advocate for the VSAT project to begin work on a "Next Steps" Flight Demonstration solicitation where industry will be encouraged to build a flight version of the their VSAT concept for demonstration on the Lunar Surface circa 2026/7.**

LSIC | Presentation

- Speaker: Ryan Wiseman
- Lockheed Martin
- Systems Engineering Lead and Deputy Project Manager

Lunar Vertical Solar Array Technology (LVSAT)

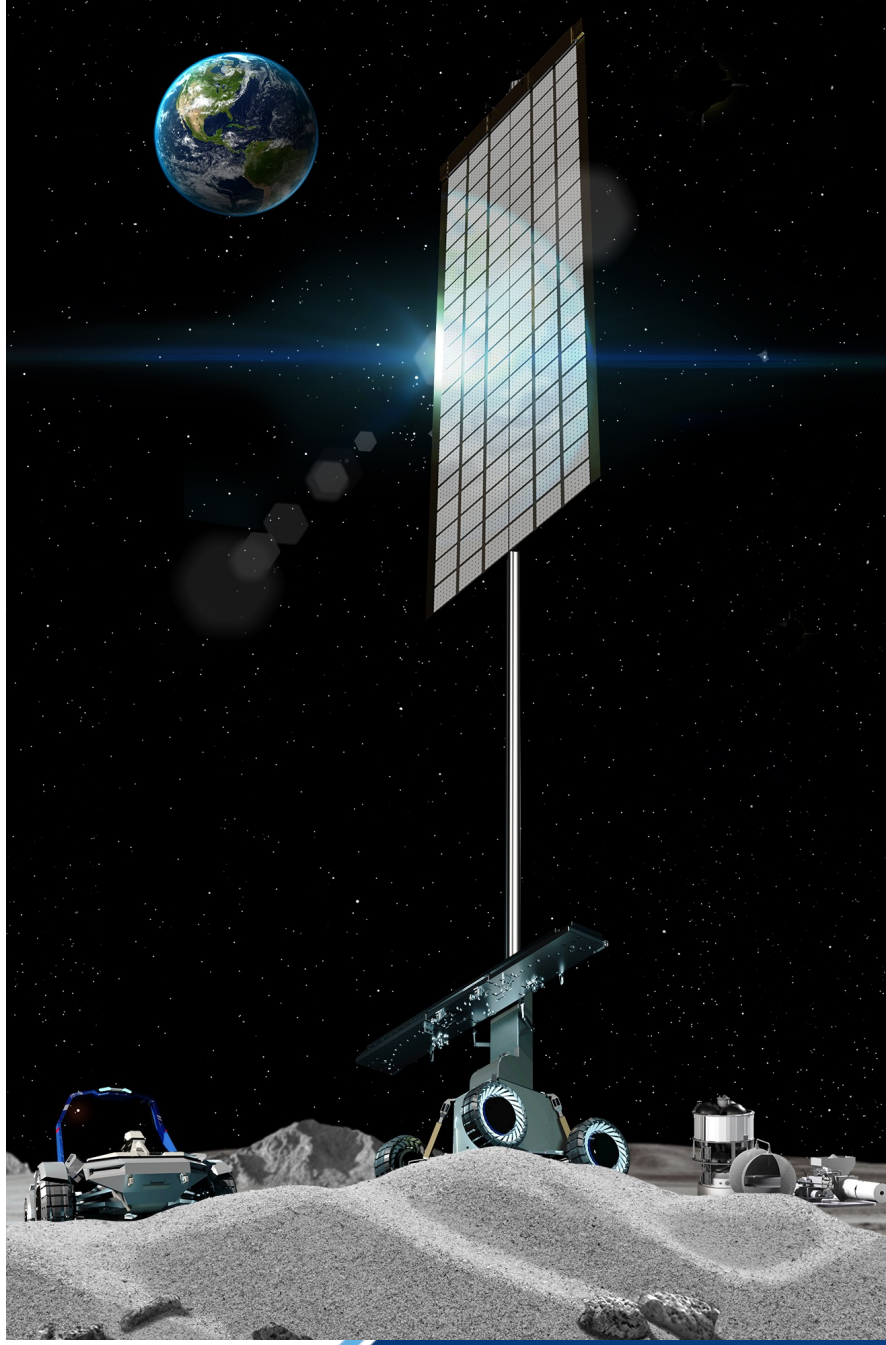
LSIC Surface Power Telecon (5/25/2023)

LOCKHEED MARTIN

Ryan Wiseman, Deputy Program Manager / Chief Systems Engineer

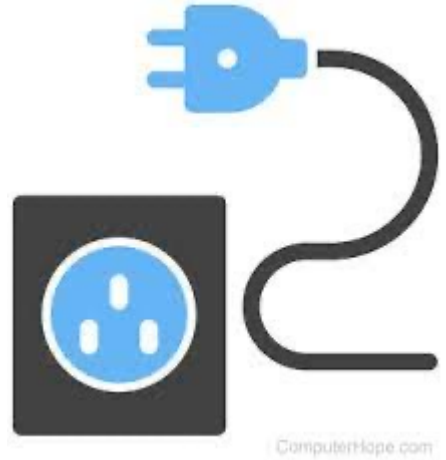
LM LVSAT Overview

- Provides 10kW of relocatable power
  - Rugged enough to survive the harsh lunar environment for up to ten years.
  - Offers 120VDC Bi-directional Power
- Transportable solar power generation by means of wheels, a mobility vehicle, and a z-fold flight-qualified array deployment and retraction mechanism.
- Leverages the heritage TRL-9 Multi-mission Modular Solar Array (MMSA) and flight proven power conditioning and mechanism hardware.
- Provides modular, flexible and reliable power solutions for early implementation in the south pole lunar architecture,
  - Scalable up to 5x the existing design implementation
- Configurable to fit on multiple CLPS landers either as a stand-alone unit or as a power-generating payload



LVSAT Challenges

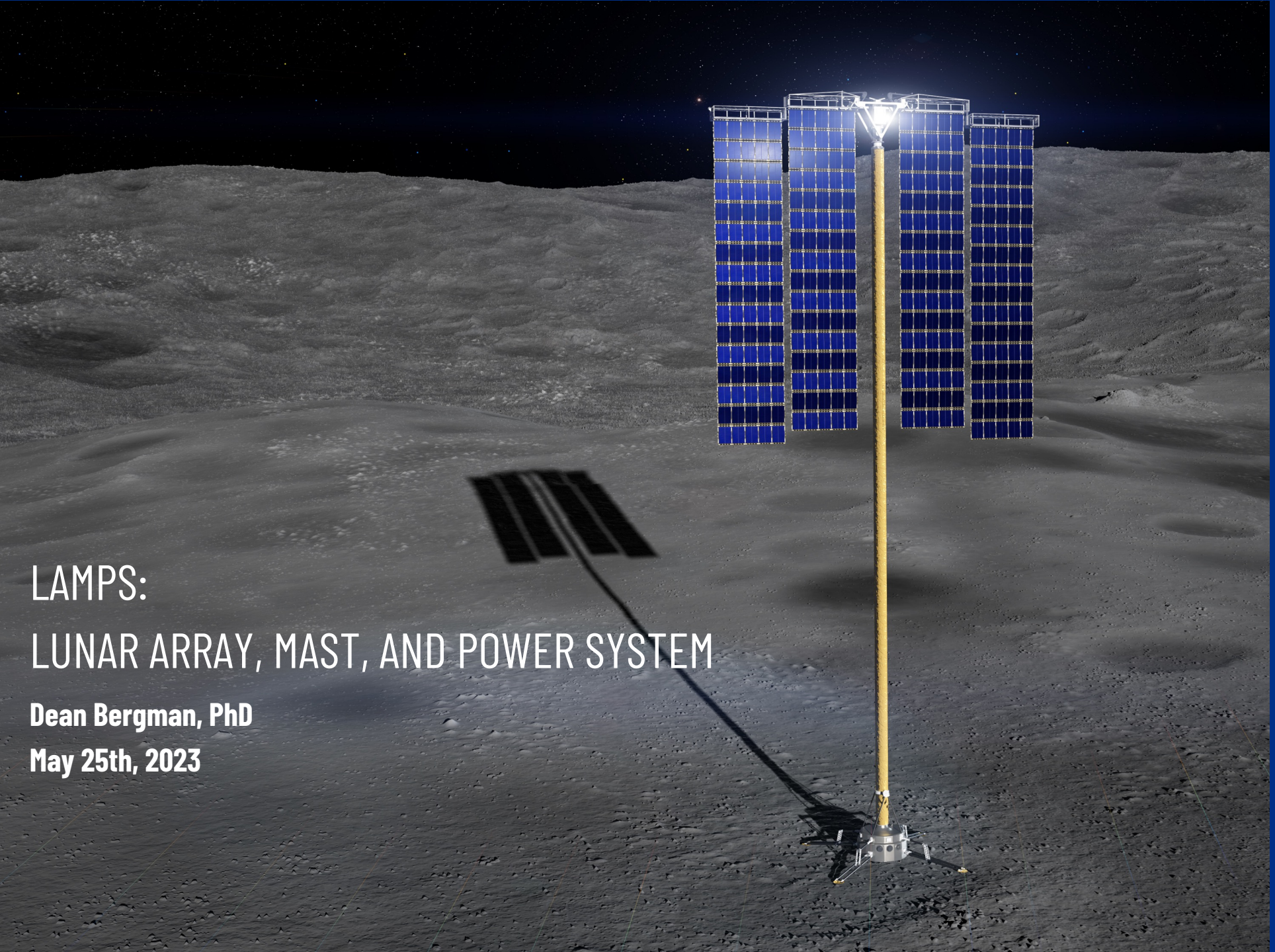
- Lunar Architecture Compatibility – Interface Standardization
  - Need common dust-tolerant connector interface
  - Need common transportation interface
- Dust intrusion and mitigation
  - “Walking on wet talcum powder” – Buzz Aldrin
  - Lunar surface has unique properties from Earth and Mars such as electrostatic and abrasive regolith with no atmosphere for erosion or wind storms to help clean
  - No single simulant can cover all tests
  - 1/6 Earth gravity can lead to high ballistic curves and dust clinging to high surfaces



LOCKHEED MARTIN

LSIC | Presentation

- Speaker: Dean Bergmann
- Honeybee Robotics
- Director of Strategy and Development for Exploration Systems



LAMPS:
LUNAR ARRAY, MAST, AND POWER SYSTEM

Dean Bergman, PhD

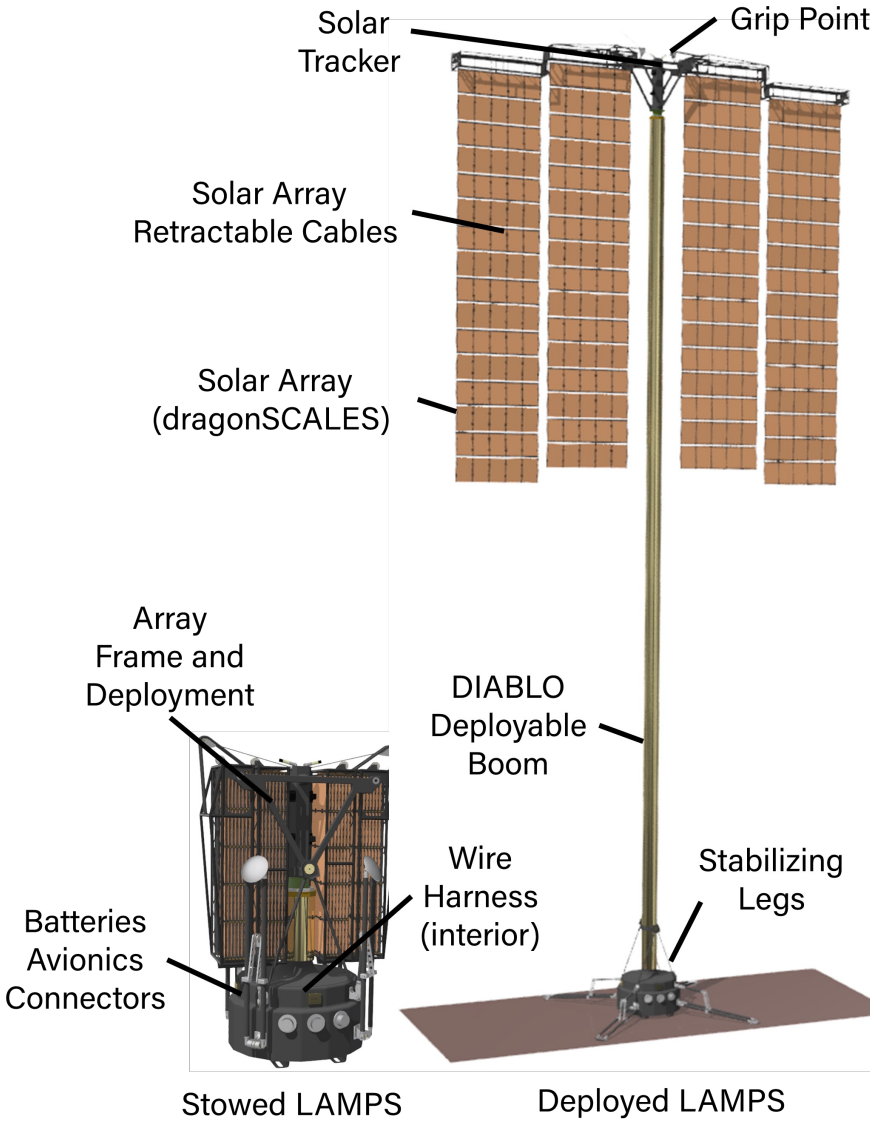
May 25th, 2023

HONEYBEE ROBOTICS
Exploration Technology

mPower
TECHNOLOGY

ISO 9001 CERTIFIED
AS9100C CERTIFIED
13485 PENDING

LAMPS Basics



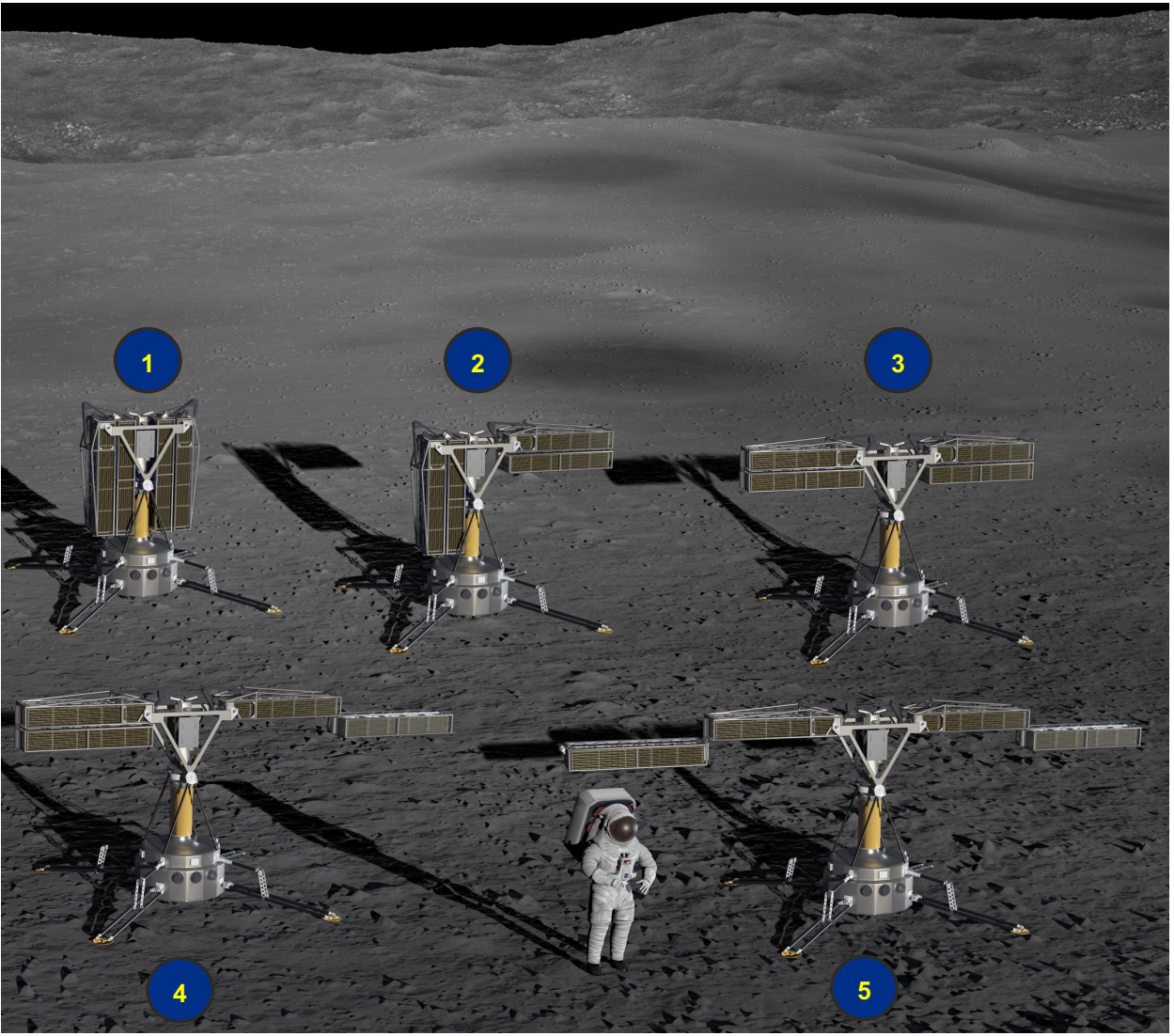
LAMPS is a 10kW mobile, deployable, Lunar vertical solar array.

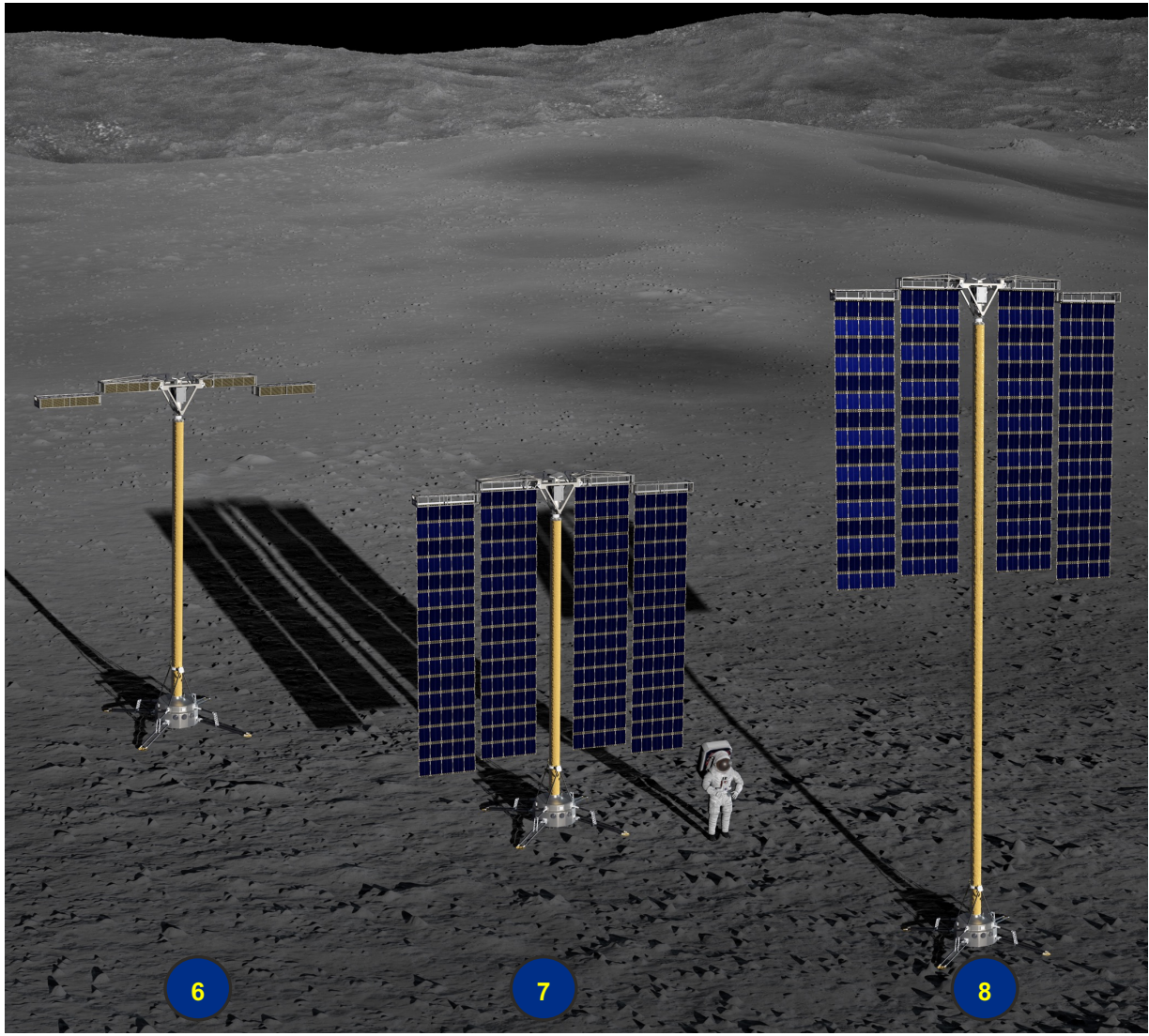
The goal of LAMPS is to jump start Lunar Permanence and provide affordable, as-needed power to a variety of end users.

Key elements of LAMPS:

- dragonSCALES flexible solar panels
- Scalable, deployable boom
- Dust tolerant electrical connectors
- Avionics with Honeybee flight heritage
- Self leveling subsystem
- Low temperature and dust tolerant actuators

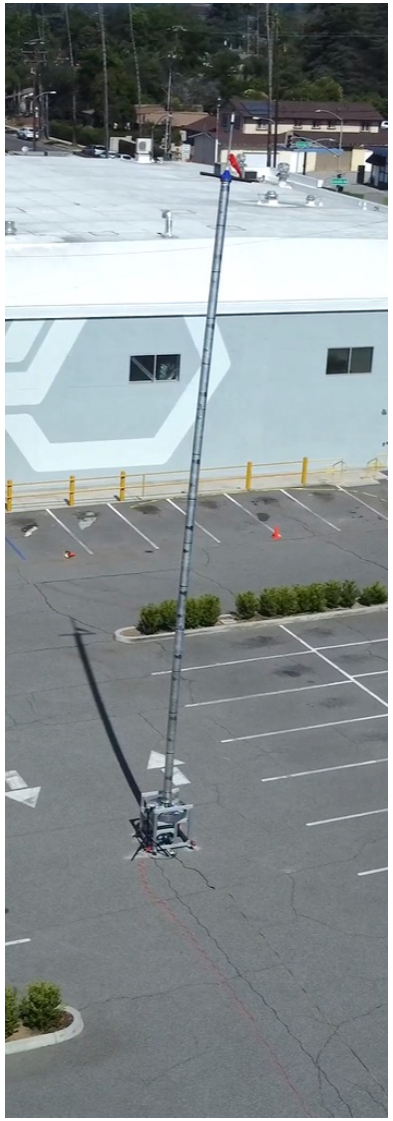
LAMPS Deployment Sequence





LAMPS Key Elements: DIABLO

- The Deployable Interlocking Actuated Band for Linear Operations (DIABLO) is both a **deployable boom system** and a pneumatic drilling / subsurface instrument emplacement system.
- DIABLO bends its initially flat sheets into a tubular shape, giving it a **small initial volume** and a **scalable diameter** based on the systems height and mass carrying needs.
- The LAMPS DIABLO boom uses stainless steel sheets and **holds over 60kg up to 20m from the surface**.
- DIABLO was initially developed through NASA DALI funding.

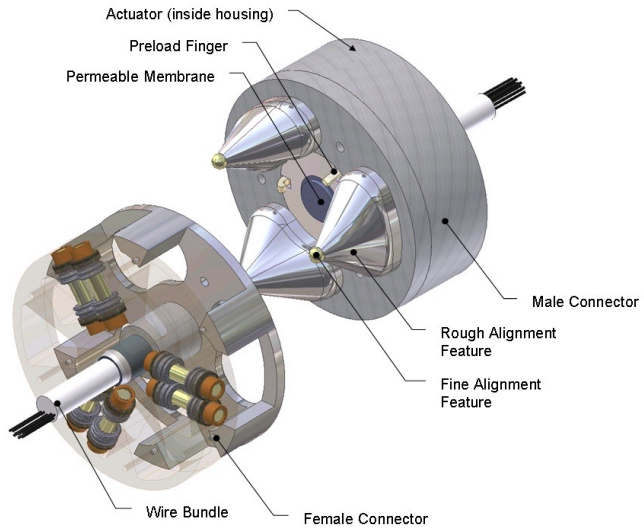


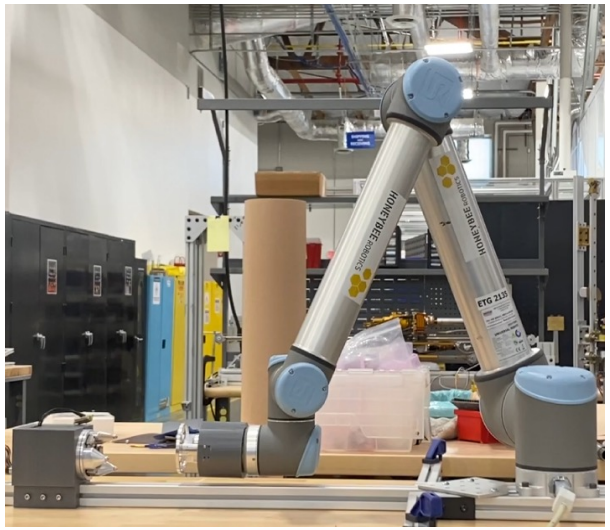
LAMPS Key Elements: Dust Tolerant Connector

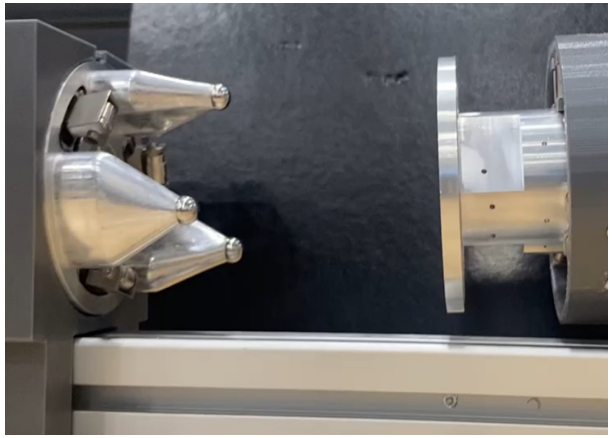
HONEYBEE ROBOTICS

mPower TECHNOLOGY

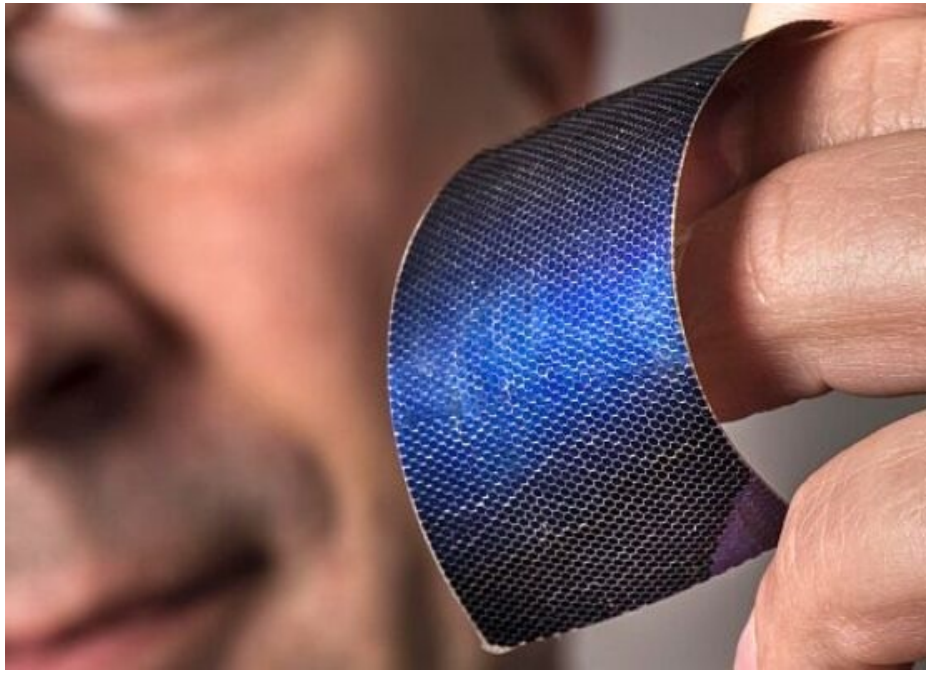
- The Dust Tolerant Connector (DTC) is a key technology for LAMPS, interfacing with payloads for two-way power and data.
- Two versions, one for astronaut operation and one for robotic operation
- DTC tested for dust clogging and connection (500+ cycles)
- Operated in plasma environment at cryogenic temperatures
- Baseline max voltage of >9.5kV and amperage of 10A, with future increases planned
- Accepts 1.5cm lateral, 20° tip angle, and 20° rotational misalignment
- Free-to-use specification available now

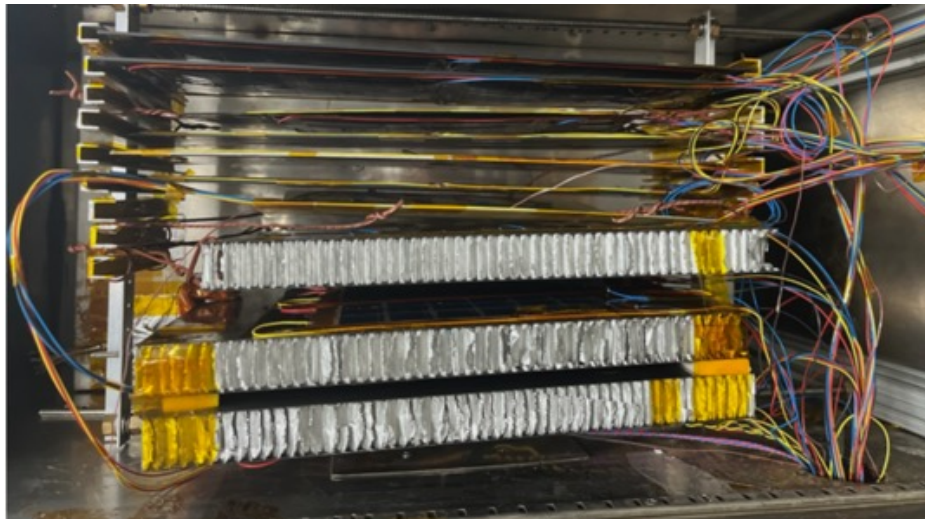






LAMPS Key Elements: DragonSCALES

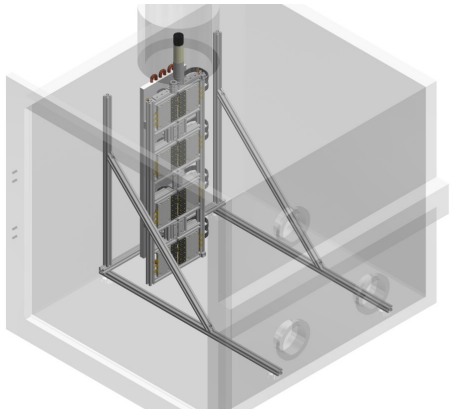


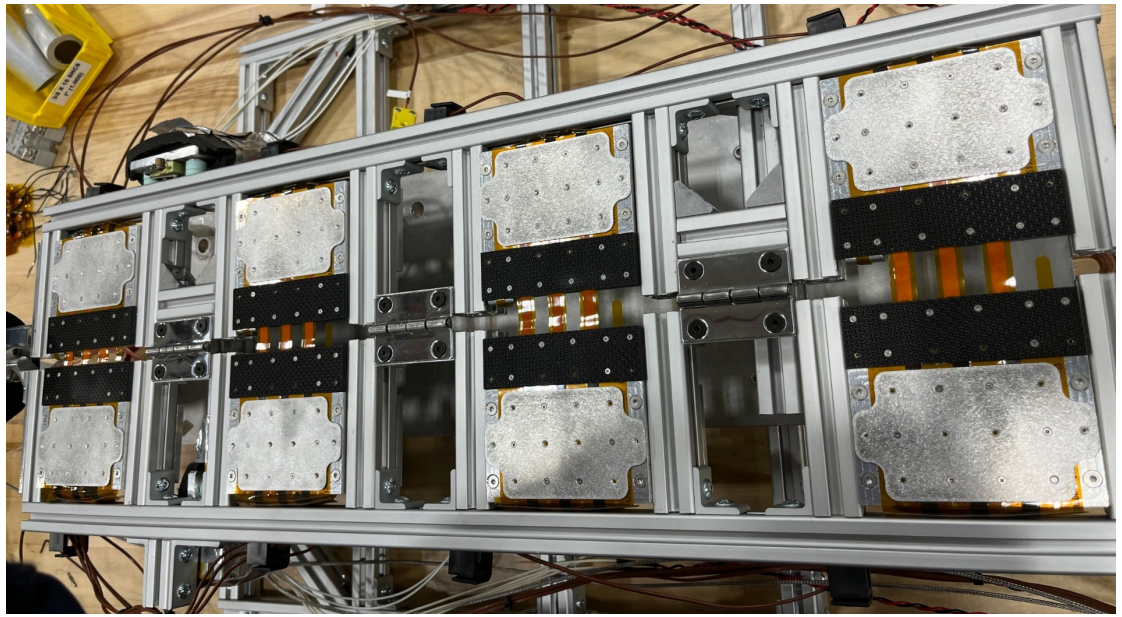


The LAMPS array is built on mPower's dragonSCALES solar cells:

- Completely customizable solar modules
- Composed of laser-diced high efficiency silicon cells interconnected on a hyper-flexible substrate
- Cells connected both in parallel and series
- Enables innovative, high-power density designs that could not be achieved with conventional cells
- Module/array costs > 5x lower than GaAs cell based arrays
- Scalable to > 10 to 100MW/yr production volumes
- Areal mass density at < 1kg/m^2 (0.7-0.6 kg/m^2 feasible)
- Power density ~ 250-300 W/kg
- Has flight heritage: On-orbit operational system active (Lynk Global), additional flight units in build
- Manufacturing line is up and running

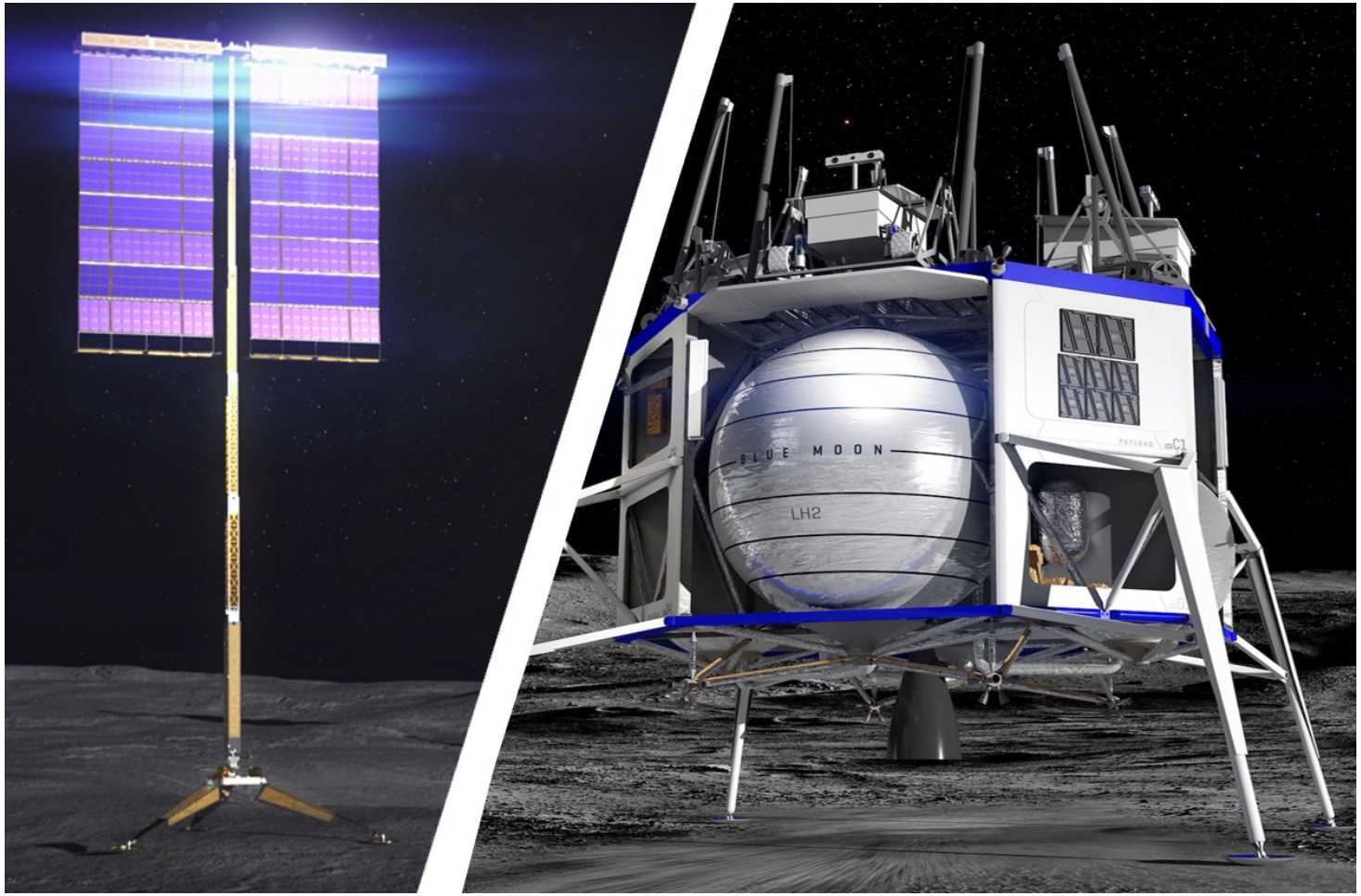
LAMPS Key Elements: Solar Array Folding Mechanisms





- Solar array connection points represent a nontrivial risk for critical mission failure
- LAMPS has multiple connection points because of its deployable arrays
- Potential gap sizes tested in vacuum at various temperatures for key engineering development level risk reduction
- 45 cycles tested without failure, more than 3x expected life for LAMPS application
- No change in resistance at trace under mechanical stress, indicating no damage

LAMPS Mission Integration Options



- Multi-deployment, mobile version of LAMPS, oriented towards robotic and human Lunar exploration
- Simplified, single deployment version of LAMPS on Lunar lander
- Scaled LAMPS providing up to 20kW+ with minimal design changes
- Ultimate goal: using LAMPS to turn lander into first element of Lunar grid **creating first permanent American hardware ever for the Lunar surface**

Honeybee's Vision for the Lunar Future

HONEYBEE ROBOTICS

mPower TECHNOLOGY

A modular Lunar grid is one of the single most enabling tools for Lunar permanence and the future Lunar economy, enabling in the near term:

- Industrial scale ISRU plants
- Long term science and prospecting operations
- Permanent human Lunar presence

- Many current extreme technology risks can be mitigated with power availability, lowering overall costs to all Lunar missions
  - Oxygen scrubbing and habitat cleaning
  - Emergency backup power and thermal control
  - Replacement part production
- A solar-based grid is modular, immediately scalable, and able to jump-start solar cell production to grow power availability exponentially

LSIC | Presentation

- Speaker: John Landreneau
- Astrobotic
- Project Manager, Lunar Surface Systems

ASTROBOTIC

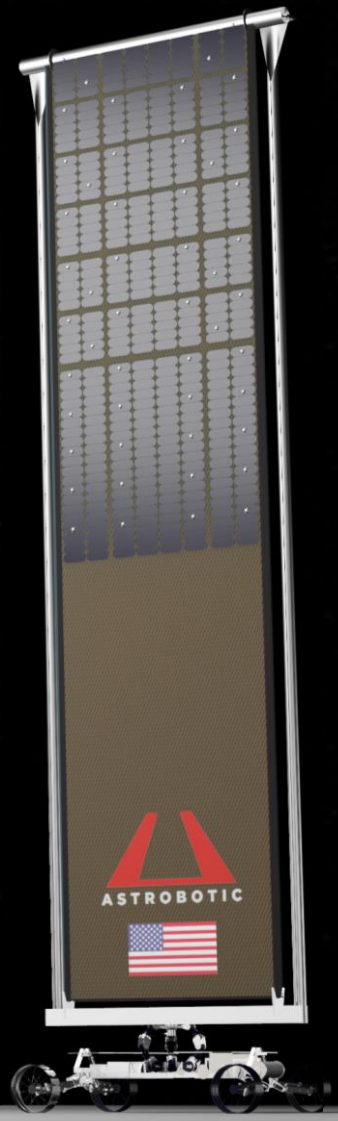
ASTROBOTIC

REDWIRE

SWAMP WORKS
NASA KENNEDY SPACE CENTER

GRC
GLENN RESEARCH CENTER

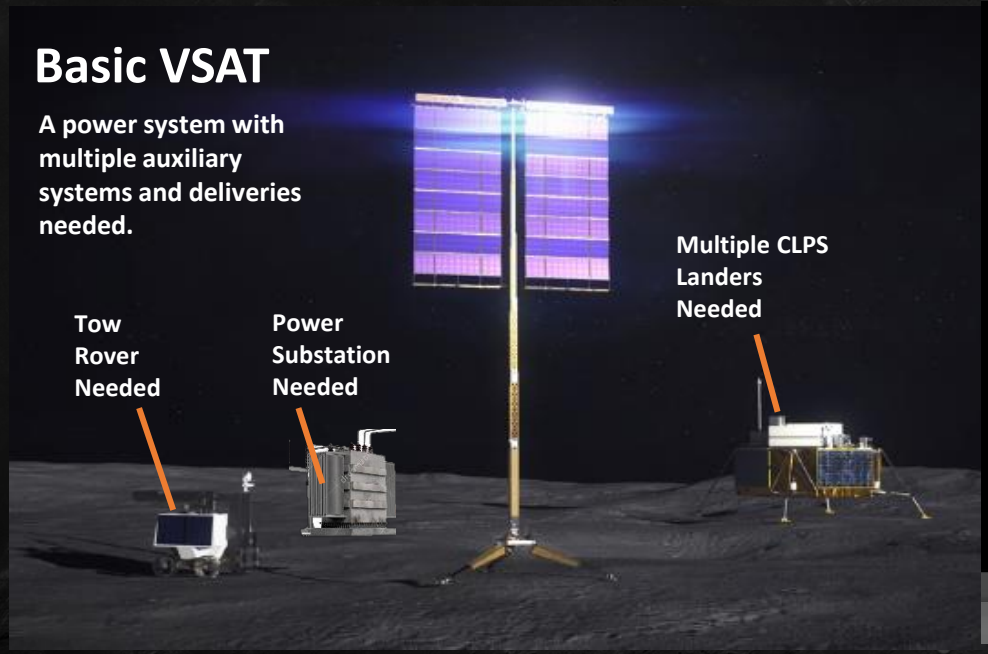
LUNAR VERTICAL SOLAR ARRAY TECHNOLOGY

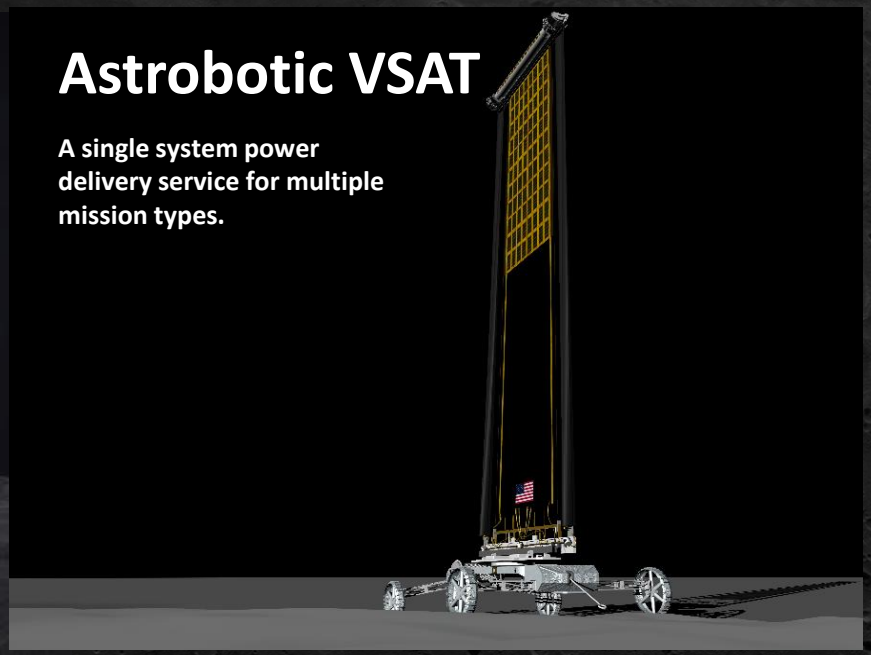


ASTROBOTIC VSAT POWER SERVICE

The Astrobotic VSAT is a stand-alone, out-of-the-box power service for Artemis Base Camp, CLPS missions, and SMD Discovery or New Frontier-class missions.

Mobility and substation elements are incorporated into Astrobotic's system, making the system a practical power service that can be deployed to support any polar mission to the Moon.





Performance Category	Basic VSAT	Astrobotic VSAT
Mobility	Requires LTV or other external tow rover	Included
Power Substation	Requires additional substation to be built and delivered	Included
Delivery	Requires multiple deliveries for mobility and substation	Delivered on a single CLPS lander

ASTROBOTIC VSAT INFUSION POTENTIAL

Decadal Science Missions

CLPS Missions

Artemis Base Camp

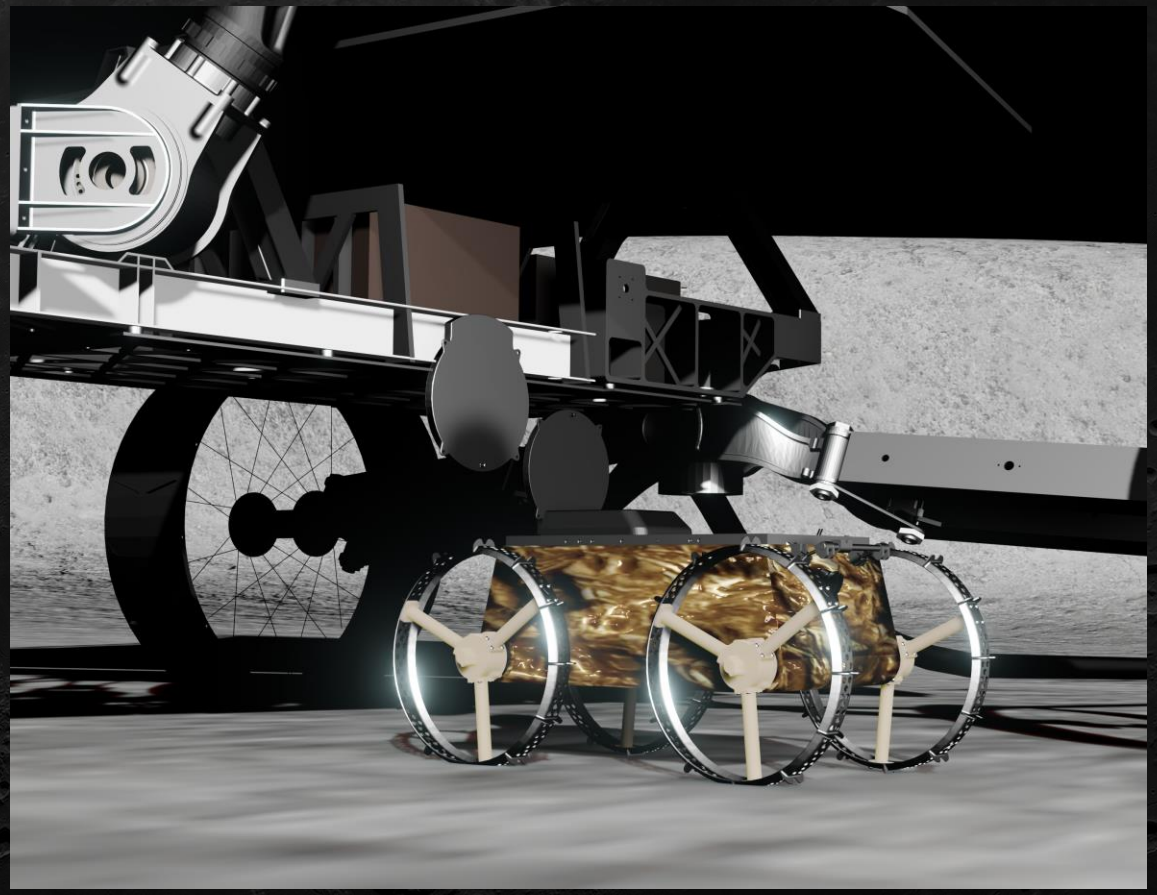
ARTEMIS

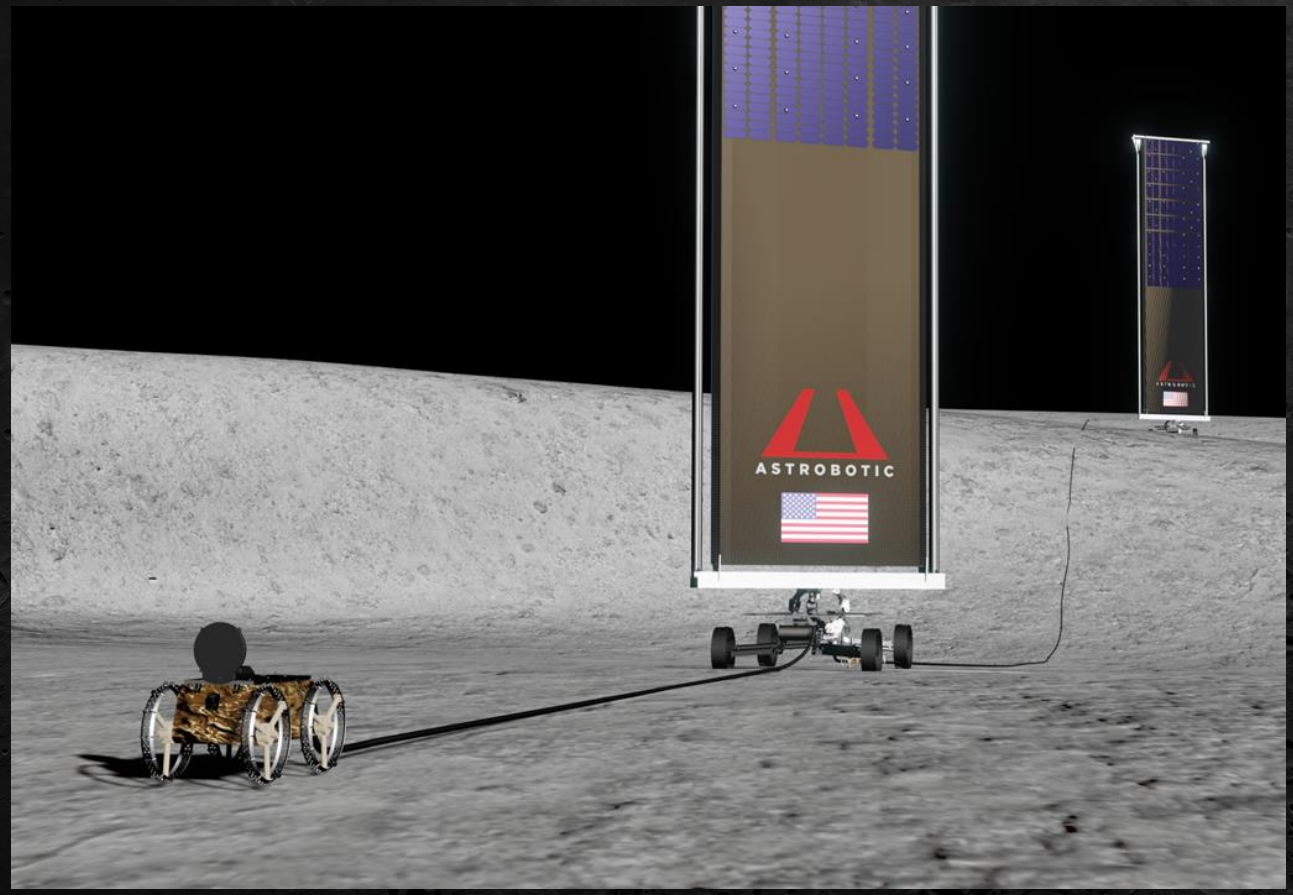
Human Landing System

Surface-Based Habitats

In-Situ Resource Utilization

ASTROBOTIC VSAT **SUPPORTING CONOPS**





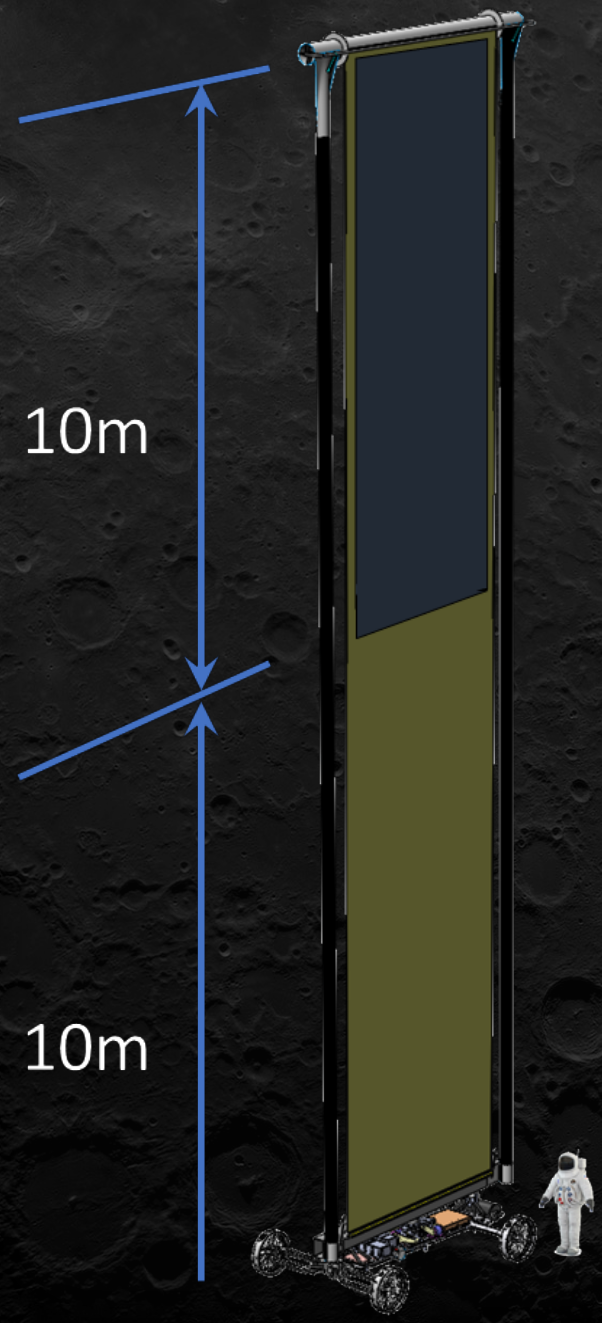
Local wired and wireless assets

Remote access points

Microgrid support

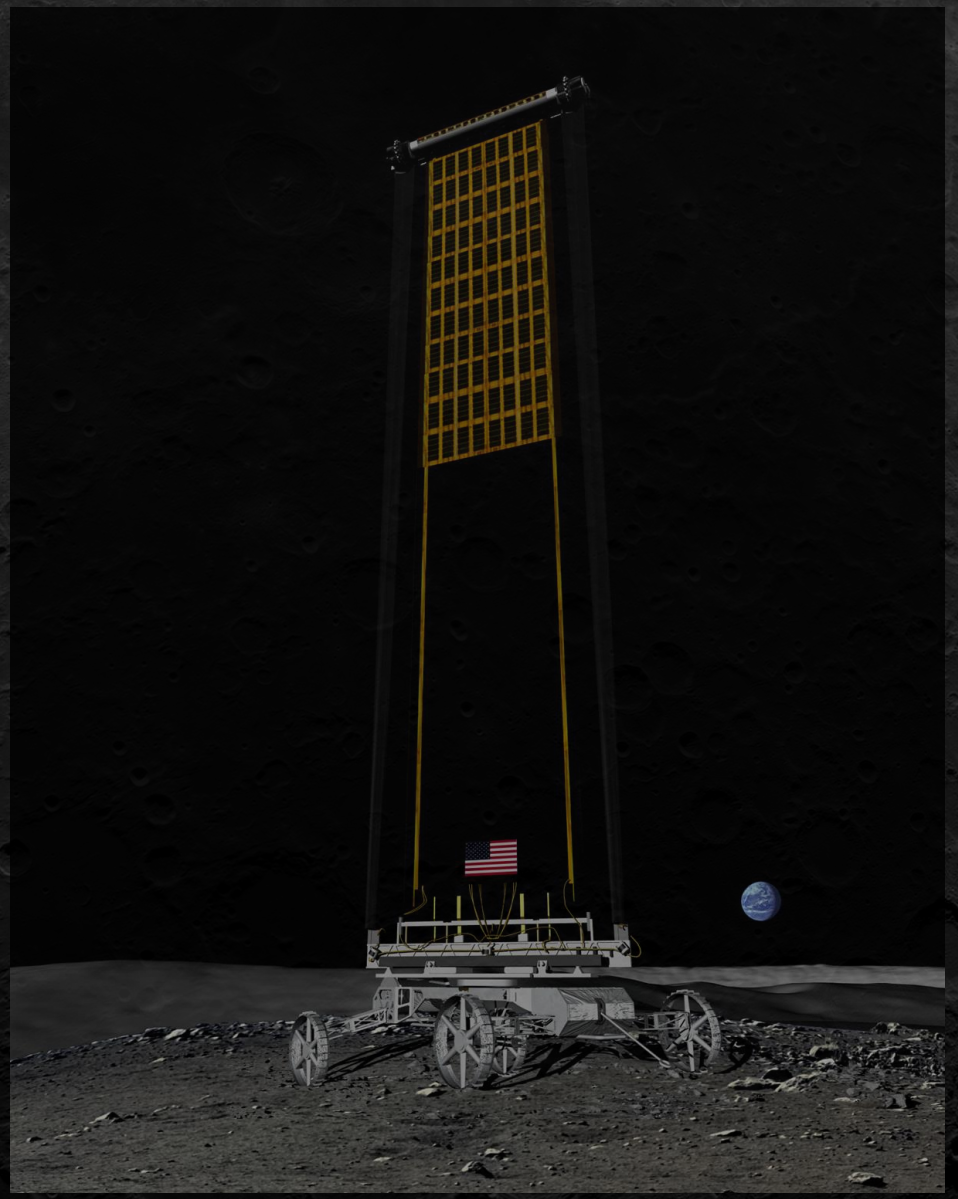
ASTROBOTIC VSAT **REQUIREMENTS**

- **Mobility to new lunar surface sites**
- **Minimum of 10 deployment / retraction cycles**
- **10kW beginning of life power**
- **10m mast height to bottom of solar array**
- **15° incline terrain stability**
- **Adaptable to changes in illumination**
- **Adaptable to multiple mission architectures**
- **10 year mission life**



ASTROBOTIC VSAT **DESIGN**

- Fits on a single CLPS delivery mission
- Comes in multiple product sizes and for a variety of science, exploration, and commercial mission types, not just Artemis
- Can be driven to any polar location, no tow vehicle needed
- Designed for deployment and egress on CLPS lander
- Able to transmit power > 2km
- Uses efficient power transmission interface with multiple options available: wired and wireless
- Uses high maturity and space heritage subsystems to support a near team demonstration launch



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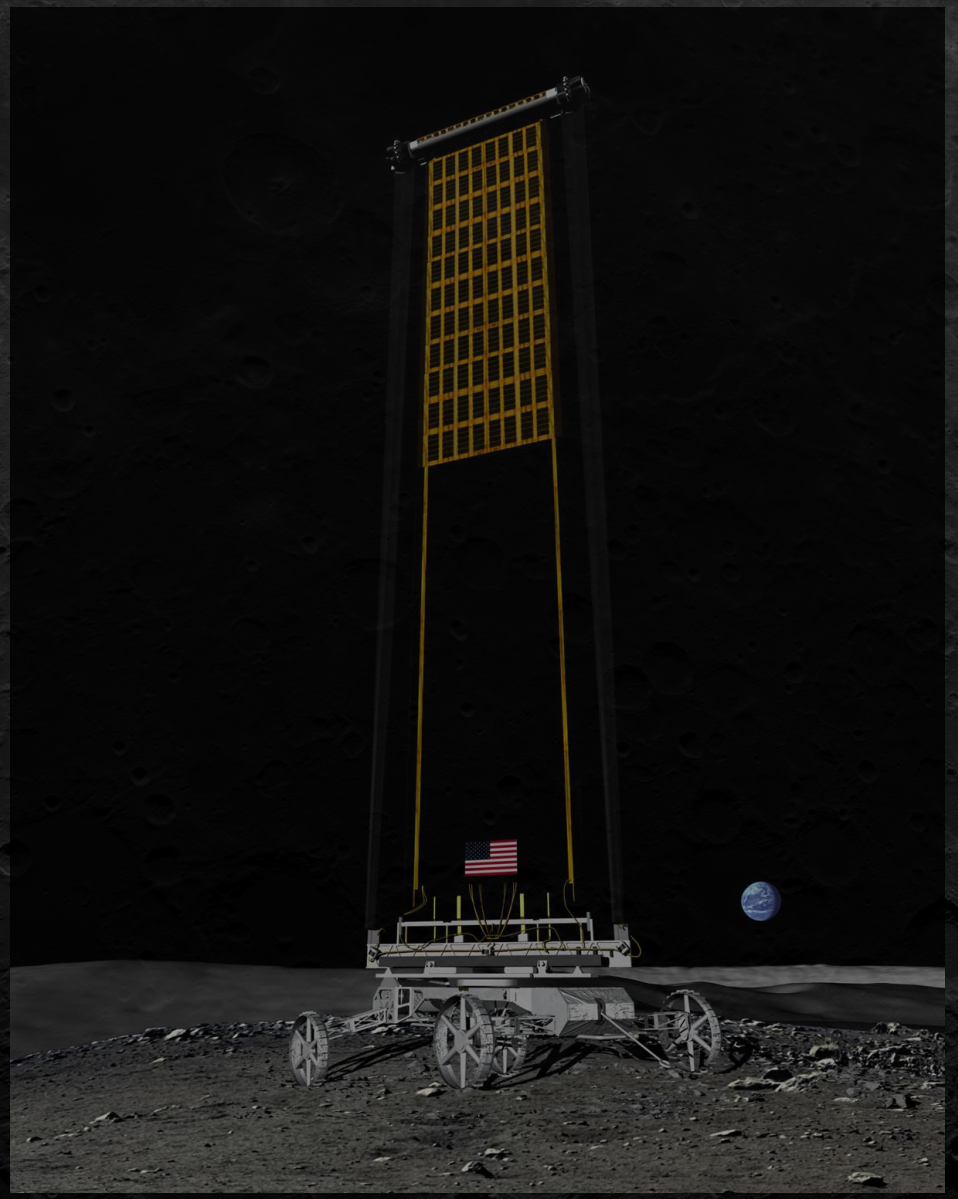

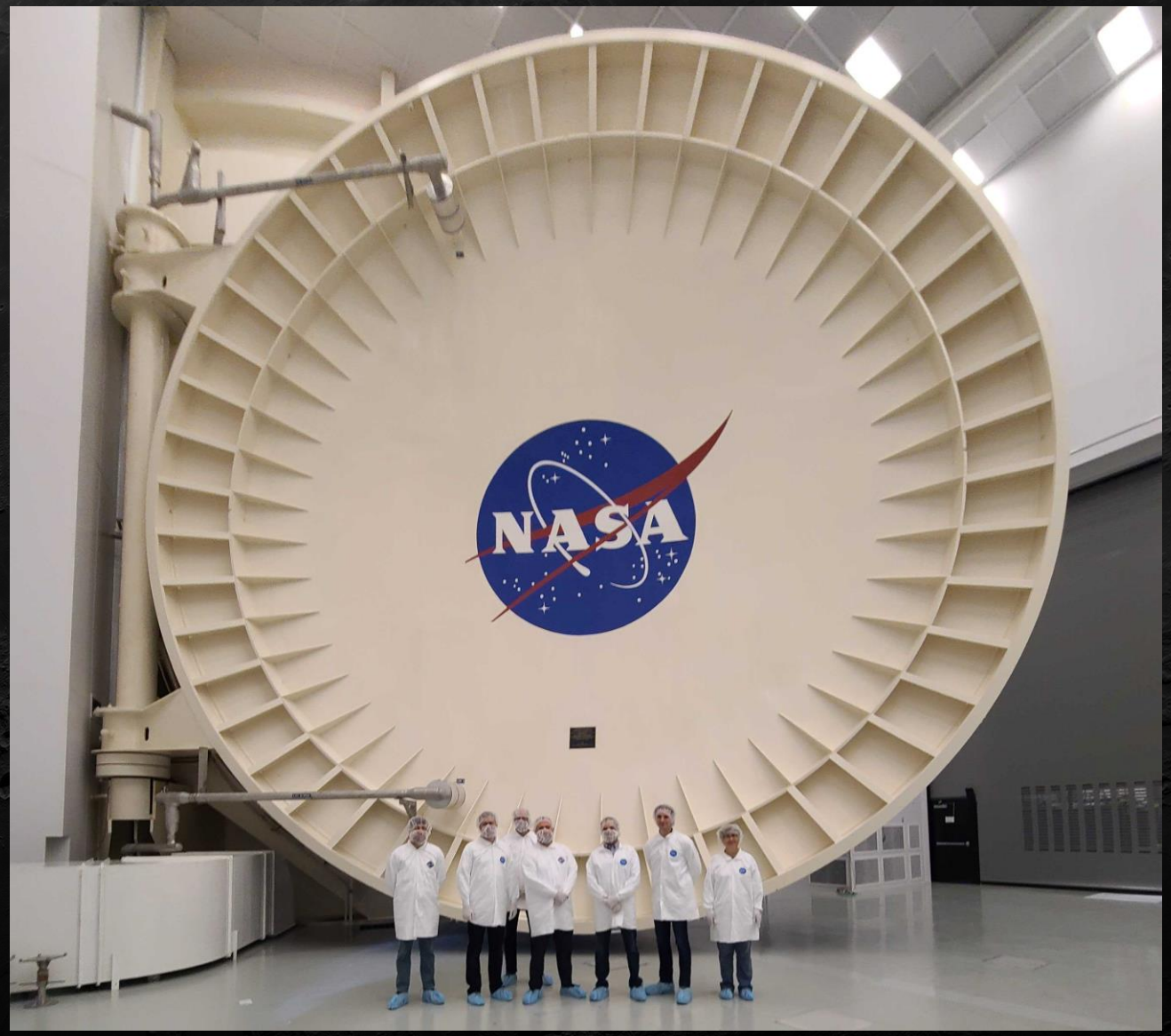
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JOHNS HOPKINS
APPLIED PHYSICS LABORATORY