NASA's Photovoltaic Energy Research Plans and Programs

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GRC PV Team

Civil Servant

- Jeremiah McNatt: PV Technology Lead
- Meghan Bush: Solar Cell Measurement / Calibration
- Geoff Landis: PV Cell Technologies for Unique Missions
- Lyndsey McMillon-Brown: Perovskite and Thin Film PV, Optical Coatings
- AnnaMaria Pal: PV Cell Tech, Lunar Surface Solar Arrays
- Timothy Peshek: Thin Film PV, Perovskites, Cell Durability and Reliability, Flight Projects
- Todd Peterson: Contracts / Agreements

Contractor

- Kyle Crowley: Post Doc – Perovskite Technologies
- Jeremiah Sims: Solar Cell Measurement
- Kaitlyn VanSant: Post Doc – Perovskite Technologies
- Boris Vayner: PV Cell/Array Arcing & Charging

Photovoltaic Needs and Goals

- General Needs for PV development programs:
  - Increased cell efficiency, reduced cost, reduced weight, improved radiation tolerance
- NASA specific needs
  - Higher power systems for Solar Electric Propulsion (Gateway, Mars Cargo, ISS, Human Landing System)
  - Power for Lunar and Mars Surface Missions (rovers, landers, power stations, site specific needs) including dust mitigation
  - Unique environments with high radiation and/or intensity/temperature extremes
- Overall Goals
  - Serve as an Independent verification/validation of pv technologies for other government agencies and industry
  - Provide expertise to flight missions
  - Build on interactions and collaborations with other government agencies

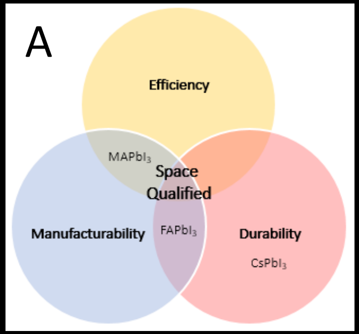
Perovskite Solar Cells for Very Large Arrays: Space power at terrestrial costs

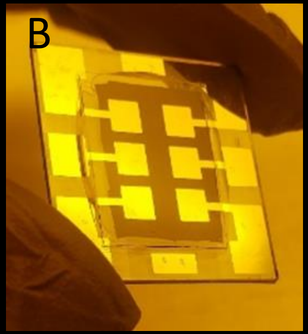
Goal: Enable large area (>100kW), flexible thin film perovskite solar arrays on flexible substrates for lunar surface habitats.

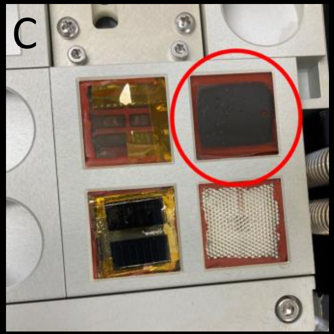
Strategy: Develop high efficiency, manufacturable, and durable space qualified perovskite solar arrays.

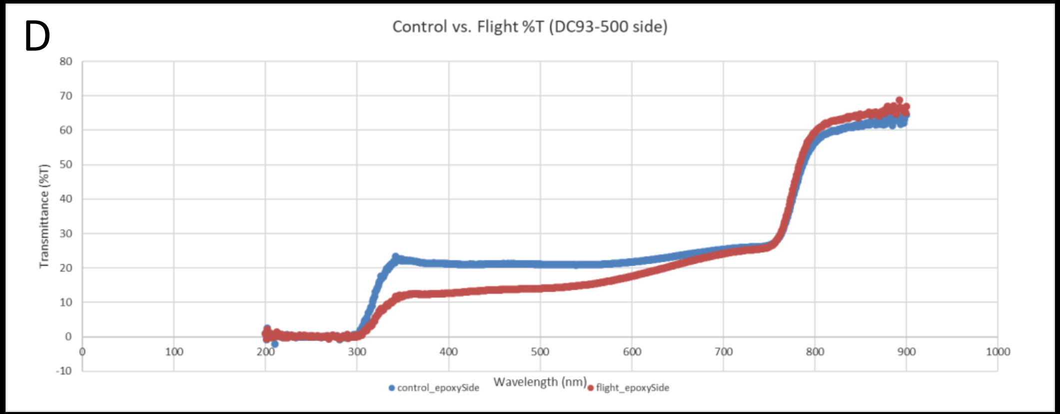
Agency Need: Lunar surface power is unlike most other space power: the need is for very large areas, significantly reduced cost. These goals are more readily met by perovskite thin films than by SOA.

External Collaborators:
Joseph M. Luther (NREL) – Perovskite Ink Development
Sai Ghosh (UC-Merced) – Electrospray Perovskite Cells









A) Design considerations schematic. B) Fabricated perovskite solar cell. C) $MAPbI_3$ thin film integrated on MISSE-13. D) Transmission spectra of $MAPbI_3$ film post 10 month LEO flight (red) compared to control sample (blue).

NASA Point of Contact: Lyndsey McMillon-Brown (lyndsey.mcmillon-brown@nasa.gov)

Graduate Student Program

- Lower Cost / High Efficiency Cell Development
  - 2 NASA Space Technology Graduate Research Opportunities (NSTGRO) at University of Illinois Urbana-Champagne with efforts focused on III-V materials on Si with improved radiation resistance
- Microcell CPV for Extreme Space Environments
  - 1 NSTGRO at Penn State developing a space-optimized system with a geometric concentration ratio of 30x that is ultra-compact (<600 μm thick) and capable of >350 W/kg at >33% power conversion efficiency under AM0

- Call for New Proposals to be Released in September on https://nspires.nasaprs.com/
  - Looking for strong candidates (MS/PhD) developing space-related technologies (PV, batteries, fuel cells, PMAD)

Recent/Current SBIR Programs

- 2020 – Phase I
  - Microlink Devices: Textured Solar Array
    - Continued into Phase II in 2021
  - Advanced Cooling Technologies: “Dark” Photovoltaic Cells for Space Power Generation

- 2021 – Phase I
  - Regher Solar: Pushing Radiation Hardness and Qualification of Ultrathin Silicon Solar Cells

  - Trans Astronautica Corp: Sun Flower: Systems Design and Technology Maturation of a Sustainable Lunar Power Generation Architecture
  - Dynovas: Motorless Extension, Leveling, and Tracking (MELT) Array System
  - Gendell Associates DBA Folditure: Project: Sunflake Solar Array and Ultra Compact Tripod Tower (UCTT)
  - Opterus Research and Development: R-ROMA VSAT Pedestal

- Expecting for SBIR Subtopics in 2022 on cell/array technology for unique mission environments (intensity/temperature extremes, high radiation, dust, corrosives) and larger lunar surface structures

Solar Array Development – Lunar Orbit

- PV Systems will be used to power many near-term lunar missions
- Gateway Power and Propulsion Element (PPE) will be powered by 2 ROSA solar arrays (50 kW class)
- Human Landing System (HLS) includes elements of photovoltaics (will discuss more in 2022)

https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf

Solar Array Development – Lunar Surface

- Vertical Solar Array Technology (VSAT) project led by STMD's Game Changing Development program and NASA Langley in collaboration with NASA Glenn
- Autonomous deployment systems of 30 ft masts, stable on steep terrain, resistant to abrasive lunar dust and minimized both mass and packaged volume for ease in delivery to the lunar surface

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

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

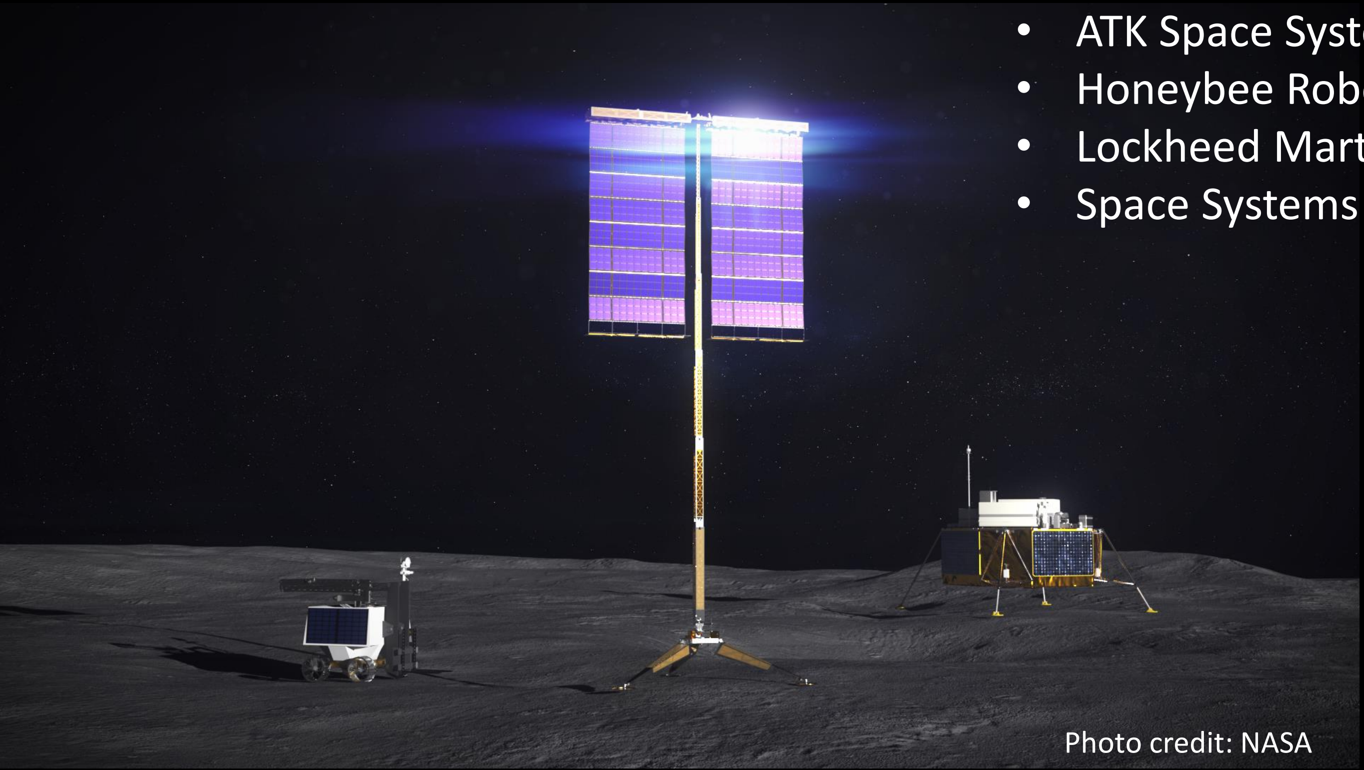


Photo credit: NASA

The companies will provide system designs, analysis, and data.

The agency plans to down select up to two companies and provide additional funding, up to $7.5 million each, to build prototypes and perform environmental testing, with the ultimate goal of deploying one of the systems on the Moon's South Pole near the end of this decade.

*Base period contracts anticipated to begin August 2021

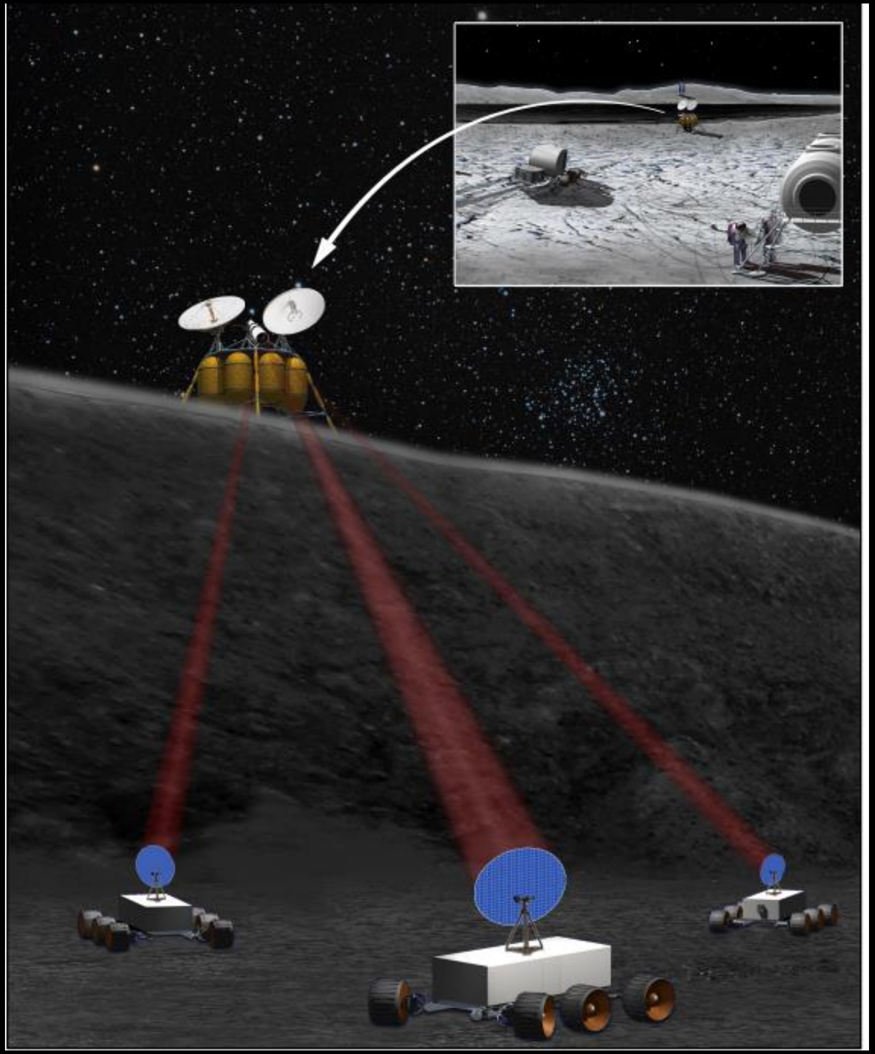
Laser Power Beaming

- Use of laser to beam power to photovoltaic cell allows application of lightweight photovoltaic power to regions with no sunlight
- Particular application being developed is power for multiple rovers operating in permanently shadowed craters near the lunar poles

NASA Glenn activities:

- Center Innovation Fund 2020-2021 developed concept and analyzed feasibility for lunar application
- GRC is technical lead for Space Technology Research Grant project with University of California Santa Barbara to develop and test laser power beaming as part of the Lunar Surface Technology Research (LuSTR) program

- Impact
  - Technology could enable future rovers in permanently shadowed craters on the moon



Laser power beaming for lunar polar power

Solar Cell & Array Development – Outer Planets (LILT)

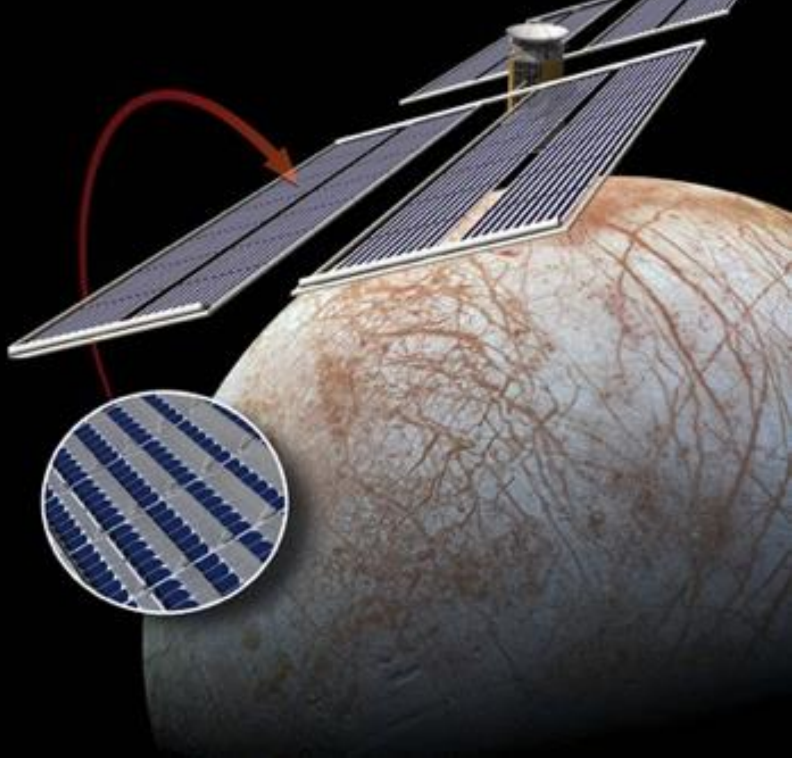
- Extreme Environments Solar Power (EESP): Develop solar cell and array technologies for use in low intensity, low temperature (LILT) environments (beyond 5 AU) and high radiation environments in this region (Jupiter and its inner moons)
- Project Goal: 35% beginning of life (BOL) cell efficiency, 28% EOL efficiency at the blanket (or equivalent) level, measured at 5 AU and -125 ^{o}C; 8-10 W/kg measured at EOL, Packaging density at least 60 kW/m^3
- Project started in June 2016 with 4 contract Base Phase Awards, 2 later Option Phases led to 1 current award to Johns Hopkins Applied Physics Laboratory (APL)

APL: Transformational Array (TA)

Flexible Array Concentrator Technology (DSS, APL)

System Concept

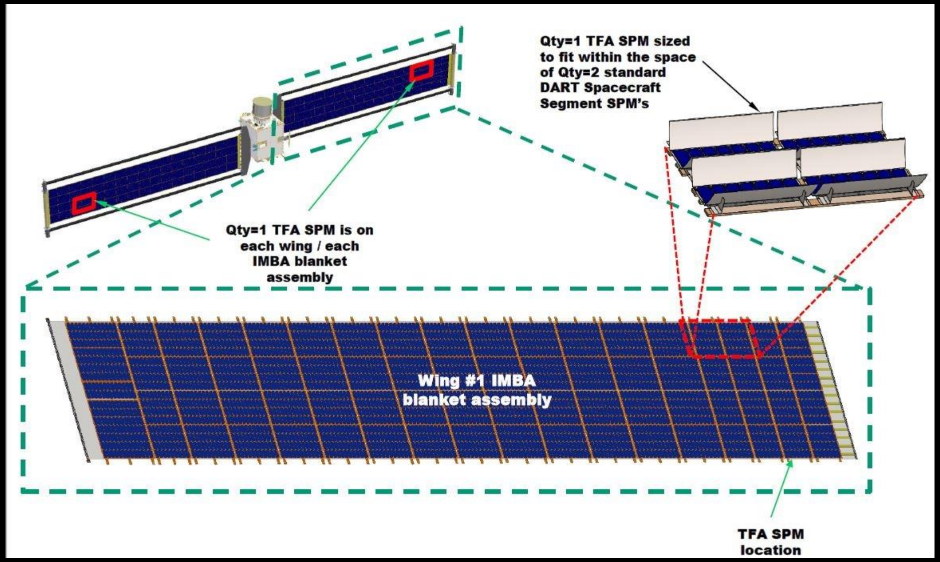
- Uses DSS Roll Out Solar Array (ROSA) for the array structure and blanket.
- Populated the array with high efficiency IMM solar cells which also offer longer life in radiation environments (SolAero IMM4 cell)
- Populated the array with concentrators to reduce array mass, volume, and cost and increase intensity on the cells by 2x.
- Current missions being planned to Jupiter's moon Io and to Neptune's moon Triton are considering including demonstrations of the Transformational Array.

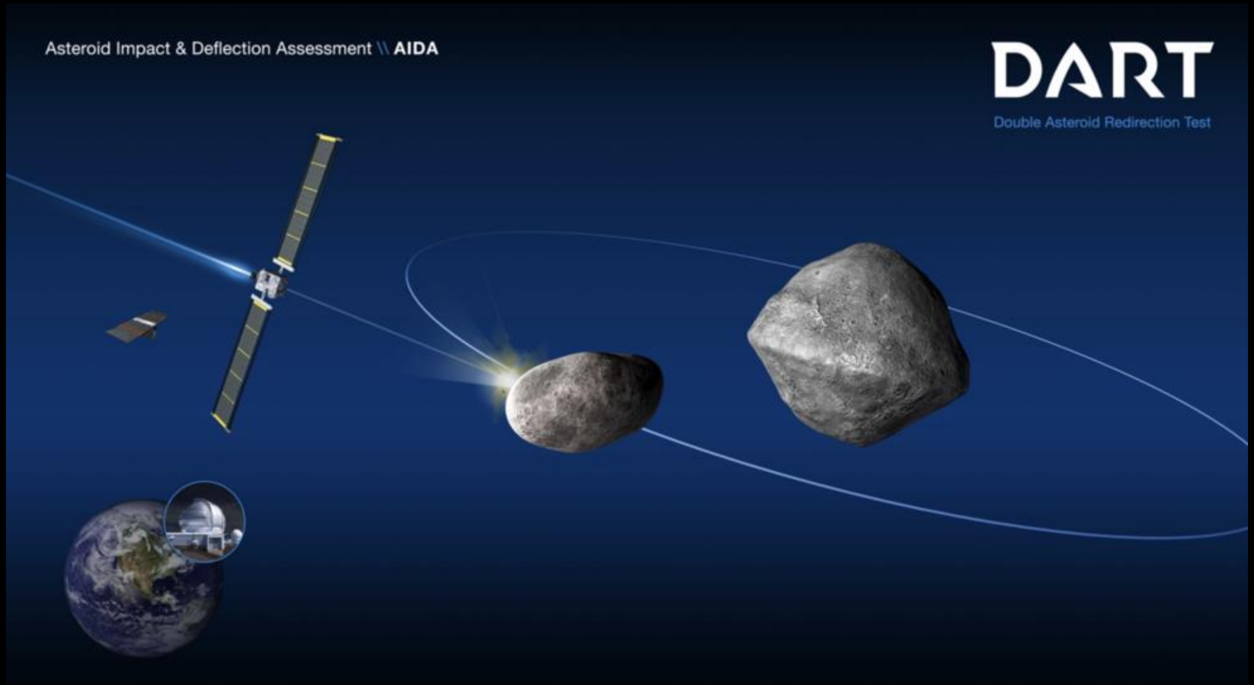


Flight Test – EESP on DART

Double Asteroid Redirection Test (DART) Mission: Launch window opens November 24th, 2021

- Opportunity existed for test of the APL Transformational Array cell and concentrator technology in similar flight configuration for near Earth mission
- The TA array technology will be placed on the portion of the array that provides power to the spacecraft
- The current from the TA strings and service strings will be measured using existing circuitry in the power system
- Data will be collected over the year long cruise to Didymos



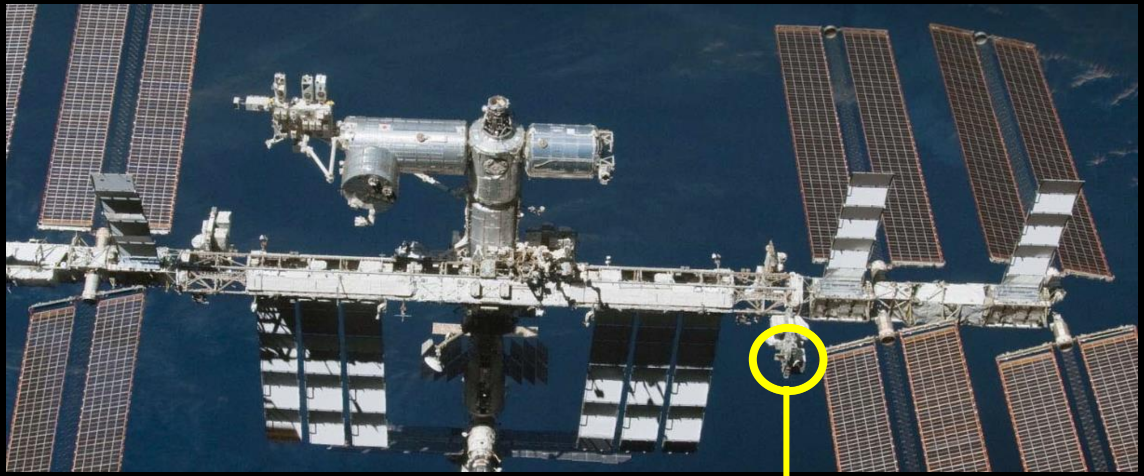


Schematic of the DART mission shows the impact on the moonlet of asteroid (65803) Didymos

Flight Test – MISSE 16

Materials ISS Experiment (MISSE)

- 6-month (planned) exposure to Low Earth Orbit (LEO) conditions launching in Aug 2021
- Includes lightweight, novel solar cells and modules (including Perovskites, Concentrators)
- Passive exposures similar to past ISS experiments in zenith direction



Previously presented MISSE13 samples are back and being examined. Initial results were presented at PVSC in 2021. Further work examining flight materials and future work is ongoing

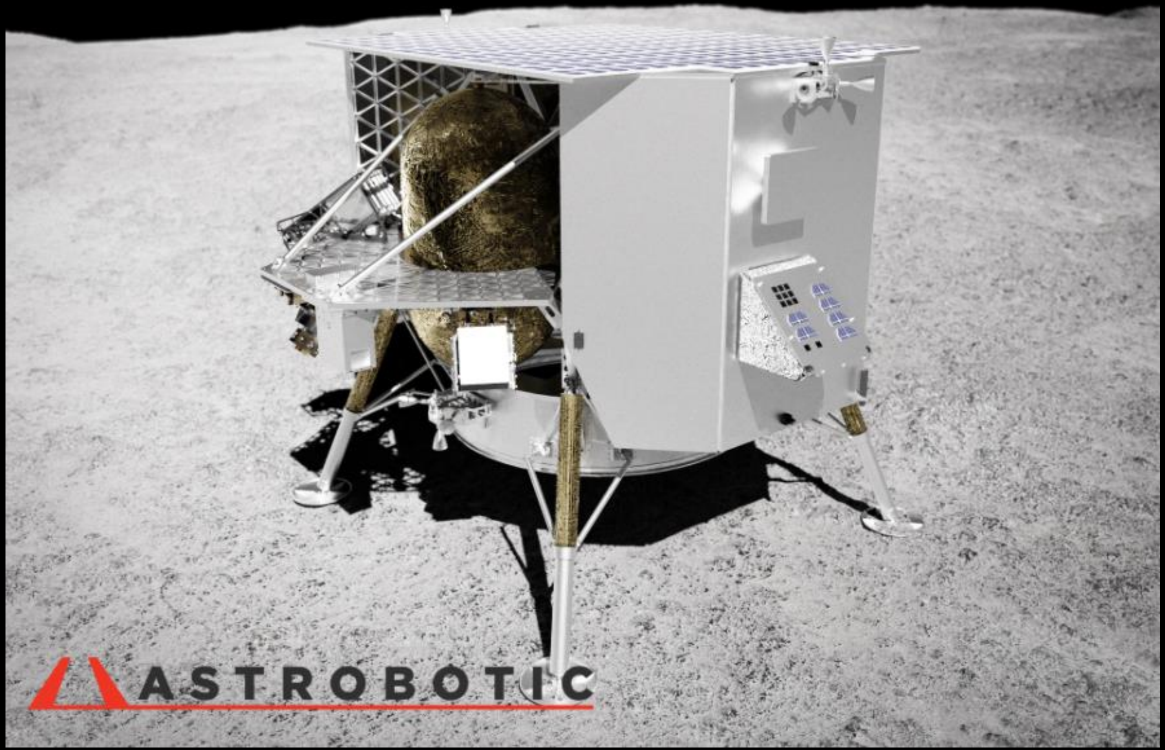
Awarded 30 sq in area in the Zenith direction

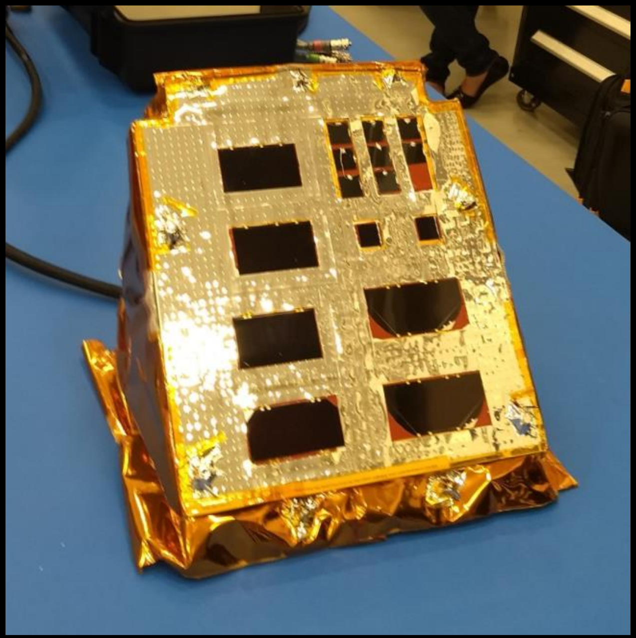
Full exposure to space environment

Flight Test – PILS

PILS – Photovoltaic Investigation on the Lunar Surface

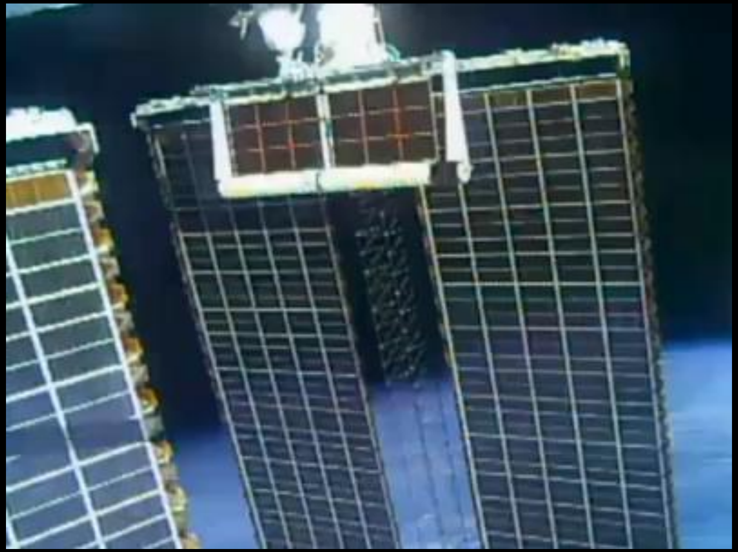
- NASA Commercial Lunar Payload Service (CLPS) project – Landing early 2022 at Lacus Mortis (45 N)
- PILS test platform originally due June 2020 (extended due to Covid-19 impacts). Now planned delivery in Fall 2021.
- Includes SOA and advanced cells: SolAero IMM-alpha, Z4J & Spectrolab XTJ-Prime, XTE-SF
- Includes Silicon HIT cells (from ASU) and small array of cells/coverglass to record surface charging
- Mission planned for one lunar day (<10 Earth days)





ROSA Power Augmentation to ISS

- 6 ROSA are being added to ISS to increase power production
- 2 ROSA have been installed (June 2021)
- Each new solar array is ~20 kilowatts (total ~120 kilowatts)
  - New arrays do partially shadow current arrays
- Remaining uncovered solar arrays and partially uncovered original arrays will continue to generate ~95 kilowatts of power
- New total for ISS ~215 kilowatts (215,000 watts) from ~160 kW previously



Advancement of Qualification Protocols for IMM-α

- NASA Space Technology Mission Directorate – Announcement of Collaboration Opportunity awarded to Maxar Technologies along with GRC and MSFC to test 5-junction solar cells through qualification protocols similar to AIAA S-111/112 to raise the TRL
  - Solar cell electrical performance testing capabilities at GRC
  - Space environment testing facilities at MSFC
  - Maxar is providing the SolAero IMM-α coupons

- Impact
  - Enable future commercial and NASA missions with higher power at a lower mass
  - For small satellites more power can enable additional payload capabilities
  - Smaller area footprint (W/m2) and higher specific power (W/kg). Driving metrics for solar arrays in space and on lunar surface

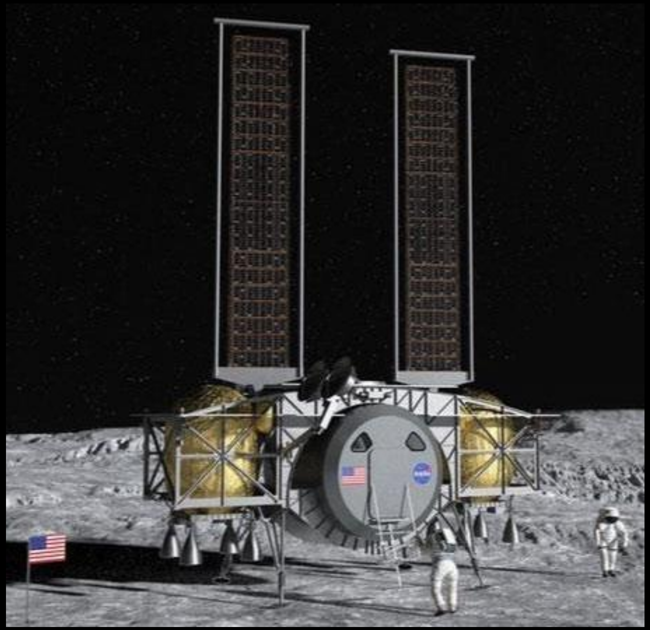
- *Electrical Checkout and performance using LED-based pulsed solar simulator*
- *Sine vibe testing*
- *Thermal balance testing*
- *Electrostatic discharge testing*
- *UV radiation exposure*
- *Electron radiation exposure*
- *Proton radiation exposure*
- *Thermal cycling*

High-Energy Accelerator Lab at MSFC
(Electron and Proton Radiation Testing)

Dust Mitigation on Flexible Solar Arrays (DMFlex)

- NASA Space Technology Mission Directorate – Announcement of Collaboration Opportunity awarded to Maxar Technologies along with GRC to explore lunar dust mitigation and removal options for vertical, flexible ROSAs
- Effort to involve the Plasma Interaction Facility, and will test whether vibratory motion and/or electrostatic dust shielding can be used to remove deposited lunar simulant on vertical arrays
- Tests performed as a function of illumination, charging level, temperature and angle of solar array.

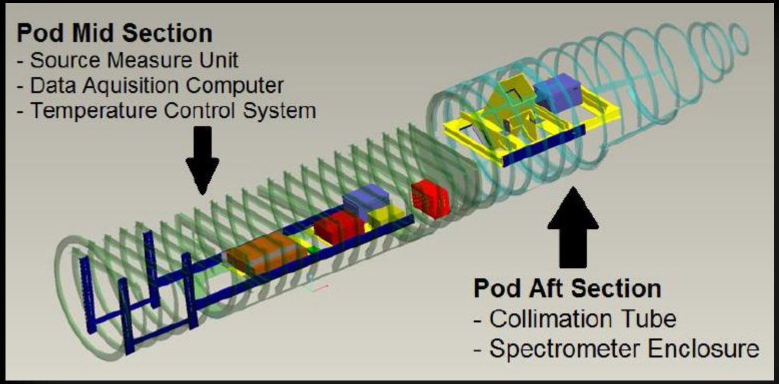
Rendition of a lunar lander with vertical solar arrays

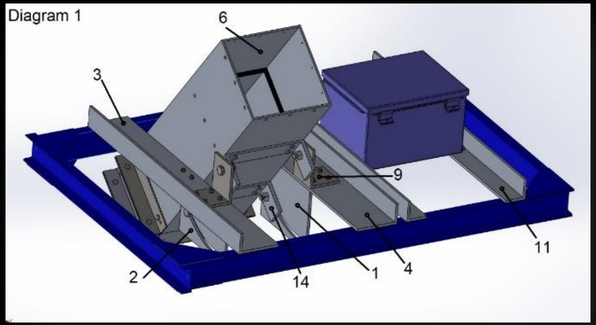


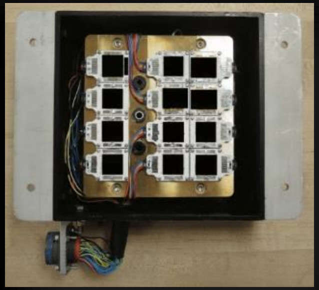
Fine regolith is notable for getting kicked up by surface activity and sticking to surfaces, including solar arrays possibly reducing power output.

Ground Testing – High Altitude Measurement

- ER-2: High altitude (70k ft) experiment platform utilized for solar cell standard development
- Planning for a Fall Campaign. 2020 season was cancelled due to Covid-19.
- Planning for build of 2nd flight pod to increase cell area per flight
- Collaborating with AM0CAL (formerly Blacksky) and Angstrom Designs on high altitude balloon testing. Both firms are NASA Flight Opportunities Flight Providers.

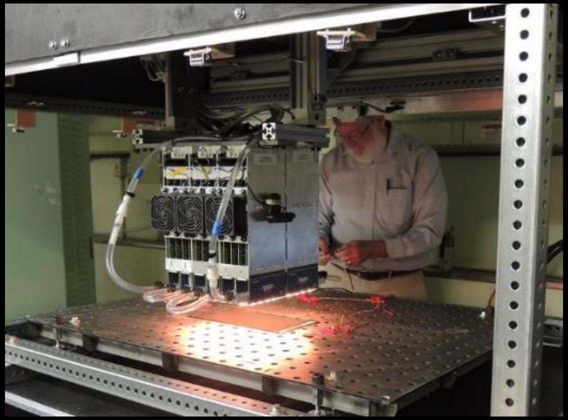


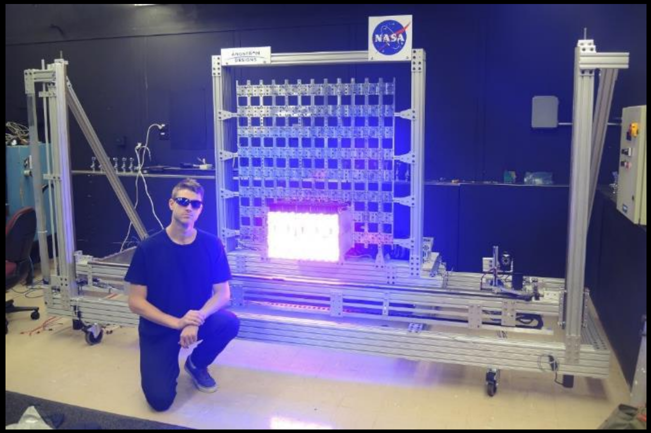




Ground Testing – Solar Simulators

- Solar Simulators
  - 3 zone – Spectrolab X25 based system
    - Option for variable temperature chamber with quartz window
  - 6 zone – Angstrom Designs LED based
    - Approximately 10” x 10” illumination area
  - 5 zone – Angstrom Designs LED based large area pulsed solar simulator
    - Current illumination area, 10 modules (~ 18” x 12”). 8 additional modules ready for install
    - Increases illumination area to about 0.2 m^2 (reconfigurable to match string length)





SPRAT 26 & 27

- Space Photovoltaic Research and Technology Conference
  - SPRAT 26 – October 19 – 21, 2021
    - Virtual Conference – Ran Through Teams
    - https://www1.grc.nasa.gov/sprat/
    - Registration will be Free – Opening in August
    - Soliciting Nominations for the Irv Weinberg Award
    - Draft Agenda will be posted on Conference Website in the coming weeks
  - SPRAT 27 – Summer 2022
    - In Person Conference (3 Days in Cleveland)
    - Student Poster Session
    - Breakout Workshop Sessions

Summary

- Improving cell technology performance while reducing cost and mass is of interest to NASA and GRC
  - Much of this work is performed through University and SBIR contracts
- Solar array development
  - Meeting NASA's future needs for solar cells and arrays for unique missions
  - Adaptability and modularity are important aspects being considered
- Flight Programs
  - Testing cells and materials in space to raise the technology readiness level for use in future missions
  - Looking for collaboration opportunities to fly/test different technologies
- Ground testing
  - Facilities at GRC are being upgraded to allow for larger samples with more junctions
  - Working with Flight Provider Firms to investigate small balloon PV cell measurement platforms

Questions?