NASA's Photovoltaic Energy Research Plans and Programs

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Outline

- NASA’s Photovoltaic Research and Development Needs and Goals
- Cell Technology Efforts
- Array Technology Development
- Testing and Mission Support

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

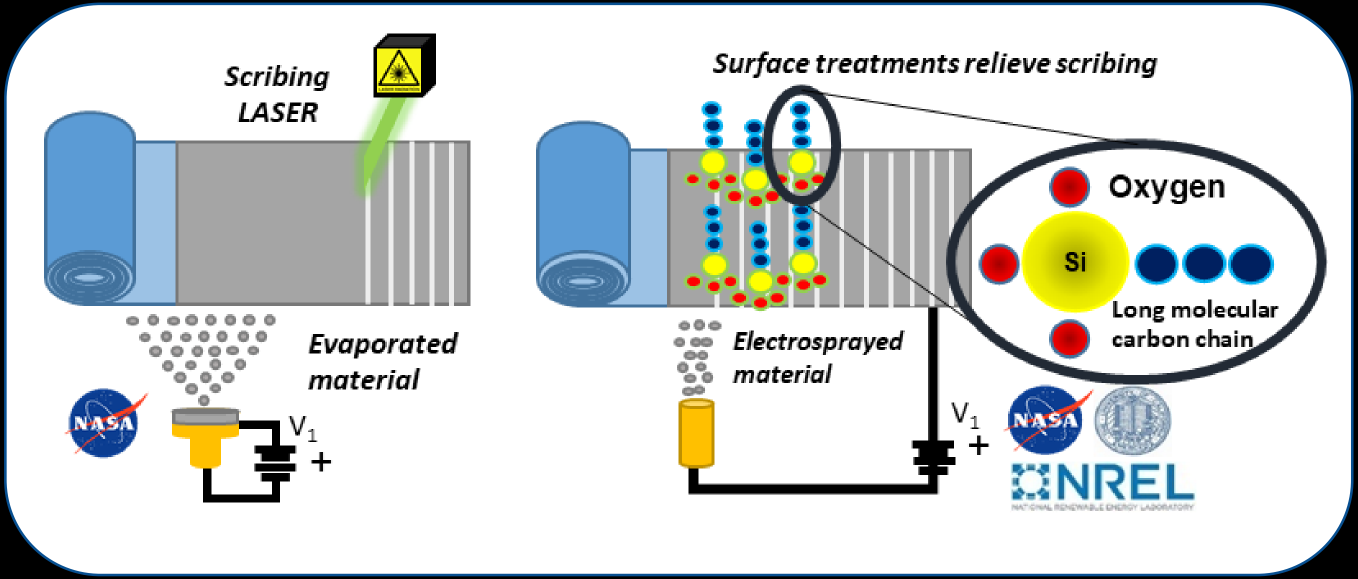
- Overall Goals
  - Serve as an Independent verification/validation of pv technologies for other government agencies and industry
  - Provide expertise to flight missions
  - Build on interactions and collaborations with other government agencies

In-Space Assembly of Perovskite Solar Cells for Very Large Arrays: Space power at terrestrial costs

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

Strategy: Develop high efficiency space qualified perovskite solar arrays. Deposition techniques are restricted to in-space compatible methods. Develop a suitable in-space fabrication of perovskites for use on a CubeSat mission.

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

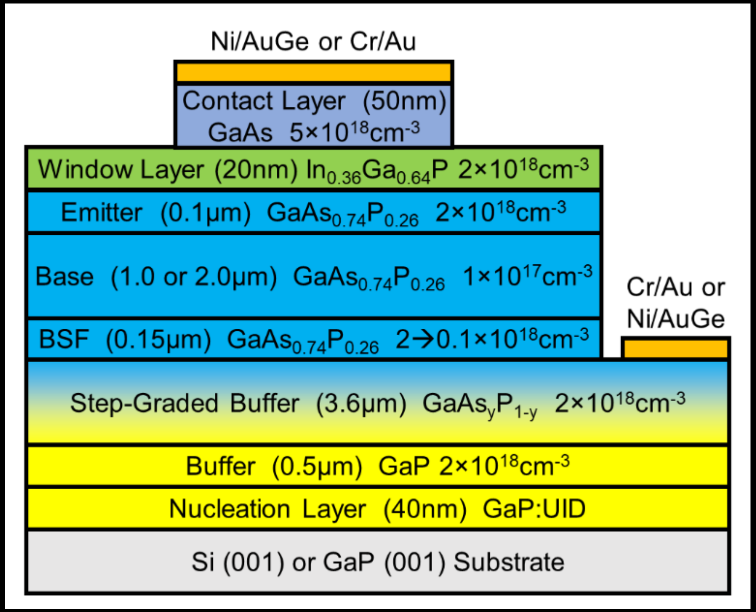


External Collaborators:
Mikel van Hest (NREL) – Perovskite Ink Development
Sai Ghosh (UC-Merced) – Electrospray Perovskite Cells

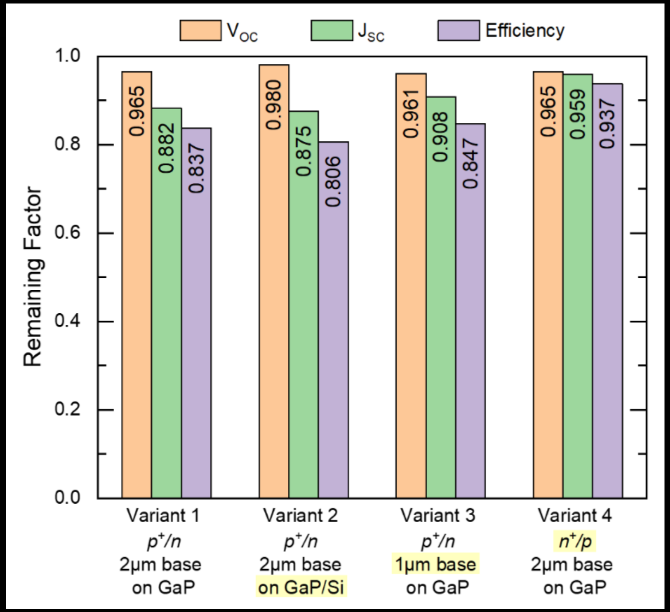
NASA Point of Contact: Lyndsey McMillon-Brown (lyndsey.mcmillon-brown@nasa.gov)

Lower Cost / High Efficiency Cell Development

- Currently funding 2 NASA Space Technology Graduate Research Opportunities (NSTGRO – Previously NSTRF) – at University of Illinois Urbana-Champagne with efforts focused on III-V materials on Si with improved radiation resistance



Schematic layer structure for fabricated GaAsP solar cells; no ARC was applied. Dopant concentrations are shown, and the dopant atom (Si for *n*-type, or Be for *p*-type) used for each layer depends on junction polarity. Ni/AuGe (Cr/Au) metal contacted *n*-type (*p*-type) material.



Remaining factors of figures of merit for GaAsP solar cell variants after irradiation with 1 MeV electrons to a fluence of 1×1015 e/cm2, as determined from 1-sun AM0 LIV of each best device. Highlighted text indicates the difference from variant 1.

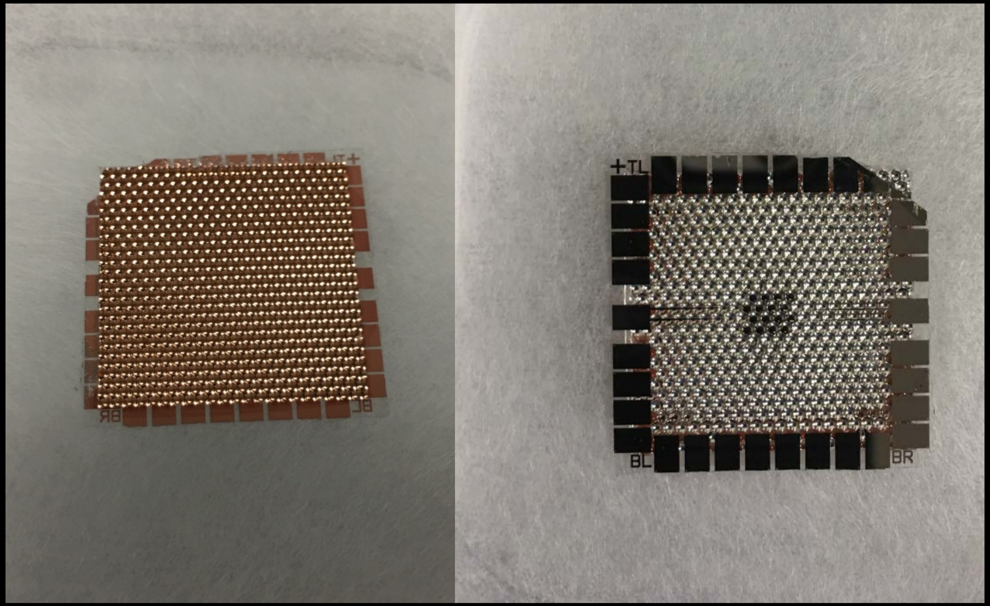
From: " Electron irradiation study of metamorphic 1.7 eV GaAsP solar cells" by Ryan Hool, 46th IEEE PVSC

NASA Research Collaborators: AnnaMaria Pal (a.pal@nasa.gov) & Geoff Landis (geoffrey.a.landis@nasa.gov)

Microcell CPV for Extreme Space Environments

- Starting a NASA Space Technology Graduate Research Opportunities (NSTGRO) – at The Pennsylvania State University this fall for efforts focused on micro-concentrators (30x) to mitigate low intensity, low temperature (LILT) and high radiation effects

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

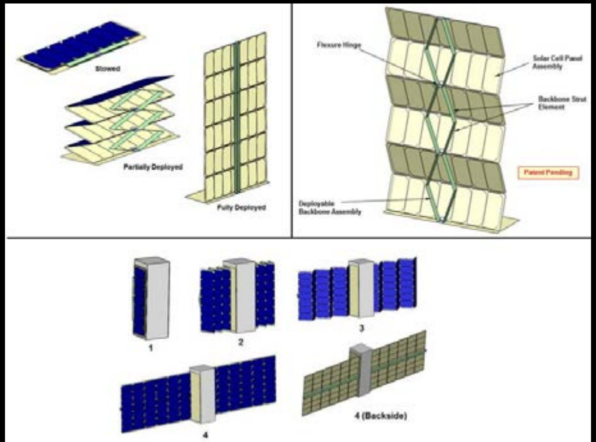


1x1 in^2, ~0.6 mm BK7G18 glass mirror array w/ protected Si coating, 0.10 mm Qioptiq coverglass w/ 4x4 170x170 um2 GaAs/InGaP cells, Bonded with DC93-500 PDMS, on MISSE-13

NASA Research Collaborators: Jeremiah McNatt (jmcnatt@nasa.gov)

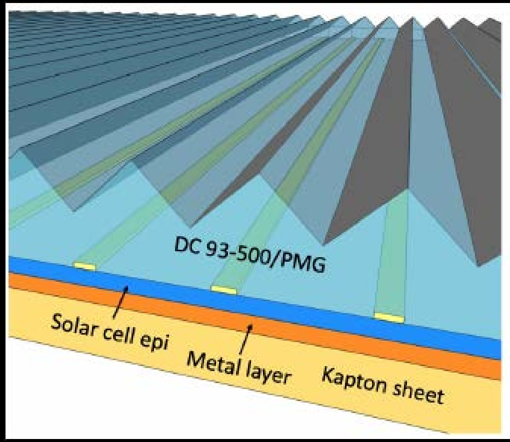
Recently Awarded Cell/Array SBIR Programs

2019 Phase II
Deployable Space Systems
Innovative Deployable Solar Array for SmallSat and CubeSat Applications



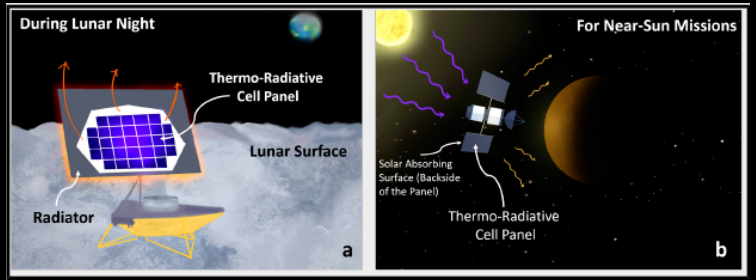
2X increase deployed area / power vs SOA CubeSat solar array systems. Array structure is also dual-use and can be configured as a deployable radiator. Design provides a robust, linear solar array deployment, maximizes the amount deployed from the side of a 3U CubeSat (>50W+ per wing)

2020 Phase I
Microlink Devices
Textured Solar Array



Novel, prismatic texturing method that will improve the performance and manufacturability of silicone-based encapsulations including PMG. Demonstrate that prismatic structures increase high-angle collection efficiency of space solar cells by up to 30% & reduce operating temperature by as much as 3 degrees. Potential benefits for UAV applications as well.

2020 Phase I
Advanced Cooling Technologies
"Dark" Photovoltaic Cells for Space Power Generation



"Dark" photovoltaic cell technology that can generate electricity when there is no sunlight. Proposed "dark" PV technology exploits the thermo-radiative (TR) cell, which is also made of semiconductor p-n junctions and can be viewed as a reversed PV cell, as a way to efficiently convert heat to electricity when radiatively coupled to a low temperature heat sink.

NASA Point of Contact: Jeremiah McNatt (jmcnatt@nasa.gov)

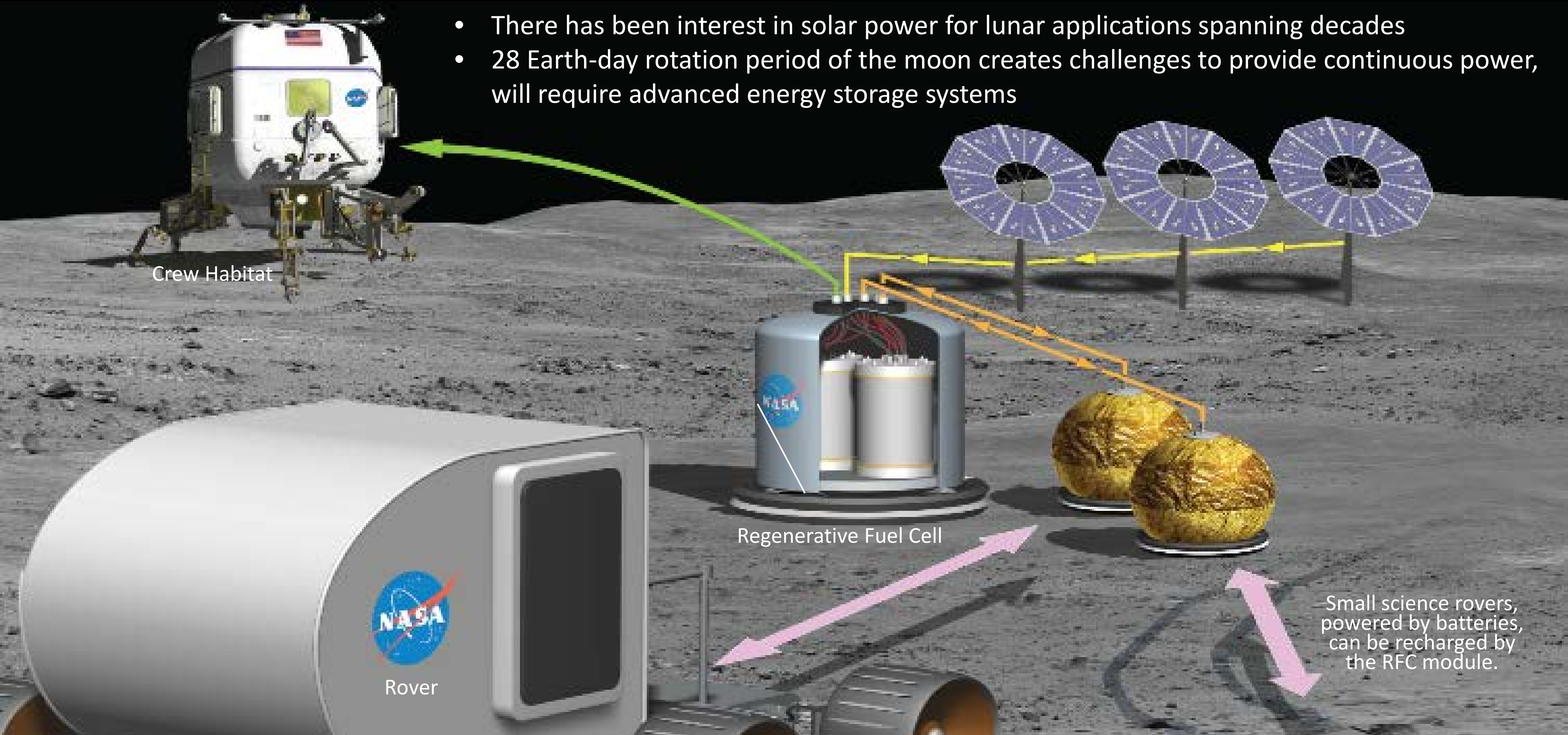
Solar Array Development – Lunar Orbit

- 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) contracts all include some elements of photovoltaics either in lunar orbit or on the descent/ascent vehicles

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

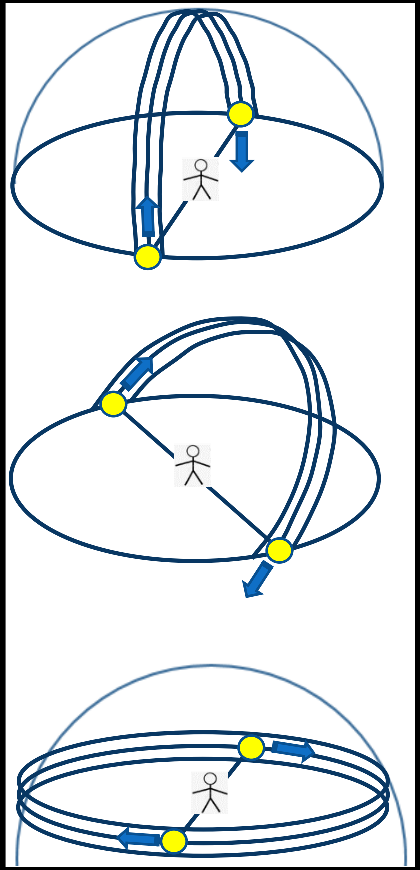
Solar Array Development – Lunar Surface

- There has been interest in solar power for lunar applications spanning decades
- 28 Earth-day rotation period of the moon creates challenges to provide continuous power, will require advanced energy storage systems



Solar Array Development – Lunar Surface

- Leverage space and terrestrial solar array structures that are adaptable to multiple lunar locations
- 10 kW class arrays expected to be needed for ISRU and extended human missions
- Arrays will include retraction/re-deployment and ability to be relocated



At the equator, the Sun passes directly overhead +/- 1.5 degs

At mid-latitudes, the Sun's path is tilted by latitude degrees +/- 1.5 degs

At the poles, the Sun traverses the horizon +/- 1.5 degs

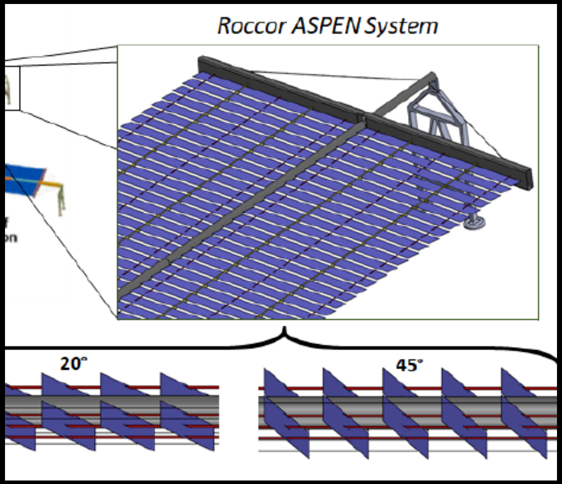
- Vertical Solar Array Technology (VSAT) project led by NASA Langley is developing solar array structures for the lunar south pole
- Lightweight, autonomous deployment systems that can accommodate sloped surfaces
- SBIR program has been leveraged for early concept development
- Solicitation in work for FY21 for TRL advancement

Illumination Near the poles is highly variable due to the rugged terrain and low sun angle

Recently Awarded Surface Array SBIR Programs

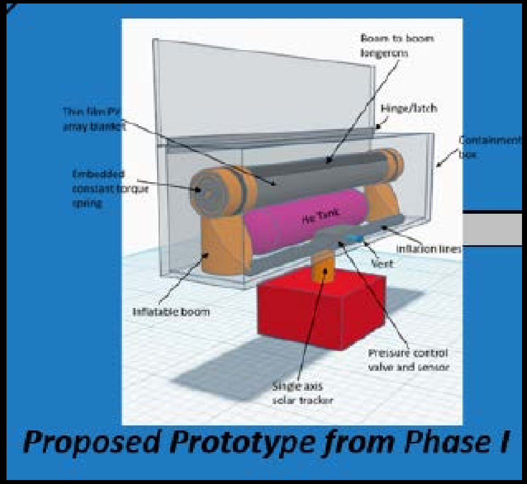
2018 Phase II
ROCCOR

Articulating Solar Panel Energy System (ASPEN)



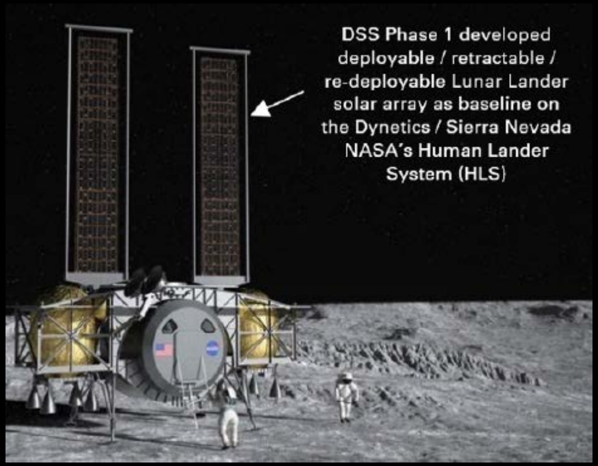
2019 Phase II
Nexolve

Simple Reliable Retractable Lunar Lander Solar Array



2019 Phase II
Deployable Space Systems

Deployable and Retractable Solar Array for Lunar Surface/Lander Mobility Operations



2019 Phase II
Opterus

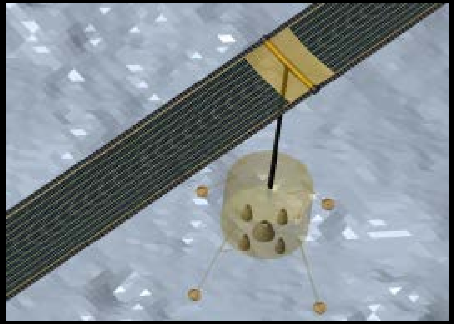
Lunar Solar Array Monolithic Truss

NASA Point of Contact: Richard Pappa (richard.s.pappa@nasa.gov)

Recently Awarded Surface Array SBIR Programs

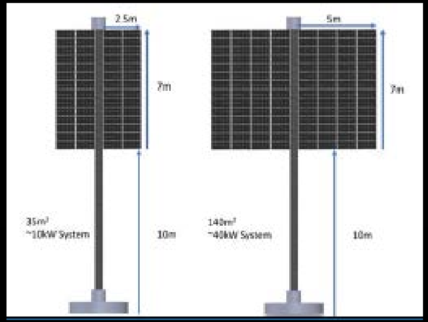
2020 Phase I
Dynovas

Motorless Array Deployment (MAD) Energy



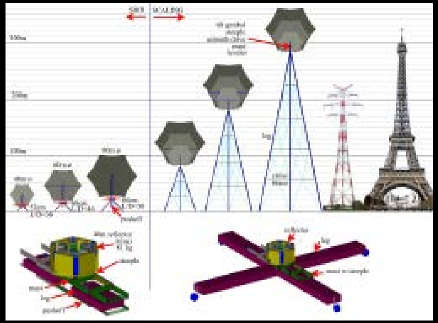
2020 Phase I
Opterus

Rollable-Retractable Mast Array (R-ROMA)



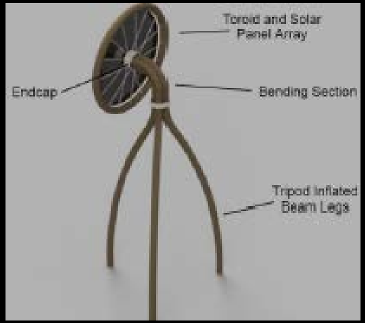
2020 Phase I
L'Garde

Lightweight Illuminating Towers



2020 Phase I
Ryzing Technology

Articulating Airbeam Tripod Boom for Solar Arrays

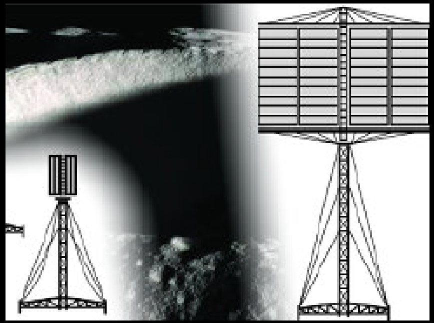


2020 Phase I
LoadPath

Origami-Based Extendable Lunar Innovative Solar Column (OBELISC)

2020 Phase I
Tent Guild

Self-Erecting Elevated Platform



NASA Point of Contact: Richard Pappa (richard.s.pappa@nasa.gov)

Solar Cell &Array Development – Outer Planets (LILT)

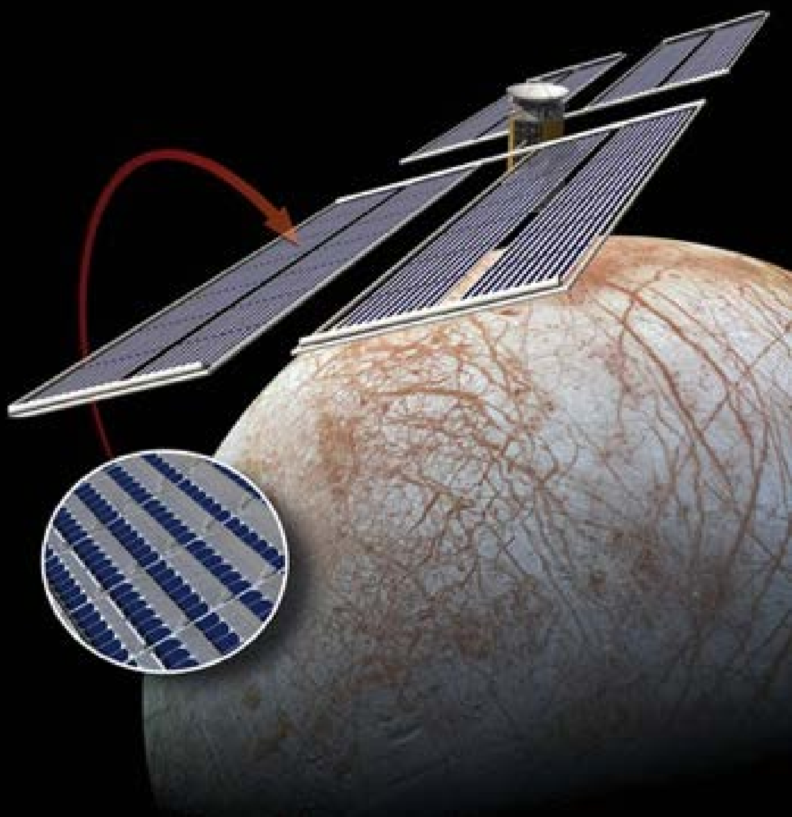
- Extreme Environments Solar Power (EESP): Develop solar cell and array technologies for use in low intensity, low temperature (LILT) environments (beyond 5 AU) and high radiation environments in this region (Jupiter and its inner moons)
- Project Goal: 35% beginning of life (BOL) cell efficiency, 28% 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)

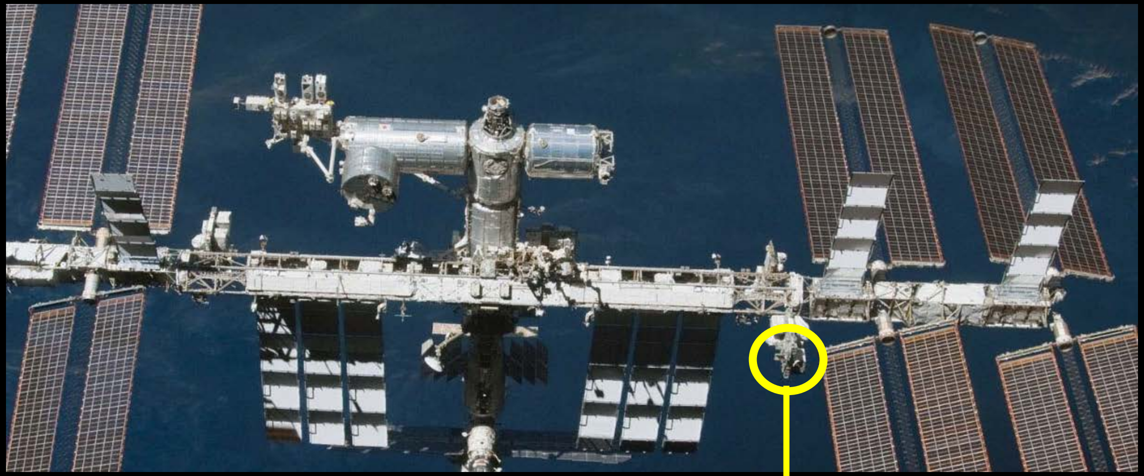
System Concept

- 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.

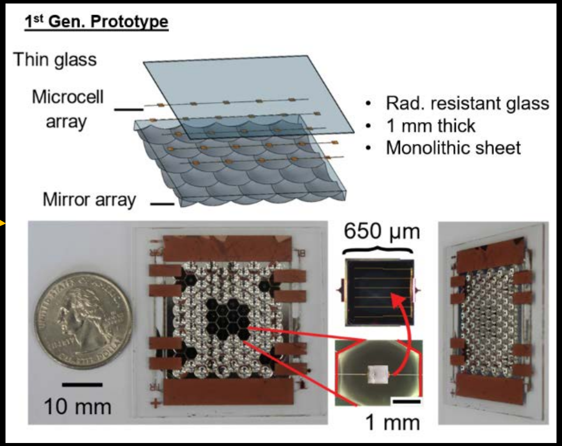


Flight Test – MISSE 13

Materials ISS Experiment (MISSE)
- 6 month (planned) exposure to Low Earth Orbit (LEO) conditions starting March 2020
- Includes lightweight, novel solar cells and modules (including Si, Perovskites, Concentrators)
- Passive exposures similar to past ISS experiments in zenith direction
- Will remain on ISS for an additional 6 months



Includes Penn State / Naval Research Lab Microcell Concentrating PV device



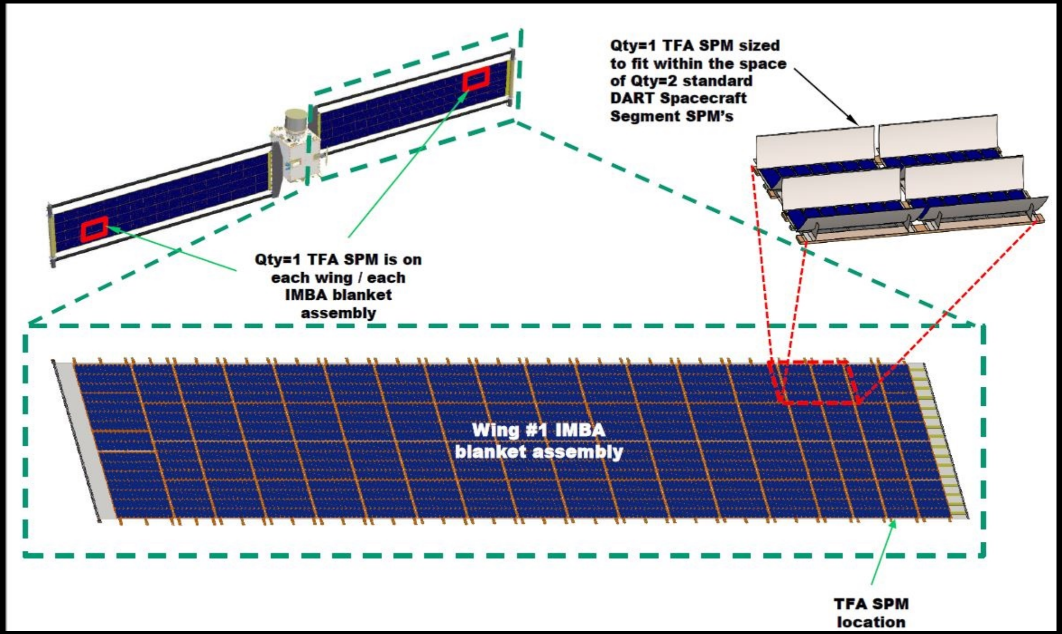
Awarded 6” x 3” area in the Zenith direction

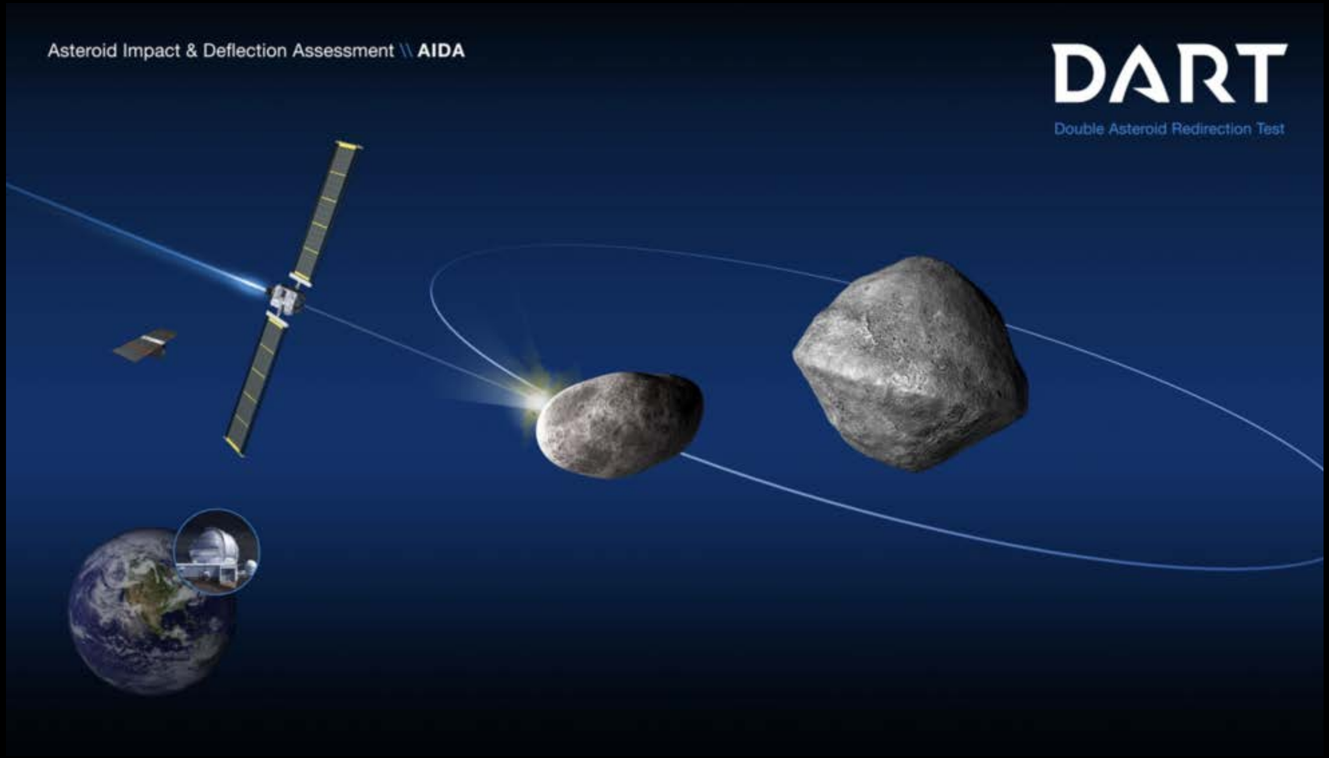
Full exposure to space environment

Flight Test – EESP on DART

Double Asteroid Redirection Test (DART) Mission: Launch window opens July 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



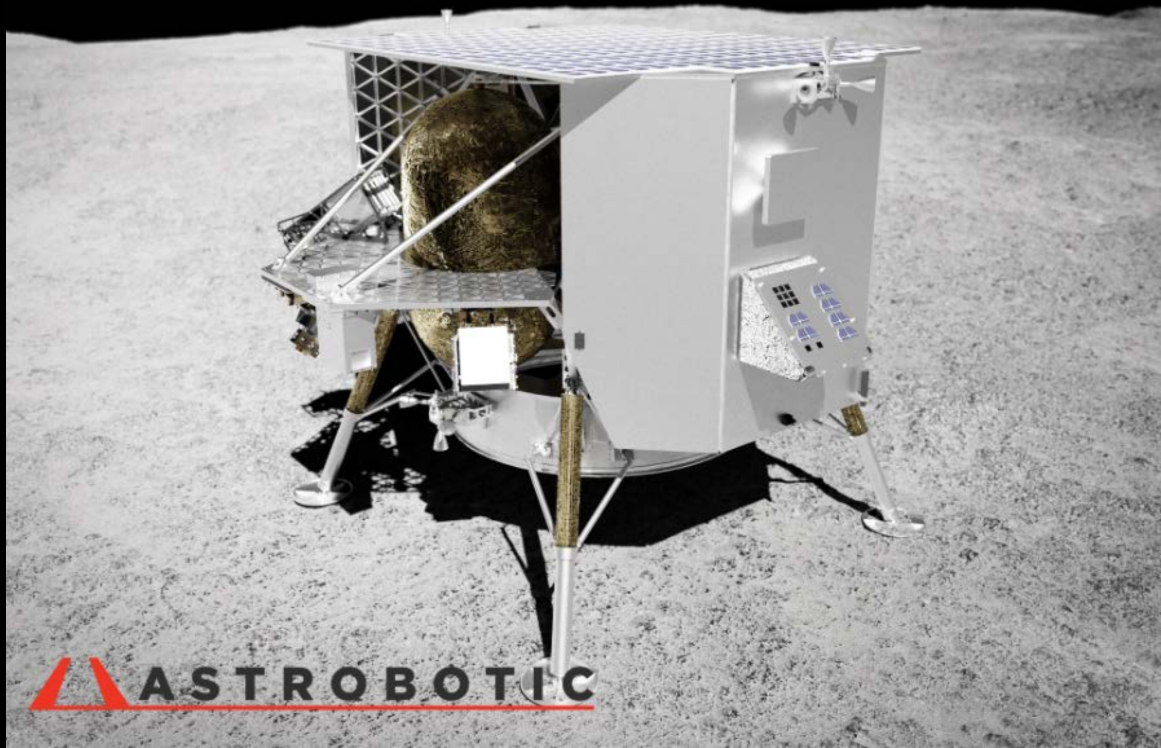


Schematic of the DART mission shows the impact on the moonlet of asteroid (65803) Didymos

Flight Test – PILS

PILS – Photovoltaic Investigation on the Lunar Surface

- NASA Commercial Lunar Payload Service (CLPS) project – Landing July 2021 at Lacus Mortis (45 N)
- PILS test platform due June 2020 (extended due to Covid-19 impacts). Now planned delivery by October 2020.
- 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)



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

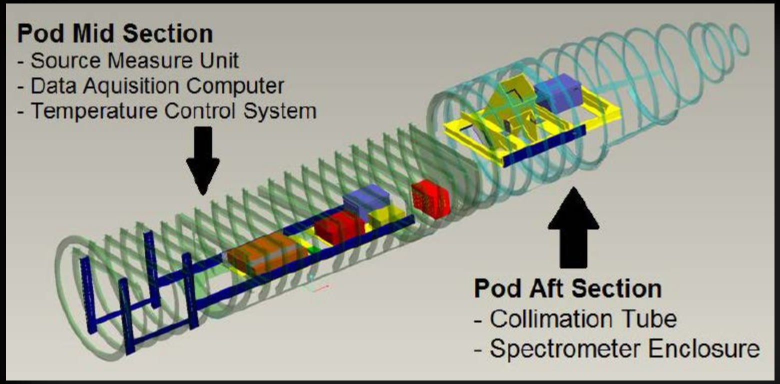
- Impact
  - Enable future commercial and NASA missions with higher power at a lower mass
  - For small satellites more power can enable additional payload capabilities
  - Smaller area footprint (W/m2) and higher specific power (W/kg). Driving metrics for solar arrays in space and on lunar surface

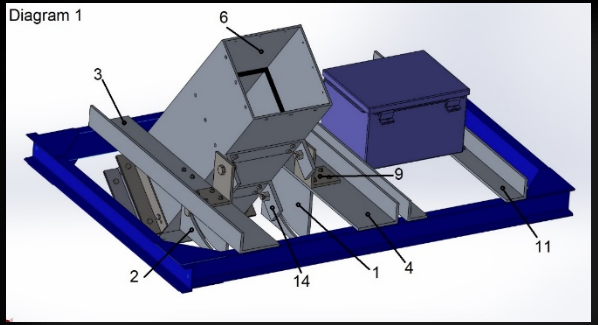
- *Electrical Checkout and performance using LED-based pulsed solar simulator*
- *Sine vibe testing*
- *Thermal balance testing*
- *Electrostatic discharge testing*
- *UV radiation exposure*
- *Electron radiation exposure*
- *Proton radiation exposure*
- *Thermal cycling*

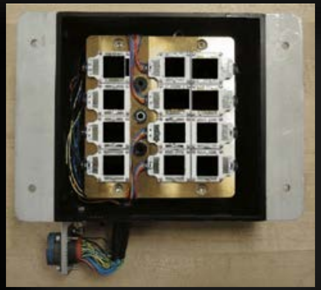
High-Energy Accelerator Lab at MSFC
(Electron and Proton Radiation Testing)

Ground Testing – High Altitude Measurement

- ER-2: High altitude (70k ft) experiment platform utilized for solar cell standard development
- Planning 2021 Spring and Fall Campaigns. 2020 season was cancelled due to Covid-19
- Building 2nd flight pod to increase cell area per flight

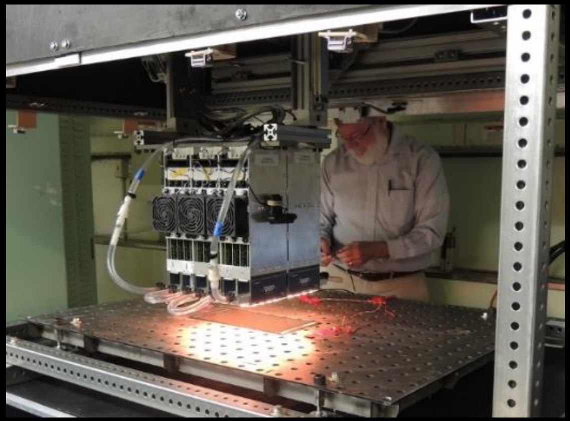


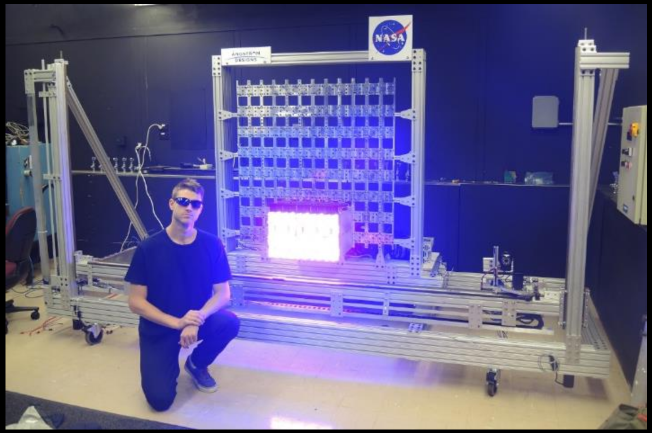




Ground Testing – Solar Simulators

- 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 (~ 19” x 12”). Expanding this fall to 18 modules





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 and through short term internal R&D
- 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
- Ground testing
  - Facilities at GRC are being upgraded to allow for larger samples with more junctions