# The CubeSat Mission to Study Solar Particles (CuSP)


Walt Downing

IEEE Life Senior Member

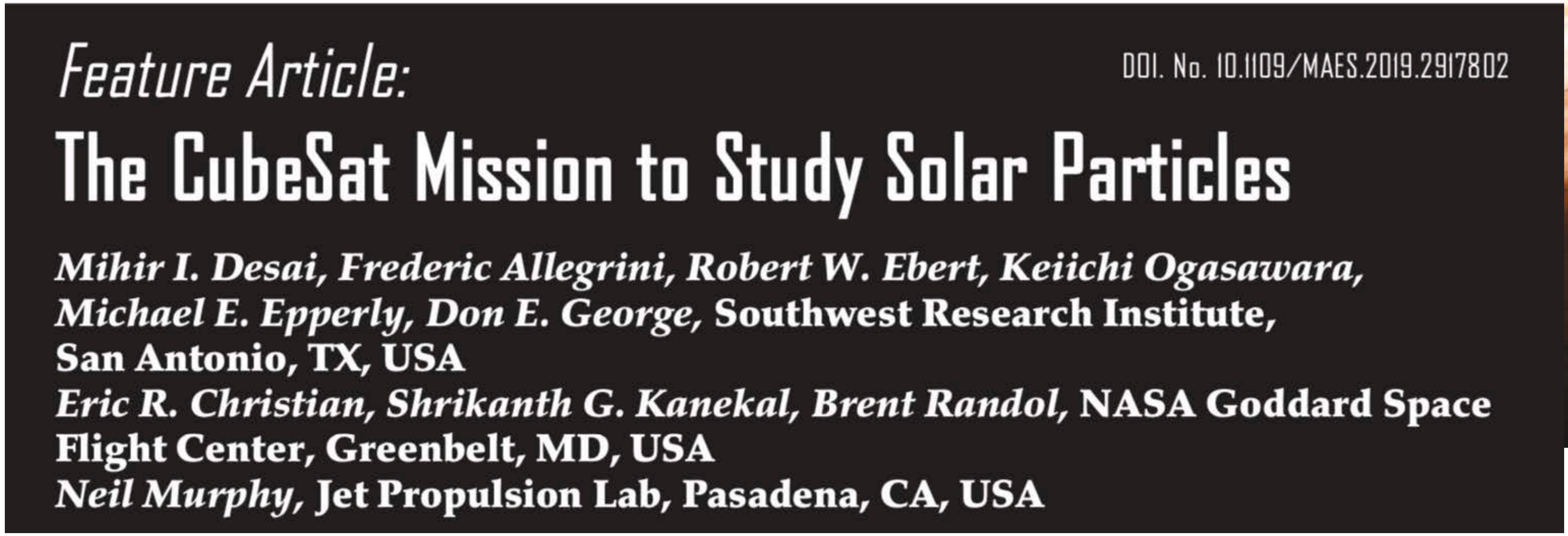
Aerospace and Electronic Systems Society President (2020-2021)



Acknowledgements – National Aeronautics and Space Administration (NASA) and CuSP Principal Investigator, Dr. Mihir Desai, Southwest Research Institute (SwRI)

# Feature Articles in SYSTEMS Magazine

- Three-part special series on Artemis I CubeSats
  - April 2019 (CuSP, IceCube, ArgoMoon, EQUULEUS/OMOTENASHI, & DSN)
  - September 2019 (CisLunar Explorers, OMOTENASHI & Iris Transponder)
  - March 2020 (BioSentinnel, Near-Earth Asteroid Scout, EQUULEUS, Lunar Flashlight, Lunar Polar Hydrogen Mapper, & Δ-Differential One-Way Range)
- Available in the AESS Resource Center [https://resourcecenter.aess.ieee.org/](https://resourcecenter.aess.ieee.org/)
- Free for AESS members

*Feature Article:*

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**The CubeSat Mission to Study Solar Particles**

*Mihir I. Desai, Frederic Allegrini, Robert W. Ebert, Keiichi Ogasawara, Michael E. Epperly, Don E. George,* Southwest Research Institute, San Antonio, TX, USA
*Eric R. Christian, Shrikanth G. Kanekal, Brent Randol,* NASA Goddard Space Flight Center, Greenbelt, MD, USA
*Neil Murphy,* Jet Propulsion Lab, Pasadena, CA, USA

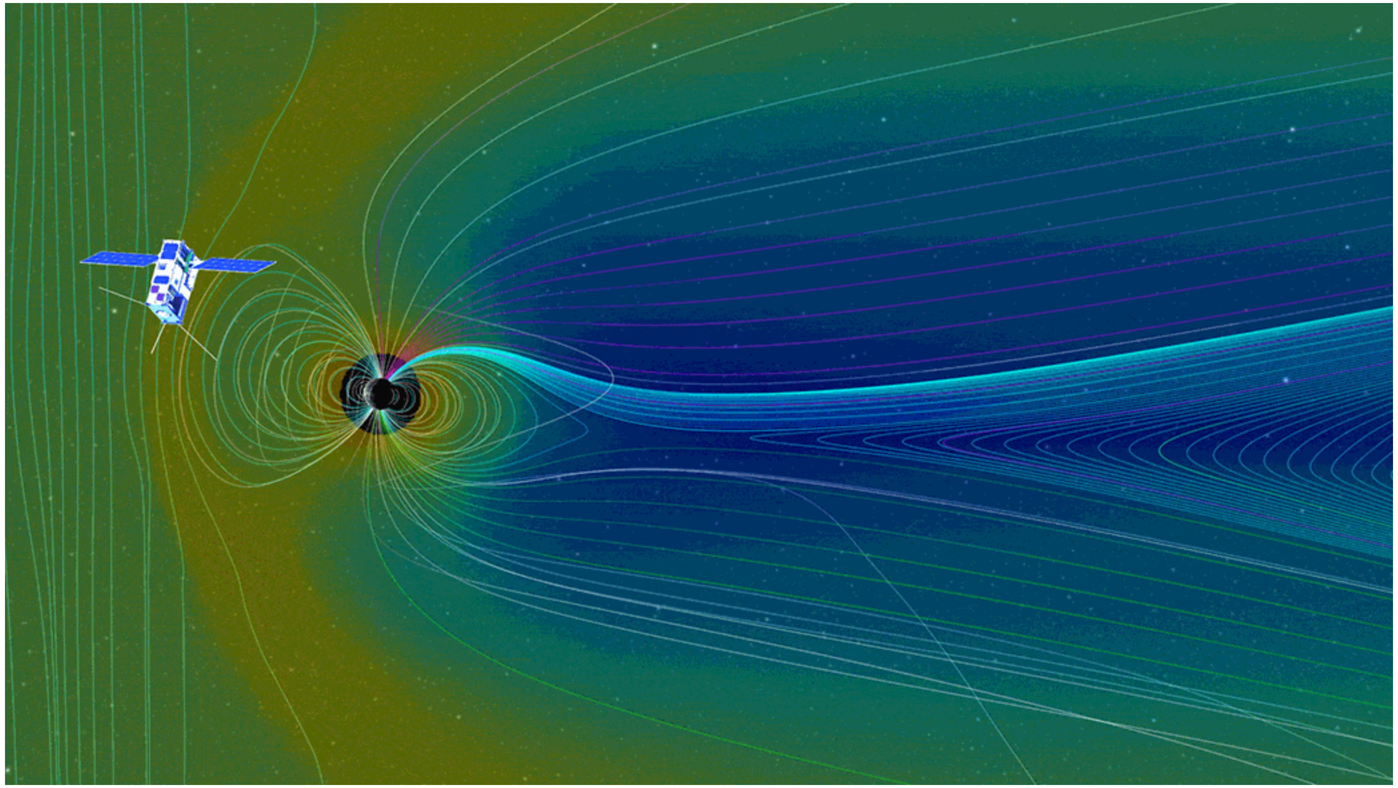
# What are CubeSats?


- A class of small research spacecraft
- Built to standard dimensions (Units or "U")
  - 1U = 10 cm x 10 cm x 11 cm (Roughly "cube-shaped")
  - Modular: 1U, 2U, 3U, 6U or 12U in size
  - Weigh less than 1.33 kg per U
- NASA's CubeSats are dispensed from a deployer such as a Poly-Picosatellite Orbital Deployer (P-POD)
- NASA's CubeSat Launch initiative (CSLI) provides opportunities for small satellite payloads to fly on rockets planned for upcoming launches. These CubeSats are flown as secondary payloads on previously planned missions.

https://www.nasa.gov/directorates/heo/home/CubeSats_initiative

# What is CuSP?

- NASA Science Mission Directorate sponsored Heliospheric Science Mission selected in June 2015 to be launched on Artemis I. https://www.nasa.gov/feature/goddard/2016/heliophysics-cubesat-to-launch-on-nasa-s-sls
- Support space weather research by determining proton radiation levels during solar energetic particle events and identifying **suprathermal** properties that could help predict geomagnetic storms.
  - Motion with velocities much larger than the characteristic local thermal velocity is called **suprathermal**.
  - Processes involving magnetic fields, such as solar flares, can produce **suprathermal** particle motions.
- Increase Technical Readiness Level of Interplanetary Space Weather Instruments.
- CuSP is a pathfinder for future interplanetary and space weather CubeSats.

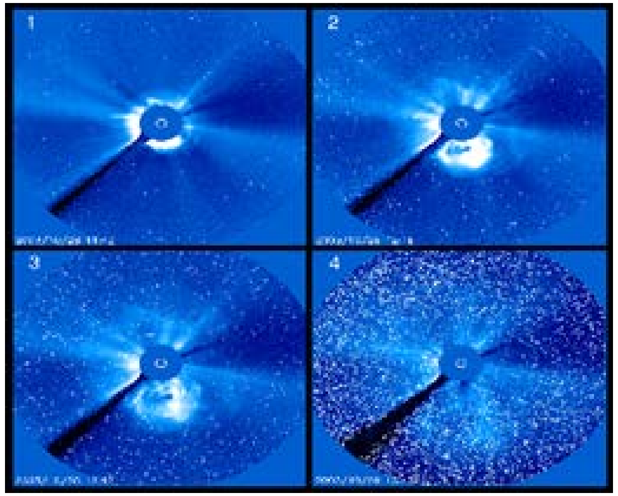


**Studying energetic particles energy, composition, and angular distributions yields information about their remote sources, sites of acceleration, and how they are transported to 1 AU.**

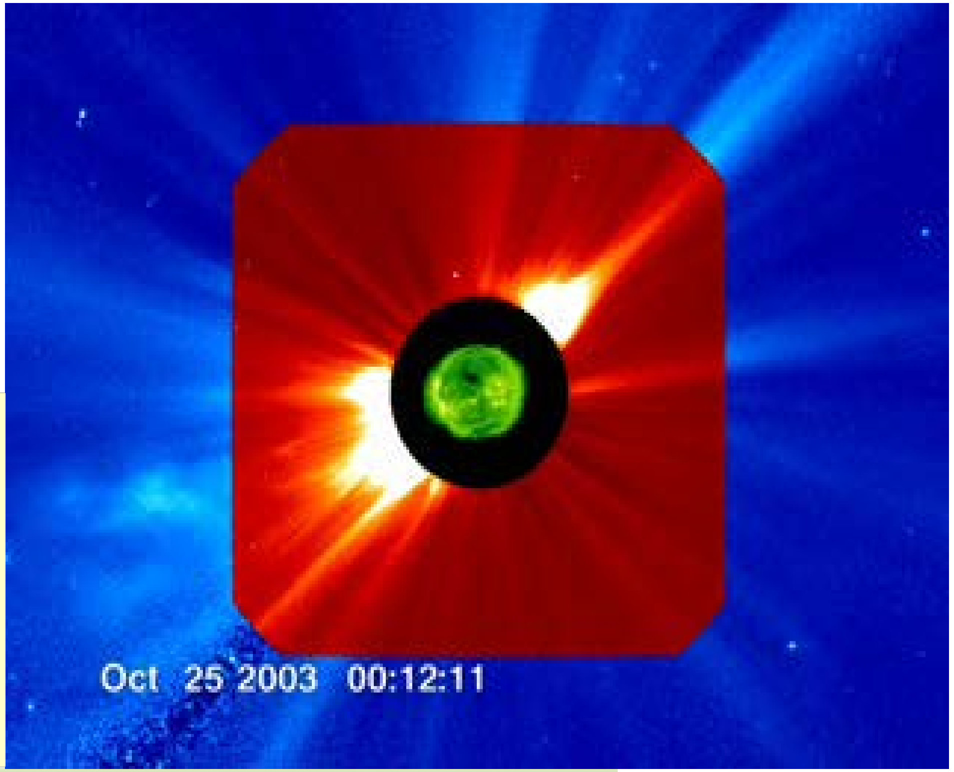
# Severe Space Weather

*Solar Particle Events and Geomagnetic Storms Caused by Solar Flares or Coronal Mass Ejections*

**Solar X-Rays:**
- Arrive in 8 Minutes
- Last minutes to hours
- Increase ionosphere density
- Systems Affected:
  - ➢ Radio Communications, Navigation



**Solar Energetic Particles:**
- Arrive in 30 Minutes to 24 hours
- Last several days
- Systems Affected:
  - ➢ Airline Routes, Astronauts, Spacecraft Electronics, Radio Communications

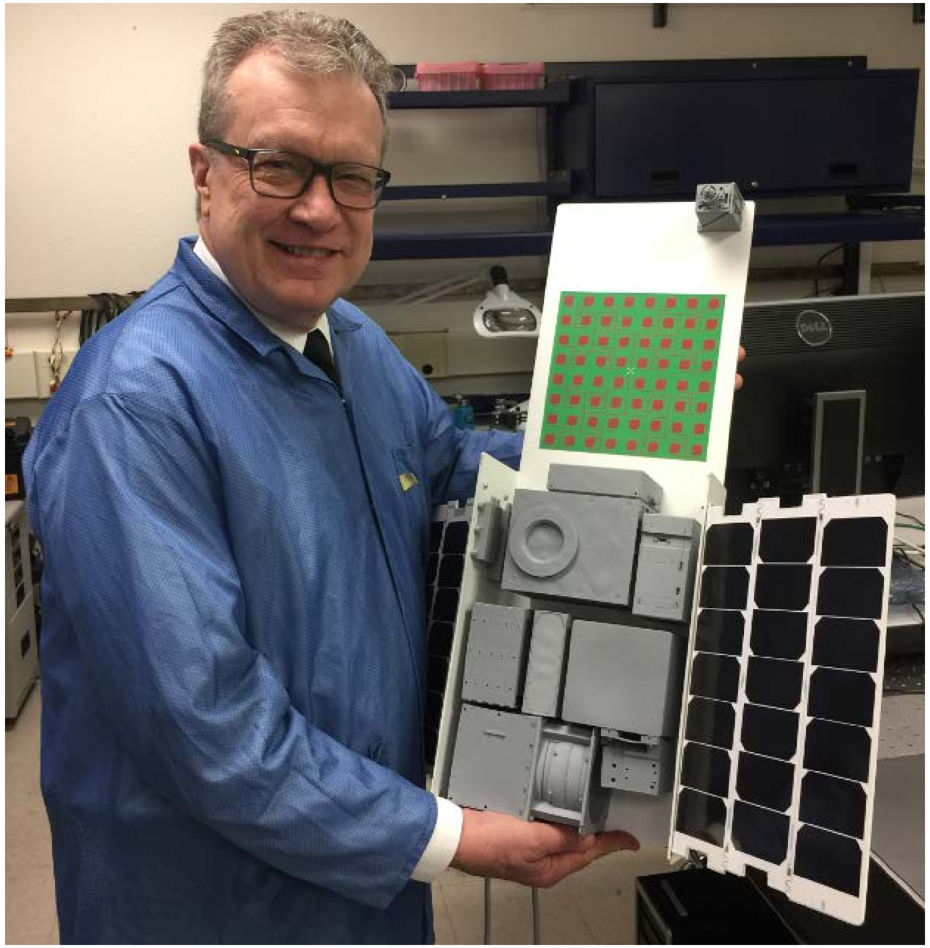



**Coronal Mass Ejections (CMEs):**
- Arrive 1- 4 Days later
- Last a day or two
- Produce Geomagnetic Storms Systems Affected
  - ➢ Radio Communications, Navigation, Electric Power Grids, Pipelines

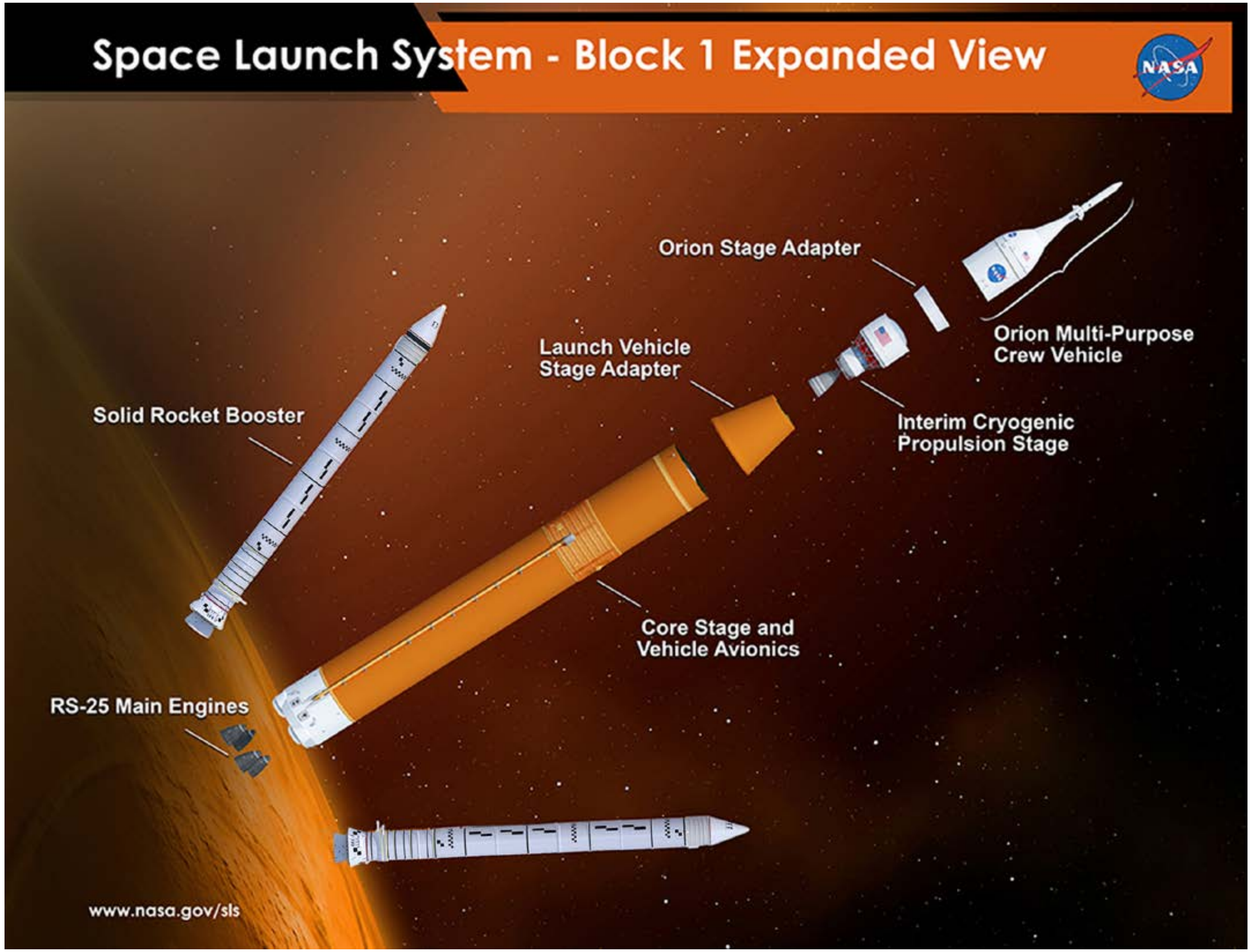
# CuSP Configuration

*6U CubeSat*

- 3-axis stabilized platform
- Avionics with Command and Data Handling (C&DH), Attitude Determination and Control System (ADCS) and Thruster
- Deployable solar arrays and batteries
- Deep Space X-Band transponder and antennas
- Ground Station
- 3 Scientific Instruments
  - Suprathermal Ion Sensor (SIS) – SwRI
  - Miniaturized Electron and Ion Telescope (MErIT) – GSFC
  - Vector Helium Magnetometer (VHM) - JPL



# Launch Vehicle
# Space Launch System (SLS)

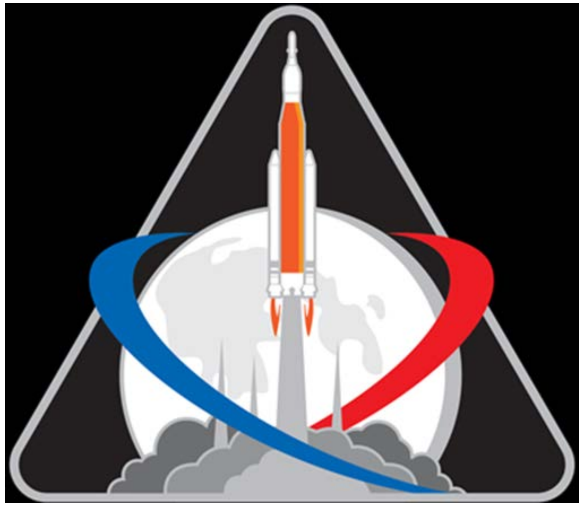



NASA's super heavy-lift expendable launch vehicle for deep space exploration

# Artemis I
# Formerly Exploration Mission-1 (EM-1)

- **Primary Mission** - Uncrewed test flight of Orion Multi-Purpose Crew Vehicle (MPCV)
- KSC Launch Complex 39B
- Three-week mission
- Trans-lunar injection
- Six days in distant retrograde orbit around the Moon
- Return to Earth
- Recovery in the Pacific Ocean

**Orion MPCV**



# Artemis I Secondary Payloads

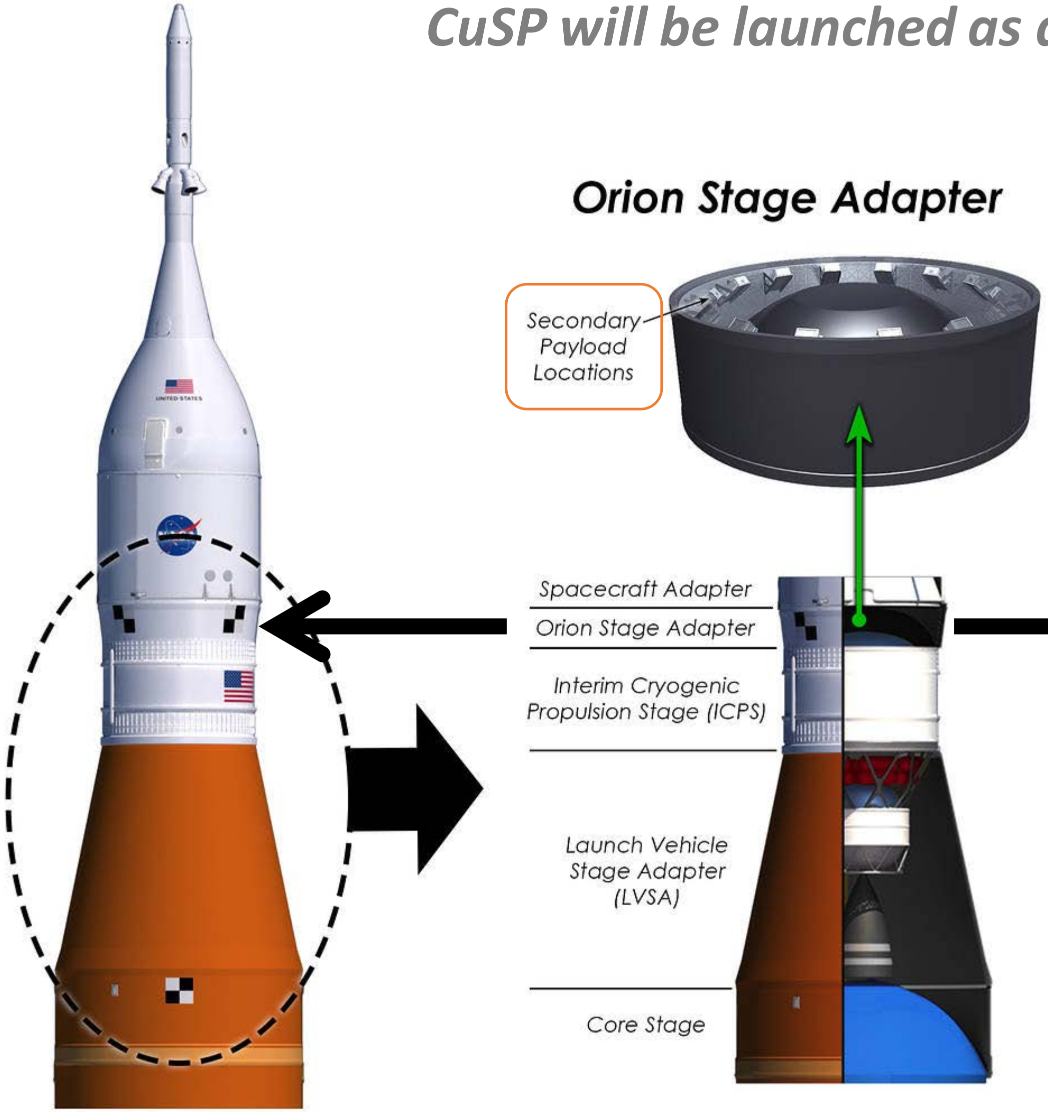
*Thirteen 6U CubeSats*

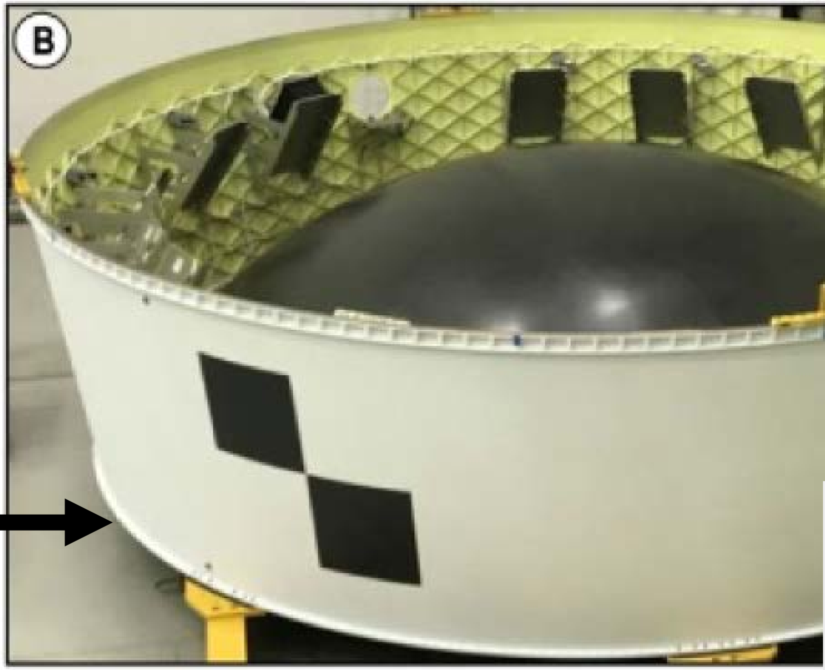
- Selected by NASA Directorates
  - CuSP*
  - BioSentinel~
  - Lunar Flashlight~
  - Lunar IceCube*
  - Lunar Polar Hydrogen Mapper~
  - Near-Earth Asteroid Scout~
  - SkyFire
- NASA's Cube Quest Challenge Winners
  - CisLunar Explorers^
  - Earth Escape Explorer
  - Team Miles
- NASA's International Partners
  - ArgoMoon (Italian Space Agency)*
  - OMOTENASHI (JAXA)*^
  - EQUULEUS (JAXA)*~

**Articles in SYSTEMS magazine issues *April 2019 / ^September 2019 / ~March 2020**

# SLS Secondary Payloads

*CuSP will be launched as a secondary payload on Artemis I*



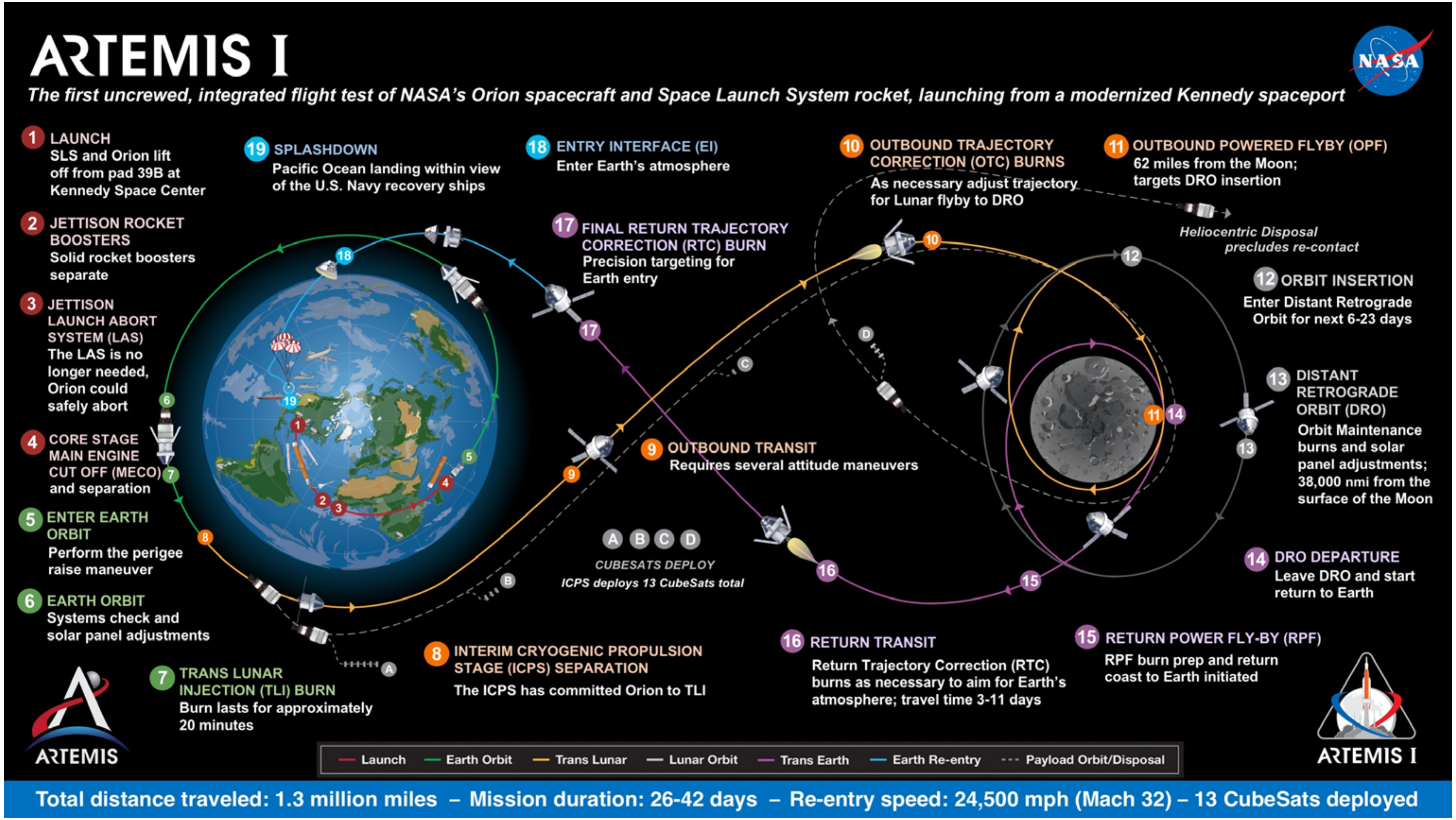




**Mounting points for thirteen 6U deployers in the Orion Stage Adapter**

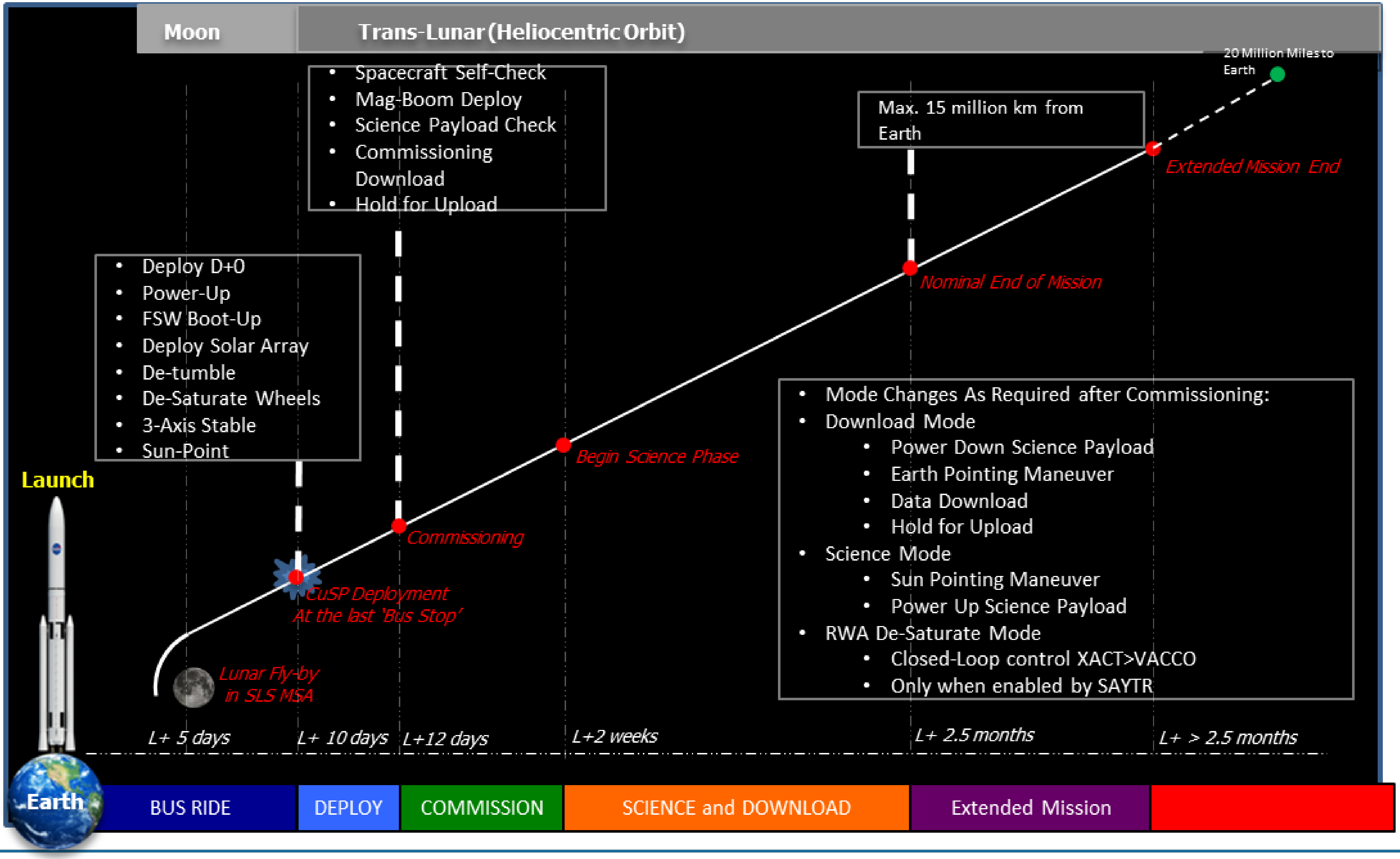
**Typical 6U Deployer**

# Artemis I Mission Map

*CuSP will deploy at the last "bus stop" after ICPS Lunar flyby ("D" on map)*



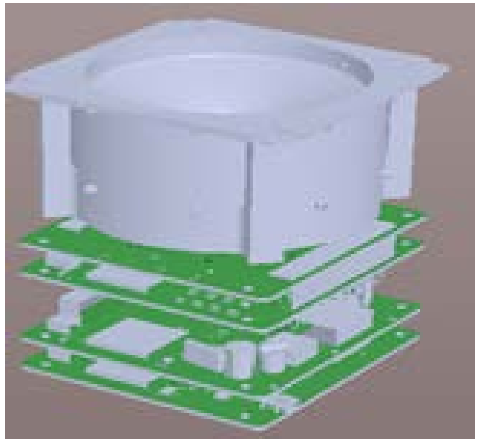
# CuSP Mission Overview



# CuSP Scientific Payload

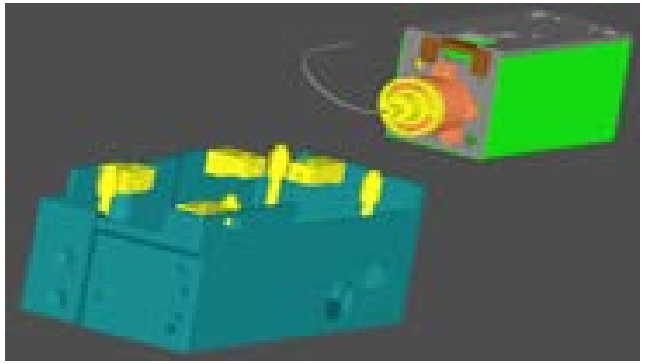
*Three Complex Instruments in One CubeSat*

**Suprathermal Ion Sensor (SIS) – SwRI**
**Miniaturized Electron and Ion Telescope (MErIT) – GSFC**
**Vector Helium Magnetometer (VHM) - JPL**



SIS measures spectral and angular distributions of suprathermal ions

MErIT measures energy spectrum and intensity of electrons, protons, and H-Fe ions

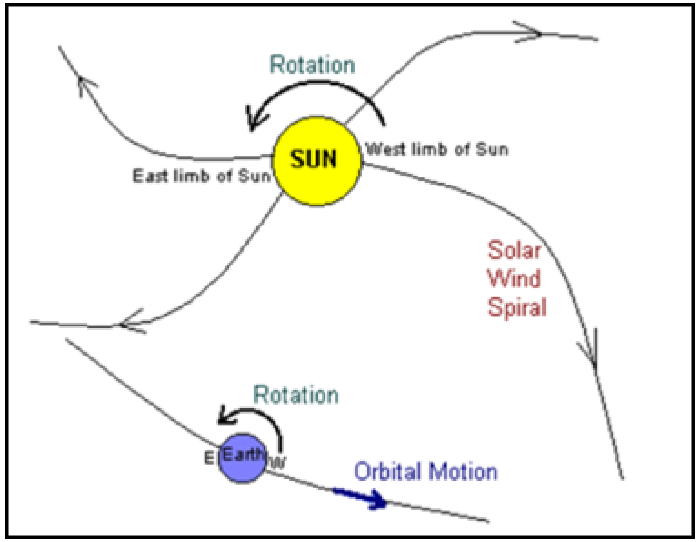


VHM measures magnetic fields

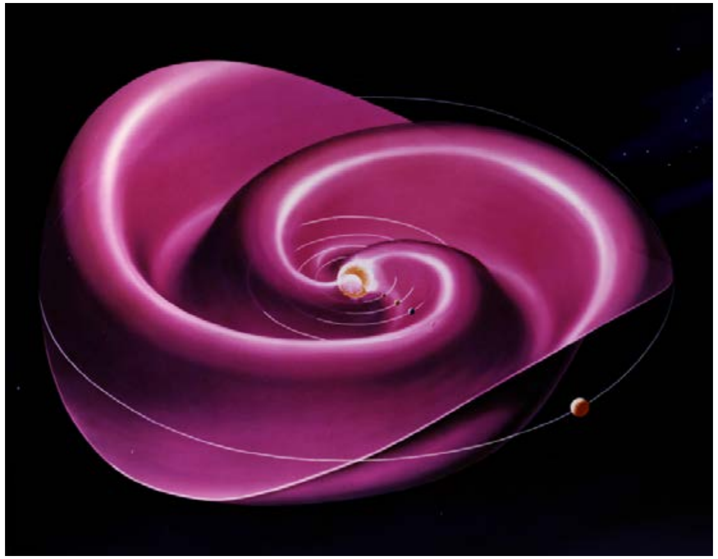
# CuSP Orbit and Orientation

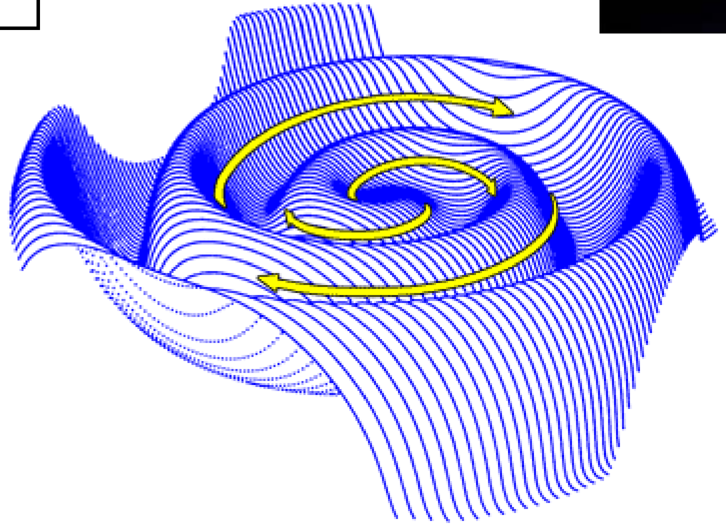
*Translunar Heliocentric Orbit (leading or lagging Earth, depending on launch date)*

CuSP is 3-axis stabilized to ensure instrument fields-of-view along the nominal Parker Spiral direction and ecliptic north

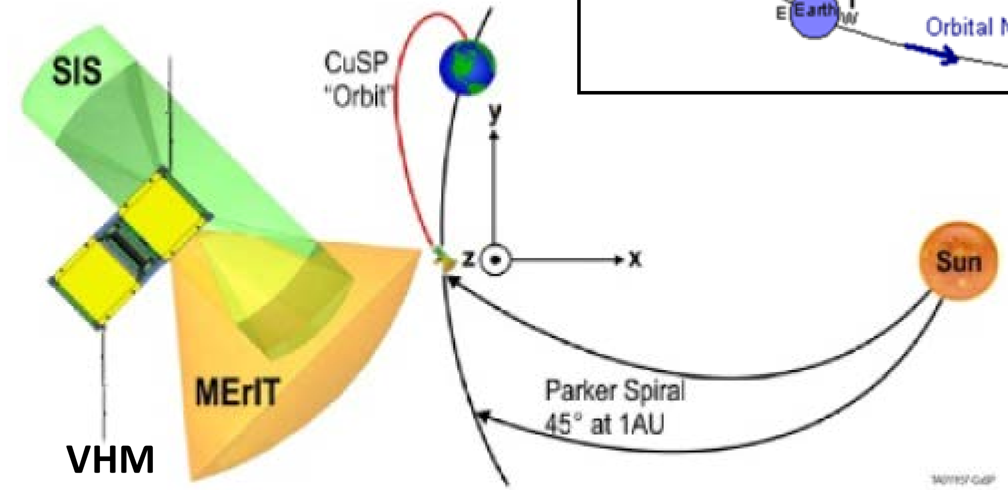



Heliospheric current sheet (Parker's Spiral) is the surface where the polarity of the Sun's magnetic field changes from north to south





Heliospheric current sheet rotates with the Sun on a period of ~25 days



# CuSP Sensor Performance

*More "bang for the buck"*

- Target high-value science
- Leverages heritage designs to achieve high technical-readiness levels with minimal non-recurring engineering
- Parts program tailored for 3-month on-orbit science operations to reduce hardware costs
- Lower costs and higher risks are typical of CubeSat missions

**CuSP Sensor Performance and Characteristics**

| Functional Parameter | Suprathermal Ion Sensor (SIS) | Miniaturized Electron and Ion Telescope (MErIT) | Vector Helium Magnetometer |
|---|---|---|---|
| Measurement Technique and Parameters | Electrostatic Analyzer & Position-sensing MCP → E/q and Incident Direction | Single-ended 8-SSD stacked telescopes → multiple ΔE versus Residual energy | Optical pumping of He atoms→ Vector components of B field |
| Species & Energy Range | H & He: ~3–69 keV/q | e-s: 100 keV–4 MeV<br>H, He: ~2–40 MeV/n;<br>Fe: ~5–170 MeV/n | N/A |
| Energy resolution (FWHM) | Δ(E/q)/E/q~26-34% | ΔE/E<30%; ~8 bins/decade | N/A |
| Time Resolution (s) | 1 full E/q spectrum at 60 s | Energy spectra and intensities at 60 s | <0.3 Hz |
| Instantaneous FOV (Elevation × Azimuth) [°] | Elevation angle: 12° to 23°<br>Azimuthal angle: 270° | Conical, ±45° pointed along Parker Spiral | N/A |
| Full FOV (Elevation × Azimuth) [°] | -16° to +24° × ~270° | | N/A |
| Angular resolution (FWHM) [°] | Ring 1 (innermost) to 5 (outermost): 12°, 18°, 20°, 23°, 20° (× 45°) | N/A | N/A |
| Geometric Factor or Sensitivity | ~0.015 [cm$^2$ sr eV/eV] for 270° in azimuth | H & He: ~1 [cm$^2$ sr]; Z>2: 10 [cm$^2$ sr] | <25 pT/√Hz at 1 Hz |
| Dynamic Range | ~0.22–0.55 MHz per pixel (corresponds to 1 MHz/cm$^2$ on the MCP) | ~100 kHz per detector segment | 0-2000 nT (±1000 nT) |

# CuSP Resource Characteristics

*High Performance at Reduced SWAP*

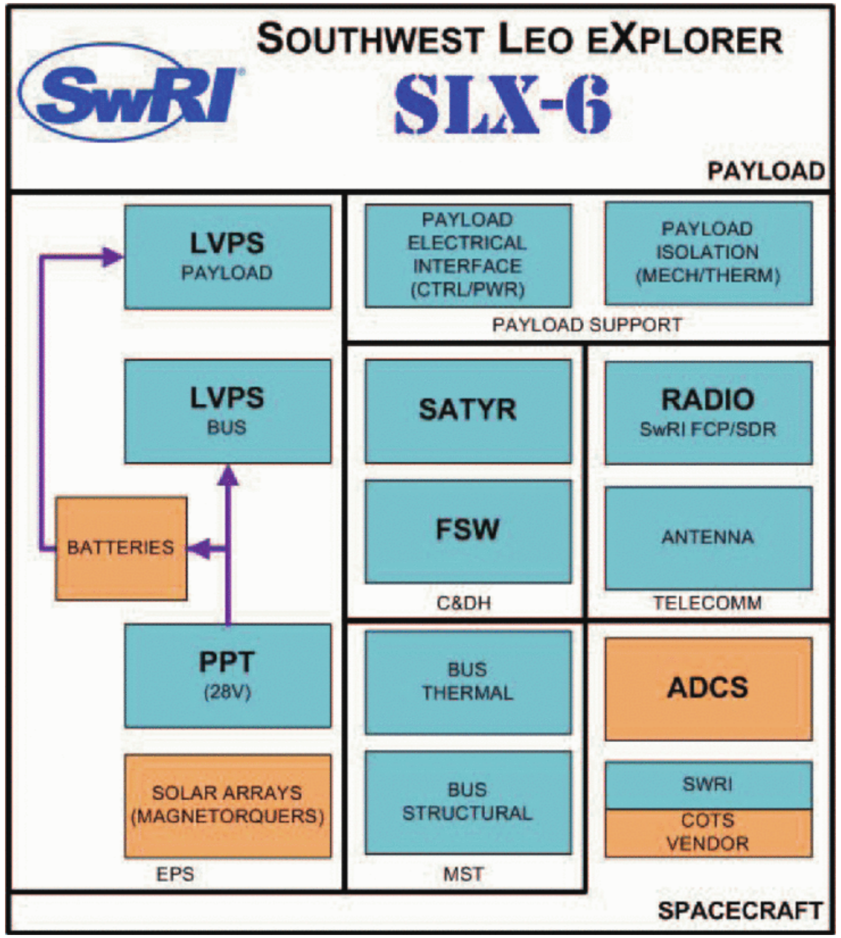
**CuSP Sensor Performance and Characteristics**

| Functional Parameter | Suprathermal Ion Sensor (SIS) | Miniaturized Electron and Ion Telescope (MErIT) | Vector Helium Magnetometer |
|---|---|---|---|
| Current Best Estimate Resource Summary | | | |
| Mass (g)[a] | 1366 | 1100 | 815 |
| Power (W)[a] | 4.5 | 1.04 | 4.41 |
| Volume ($cm^3$)[b] | 10 cm × 10 cm × 15 cm | 10 cm × 10 cm × 9 cm | 10 cm × 10 cm × 5 cm |
| Telemetry (bps) | 45.3 | 32.5 | 288 |

# CuSP Spacecraft Bus

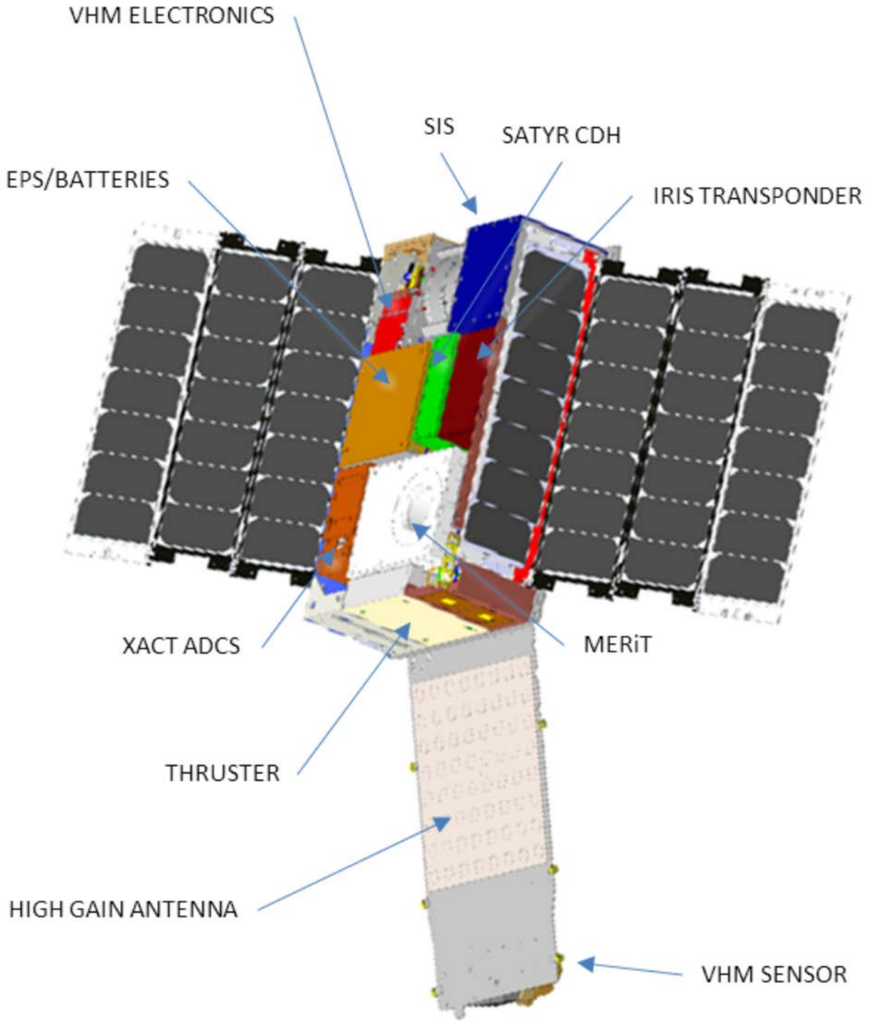
*Southwest Deep EXplorer (SDX-6)*

- Based on Southwest Leo Explorer (SLX-6) with accommodations for deep space operations
- 6U CubeSat (2U x 3U configuration)
- Seven Subsystems
  - Command and Data Handling (C&DH)
  - Electrical Power (EPS)
  - Attitude Determination and Control (ADCS)
  - Telecommunications (TELECOMM)
  - Mechanical, Structural and Thermal (MST)
  - Payload Support
  - Flight Software (FSW)
- See Proceedings of the 2016 IEEE Aerospace Conference, March 2016
  - Authors – Don George & John Dickinson, SwRI
  - AESS Flagship Conference on Space Systems



# CuSP Subsystem Overview

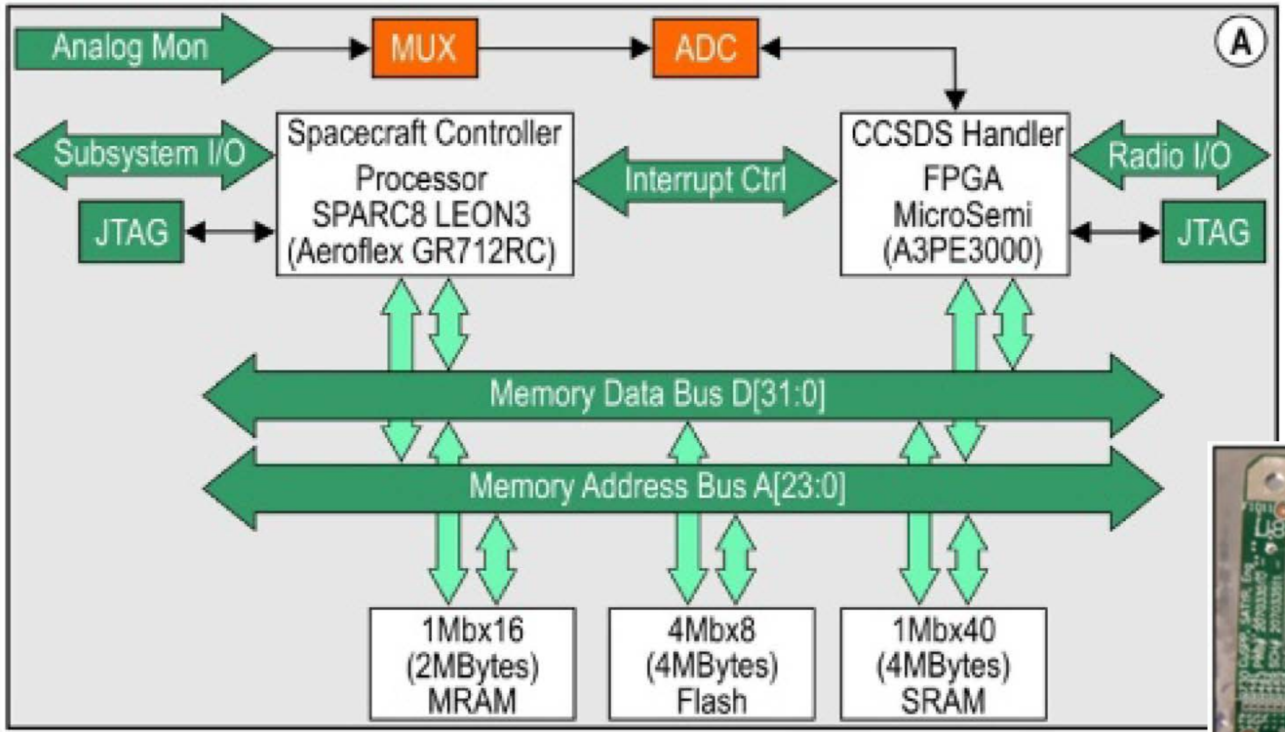
| | |
|---|---|
| **Mechanical, Structural, Thermal** | • "6U" CubeSat form factor (~10x20x30 cm)<br>• <14 kg total launch mass<br>• Modular flight system concept |
| **C&DH** | • SwRI SATYR (LEON-3) C&DH |
| **Electrical Power System (EPS)*** | • +12V, +/-5V, +3.3V<br>• Solar Arrays, 6U-Deployed, + 2U-Fixed<br>• 80 Whr, Lithium-Ion Polymer Cells |
| **Telecom*** | • X-Band Transponder<br>• Supports Doppler, ranging, and D-DOR<br>• 2 Low Gain Patch Array Antennas<br>• 1 Medium Gain Patch Array Antenna<br>• ~8 kbps to 34m DSN at all times |
| **ADCS*** | • 3-Axis Stable, Sun-Pointing<br>• Nano StarTracker, Coarse Sun Sensors & MEMS IMU (inertial momentum Unit) for attitude determination<br>• Directly commands Reaction Control |
| **Reaction Control*** | • Cold Gas Thruster<br>• Inertia Shedding Only<br>• Closed Loop control |




* Commercial Off-The-Shelf Item (COTS)

# Command and Data Handling (C&DH)

*SwRI Space-Qualified Heritage Single-Board Computer*

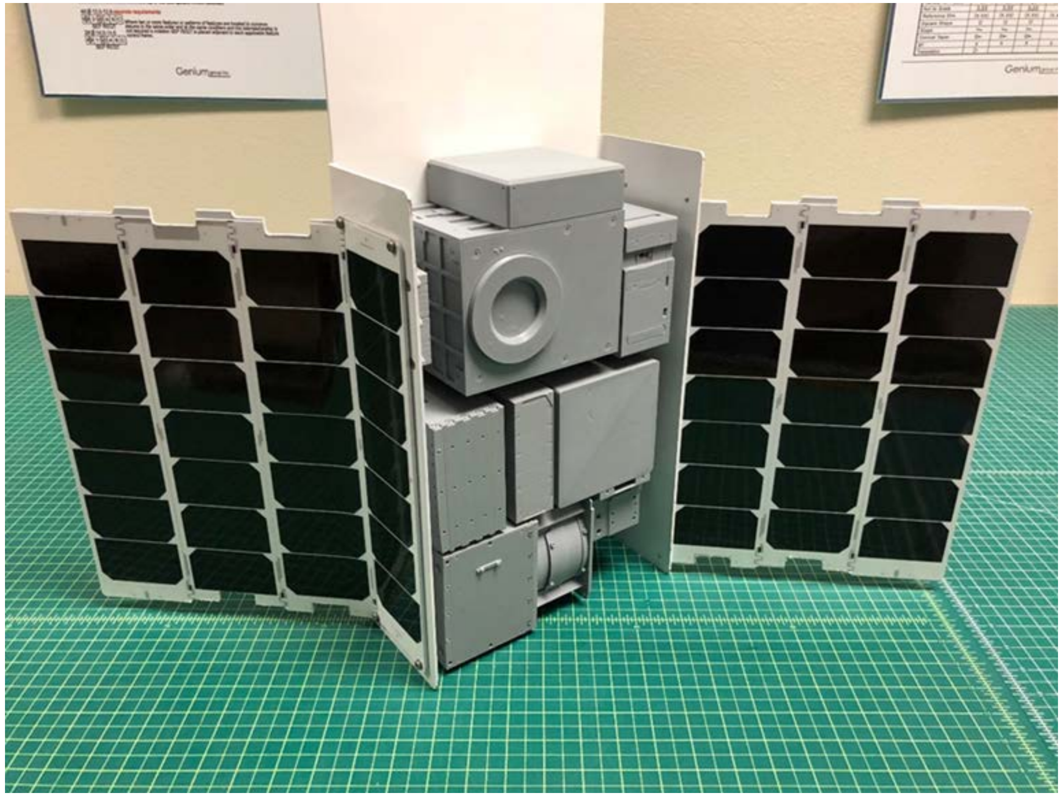



- SATYR Computer
  - SPARC8 processor
  - CCSDS-compliant FPGA interface
- Based on CENTAUR design
  - Currently flying aboard CYGNSS satellites
  - Reformatted for CubeSat form factor

# Ancillary Subsystems

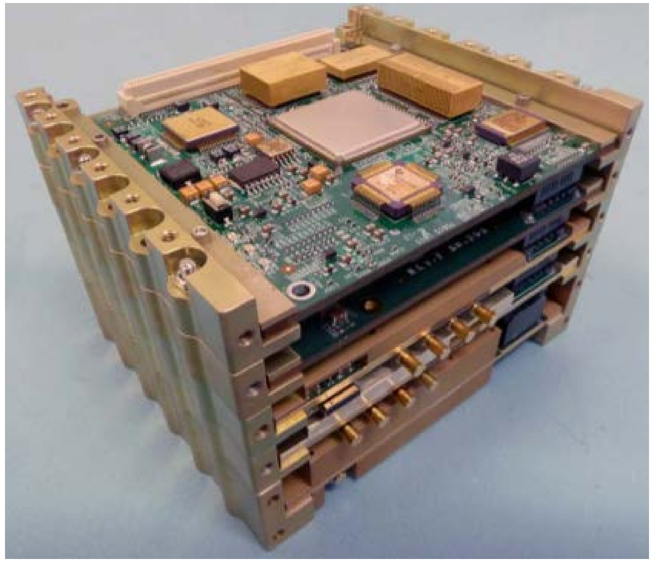
*Extensive use of Commercial Off-the-Shelf Equipment*

- Electrical Power Subsystem (Clyde Space)
  - Eight Solar panels (2 triple-deployed arrays and 2 fixed-body arrays)
  - Two 40-Wh battery packs
  - 28 VDC primary power bus with dc/dc converters producing +3.3, ±5, and +12 VDC regulated outputs
- 3-Axis Attitude Determination and Control Subsystem
  - XACT (Blue Canyon Technologies)
    - Integrated ADCS with 3 reaction wheels, 2 sun sensors and star tracker
    - ±0.007° pointing accuracy
    - 0.5U, 885g
  - Micro-Propulsion System (MiPS) (VACCO Industries)
    - four cold gas thrusters
    - Direct interface between XACT & MiPS for inertia shedding without C&DH intervention
    - 0.3U, 690g



# Telecommunications

*Same baseline for most Artemis I CubeSats*



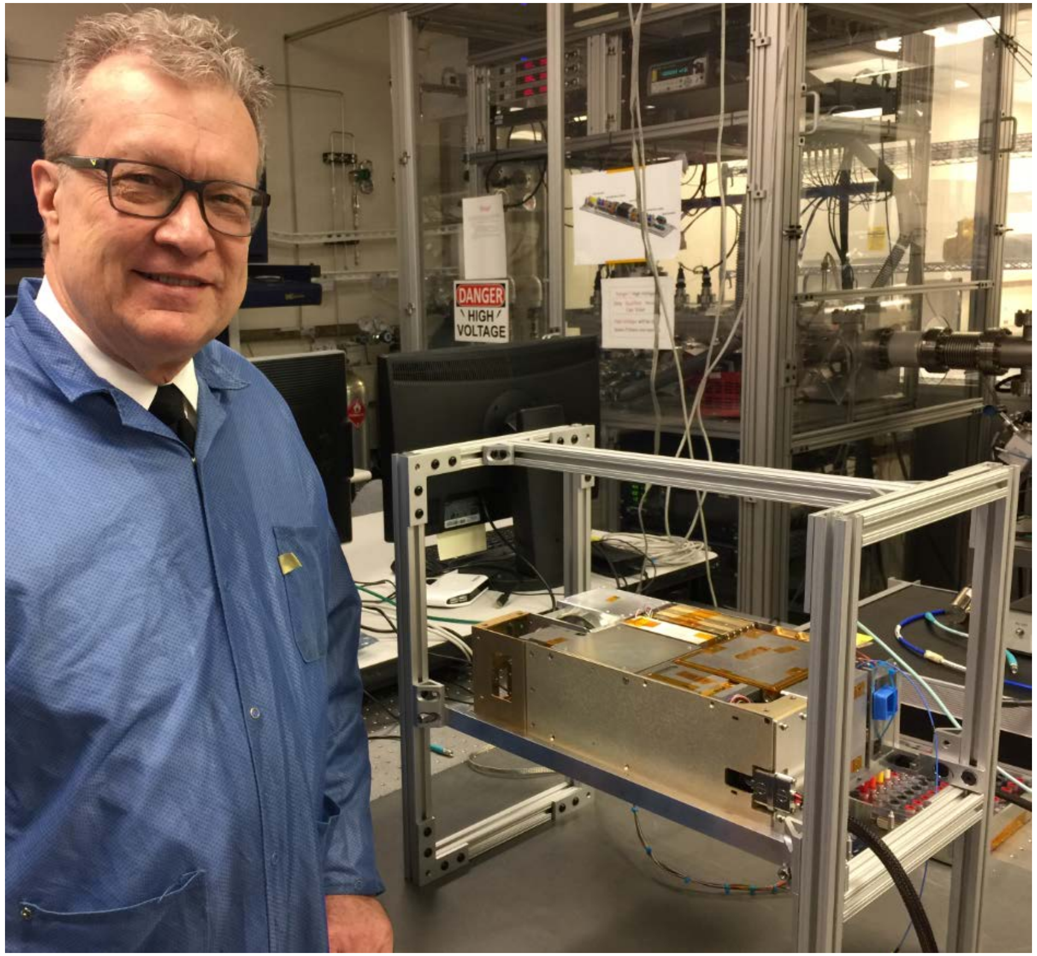
- Iris v2.1 Deep Space X-Band Transponder (JPL)
  - Communicates with NASA Deep Space Network (34-m antenna)
  - Three low-gain patch antennas and One medium-gain 64-patch array
  - 7.2-GHz uplink and 8.4 GHz downlink
  - 0.5U, 1.2 kg, 35W power consumption
- CuSP Telecommunications Plan
  - Transmission rate - 1K bps uplink and 8K bps downlink
  - Science operations require weekly, 4-hour DSN contacts for a 14-week mission duration
  - Each weekly DSN contact will downlink ~73 Mb of telemetry (C&DH has 8 Gb flash memory)
  - 6 dB link margin at max range ~15M km (distance from the Earth to the Moon is ~384K km)
- See related articles in SYSTEMS magazine special issues on Artemis I CubeSats
  - *Deep Space Network in the CubeSat Era* (April 2019)
  - *The Iris Deep-Space Transponder for the SLS EM-1 Secondary Payloads* (September 2019)
  - *Regenerative Ranging for JPL Software-Defined Radios* (September 2019)
  - *Improved Signals for Differential One-Way Range* (March 2020)

# Engineering Challenges

- CubeSat Programs in General
  - Low Budget
  - Form Factor Limitations
  - SWAP Constraints
  - COTS are “NOT”
    - Battery quality issues
    - Power supply failures
    - Supplier schedule delays
  - Issues required extensive monitoring
  - Interface Control Documents are more like “Interface Suggestion Documents”
- CuSP on Artemis I
  - Rigorous Hazard Analyses and Payload Safety Review Process
    - Ensure that CuSP does no harm to SLS or Orion
    - Extensive NASA reviews
    - Requirements similar to manned space flight programs
  - Technical challenges associated with miniaturization of heritage designs (e.g. noise, isolation, thermal management, etc.)
  - Launch delays and uncertainties
    - Original launch planned for December 2017
  - Delays impact staffing continuity and budget

# Current Status

- Ongoing system integration
- Delivery to site for installation (October 2020)
- Artemis I Launch (July 2021) – may slip more




CuSP in Handling Fixture

# Thank You!

*Questions?*