National Aeronautics and Space Administration

SPACE LAUNCH SYSTEM

CubeSats - To The Moon & Beyond

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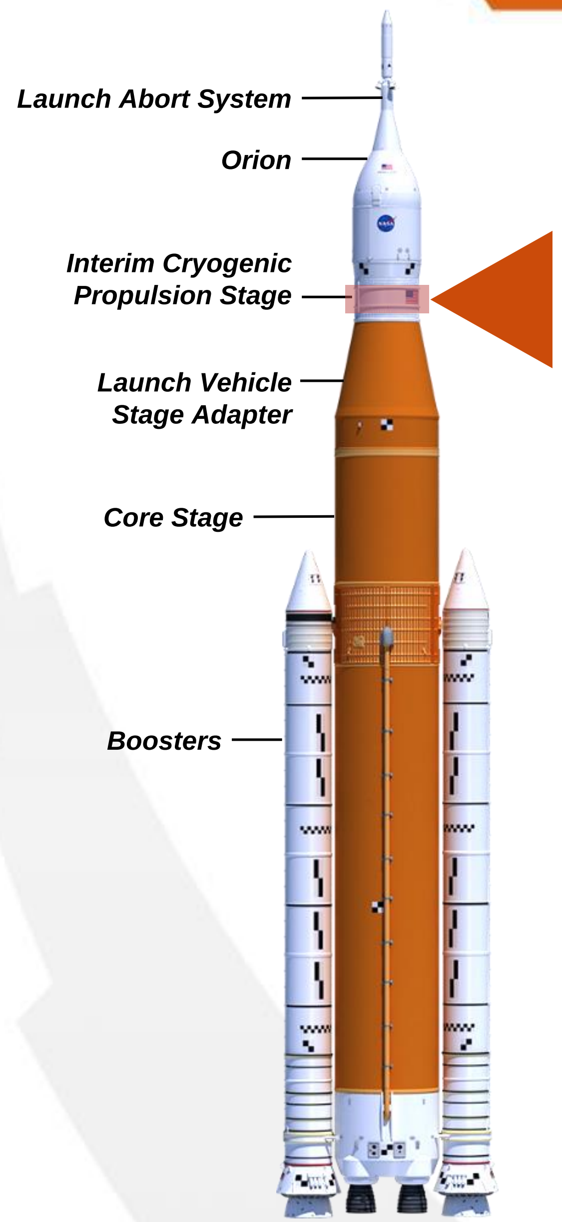
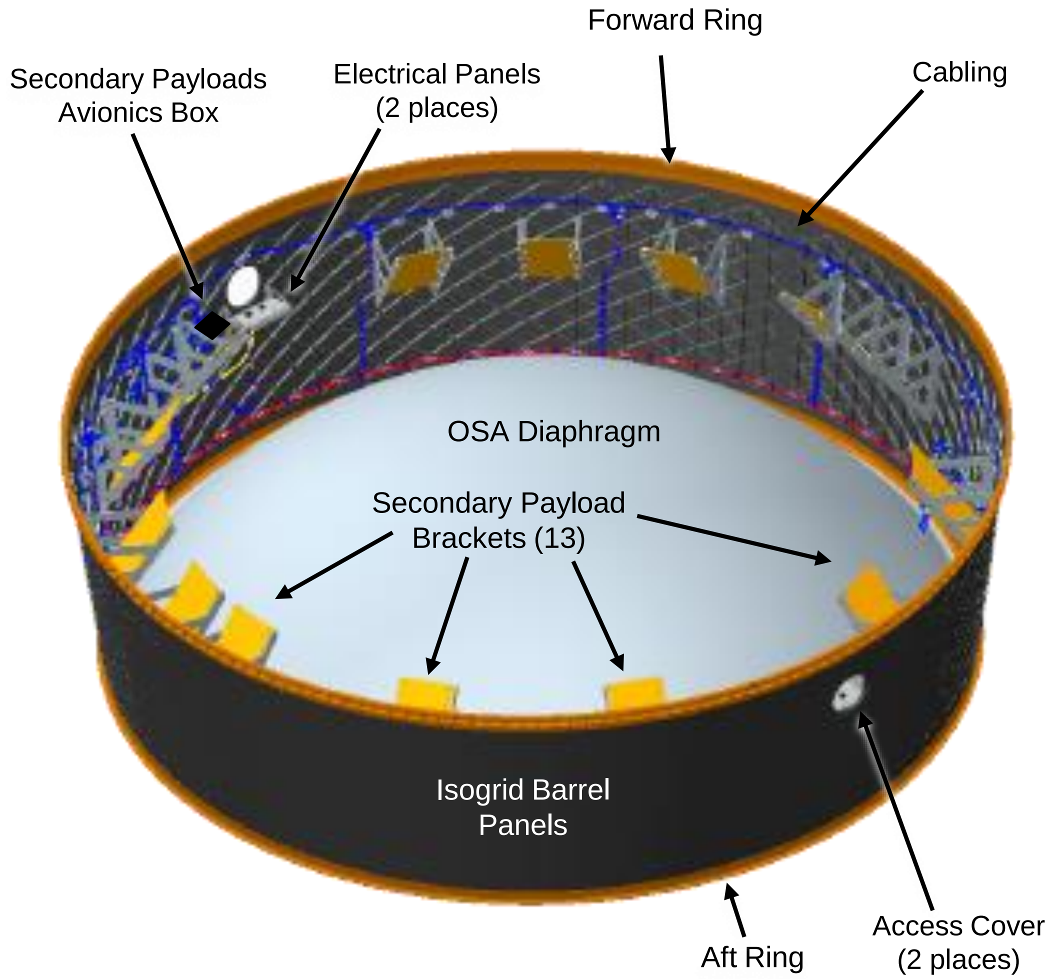
Space Launch System Program

March 1, 2018

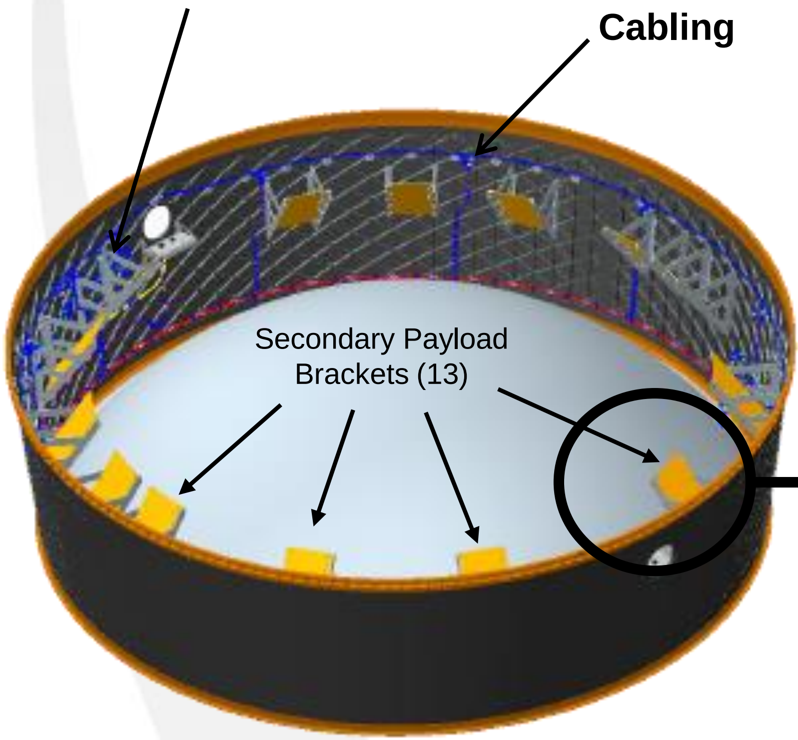
SLS BLOCK 1 EXPLORATION MISSION-1 (EM-1)

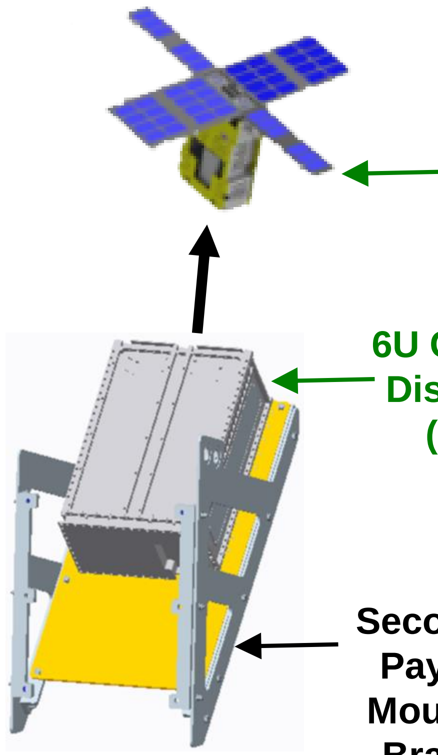




Orion Stage Adapter (OSA)

EM-1 OSA SECONDARY PAYLOAD ACCOMMODATIONS





LEGEND:

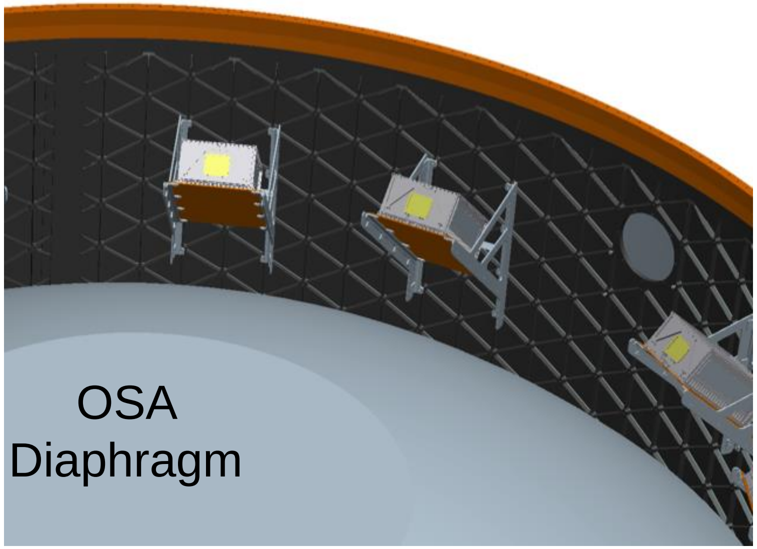
SLS Provided

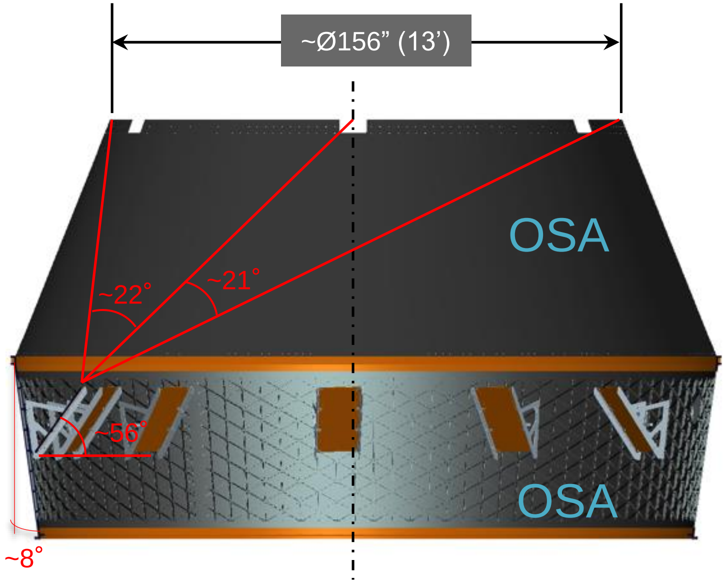
PD Provided

EM-1 SYSTEM DESCRIPTION AND PURPOSE

Expand and fully utilize the SLS capabilities for exploration purposes without causing harm or inconvenience to SLS or its primary payload.

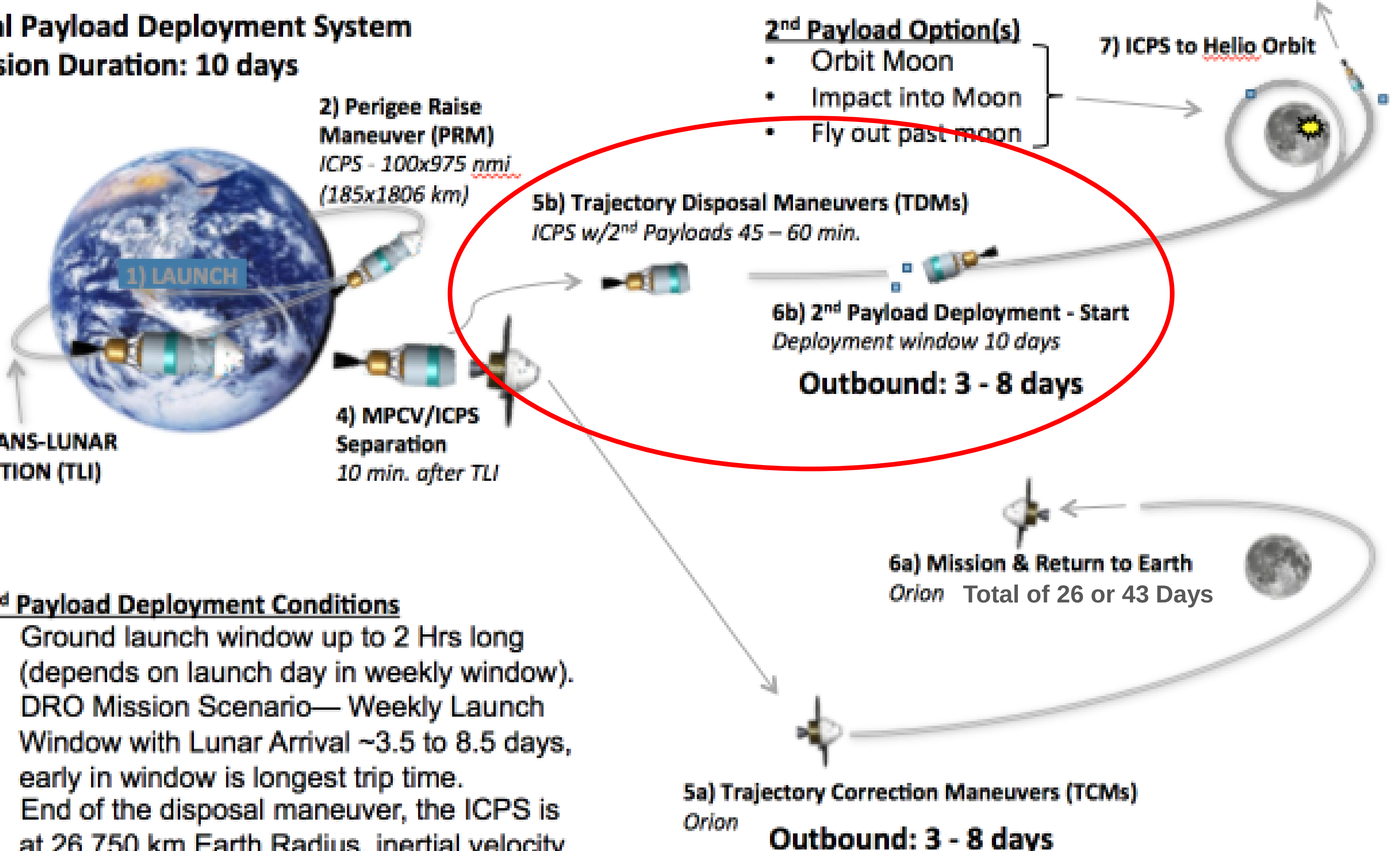
- **Thirteen (max capability 17)** 6U payload locations
- 6U volume/mass is the current standard (14 kg payload mass)
- Payloads will be **"powered off"** from turnover through Orion separation and payload deployment
- Payload Deployment System Avionics Unit; payload deployment will begin with pre-loaded sequence following Orion separation and **ICPS disposal** burn
- Payload requirements captured in Interface Definition and Requirements Document **(IDRD)**





EM-1 OVERVIEW

Total Payload Deployment System
Mission Duration: 10 days



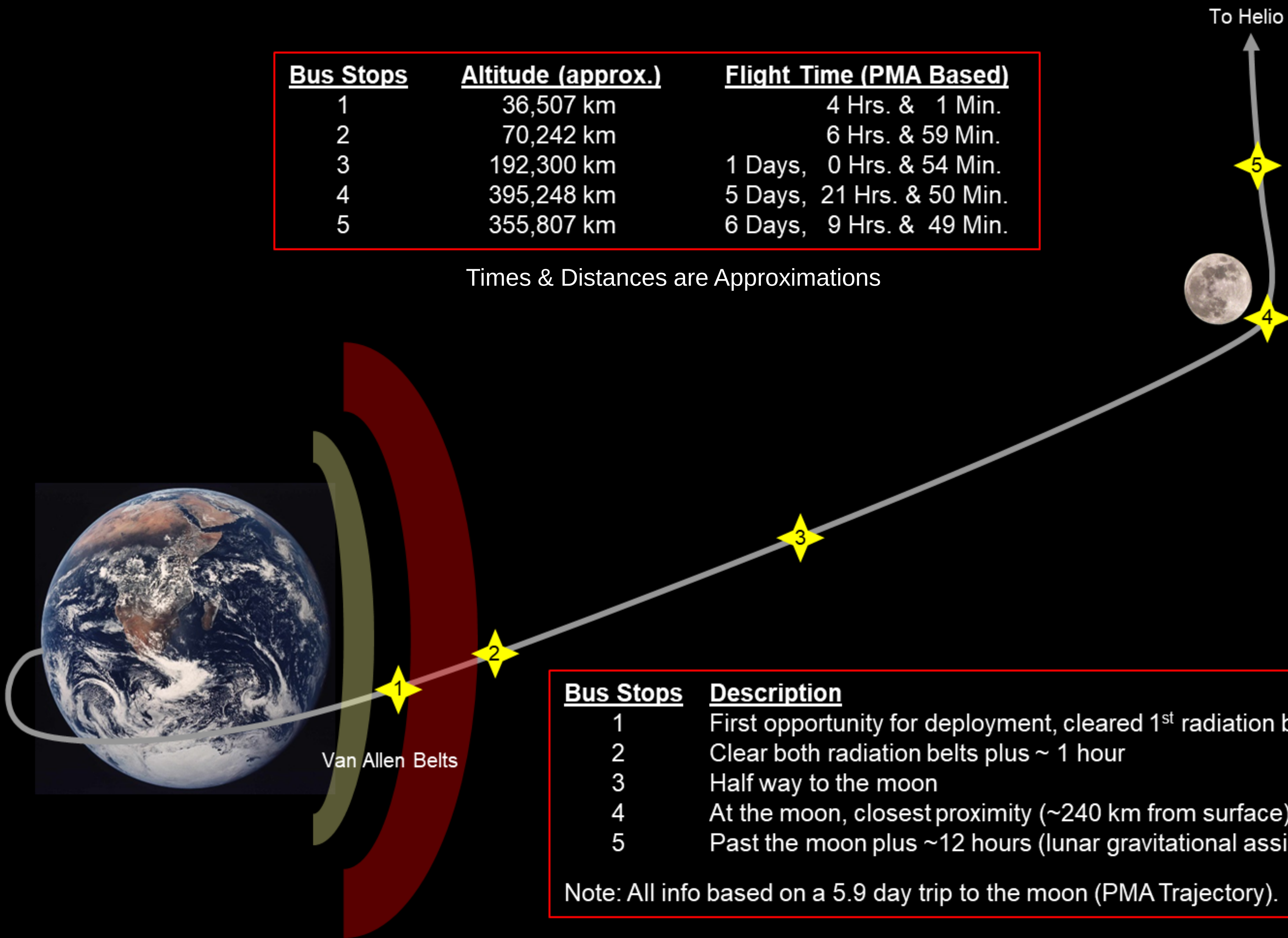
2nd Payload Deployment Conditions

- Ground launch window up to 2 Hrs long (depends on launch day in weekly window).
- DRO Mission Scenario— Weekly Launch Window with Lunar Arrival ~3.5 to 8.5 days, early in window is longest trip time.
- End of the disposal maneuver, the ICPS is at 26,750 km Earth Radius, inertial velocity of 5.279 km/s.

EM-1 CUBESAT BUS STOPS

Bus Stops	Altitude (approx.)	Flight Time (PMA Based)
1	36,507 km	4 Hrs. & 1 Min.
2	70,242 km	6 Hrs. & 59 Min.
3	192,300 km	1 Days, 0 Hrs. & 54 Min.
4	395,248 km	5 Days, 21 Hrs. & 50 Min.
5	355,807 km	6 Days, 9 Hrs. & 49 Min.

Times & Distances are Approximations

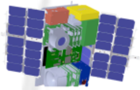


Bus Stops	Description
1	First opportunity for deployment, cleared 1st radiation belt
2	Clear both radiation belts plus ~ 1 hour
3	Half way to the moon
4	At the moon, closest proximity (~240 km from surface)
5	Past the moon plus ~12 hours (lunar gravitational assist)

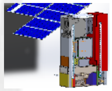
Note: All info based on a 5.9 day trip to the moon (PMA Trajectory).

EM-1 SECONDARY PAYLOAD DEPLOYMENT

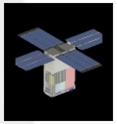
EM-1 PAYLOAD MANIFEST (HEO, SMD, STMD & IP)



- **Cubesat to Study Solar Particles (CuSP)**
  - Payload Developer: Southwest Research Institute (SwRI)
  - Objective: Observations of Interplanetary Space environment to gain insight into space weather
  - Destination: Heliocentric Trajectory

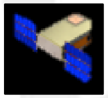


- **Lunar polar Hydrogen Mapper (LunaH-Map)**
  - Payload Developer: Arizona State University (ASU)
  - Objective: Perform neutron spectroscopy of lunar surface to determine H abundance
  - Mission Destination: Lunar Orbit



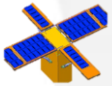
- **Lunar Flashlight**
  - Payload Developer: Jet Propulsion Laboratory
  - Objective: Search for lunar surface ice deposits using near-IR band lasers
  - Mission Destination: Lunar Orbit

- **Near Earth Asteroid Scout (NEA Scout)**
  - Payload Developer: Marshall Space Flight Center
  - Objective: Perform target detection, reconnaissance and close proximity imaging of a NEA
  - Mission Destination: a Near Earth Asteroid (within ~1.0 AU distance from Earth)



- **BioSentinel**
  - Payload Developer: Ames Research Center
  - Objective: Quantify DNA damage from space radiation environment
  - Destination: Heliocentric Trajectory

- **Lunar IceCube**
  - Payload Developer: Morehead State University
  - Objective: Prospect for water (ice, liquid & vapor) & other lunar volatiles using IR spectrometer
  - Mission Destination: Lunar Orbit

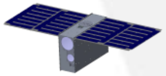


- **LunIR**
  - Payload Developer: Lockheed Martin Space Systems
  - Objective: Collect IR imaging of Lunar Surface
  - Mission Destination: Heliocentric via Lunar Flyby

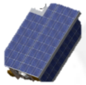
Centennial Challenge Payloads on next page (three will fly)

↑ Domestic

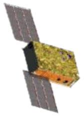
International ↓



- **ArgoMoon**
  - Payload Developer: ASI
  - Objective: Provide photography of EM-1 Mission, detailed imagery of ICPS as well as demonstrate image system operability
  - Mission Destination: Elliptical Earth Orbit (ICPS proximity)



- **Outstanding Moon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor (OMOTENASHI)**
  - Payload Developer: JAXA
  - Objective: Develop worlds smallest lunar lander and observe lunar radiation environment
  - Mission Destination: Lunar Surface



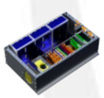
- **EQUilibriUm Luna-Earth point 6U Spacecraft (EQUULEUS)**
  - Payload Developer: JAXA
  - Objective: Characterize radiation environment in geospace by imaging the Earth's plasmasphere
  - Mission Destination: Earth-Moon L2

STMD EM-1 CENTENNIAL CHALLENGES PAYLOADS

- **STMD Centennial Challenges**
  - Ground Tournaments #1 - #4 complete
  - Three were selected from the 6 payloads identified below (Mar 2017)

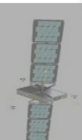
Cube Quest CubeSats

- **KitCube**
  - Payload Developer: Project Selene – Collaborative set of California High Schools
  - Objective: Compete in **Lunar Derby** for the Achieve Lunar Orbit, Best Burst Data Rate, Largest aggregate Data Volume Sustained over time and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit



- **Team Miles**
  - Payload Developer: Fluid & Reason, LLC
  - Objective: Compete in the **Deep Space Derby** for Furthest Communication Distance from Earth prize
  - Mission Destination: Deep Space

- **Cislunar Explorers**
  - Payload Developer: Cornell University
  - Objective: Compete in the **Lunar Derby** for Achieving Lunar Orbit and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit



- **Heimdallr**
  - Payload Developer: Ragnarok Industries
  - Objective: Compete in the **Lunar Derby** for the Achieve Lunar Orbit, Best Burst Data Rate, Largest aggregate Data Volume Sustained over time and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit

- **University of Colorado Earth Escape Explorer (CU-E^3)**
  - Payload Developer: University of Colorado
  - Objective: Compete in the **Deep Space Derby** for Best Burst Data Rate, Largest Aggregate Data Volume Sustained over time, Spacecraft Longevity and Furthest Communication Distance from Earth prizes
  - Mission Destination: Deep Space

- **SEDS Triteria**
  - Payload Developer: University of California San Diego
  - Objective: Compete in the **Lunar Derby** for the Achieve Lunar Orbit and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit

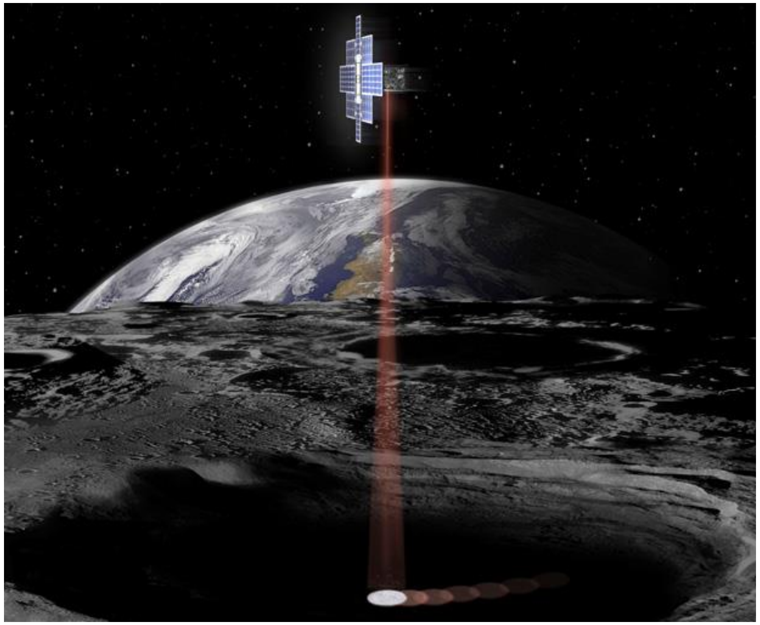
Lunar Flashlight - LUNAR RESEARCH

Payload Sponsor: Advanced Exploration Systems (AES) Division, NASA

Payload Developer: Jet Propulsion Laboratory (JPL)

Mission Objective: Lunar Flashlight will demonstrate its scouting capability from lunar orbit by performing multiple passes of the surface to look for ice deposits and identifying favorable locations for in-situ resource extraction.

How: Lunar Flashlight will use lasers & illuminate permanently shadowed craters at the lunar poles. A spectrometer will observe the reflected light to measure the surface water ice. The spacecraft will continue to make repeated measurements over multiple points in the craters, creating a map of the surface ice concentration. This data will be correlated with previous mission data, providing crucial guidance to future mission planning.



Unique Feature(s): Using new chemical "green propellant" propulsion system. Also using four lasers for the surface scanning.

End of Mission: Deposited on the moon.

Mission Duration: <1 Year

Lunar IceCube - LUNAR RESEARCH

Payload Sponsor: NASA NextSTEP (AES)

Payload Developer: Morehead State University

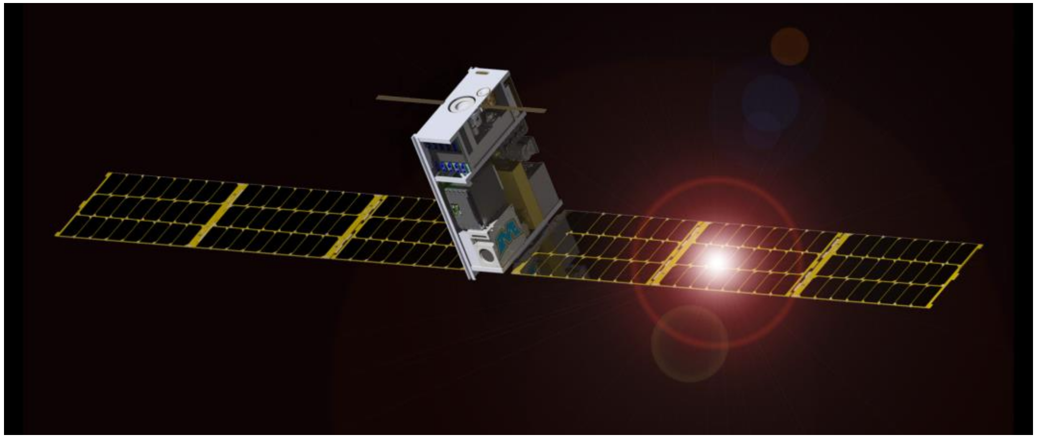
Mission Objective: Lunar IceCube is designed to prospect for water in solid (ice), Liquid and vapor forms and other lunar volatiles from a low-perigee, highly inclined lunar orbit.

How: Lunar IceCube be using an innovating RF Ion engine to achieve lunar capture & a science orbit to investigate the distribution of water ice as a function of time of day, latitude & regolith composition in the context of mineralogy. IceCube will include the Broadband InfraRed Compact High Resolution Exploration Spectrometer (BIRCHES) – a compact version of the successful volatile-seeking New Horizons Ralph instrument. BIRCHES has the high spectral resolution (5nm) and wavelength range (1 to 4μm) needed to distinguish phase states of water.

Unique Feature(s): Using new iodine ion engine w/Isp of 2500.

End of Mission: Deposited on the moon.

Mission Duration: 1 ½ to 2 Years



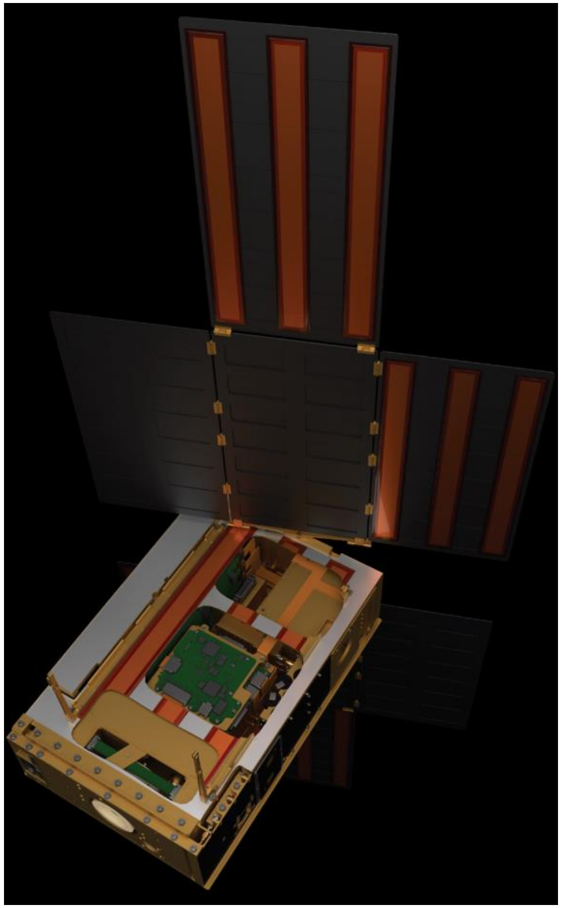
LunaH-Map - LUNAR RESEARCH

Payload Sponsor: SIMPLEX SMD, NASA

Payload Developer: Arizona State University

Mission Objective: LunaH-Map is a planetary science CubeSat mission to map hydrogen enrichments at the moon's south pole. Using a high-efficiency neutron spectrometer.

How: LunaH-Map will enter a low perilune polar orbit & will use a miniaturized neutron spectrometer to measure the count rates of neutrons leaking from the lunar surface at low altitude for a 2 month period of time. LunaH-Map will determine the spatial distribution of hydrogen within permanently shadowed regions at the south pole at unprecedented spatial resolution.



Unique Feature(s): Using new iodine ion engine w/Isp of 2500.

End of Mission: Deposited on the moon.

Mission Duration: 1 ½ Years

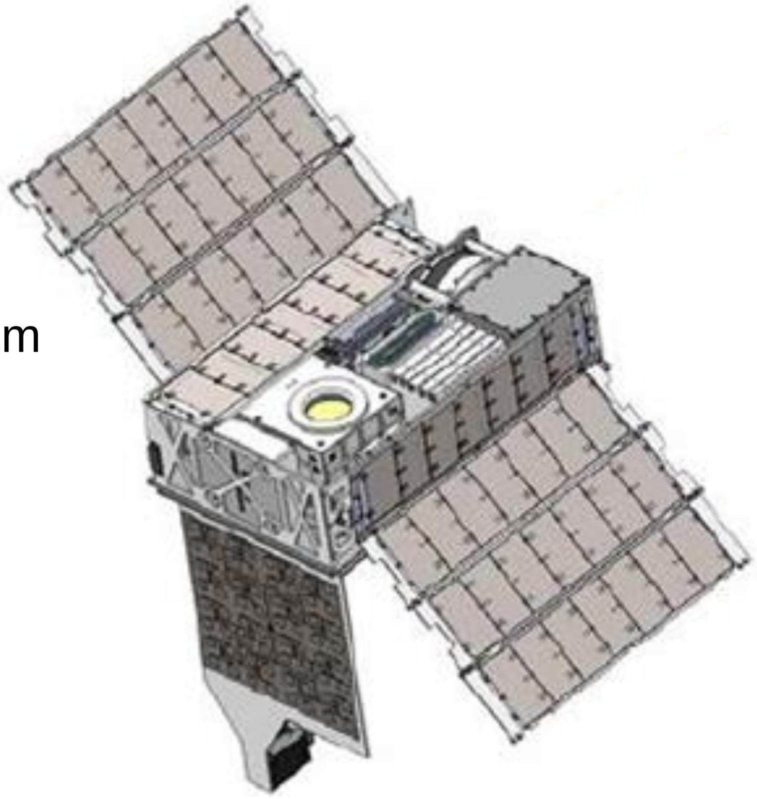
CuSP - DEEP SPACE RESEARCH

Payload Sponsor: Science Mission Directorate (SMD), NASA

Payload Developer: Southwest Research Institute

Mission Objective: CubeSat mission to study Solar Particles (CuSP) will study the sources & acceleration mechanisms of solar & interplanetary particles affecting near-Earth orbit while supporting space weather research.

How: Away from Earth, CuSP will utilize a Suprathermal Ion Spectrograph (SIS), a Miniaturized Electron Proton Telescope (MERiT), & a Vector Helium Magnetometer (VHM) while flying in deep space.



Unique Feature(s): No delta-V propulsion system but cold gas (refrigerant) attitude control system.

End of Mission: Heliocentric orbit.

Mission Duration: 2 ½ Months

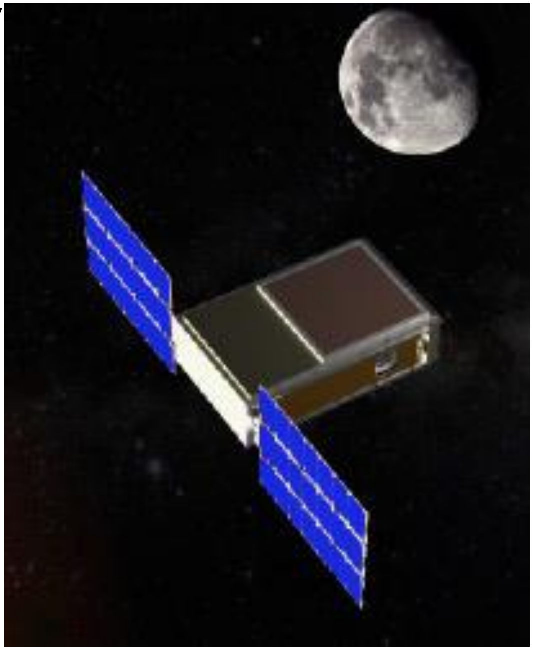
BioSentinel - DEEP SPACE RESEARCH

Payload Sponsor: Advanced Exploration Systems (AES) Division, NASA

Payload Developer: Ames Research Center (ARC), NASA

Mission Objective: BioSentinel mission will to help inform us of the greatest risks to humans exploring beyond LEO, so that appropriate radiation protections can be developed & those dangers can be mitigated

How: Since the unique deep space radiation environment cannot be replicated on or near Earth, BioSentinel will use yeast to detect, measure, & compare the impact of deep-space radiation on living organisms over long durations beyond LEO. When the chromosomes of the yeast are hit by radiation they will split then reform, trapping a chemical in the solution that surrounds the yeast. This will cause the yeast to glow & can be measured to determine radiation impacts to humans.



Unique Feature(s): Only biological cubesat on EM-1. No Delta-V propulsion system but cold gas (refrigerant) attitude control system.

End of Mission: Heliocentric orbit.

Mission Duration: 1 ½ Years

LunIR – Lunar RESEARCH

Payload Sponsor: NASA NextSTEP (HEOMD)

Payload Developer: Lockheed Martin

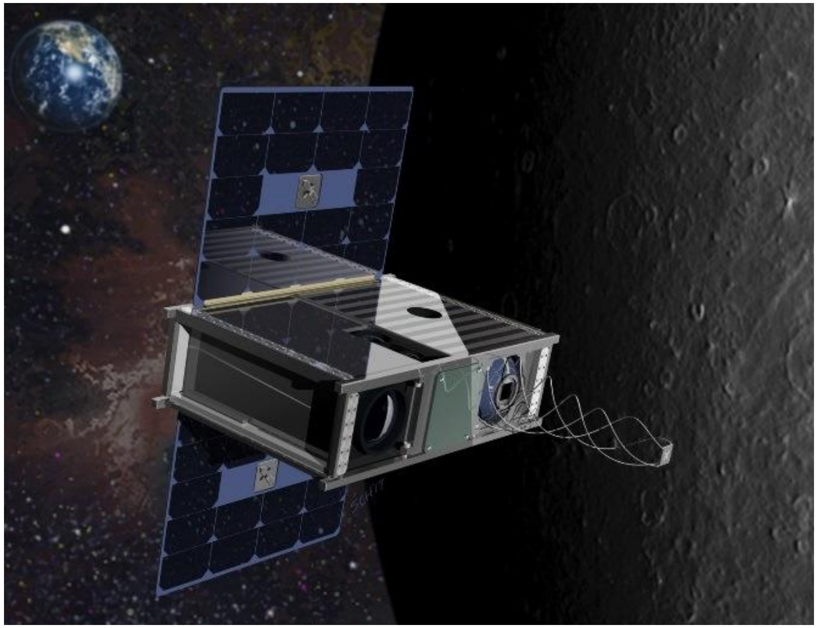
Mission Objective: LunIR will exercise a new miniaturized IR sensor the moon during the initial lunar flyby.

How: LunIR is testing a miniature high temperature Mid-Wave Infra-Red (MWIR) sensor. Key technology elements of the MWIR sensor are an integrated micro-cryocooler & a high temperature nBn based 1 Megapixel focal plane. Mission data will be analyzed for extensibility & application toward NASA lunar, Mars and deep space Strategic Knowledge Gaps.

Unique Feature(s): No delta-V propulsion system but cold gas (refrigerant) attitude control system.

End of Mission: Heliocentric orbit.

Mission Duration: 1 to 6 Months



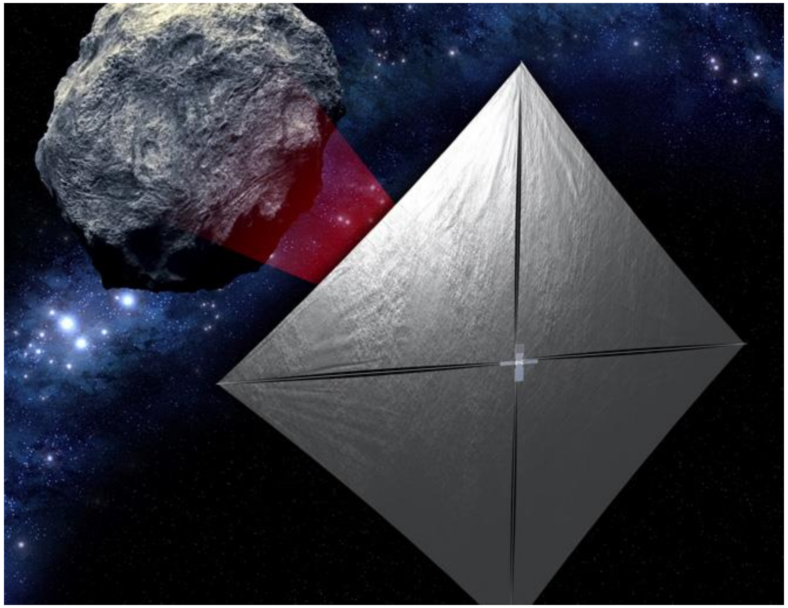
NEA Scout - DEEP SPACE RESEARCH

Payload Sponsor: Advanced Exploration Systems (AES) Division, NASA

Payload Developer: Marshall Space Flight Center (MSFC), NASA

Mission Objective: Near-Earth Asteroid Scout, or NEA Scout, will perform reconnaissance of an asteroid using a CubeSat & solar sail propulsion, which offers navigation agility during cruise for approaching the target.

How: Propelled by sunlight, NEA Scout will flyby & observe a small asteroid (<300' in diameter), taking pictures & observing its position in space, the asteroid's shape, rotational properties, spectral class, local dust & debris field, regional morphology & regolith properties. NEA Scout's observations will enhance the current understanding of asteroidal environments & assist in retiring the Strategic Knowledge Gaps related to human exploration of asteroids.



Unique Feature(s): Using a ~86 m^2 solar sail as its main propulsion. Also using cold gas (refrigerant) attitude control system.

End of Mission: Out amongst the asteroids.

Mission Duration: 2.5 Years

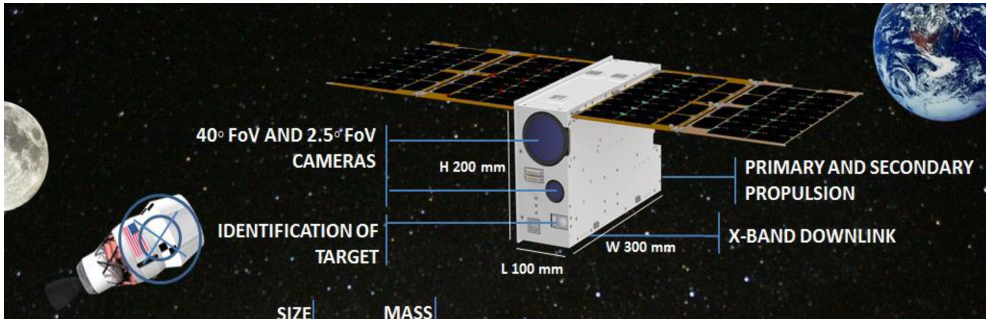
ArgoMoon (ASI) - INTERNATIONAL

Payload Sponsor: Italian Space Agency (ASI)

Payload Developer: Argotec

Mission Objective: ArgoMoon will perform a proximity fly around of ICPS, collect images of the Earth-Moon system, & validate nanotechnology on the cubesat.

How: ArgoMoon will deploy from OSA, stabilize its attitude, & start the proximity flight around ICPS. During this mission phase, ArgoMoon will recognize & point & maneuver at the second stage of SLS using an automatic/complex software algorithm. The ICPS targeting will collect detailed inspection photos of the second stage of SLS provide historical mission information images of secondary payload deployments may also be captured. Next, ArgoMoon will perform a maneuver going into a geocentric orbit w/high eccentricity & apogee close to the moon distance. This part of this mission will last a few months up to the natural decay of the satellite.



Unique Feature(s): Using new chemical “green propellant” (ADN) propulsion system.

End of Mission: Earth’s atmosphere.

Mission Duration: ~6 months.

EQUULEUS (JAXA) - INTERNATIONAL

Payload Sponsor: Japan Aerospace eXploration Agency (JAXA)

Payload Developer: University of Tokyo

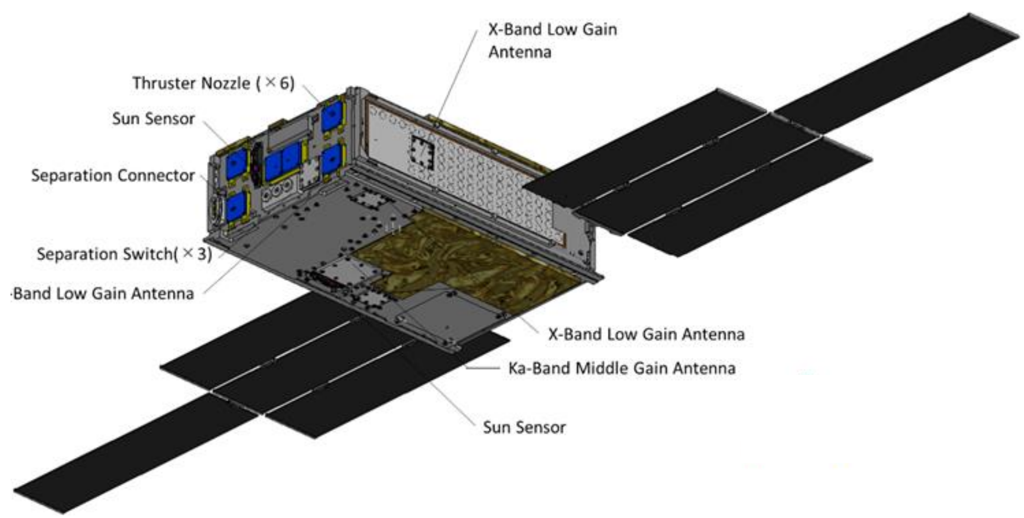
Mission Objective: EQUilibriUm Luna-Earth point 6U Spacecraft (EQUULEUS) will fly to the second Lagrangian (L2) point of the Earth-moon system & conduct three science missions.

How: During the flight to the 2nd Lagrangian point, EQUULEUS will perform a technology demonstration in orbital control & science observations. The science activities will involve: image the plasma around the Earth, image possible meteoroid impacts on the moon via luminescence, & measure micro-particle impacts in cis-lunar space on the cubesat multi-layer blankets.

Unique Feature(s): Using a pressurized water propulsion system.

End of Mission: Heliocentric orbit.

Mission Duration: 3 to 5 months.



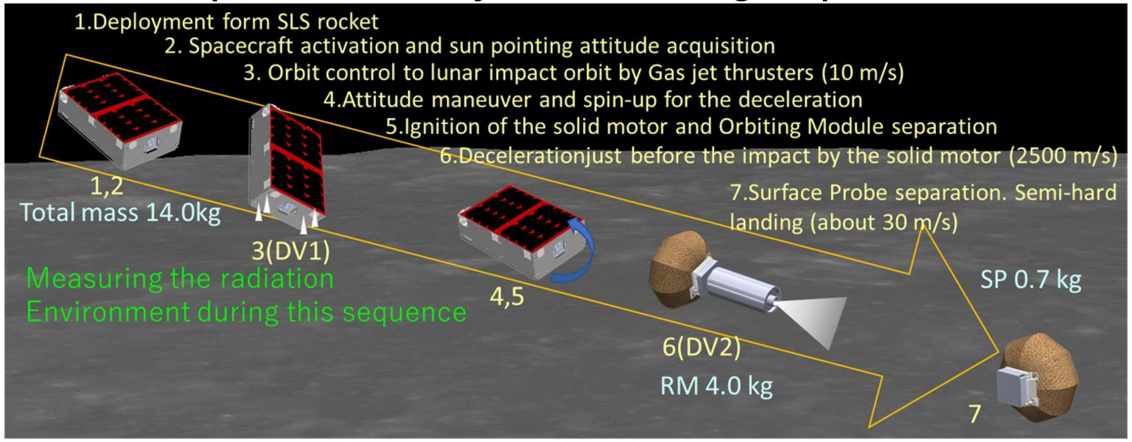
OMOTENASHI (JAXA) - INTERNATIONAL

Payload Sponsor: Japan Aerospace eXploration Agency (JAXA)

Payload Developer: University of Tokyo

Mission Objective: The purpose of Outstanding MOon exploration Technologies demonstrated by NAno Semi-Hard Impact (OMOTENASHI) is development & demonstration of ultra-small moon landing technologies. Another purpose of OMOTENASHI is to measure radiation environment in orbit between Earth & moon.

How: After separation from SLS, OMOTENASHI will be inserted into moon impact path by using cold-gas jet propulsion. After insertion into moon impact path the solid rocket motor reduces the velocity for 9000 km/h to 108 km/h immediately before impact with the moon's surface. The rocket motor & the surface probe are separated after rocket motor ignition. When landing, the airbag & crushable material absorbs the impact to the surface probe. Finally, the landing impact data is transmitted to Earth.



Unique Feature(s): Using a pressurized cold gas & solid rocket motor propulsion system.

End of Mission: Deposited on the moon.

Mission Duration: ~ 6 days.

STMD EM -1 CENTENNIAL CHALLENGES

Centennial Challenge – Cube Quest

Science and Technology Mission Directorate (STMD), NASA

The Cube Quest competition offers a total of $5 million to teams that meet the challenge objectives of designing, building, & delivering flight-qualified, small satellites capable of advance operations near & beyond the moon.

Payloads had to participate in “ground tournaments” which were used to make a final down selection from 14 to 3 cubesats to fly on EM-1.

Two types of challenges:

- Lunar Derby – orbit the moon & meet data transmittal requirements
- Deep Space Derby – be 4,000,000 km from Earth & meet data transmittal requirements

Payload developers are building their payloads with their own funding.

Contestants initially included: universities, small businesses, private groups, & a consortium of high schools

CisLunar – CENTENNIAL CHALLENGE

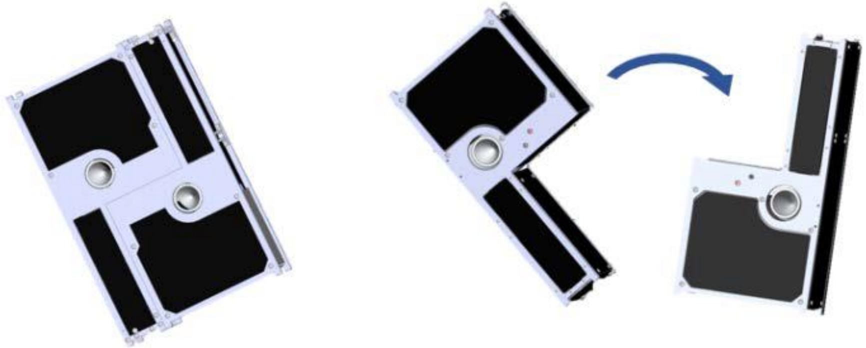
Payload Sponsor: Centennial Challenge - STMD

Payload Developer: Cornell University

Mission Objective: CisLunar plans to orbit the moon w/two 3U cubesats & transmit the required data to win up to $3.1 M. (Lunar Derby)

How: The centerpiece of the Cislunar Explorers flight experiment is the use of water as a green, dense, & high-efficiency propellant. Zapping H_2O with electricity can overcome the bond between hydrogen & oxygen, decomposing the liquid into a gaseous mixture that readily combusts. Storing water is much lighter & simpler than storing liquid oxygen & hydrogen. The spacecraft spins continuously around the thruster's axis, flinging the water out like a centrifuge & separating inert from electrolyzed propellant.

Unique Feature(s): Splits apart into two 3U cubesats to double its chances for success. Using water, electrolyzing into H_2 & O_2 then burning for a propulsion system.



End of Mission: Deposited on the moon.

Mission Duration: 1 Year

CU-E^3 – CENTENNIAL CHALLENGE

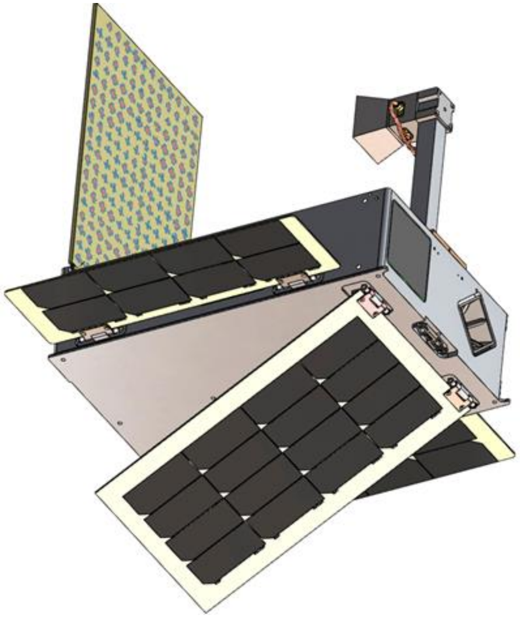
Payload Sponsor: Centennial Challenge - STMD

Payload Developer: University of Colorado

Mission Objective: University of Colorado Earth Escape Explorer (CU-E^3) plans to travel to 4 M km & transmit the required data to win up to $1.6 M. (Deep Space Derby)

How: CU-E3's mission objective is to foster innovative CubeSat communication technologies. The CubeSat will be attempting to communicate beyond Earth orbit at more than 10 times the distance to the Moon. This will require the CubeSat to escape the sphere of influence of the Earth and enter deep space.

Unique Feature(s): No propulsion system. Leverages solar radiation for pointing. Student designed reflector array & feed horn antennas.



End of Mission: Heliocentric orbit.

Mission Duration: 1 Year

Team Miles – CENTENNIAL CHALLENGE

Payload Sponsor: Centennial Challenge - STMD

Payload Developer: Team Miles is a group of citizen scientists

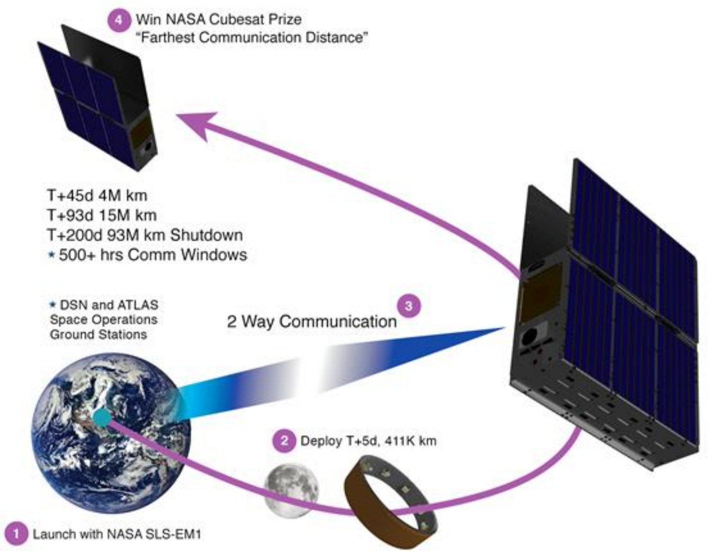
Mission Objective: Team Miles plans to travel to 4 M km & transmit the required data to win up to $1.6 M. (Deep Space Derby)

How: Team Miles has chosen to be deployed beyond the moon, and from there will travel into deep space. To communicate, the thrusters will be used to turn the craft 90 degrees in order to point the antennas towards Earth during communication windows. At the end of the mission, they expect to have traveled more than 93,000,000 km.

Unique Feature(s): No delta-V propulsion system. Using an ion thruster for attitude control.

End of Mission: Heliocentric orbit.

Mission Duration: 1 Year

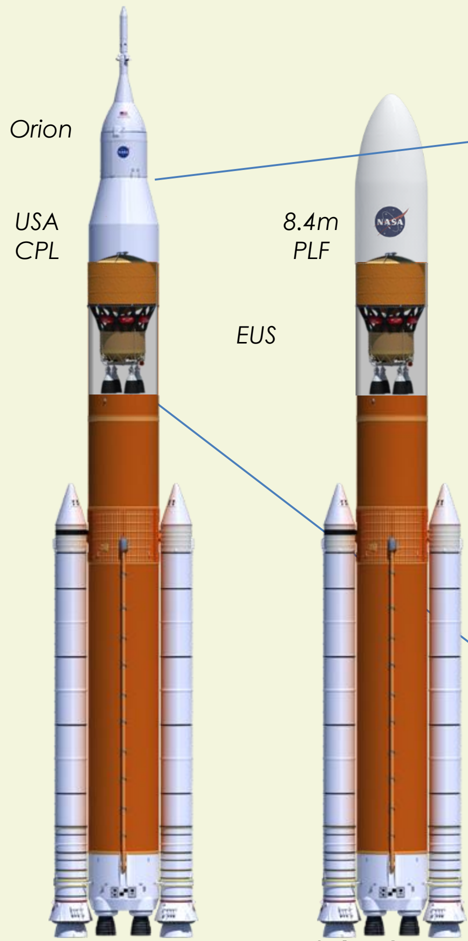


SECONDARY PAYLOADS BEYOND EM-1

SLS Block 1
70t+ to LEO
(No Earlier than 2019)

Crew
10008

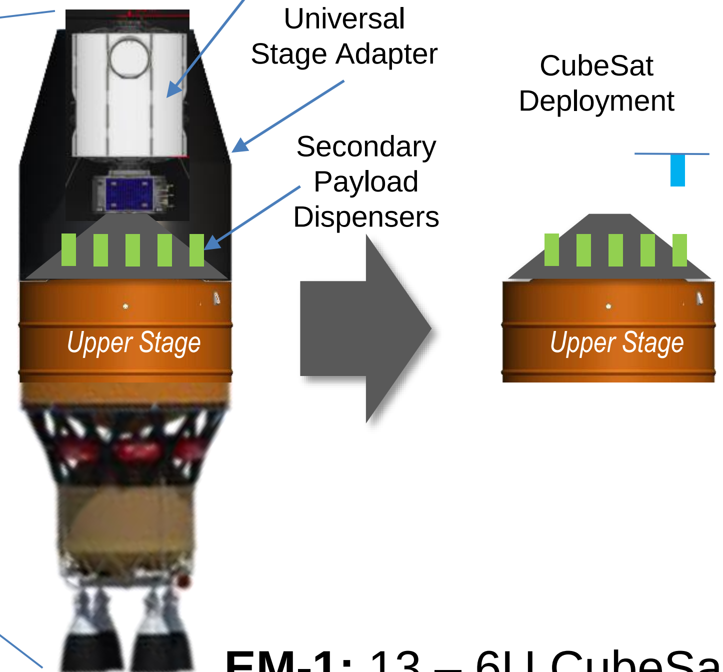
SLS Block 1B
105t+ to LEO
(No Earlier than 2022)



Crew
28004

8.4m Cargo
27004

CubeSat deployments start after USA & CPL departure, and continue for 10 days



EM-1: 13 – 6U CubeSats
EM-2: Up to 21 – 6U CubeSats
Added ability 12U & 27U CubeSats

SLS B1B 2nd Payload Accommodation Concept

- Mounting on the Payload Adapter and Universal Stage Adapter (USA)
- Possible Complement
  - 21 – 6U
  - 2 – 12U
  - 2 – 27U
- Trade study being conducted for optimal CubeSat accommodation location in SLS

Your imagination is the limit!

Back – Up Charts

BRIEF DESCRIPTION

The Secondary Payload Deployment System (SPDS) is comprised of the mounting brackets, cable harnesses, & the avionics unit. The payloads are responsible for their payload, the dispenser, & any vibration isolation system or thermal protection. The cable harnesses and the brackets are being developed, built, & installed into the MSA by NASA at MSFC. They have agreed to install the avionics unit (vendor developed) into the MSA at MSFC. We plan to do an integrated end-to-end test of the SPDS using the MSFC developed EGSE. The EGSE will simulate the ICPS & dispenser functions. The SPDS will be shipped to KSC in the MSA. An abbreviated check-out test will be performed as part of MSFC handover to KSC GSDO. Exactly where the MSA will be at KCS for payload integration is currently in flux. The payloads will be delivered to KSC via an LSP vendor (Tyvak). The payloads will already be integrated into the dispensers and cable pigtails, vib isolation, & thermal protection (if needed) will be attached to the dispenser at the time of handover to GSDO. GSDO will install the integrated payload/dispenser into the MSA, record fastener torqueing's, & measure/record grounding/bonding between the dispenser and the bracket. At some point (this part is in flux) the MSA will be attached to the ICPS and Orion will be installed on top. When Orion is installed there is no further physical access to the payloads. Approx. 2 weeks prior to the first roll out (vehicle wet rehearsal) GSDO will connect the SPDS EGSE to the SPDS via the ICPS forward skirt access to the MSA “dog house” connectors. GSDO will then provide battery charging to the SPDS avionics unit & the appropriate payloads that meet the conditions for battery charging. If needed we will also have the ability to reload the “skit” tables in the avionics unit at that time. The skits are what determine which payloads are deployed at what time based on the flight time to the moon. Just prior to the final vehicle roll-out the EGSE is removed from the vehicle. There is no further interaction w/the SPDS or payloads by GSDO, in a nominal process. The day of launch ULA will load the ICPS operational parameters for that day’s flight. One of those parameters is the number (1, 2, or 3) for which skit will be selected for that flight (based on trip time to the moon). After the launch, ICPS separation from the core, TLI burn, Orion separation/departure, & majority of ICPS disposal activities the ICPS will turn on the SPDS and send the appropriate number of discretes for skit selection. The ICPS will put itself into a 1 rpm roll and proceed w/ hydrazine depletion. Once the propellant is spent ICPS plans to take one more set of readings, downlink those readings, & shut down. At this point ICPS is a dead rock in space. Shortly there after SPDS, which has been counting since it was activated, comes to “bus stop” #1 & starts deploying the first set of payloads per the selected skit. Currently bus stop #1 has 7 payloads being deployed. Currently we are planning to deploy payloads at 1 minute intervals even though we can deploy them at 5 sec. intervals. We are currently using 1 minute to help assure no re-contact between payloads during their initial release. When the avionics unit sends the discrete to the dispenser the door will open & the spring loaded dispenser plate will shove the payload into space. At bus stop #2 5 more payloads will be released. Bus stop #2 is roughly 1 hour outside of the second belt of the Van Allen Belt. Once the ICPS flies past the moon (approximately 8 hours), at the final bus stop, the last payload will be released. Shortly after that the avionics system will shut itself down, completing the SPDS mission. Since there is no SPDS system feedback to Earth and ICPS is dead. The only way we’ll know if the SPDS was successful is if the payloads make contact w/Earth or if a payload with a camera takes a picture of the inside of the MSA to show all of the dispenser doors open & sends that back to Earth.