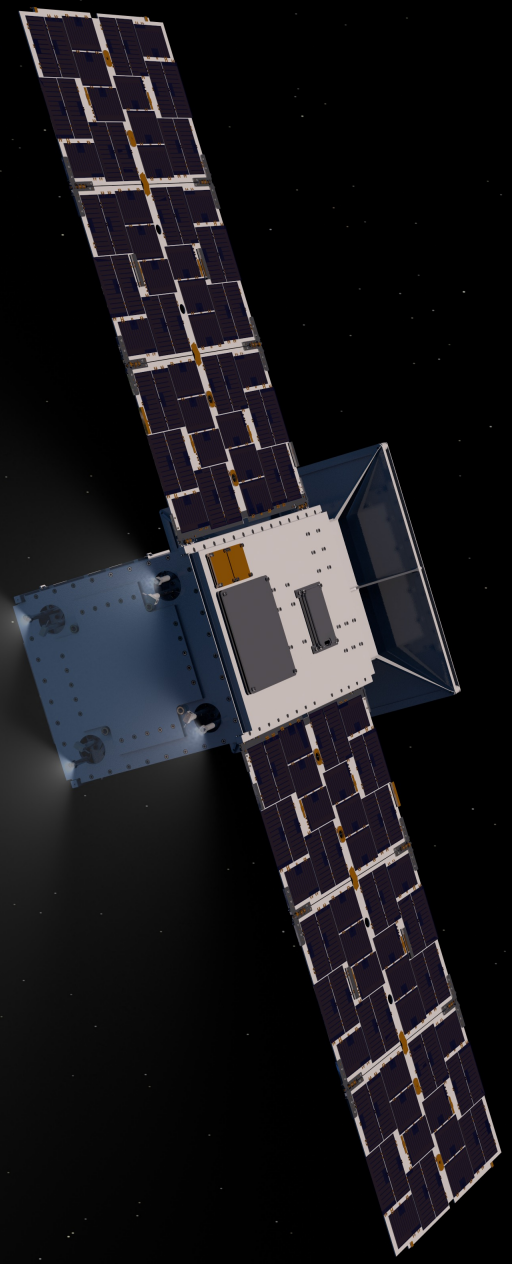
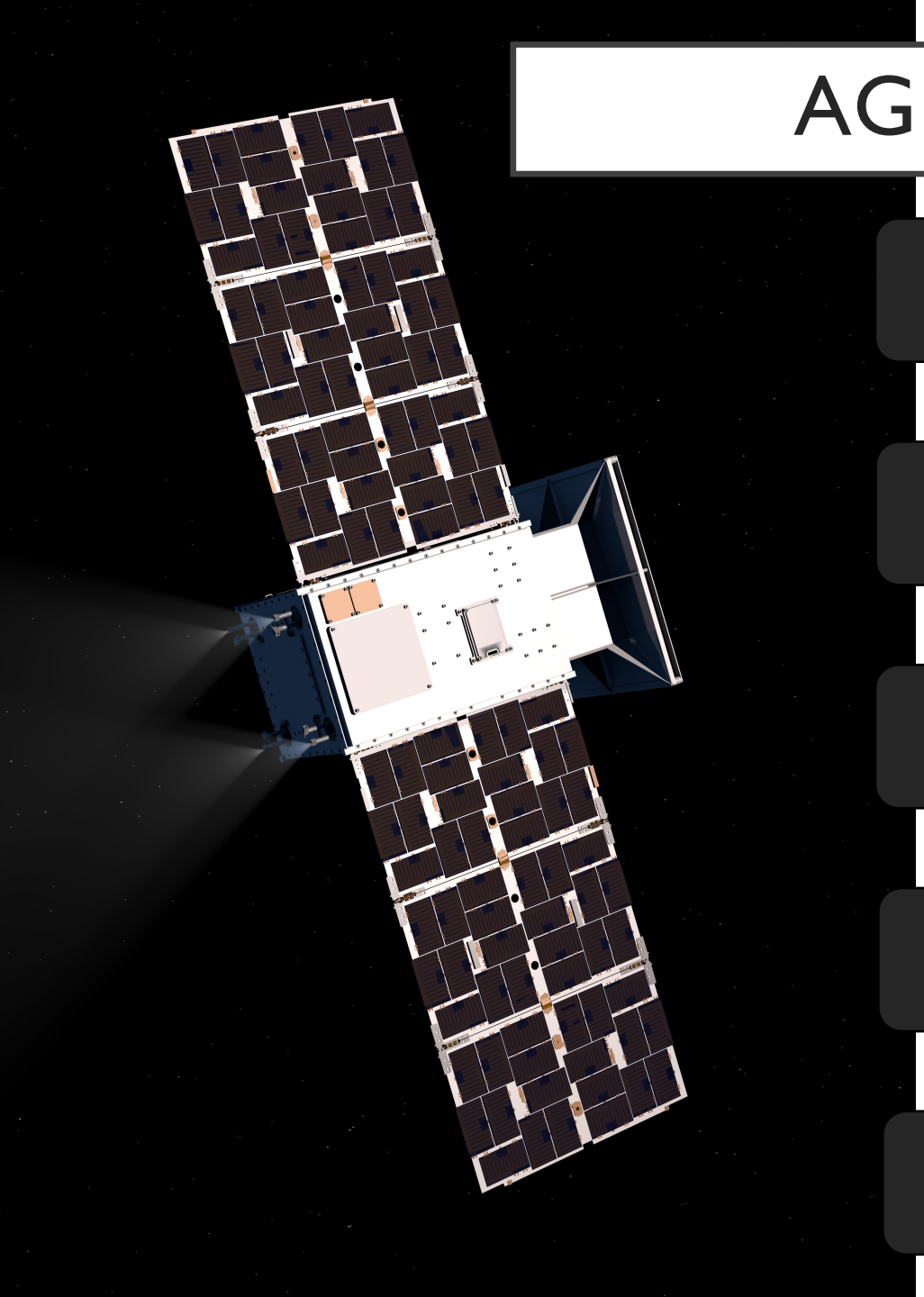


National Aeronautics and Space Administration

Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) Mission

Elwood F. Agasid
Deputy Program Manager
Small Spacecraft Technology Program

CubeSat Developers Workshop ✦ April 27-29, 2021



AGENDA

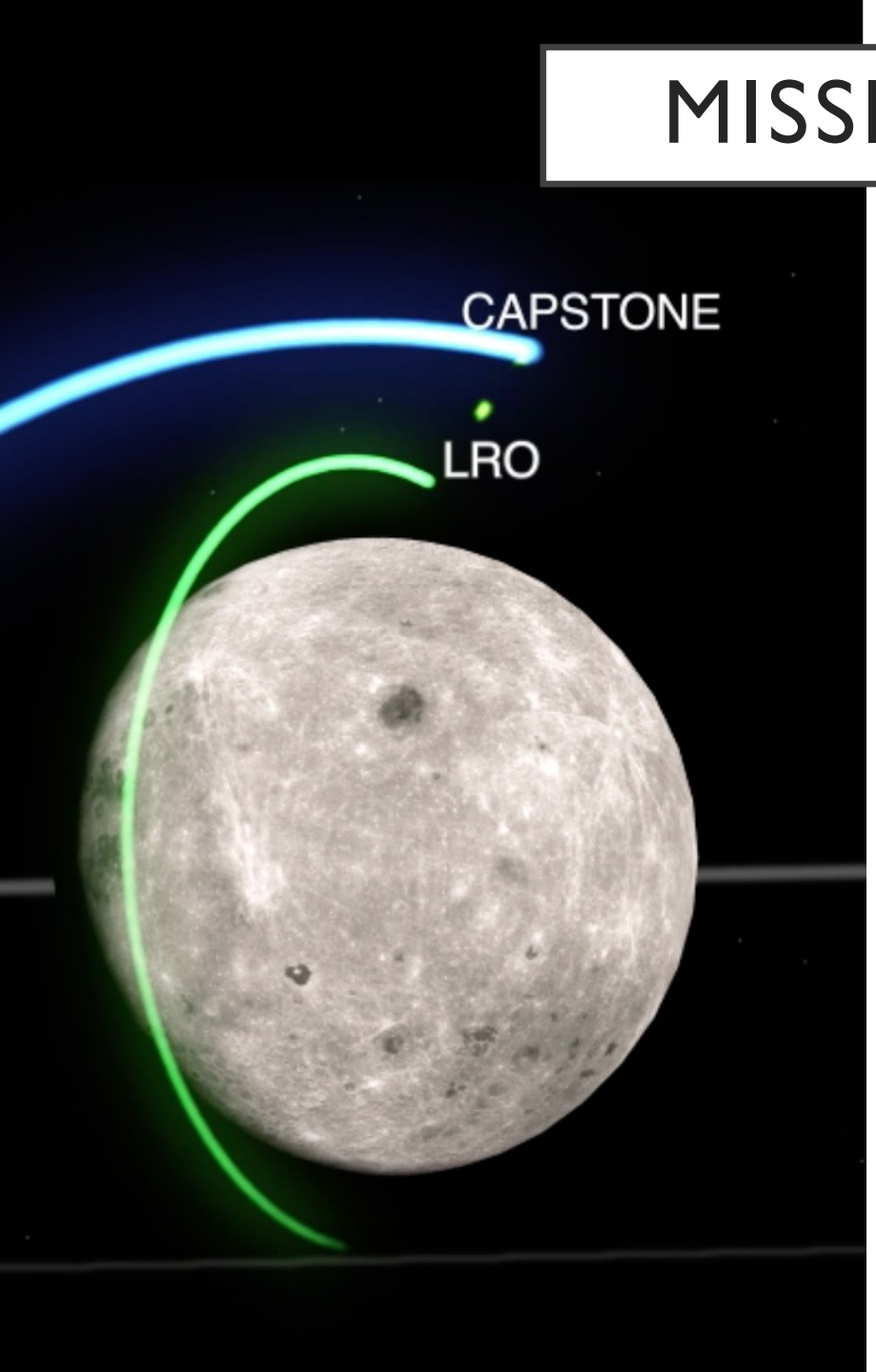
1. Mission Overview and Objectives
2. Experiment Description
3. Spacecraft Systems
4. Launch Vehicle Systems
5. Mission Operations

MISSION OVERVIEW

CAPSTONE is….

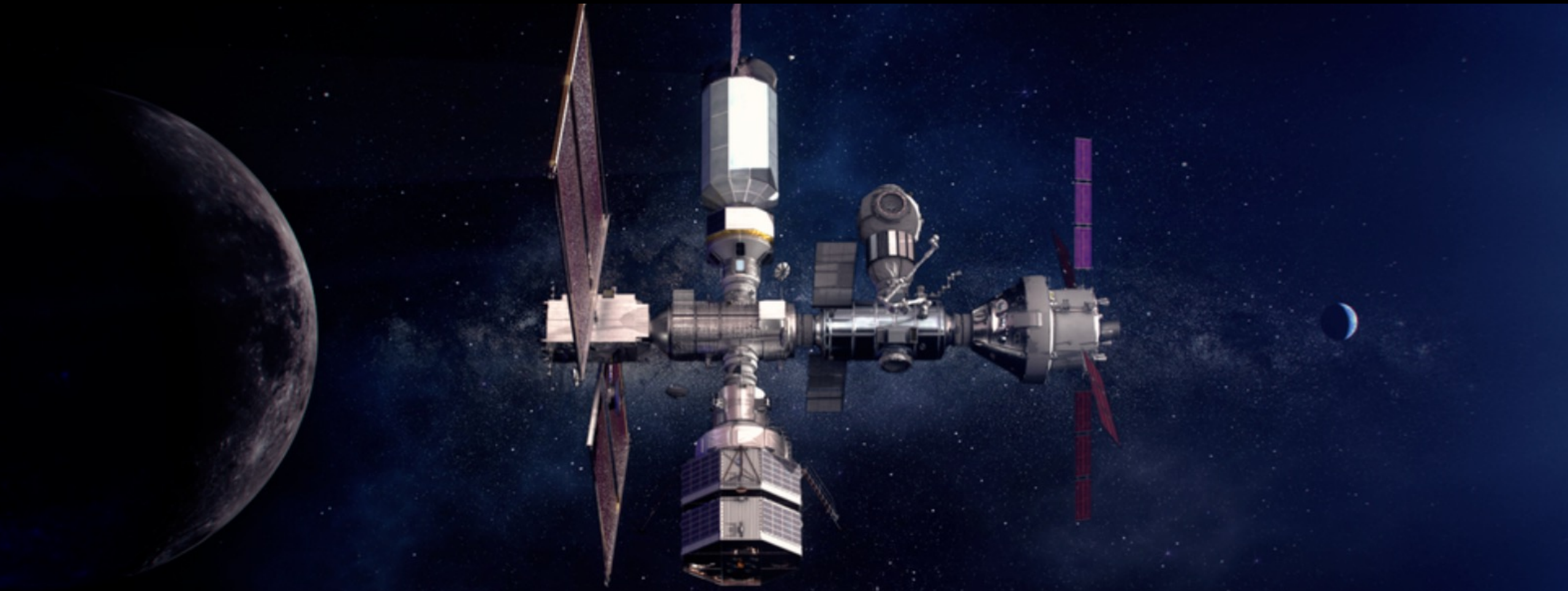
- A 12U CubeSat that will serve as the first spacecraft to enter into the near rectilinear halo orbit (NRHO) destined for Gateway, the Moon-orbiting outpost that is part of NASA's Artemis program.
- Expected to be the first CubeSat to fly in cislunar space.
- Planned to take 3 months to arrive at its target destination around the Moon using its own propulsion system.
- Scheduled to orbit this area around the Moon for at least six months to understand the characteristics of the orbit and perform technology demonstrations.
- Helping reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of the NRHO.
- Manifested for launch in 2021 aboard a Rocket Lab Electron rocket.

MISSION OBJECTIVES



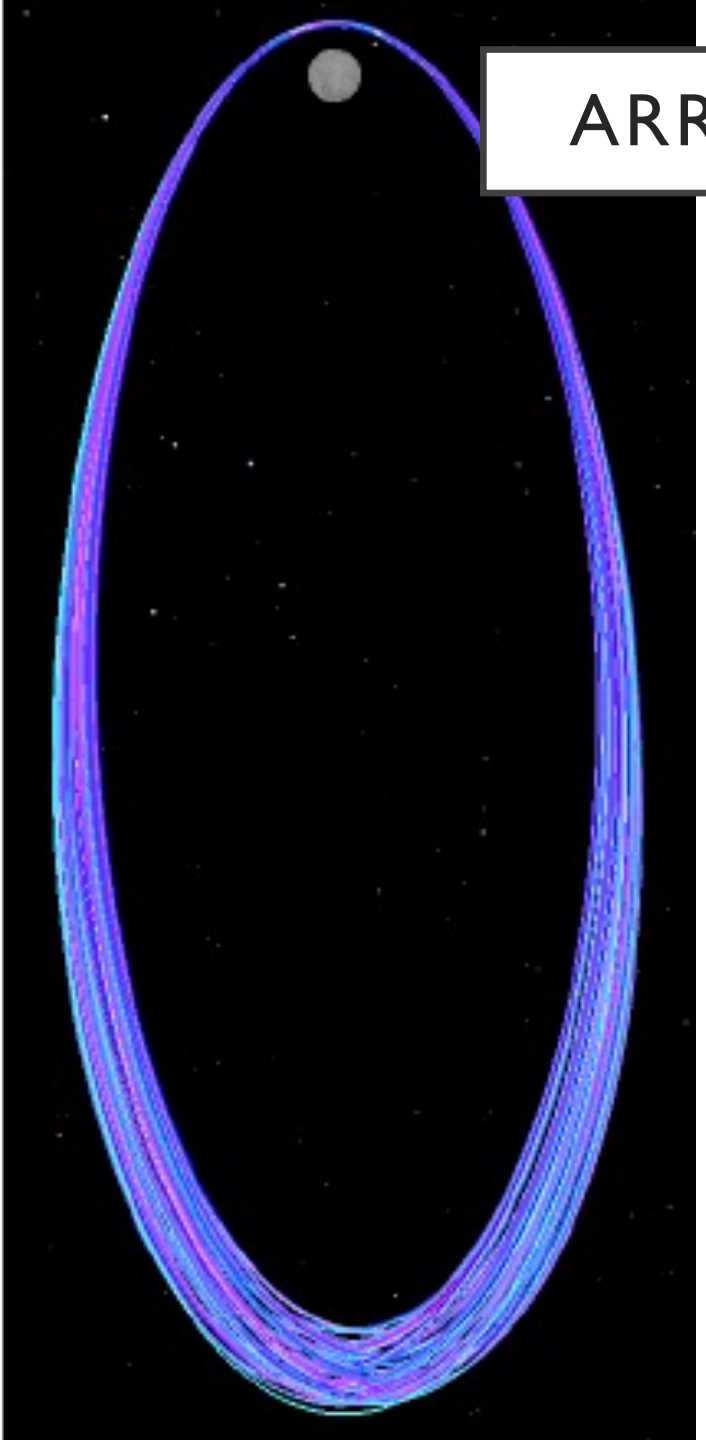
- CAPSTONE is a pathfinder mission for NASA's Gateway Operations team at NASA's Johnson Space Center. The mission will inform the requirements and mission operations approach necessary to operate in the NRHO.
- The mission will demonstrate inter-spacecraft ranging between the CAPSTONE spacecraft and NASA's Lunar Reconnaissance Orbiter (LRO), orbiting the Moon since 2009.
- CAPSTONE will validate the Cislunar Autonomous Positioning System (CAPS) navigation software system.
- CAPSTONE will lay a foundation for commercial support of future lunar operations.
- The mission will help gain experience with small dedicated launches of CubeSats beyond low-Earth orbit, to the Moon.

CAPSTONE PATHFINDER FOR GATEWAY PLATFORM



Gateway Elements

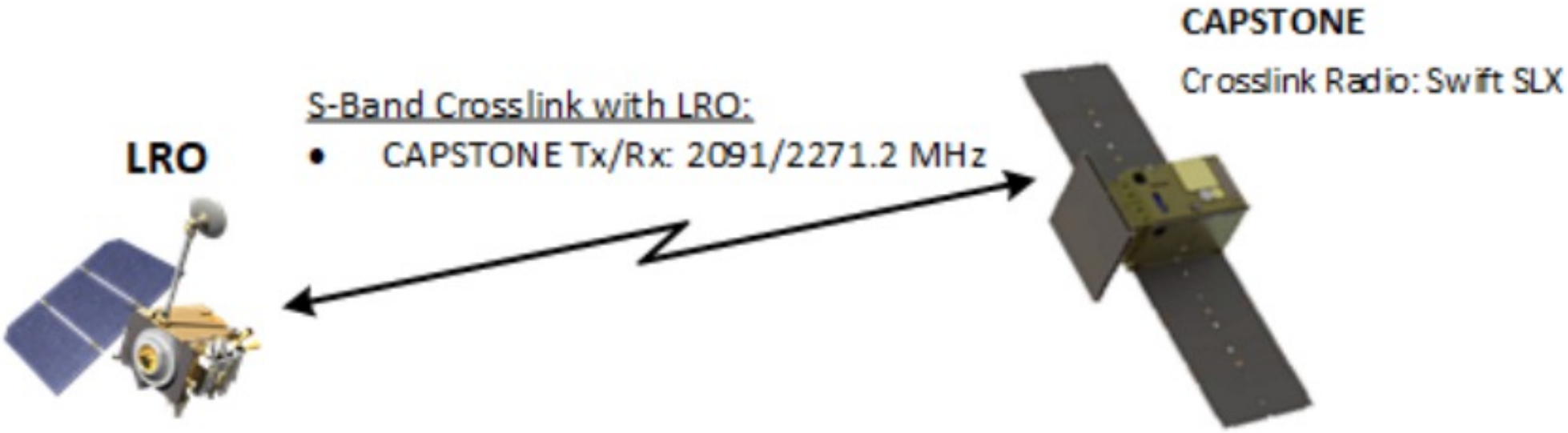
- Power & Propulsion Element (PPE) & Habitation and Logistics Outpost (HALO)
- Both targeted to launch together NET May 2024 on a Falcon Heavy Rocket from LC 39A at KSC



ARRIVAL AND INSERTION INTO THE NRHO

- The NRHO is desired for NASA's Gateway
  - This stable orbit minimizes the propellant required for orbit maintenance
  - Offers a continuous view of Earth
  - Provides coverage of both the lunar North and South Poles
- CAPSTONE is planned to arrive at the NRHO about 3 months after launch
  - Rocket Lab Electron will take the Photon spacecraft containing CAPSTONE to low-Earth orbit (LEO)
  - Photon will perform a series of orbit-raising maneuvers to inject the CAPSTONE spacecraft into its transfer path to the Moon
  - CAPSTONE will utilize a Low Energy (Ballistic) Lunar Transfer (BLT) to enter the NRHO. This approach will also be used by the Artemis Program.
- CAPSTONE vehicle propellant requirements include
  - 120 m/s of dV for insertion into NRHO once deployed from Photon
  - 40 m/s of dV is required to maintain orbit for 18 months
  - 5 m/s of dV is required for disposal

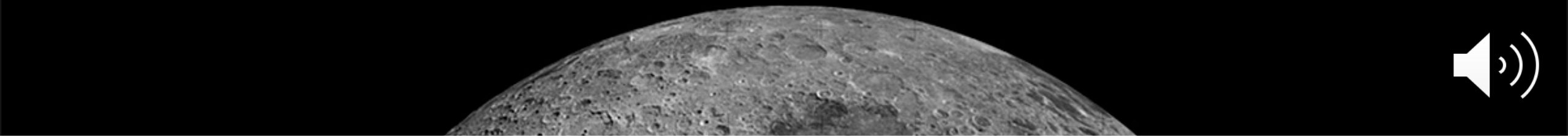
CROSS LINK RANGING EXPERIMENT WITH LRO

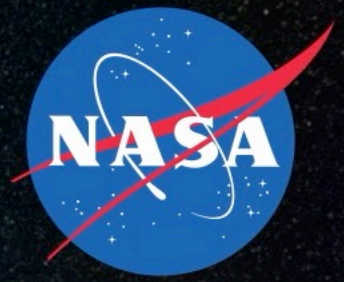


- The cross-link experiment between CAPSTONE and the LRO spacecraft will evaluate ranging capability.
- The Cis-Lunar Autonomous Positioning System (CAPS) will be demonstrated for lunar missions to utilize automated navigation solutions to reduce ground segment burden and enhance future mission operations.
- CAPS will perform peer-to-peer measurements between CAPSTONE and the LRO spacecraft to generate absolute estimates of spacecraft position and velocity.

BASELINE MISSION TIMELINE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
L + 3-4 months: • Launch to LEO • Orbit raising via Photon • BLT & insertion into NRHO				L + 4-5 months: Conduct primary demonstration operations for 6 months • NRHO operations and flight dynamics assessment • CAPSTONE to LRO cross-link experiment					L + 10-11 months: Conduct technology enhancement operations for 12 months • Perform additional NRHO operations and autonomous system evaluation • Continued CAPSTONE to LRO ranging experiments • Increase fidelity of CAPS system demonstration											• End of mission (EOM) • Spacecraft disposal		





(CAPSTONE)

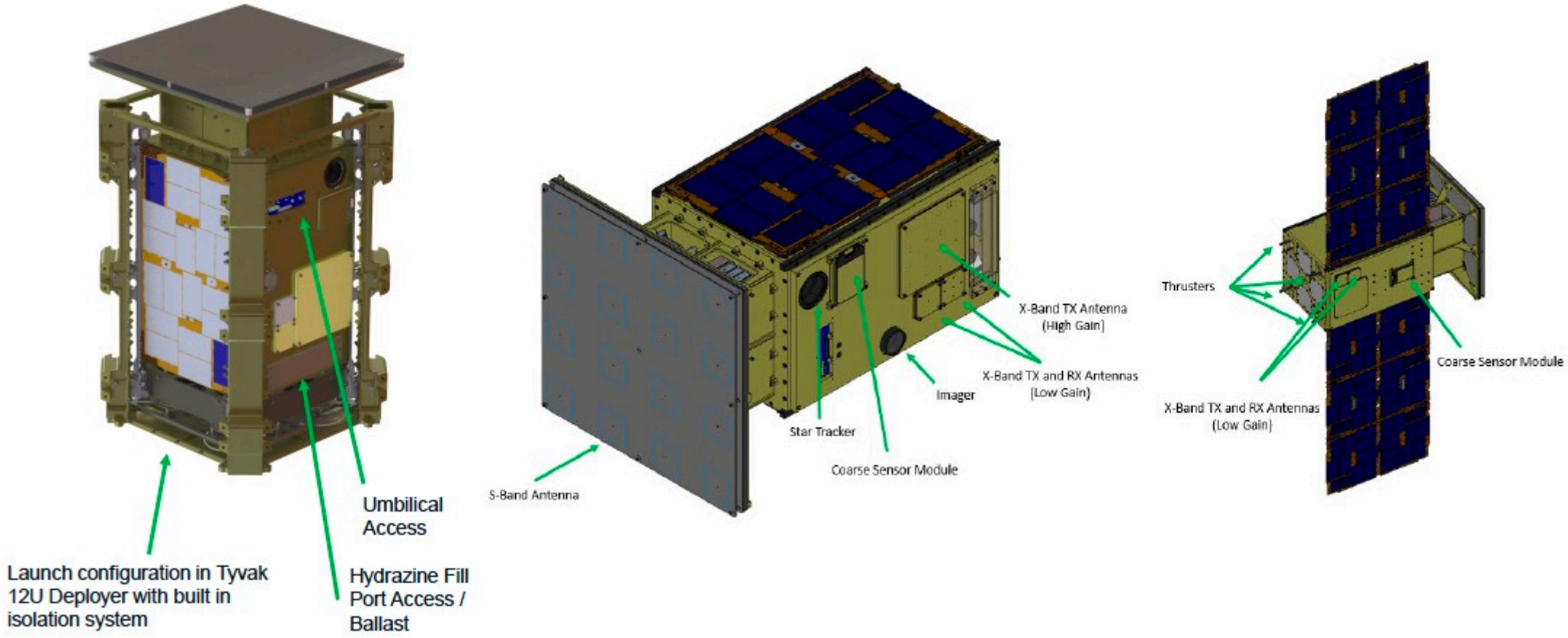
Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment

Demonstrating an innovative spacecraft-to-spacecraft navigation solution at the Moon from a near rectilinear halo orbit slated for Artemis' Gateway.

The CAPSTONE mission is managed by NASA's Small Spacecraft Technology Program. NASA's Advanced Exploration Systems funds the launch and supports mission operations. The mission is developed and operated by Advanced Space, LLC.

SPACECRAFT SYSTEMS DESCRIPTION

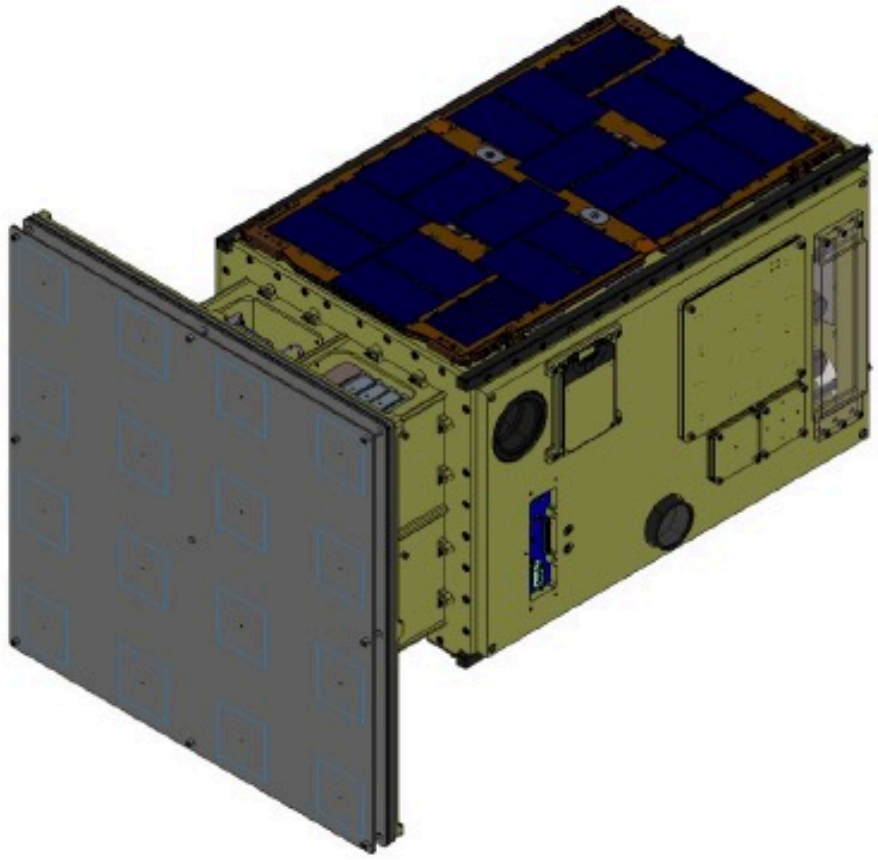
CAPSTONE Satellite Custom 12U Configuration



CAPSTONE SPACECRAFT SPECIFICATIONS

CAPSTONE Specifications

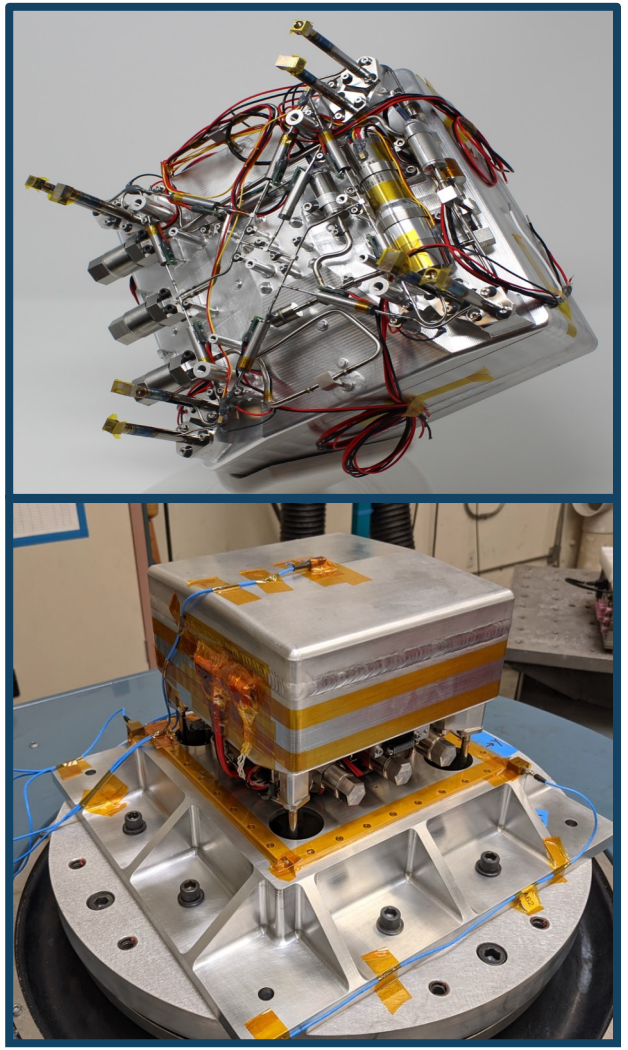
Subsystem	Value
Battery Modules	QTY 3x, 182 W-hr storage
Solar Panels	Deployable Fixed Angle Arrays, Peak Power 114W (BOL), 120 XTJ Prime cells
Space / Ground Radio	Iris Radio, 3.8W, operating at 8.45 GHz downlink, 7.19GHz receive
Space / Ground Antennas	X-band high gain & low gain patch antennas, on spacecraft Y- and Y+ faces
LRO Crosslink Radio	TUI SLX, 2W, operating at 2.091 GHz transmit, 2.271 GHz receive
LRO Crosslink Antenna	S-band patch antenna on Z+ face
ADCS Control	Coarse sensor module, redundant star trackers, redundant IMUs with STIM 320 10g, four pyramidal reaction wheels
Thermal Control	Active battery heaters, 16 thermistor channels, 8 independent heaters, passive coatings and MLI
Propulsion	8x 0.25N thrusters, 3.25 kg fuel, > 200 m/s ΔV



STELLAR EXPLORATION HYDRAZINE PROPULSION SYSTEM

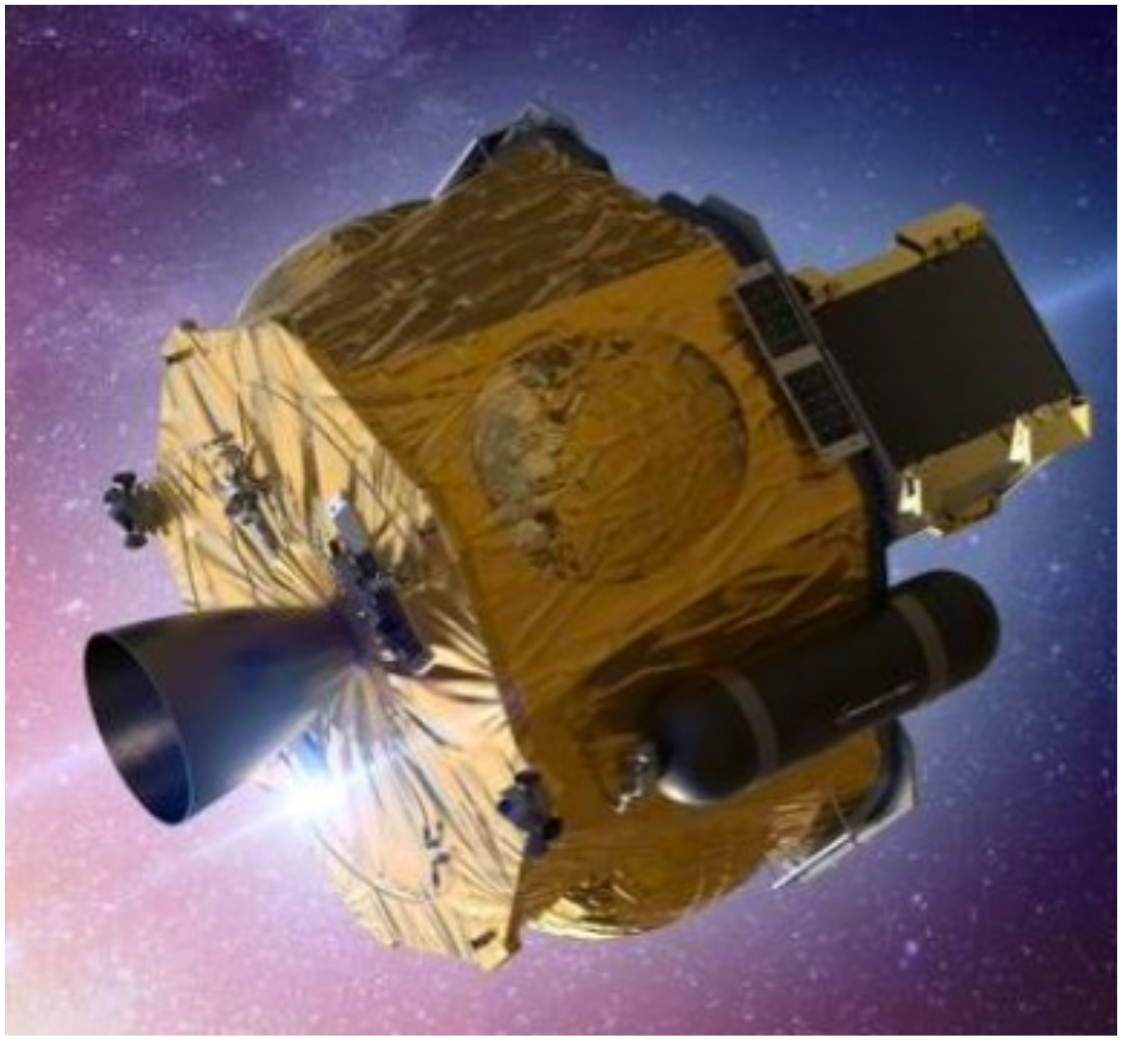
Propulsion System Specifications

Subsystem/Spec	Value
Dimensions	2U X 2U footprint for 12U spacecraft
Fuel Capacity	Variable height for fuel load ~ 3 – 6 kg
Delta V	200 – 550 m/sec
Thrusters	8 thrusters with 0.25 N thrust (200 sec Isp)
Attitude Control	Translational & 3-DOF rotational capability
Propellant	Hydrazine with catalyst decomposition
Pressurization	Electric gear pump
Launch Safety	91-710 compliant, propellant tank not pressurized at launch, fully welded and sealed



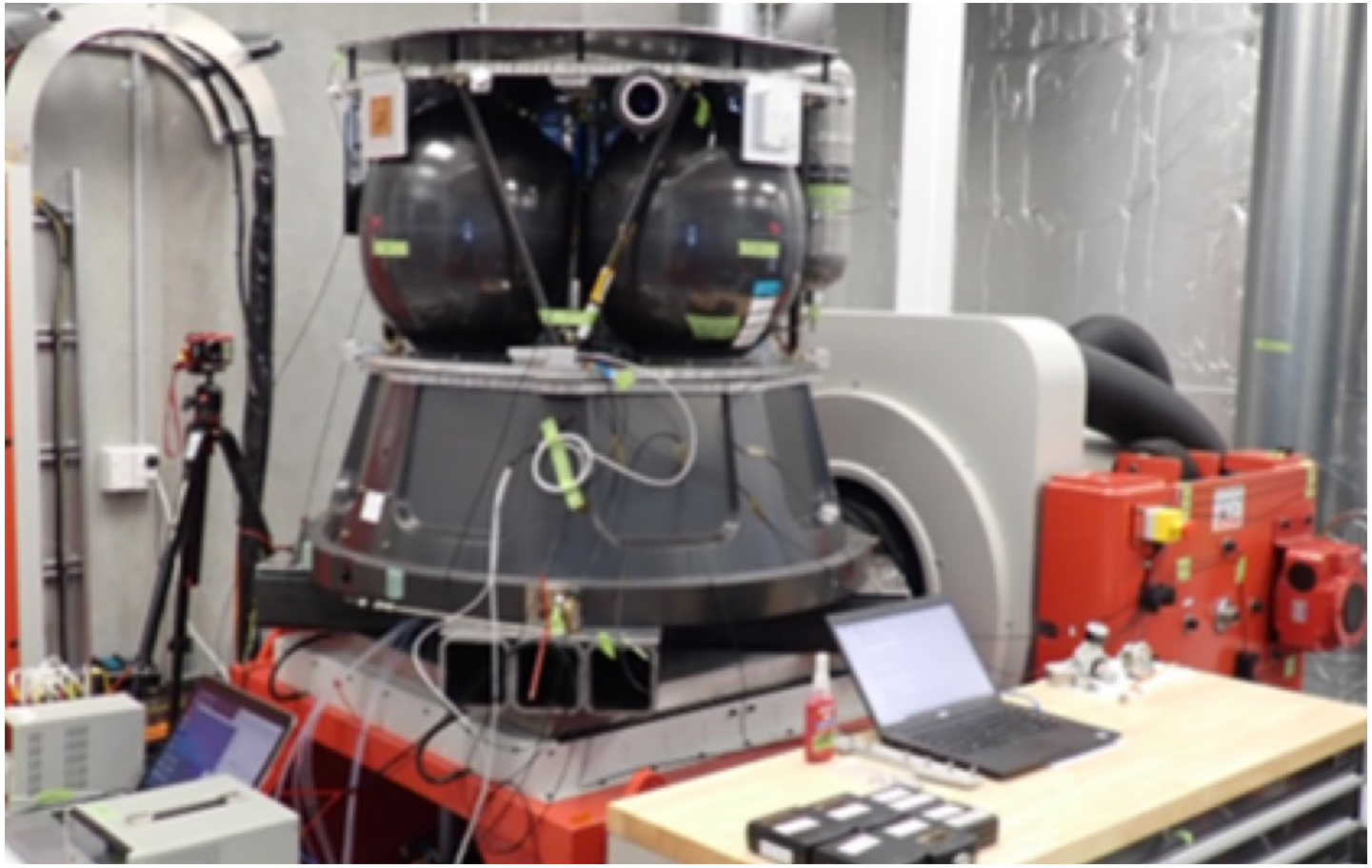
ROCKET LAB LAUNCH VEHICLE SYSTEM

Rocket Lab Electron Rocket – 2 Stage +
Photon Spacecraft with Hyper-Curie Motor

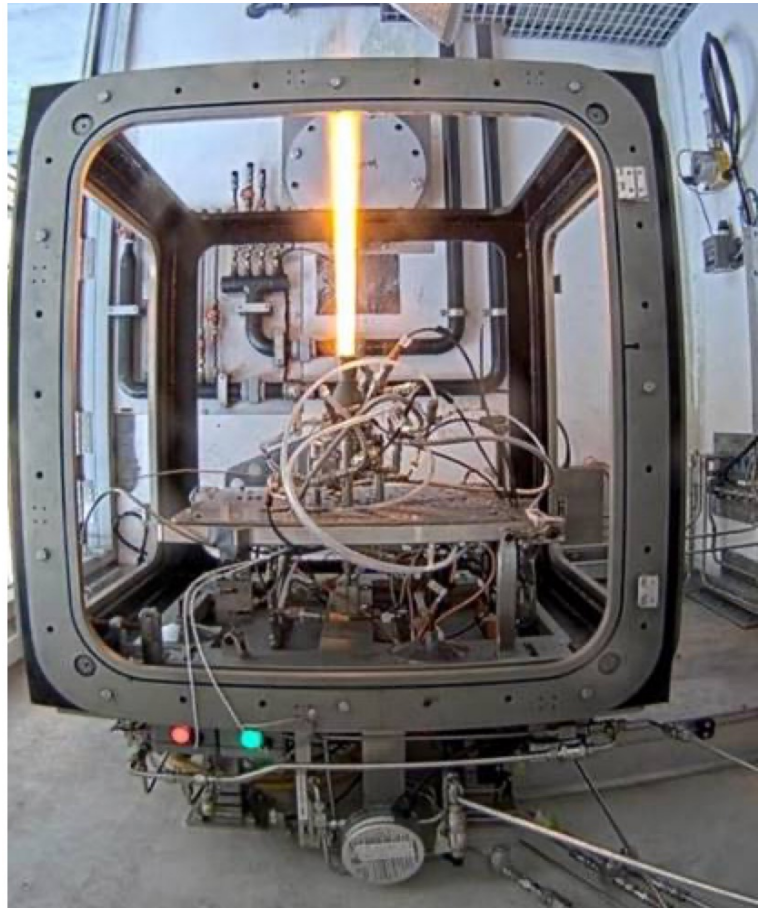


Photon is the Trans Lunar Injection Stage
for the CAPSTONE Spacecraft

ROCKET LAB PHOTON SPACECRAFT AS UPPER STAGE



***Photon Spacecraft**



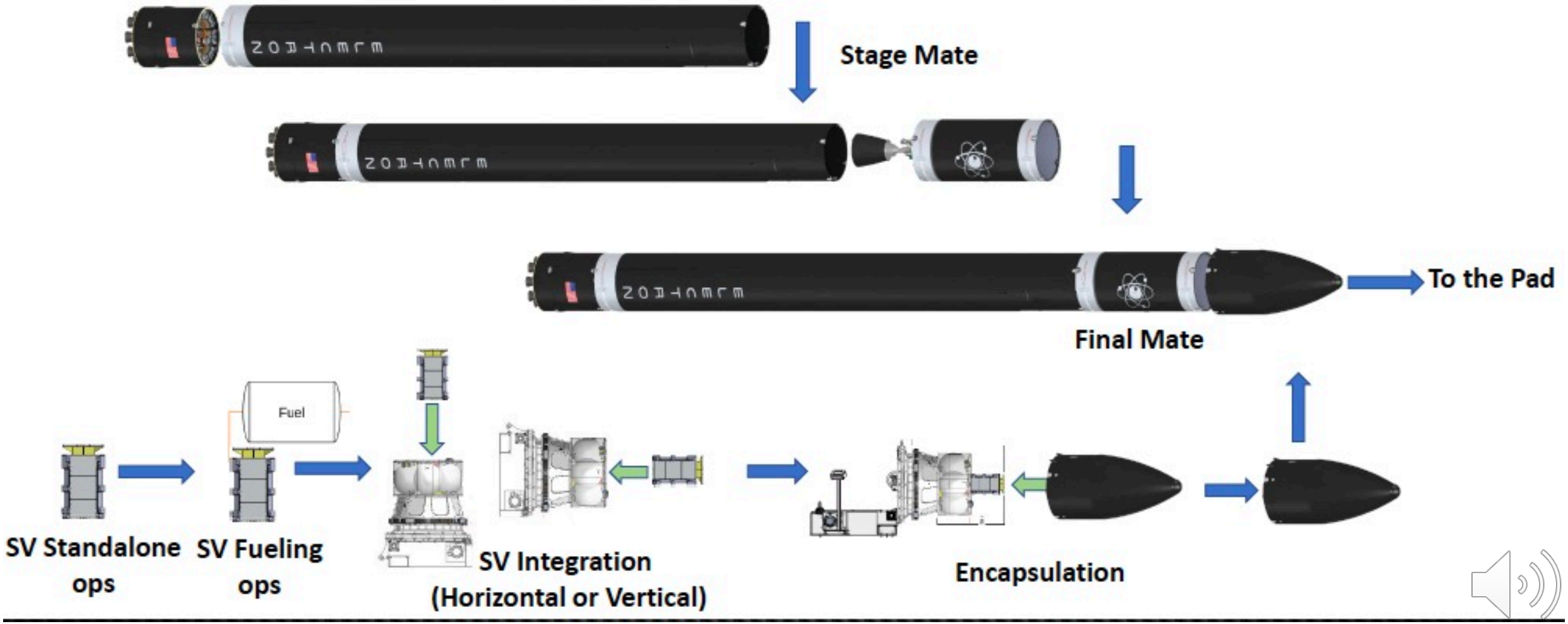
Hyper-Curie Motor Test Fire

*CAPSTONE spacecraft and deployer will sit on top deck

ROCKET LAB
LAUNCH COMPLEX 1, NEW ZEALAND

CAPSTONE Spacecraft to be Transported to New Zealand for Integration and Launch

LAUNCH VEHICLE PROCESSING OVERVIEW



GROUND SYSTEMS & MISSION OPERATIONS

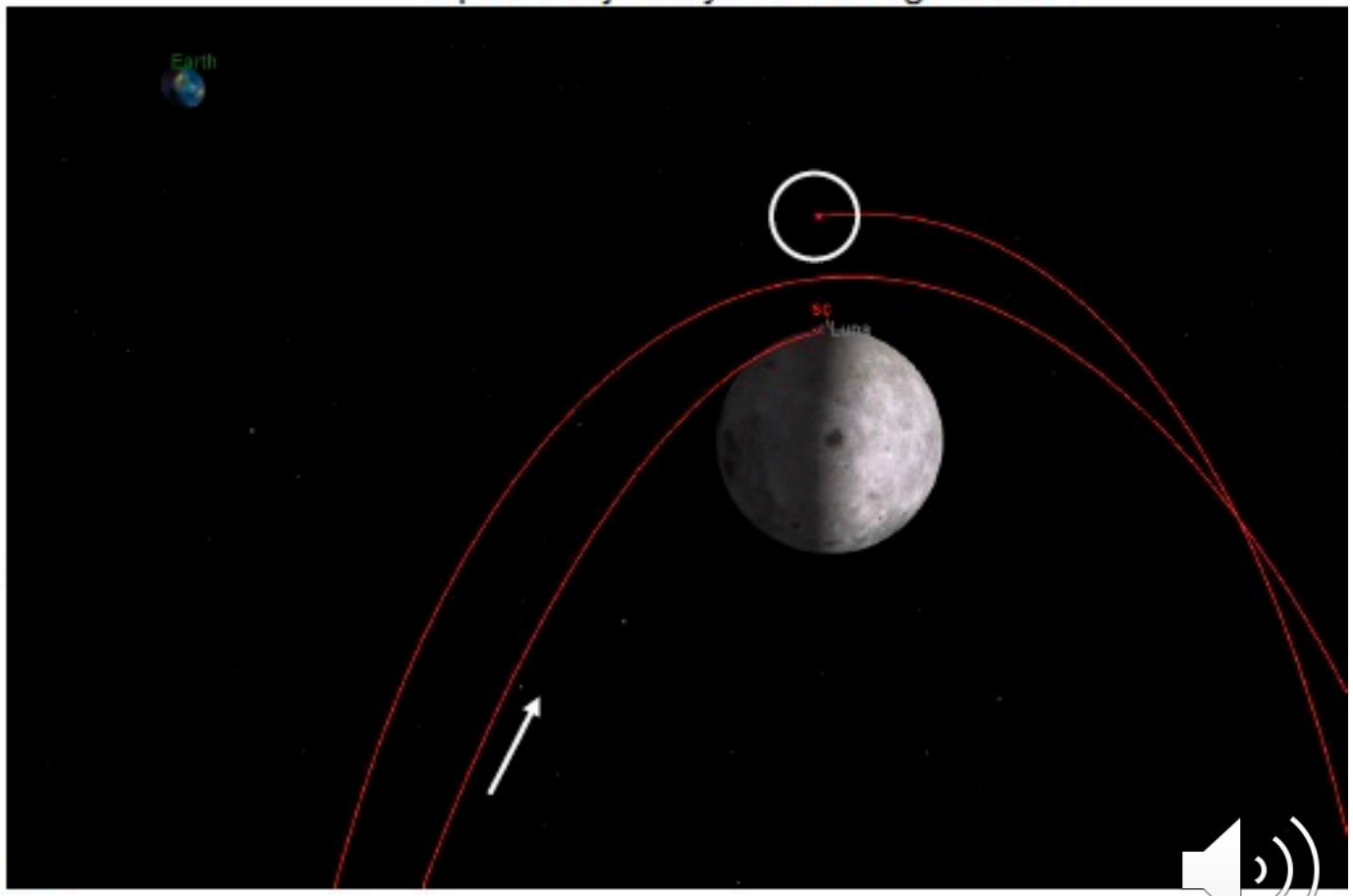
- NASA Deep Space Network
- LRO Operations, NASA GSFC
- Tyvak Mission Ops, Irvine, CA
- Advanced Space, Westminster, CO
  - Flight Dynamics & Navigation
  - CAPS Payload Operations
- Launch Systems, New Zealand

CAPSTONE DECOMMISSIONING

- Baseline disposal maneuver is 5 m/s burn at perilune, impact two revolutions later
- Navigation all the way to impact

Maneuver magnitude and direction (VNB Frame, Moon-Centered)	[-5, 0, 0] m/s
Lunar Impact Coordinates	81.89421° North 15.22779° East
Impact Velocity (Inertial Frame)	2.349 km/s
Impact Angle (From local horizontal)	6.63°

Impact Trajectory in Rotating Frame



https://www.nasa.gov/directorates/spacetech/small_spacecraft/capstone

nasa.gov/directorates/spacetech/small_spacecraft