Optical Communications for Human Space Exploration– Status of Space Terminal Development for the Artemis II Crewed Mission to the Moon

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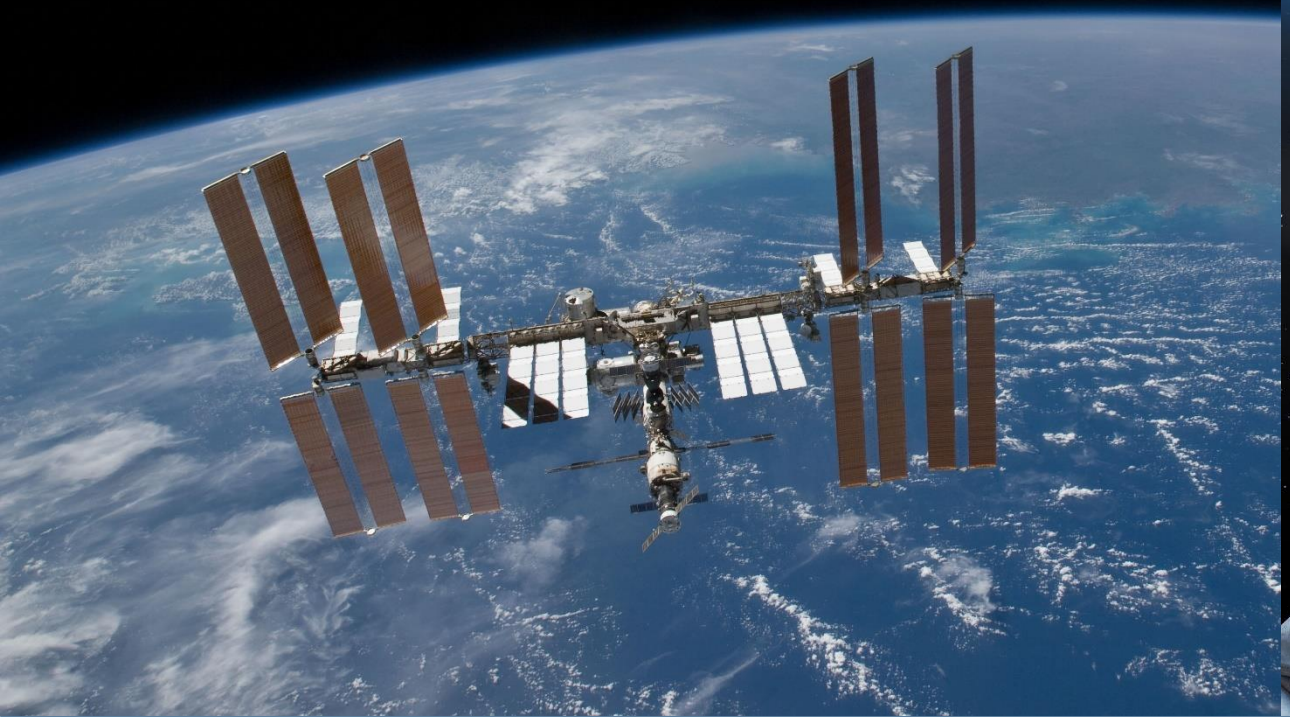
Human Exploration

Today…
ISS in Low Earth Orbit

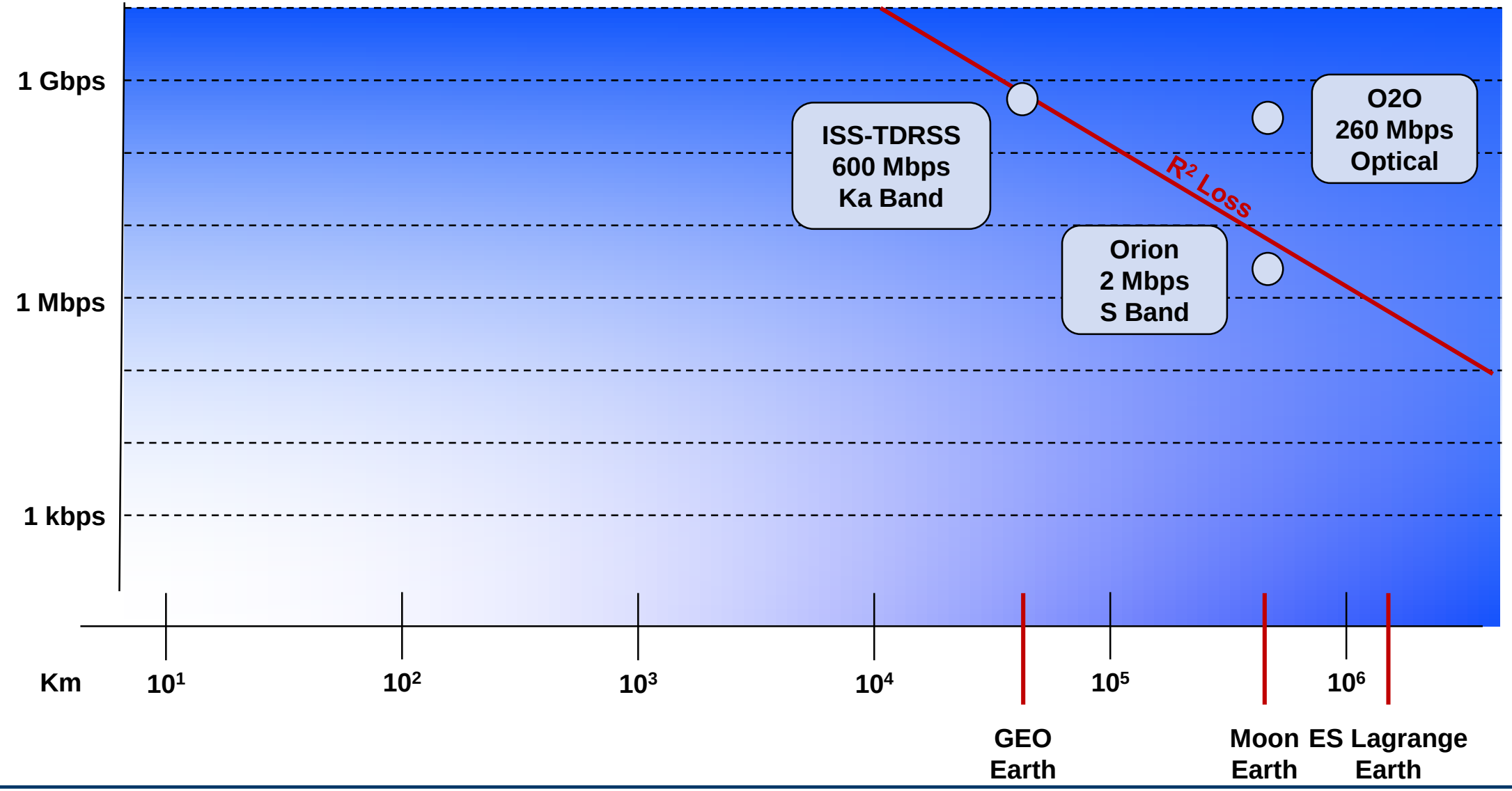
8K HD Video



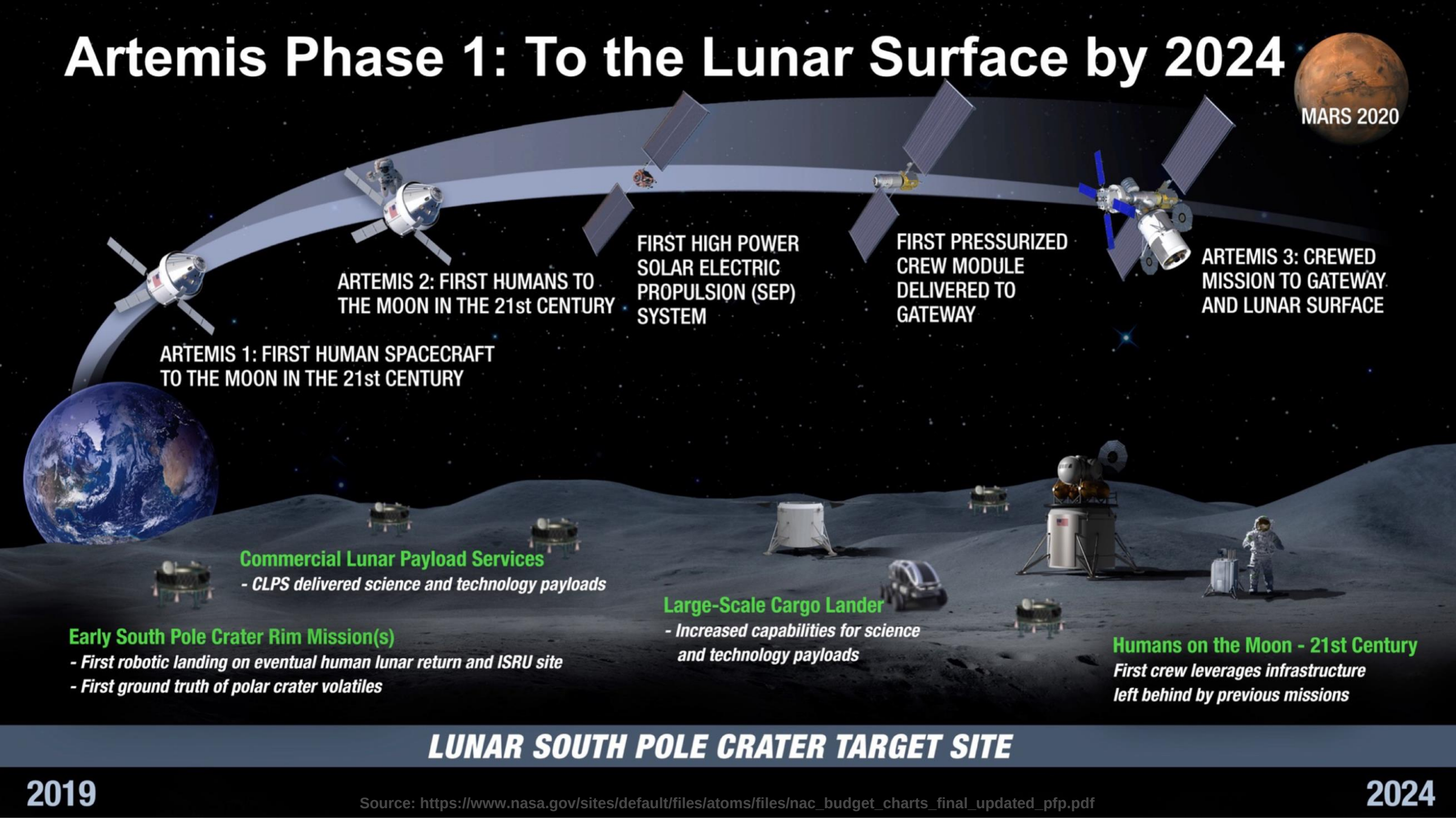
Tomorrow…
Moon, then Mars

ARTEMIS

Space Communications



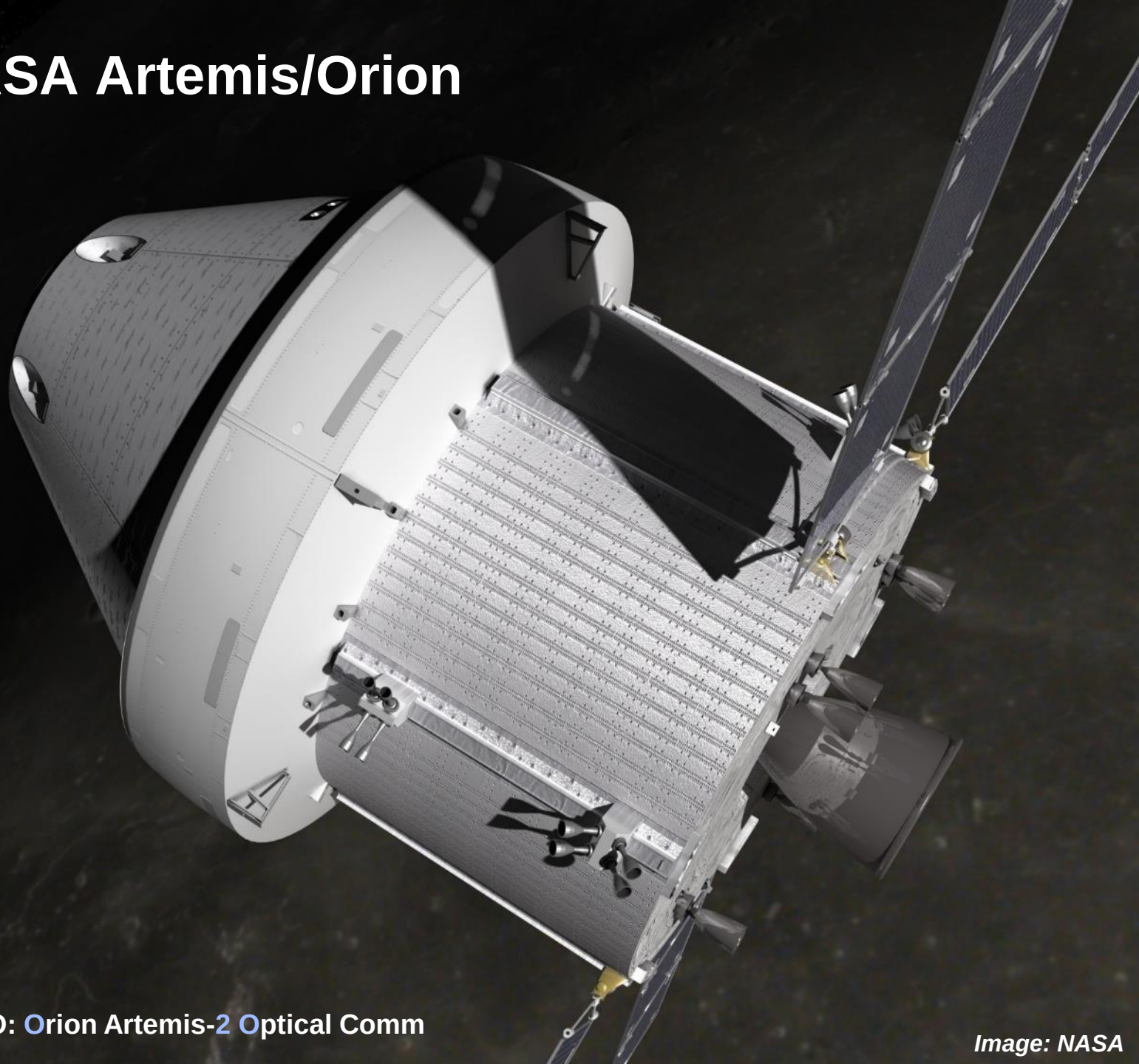
Artemis Phase 1: To the Lunar Surface by 2024



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

NASA Artemis/Orion

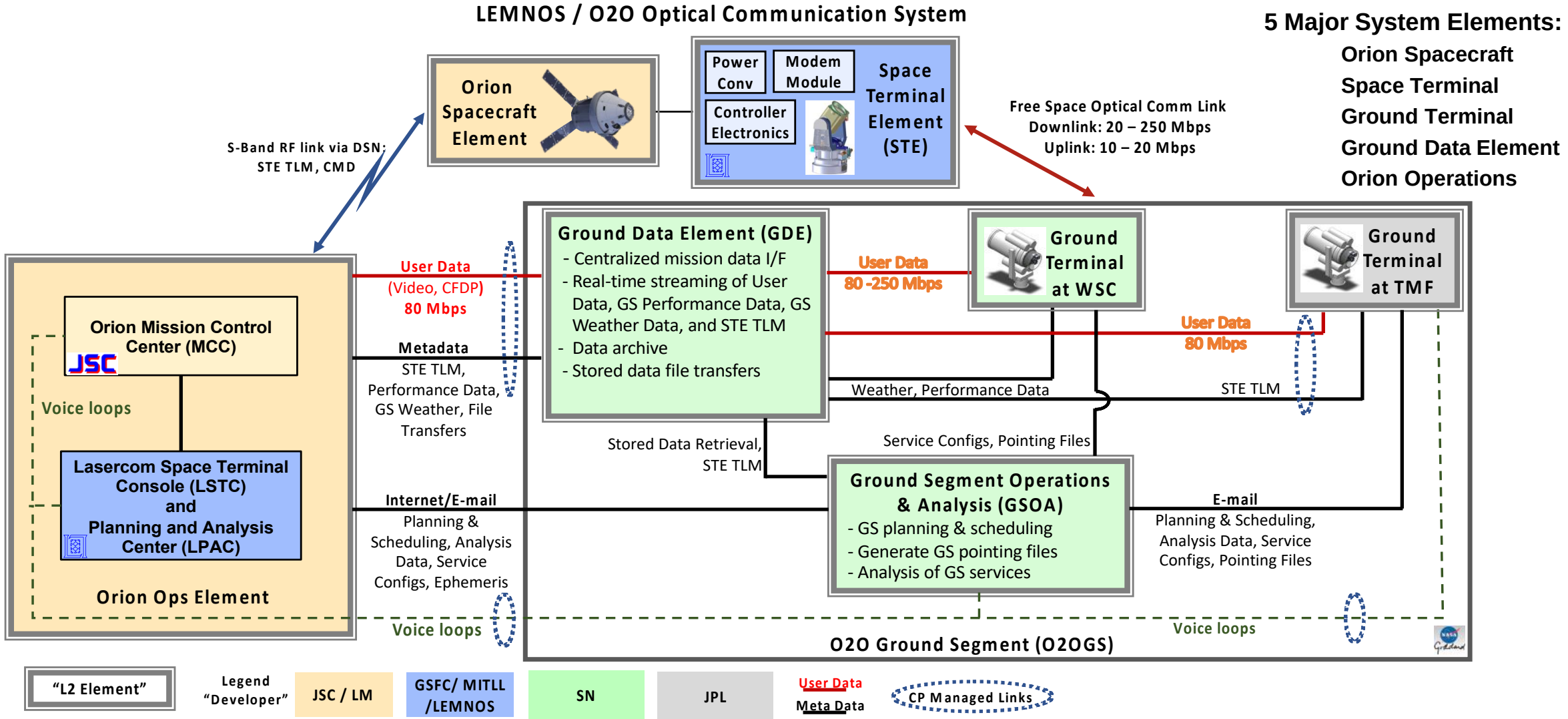
- Orion comm capability
  - S-band phased array transmitters
  - Up to ~2 Mb/s from lunar ranges to NASA Deep Space Network
- O2O* to provide
  - Up to 260 Mbps return
  - 20 Mbps forward
- Moon provides staging ground for eventual missions to Mars



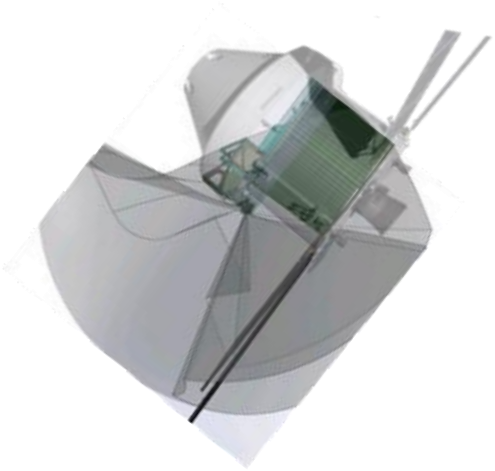
O2O: Orion Artemis-2 Optical Comm

Image: NASA

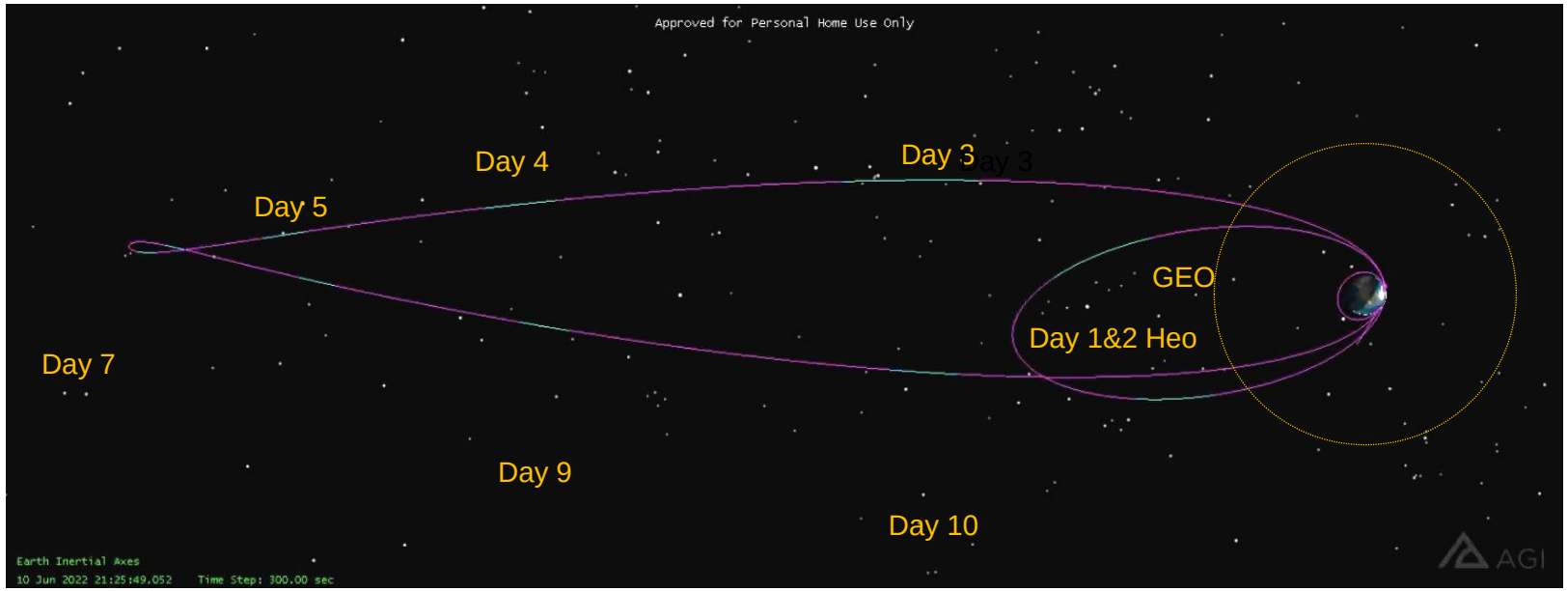
O2O Mission Level Architecture Diagram



Artemis II Mission Trajectory (Example)

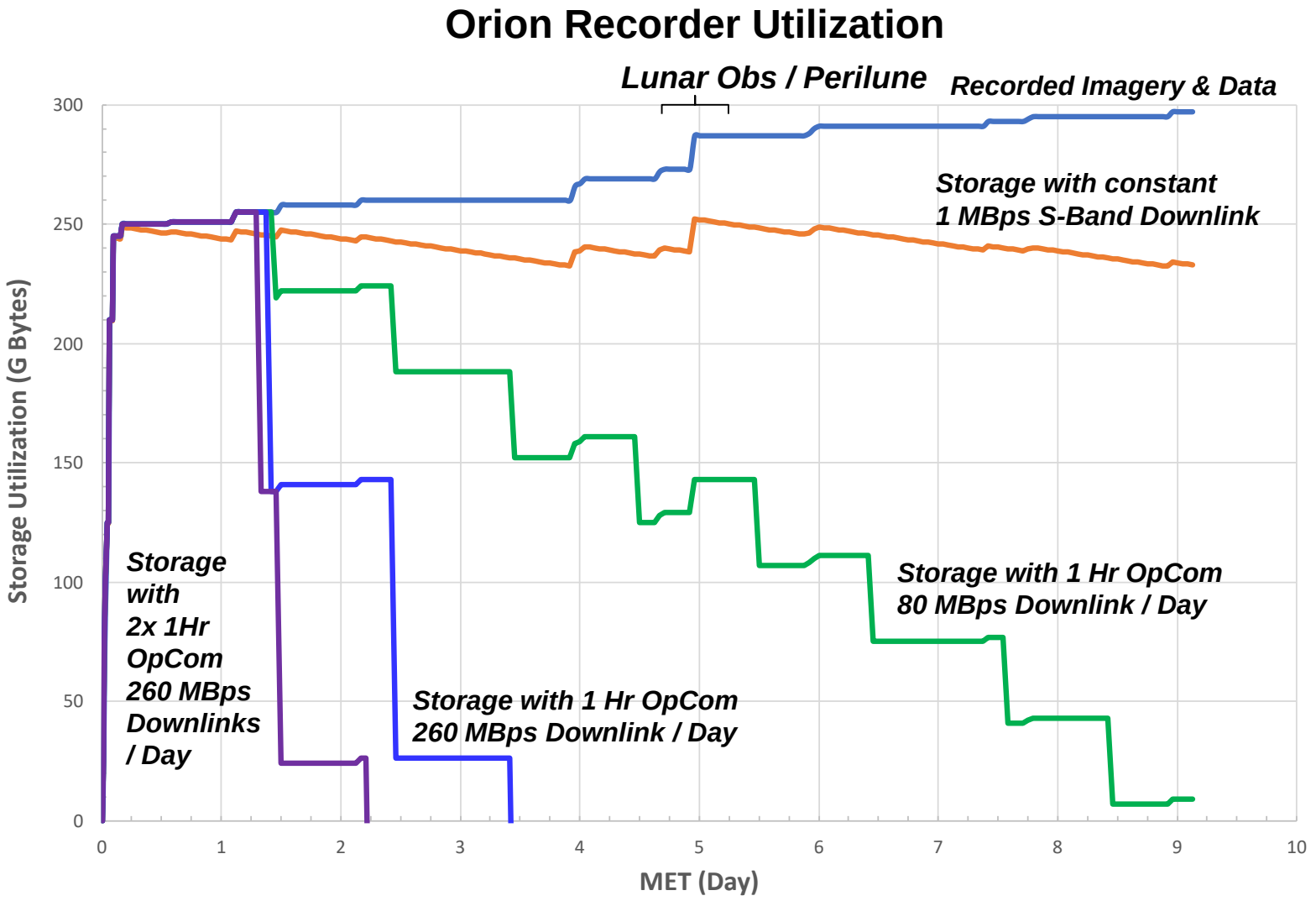


Orion Orientation (Tail to Sun)

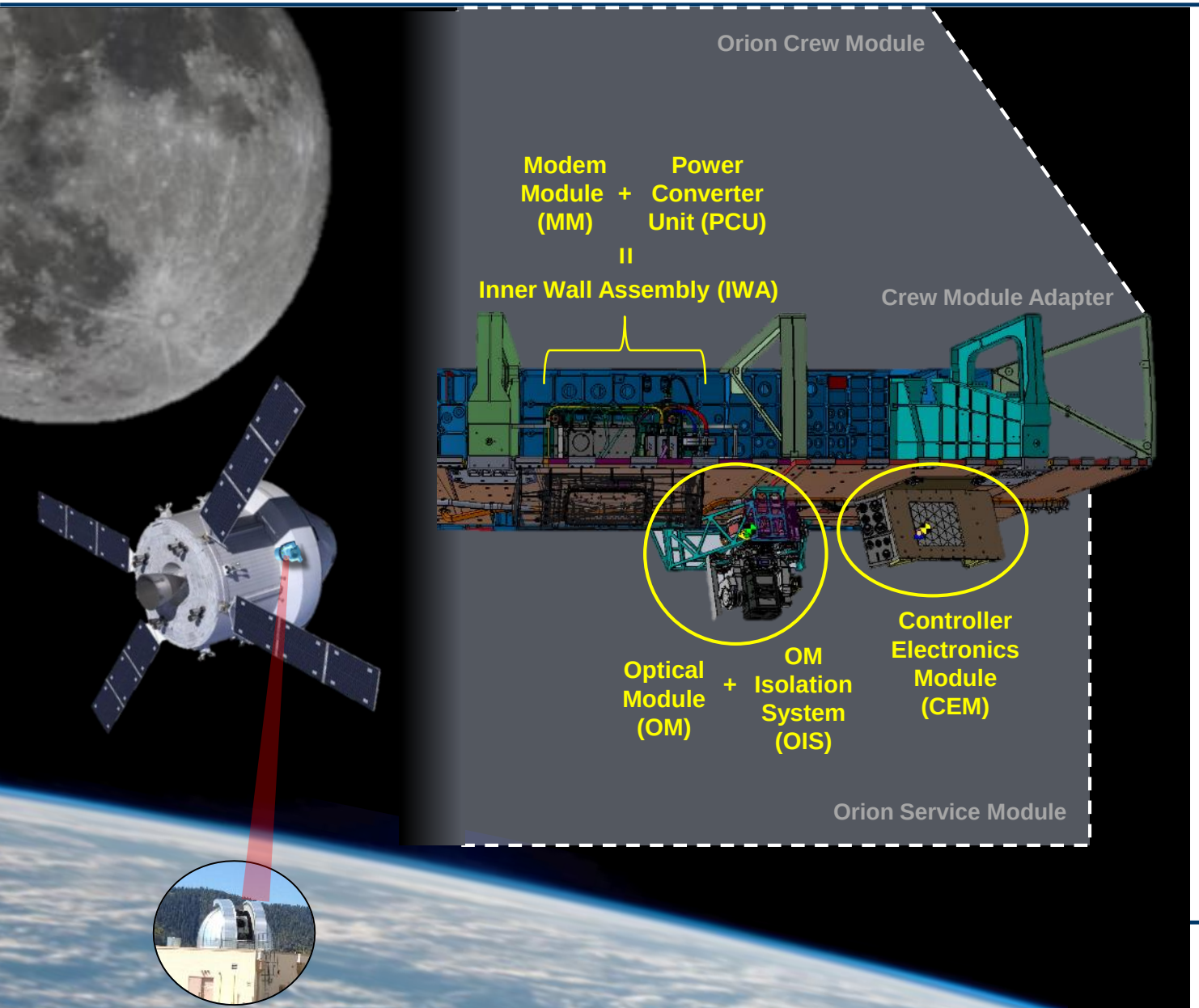


Orion Storage and Data Rates

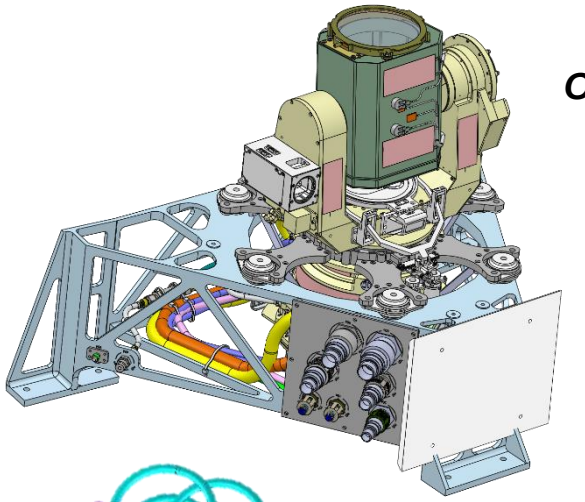
- Orion subsystems expected to generate ~250 GB of data in first day of mission and ~300GB by end of mission
- Using S-Band alone, Orion limited to ~ 7GB of data downlink per day. Can not downlink all recorded data. 230GB remains on board at landing
- With just 1 hour/day of Optical Comm, Orion could downlink ~ 36GB of data per day, a 6x increase per day!
- At the 260MBps link capacity, Orion could downlink 117GB per day almost 20x increase
- Two 1 Hr 260MBps contacts per day, Orion could downlink 234GB per day, and all of the recorded data on the second day



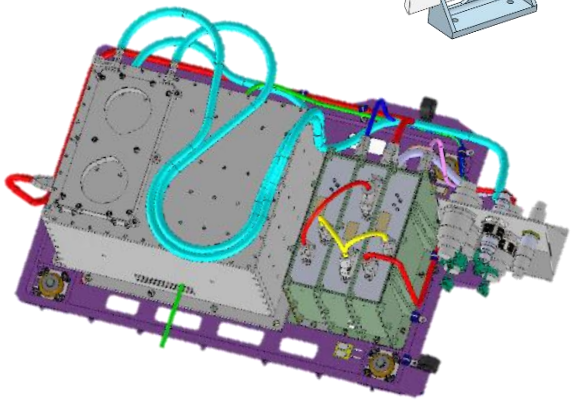
O2O Space Terminal Element



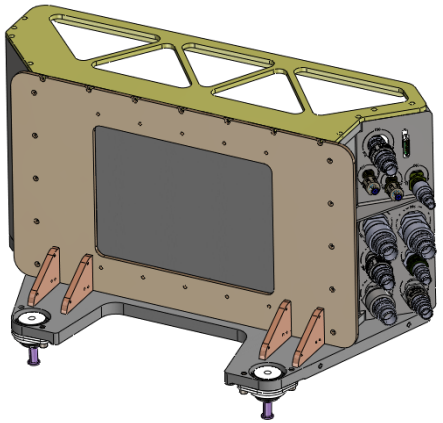
Three Space Payload "Islands"



Optical Module



Inner Wall Assembly

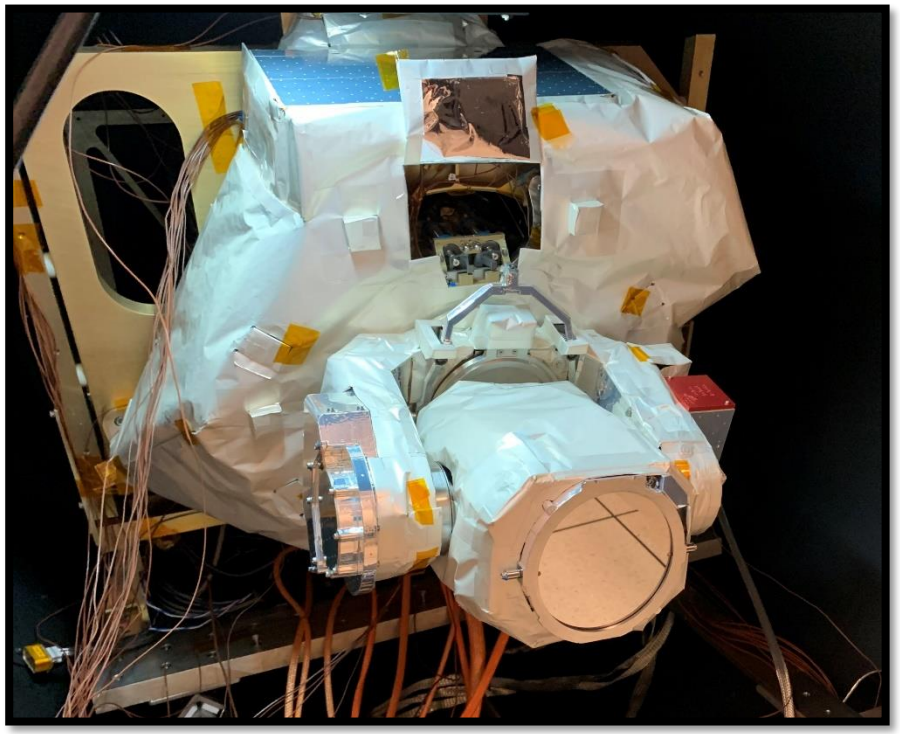


Controller Electronics

Mass: 76 kg (incl. mounting & thermal control structure)
Power: 165W (incl. power conversion & thermal control)

Optical Module Island

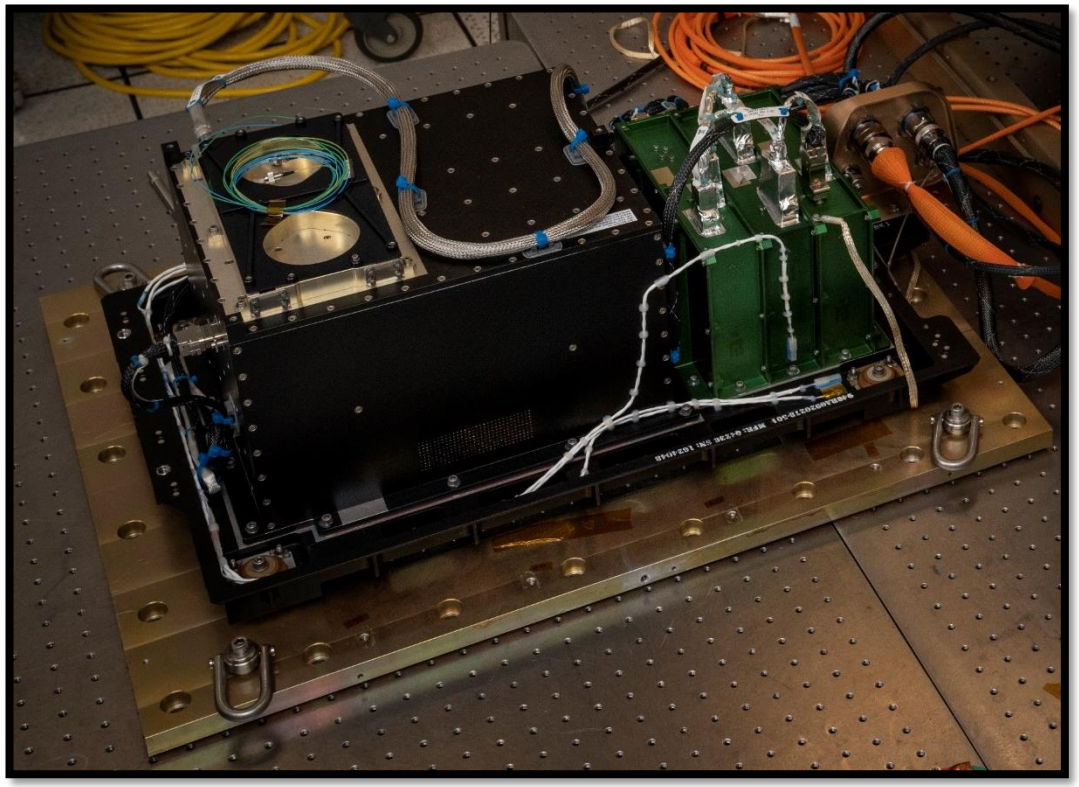
- **Industry and MITLL-built optical module**
  - **10-cm off-axis telescope**
  - **Hemispherical field of regard**
  - **Coudé-path to small optics bench**
  - **Star tracker for attitude knowledge**
  - **Multiple fine-steering optics for simplifying alignment process and maintaining alignment during mission**
- **Island structure allows mounting to Orion exterior panels**
  - **Includes isolation system for mitigation of launch loads**
- **Island provides self-contained thermal control system**
  - **Radiator for small optics**
  - **Controller Electronics controls multiple operational heater zones**



Assembled Optical Module Island Installed in Thermal Vacuum Tank

Inner Wall Assembly

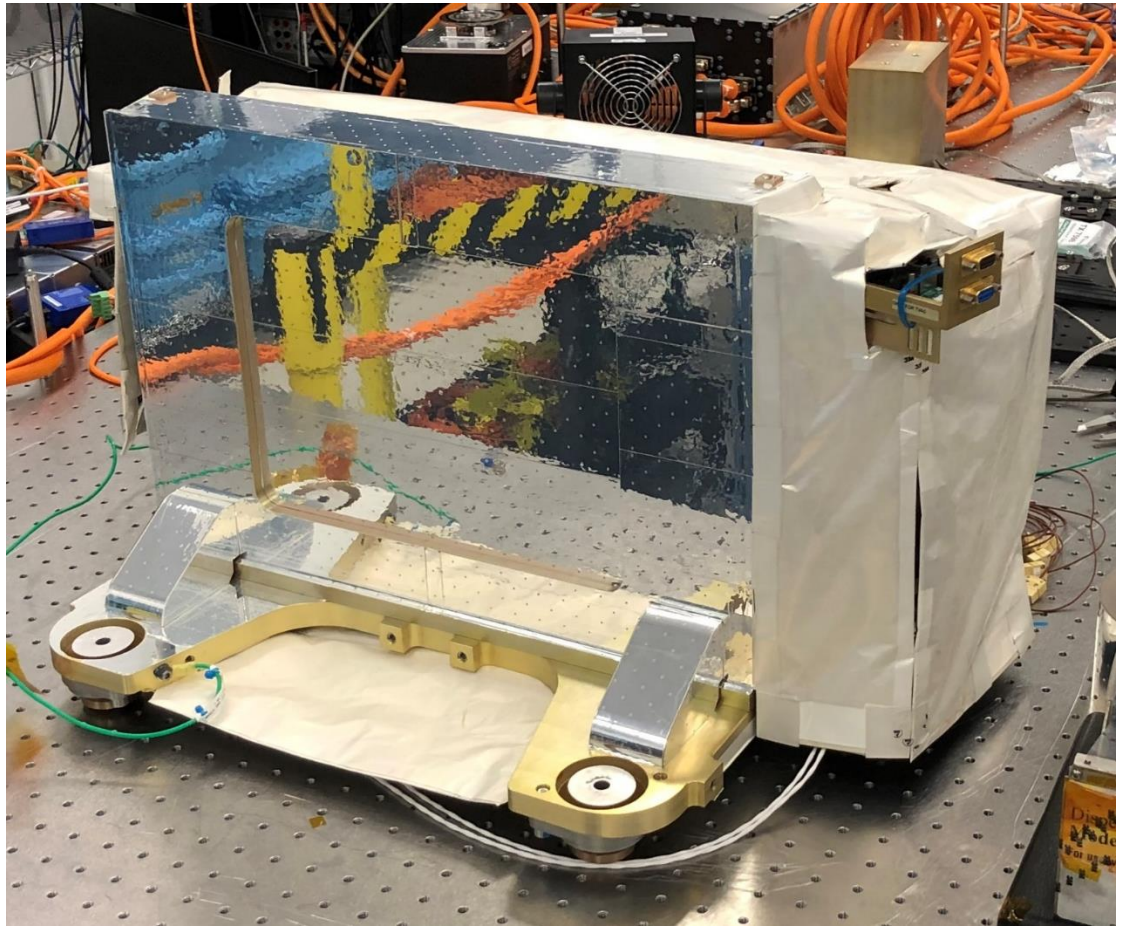
- **Industry-developed modem provides**
  - **Data interfaces to spacecraft**
  - **Data encoding and modulation onto transmit laser**
    - **Pulse position modulation (CCSDS standard)**
    - **Downlink data rates of 20-260 Mbps**
  - **High power transmit signal amplifier (1W)**
  - **Low-noise optically-preamplified receiver**
    - **Pulse position modulation (CCSDS standard)**
    - **Uplink data rates of 10, 20 Mbps**
  - **Fiber interfaces to optical module**
- **NASA GSFC-developed power converter converts between spacecraft and module power interfaces**
- **Avionics mounted on isolated plate inside Crew Module Adapter**
- **Limited thermal control– operations duration may be driven by modem temperature limits, depending on thermal conditions**



Inner Wall Assembly

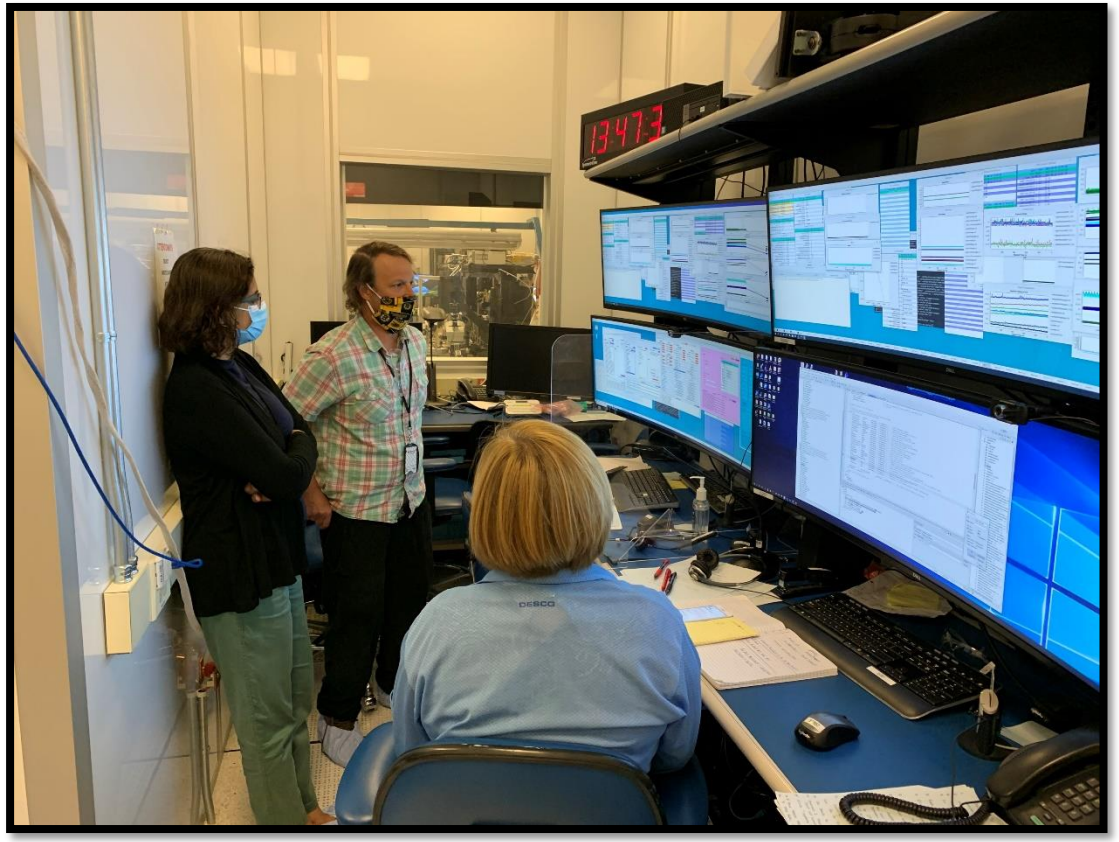
Controller Electronics

- **Industry-developed general purpose processor avionics provides**
  - **Control of pointing mechanisms in optical module**
  - **Command and telemetry interfaces to spacecraft**
  - **Control and monitoring of modem**
  - **Temperature control of optical module**
- **Mounted on exterior of spacecraft**
  - **Includes radiator and heaters for thermal control**
  - **Includes isolation for launch loads**



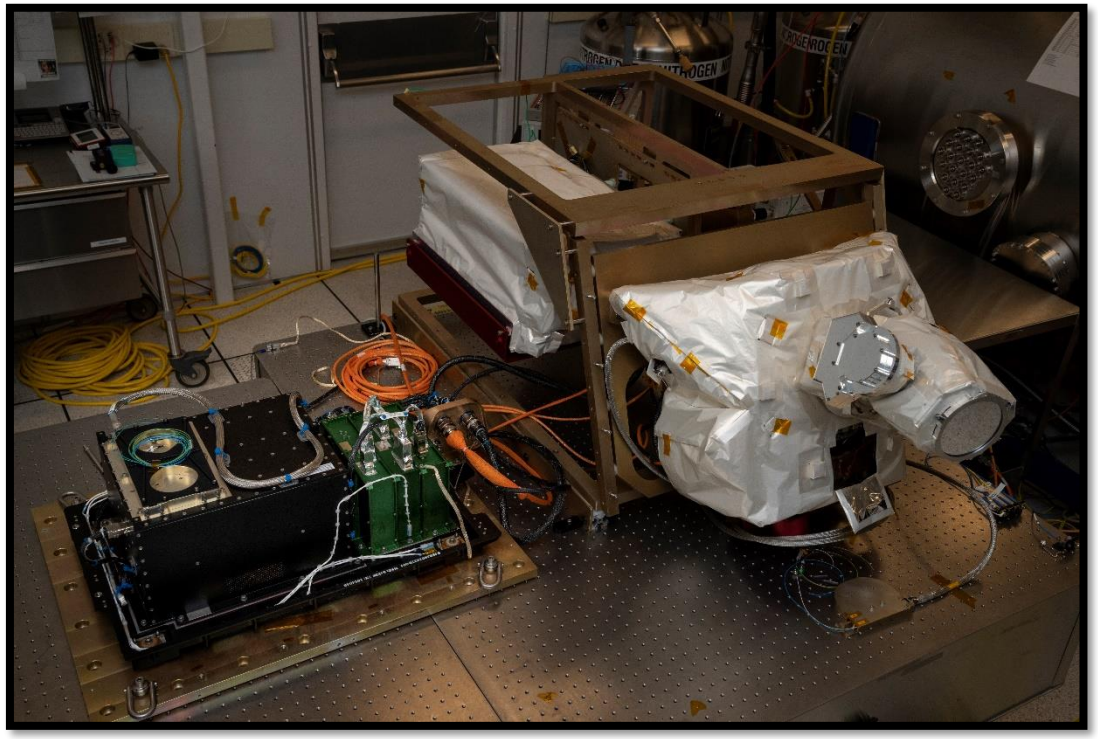
Operations Center

- **“Test As You Fly” approach used for terminal control**
- **Ground operations software deployed and used with spacecraft simulator for all phases of terminal testing**
- **Ground control and monitoring software will be installed in annex to Mission Control Center at Johnson Space Center for mission operations**



Terminal Development Status

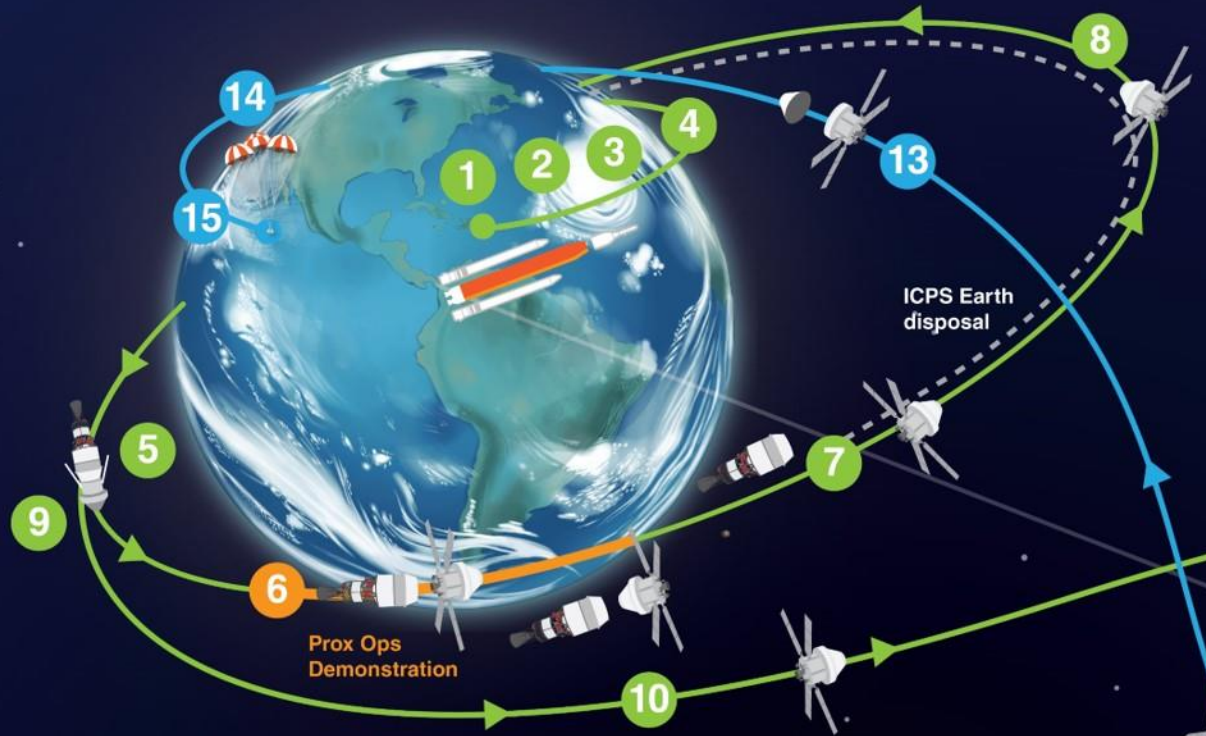
- Island-level vibration testing completed
- Terminal-level thermal vacuum testing completed
- Final software integration and testing in progress
- Completion expected in Spring 2022
- Installation onto Orion spacecraft in early 2023
- Launch and mission operations in 2024



Summary

- Optical communications can extend the reach of high-rate communications in support of human exploration
- O2O will demonstrate this capability for the upcoming Artemis 2 crewed mission to the Moon
- O2O space terminal development is nearing completion
- Terminal to be integrated onto Orion later in 2022 in preparation for 2024 launch and operations

Source: https://www.nasa.gov/sites/default/files/thumbnails/image/gcd_pcm_feature_photo1_0.jpg



ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

1. **LAUNCH**
   Astronauts lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **APOGEE RAISE BURN TO HIGH EARTH ORBIT**
   Begin 24 hour checkout of spacecraft.
6. **PROX OPS DEMONSTRATION**
   Orion proximity operations demonstration and manual handling qualities assessment for up to 2 hours.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) DISPOSAL BURN**
8. **HIGH EARTH ORBIT CHECKOUT**
   Life support, exercise, and habitation equipment evaluations.
9. **TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE**
   Lunar free return trajectory initiated with European service module.
10. **OUTBOUND TRANSIT TO MOON**
    4 days outbound transit along free return trajectory.
11. **LUNAR FLYBY**
    4,000 nmi (mean) lunar farside altitude.
12. **TRANS-EARTH RETURN**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
13. **CREW MODULE SEPARATION FROM SERVICE MODULE**
14. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
15. **SPLASHDOWN**
    Ship recovers astronauts and capsule.

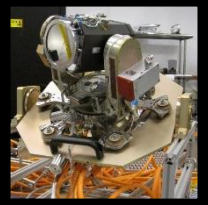
PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE

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

Potential Applications of Lasercom in Cis Lunar Space

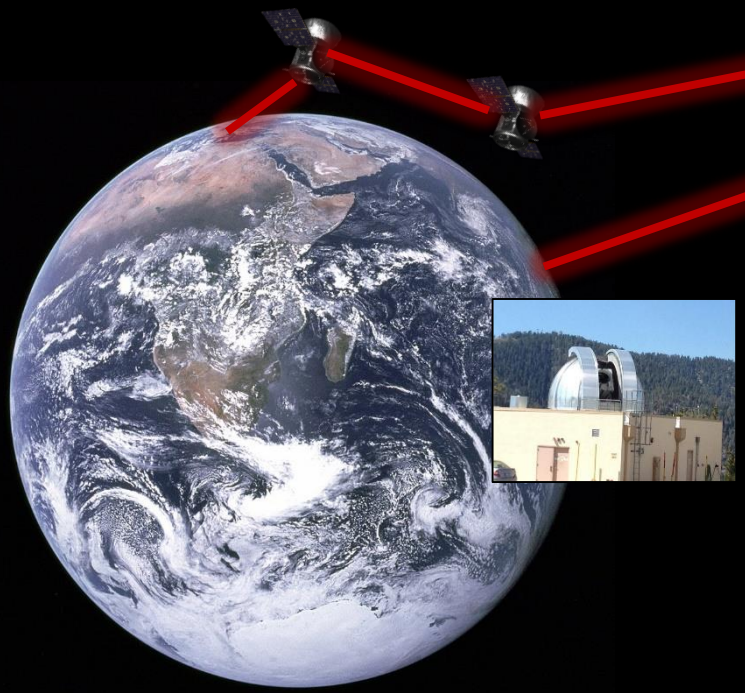
Lasercom Network

10-cm Optical Module
10-W Modem

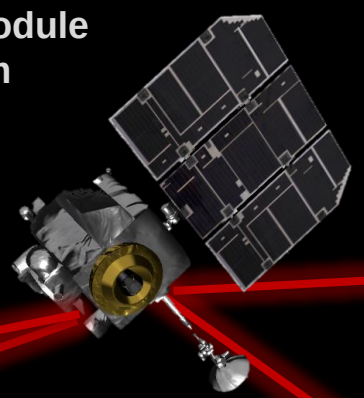


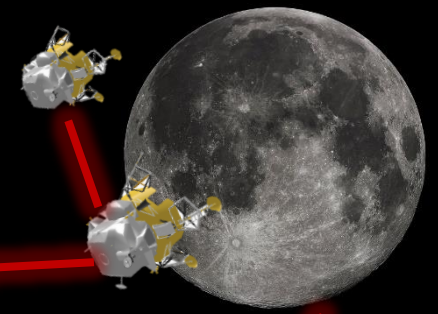
High-Rate Trunking
Connecting Lunar / near-lunar assets
to Earth / near-Earth assets
Long ranges, highest rates, fairly stable

5 Gbps Return, 200 Mbps Forward



1-m Ground Aperture
20W Coherent Modem





Lunar Proximity Operations
Connecting lunar surface and orbiting assets
Relay / backbone services: Medium ranges, high rates
End user equipment: low SWAP, medium rates

All links provide range and PNT assistance in addition to communications

LEMNOS

(Laser Enhanced Mission Communications Navigation and Operational Services)

ILLUMA-T

(Integrated LCRD LEO User Modem and Amplifier Terminal)

1.2 Gbps return
51-155 Mbps forward
To ground via LCRD* relay

Launch on SpaceX Dragon: January 2023

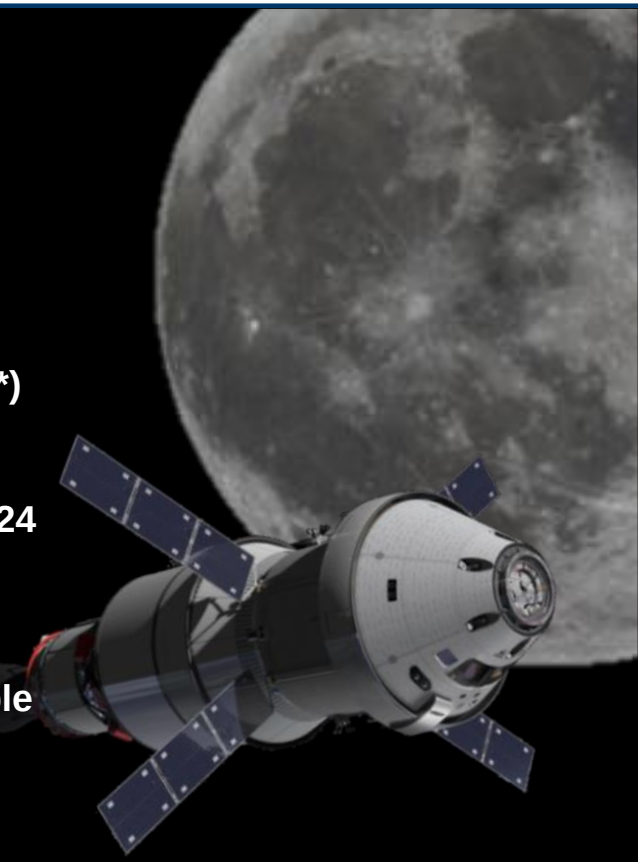
~ 6 months mission

*LCRD=Laser Communications Relay Demonstration, launched Dec 2021

NASA Goddard | NASA Johnson Space Center | JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

O2O

(Orion AM-2 Optical Comm)



80 Mbps return
20 Mbps forward
Direct to ground (WSC, TMF**)

Launch on Orion/SLS: May 2024

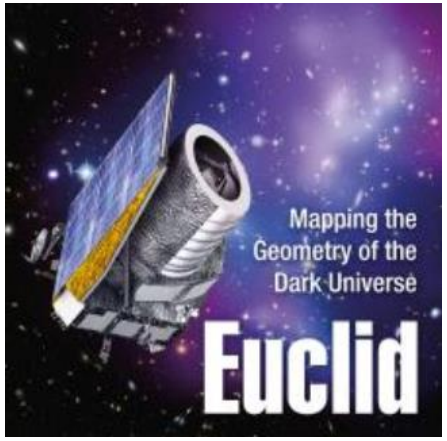
8-21 day mission

**White Sands Complex & Table Mountain Facility

NASA Goddard | LOCKHEED MARTIN | NASA Johnson Space Center | JPL | NASA Marshall Space Flight Center

(Un-crewed) Science User Communications Needs

Link Purpose	Type	Un-crewed/ Science Bandwidth
Science Data Delivery	Return/Downlink	~ Mbps – Gbps
S/C Command & Control	Forward/Uplink	~ 50 Kbps
S/C Health Telemetry	Return/Downlink	~ 50 Kbps
S/C Software Updates	Forward/Uplink	?



(Cis-Lunar) Human User Communications Needs

Astronauts Scott Kelly and Kjell Lindgren prepare for EVA.

- **S/C Life Support & Human Cmd & Control**
  - Haptics
- **S/C Life Support & Human Health Telemetry**
  - Basic astronaut health monitoring
- **S/C + Human device software updates**
- **Human User Streaming "Real-time" Data**
  - Weekly medical / psychiatric evaluations
  - Medical procedures
  - EVA support (haptics)
  - Twice daily video calls with MCC
  - Troubleshooting
  - Basic internet functionality (Superbowl!)
- **Human User Store & Forward "Burst" Data**
  - Internet downloads (Netflix, etc.)
  - Detailed health/safety S/C monitoring
  - Detailed astronaut health monitoring

(CisLunar) S/C + Human User Communications Needs

Link Purpose	Type	Human/ Crewed & Some Science Bandwidth
Science Data Delivery	Return/Downlink	~ Mbps - Gbps
S/C, S/C Life Support + Human Cmd & Control	Forward/Uplink	50 Kbps - ?
S/C, S/C Life Support + Human Health Telemetry	Return/Downlink	50 Kbps - ?
S/C + Human device software updates	Forward/Uplink	?
Human User Streaming “Real-time” Data	Bi-directional	?
Human User Store & Forward “Burst” Data	Bi-directional	?