Optical Communications for Artemis II Crewed Mission

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https://www.nasa.gov/wp-content/uploads/2023/05/background-02.png

Outline

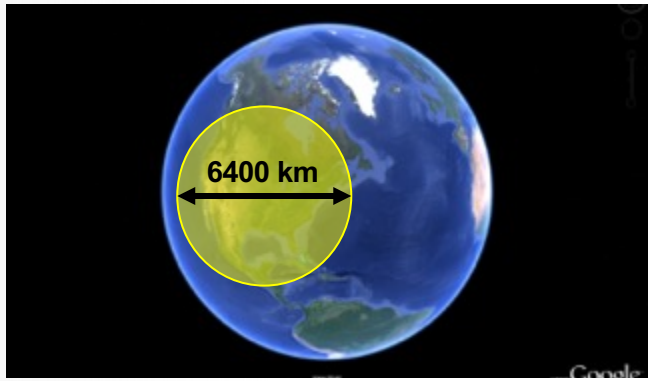
- Introduction
- Human space exploration
- O2O* mission
- Summary

*Orion Artemis 2 Optical Communications

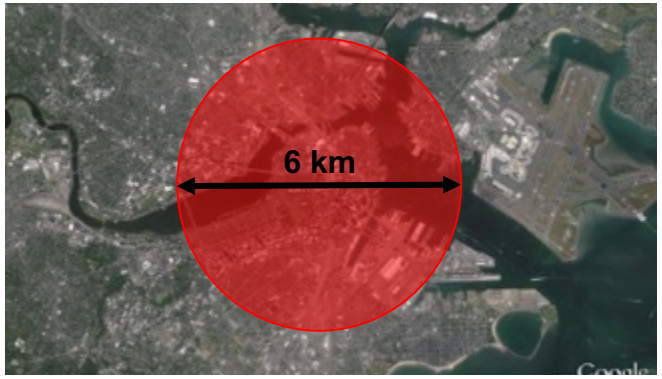
Benefits of Laser Communications

- **Extremely narrow beams with small apertures**
- **Unlimited, unregulated spectrum**
- **High data rates**
  - **Provides high speed real-time data (e.g. for video)**
  - **Enables shorter contact times**
  - **Delivers large data volume over the duration of mission**
- **Historic technical challenges**
  - **Efficient transmitters and receivers**
  - **Pointing narrow beams**
  - **Atmosphere and weather**

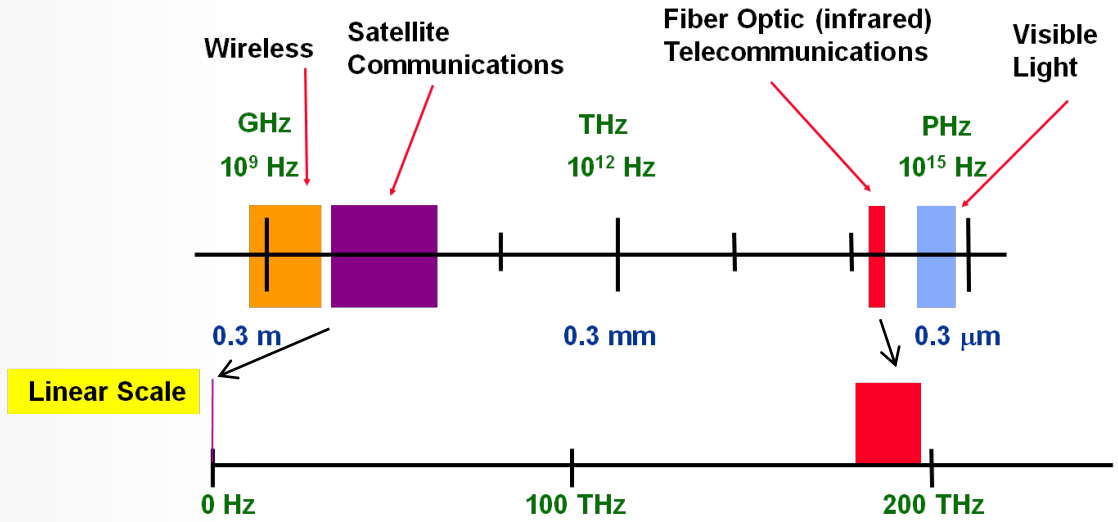
Beam Size From Moon



RF Ka Band (26 GHz)
75-cm Antenna → 6400 km Spot



Optical C-Band (1550 nm)
10-cm Antenna →6 km Spot



Operational Differences between RF & Optical Comm Systems

	RADIO	OPTICAL
Beam width	0.5 - 30°	1 - 100 μrad (<0.006°)
Point / Acquire Beam	Open loop	Scan or wide-field sensor (cooperative)
Stabilize / Track Beam	N/A	Optical-based tracking (cooperative), inertial sensors-based tracking, passive jitter rejection
Atmosphere Interactions	Rain can degrade > 20 GHz	Clouds can block lasers; turbulence must be considered
Regulatory / Permissions	Spectrum is regulated and licensed	Unregulated; need care with sensor satellites / aircraft

From: Khatri & Robinson, "Operational Considerations for Future Laser Communications Systems," *AIAA Improving Space Operations Workshop*, Pasadena, CA, May 5-6, 2015.

LLCD*: A Successful Operational Lasercom Demo

*Lunar Laser Communication Demonstration

- In 2013, NASA's LLCD showed operational utility of lasercom
  - 622 Mbps downlink, 20 Mbps uplink
  - Automated point/acq/track of 15 μrad beam
  - Daily downlink of entire 1 GB s/c buffer
  - File transfers up / down
- Demonstrated reliable data delivery over lasercom links through Earth atmosphere:
  - Link worked through thin cirrus clouds
  - Multiple ground sites and higher layer data protocols to combat clouds
  - Data interleaving and multiple apertures to mitigate turbulence
  - Aircraft/sensor sat avoidance easily achieved

OPTICAL – NOW KNOWN!	
Narrow beam (<0.006°)	✓
Is space craft position information good enough to point?	✓
Is it possible to stabilize if space craft jitter is >> beam?	✓
Can clouds, weather, and turbulence be managed?	✓
Can sensor satellites / aircraft be easily avoided and not disruptive to link?	✓
Can lasercom ever be routine and automated?	✓

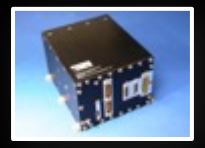
From: Khatri & Robinson, "Operational Considerations for Future Laser Communications Systems," *AIAA Improving Space Operations Workshop*, Pasadena, CA, May 5-6, 2015.

Commercialization of Lasercom

Components

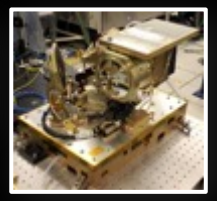
SNDA

Space Modules and Sub-Modules



Controller

Modem



Optical Module

Ground Terminals

Standards

SDA

Systems and services

ILLUMA-T

Examples of Industries with ties to lasercom technologies

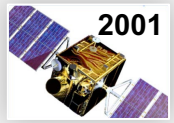
Photon Spot
SINGLE QUANTUM
Quantum Opus
SCONTEL
IDQ
CACI
FIBERTEK, INC.
RT LOGIC
MOOG
mynaric
L3
TESAT
BLUEHALO
BRIDGE SAT. INC.
cailabs
SEA WEST OBSERVATORIES
OFFICINA STELLARE
WORK MICROWAVE
ARCHANGEL LIGHTWORKS
MDA
SPACEX
SONY
KEPLER
TELESAT
Skyloom
NORTHROP GRUMMAN
LOCKHEED MARTIN
Ball Aerospace & Technologies Corp.
amazon project kuiper
LASERLIGHT
TRANSCELESTIAL
TESAT

- Technologies and end-to-end systems demonstrated by LLCD mission are commercially available and lasercom standards have emerged
- Lasercom systems are now offering network layer services

Free Space Lasercom Projected Market Growth

Global Free space lasercom market:	2013	2021-2023	2030-2034
	$33M $42M	$0.5-1.6B	$3.6-15B

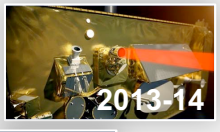
Early Demos



GEOLITE
GEO-Gnd
(MITLL)

LLCD
Moon-Gnd
(NASA/MITLL)

Alphasat
(ESA)



OSIRIS
(DLR)

EDRS/
Sentinel
(ESA)

Mature Demos & Operational Systems

LCRD
GEO-Gnd
(NASA)

ILLUMA-T
LEO-GEO
(NASA/MITLL)

Orion EM-2
Moon-Gnd
(NASA/MITLL)

TBIRD
LEO-Gnd
(NASA/MITLL)

DSOC
Deep Space-Gnd
(NASA/JPL)

Mandrake
LEO-LEO
(DARPA)

Starlink
LEO-LEO

SPACEX

TELESAT

SDA

Service Providers

amazon project kuiper

- Zion Market Research: $1.6B (2022) → $10.2B (2030), CAGR 26.2%
- Straits Research: $11.1B (2032), CAGR 25.7% (2024-2032)
- Visiongain: $1.6B (2023), CAGR 13.6% (2024-2034)
- Global Market Insights: $0.7B (2023) → $15B (2032), CAGR 40% (2024-2032)
- Astute Analytica: $0.5B (2021) → $3.6B (2030), CAGR 24.2%

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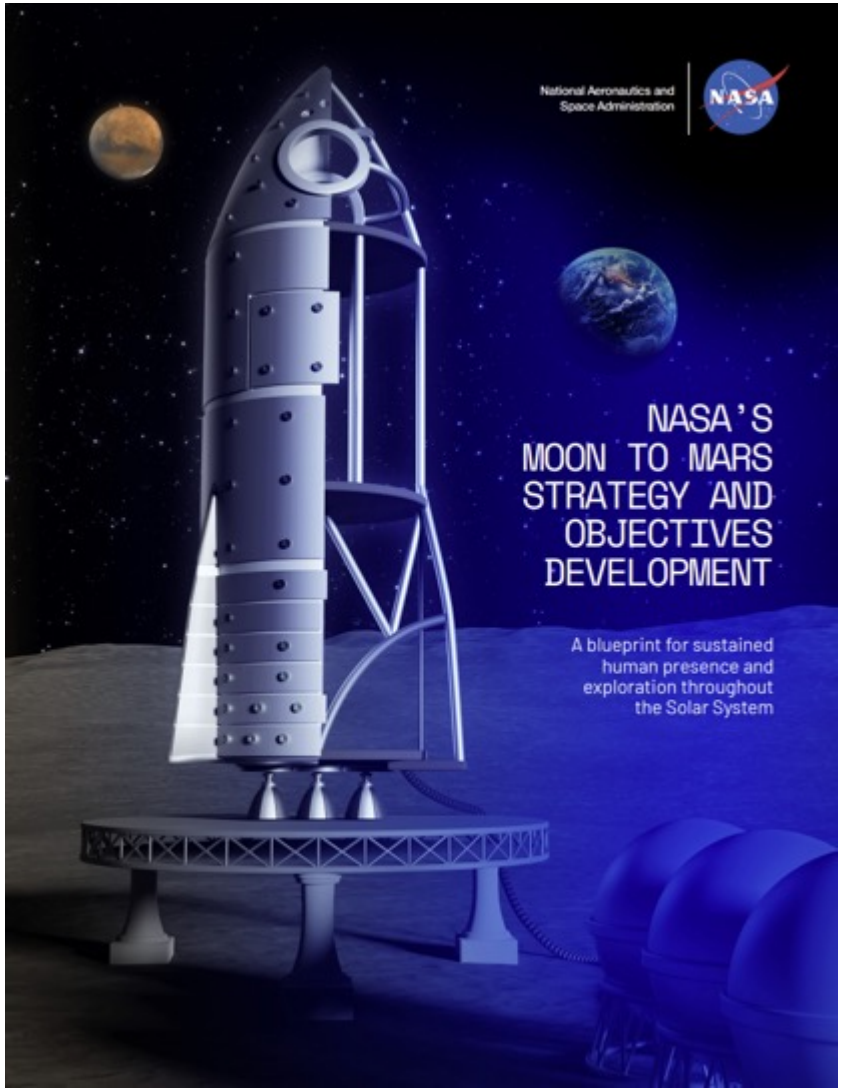
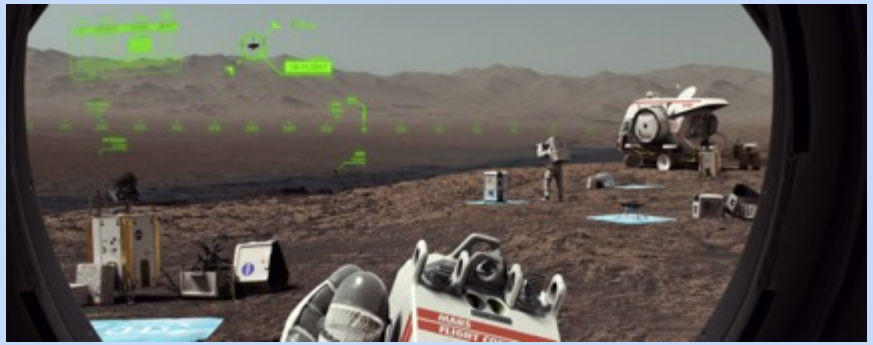
NASA Human Exploration

Communications for Human Space Exploration



Monitor and maintain crew health



Characterize and monitor space and surface environments

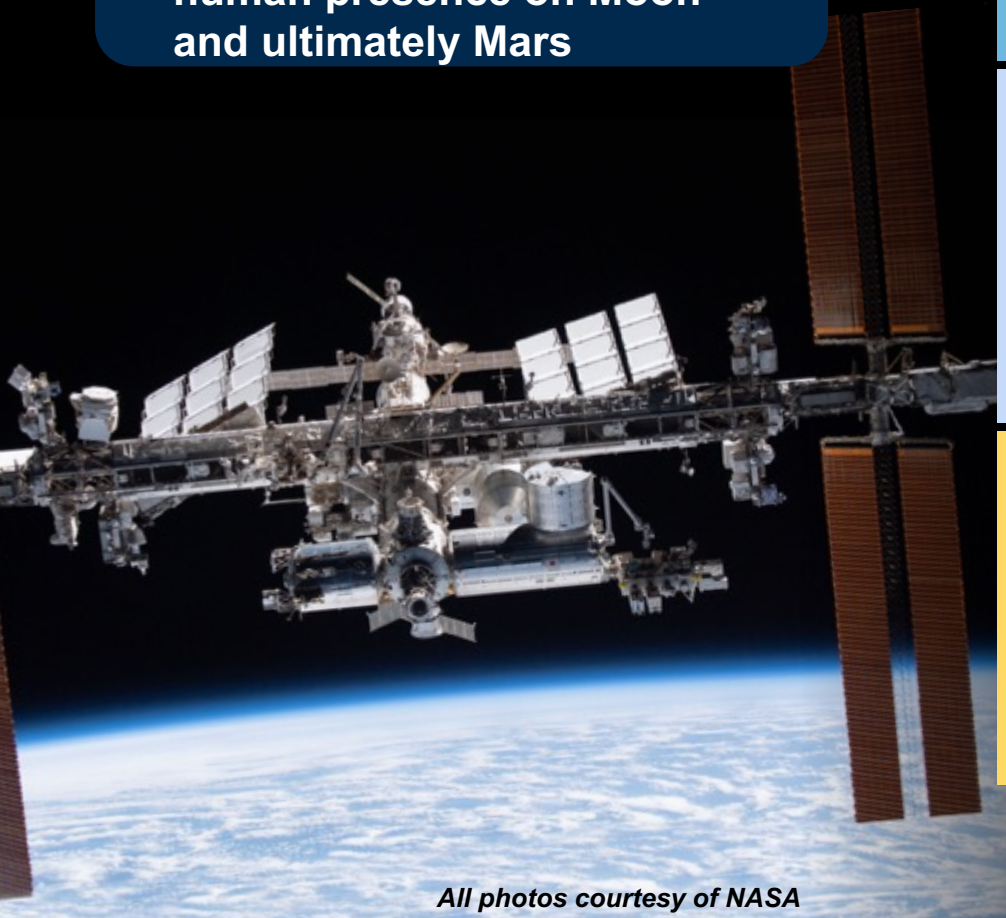
Remote support of astronaut and science missions

https://www.nasa.gov/wp-content/uploads/2023/04/m2m_strategy_and_objectives_development.pdf

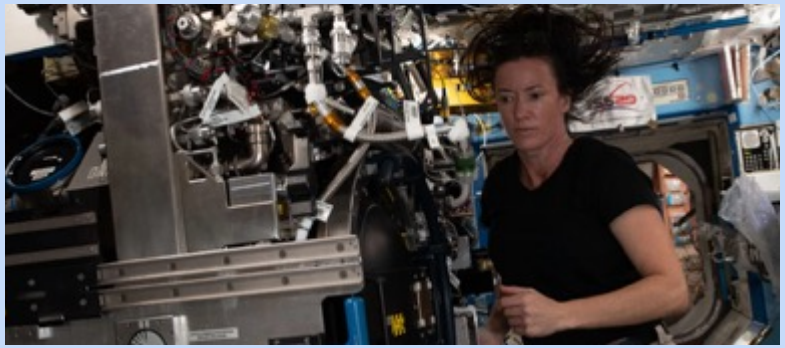
International Space Station (ISS):

Continued human presence in space since Nov 2, 2000

Critical proving ground for human presence on Moon and ultimately Mars



Ultrasound scan on Canadian astronaut Chris Hadfield



Scientific experiments

8K HD Video

All photos courtesy of NASA

NASA's Artemis Campaign

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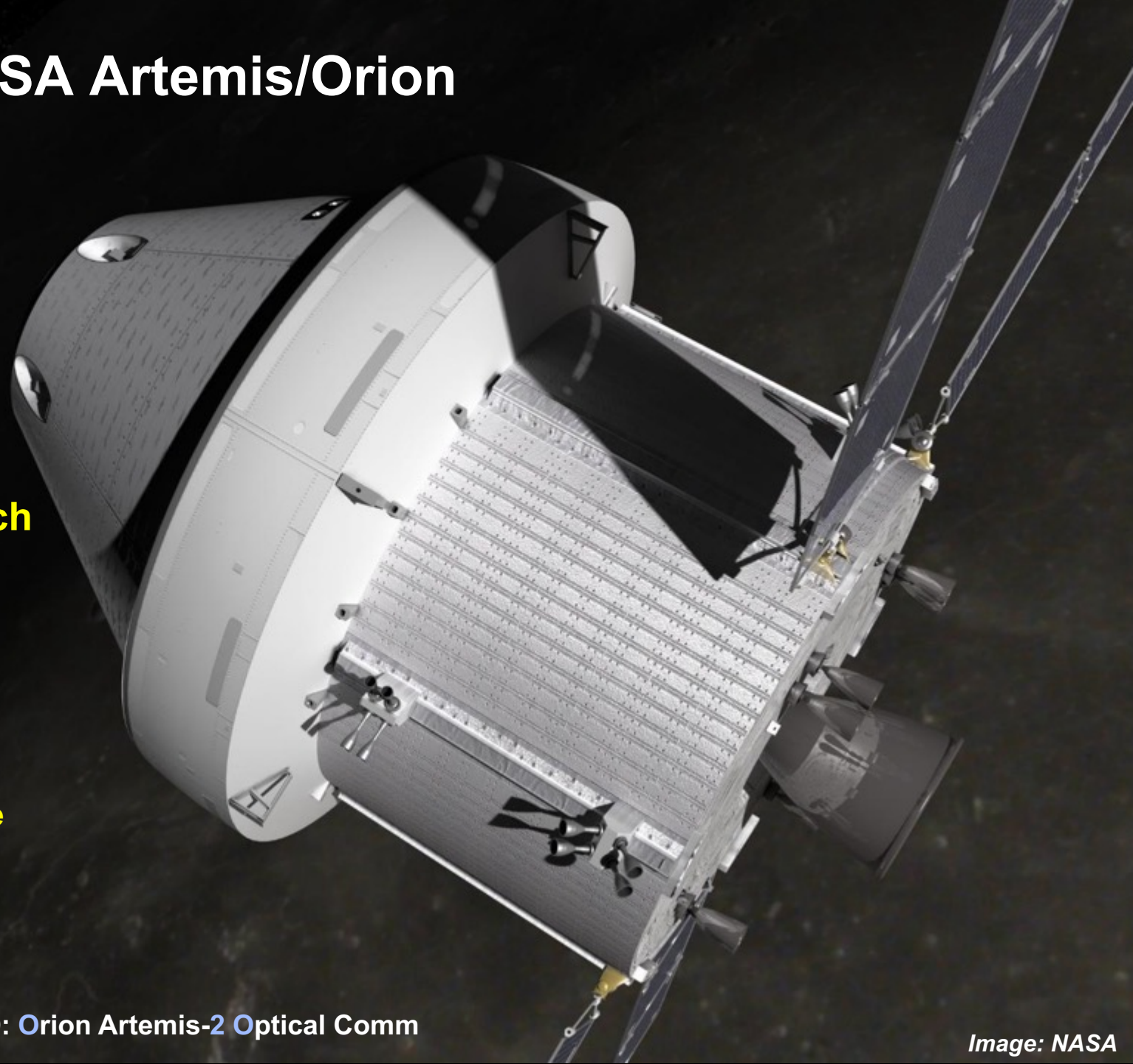
*Orion Artemis 2 Optical Communications

NASA Artemis/Orion

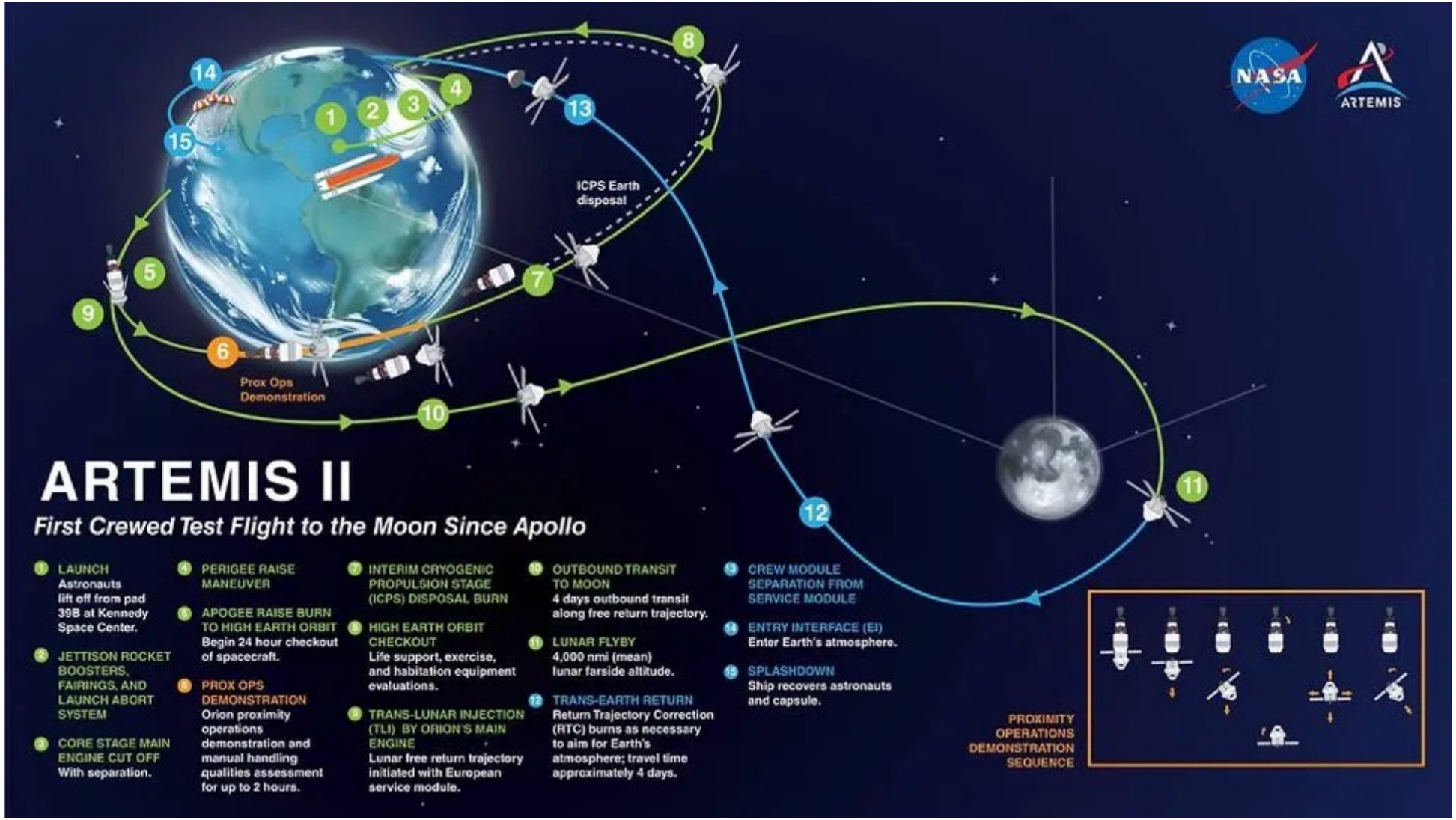
- Artemis Program is NASA's pathway for their Journey to Mars
- Artemis I uncrewed mission successful flight in 2022
  - Radio Frequency comm link, S-band downlink of ~ 1 Mbps at lunar ranges
- **Artemis II crewed mission to launch in 2026**
  - **Optical communications capability provides 80 Mbps return link and 20 Mbps forward link from Lunar vicinity**
    - **Crew brings more mission video up/downloads, file transfers, and real-time video conferencing to the Mission**
- Artemis III to land astronauts on Lunar surface



O2O: Orion Artemis-2 Optical Comm

Image: NASA

Artemis II Map



https://www.nasa.gov/image-article/artemis-ii-map-2/

Artemis II Flight Trajectory

https://images-assets.nasa.gov/video/NHQ_2023_0404_Artemis%20II%20Mission%20Animation%20Broll/NHQ_2023_0404_Artemis%20II%20Mission%20Animation%20Broll~orig.mp4

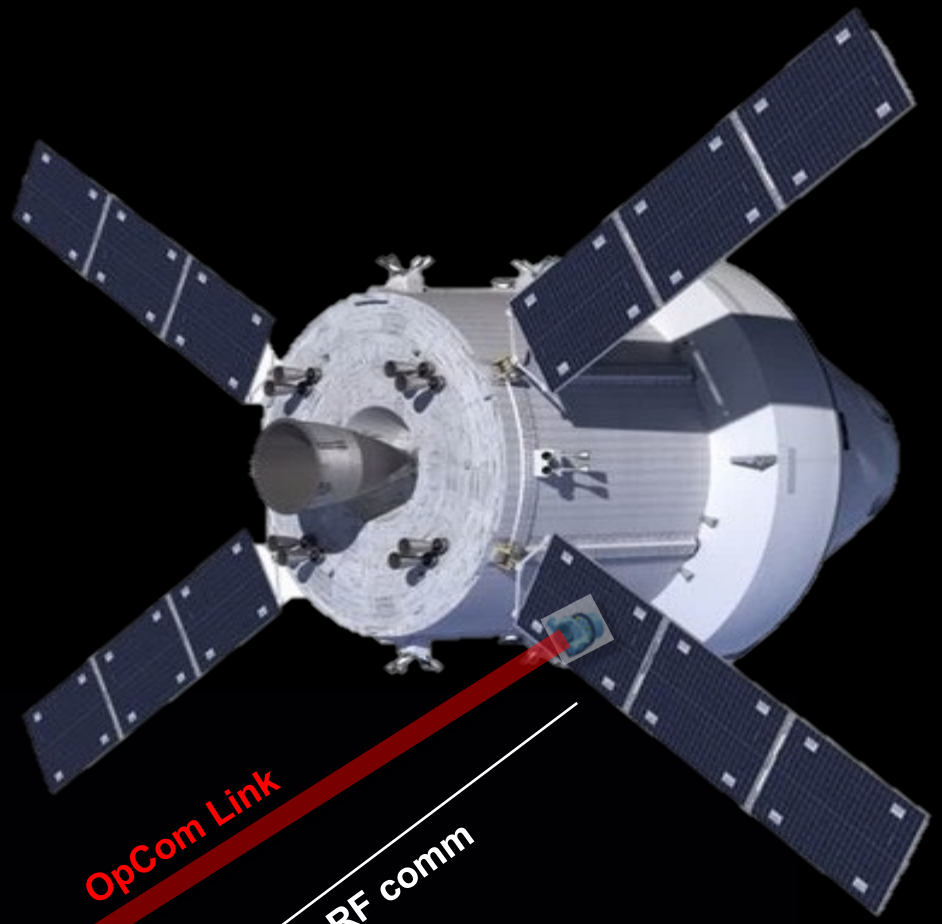
Artemis II / OpCom Mission Objectives

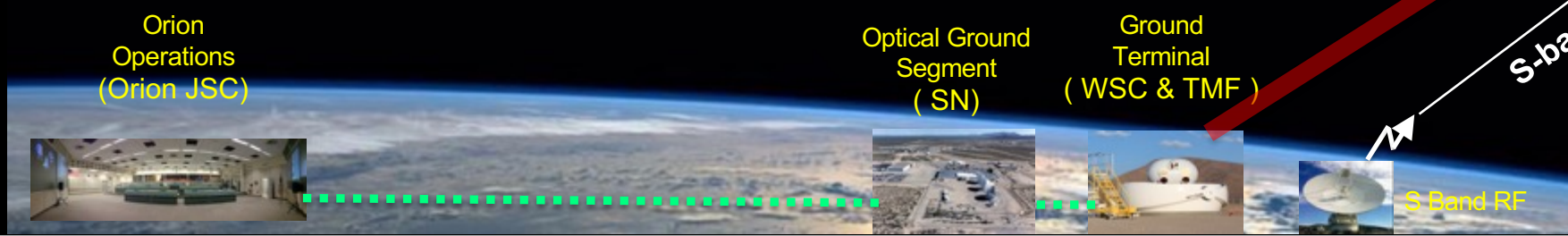
Development Test Objective (DTO):
Implement a laser communications capability for the Orion series of spacecraft, starting with Artemis II, in order to enhance its operational utility by

1. Transferring files from Mission Control Center(MCC) in Houston to/from Orion
2. Transferring real-time video downlinks from Orion to MCC
3. Utilizing operational performance envelope by demonstrating optical comm during various conditions

Optical Link Direction	Data Rates (Mbps)
Up/Fwd	10, 20*
Down/Rtn	20, 40, 80*, 130, 190, 260

***Nominal Rate**

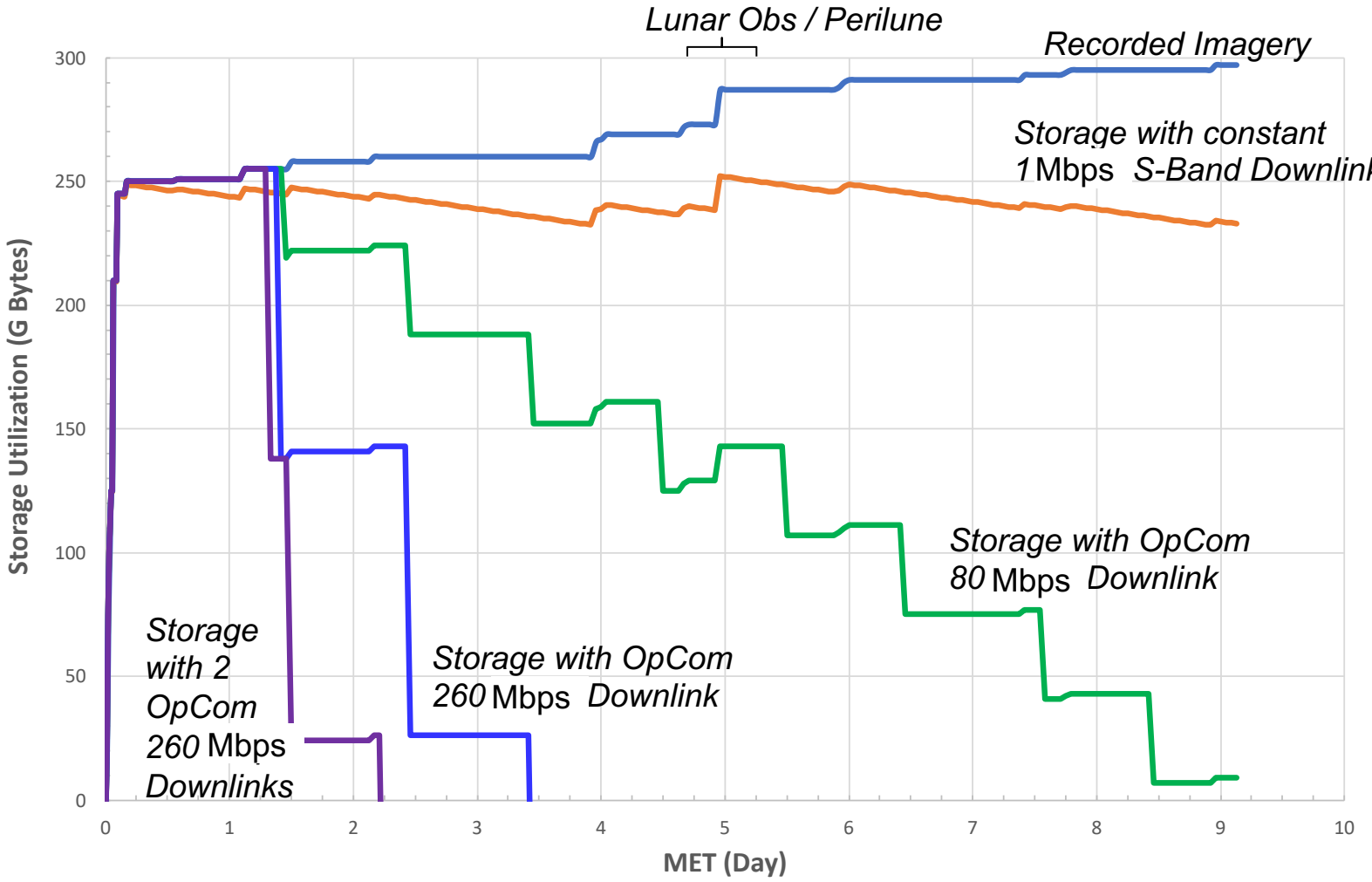




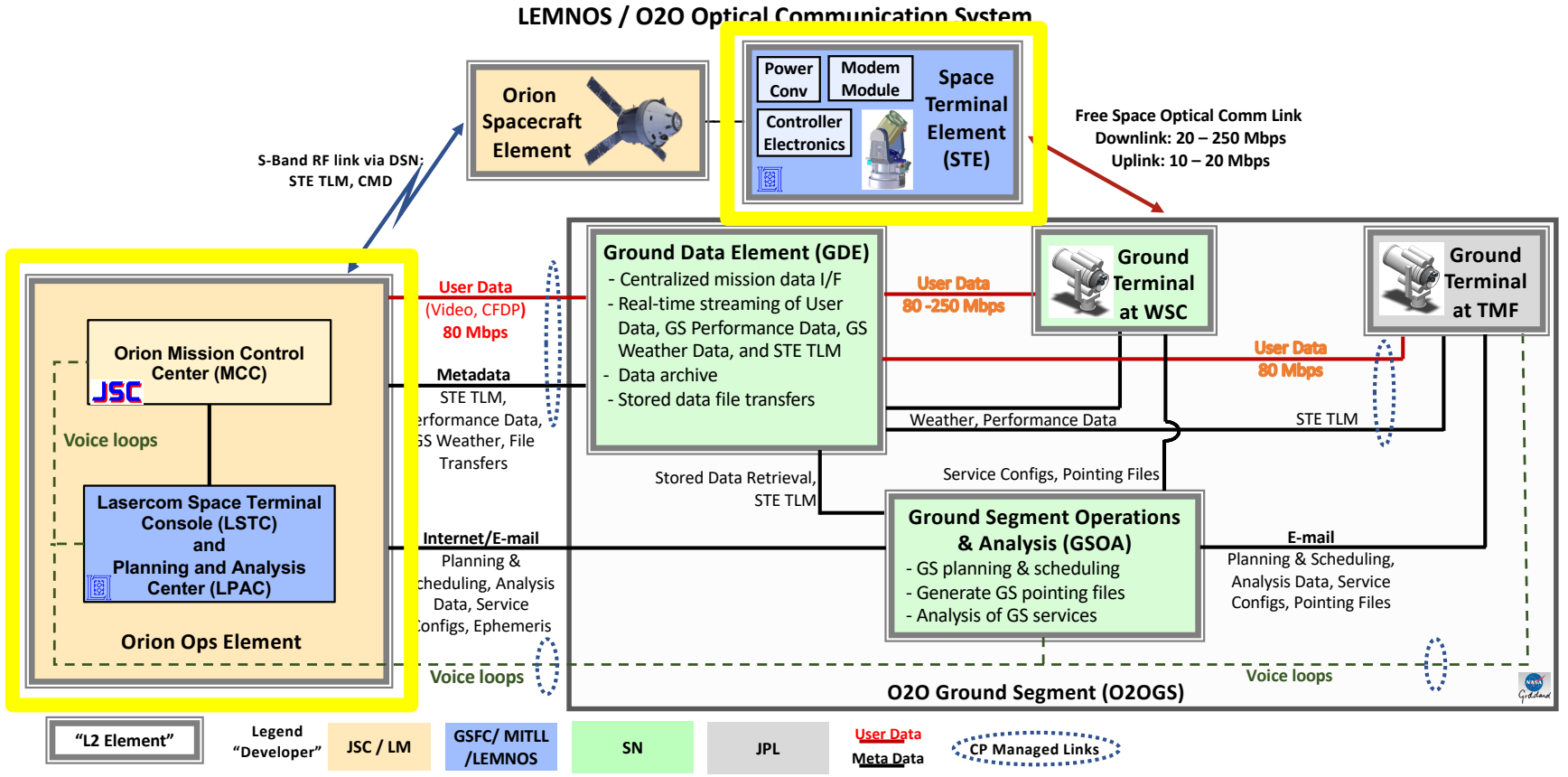
Orion Storage and Data Rates

- Orion subsystems expected to generate ~250 GB of data by FD1 alone 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
- 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

Orion Recorder Utilization



OpCom Mission Level Architecture Diagram



6 organizations

- Johnson Space Center (JSC)
- Lockheed Martin (LM)
- Goddard Space Flight Center (GSFC)
- Space Network (SN)
- MIT Lincoln Lab (MITLL)
- Jet Propulsion Lab (JPL)

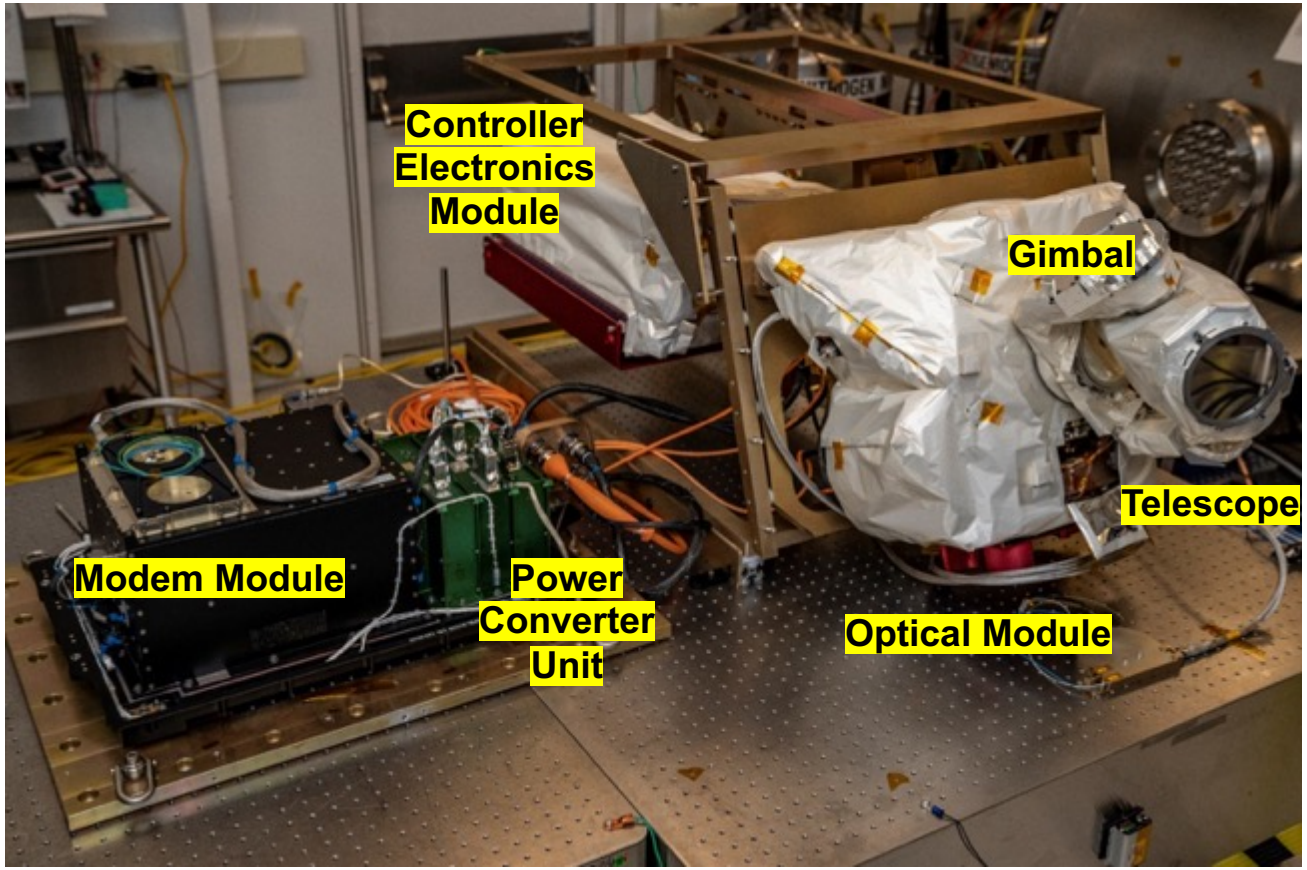
5 major system elements:

- Orion Spacecraft
- Space Terminal (OpCom Payload)
- Ground Terminal
- Ground Data Element
- Orion Operations

2 possible ground terminals

- White Sands
- JPL's Table Mountain Facility (TMF)

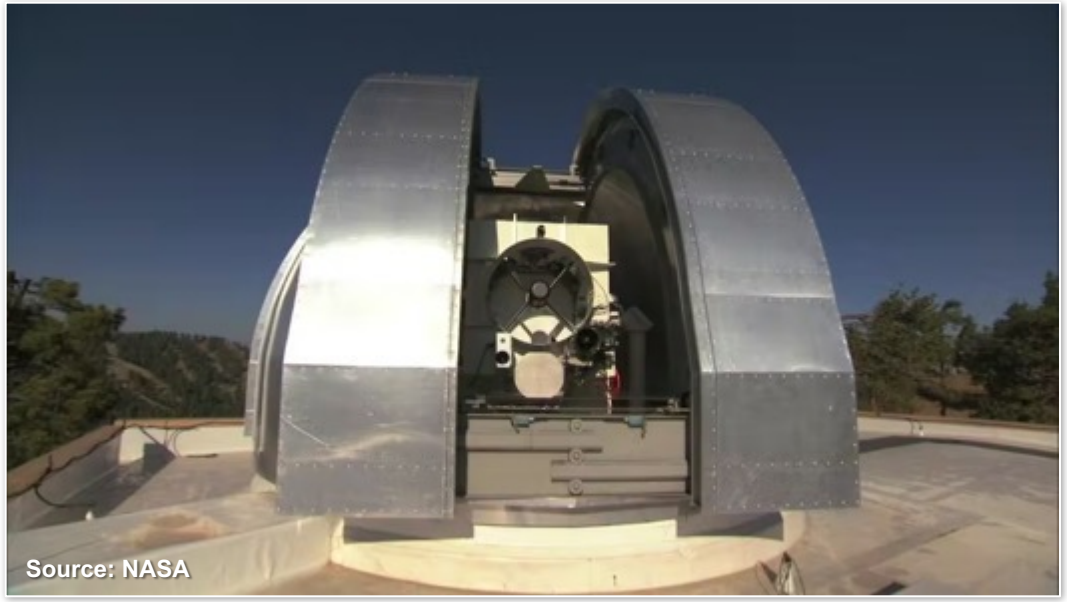
O2O Space Terminal Payload



- O2O payload employs industry-built modules/sub-assemblies
  - Modem module
  - Controller electronics module
  - Gimbal subassembly
  - Telescope subassembly
  - Power converter unit
- Optical Module integrated in-house by MIT Lincoln Laboratory
- Complete payload integrated and tested at MIT Lincoln Laboratory

Status: O2O payload is currently integrated on Artemis II spacecraft!

O2O Mission Ground Terminals

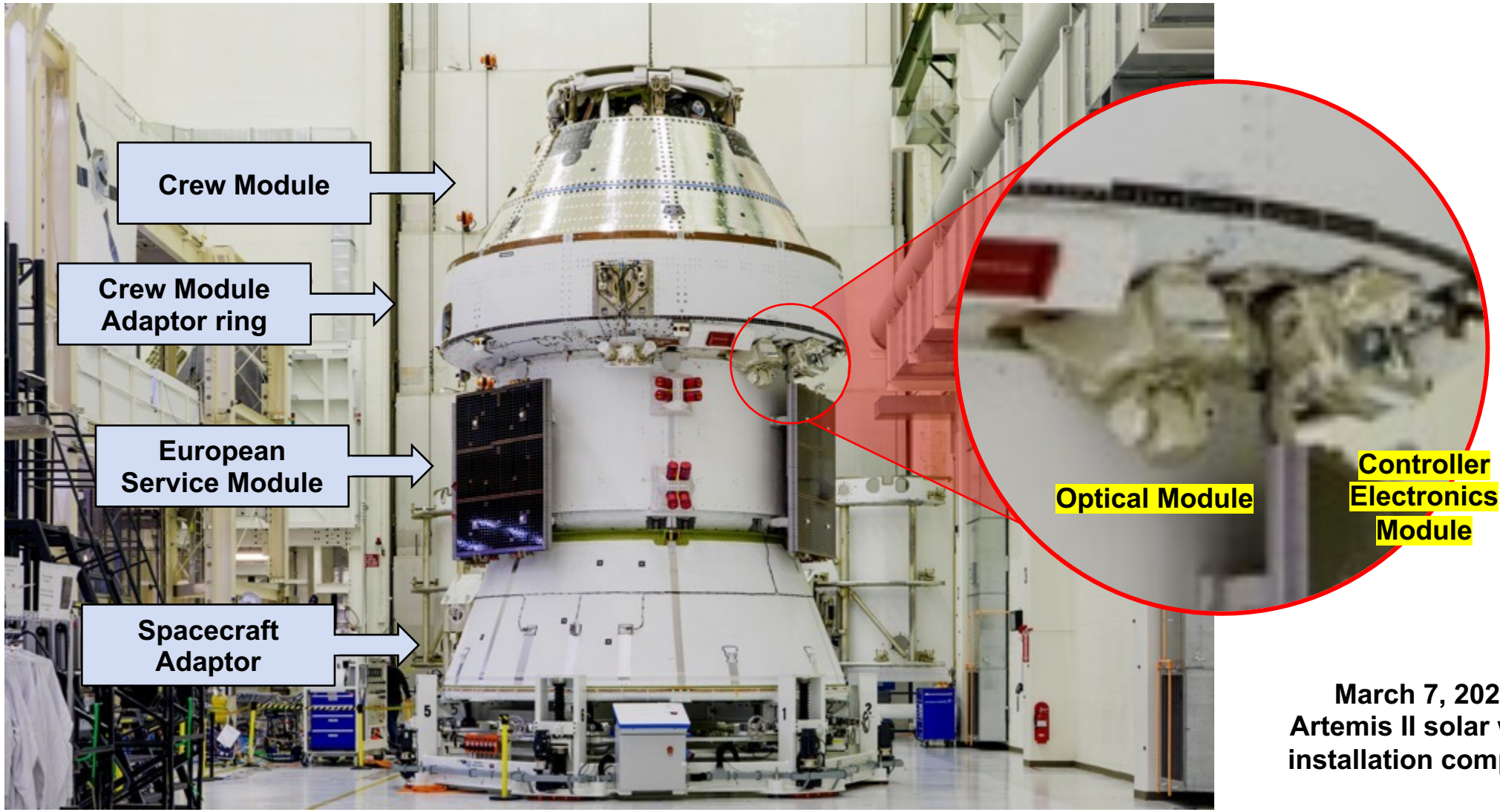


- **White Sands Facility**
  - MIT LL/NASA GSFC collaboration
  - Previously used as ground terminal for LLCD
  - 2 x 40 cm apertures for downlink, SNSPD arrays
  - 4 x 15 cm apertures for uplink

- **Table Mountain Facility**
  - NASA JPL's Optical Comm Telescope Laboratory
  - Provided ground terminal for LLCD, LCRD, TBIRD
  - 1 meter aperture
    - SNSPD array for downlink receiver
    - 4 sub-apertures for uplink

LLCD: Lunar Laser Communications Demonstration
LCRD: Laser Communications Relay Demonstration
TBIRD: TeraByte InfraRed Delivery

O2O Payload as installed on Artemis II Orion Vehicle



March 7, 2025
Artemis II solar wing installation complete

https://images-assets.nasa.gov/image/jsc2025e016293/jsc2025e016293~orig.jpg

Where is Artemis II Orion Now?

https://images-assets.nasa.gov/image/KSC-20250503-PH-KLS01_0048/KSC-20250503-PH-KLS01_0048~large.jpg?w=1920&h=1280&fit=clip&crop=faces%2Cfocalpoint

May 3, 2025:
Artemis II Orion capsule on its way to Multi-Payload Processing Facility

https://www.nasa.gov/image-article/nasas-orion-spacecraft-secures-critical-abort-system-hardware-for-artemis-ii/

September 19, 2025:
launch abort system facility

https://www.nasa.gov/wp-content/uploads/2023/03/s70-54121.jpg.

October 2025 (TBD)
Vehicle Assembly Building (VAB) for installation on top of rocket!!

Summary

- Recent surge in laser communications for Low Earth Orbit fueled by easily available telecom parts and newer specialty space-grade components, subsystems, and systems
- Laser communications offers high bandwidth communications links required to support human exploration to Moon and beyond
- Artemis II mission will carry lasercom payload (260 Mbps downlink, 20 Mbps uplink)
  - High-def video, file transfer, real-time bi-directional conference calling will all be enabled
- O2O payload is currently installed on Artemis II Orion capsule and ready for launch in 2026