Optical communications operations concept for the Artemis II crewed mission to the Moon

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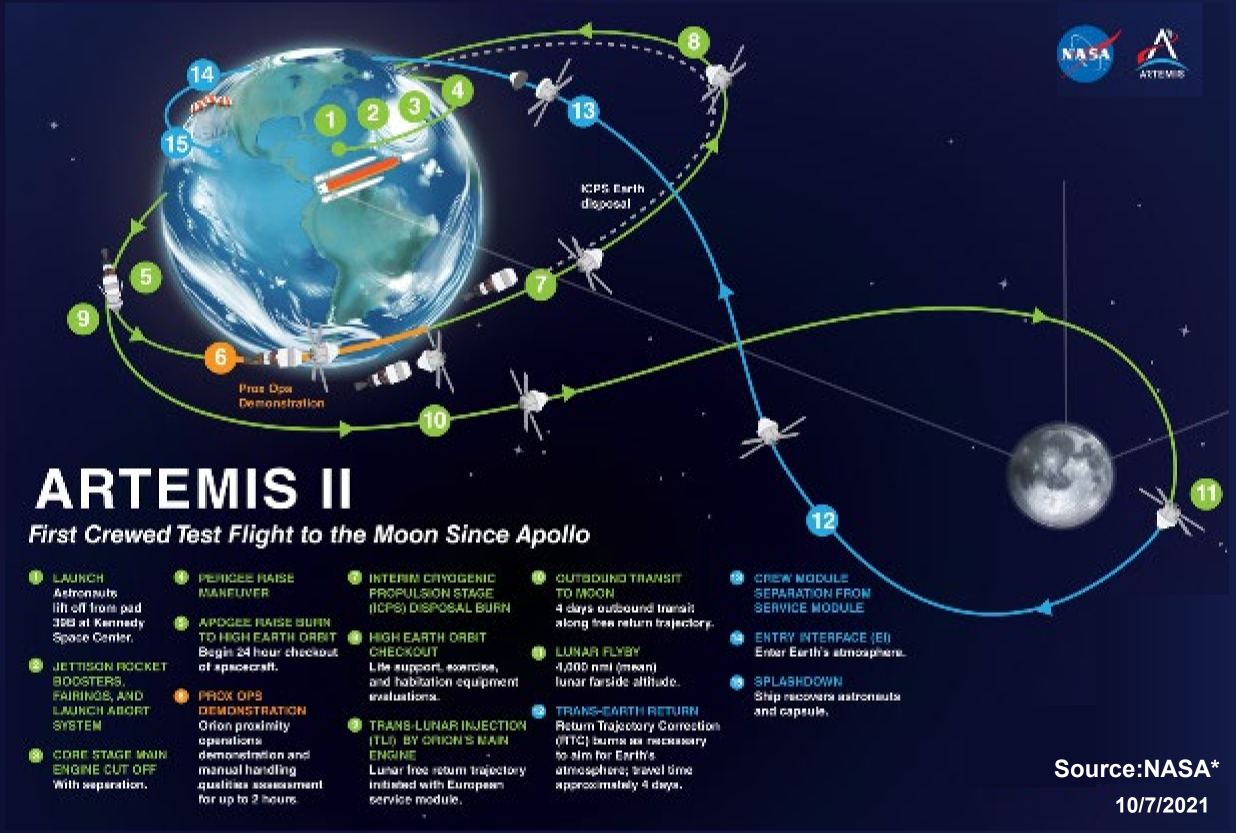
Outline

- Background
- Optical comm system description
- Link operations plan
- Summary

Artemis II Mission includes Optical Comm Payload!

- Artemis Program is NASA’s pathway 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 2024
  - 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



Source:NASA*
10/7/2021

*https://www.nasa.gov/feature/nasa-s-first-flight-with-crew-important-step-on-long-term-return-to-the-moon-missions-to

Operational Differences between RF & Optical

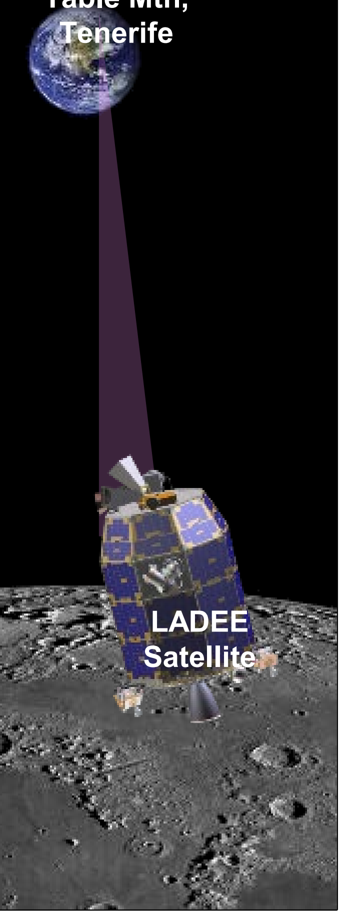
	RADIO	OPTICAL
Beam width	0.5 - 30°	1 - 100 μrad (<0.006°)
Point / Acquire Beam	Open loop	Scan or wide-field sensor (cooperative)
Stabilize / Track Beam	N/A	Optical-based tracking (cooperative), inertial sensors-based tracking, passive jitter rejection
Atmosphere Interactions	Rain can degrade > 20 GHz	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

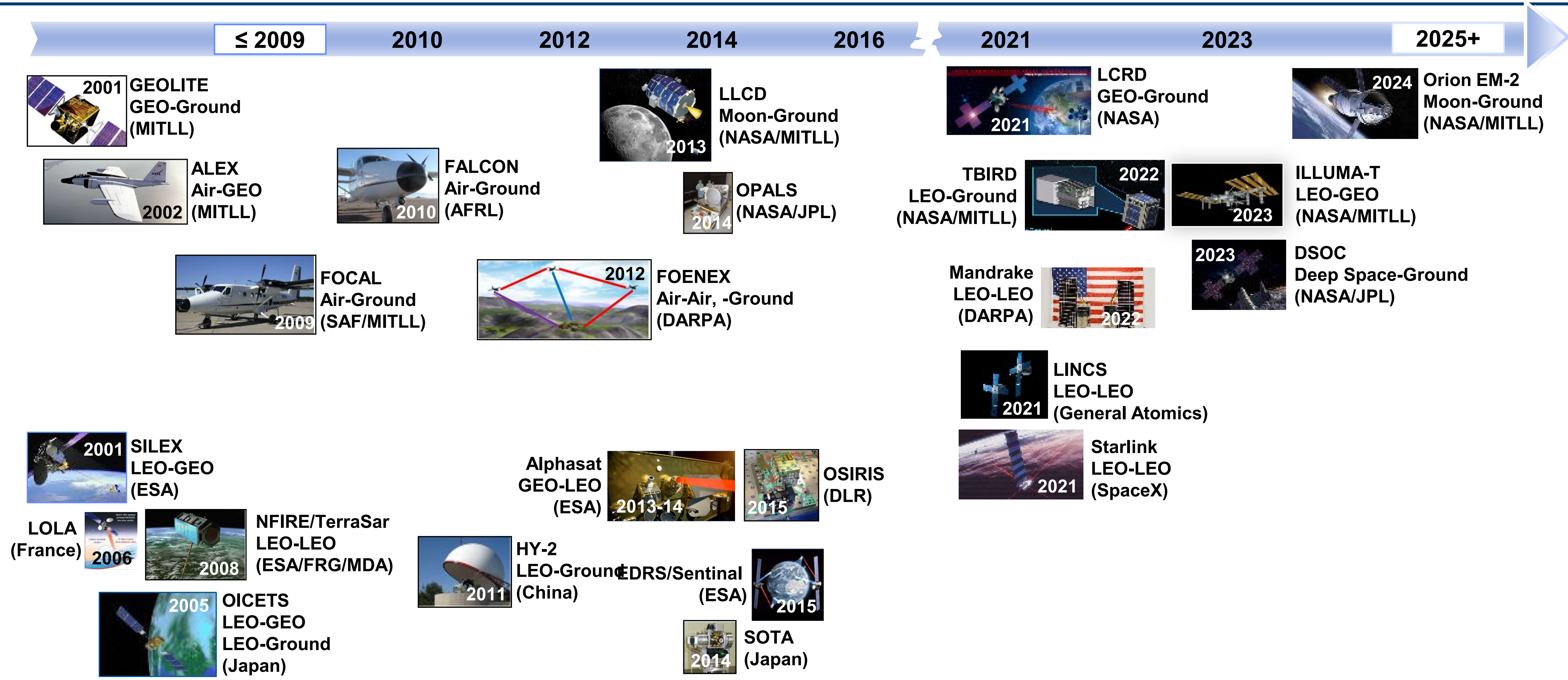
- In 2013, NASA's LLCD showed operational utility of lasercom
  - 622 Mbps downlink, 20 Mbps uplink
  - Automated point/acq/track of 15 μrad beam
  - Daily downlink of entire 1 GB s/c buffer
  - File transfers up / down
- Demonstrated reliable data delivery over lasercom links through Earth atmosphere:
  - 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 informatio 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 e avoided and not disruptive to lin	✓
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.

A Sampling of Space Lasercom Activities to Date



Adapted from D.M. Boroson, "Laser Communications," ICSSC 2014 Colloquium.

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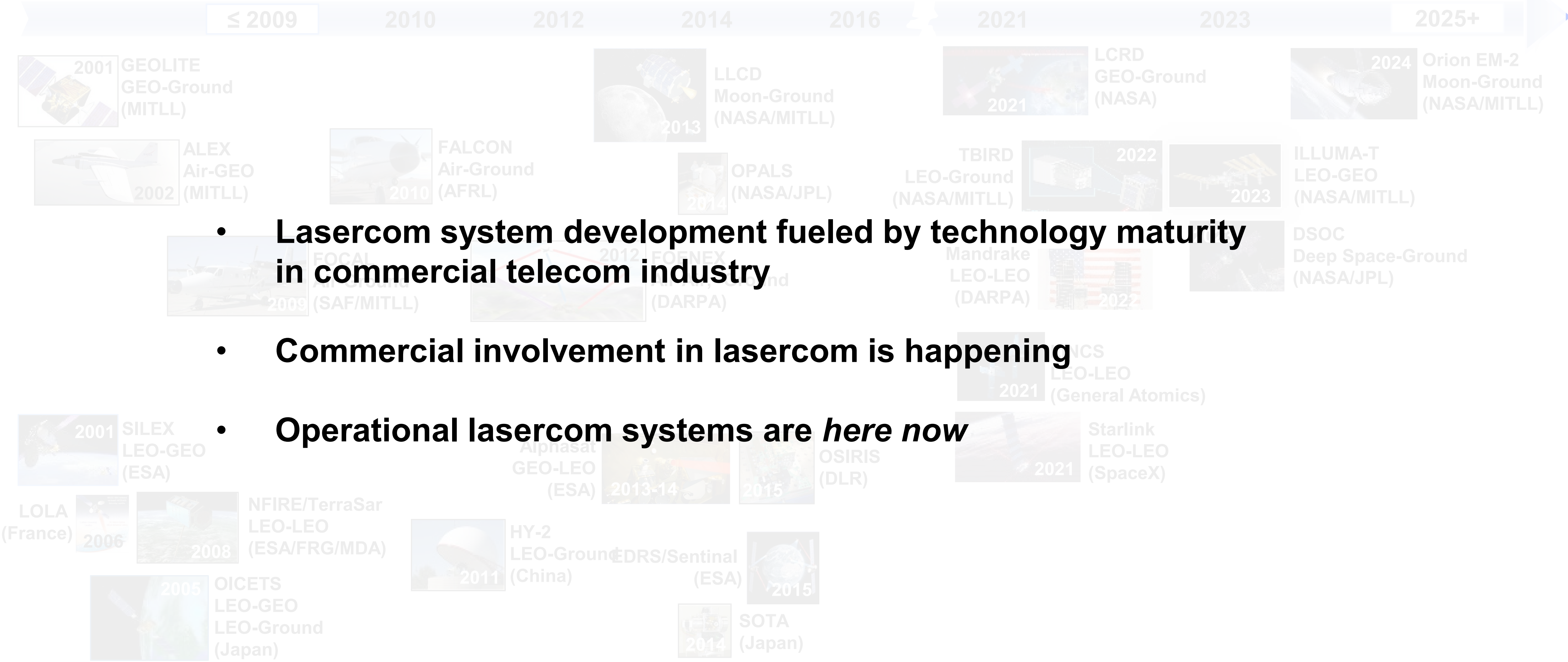


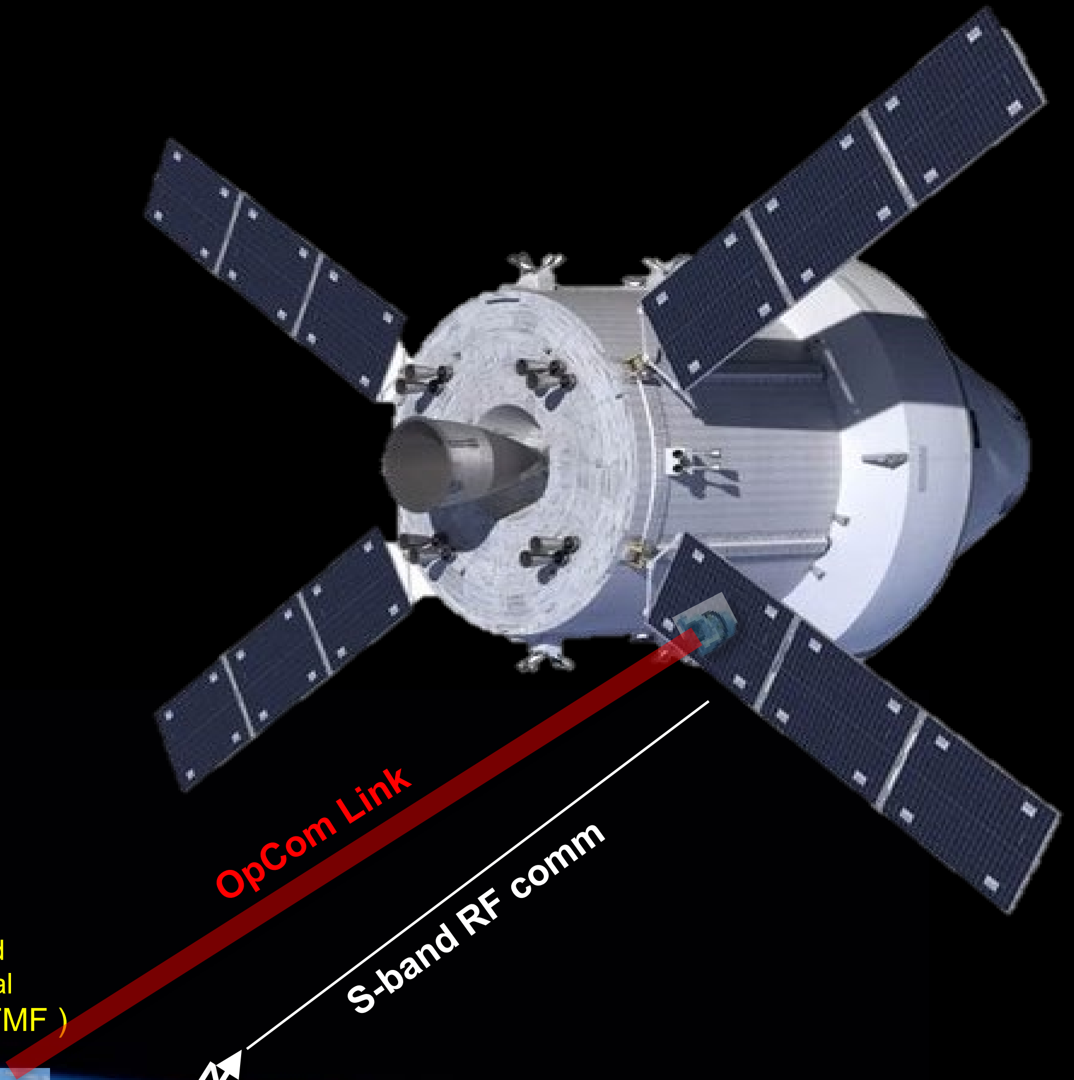
- **Lasercom system development fueled by technology maturity in commercial telecom industry**
- **Commercial involvement in lasercom is happening**
- **Operational lasercom systems are *here now***

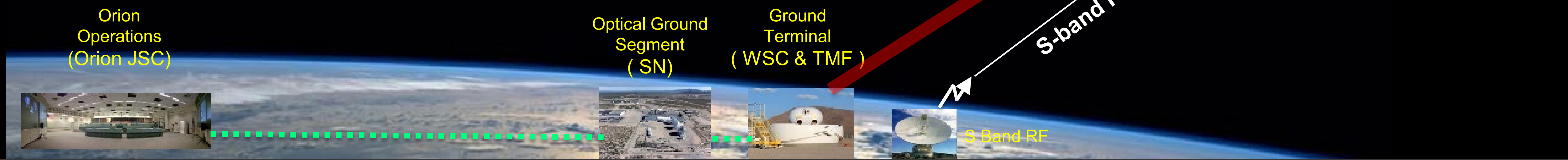
Adapted from D.M. Boroson, "Laser Communications," ICSSC 2014 Colloquium.

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

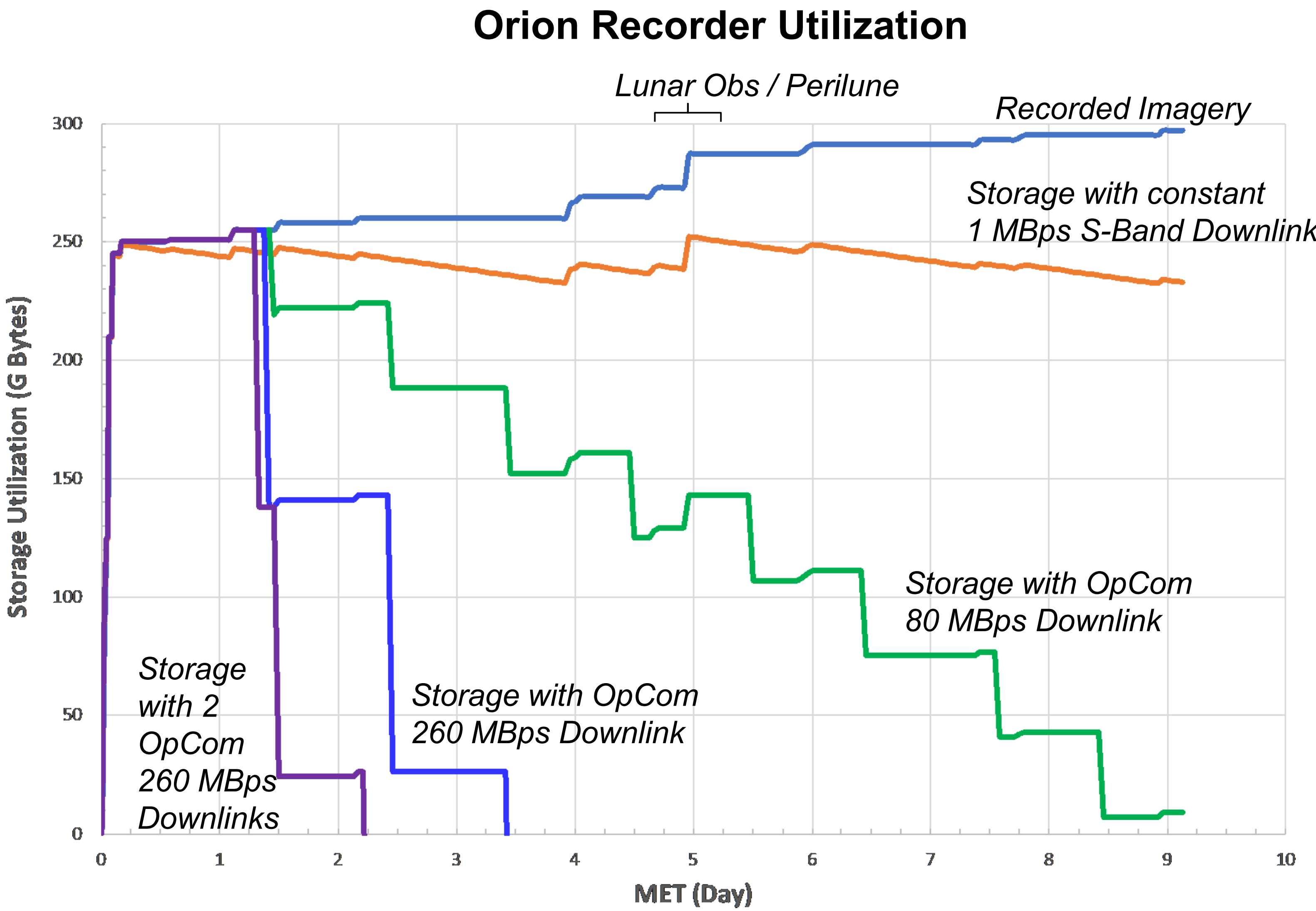
1. Transferring files from MCC to/from Orion
2. Transferring real-time video downlinks from Orion to MCC
3. Utilizing operational performance envelope by demonstrating optical comm during various conditions



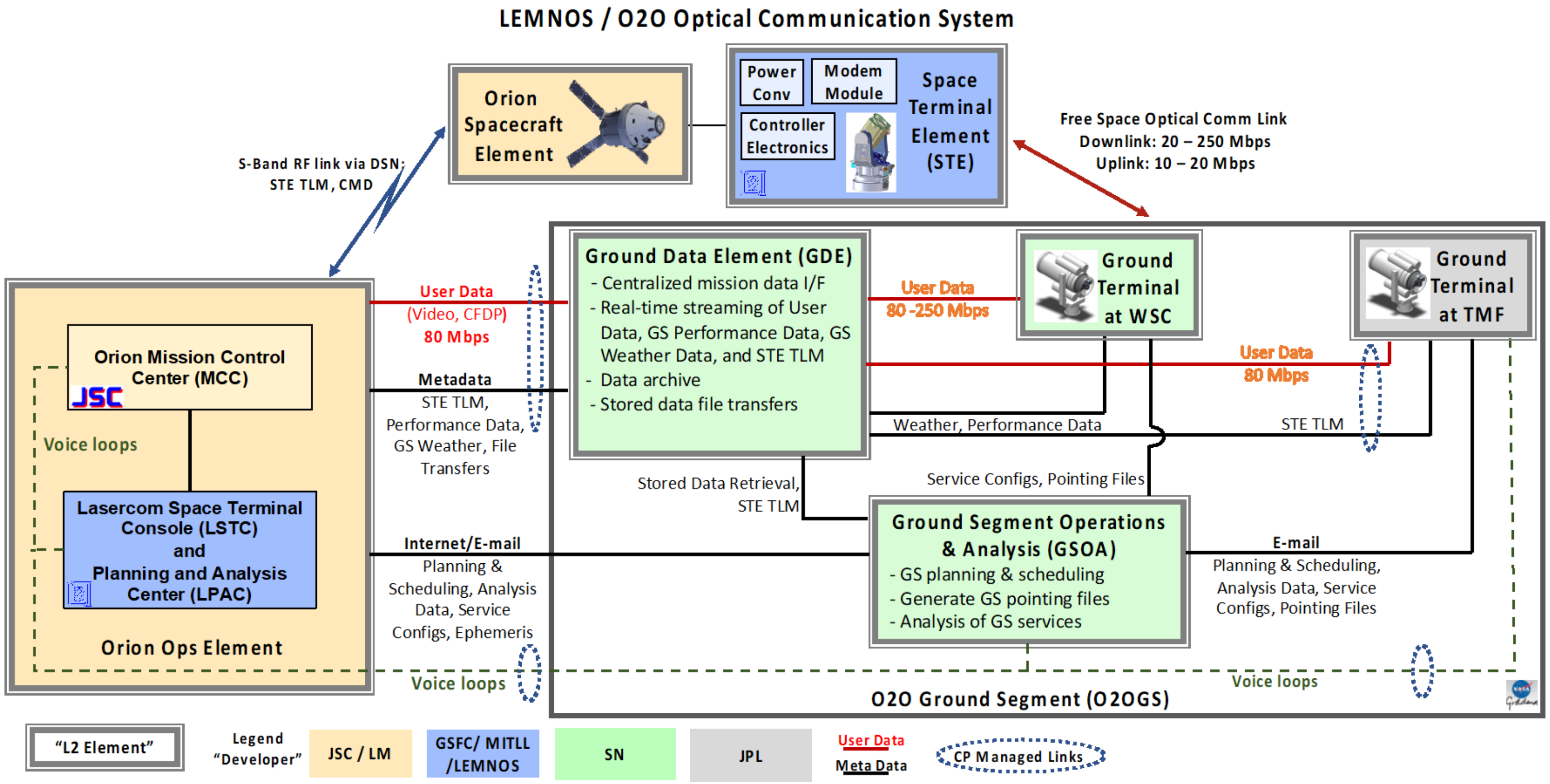


Orion Storage and Data Rates

- 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



OpCom Mission Level Architecture Diagram

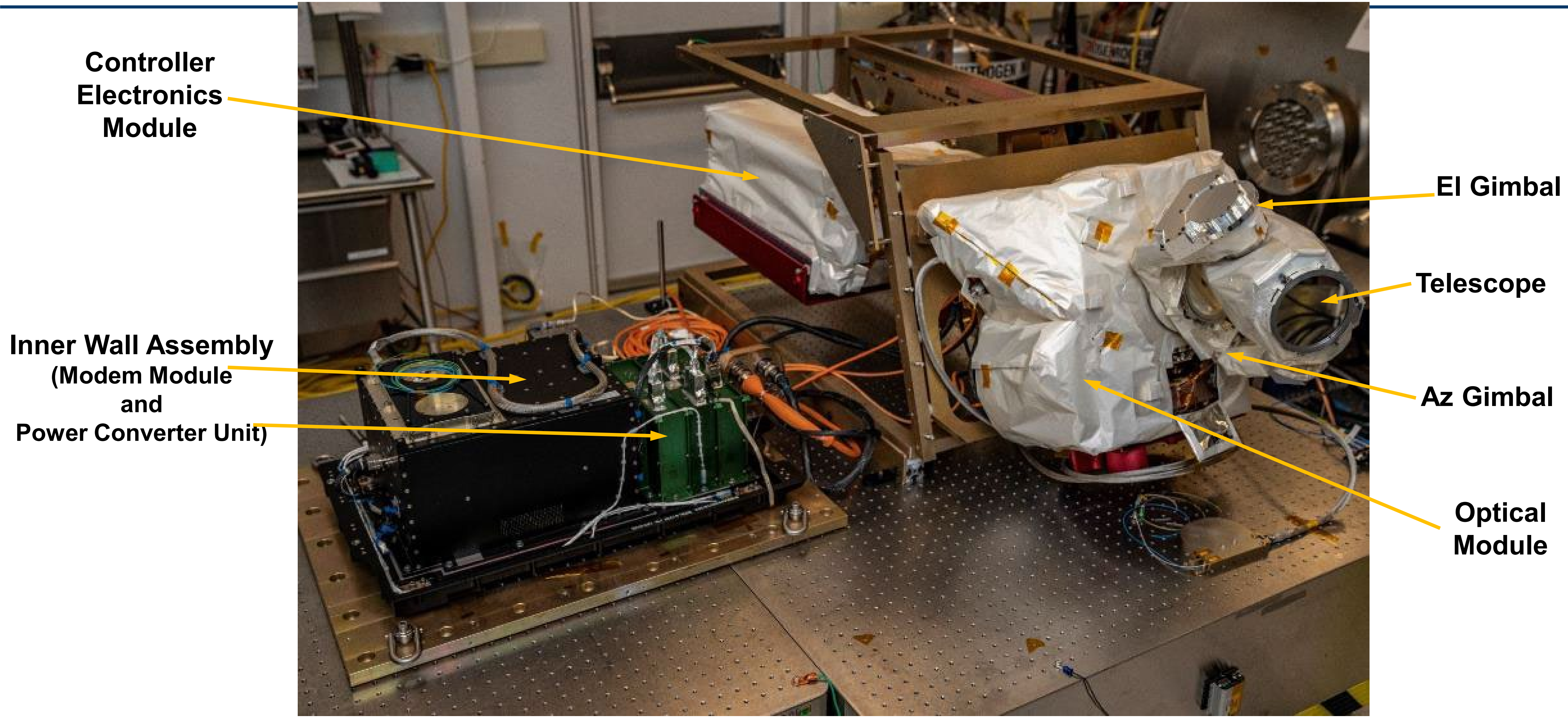


6 organizations
- Johnson Space Center (JSC)
- Lockheed Martin (LM)
- Goddard Space Flight Center (GSFC)
- Space Network (SN)
- MIT Lincoln Lab (MITLL)
- Jet Propulsion Lab (JPL)

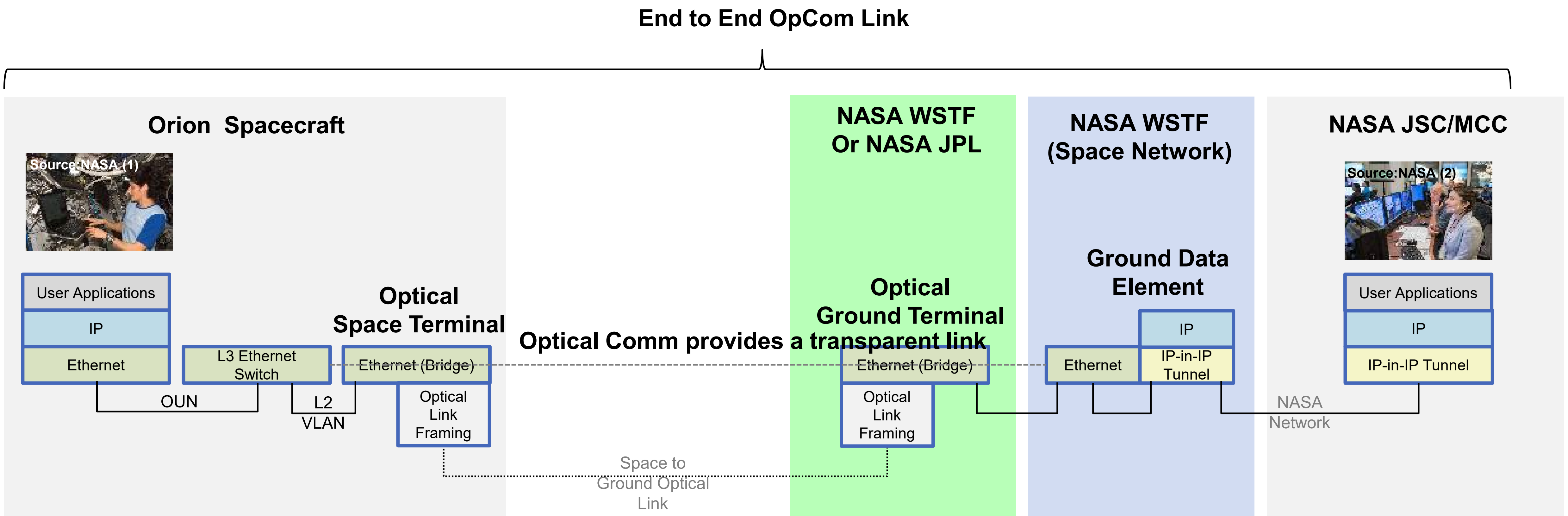
5 major system elements:
- Orion Spacecraft
- Space Terminal
- Ground Terminal
- Ground Data Element
- Orion Operations

2 possible ground terminals
- White Sands
- JPL's Table Mountain Facility (TMF)

O2O Space Terminal Payload



Data Rates and Data Paths



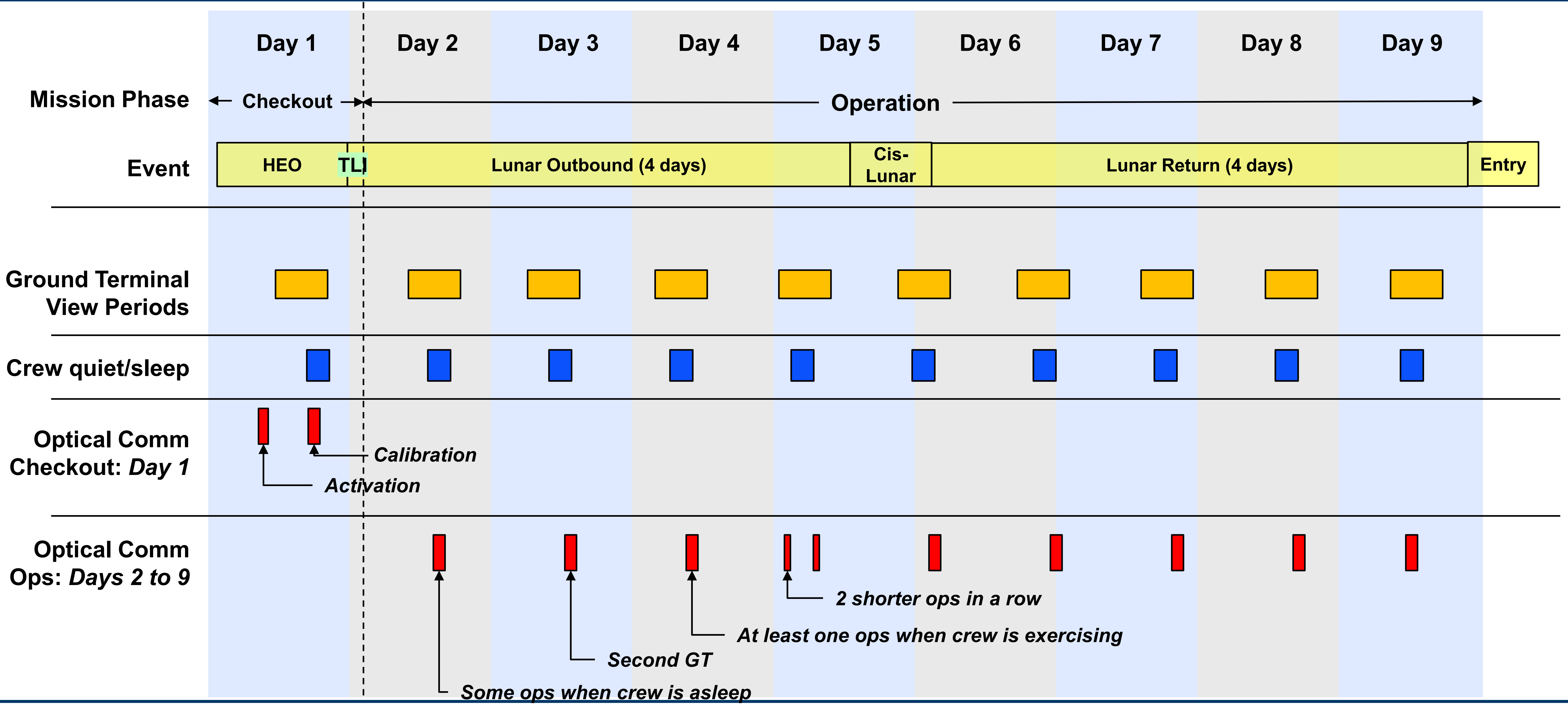
Link Direction	Data Rates (Mbps)
Up/Fwd	10, 20*
Down/Rtn	20, 40, 80*, 130, 190, 260

Onboard network uses IP over Ethernet. L3 Switch forwards Orion User data on the Orion Utility Network (OUN) to/from Optical Space Terminal via L2 VLAN

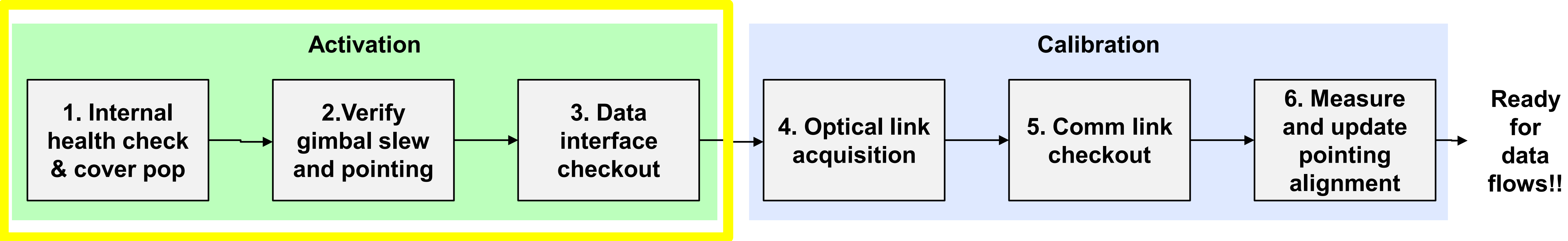
Behind the tunnel, JSC IP routing and/or L2 switching without impact to system design

(1) https://www.nasa.gov/sites/default/files/thumbnails/image/iss015e09442crop.jpg
(2) https://www.nasa.gov/sites/default/files/thumbnails/image/jsc2017e049159.jpg

Notional Artemis II OpCom Mission Timeline



Optical Comm Checkout (Day 1)



1. Internal health check & cover pop

- Power up payload controller
- Send “no op” to validate commanding
- Verify telemetry packet timing
- Verify operational heaters
- Verify on-board star tracker
- Power up modem
- Perform “closed cover” self test to assess health of optical module
- Activate HOPAs to un-latch (pop) cover
- Repeat “closed cover” self test

2. Verify gimbal slew and pointing

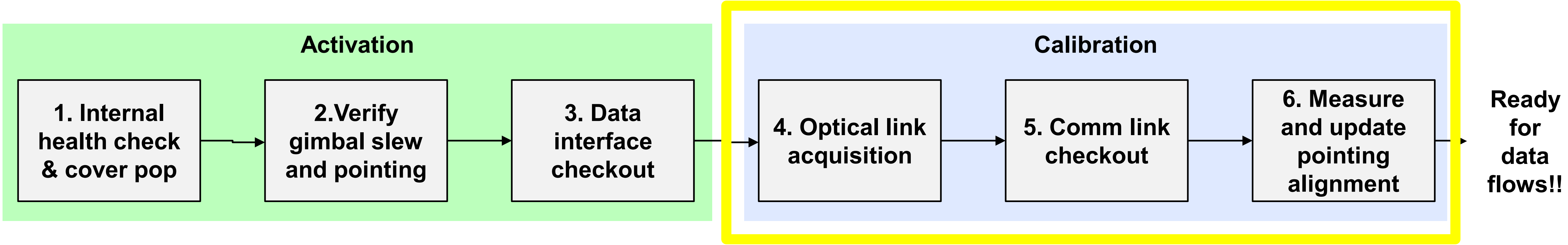
- Explore gimbal operational envelope
- Point gimbal using live spacecraft position and attitude
- Stow and hold gimbal to point at latch

3. Data interface checkout

- Put modem in data loopback mode and count incoming and outgoing Ethernet frames

HOPA=High Output Paraffin Actuator)

Optical Comm Checkout (Day 1 – cont'd)



4. Optical link acquisition

- Grossly point gimbal to ground terminal using live spacecraft position and attitude (ground terminal points to space terminal and transmits wide divergence beacon)
- Automatic scan of acquisition sensor until beacon is detected → system pulls in and tracks on beacon
- Transmit downlink comm signal (ground terminal receives and tracks → improves its pointing and narrows beam)
- Additional beacon signal detected, system can high bandwidth track

5. Comm link checkout

- Verify comm link for various comm link pairs by monitoring codework error rates (at the optical link layer)

6. Measure and update pointing alignment

- Identify difference between "open loop" and "fine tracked" pointing
- Compute and update alignment matrix

HOPA=High Output Paraffin Actuator)

Optical Comm Operations (Days 2-10)

- Provision optical link and run the following applications:
  - File transfer
    - PDF files: crew files, news, email, text
    - Recorded data
    - Procedures
    - Op Nav files
    - Recorded Video files
    - Recorded JPEG
  - Real-time video
    - Solar array wing cameras
    - Op nav video
    - Crew Module high rate cameras
    - HD cameras
    - Crew cabin cameras, GoPro
    - Video conference

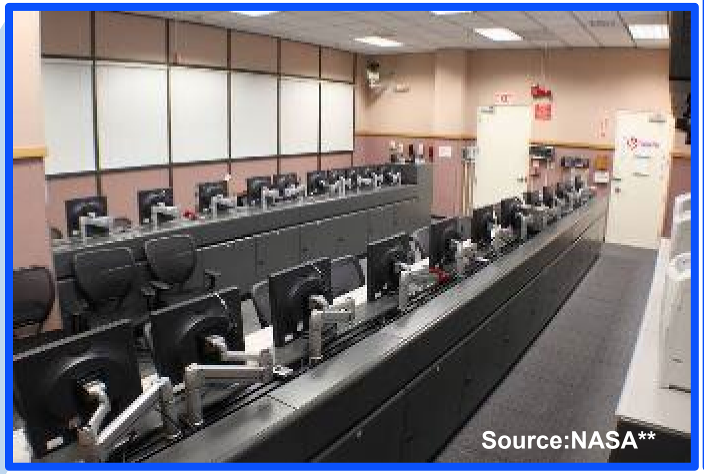
- Utilize operational performance envelope:
  - High and low elevation, day/night
  - Acq/track optical comm signal during
    - Solar array track/step/slew
    - Crew activity/exercise
    - Thruster fires
  - Different ground terminals, handover
  - Thermal system effects
  - Atmospheric effects

Payload Operations Control Center

Kraft Building
JSC, NASA

Artemis MCC
(Mission Control Center)

Artemis MSE
(Mission Support Environment)



Lasercom Space Terminal
Console (LSTC)

- **Payload will be operated by the Instrumentation and Communications Officer (INCO) in the Artemis MCC**
- **MSE / LSTC offer backup support and trouble shooting**

*https://www.nasa.gov/feature/artemis-i-mission-control-at-a-glance

**https://www.nasa.gov/centers/dryden/capabilities/CodeM/CodeMR/multimedia/imagegallery/MCC2_5.html

OpCom Payload Commanding

3 methods to command OpCom payload are available for MCC/INCO:

1. **Native commands:**
   - Low level commands understood by OpCom controller electronics
   - A subset of these native commands have been given Compact Unique Identifiers (CUI) so that they can be run directly by MCC/INCO
2. **Macro commands:**
   - "Programs" or scripts written in STOL[1] that employ native commands and simple logic; macros can be nested as well
   - Each macro has a unique identifier number
   - A subset of these macros have been given Compact Unique Identifiers (CUI) so that they can be run directly by MCC/INCO
   - Macros can also be run using a native command that runs macro its by identifier number
3. **Block commands:**
   - The most generic transfer of information from MCC/INCO to OpCom controller electronics
   - Used for file transfer (CFDP) or for running any non-CUI native commands

[1]Systems Test and Operation Language (STOL) developed by NASA GSFC

OpCom Payload Operation

With animations

Space Payload

Initial State:
- Powered on
- Gimbal "hold" (telescope stowed, pointed at cover)
- Lasers off

Gimbal scan to search for ground beacon; once acquired, automatic transition to low bandwidth tracking, high bandwidth tracking, comm clock recovery

Final State: Communication link active!

MCC/INCO commands send:

GoTo_Operate — Start payload heater control

GoTo_Active — Powers on modem

SetLaserPower — Sets transmit power laser, typically 1 Watt

GoTo_Comm
- Input variables select comm data rates, ground terminal, elevation sign, attitude
- Begins pointing telescope at ground terminal using spacecraft position and attitude
- Enables laser transmission
- Kicks off cooperative acquisition process

Key
- Macro
- Command

Ground Terminal

Initial State:
- Ground telescope open loop pointed to Orion spacecraft
- Transmitting wide angle beacon laser

Once downlink is acquired, narrow beacon beam, decrease beacon power, begin transmitting comm signal

Final State: Communications link active!

Summary

- **Artemis II mission will utilize OpCom to provide operational laser communications service**

- **OpCom will enable video up/downloads, file transfers, and real-time video conferencing, for the 10-day mission**

- **OpCom operated by MCC/INCO using simple pre-defined commands and macros that are highly automated**