Optical Communications for Space Exploration and Science

Bryan S. Robinson

Optical Fiber Communications Conference

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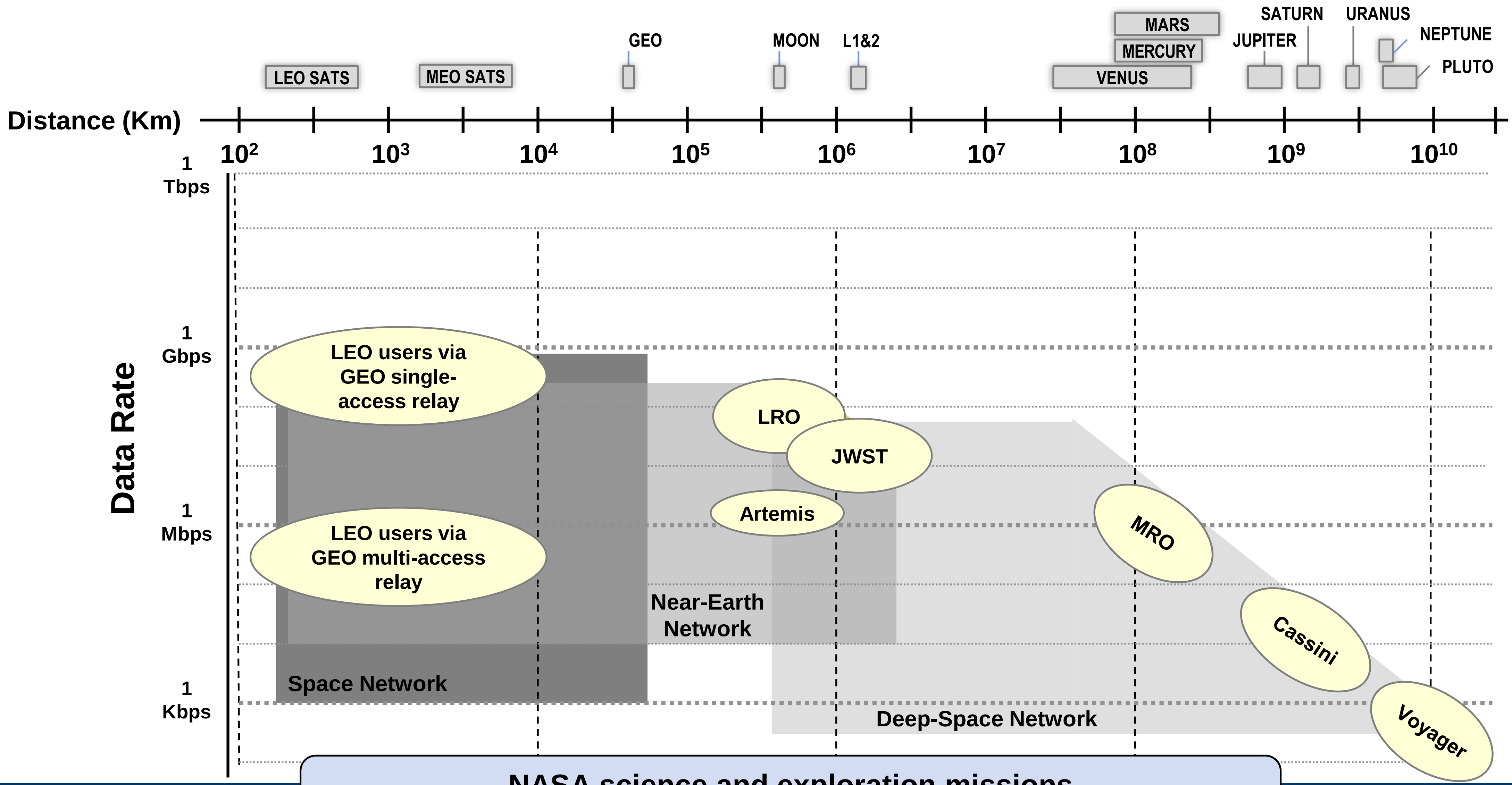
IN REVIEW

NASA Communications



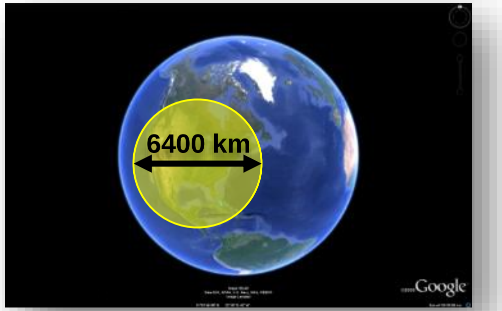
NASA science and exploration missions fully exploit and are constrained by communications

Breaking the Communications Constraint

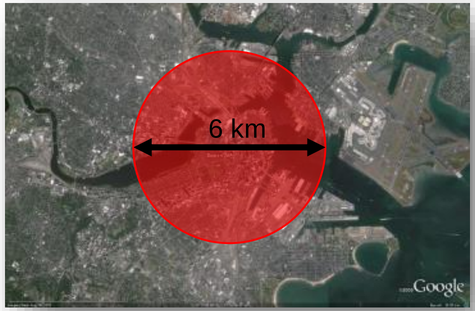
Lasercom

- **Extremely narrow beams with small apertures**
  - **Small, low power terminals**
    - **S-band, 20 kW, 34m = 8 GW EIRP**
    - **Lasercom, 0.5W, 10cm = 8 GW EIRP**
  - **Security**
    - **Anti-jam, reduced probability of detection**

Beam Size From Moon



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

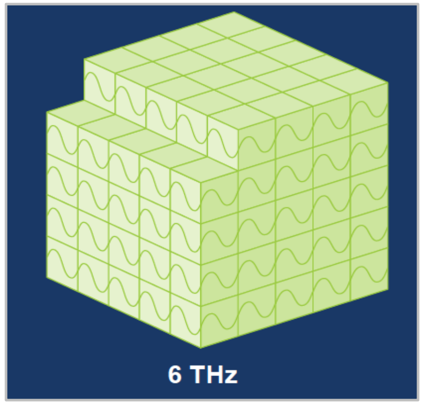


Optical C-Band (1550 nm)
10-cm Antenna →6 km Spot

- **Unlimited, unregulated spectrum**

RF Spectrum

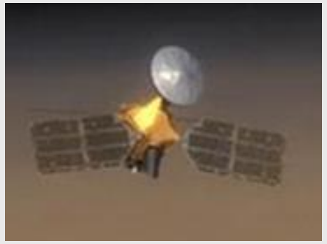
Optical Spectrum (1530-1580 nm)



- **High data rates**
  - **Provides high speed real-time data**
  - **Enables shorter contact times**
  - **Delivers large data volume over the duration of mission**

Examples of Removing the Comm Constraint

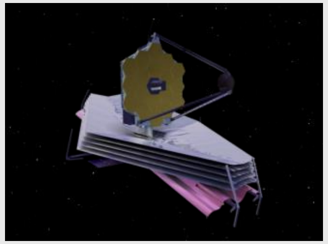
Mars Reconnaissance Orbiter



- Launched 12 August 2005
- ~0.1 – 6 Mbps X band radio link from Mars (50 – 400 million km)
- Lifetime data returned: 54 TB–record for deep space mission!
- Imaged ~5% of surface with high-resolution HiRise imager

100 Mbps would allow for 100% imaging of Mars' surface every 3 years

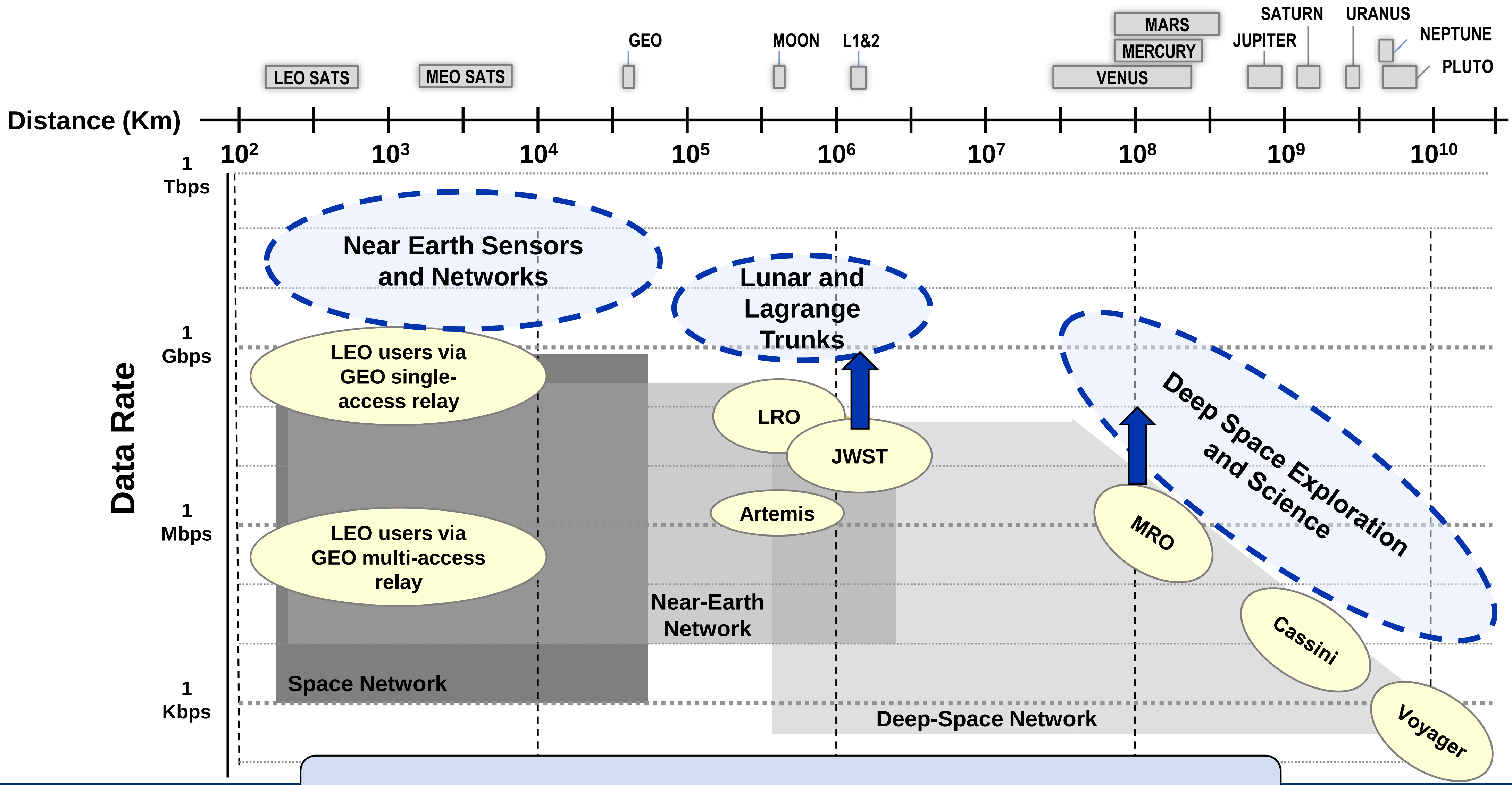
James Webb Space Telescope



- Launched 25 December 2021
- 28 Mbps Ka-band radio link from L2 (1.5 million km)
- 57 GB downlinked each day (as little as 2 hours of image collection)

1 Gbps would allow for up to 20 hours of imaging per day

NASA Communications Needs



Challenge: Enhance ground infrastructure by 100x to 1000x

Where Does Optical Communications Have a Role?

- Space-to-space links
- Deep space links
- High rate links
- Loss constrained links

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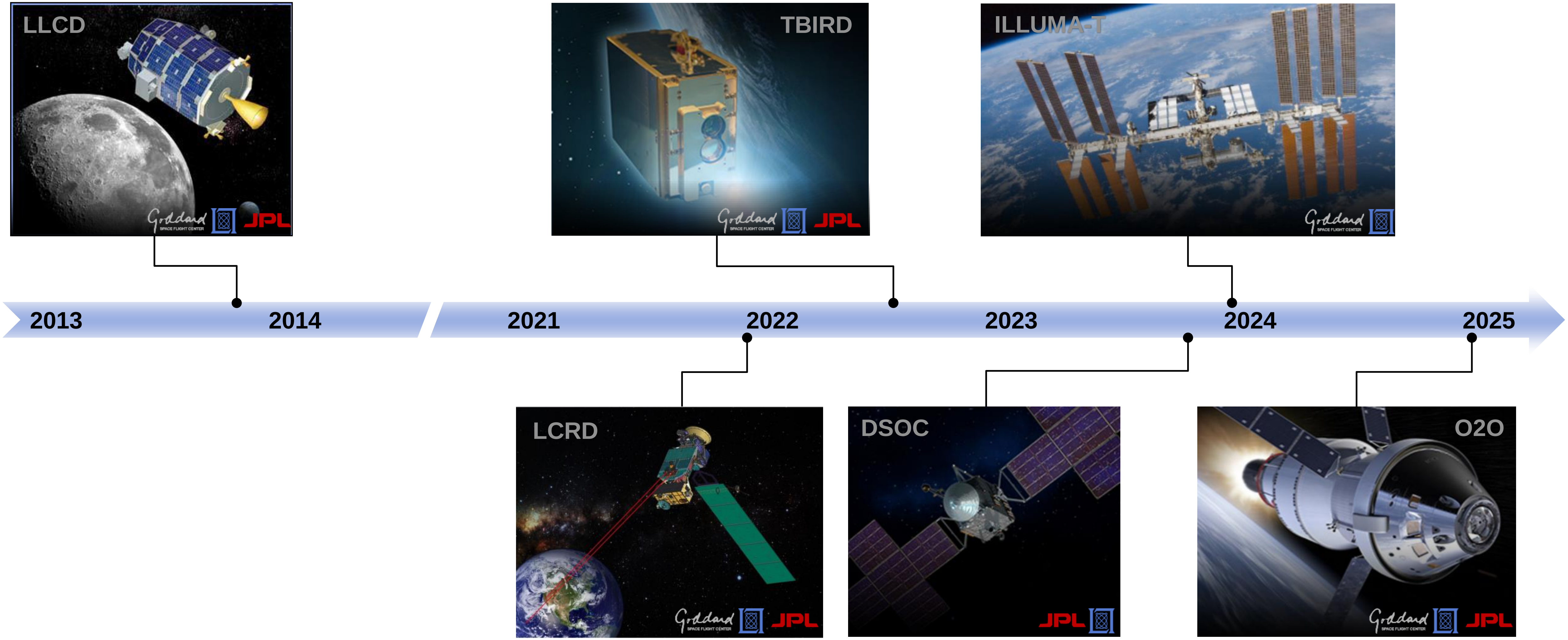
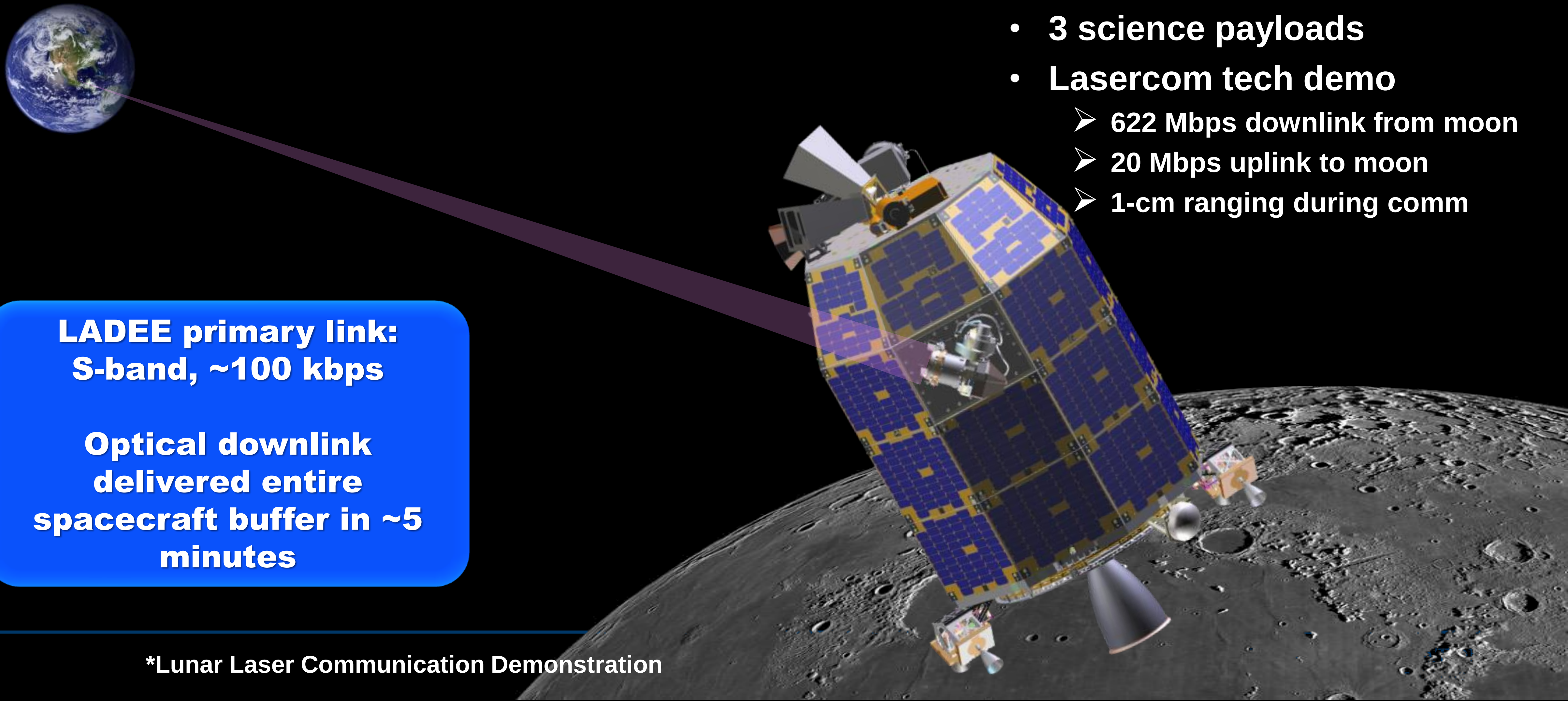
NASA Laser Communications Demonstrations



Lasercom Demo on the Lunar Atmosphere and Dust Environment Explorer (LADEE)

LADEE's main science mission: measure dust grains in lunar atmosphere

- 3 science payloads
- Lasercom tech demo
  - ➢ 622 Mbps downlink from moon
  - ➢ 20 Mbps uplink to moon
  - ➢ 1-cm ranging during comm

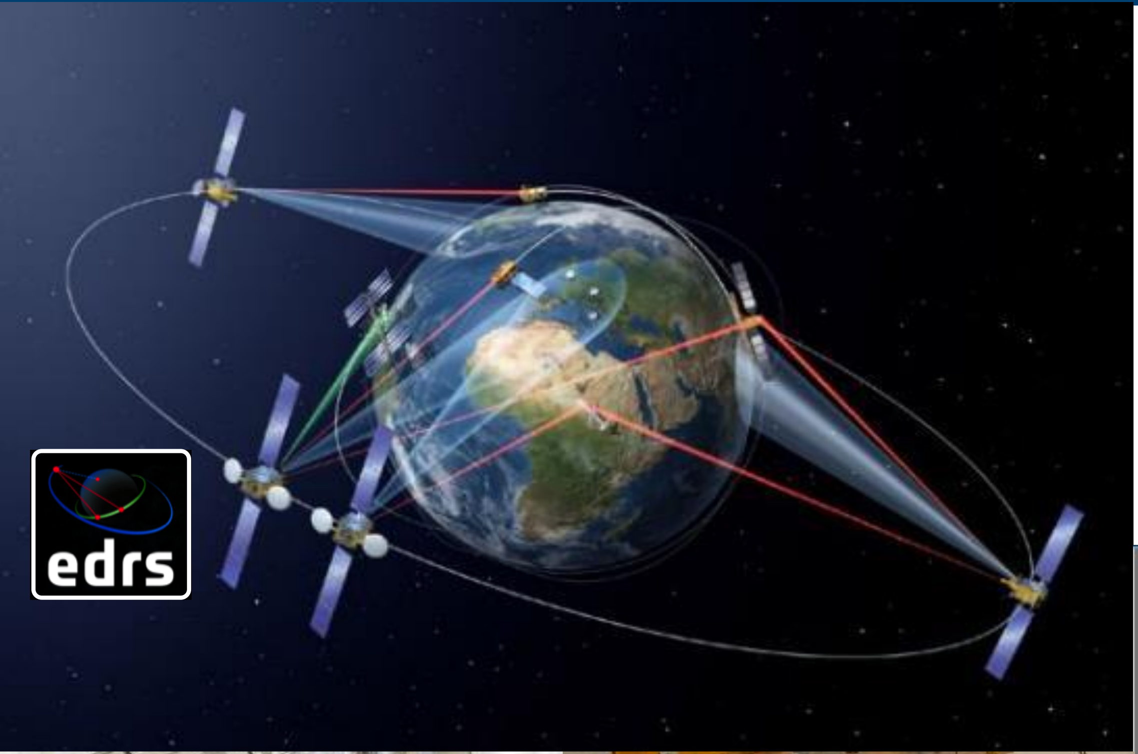


LADEE primary link:
S-band, ~100 kbps

Optical downlink delivered entire spacecraft buffer in ~5 minutes

*Lunar Laser Communication Demonstration

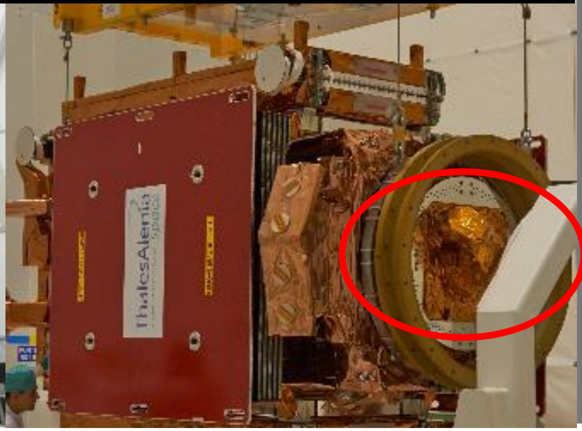
EDRS- The Space Data Highway



Connect LEO earth observation S/C with GEO data relay service

Longer link times and nearly real time data transfer

Started in 2016, increased data downlink capacity by 50% compared with RF only



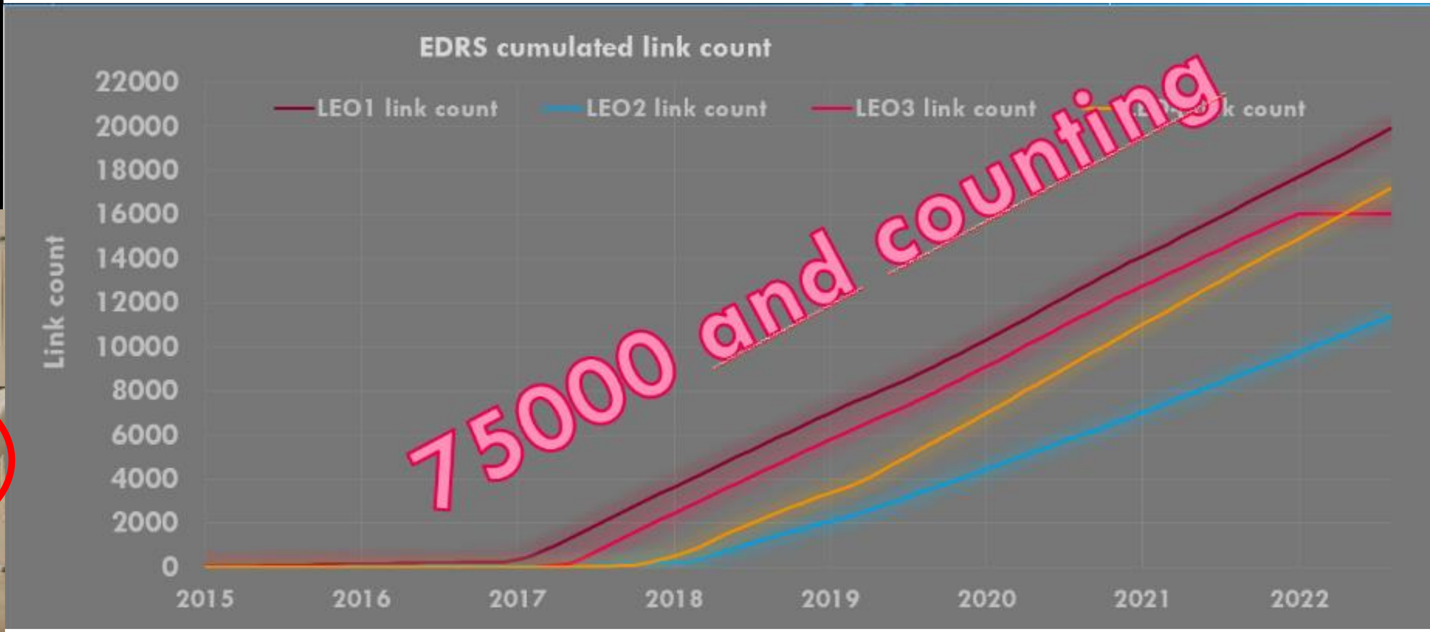
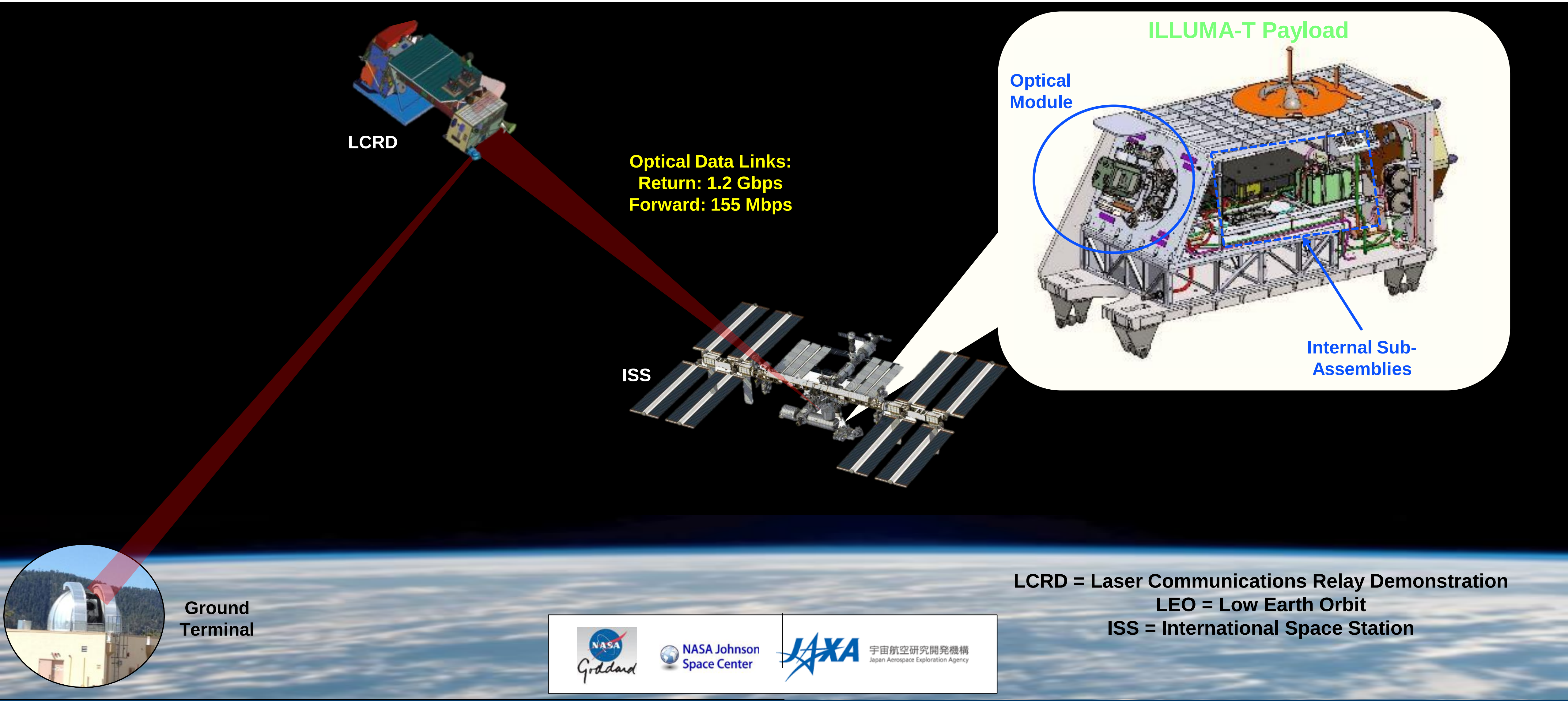


Chart courtesy of F. Heine, TESAT

Integrated LCRD LEO User Modem and Amplifier-Terminal (ILLUMA-T)

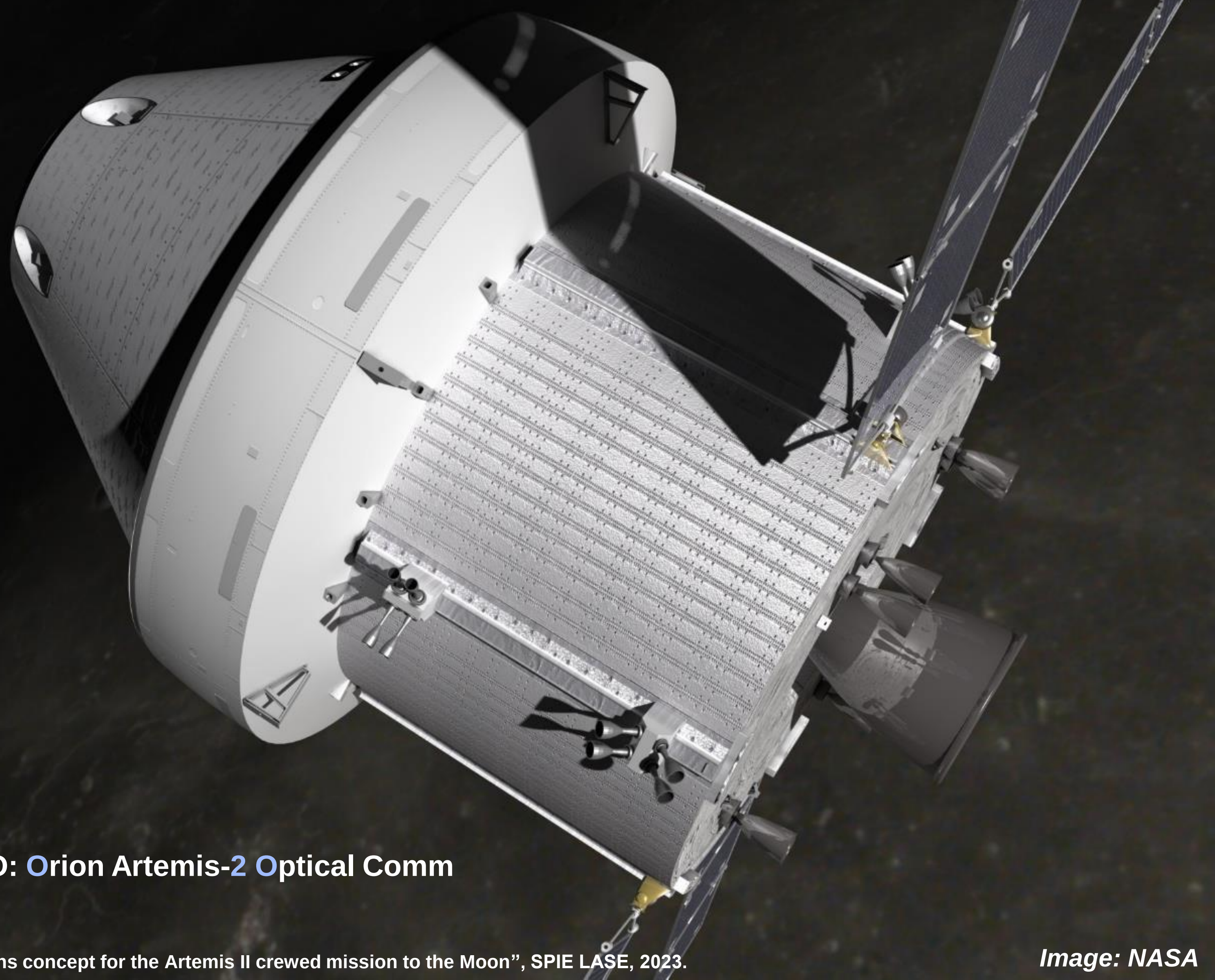


LCRD = Laser Communications Relay Demonstration
LEO = Low Earth Orbit
ISS = International Space Station

J. P. Wang, et al., "System level TVAC functional testing for the Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) payload destined for the International Space Station", SPIE LASE, 2023.

NASA Artemis
Orion Artemis-2 Optical Communications (O2O)

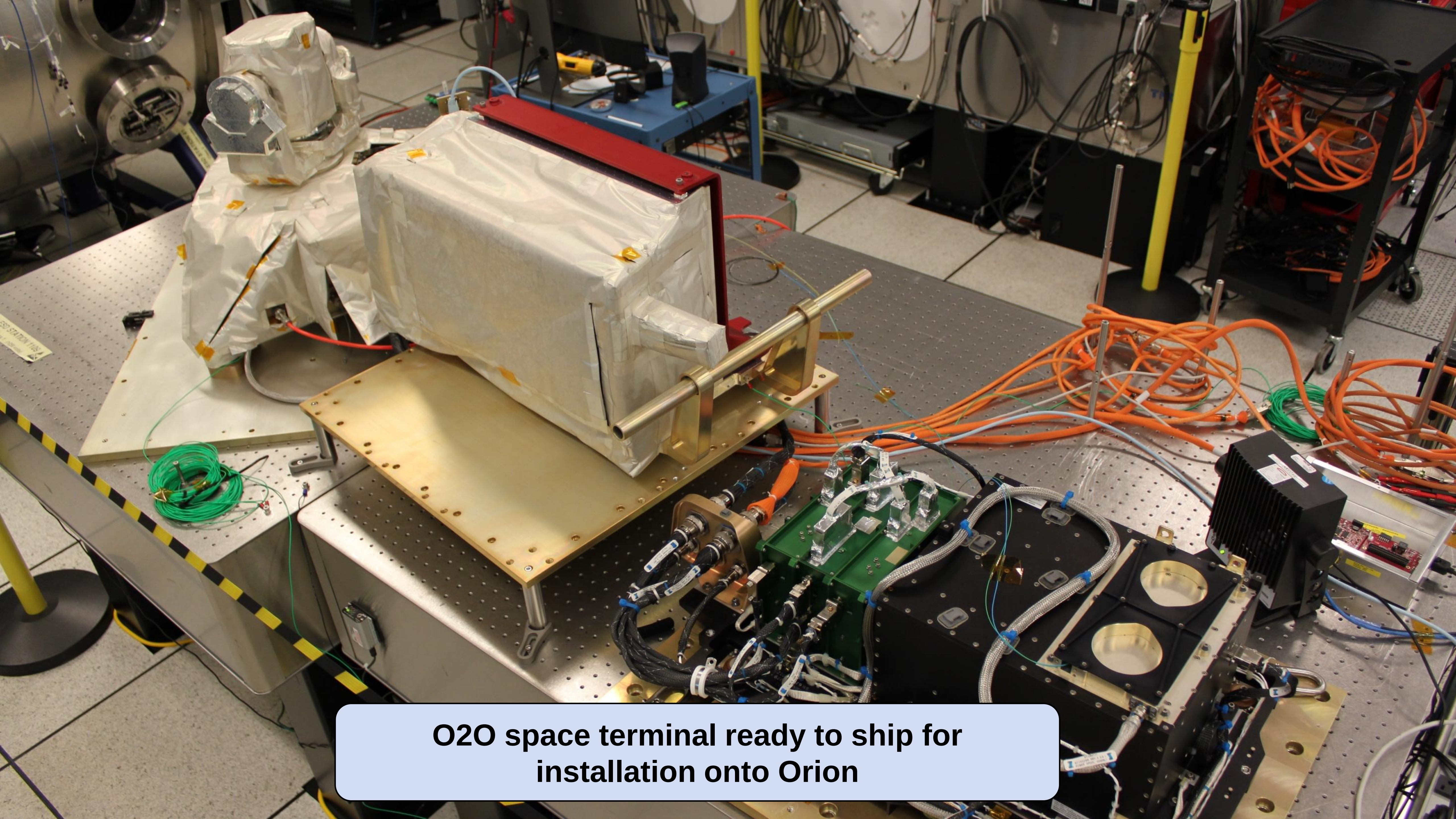
- **Orion baseline comm capability**
  - S-band phased array transmitters
  - Up to ~2 Mb/s from lunar ranges to NASA Deep Space Network
- **O2O* to provide**
  - Up to 260 Mbps return
  - 20 Mbps forward
  - Ranging similar to LLCD
- **Moon provides staging ground for eventual missions to Mars**



O2O: Orion Artemis-2 Optical Comm

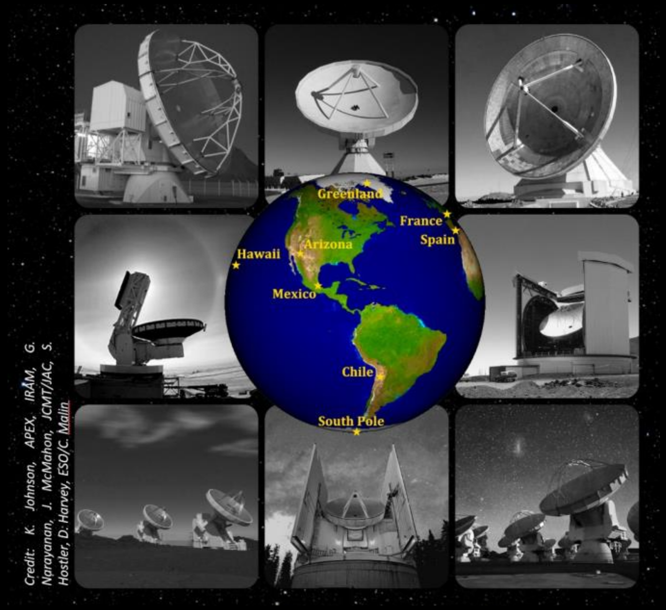
F. I. Khatri, et al., "Optical communications operations concept for the Artemis II crewed mission to the Moon", SPIE LASE, 2023.

Image: NASA

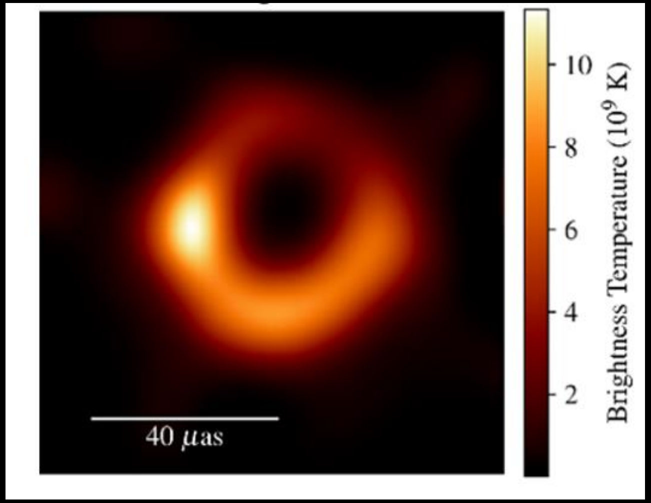


O2O space terminal ready to ship for installation onto Orion

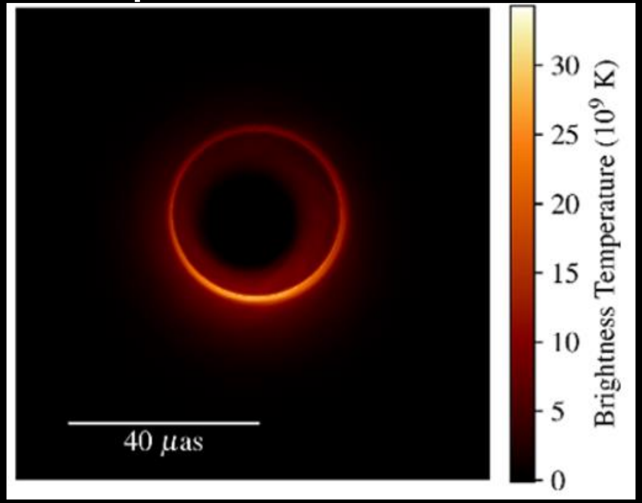
Extending Event Horizon Telescope (EHT) to GEO(+)



EHT Image of M-87



Simulated image with space-based VLBI node

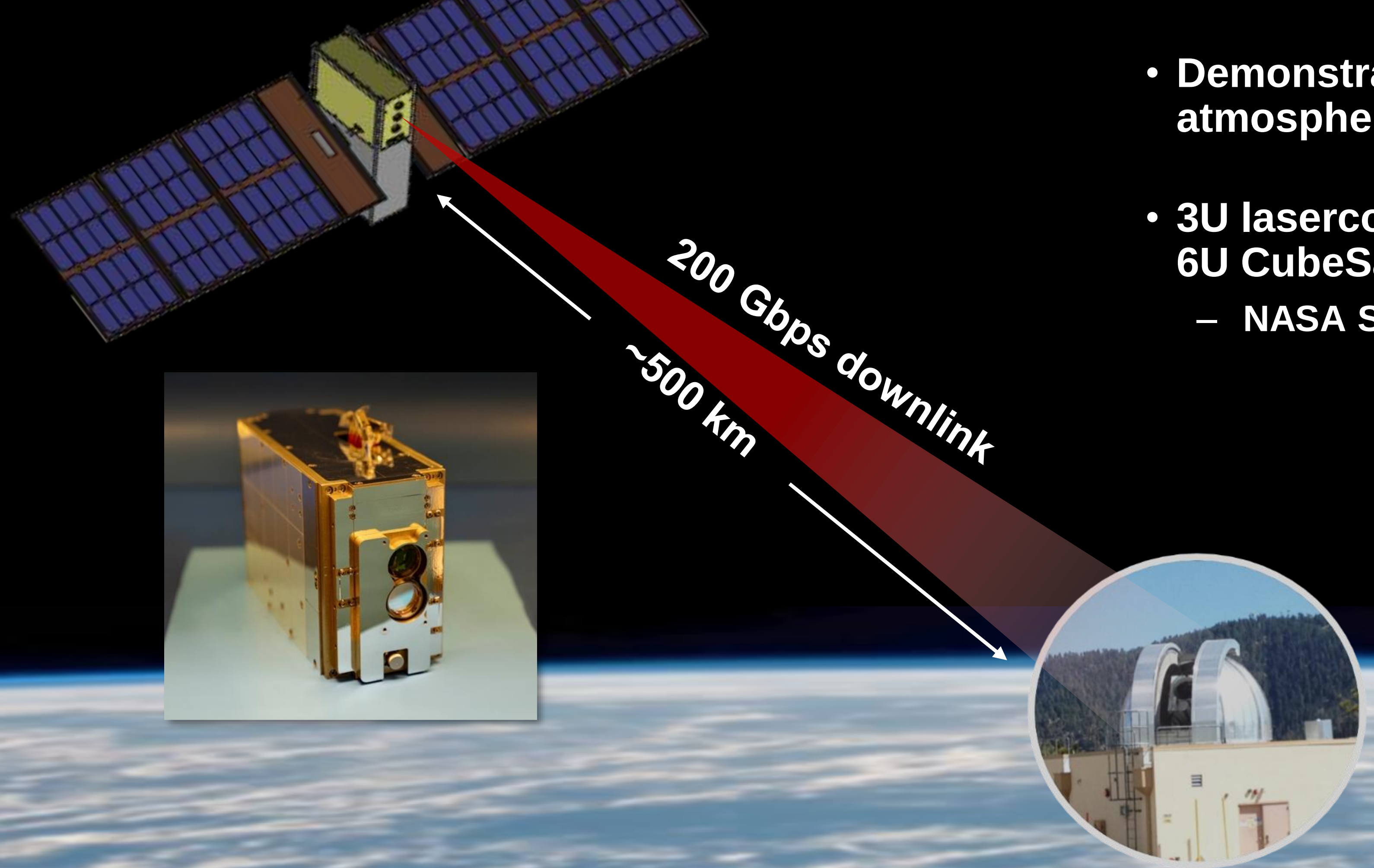


- **Adding space-based node increases resolution of EHT, enabling**
  - **Image the “photon ring” – predicted fractal structure which can allow high-precision tests of General Relativity**
  - **Reveal detailed physics of black hole – turbulence and behavior of gases**
- **Existing Earth-based sensors generate petabytes of data during collections**
- **Space node requires high data rate downlinks (>200 Gbit/s!) and precise synchronization**

J. P. Wang, et al., “High-rate 256+ Gbit/s laser communications for enhanced high-resolution imaging using space-based very long baseline interferometry (VLBI)”, SPIE LASE, 2023.

Terabyte Infrared Delivery (TBIRD)

6U CubeSat in LEO
3U Lasercom payload



JPL/OCTL
Ground terminal

- Leverage fiber telecom equipment for 200 Gbps burst delivery (TBs per pass)
- Demonstrate robust data transfer through atmospheric channel with ARQ
- 3U lasercom terminal payload hosted on 6U CubeSat
  - NASA Small Sat Pathfinder Tech Demo

C. Schieler, et al., "On-orbit Demonstration of 200-Gbps Laser Communication from the TBIRD CubeSat"SPIE LASE, 2023.

GEO Streaming Downlink from [16-256 Gbps] Sensor

GEO Node

60-256 Gbps
Downlink
Throughput

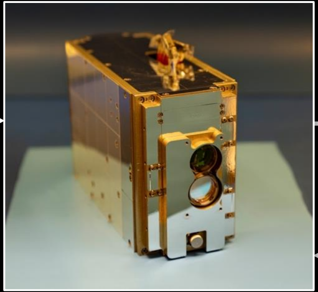
3-kbps Uplink
ARQ channel

~40,000 km
(>30 dB harder)

EHT Sensor

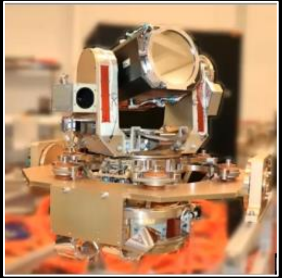
16-256G

High speed buffer



Modem leverages TBIRD technology

High power amplifier



10-cm Optical Module leverages previous lasercom development

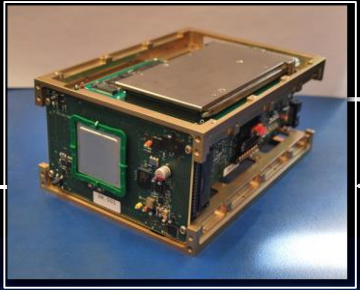
Two Ground stations sited for cloud diversity

Optical Ground Station #1

Optical Ground Station #2

Data Sink

16-256G



Modem leverages TBIRD technology

Optical telescope with adaptive optics leverages previous development

LCRD Optical Ground Station

J. P. Wang, et al., "High-rate 256+ Gbit/s laser communications for enhanced high-resolution imaging using space-based very long baseline interferometry (VLBI)", SPIE LASE, 2023.

Summary

- Numerous successful demonstrations have shown the utility of optical communications for future science and exploration needs
  - Low SWaP terminals
  - Large bandwidths
  - High data rate links

- Many fiber telecom technologies and components are directly applicable to space-based optical communications

- Operational space optical communications systems are beginning to come online