National Aeronautics and
Space Administration

An Overview of NASA's Optical Communications Efforts

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Benefits of Optical Communications

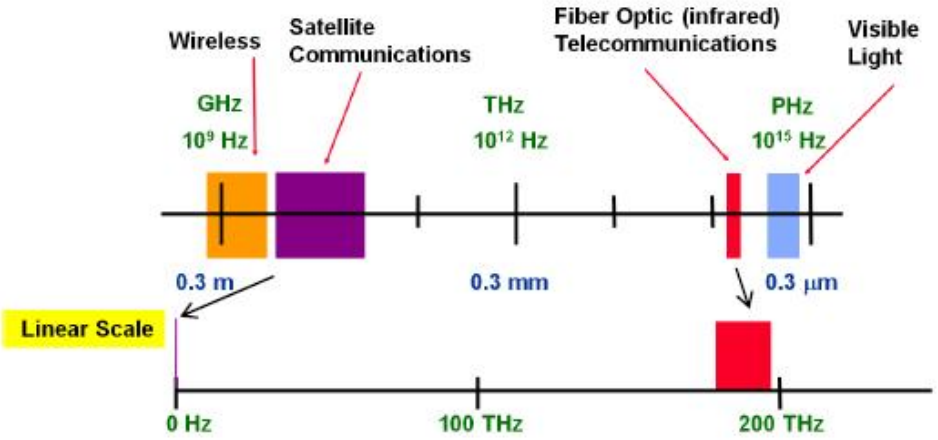
- Extremely narrow beams with small apertures
- Small, low power terminals
- Unlimited, unregulated spectrum
- High data rates
  - Provides high speed real-time data (e.g. for video)
  - Enables shorter contact times
  - Delivers large data volume over the duration of mission

Historic Challenges:
beam pointing, efficient transmitters and receivers, high bandwidth processing, atmospheric effects

Beam Size From Moon

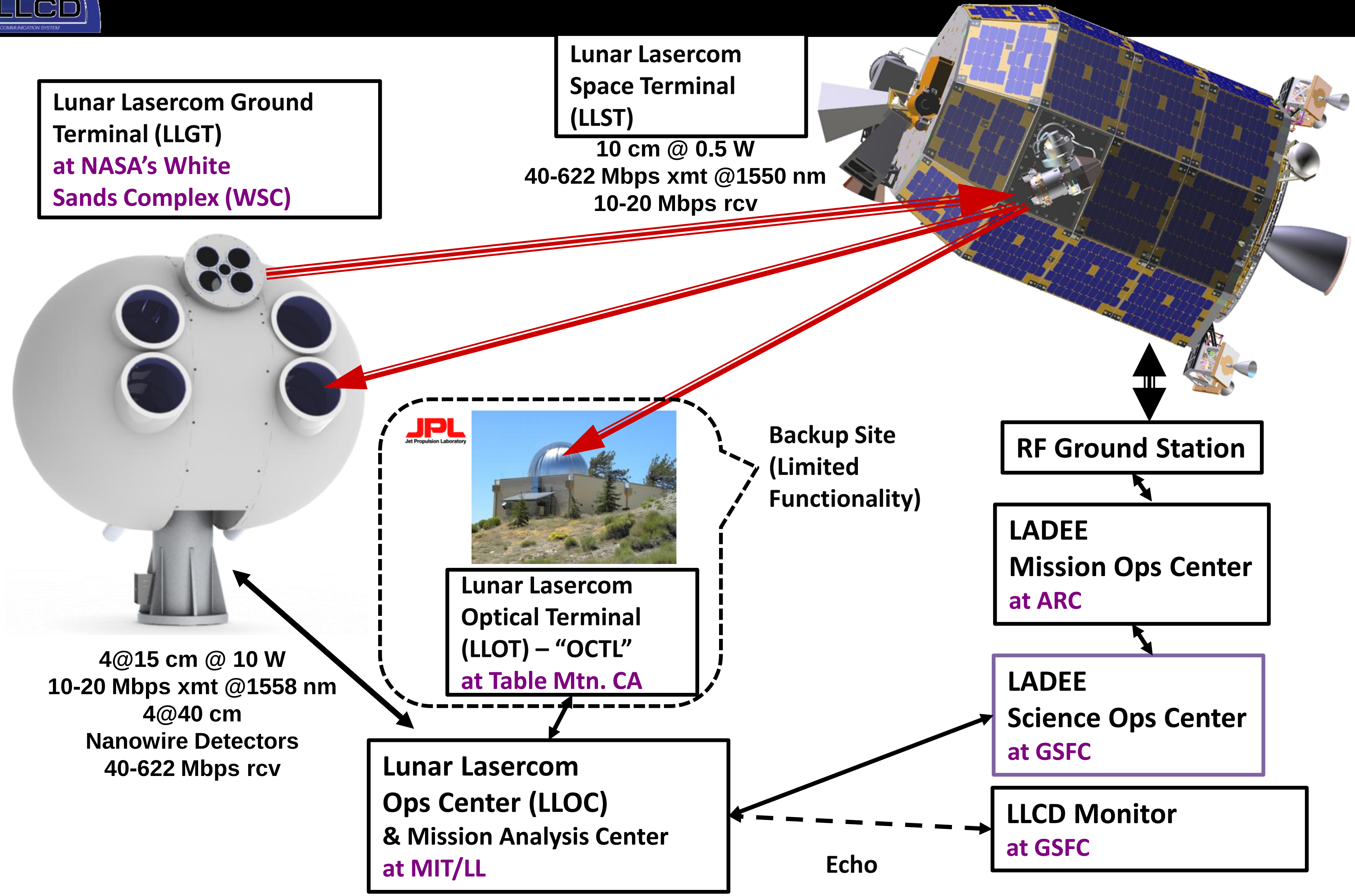
RF Ka Band (26 GHz)
75-cm Antenna → 6400 km Spot

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



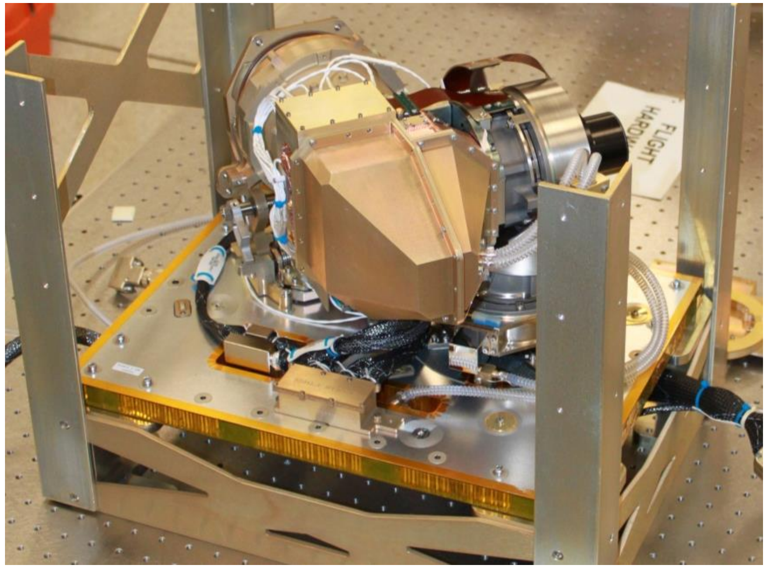
NASA wants to build upon the success of the 2013 Lunar Laser Communications Demonstration (LLCD) and previous efforts

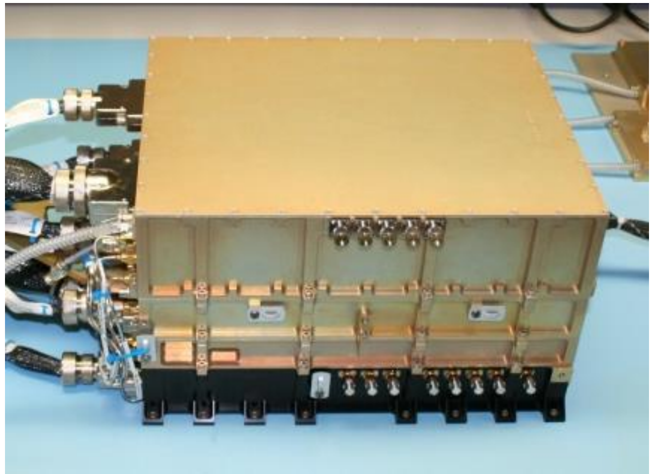
2013 LLCD Architecture



2013 Lunar Lasercom Space Terminal (LLCD)

Optical Module
- Designed and fabricated by MIT LL
- Inertially-stabilized 2-axis gimbal
- Fiber-coupled to Modem transmit (Tx) and receive (Rx)





Modem Module (MM)
- Designed and fabricated by MIT LL
- Pulse Position Modulation Only
- Digital encoding/decoding electronics,1550 nm fiber Tx and Rx

Controller Electronics
- Built by Broad Reach Engineering for OM/ MM control
- Telemetry & Command (T&C) interface to S/C

All Modules Interconnected via electrical cables and optical fibers

2021 Laser Communications Relay Demonstration (LCRD)

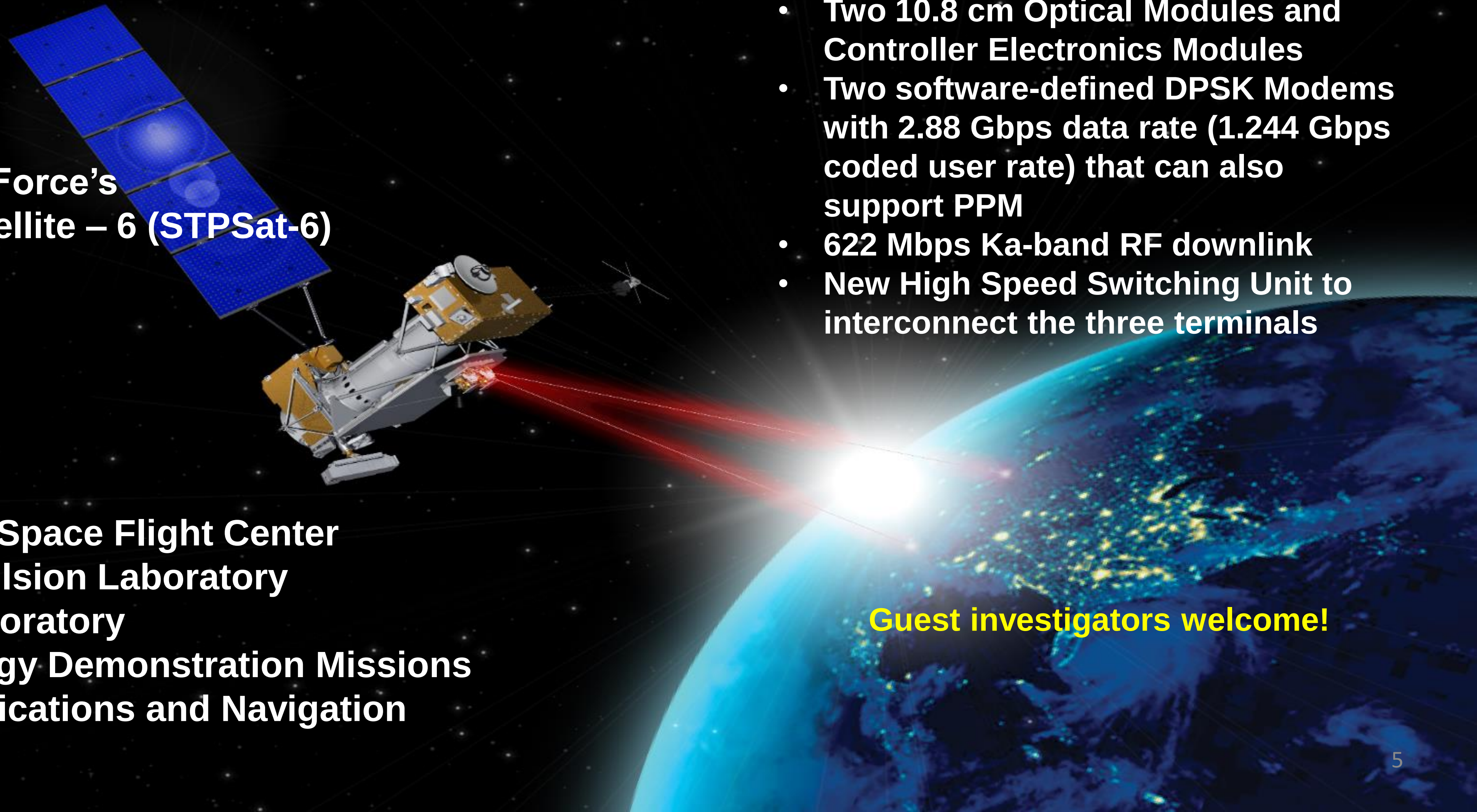
Launched in December 2021

Mission duration:
Two year ops demo
Six years ops

Hosted payload: US Air Force's Space Test Program Satellite – 6 (STPSat-6)

Ground stations:
- California
- Hawaii

Partnership:
- NASA Goddard Space Flight Center
- NASA Jet Propulsion Laboratory
- MIT Lincoln Laboratory
- STMD/Technology Demonstration Missions
- Space Communications and Navigation

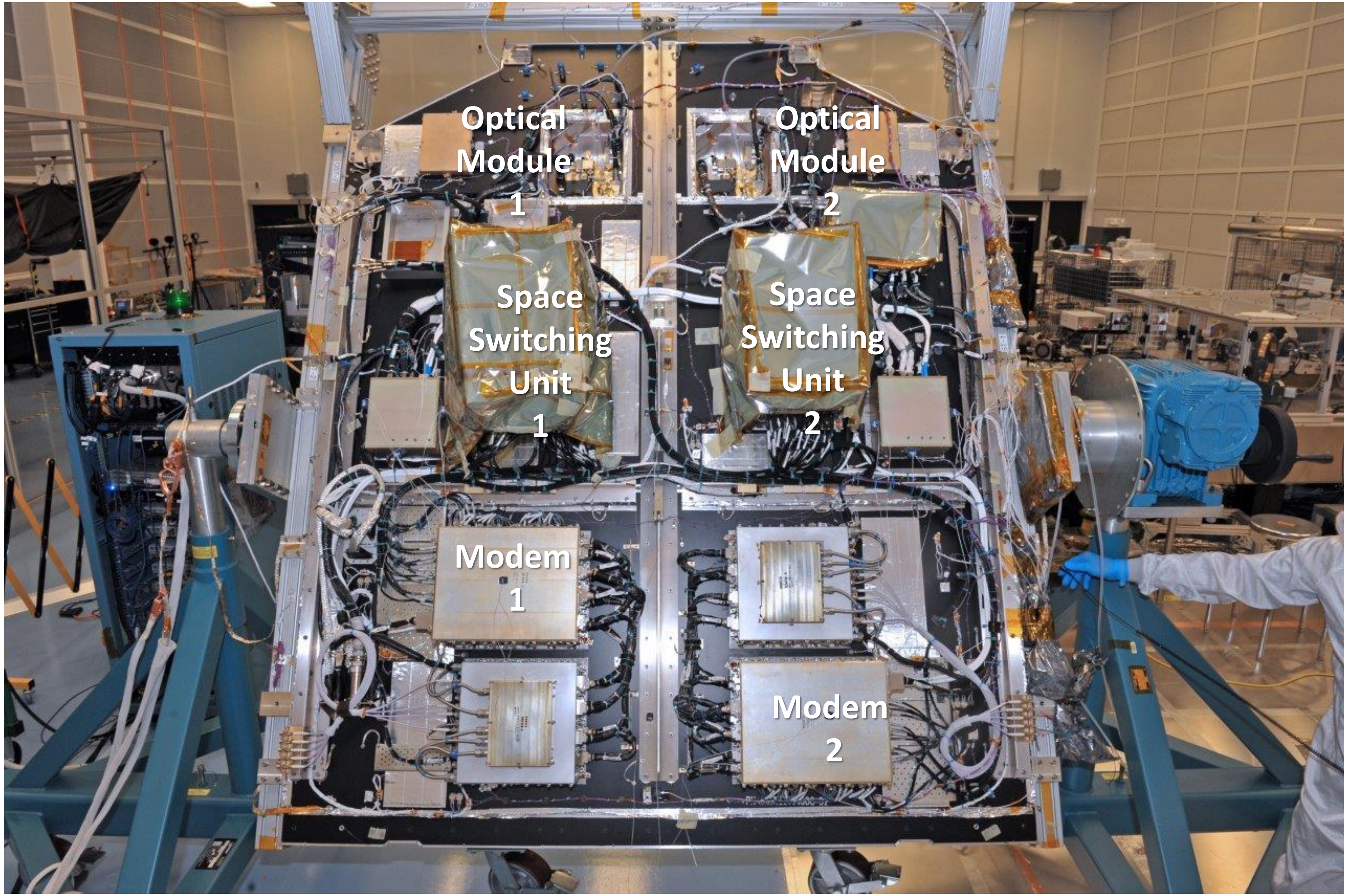


Flight payload:

- Two 10.8 cm Optical Modules and Controller Electronics Modules
- Two software-defined DPSK Modems with 2.88 Gbps data rate (1.244 Gbps coded user rate) that can also support PPM
- 622 Mbps Ka-band RF downlink
- New High Speed Switching Unit to interconnect the three terminals

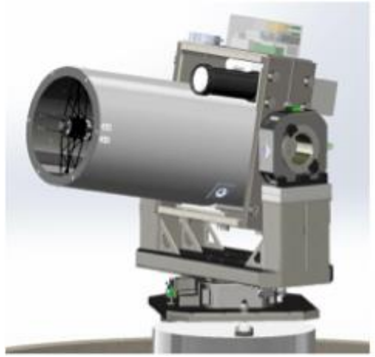
Guest investigators welcome!

Integrated Laser Communication Relay Demonstration Payload at NASA Goddard Space Flight Center



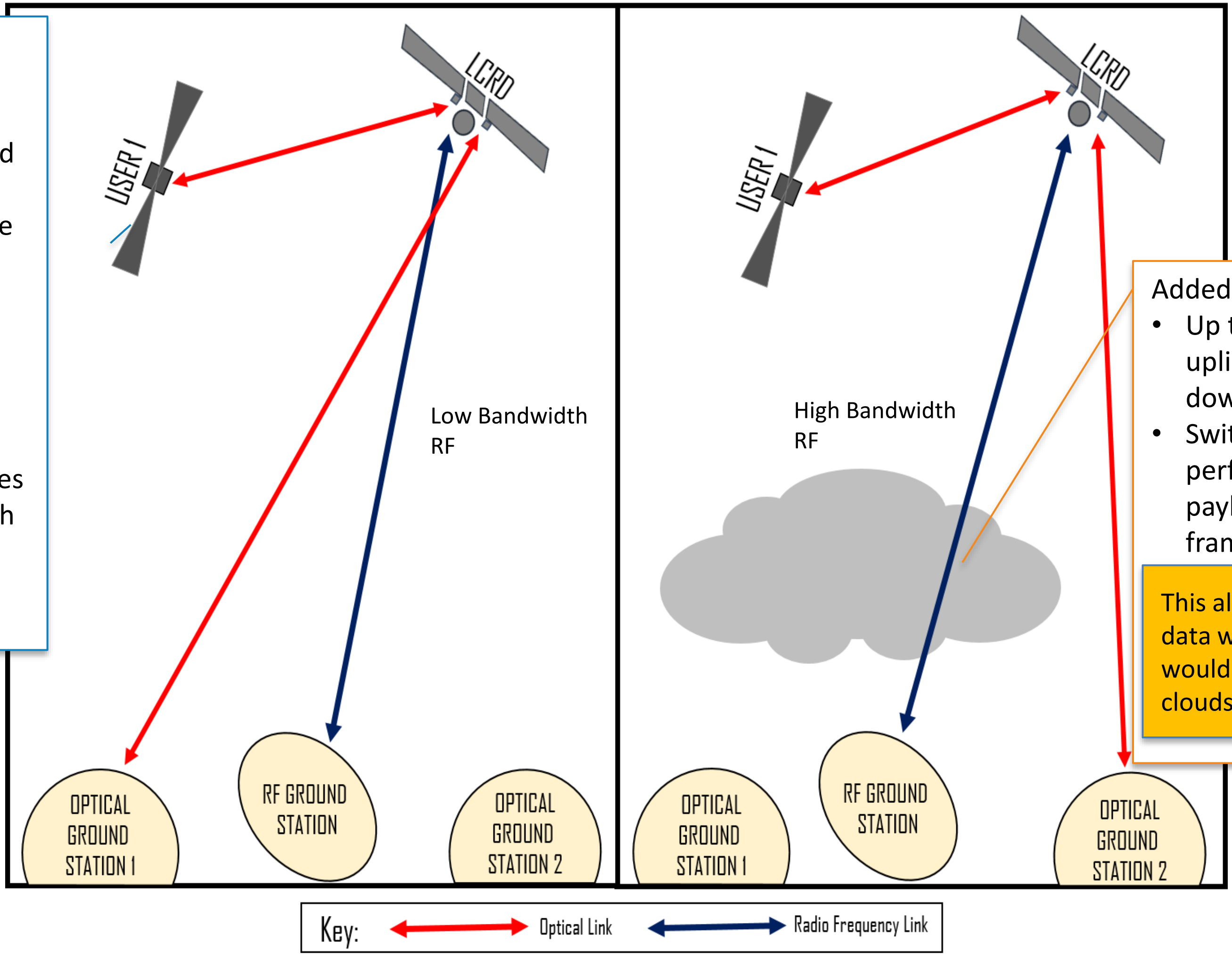
LCRD Optical Ground Stations

- **The LCRD baseline includes two Optical Ground Stations (OGS)**
  - Supports optical comm relay demonstrations before user terminals are available
  - Allows for future handover demonstrations
- **OGS-1 is the Optical Communications Telescope Laboratory (OCTL) on Table Mountain, California**
  - 1 Meter Receive Aperture
  - This was used in the Lunar Laser Communication Demonstration (LLCD)
- **OGS-2 is at the Maui Space Surveillance Complex on Haleakala, Maui**
  - Single 5.5 m Diameter Dome on the roof contains:
    - 60 cm Receive Aperture
    - 15 cm Transmit Aperture
    - 5.4 W of Transmit Optical Power (outside the dome)



LCRD High Bandwidth RF Link

Original Design:
- Two optical space terminals and
- Two optical ground stations
  - One acts as the user
  - One receives the optical trunkline
- One very low rate TT&C RF link
- The trunkline carries the same bandwidth as the link between the relay and the user.

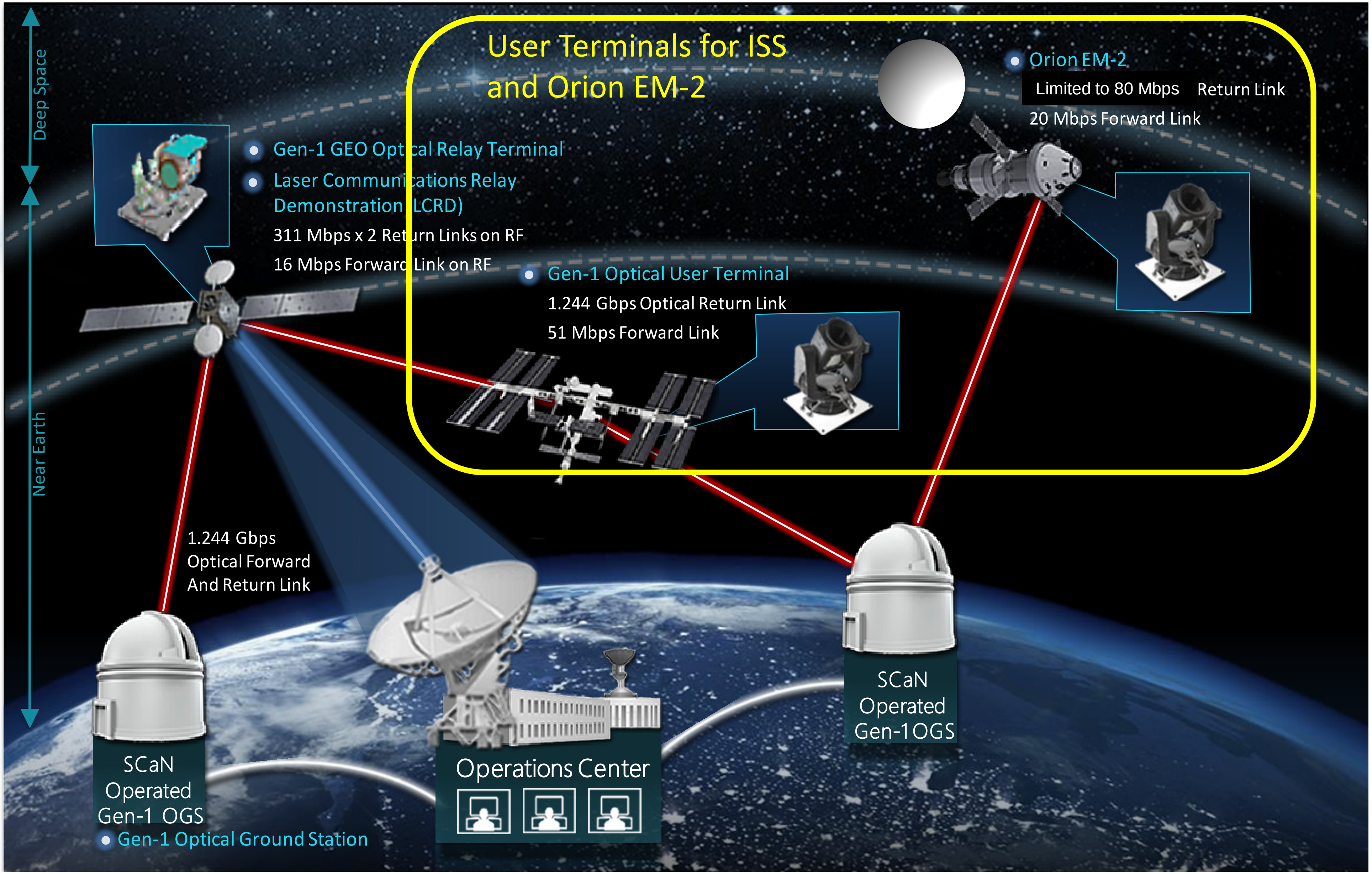


Added high bandwidth RF
- Up to 64 Mbps uplinks/622 Mbps downlinks
- Switching will be performed on the LCRD payload on a frame by frame basis.

This allows for the delivery of data when an optical link would be compromised due to clouds

High Bandwidth RF ensures that requirements for real-time or very low latency delivery (such as commanding, telemetry, science alerts, voice, video, etc.) will be delivered, even when clouds happen!

NASA's Optical Plan Forward:
User Terminals for LEO and the Moon



Laser Communications for Human Space Exploration

ILLUMA-T

(Integrated LCRD LEO User Modem and Amplifier Terminal)

1.2 Gbps return
51 Mbps forward
To ground via LCRD relay

April 2022 delivery to GSFC

Jan 2023 Launch on SpaceX Dragon

~6 Month Mission

NASA Johnson Space Center

JAXA

O2O

(Orion AM-2 Optical Comm)

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

8-21 day mission on first crewed Artemis Mission (AM-2)

October 2022 Delivery to KSC

2024 Launch on Orion/SLS

8 – 21 Day Mission

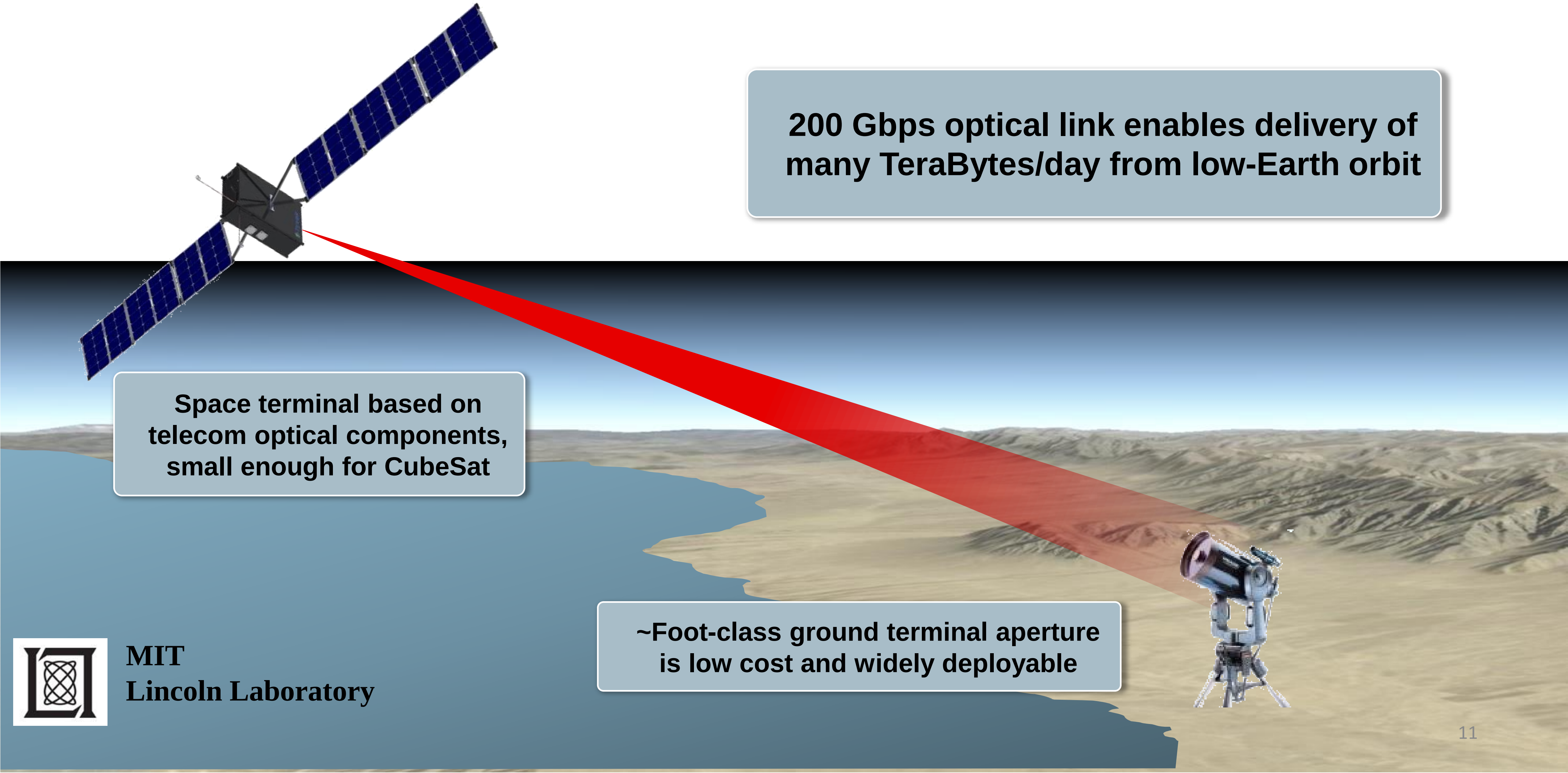
LOCKHEED MARTIN

NASA Johnson Space Center

JPL

Marshall Space Flight Center

NASA's Optical Plan Forward:
LEO Direct to Earth: TeraByte InfraRed Delivery (TBIRD) in 2022



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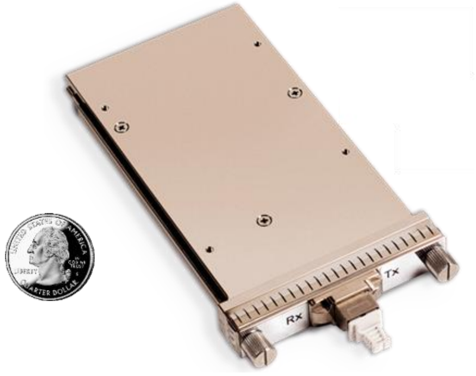
TBIRD: Highly Integrated COTS Components Enable Small, Low-Power Space Terminal Designs

High-Rate Optical Modem



100 Gbps Fiber Telecom Transceiver
Compact Form Pluggable (CFP)

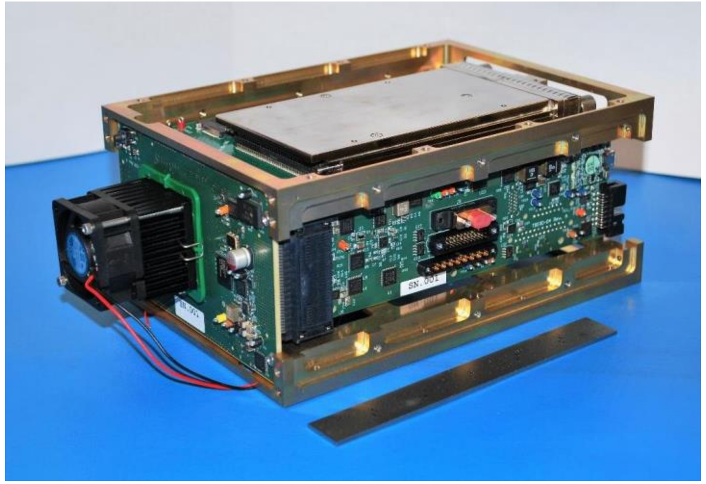
Large, High-Speed Storage

>500 GB, >25 Gbps Readout
Solid-State Drive (SSD)

Optical Amplifier

~1W Erbium Doped Fiber Amplifier
Optical C-Band (~1550nm)

TBIRD Proto-Flight HW
Mass: 2.24 kg
Power: 120W
(5 minute ops)
Volume: 1.8 U



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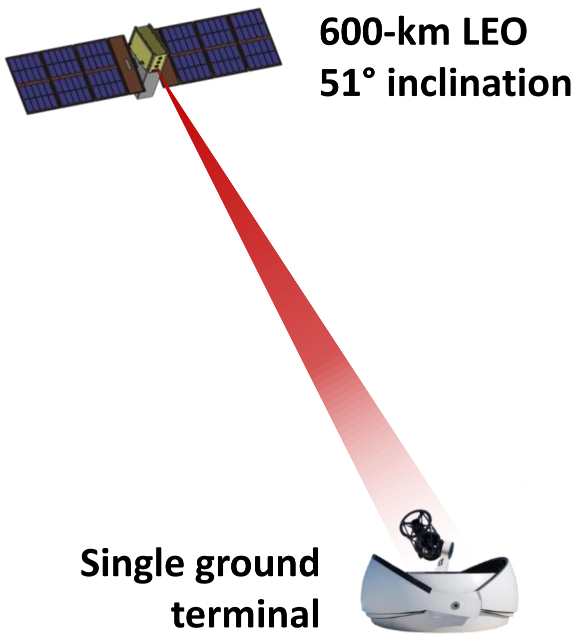
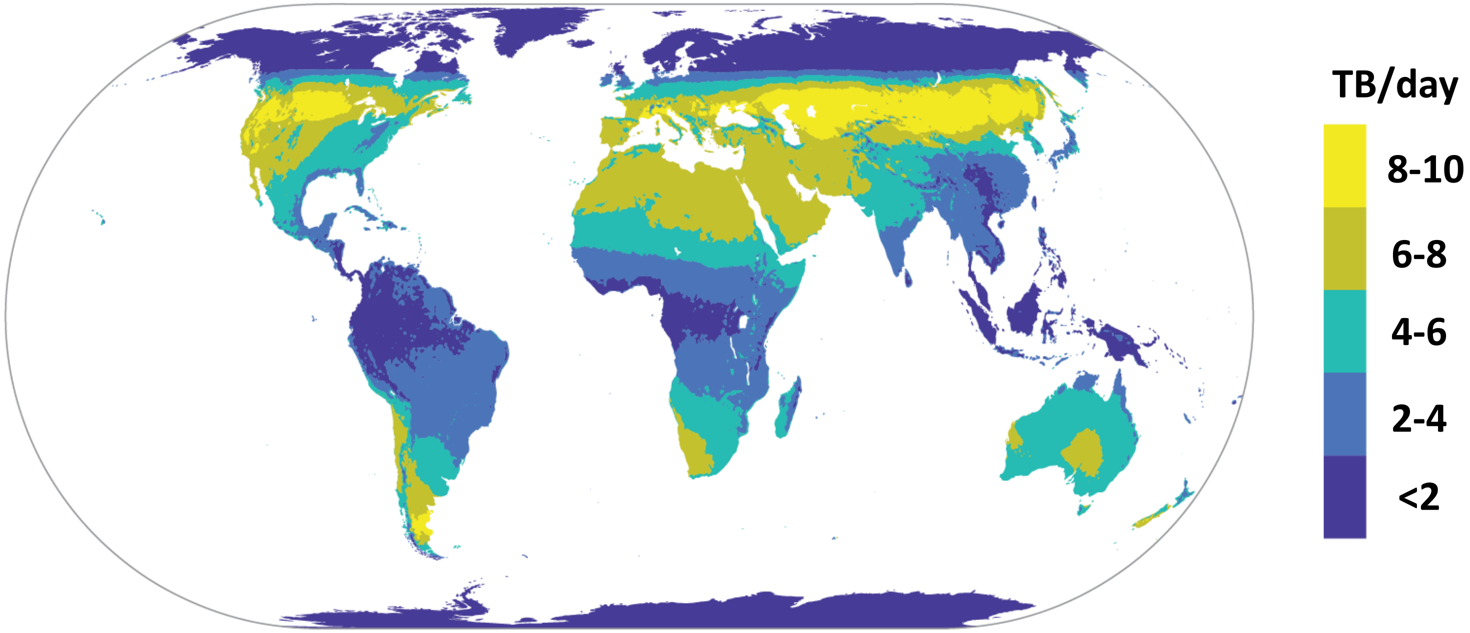
Example Geometry



Average Terabytes per day from LEO to Earth



Link analysis accounts for cloud statistics

The TBIRD system is capable of delivering many TBytes per day from LEO to a delay-tolerant ground user

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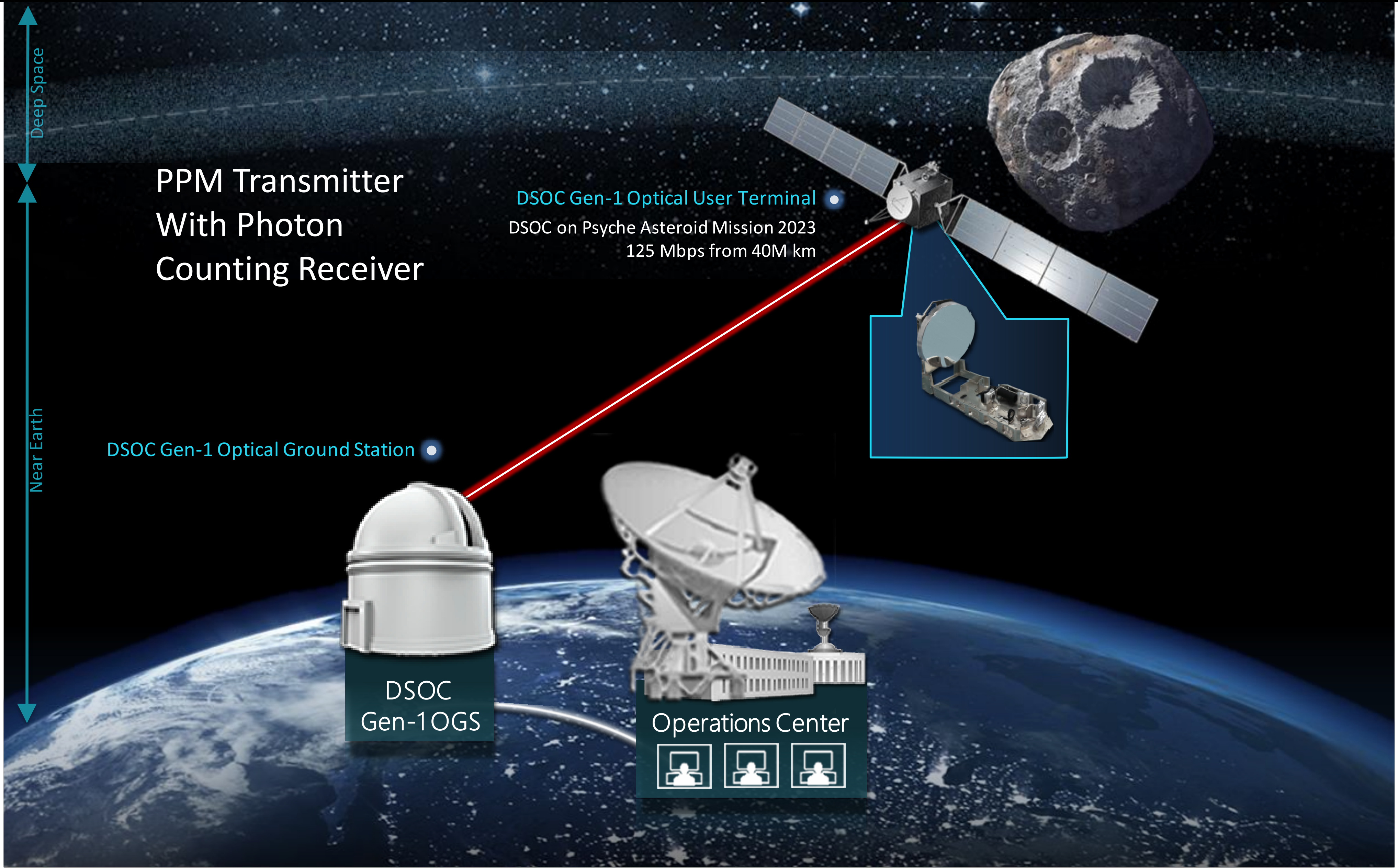
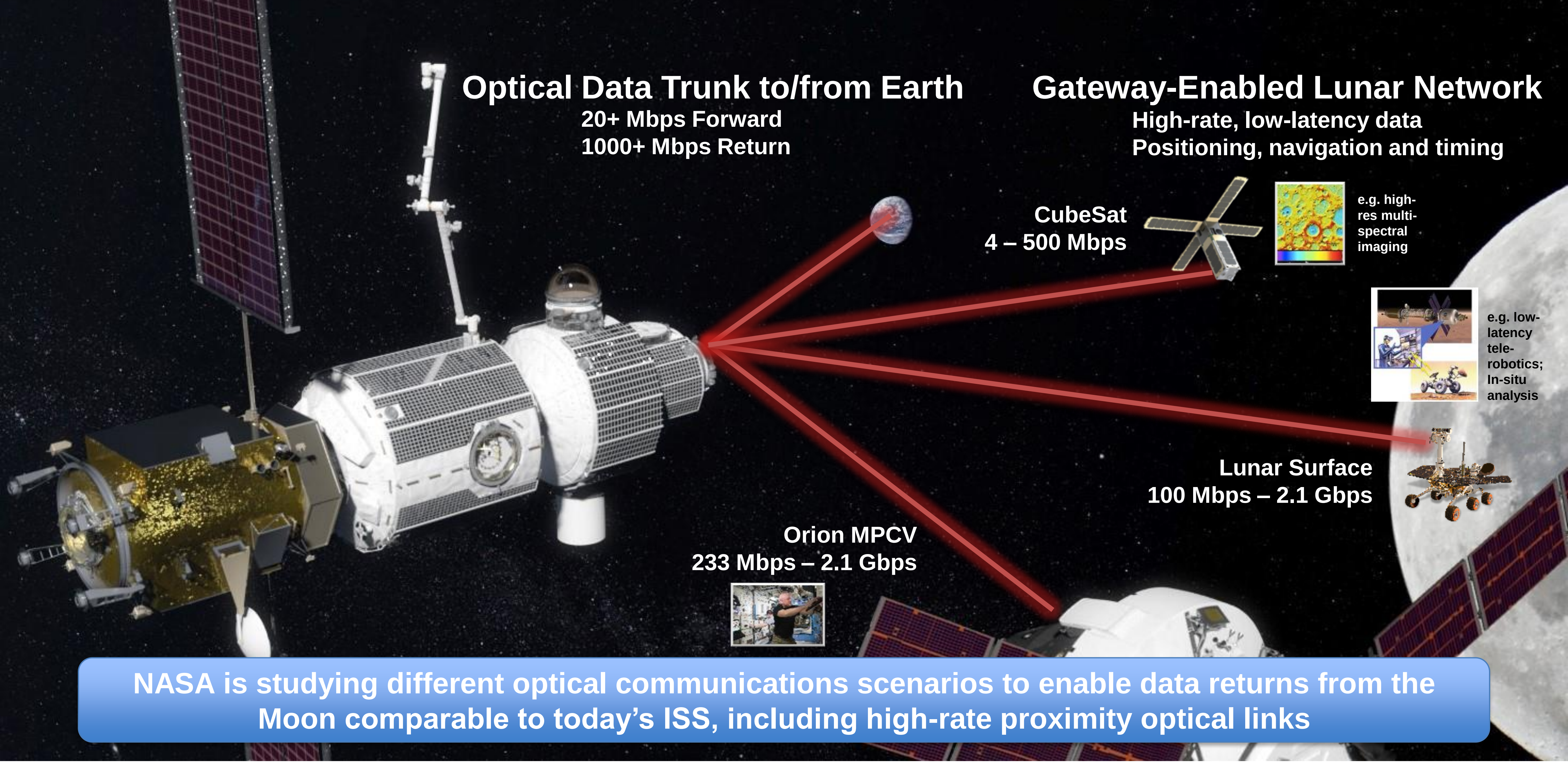
NASA's Optical Plan Forward:
Deep Space Optical Communications (DSOC in 2022)



Laser Communications from the Moon for Future Artemis and Science Missions



NASA is studying different optical communications scenarios to enable data returns from the Moon comparable to today's ISS, including high-rate proximity optical links

Increasing Communications Through Standardization and Resource Sharing

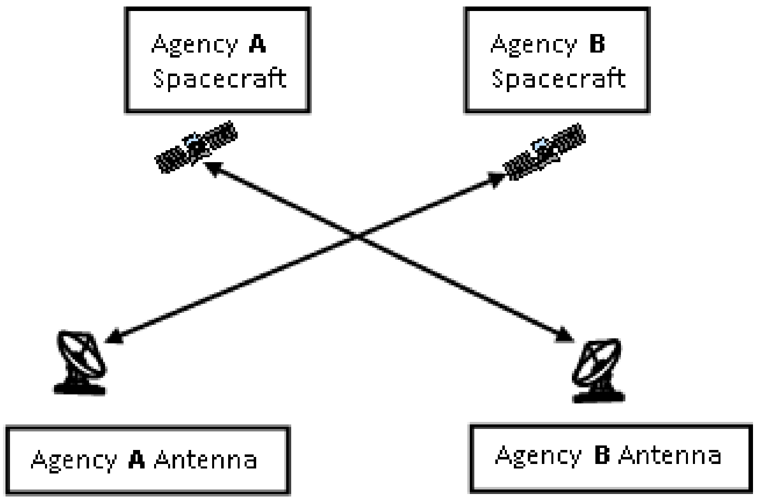
- **Resiliency in both space and on the ground can be increased by sharing communications resources**

- **Sharing optical communication ground stations or relay satellites would also allow agencies to share the cost of the communications infrastructure.**

  - For example, due to cloud blockage, it is critical to have multiple ground stations in use during space-to-ground optical operations to provide high availability.

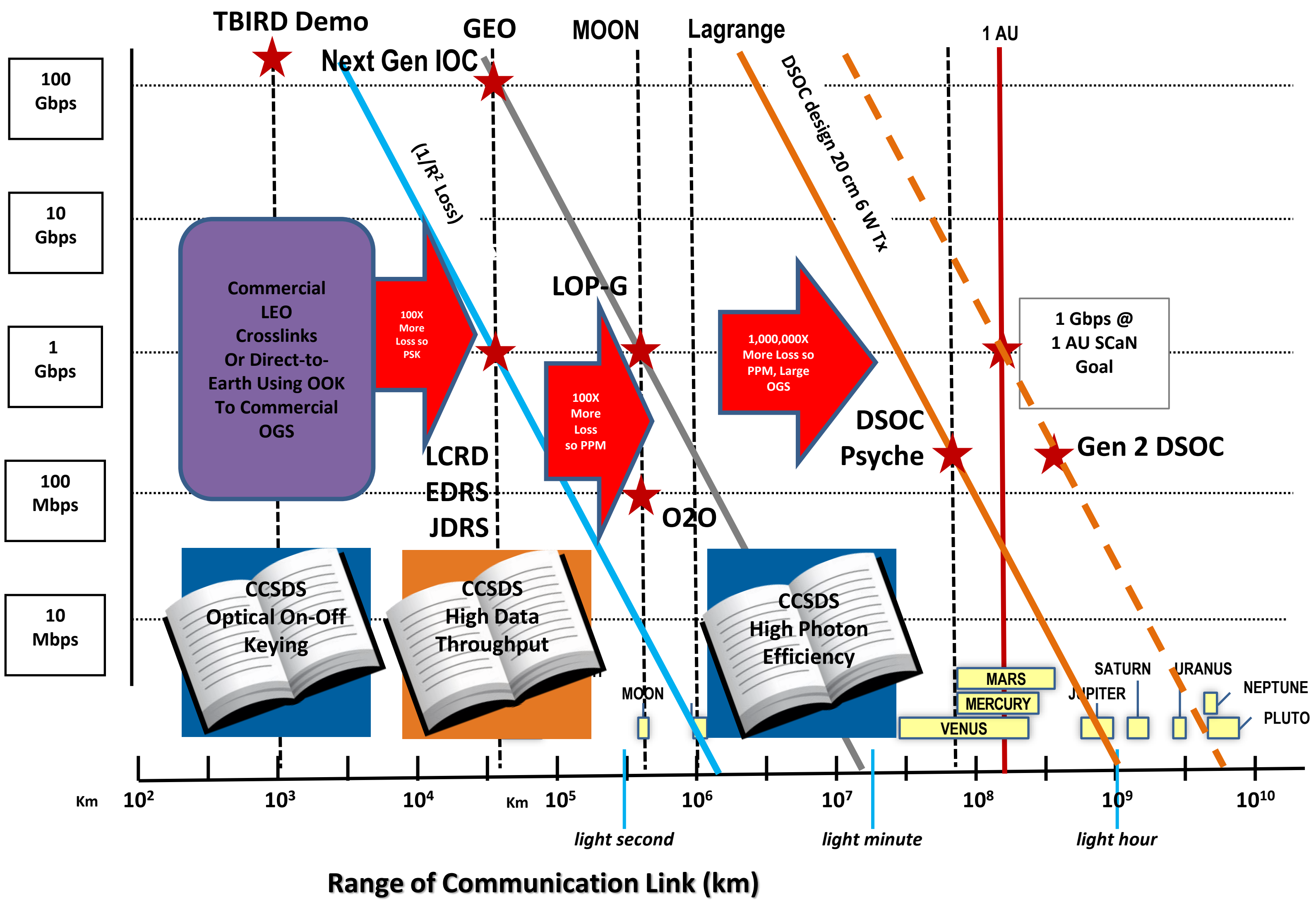
- **International cross support for civil space agencies is being worked within the Interagency Operations Advisory Group (IOAG) and the Consultative Committee for Space Data Systems (CCSDS).**

- **The goal is to develop optical communications cross support by various agencies as we have today in traditional Radio Frequency (RF) communications.**

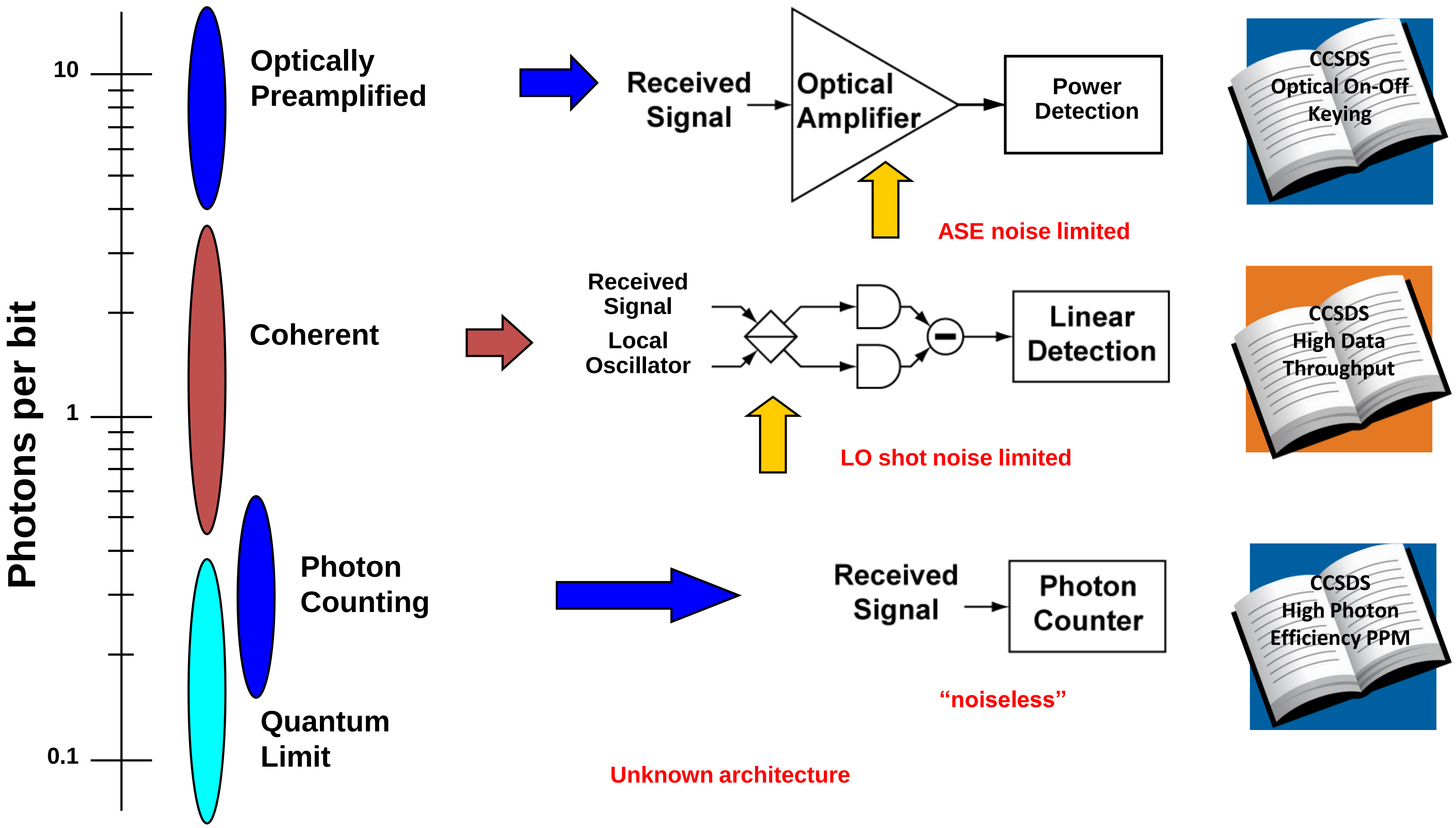


Traditional International RF Cross Support

NASA's Optical Plan Forward: Optical Communication Standards in CCSDS



Detection Sensitivity in Optical Communications



Questions?

Please feel free to contact:

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