National Aeronautics and Space Administration

An Envisioned Future for Space Optical Systems

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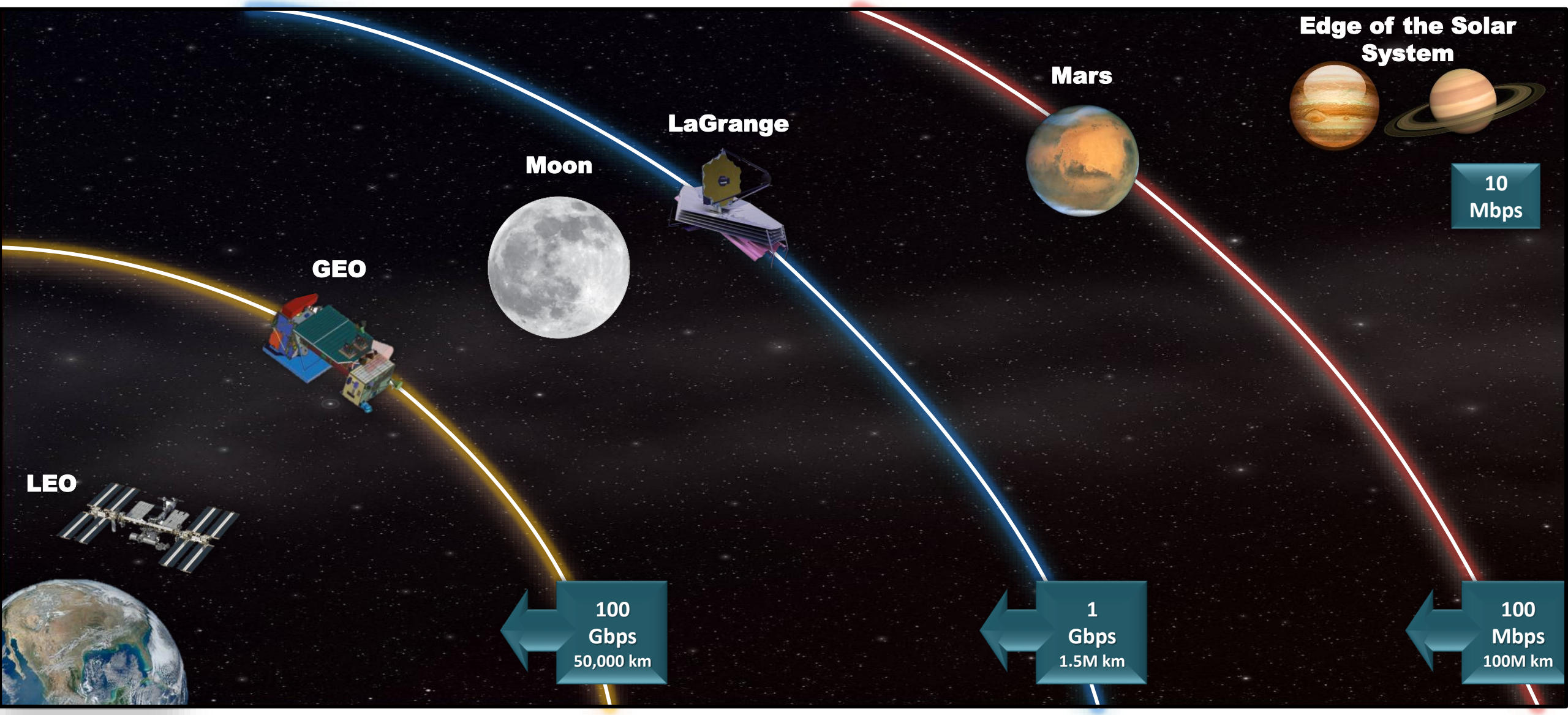
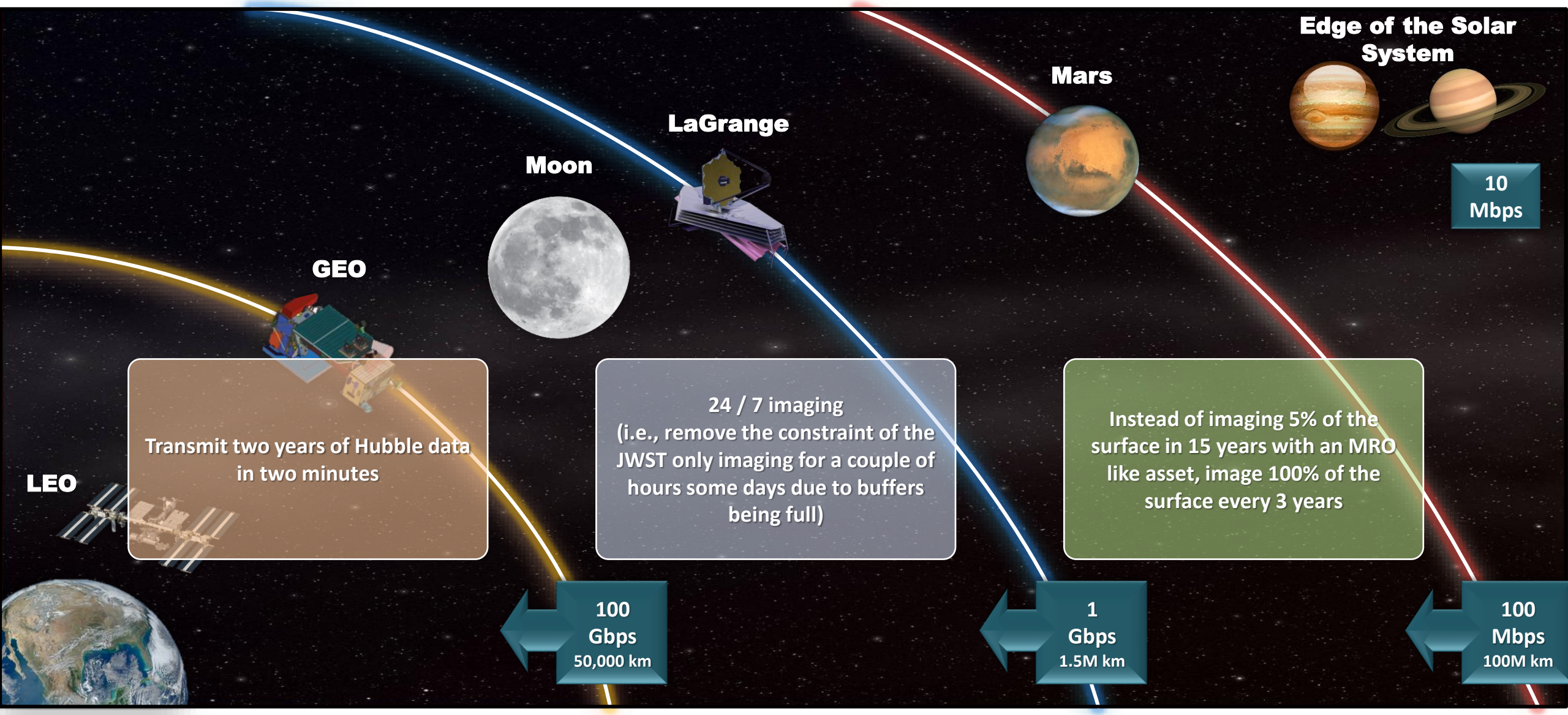
A Vision for NASA Communications

Contour Map for the Solar System



Notional Examples of the Impact of Achieving the Communications Vision



NASA's Transition to Commercial Communications Services

Trends	Current NASA activities	Impact on 2030+ Near Earth communications
Transition to commercial SATCOM	End-to-end commercial services demonstrations using various technologies, orbits, and data pathways are taking place through 2030.	Users will transition from the NASA Tracking and Data Relay Satellite System to commercial SATCOM services.
Growing direct-to-Earth market	NASA is establishing a broader direct-to-Earth commercial market and is transitioning from service provider to commercial user.	Users will be able to access and seamlessly switch between a variety of service provider options based on real-time mission needs.
Adoption of standards and technologies	NASA is increasing engagement with commercial standards bodies such as 3GPP (3rd Generation Partnership Project) Cellular Standards Group and investing in critical technologies like wideband terminals.	Adoption of commercial standards in addition to the continued use of CCSDS stnardss where appropriate will provide operational efficiencies and interoperability benefits to NASA missions.

Commercial Services Can Meet NASA's Near Earth and Lunar Communications and Navigation Needs

Near Earth Optical (1 of 3)

Direct-to-Earth User and Ground Terminals – Investments Paving the Way for Future Ops

COTS-based Small User Terminal is demonstrated on the TeraByte InfraRed Delivery (TBIRD) mission

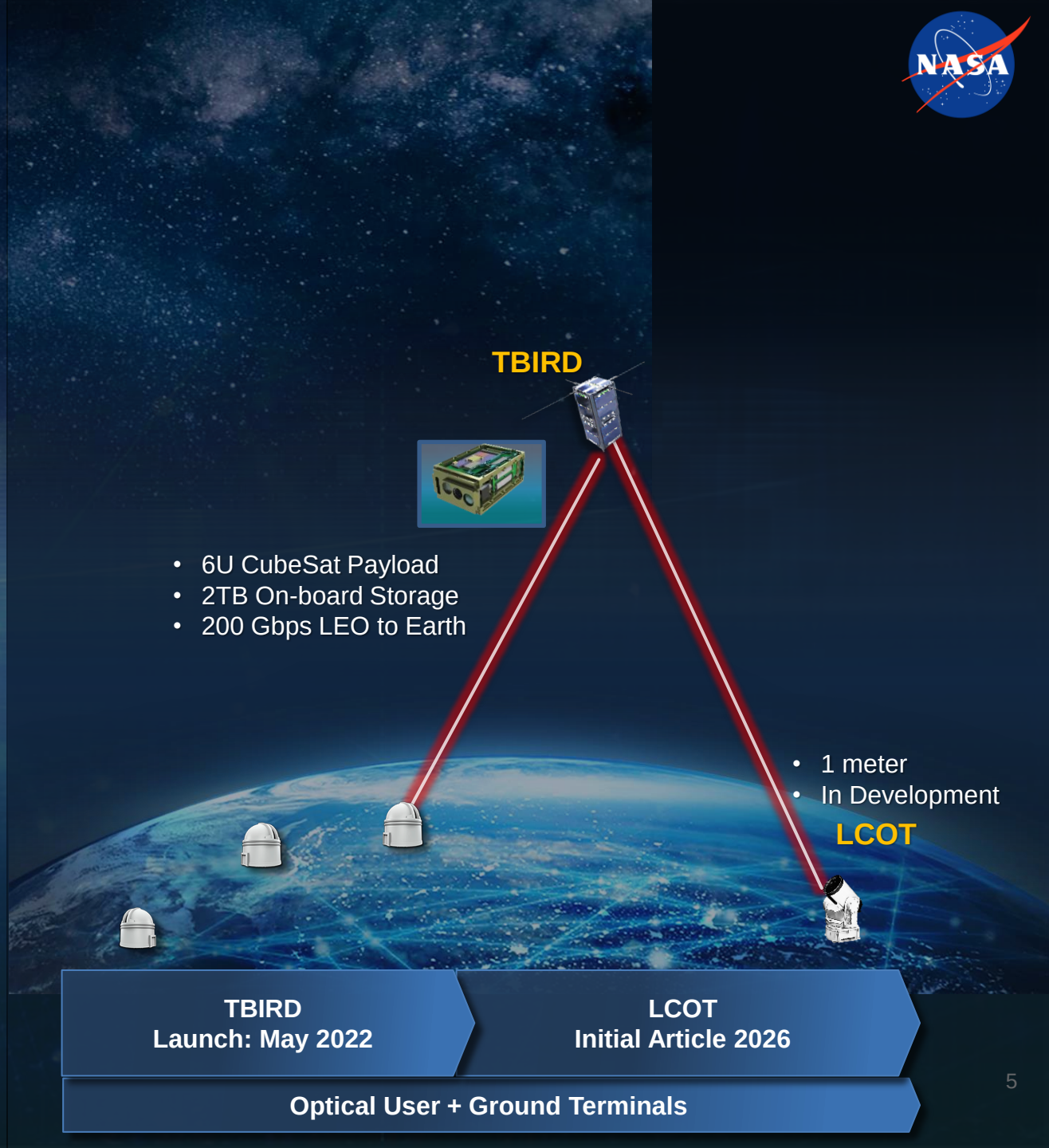
- Launch: May 2022, 6-month primary mission
- Data rate: 200 Gbps
- Collaboration with STMD/SST
- Ready for operational infusion once TBIRD has completed full capability testing

Low-Cost Optical Terminal (LCOT)

- Initial Article: 2026
- 1 m aperture capable of coherent lunar DTE support
  - International collaboration target
- Atmospheric correction system
- In development

Optical Ground Terminals – Need minimum set of ground locations

- Would like to use commercial ground terminals
- *NASA Experimental* optical grounds stations in HI, CA and NM



Near Earth Optical (2 of 3)

Experimental GEO Relay Optical Terminal in Operations

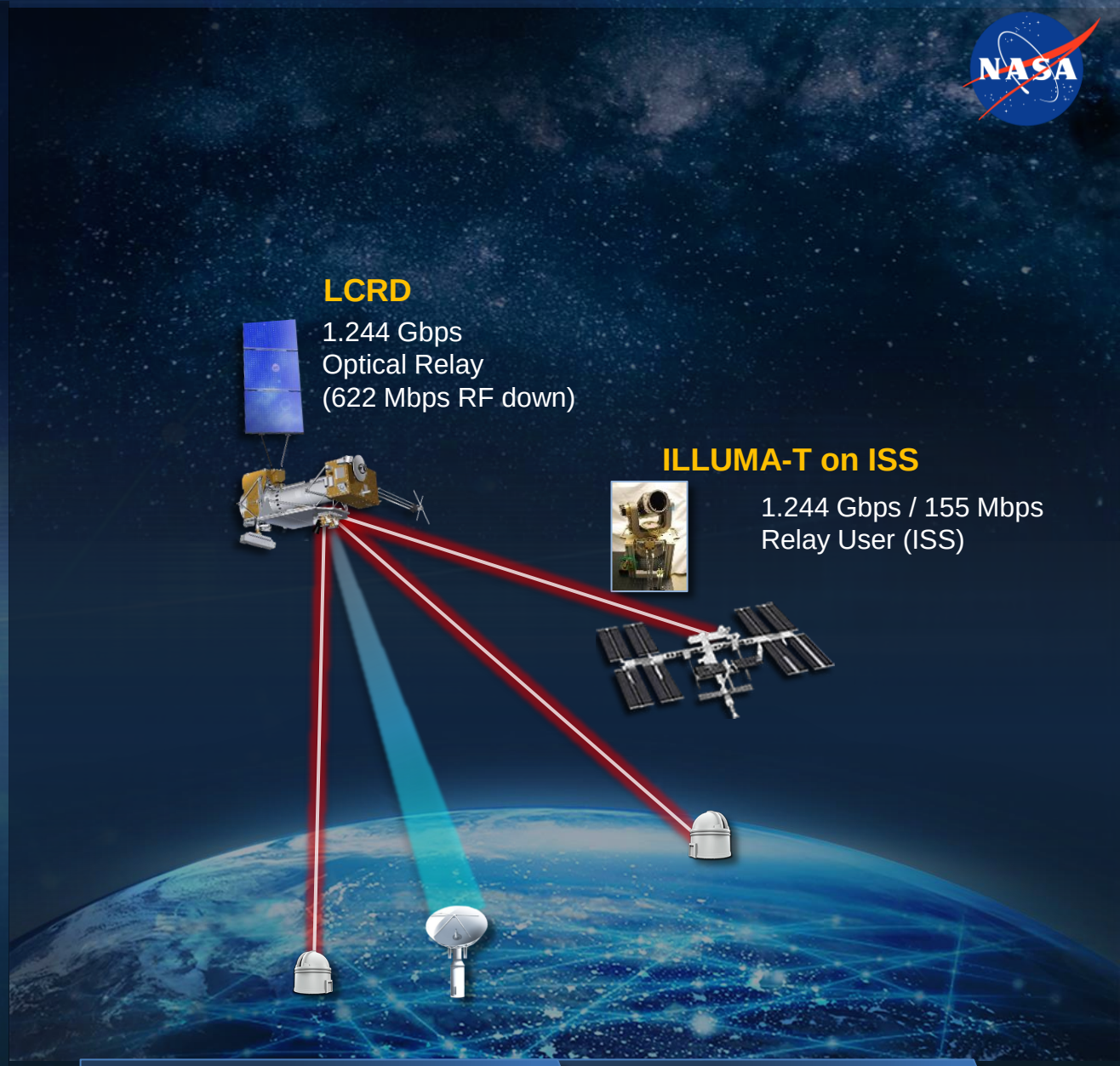
Laser Communications Relay Demonstration (LCRD)

- Launch Date: December 2021
- Purpose: Demonstrate GEO optical relay (Similar to TDRS for RF)
- Hosted payload: US Air Force; STPSat-6 (GEO satellite)
- Date rate: 1.244 Gbps user rate (2.88 Gbps uncoded)

LEO User Relay Terminal ready for Demonstration

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

- Launch Date: Late 2023 on SpaceX-27 to ISS
- 6-month primary mission
- Purpose: Demonstrate optical communication via GEO relay with ISS/ILLUMA-T as the LEO user



Near Earth Optical (3 of 3)

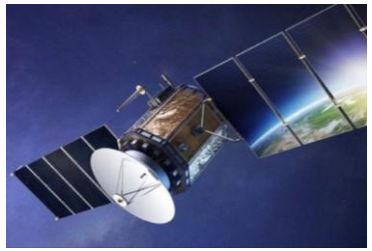
- Six SATCOM vendors were selected in June 2022 for the first cycle of development and demonstration activities, laying the groundwork to replace TDRS with commercial services
- Two of the six will demonstrate optical communication
- Numerous commercial communications service providers and aerospace companies are developing optical communications with primary focus on intersatellite links

Inmarsat

- Commercial GEO L-band relay network
- Low-rate SATCOM services
- Support to routine missions, contingency operations, launch, ascent, and early operations

Kuiper Government Solutions

- Optical LEO network
- High and low-rate services
- Supporting routine, contingency, and early operations



SES Government Solutions

- GEO and MEO network with C-band and Ka-band
- High and low-rate services
- Supporting routine, contingency, launch and ascent, and early operations

SpaceX

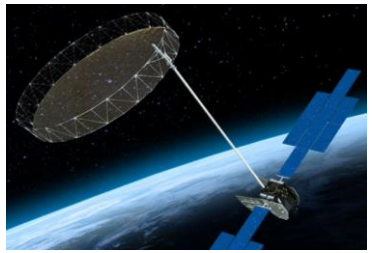
- Optical LEO network
- High-rate services
- Routine, contingency, launch and ascent, and early operations support

Telesat U.S. Services

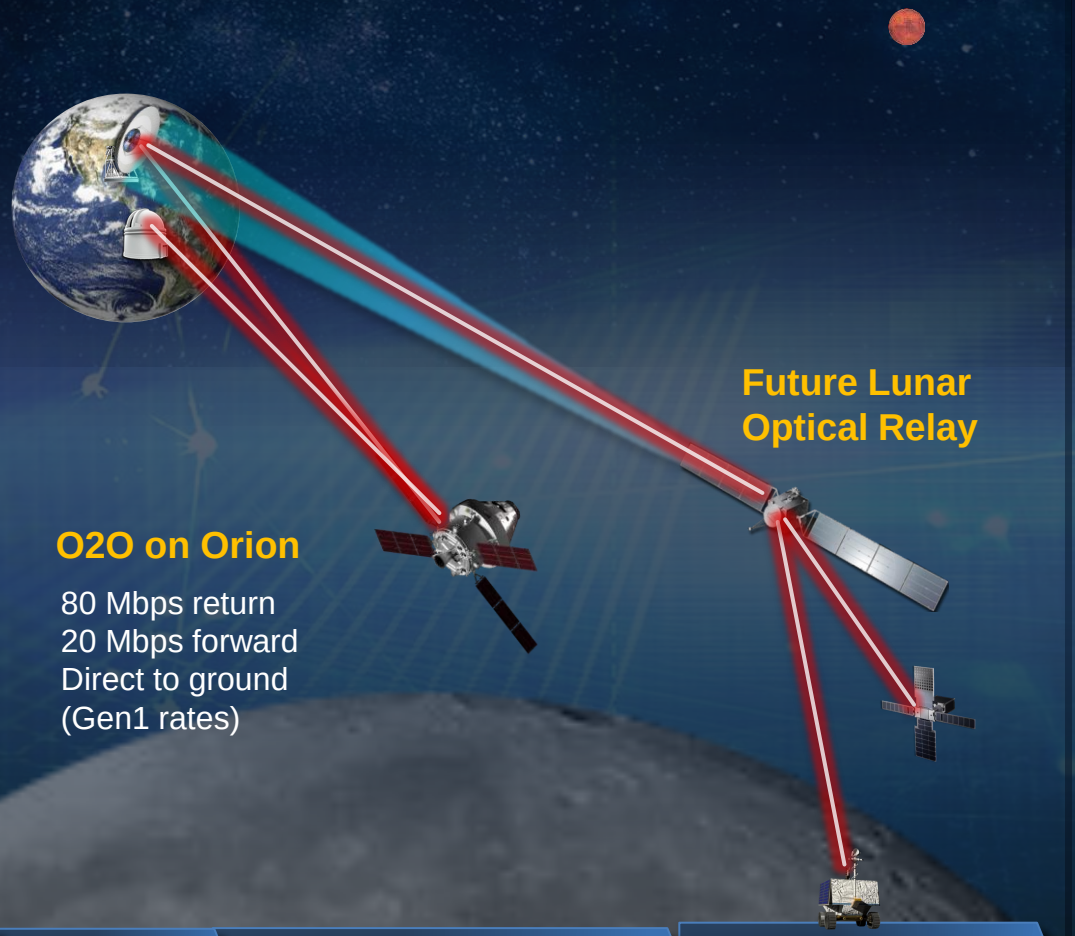
- RF relay networks offering C- and Ka-band services for high and low-rate communications
- Support to routine missions

Viasat

- GEO Ka-band relay network
- High- and low-rate communications services
- Routine launch and mission support



Lunar Optical



LLCD 2013 → O2O 2024 → Coherent Modulation for lunar trunk links → Future Lunar Optical Relay

Optical Ground Terminals

Lunar Optical Capabilities ready for infusion with investment and user commitment

Lunar Laser Communications Demonstration (LLCD)

- Launch Date: Sep 2013
- Demonstrated fundamental concepts of laser communications from Moon for Direct-to-Earth links at 622 Mbps

Lunar user optical terminal demonstration on Orion Artemis II Optical (O2O)

- Lunch Date: 2024 (Artemis II)
- Demonstrate crewed DTE optical link capability from Moon
- Enables return of all onboard data before vehicle Earth return

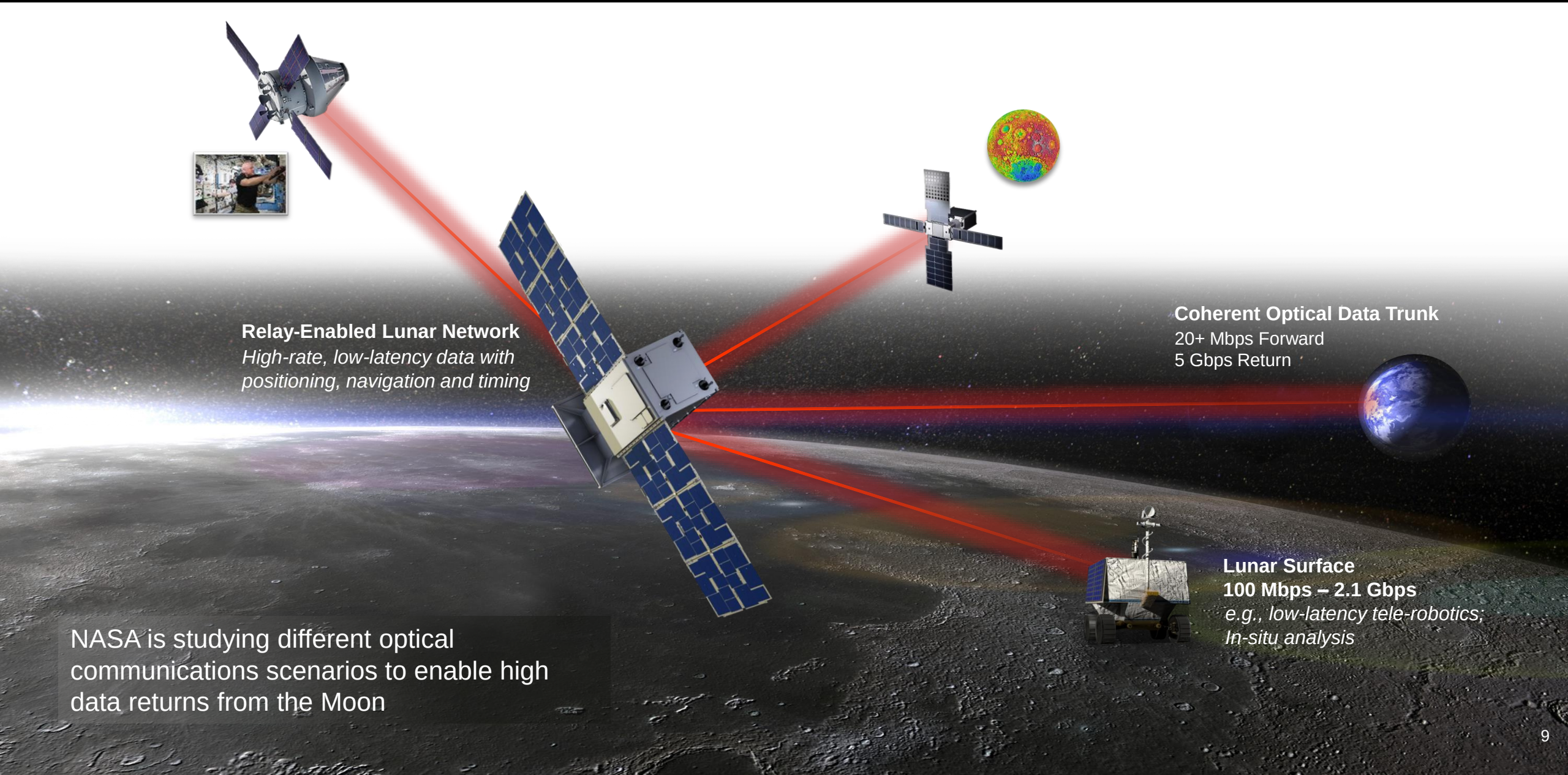
Higher data rates for lunar trunk links

- Current deep space optical links support data rates < 1 Gbps
- Coherent optical links enable 5–10 Gbps from Moon
- Could be available for lunar demo in late 2020s

Lunar Optical Ground Terminals for Artemis

- Existing *experimental* optical ground terminal in HI, CA, and NM
- Would like an additional 3-4 optical ground terminals around the globe to support Artemis; gaining southern hemisphere coverage is especially important

Potential Optical Communications for Future Artemis Missions



NASA is studying different optical communications scenarios to enable high data returns from the Moon

Deep Space Optical

Deep Space Optical Capability is ready to be demonstrated; deep space mission adoption to follow

Deep Space Optical Communications (DSOC) on Discovery Pysche Mission

- Launch Date: Oct 2023
- Purpose: Demonstrate deep space optical links on outbound trajectory to 2.6 AU (Mars-far-like distance)
- Collaboration with STMD/GCD and SMD

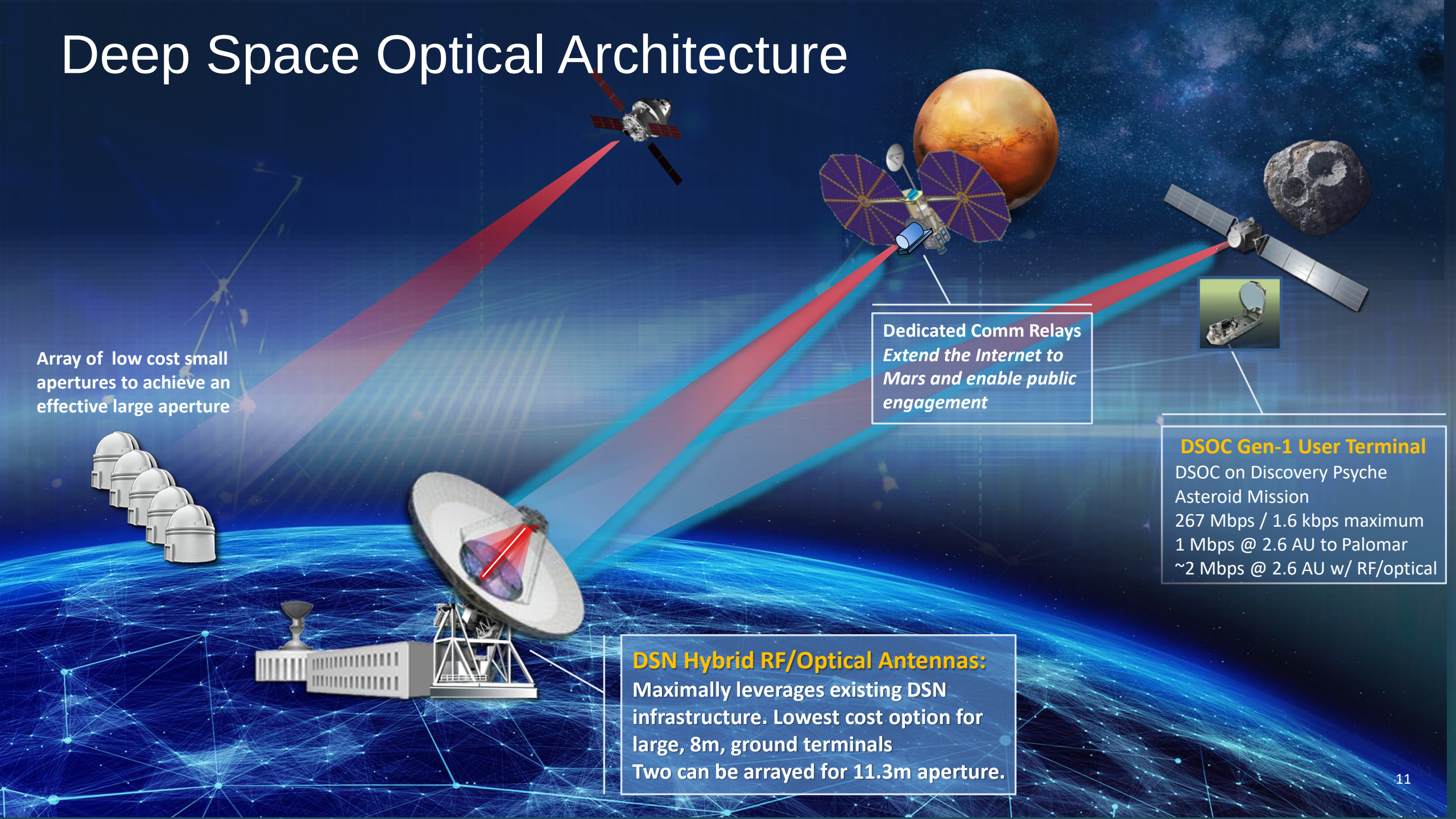
RF/Optical Hybrid Antenna

- Lowest cost option for large, 8m, ground terminals
- Two can be arrayed for 11.3m aperture
- Maximally leverages existing DSN infrastructure

Optical will be essential for future human missions to Mars

- RF insufficient even for first missions to collect planning data/imagery
- Up/down-link rates needed for crewed operations

Deep Space Optical Architecture



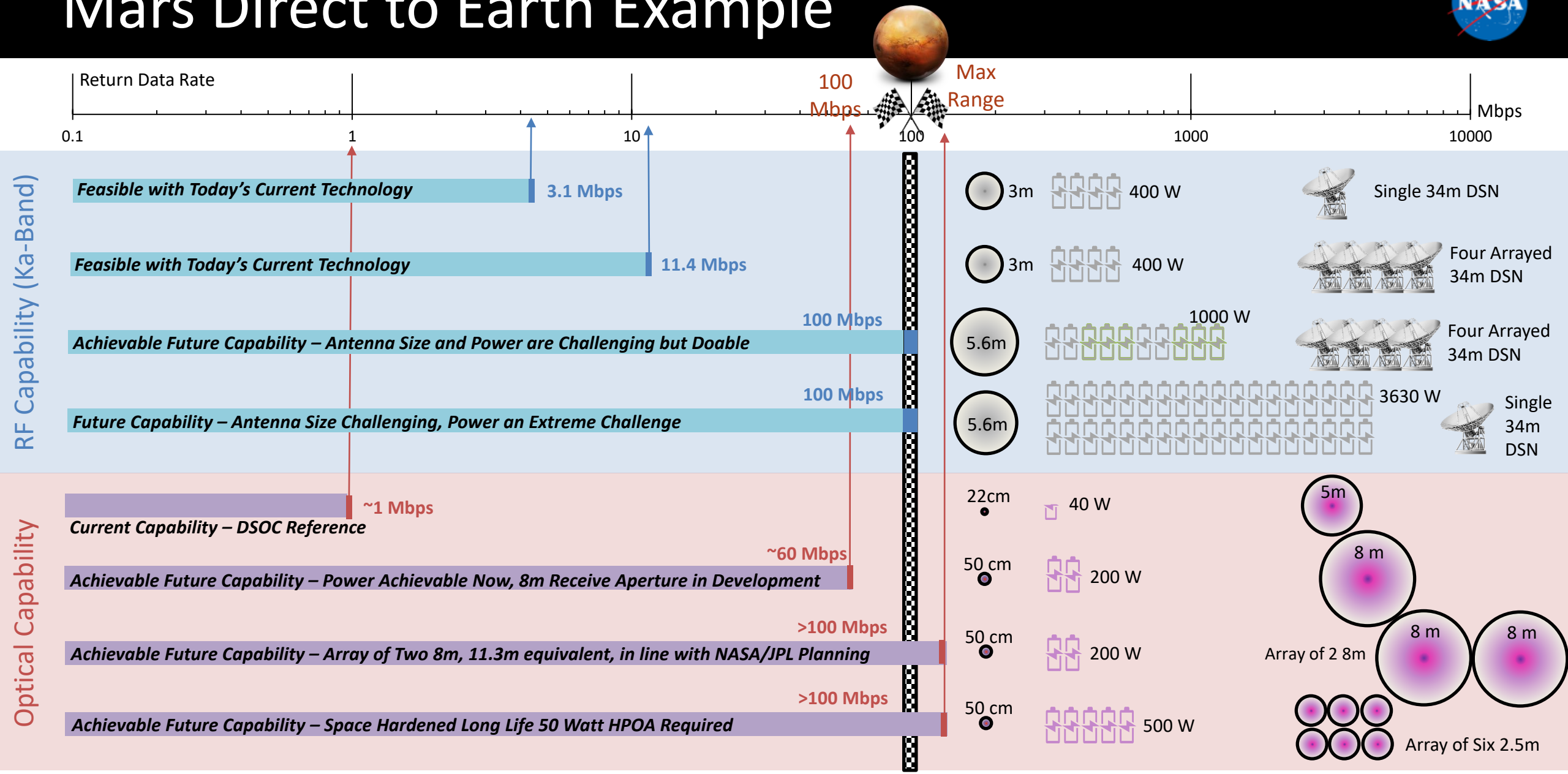
Array of low cost small apertures to achieve an effective large aperture

Dedicated Comm Relays
Extend the Internet to Mars and enable public engagement

DSOC Gen-1 User Terminal
DSOC on Discovery Psyche Asteroid Mission
267 Mbps / 1.6 kbps maximum
1 Mbps @ 2.6 AU to Palomar
~2 Mbps @ 2.6 AU w/ RF/optical

DSN Hybrid RF/Optical Antennas:
Maximally leverages existing DSN infrastructure. Lowest cost option for large, 8m, ground terminals
Two can be arrayed for 11.3m aperture.

Mars Direct to Earth Example



Spacecraft RF antenna size (m)

Spacecraft Power for RF TX, 100W (50% eff)

Spacecraft Power for Optical Transmit, 100W (10% eff)

Spacecraft Optical Transmit Aperture (cm)

Optical Receive Aperture (m)

Not to scale

Summary

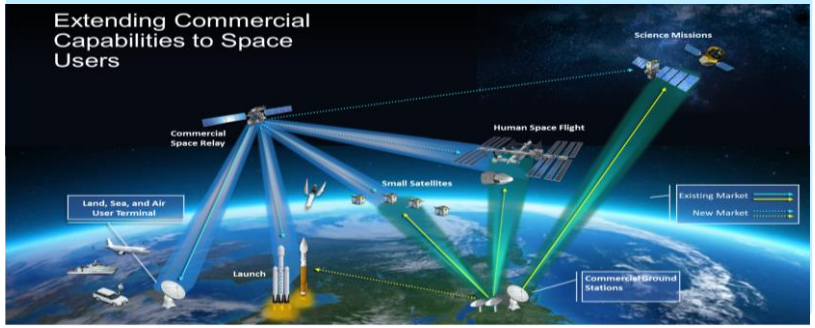
Near Earth

SCaN Foundation / Accomplished:

- T-BIRD demonstration 2022
- LCRD in demonstration operations
- ILLUMA-T ready for ISS demo in 2023
- Commercial SATCOM optical demos awarded
- Low-Cost Optical Terminal (Ground) advancement

Forward Strategy:

- Transfer optical DTE capability to commercial
- Bring commercial space-to-space optical services into operations



Lunar

SCaN Foundation / Accomplished:

- Building upon the 2013 Lunar Laser Communications Demonstration (LLCD)
- Optical demo on Orion on track for 2024 (O2O)

Forward Strategy:

- Pursue optical trunk and local optical relay capability
- Leverage O2O terminal into future Orion flights
- Diversify optical Earth ground sites with partners and industry, build on LCOT

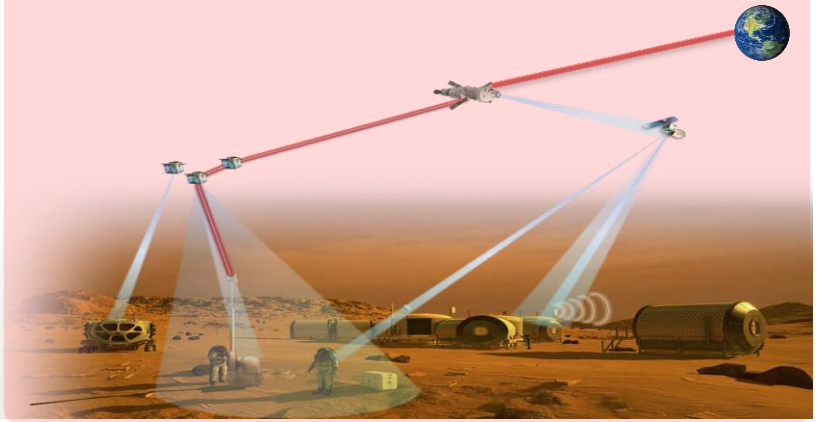
Mars and Deep Space

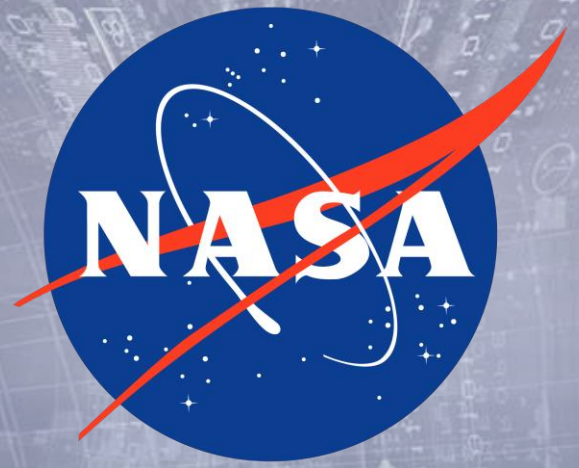
SCaN Foundation / Accomplished:

- Deep Space Optical Comm (DSOC) terminal ready for flight
- DSN hybrid RF/optical progress – 7 segment mirror installed on DSS-13

Forward Strategy:

- Psyche demo to validate architecture
- Optical infusion essential for human Mars





Questions?

Please feel free to contact:

Bernie Edwards

Deputy Communications & Navigation Systems Capability Lead

Space Technology Mission Directorate

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BACKUP

Optical Communications Technology Demonstrations

From Near Earth/Moon

LCRD
1.244 Gbps
Optical Relay
(622 Mbps RF down)

O2O
Lunar: 250/20 Mbps
(Gen2 Rates)

ILLUMA-T on ISS
1.244 Gbps / 155 Mbps
Relay User (ISS)

TBIRD
2U CubeSat Payload
2TB On-board Storage
200 Gbps LEO to Earth

To Deep Space

DSOC Gen-1 User Terminal
DSOC on Discovery Psyche Asteroid Mission
267 Mbps / 1.6 kbps maximum
1 Mbps @ 2.6 AU to Palomar
~2 Mbps @ 2.6 AU w/ RF/optical

RF/Optical Hybrid Antenna
Integrate 8-m optical apertures into a DSN 34m Beam Waveguide antenna

LCRD 2021	TBIRD 2022	ILLUMA-T 2023	O2O 2024 (Artemis II)	Lunar Relay *TBD*

Psyche/DSOC Optical User Terminal (2023)	Advanced DSOC Optical User Terminal (2026+)

PSC73_092419

Optical Roadmap

Pre-2021 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028

Demonstrations

- LADEE
- LCRD
- TBIRD
- Illuma-T
- Psyche
- 7 Segment Hybrid RF
- O2O
- 64 Segment Hybrid RF (Planned)

Near Earth

inmarsat | amazon | project kuiper | SES | SPACEX | TELESAT | Viasat

Services

- Communications Services Project: Capability Development and Demonstrations
  - Round 1 Demonstrations Complete
  - Validation Tasks Complete
- Early Adopter & Service Validations

User Terminal

- User Terminal Development
- Demonstration Missions
- Terminal Market Maturation

Ground Terminals

- Mission Specific Terminals
- Demonstration Missions
- Commercial Transfer

Operational Commercial Services

Moon to Mars

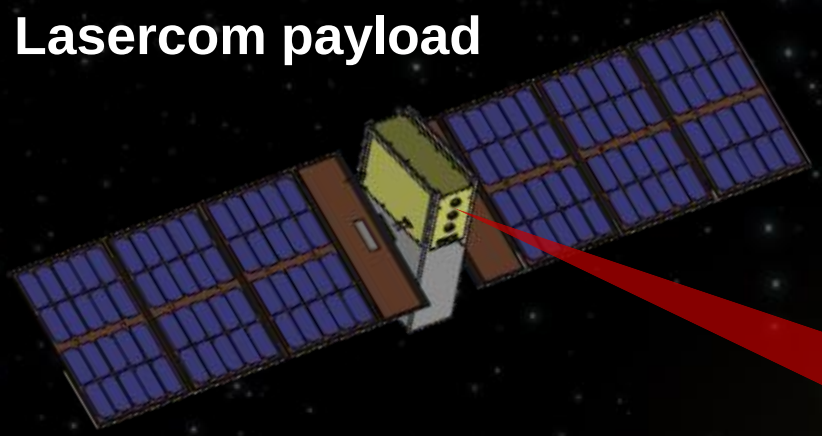
- Deep Space User Optical Terminals
- Prototype Ground Terminal Development

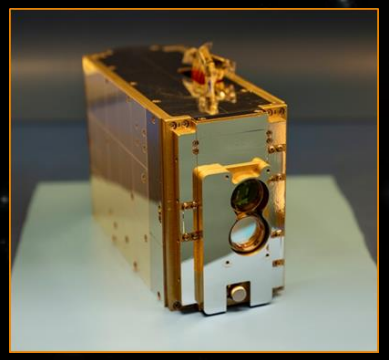
Unfunded Goals

Today

Terabyte Infrared Delivery (TBIRD) Mission

6U CubeSat in LEO
3U Lasercom payload





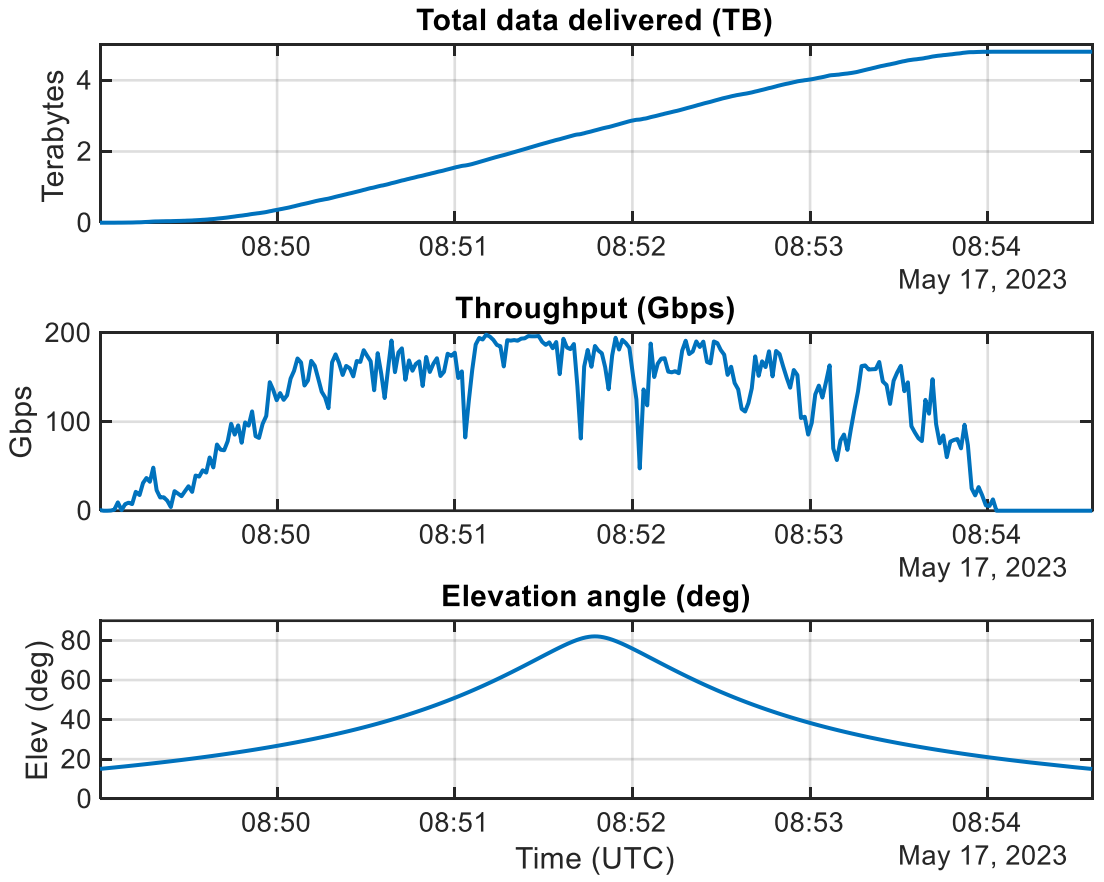
200 Gbps downlink

- Leverage fiber telecom equipment for 200 Gbps burst delivery (TBs per pass)
- Downlinked 4.8 TB error-free in single pass
- Body pointed with payload pointing feedback

Ground terminal at JPL's Optical Communication Telescope Laboratory (OCTL) in Southern California

TBIRD Data Delivery Example (5/17/23)

- Operated in 200 Gbps mode (100 Gbps on two wavelength channels)
- Downlinked 4.8 TB error-free in 5 minutes
- Throughput is the end-to-end error free data rate (1-second averaging)
- Reached 200 Gbps throughput



TBIRD has achieved the fastest downlink from space

Upcoming Commercial SATCOM Demonstrations

- Six SATCOM vendors were selected in June 2022 for the first cycle of development and demonstration activities, laying the groundwork to replace TDRS with commercial services
- Two of the six will demonstrate optical communication
- Numerous commercial communications service providers and aerospace companies are developing optical communications with primary focus on intersatellite links

inmarsat

- Commercial GEO L-band relay network
- Low-rate SATCOM services
- Support to routine missions, contingency operations, launch, ascent, and early operations

Kuiper Government Solutions

amazon | project kuiper

- Optical LEO network
- High and low-rate services
- Supporting routine, contingency, and early operations

SES GOVERNMENT SOLUTIONS

- GEO and MEO network with C-band and Ka-band
- High and low-rate services
- Supporting routine, contingency, launch and ascent, and early operations

SPACEX

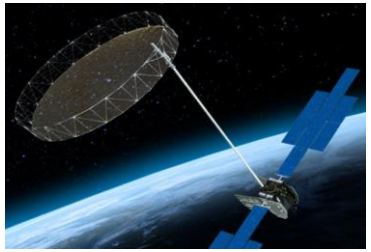
- Optical LEO network
- High-rate services
- Routine, contingency, launch and ascent, and early operations support

TELESAT U.S. SERVICES

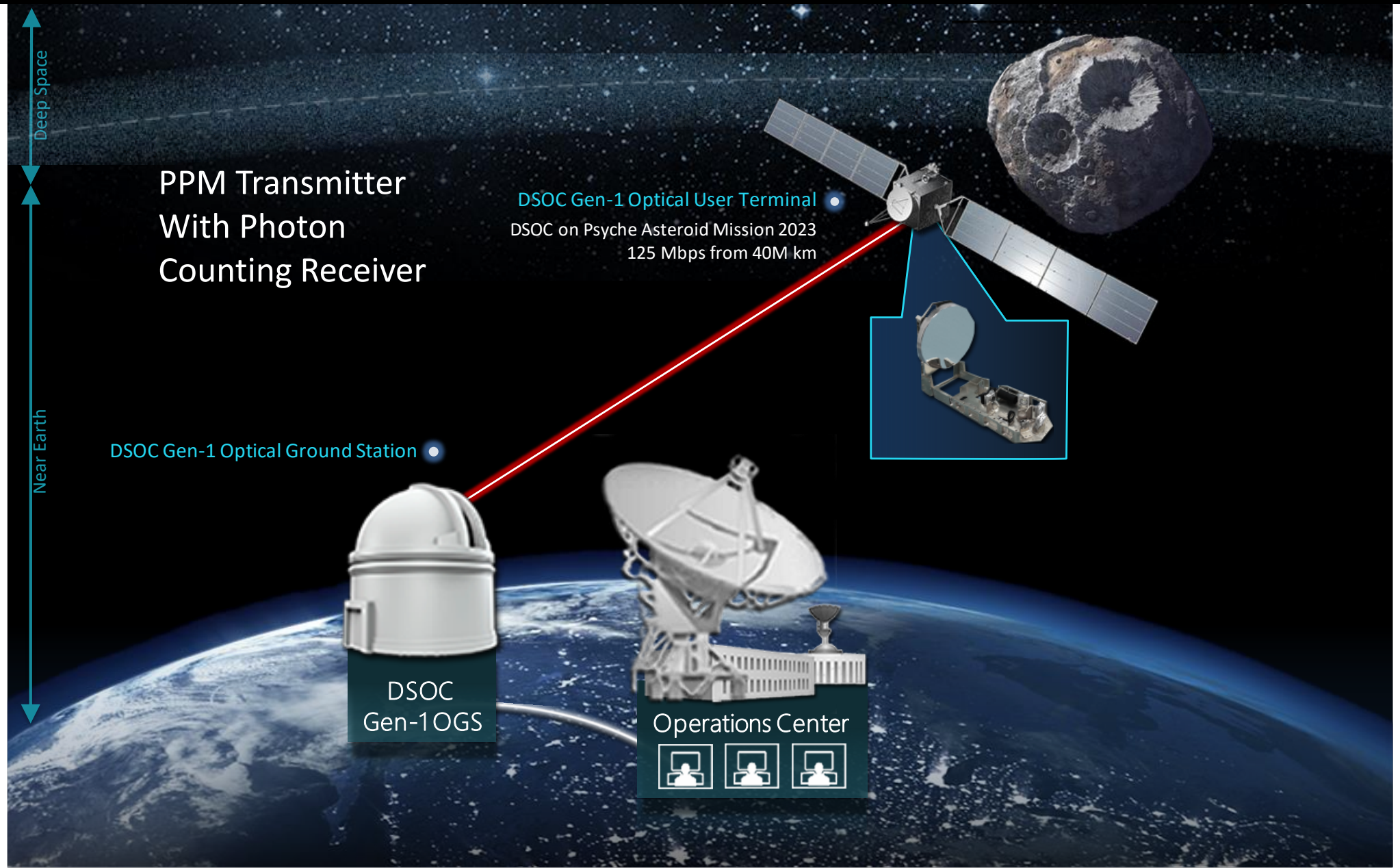
- RF relay networks offering C- and Ka-band services for high and low-rate communications
- Support to routine missions

Viasat

- GEO Ka-band relay network
- High- and low-rate communications services
- Routine launch and mission support

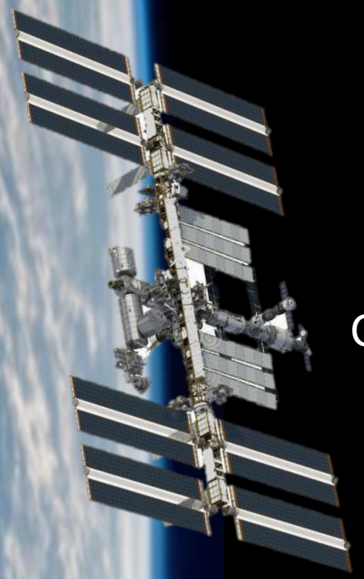


Deep Space Optical Communications (DSOC)



Optical Communications for Human Space Exploration

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



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

Completed system level vibe and TVAC – July 2023

November 1, 2023 Launch on SpaceX-29

~6 Month Mission

O2O
(Orion AM-2 Optical Comm)

80 Mbps return
20 Mbps forward
(Gen1 rates)
Direct to ground (WSC, TMF)

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

Handover and mechanical integration to Orion completed July 2023

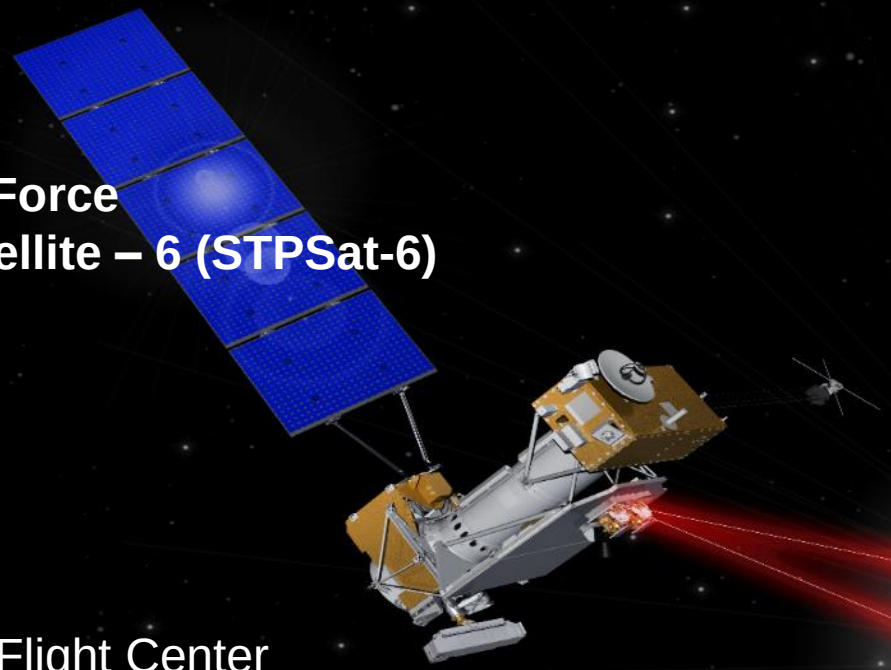
2024 Launch on Orion/SLS

2021 Laser Communications Relay Demonstration (LCRD)

Launched December 2021

Mission duration:
- Two-year ops demo

Hosted payload: US Air Force 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

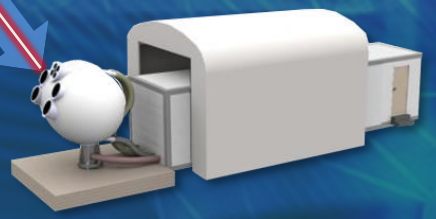
Guest investigators welcome!
URL: https://esc.gsfc.nasa.gov/projects/LCRD
Email: lcrd-experiments@nasa.onmicrosoft.com

Lunar Laser Communications Demonstration (LLCD)

- Launched Sep 6, 2013
- Flown on Moon on the Lunar Atmosphere and Dust Environment Explorer (LADEE)
  - Goal: demonstrate fundamental concepts of laser communications beyond GEO
- Led by NASA GSFC, space terminal and primary ground terminal (Lunar Laser Communication System) built by MIT/LL
- LLCD resulted in record-breaking achievement using broadband lasers for space communications
- Used pulsed laser beam to exchange data and high-definition video between lunar-orbiting terminal and ground station at White Sands, New Mexico

LLCD system:
- ✓ **50% less mass**
- ✓ **25% less power**
- ✓ **6x data-rate than comparable (LRO) RF system**

- ***IMMEDIATE LASER CONTACT* on October 17, 2013**
- **LLCD returned data by laser to Earth at a record 622 Megabits per second (Mbps)**
- **= Streaming 30+ HDTV Channels Simultaneously**
- **Ended Nov 22, 2013**



Data received via four **40 cm** downlink telescopes (0.50 m^2 surface area)

2014 Popular Mechanics Breakthrough Award for Leadership and Innovation for LADEE

2014 R&D 100 Winning Technology in Communications category

Nominated for the National Aeronautic Association's Robert J. Collier Trophy

Winner of the National Space Club's Nelson P. Jackson Award for 2015

Revolutionary capability for space users