National Aeronautics and
Space Administration

Addressing High-Rate Communications in NASA’s Space Technology Mission Directorate’s Envisioned Future

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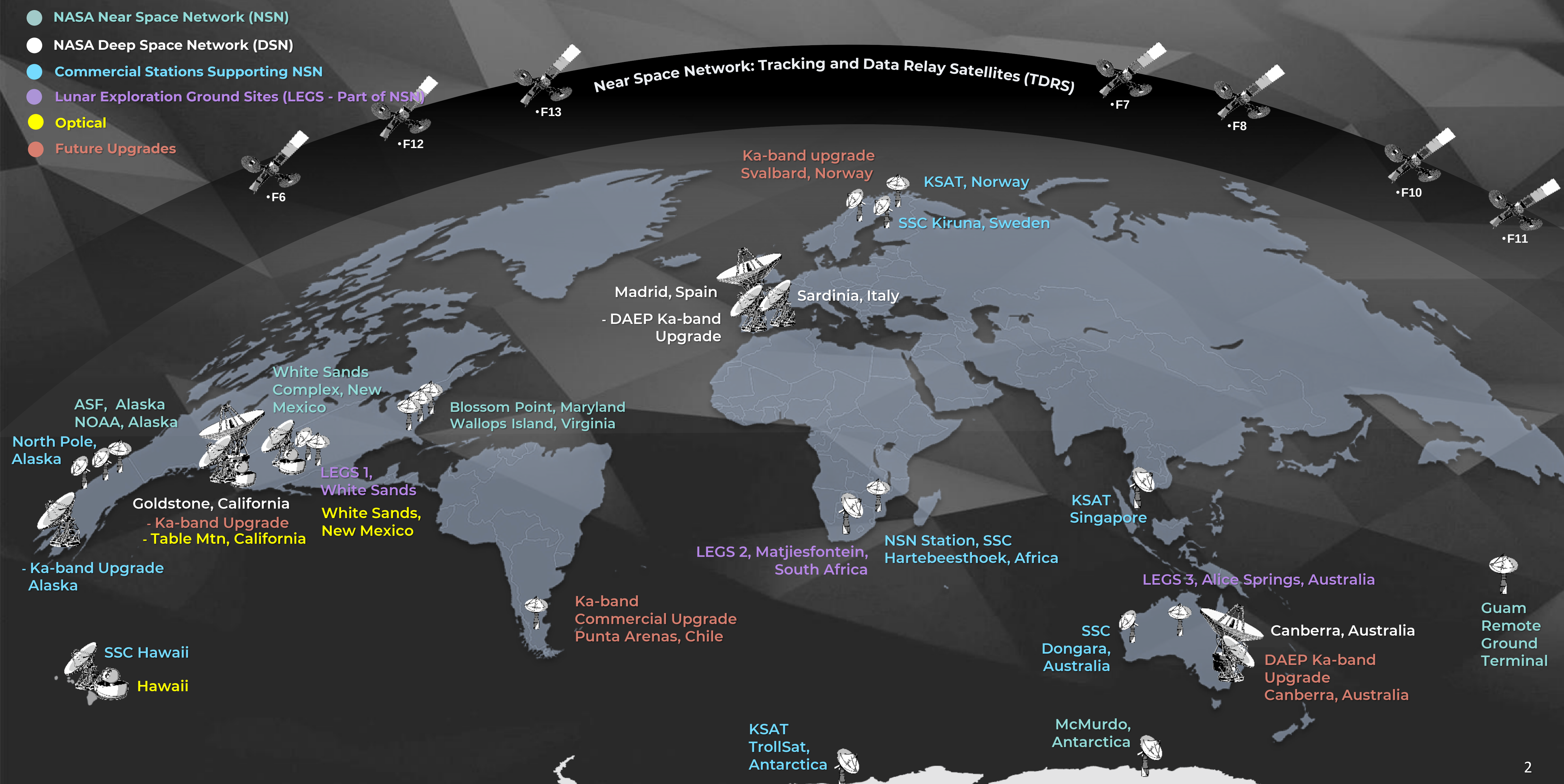
Deputy Communications & Navigation Systems Capability Lead
NASA Space Technology Mission Directorate

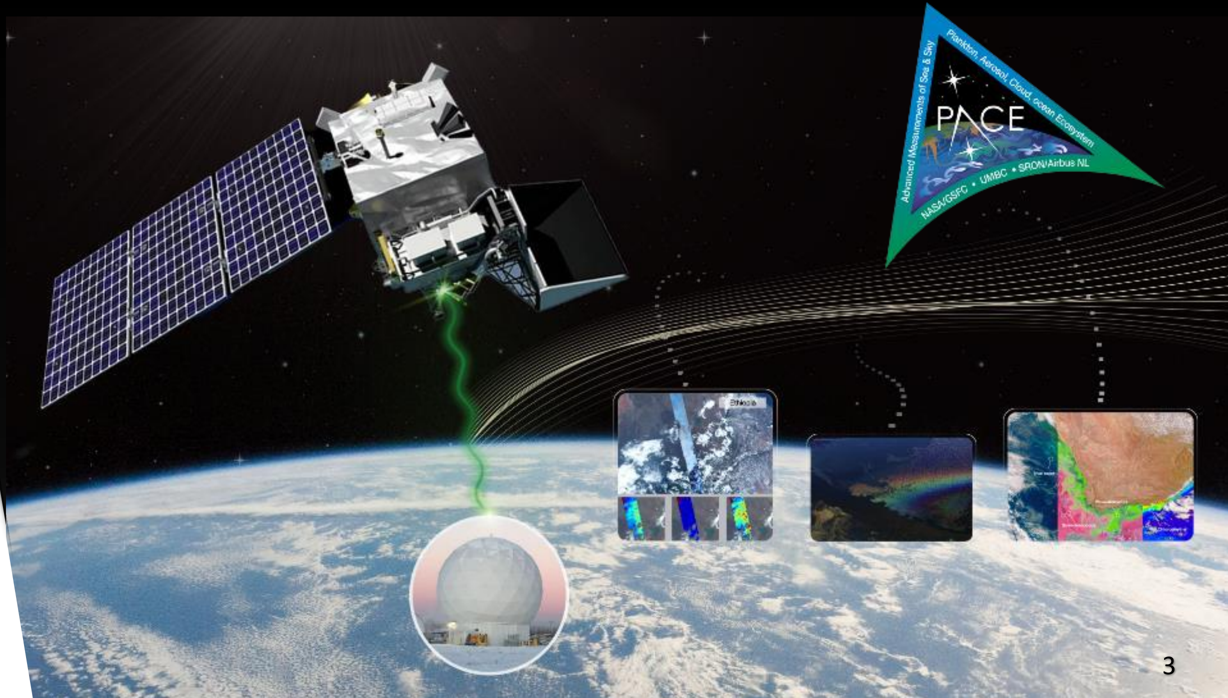
June 2025

NASA's Communications Networks



Today’s High Data Intensive Missions

- Evolving instruments, payloads, and needs are driving data volume demand
  - The Plankton, Aerosol, Cloud and Ocean Ecosystem (PACE) mission, launched in 2024, produces 5 terabits of data per day
  - The NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) mission, to be launched in 2025, will produce 85 terabytes of data per day
- This class of mission creates three orders of magnitude more data than the Hubble Space Telescope (HST)
- Exponential demand growth will strain NASA’s current network capabilities



The Deep Space Network

- **Today, NASA's deep space communications are provided by the Deep Space Network (DSN), a worldwide network of radio frequency ground stations located in Australia (Canberra), Spain (Madrid), and the United States (Goldstone, California).**
- **Each of the three DSN sites has at least four antennas with ultra-sensitive receiving systems:**
  - **One 70-meter antenna**
  - **Three or more 34-meter beam waveguide antennas**
- **The DSN has been a huge success since its inception. However, the DSN is at capacity and oversubscribed.**
  - **At times, demand exceeds capacity by > 40%**
- **Furthermore, future deep space science missions will require higher data rates than possible today. The sustained human exploration of the Moon and eventually Mars will also exceed the current capabilities of the DSN.**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NASA officials sound alarm over future of the Deep Space Network

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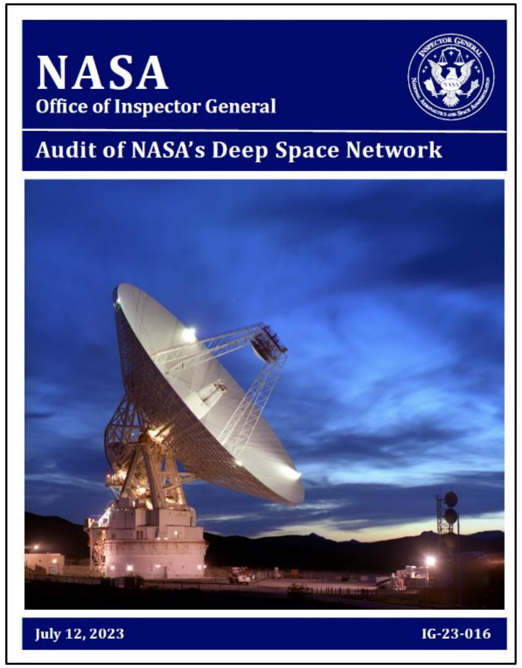
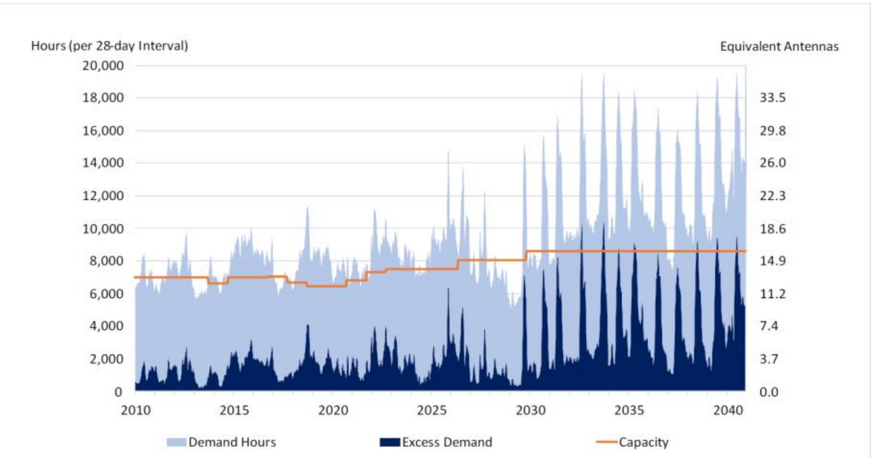
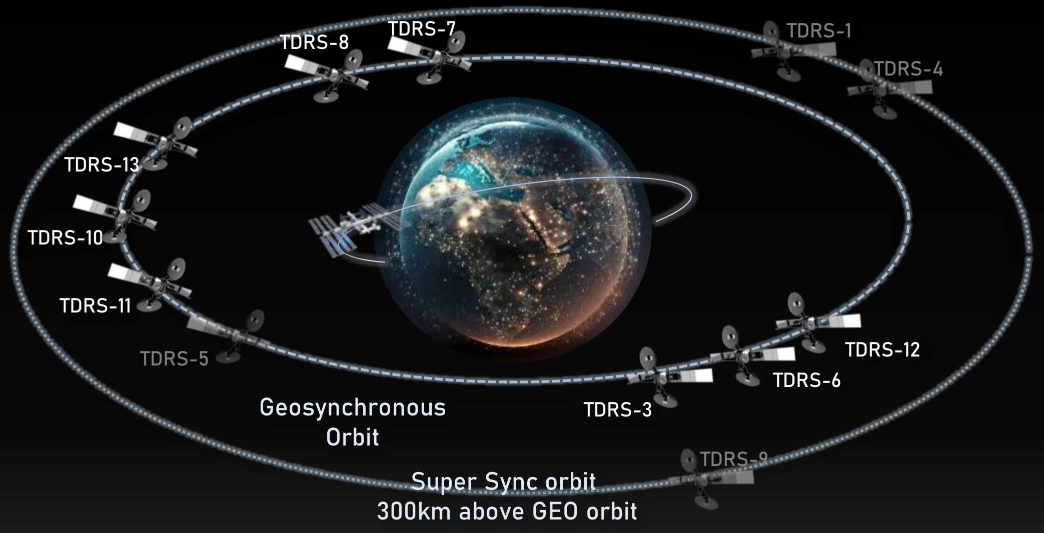




The Tracking and Data Relay Satellite System

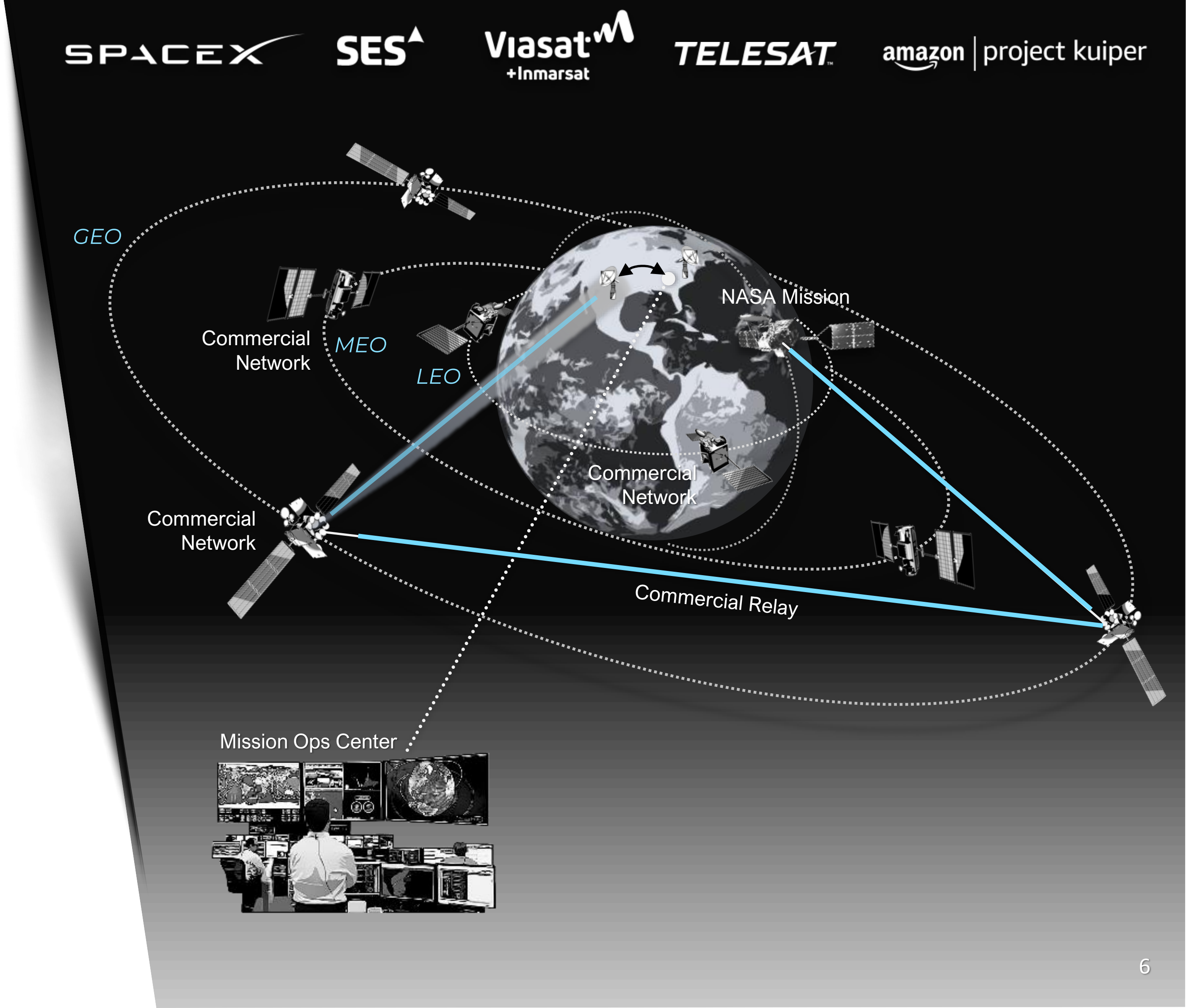
- **Origins of NASA's Tracking and Data Relay Satellite (TDRS) System were with the Space Shuttle and the driving need for 24x7 coverage**
  - Built up over decades with three generations of satellites – the first launched in 1983 and the last satellite in 2017
  - Capabilities incrementally improved, but the fundamental architecture remained consistent over 40+ years
- **The TDRS Fleet is anticipated to be reduced to 3 satellites as early as 2028**
  - Preventing new missions from entering the service queue is critical to risk mitigation
  - O&M of the remaining fleet will be focused on retaining global coverage into the 2040s for current users (e.g., Hubble Space Telescope)

- Options for new TDRS spacecraft is not supported by US National Space Policy
- As of August 8, 2024, NASA suspended acceptance of new mission commitments for TDRS support.



A Pivot to Commercial Space Relay

- **In 2020, NASA's Space Communications and Navigation (SCaN) Program defined a strategy to transition NASA's Low Earth Orbit missions to commercial Space Relay services**
  - Commercial services will provide transformative new capabilities to science missions
  - Communications Services Project (CSP) is targeting operational commercial space relay service by 2031



Unlocking Next Generation Technology and Services

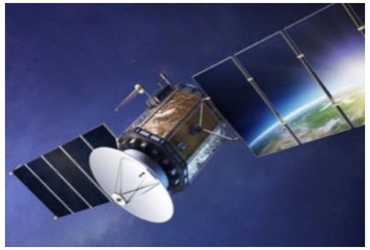
- Six SATCOM vendors were selected in June 2022 for the first cycle of development and demonstration activities, laying the groundwork to replace TDRS with commercial services
- Two of the six will demonstrate optical communication
- Numerous commercial communications service providers and aerospace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

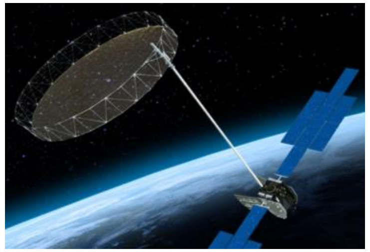
- Optical LEO network
- High-rate services
- Routine, contingency, launch and ascent, and early operations support

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



WHAT IS STMD?

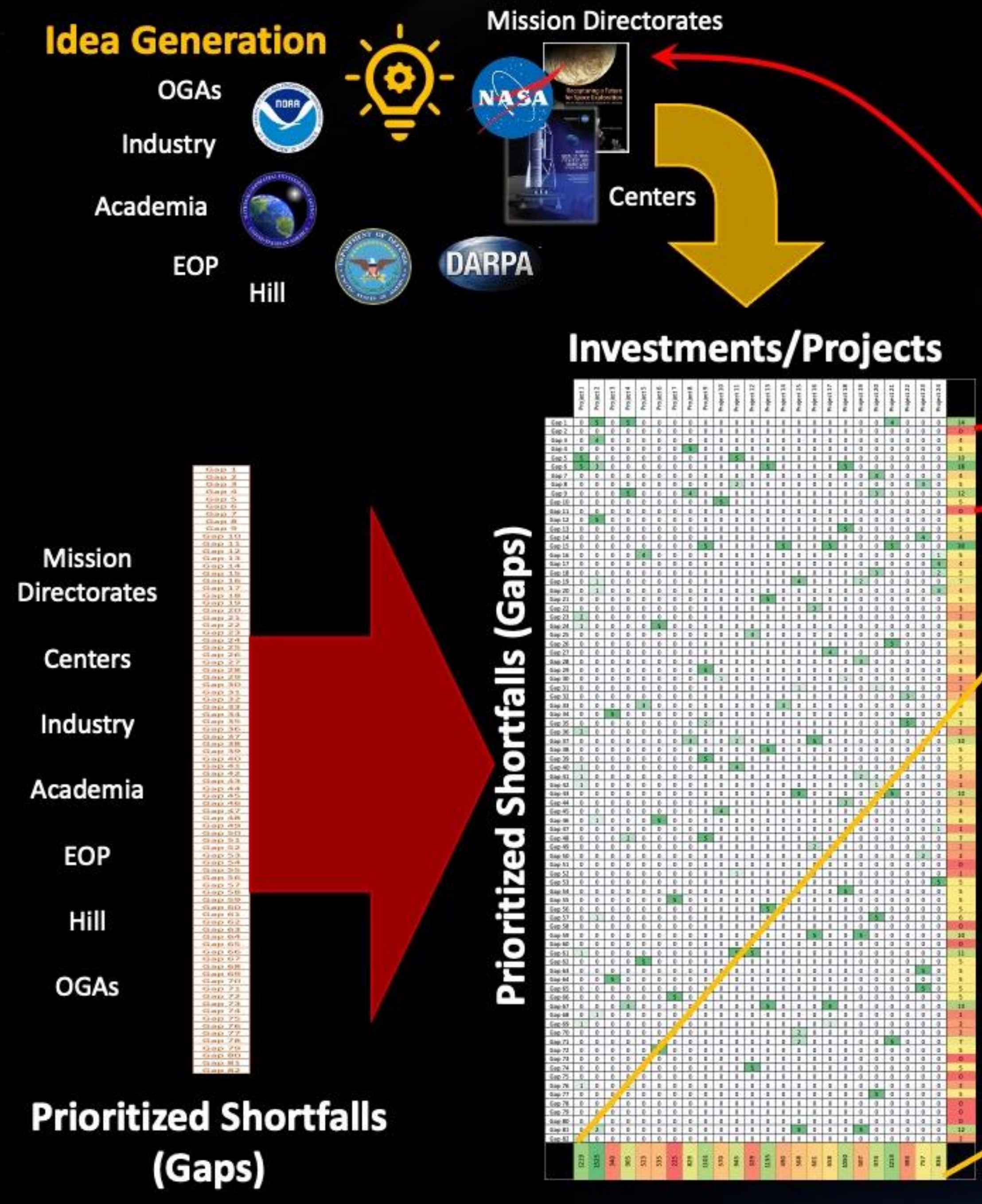
NASA's Space Technology Mission Directorate (STMD) is charged with developing the technology base for civil space, enabling key capabilities for all aspects of space exploration and discovery.

This is accomplished with limited resources and a need for balanced portfolios across various technologies.

A critical technology area is Communications & Navigation

National Tech Base Priorities

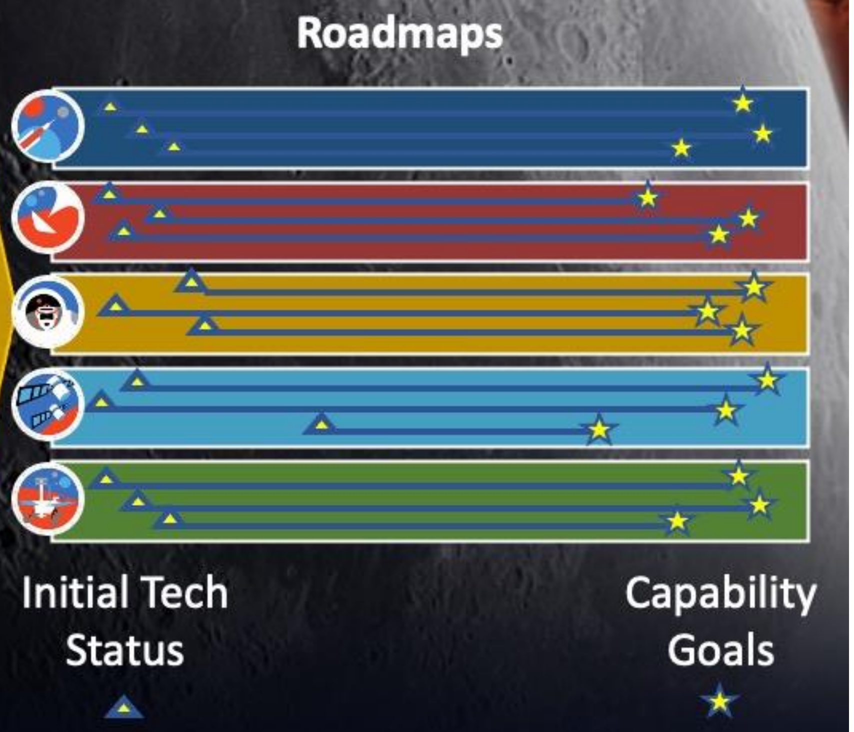
Publicly-transparent, rigorously-developed process by which we establish our priorities based on comprehensive prioritized needs of our stakeholders



Projects

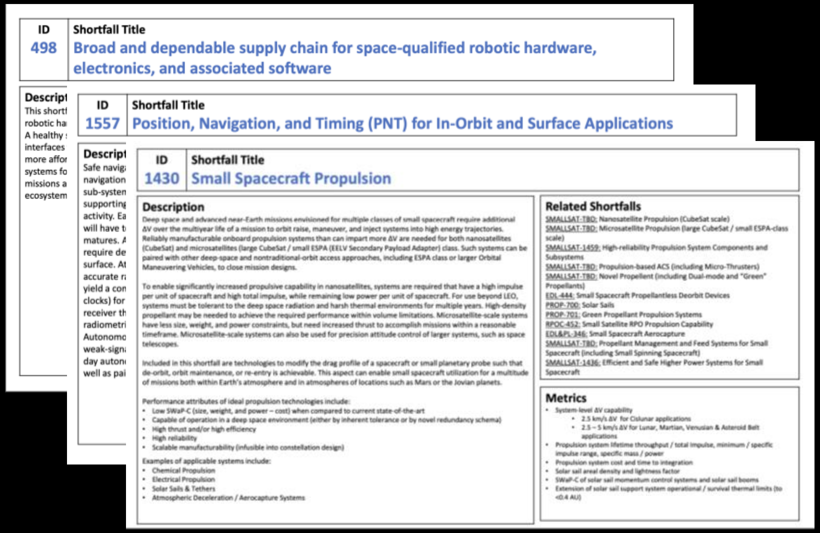
Project 2	1525
Project 1	1219
Project 21	1213
Project 13	1135
Project 9	1101
Project 18	1050
Project 20	974
Project 11	535
Project 4	905
Project 24	836
Project 8	393
Project 23	757
Project 17	658
Project 16	601
Project 10	570
Project 15	568
Project 6	829
Project 5	523
Project 19	507
Project 14	490
Project 22	393
Project 3	340
Project 12	329
Project 7	225

$$$



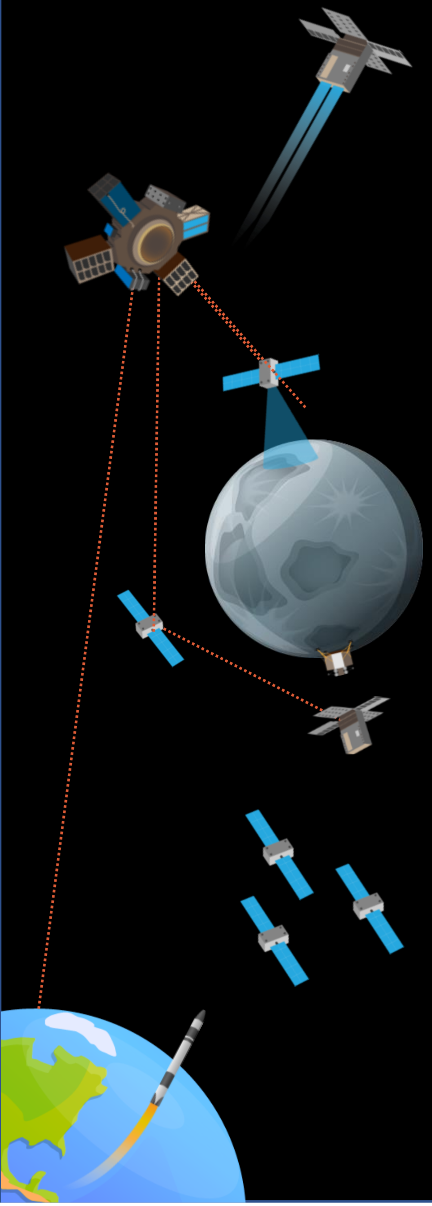
Civil Space Shortfalls

- NASA compiled an initial list of **187 shortfalls** organized into **20 capability areas**
- The shortfall description document and feedback form were organized accordingly



NASA identified an initial list of 187 shortfalls and invited the community to give input on <u>your critical technology needs</u> using this feedback mechanism.

Capability Categories	# of Shortfalls
Advanced Habitation Systems	16
Advanced Manufacturing	12
Advanced Materials & Structures	4
Autonomous Systems & Robotics	23
Avionics	7
Communication & Navigation	4
Cryogenic Fluid Management	5
Dust Mitigation	3
Entry, Descent & Landing	13
Excavation, Construction & Outfitting	9
In-Situ Resource Utilization	10
In-Space Servicing, Assembly & Manufacturing	9
Orbital Debris	3
Power	8
Propulsion	18
Sensors & Instruments	12
Small Spacecraft	8
Surface Systems	10
Thermal Management Systems	8
Miscellaneous	5



Driven by stakeholder needs, four high-priority Communications & Navigation technology shortfalls were identified:

- In-Situ Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications
- High-Rate Communications Across the Lunar Surface
- Deep Space Autonomous Navigation
- High-Rate Deep Space Communications

Notional

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:

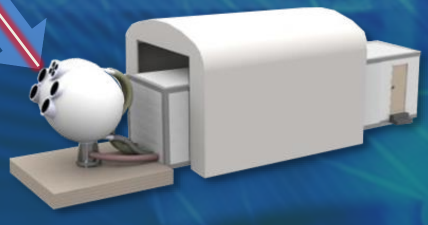
- ✓ **50% less mass**
- ✓ **25% less power**
- ✓ **6x data-rate than comparable (LRO) RF system**

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 WINNER

2014 R&D 100 Winning Technology in Communications category

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

NATIONAL SPACE CLUB WASHINGTON D.C.

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

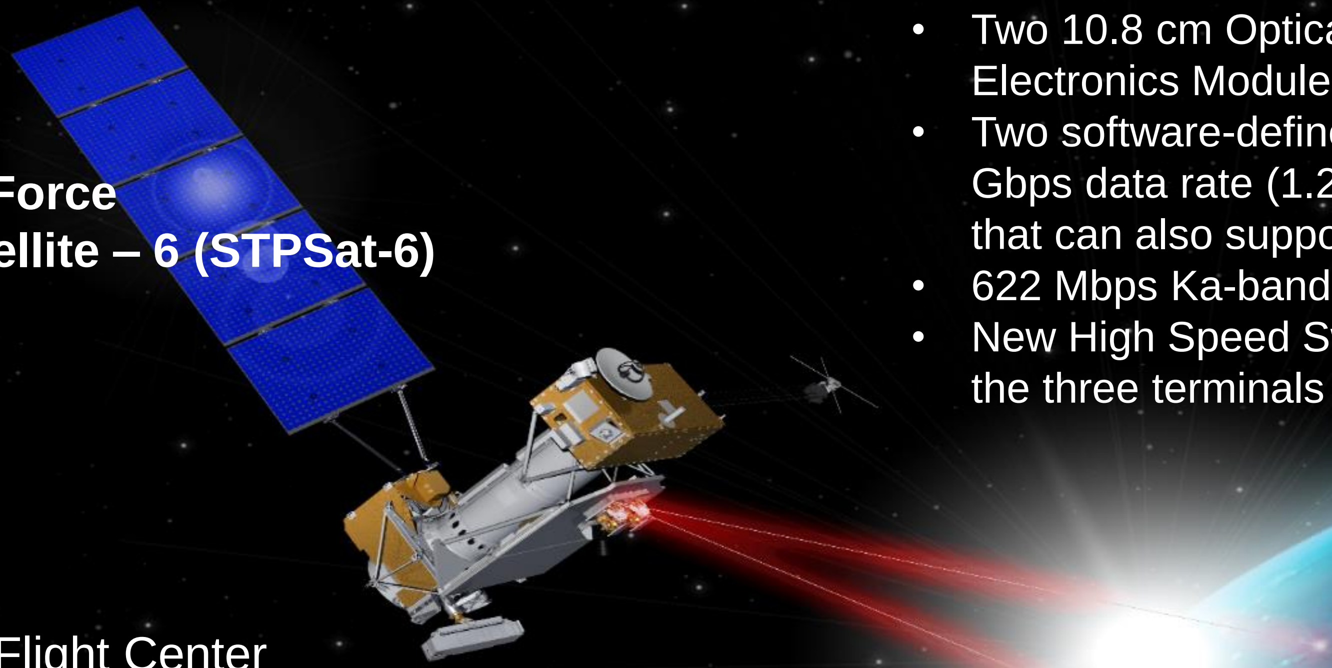
Revolutionary capability for space users

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

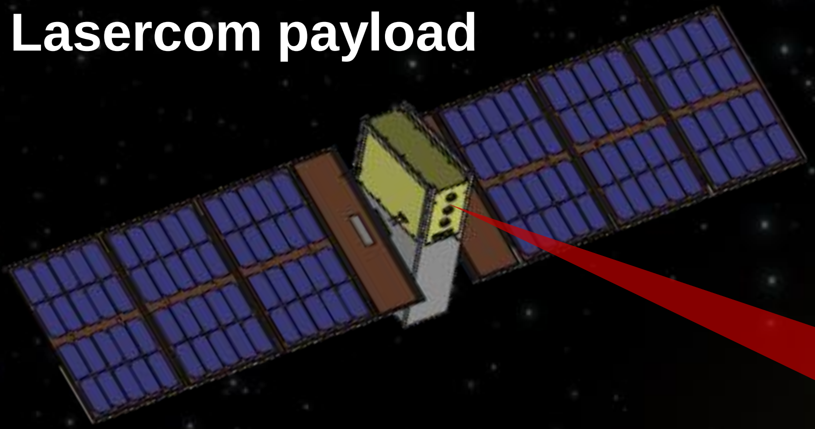
Flight payload:

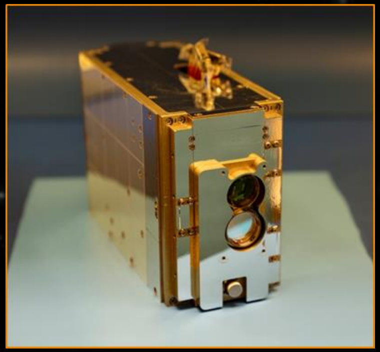
- Two 10.8 cm Optical Modules and Controller Electronics Modules
- Two software-defined DPSK Modems with 2.88 Gbps data rate (1.244 Gbps coded user rate) that can also support PPM
- 622 Mbps Ka-band RF downlink
- New High Speed Switching Unit to interconnect the three terminals

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

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

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

2026 Launch on Orion/SLS

Deep Space Optical Comm

First Optical communications demo beyond earth-moon system

Sponsors

STMD/Technology Demonstration Mission
- Flight terminal
- Project Lead

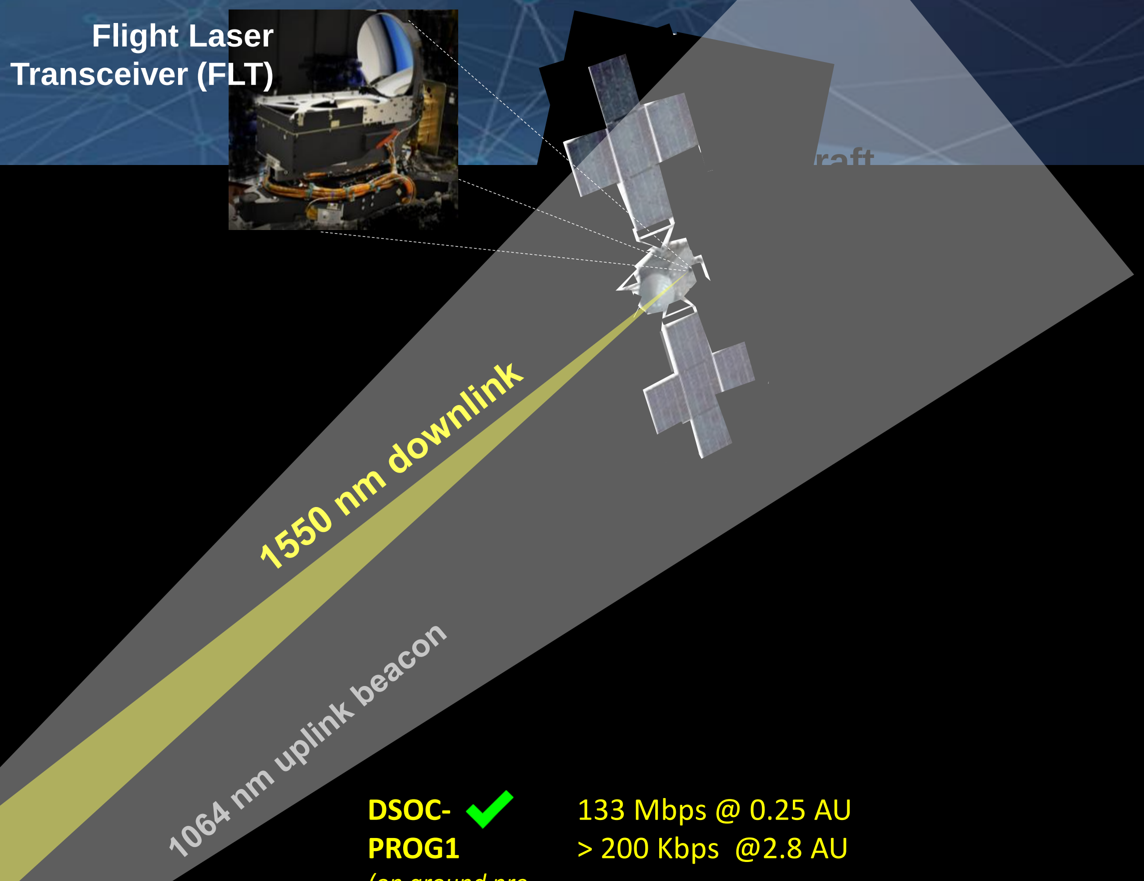
SOMD/Space Communications and Navigation
- Ground network

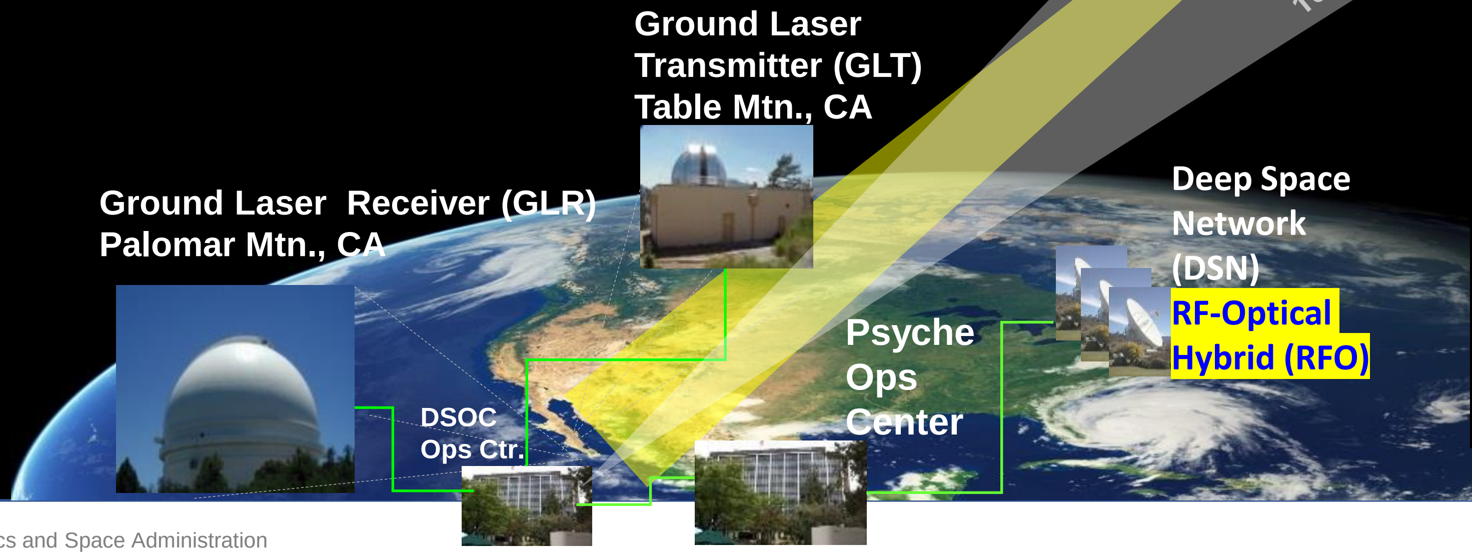
SMD
- Host Mission

Risk Category 7120.5E, Category 3, 8705.4 Payload Risk Classification D

Psyche Host PI Lindy Elkins-Tanton (ASU)
PM Henry Stone (JPL)

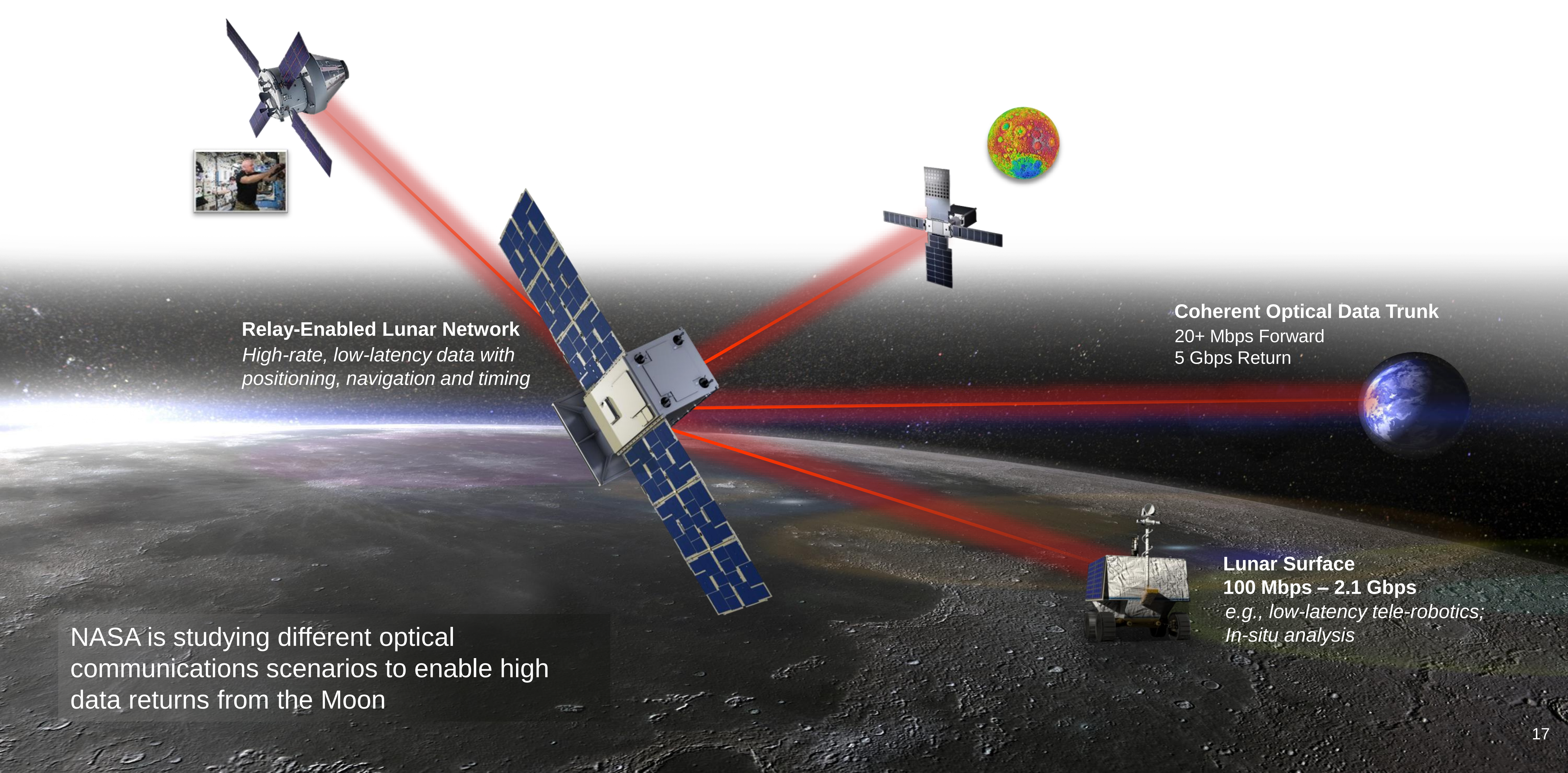
Lifetime 2 year





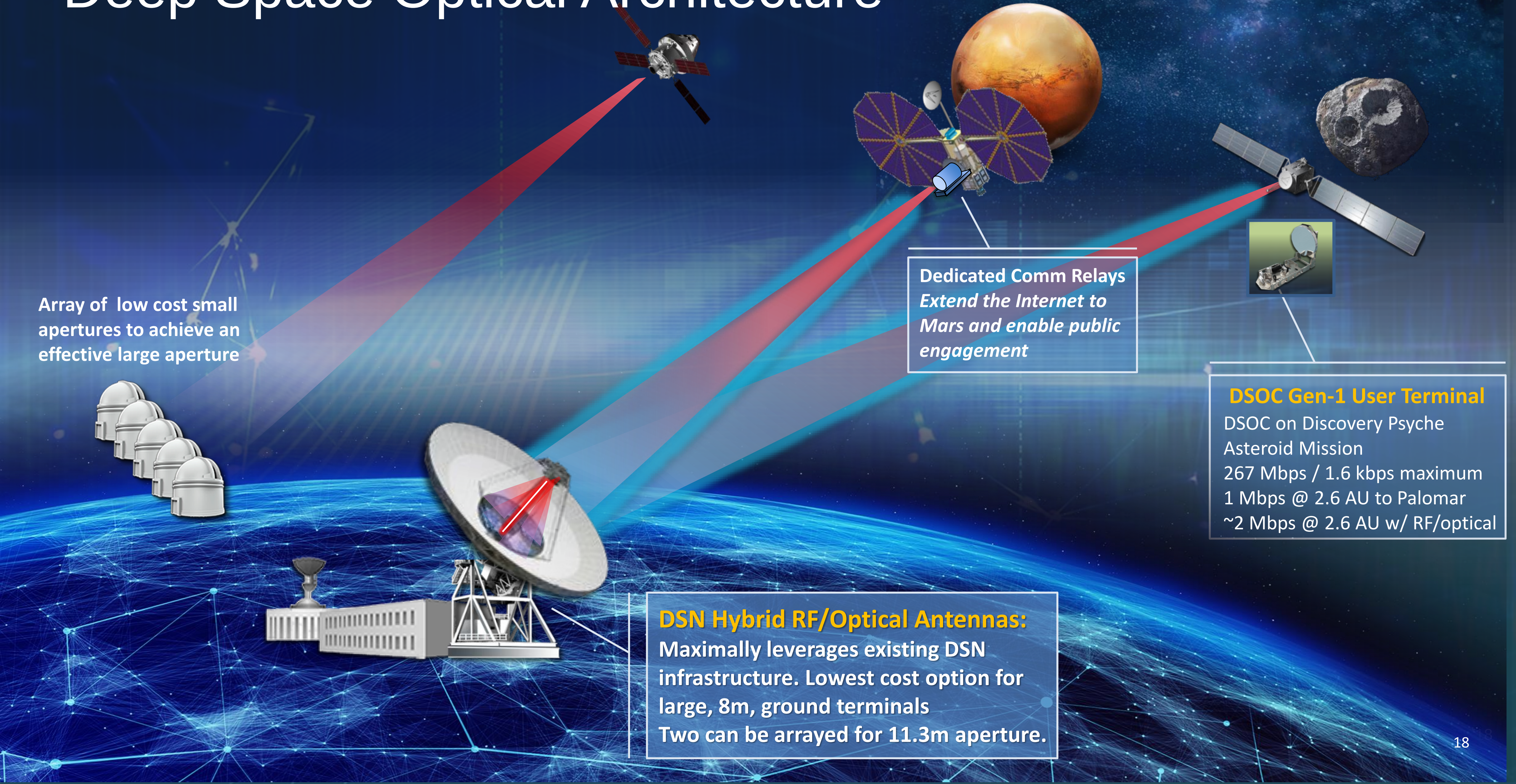
DSOC-PROG1 ✔ *(on ground pre-launch)*	133 Mbps @ 0.25 AU > 200 Kbps @2.8 AU
DOC-PROG2	> 6.3 Mbps < 1.5 AU ✔ > 1 Mbps > 1.5 AU
DSOC-PROG3 ✔ *(numerous times)*	1.6 Kbps @ 0.25 – 1AU
DSOC-PROG4	Operate in space for at least 1 year

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 Architecture



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

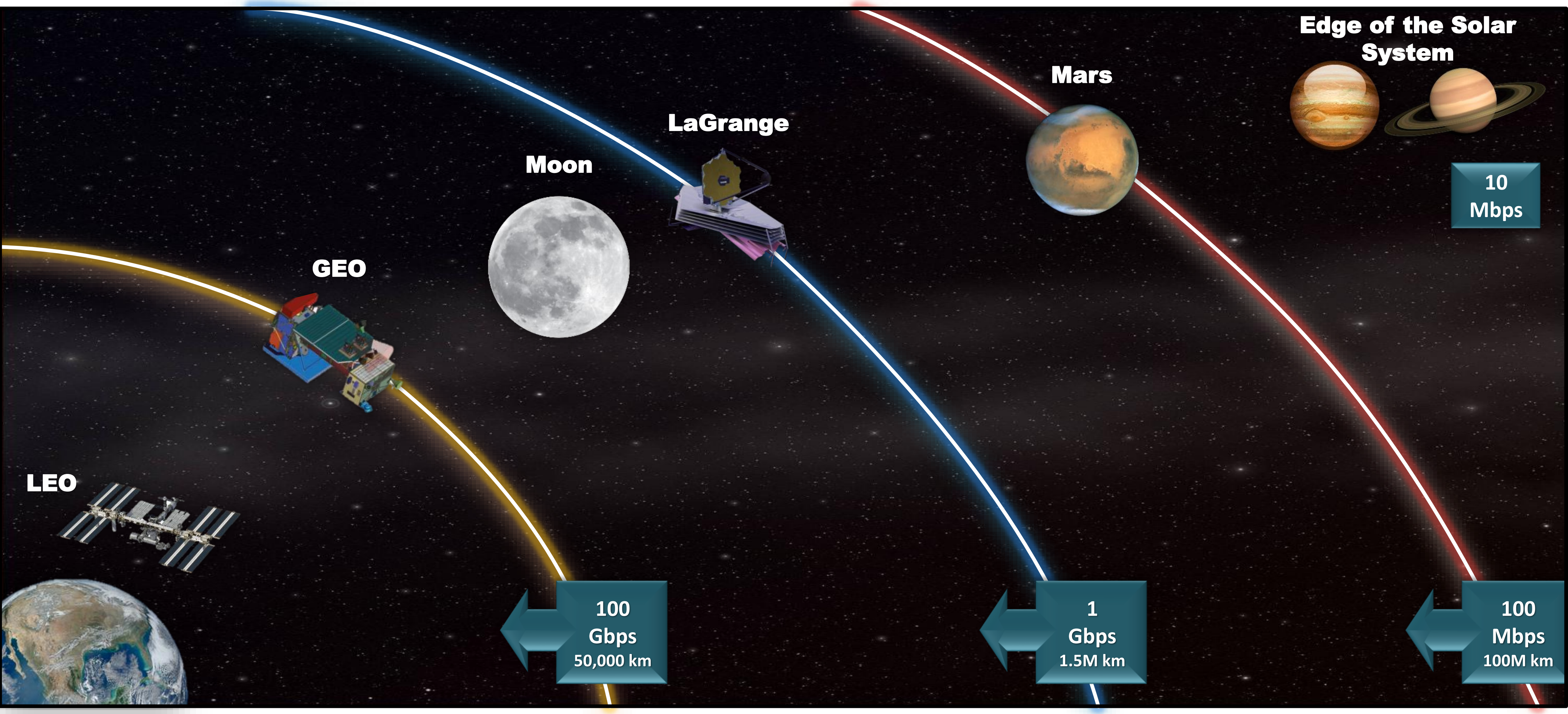
Dedicated Comm Relays
Extend the Internet to Mars and enable public engagement

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

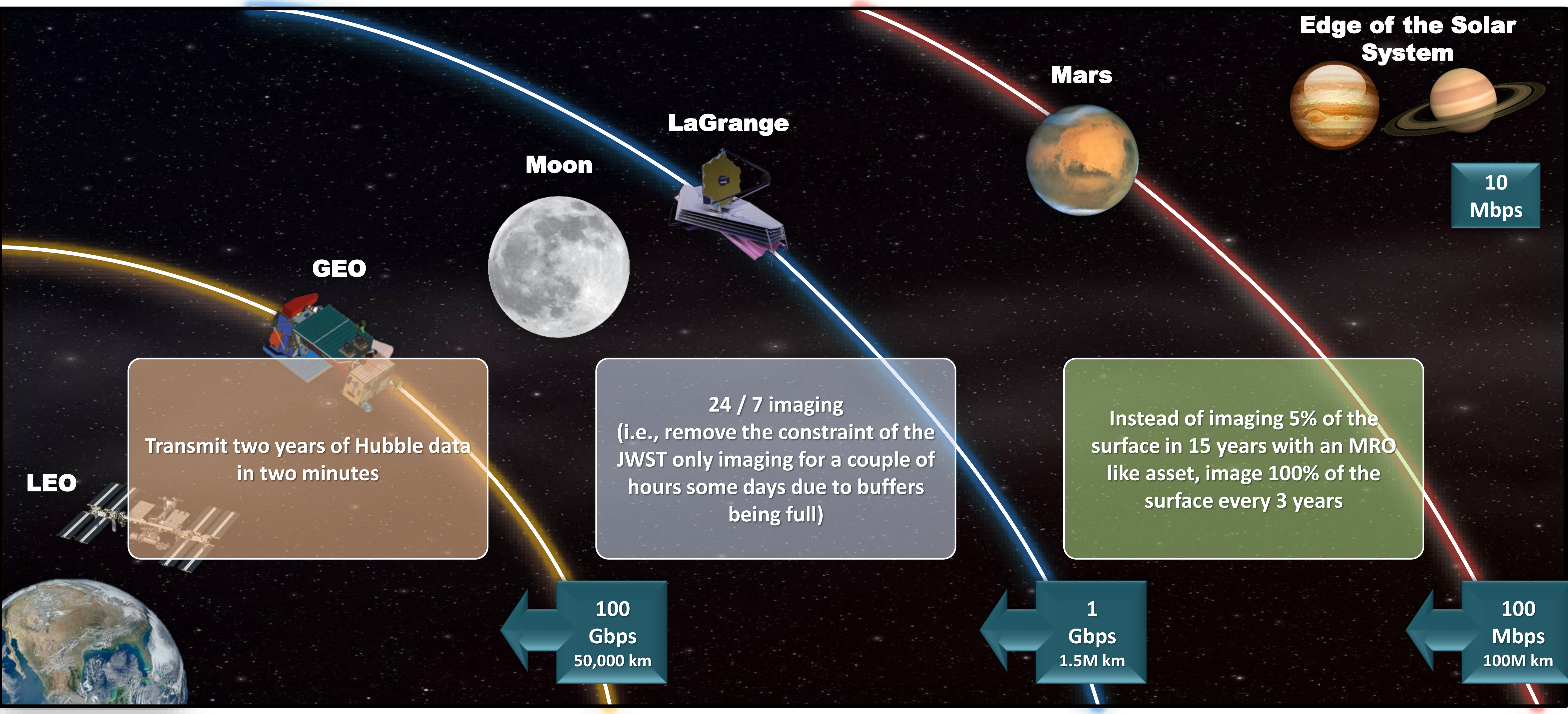
DSN Hybrid RF/Optical Antennas:
Maximally leverages existing DSN infrastructure. Lowest cost option for large, 8m, ground terminals
Two can be arrayed for 11.3m aperture.

A Vision for NASA Communications

Contour Map for the Solar System



Notional Examples of the Impact of Achieving the Communications Vision



CONCLUSION

- Current and future NASA exploration and science missions are constrained by existing communications capabilities
- NASA is pivoting to using commercial services wherever possible
- Over the last 20 years, NASA has demonstrated optical communications at all ranges of interest to NASA
    - It is time for NASA to move operationally towards optical, especially when spectrum considerations are taken into mind
- Remember that STMD leverages NASA expertise and industry partners to advance needed technologies
    - Review the integrated ranked shortfall list and participate in future feedback opportunities: nasa.gov/civilspaceshortfalls
    - Stay up-to-date on funding opportunities through STMD: techport.nasa.gov/opportunities

BACKUP

Data Rate Examples

- POTS Voice Grade Channel: 64 Kbps
- 1080p Video: 3 – 6 Mbps (depending on the codec)
- 4K Video: 15 -32 Mbps (depending on the codec)
- Typical 4G/LTE Cell Phone Download: 12-30 Mbps (Max is 150 Mbps)
- Typical Residence Internet Connection in the United States: 42.86 Mbps (from HighSpeedInternet.com) - 242.38 Mbps (from Speedtest.net)
- Space Shuttle: 216 Kbps Forward / 50 Mbps Return
- Space Station: 25 Mbps Forward / 600 Mbps Return
- Gateway: 20 Mbps Forward / 100 Mbps Return
- HLS: 10 Mbps Forward / 24 Mbps (48 Mbps in Discussion) Return

Comm Online Activity on Earth	Minimum Data Rate	Recommended Data Rate
E-Mail Checking	0.5 Mbps	1 Mbps
Web Browsing	1 Mbps	2 – 5 Mbps
HD Video Streaming	5 Mbps	8 Mbps
Video Conferencing	2 Mbps	8 Mbps
4K Video Streaming	15 Mbps	25 Mbps

Maximum Data Return from Mars TODAY at Maximum Range with one 34m Antenna:

Approximately 0.5 Mbps, at X-band, on MRO, with its 3m HGA and 100W TWTA. That HGA and TWTA are the largest ever flown to Mars. Cassini, however, had a 4m antenna.

Approximately 0.5 Mbps at Ka-Band, on MRO, with a 35W TWTA. However, the Ka-Band system was only used near Earth due to a transistor failure in an amplifier.

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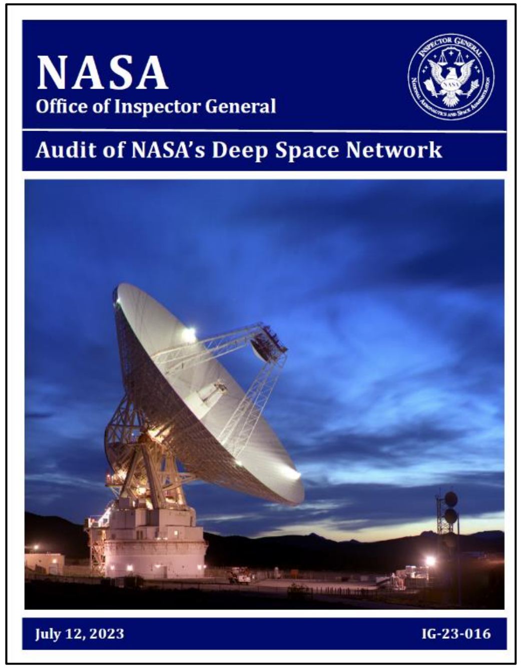
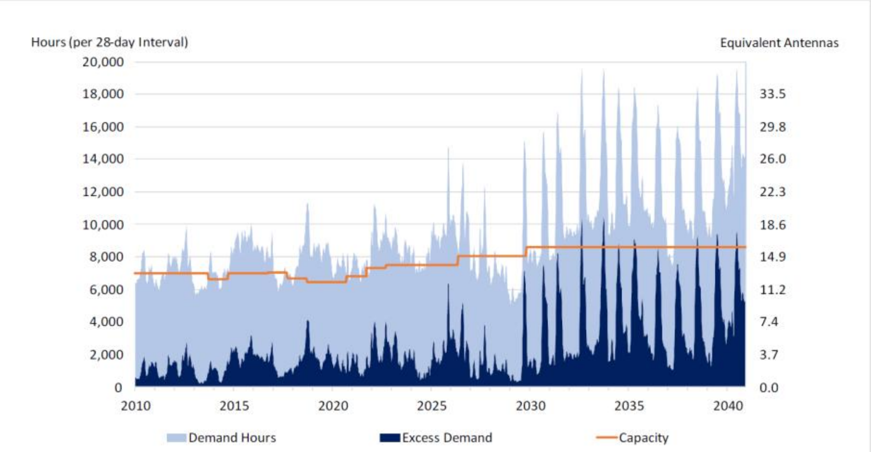
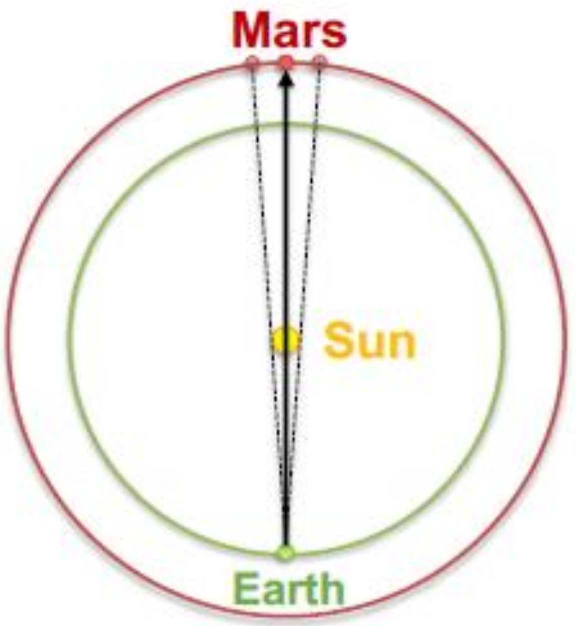
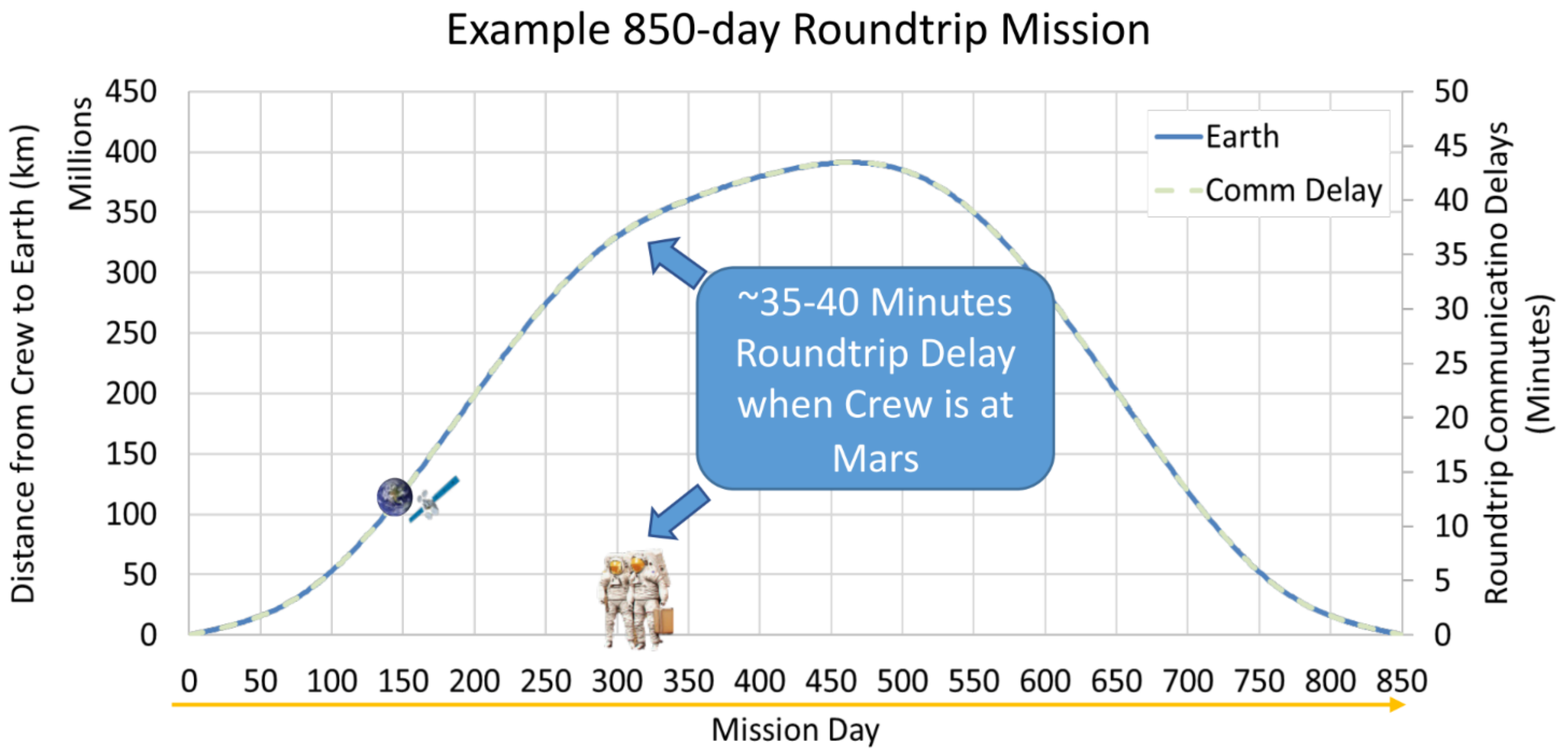




CAPABILITY GOAL IS FOCUSED ON MARS AT ~2.7 AU

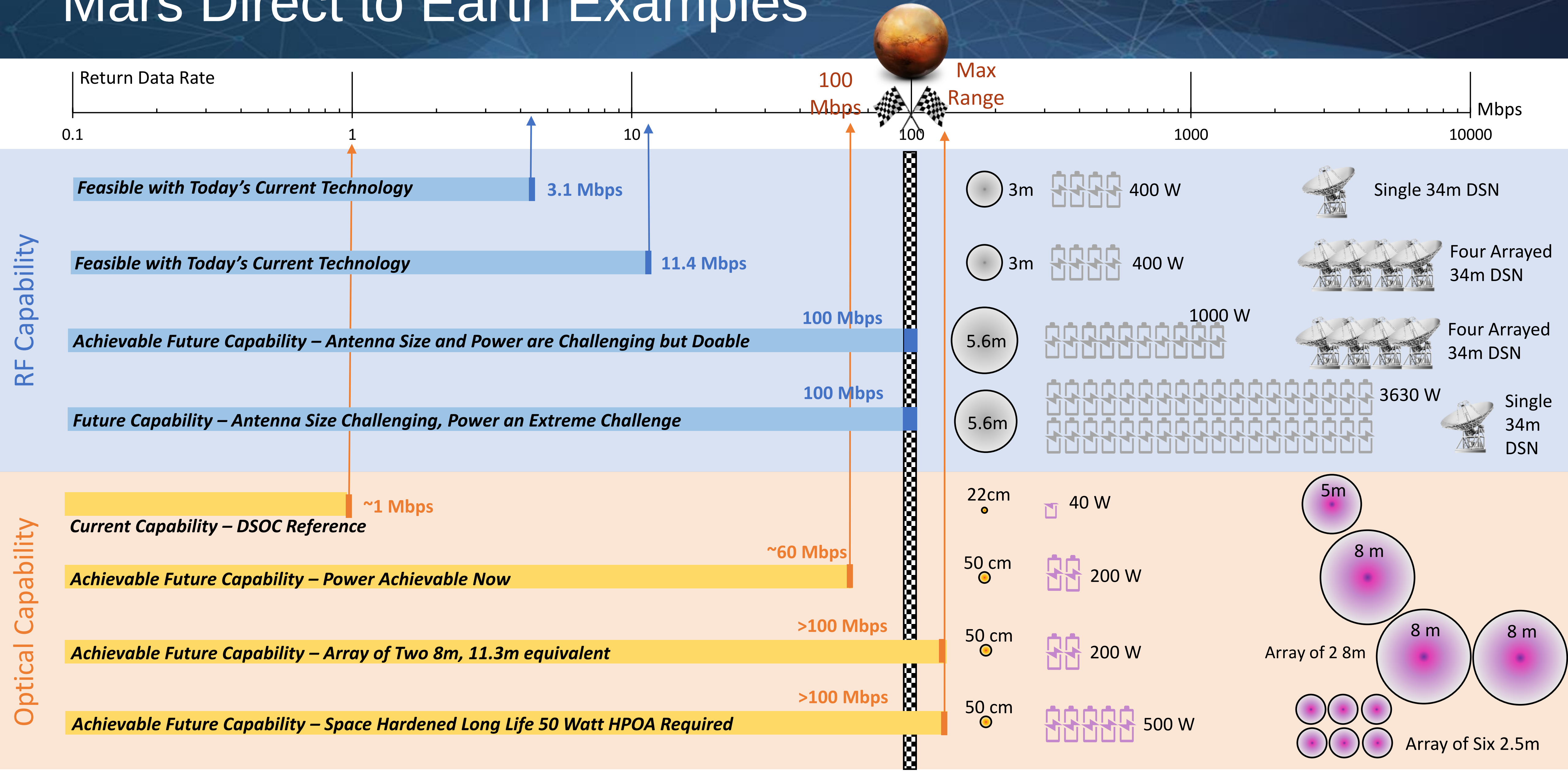


Solar Conjunction Causing Communications Disruption



From the 2024 Moon to Mars Architecture Workshops:

Mars Direct to Earth Examples



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

100 Mbps Mars Direct to Earth via Ka-Band Examples