National Aeronautics and Space Administration

NASA Optical Communications Update

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Benefits of Optical Communications

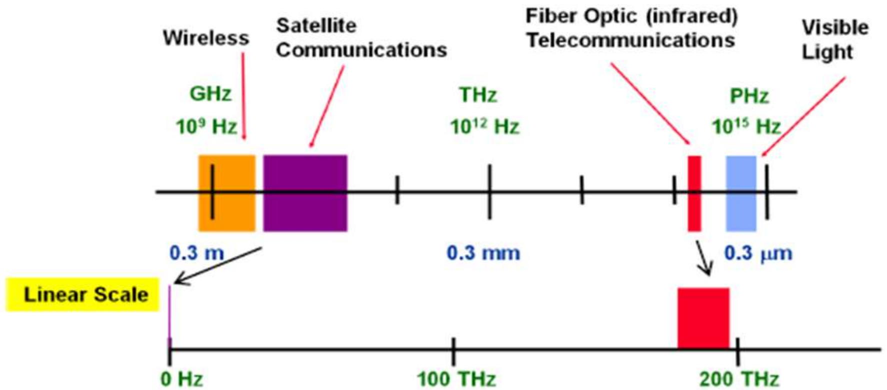
- Extremely narrow beams with small apertures
- Small, low power terminals
- Unlimited, unregulated spectrum
- High data rates
  - Provides high speed real-time data (e.g. for video)
  - Enables shorter contact times
  - Delivers large data volume over the duration of mission

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

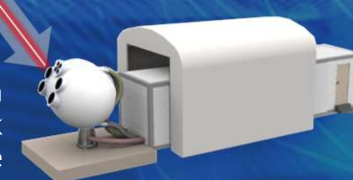
Lunar Laser Communications Demonstration (LLCD) - 2013

LLCD was a mission led by the NASA Goddard Space Flight Center to prove the fundamental concepts of laser communications at extremely long distances. Lincoln Laboratory built the space terminal and primary ground terminal — the Lunar Laser Communication System — for the demonstration.

> LLCD resulted in a record-breaking achievement using broadband lasers for space communications.

> Using a pulsed laser beam to communicate and exchange data and high-definition video sent from a lunar-orbiting terminal with the main LLCD ground station in White Sands, New Mexico.

- **LLCD returned data by laser to Earth at a record 622 Megabits per second (Mbps)**
- **= Streaming 30+ HDTV Channels Simultaneously**



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

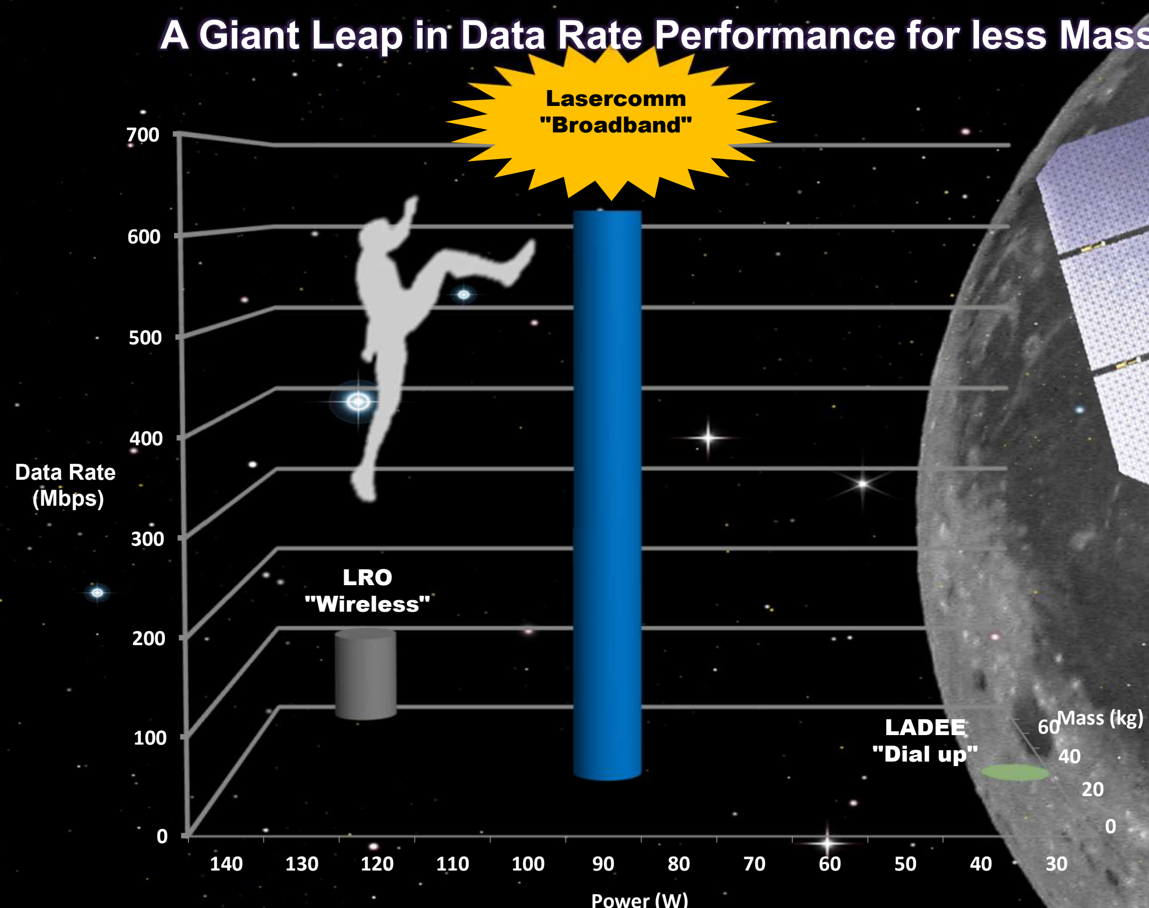
2014 Popular Mechanics Breakthrough Award for Leadership and Innovation for LADEE

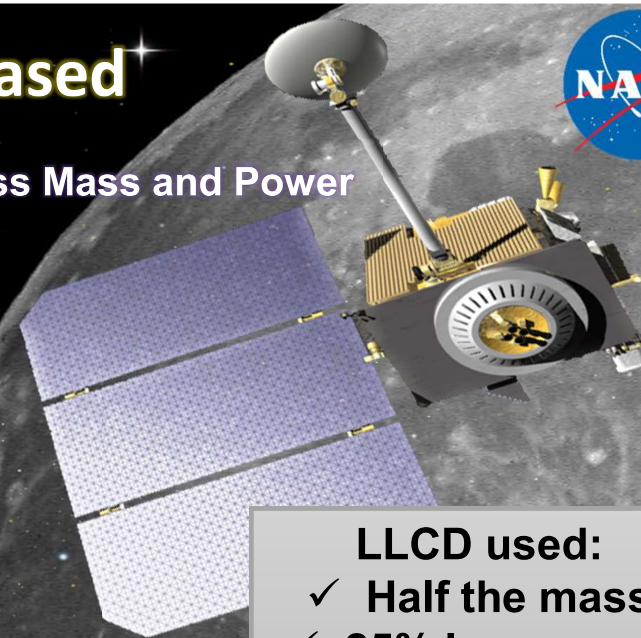
2014 R&D 100 Winning Technology in Communications category

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

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

Lasercomm – Higher Performance AND Increased Efficiency

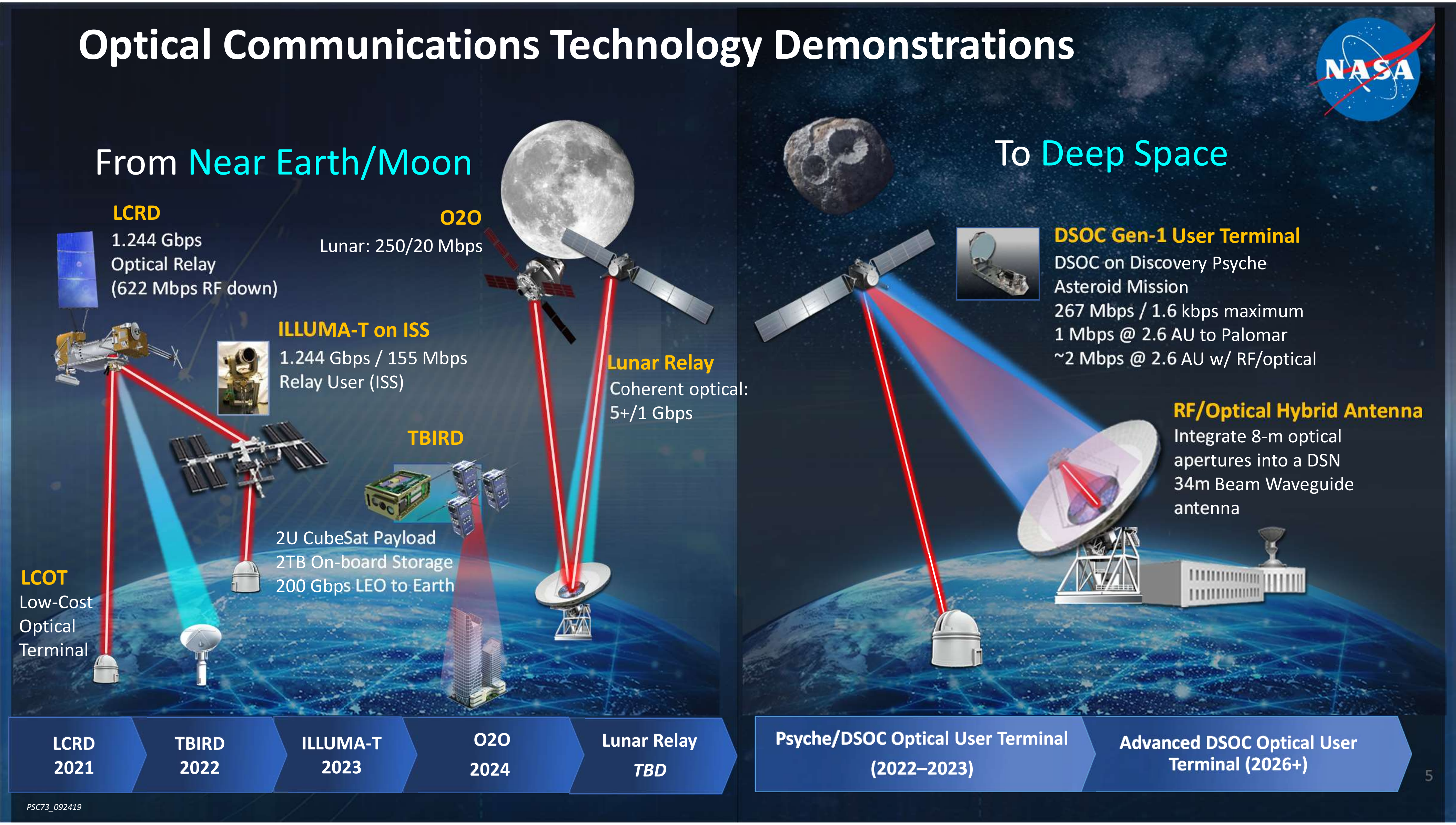




LLCD used:

- ✓ Half the mass
- ✓ 25% less power
- ✓ While sending 6x more data

This will revolutionize satellite and mission design for NASA and other spacecraft providers


Optical Communications Technology Demonstrations
NASA
From Near Earth/Moon
LCRD
1.244 Gbps
Optical Relay
(622 Mbps RF down)
O2O
Lunar: 250/20 Mbps
ILLUMA-T on ISS
1.244 Gbps / 155 Mbps
Relay User (ISS)
Lunar Relay
Coherent optical:
5+/1 Gbps
TBIRD
2U CubeSat Payload
2TB On-board Storage
200 Gbps LEO to Earth
LCOT
Low-Cost
Optical
Terminal
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
Lunar Relay TBD
Psyche/DSOC Optical User Terminal (2022–2023)
Advanced DSOC Optical User Terminal (2026+)
5
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LCRD Experiments Overview

Experiments will begin immediately following launch and Payload checkout

- **The high priority experiments will demonstrate technology readiness for operational optical communications systems**
  - Laser Communications Link and Atmospheric Characterization
  - Relay operations
  - Optical-based Networking Services
- **Other Experiment Include**
  - Development of operations efficiency (handover strategies, more autonomous ops, etc)
  - Planetary/Near-Earth Relay scenarios (additional delays, reduced data rates, non-continuous trunkline visibility
  - Low Earth Orbit (LEO) - real or simulated
  - User-to-User Relay
  - Direct Uplink/Downlink
  - Commercial applications

LCRD Introduction for Experimenters document describes experiment types as an introduction for the Guest Experimenter Program

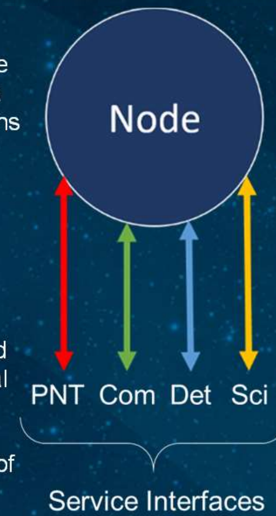
- **https://go.nasa.gov/3N53WLT**

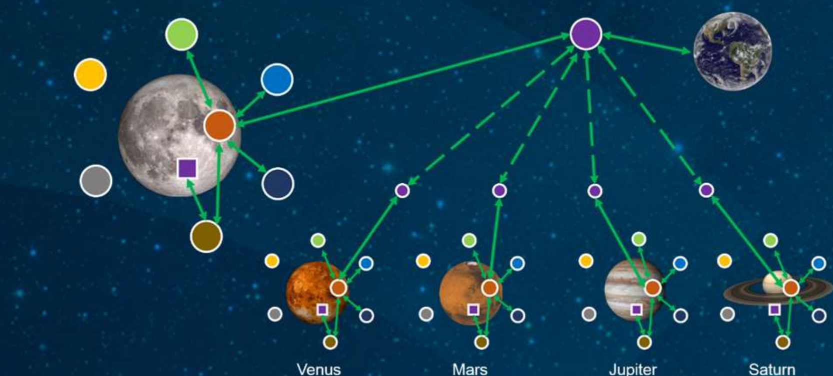
LunaNet

- A flexible scalable architecture for providing communications and navigation services to all lunar missions
- Disaggregated approach allows for phased implementation of infrastructure as driven by user needs and technology developments
- Architecture implementation comprised of NASA, International, and Commercial interoperable lunar surface, lunar orbiting, and earth-based elements
- Incorporates in-situ capabilities to detect events and distribute situational alerts
- Is fully compatible with future deployments at Mars or any other destination

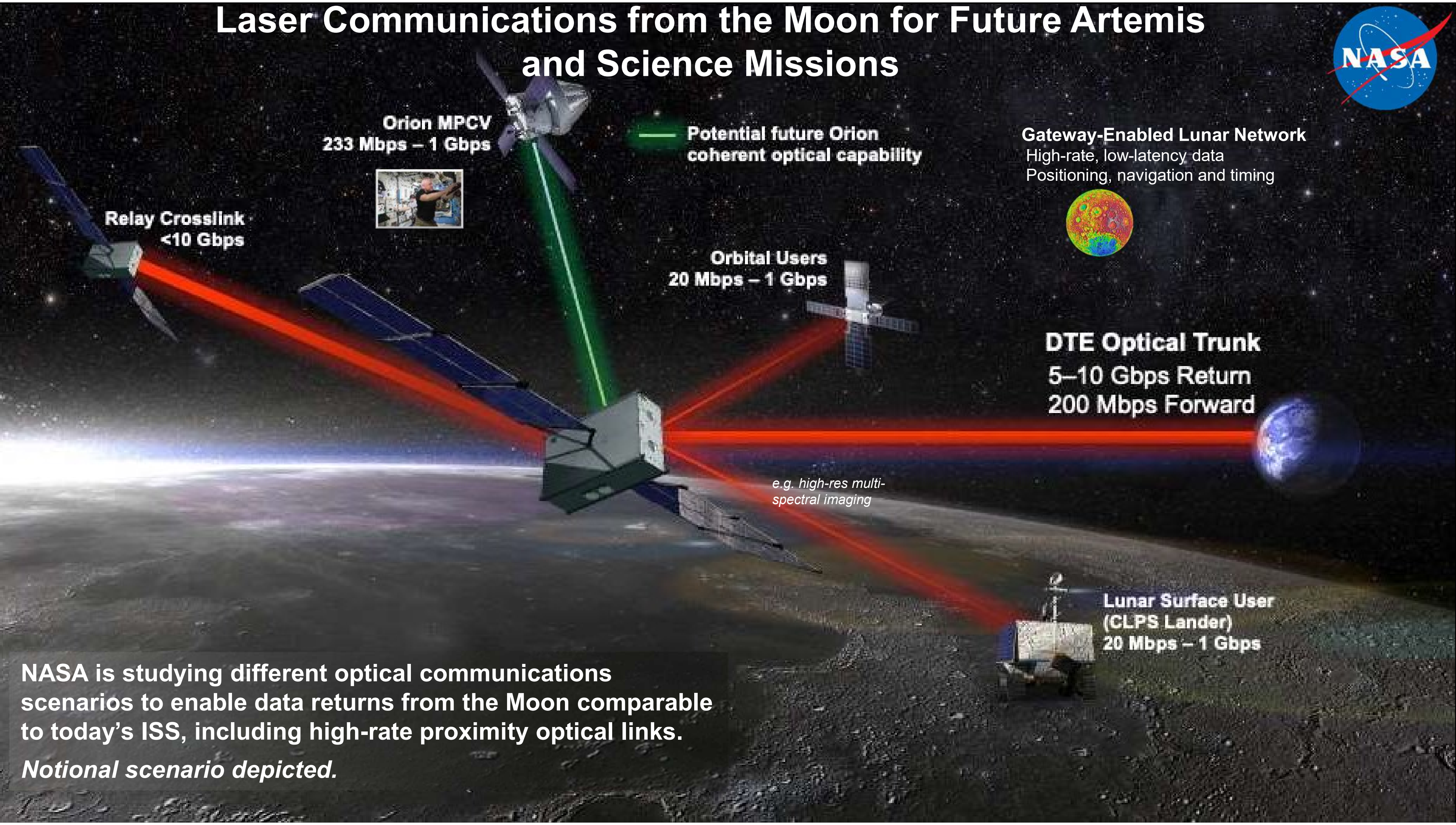
LunaNet Service Types

1. **Communications Services (Com):** Data transfer services capable of moving addressable and routable data units between nodes in a single link or over a multi-node, end-to-end path via communications or networking services.
2. Position, Navigation, and Timing Services (PNT): Services for position and velocity determination, and time synchronization and dissemination. This includes search and rescue location services.
3. Detection and Information Services (Det): Services providing detection of events in order to generate timely alerts for human and asset safety and protection. These services publish other beneficial information to users as well.
4. Science (Sci): Services that use the RF and/or optical capabilities of the node as a science instrument or part of an instrument.





Just as the Internet and GPS have transformed our lives on Earth, LunaNet will transform lunar science and exploration.


Laser Communications from the Moon for Future Artemis and Science Missions
Orion MPCV
233 Mbps – 1 Gbps
Potential future Orion coherent optical capability
Gateway-Enabled Lunar Network
High-rate, low-latency data
Positioning, navigation and timing
Relay Crosslink
<10 Gbps
Orbital Users
20 Mbps – 1 Gbps
DTE Optical Trunk
5–10 Gbps Return
200 Mbps Forward
e.g. high-res multi-spectral imaging
Lunar Surface User
(CLPS Lander)
20 Mbps – 1 Gbps
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.
Notional scenario depicted.

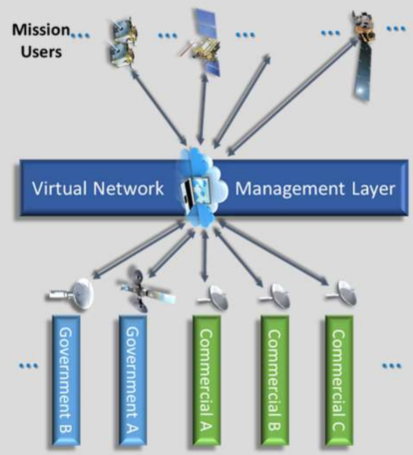
NASA Commercial Communications Services Efforts

Commercial SATCOM for Space Mission Users

- Significant US SATCOM infrastructure for terrestrial/aeronautical users but demos required to validate application to space users
- Communications Services Project awards Funded Space Act Agreements for SATCOM demos – Q2 CY22
    - https://go.nasa.gov/3N1hAzy
- Demos for end-to-end services
- Demonstrations are agnostic on technology, orbits, and data pathway
- Anticipate rolling wave of demos through the decade to meet 2030 goal of moving new users off the NASA Tracking and Data Relay Satellite System

Increasing Role of Commercial Providers in Direct-to-Earth Comms

- Established DTE commercial market = opportunity for a service portfolio with multiple vendors
- Shift from NASA as service provider to Virtual Network Manager
- Consistent interfaces through Near Space Network Points of Presence – seamless access to many providers, reduces burden
- RFP for DTE services anticipated Q3 FY22



Enabling Tech and Standards Activities

- Objective to address interoperability through standards
- NASA is pushing to adopt more commercial standards; joined 3GPP to understand scope of non-terrestrial network (NTN) development, and advocate for 5G and NTN support of space user needs
- Wideband multi-lingual terminals → achieve a form of interoperability in the interim
- Ground demos complete; flight demos upcoming

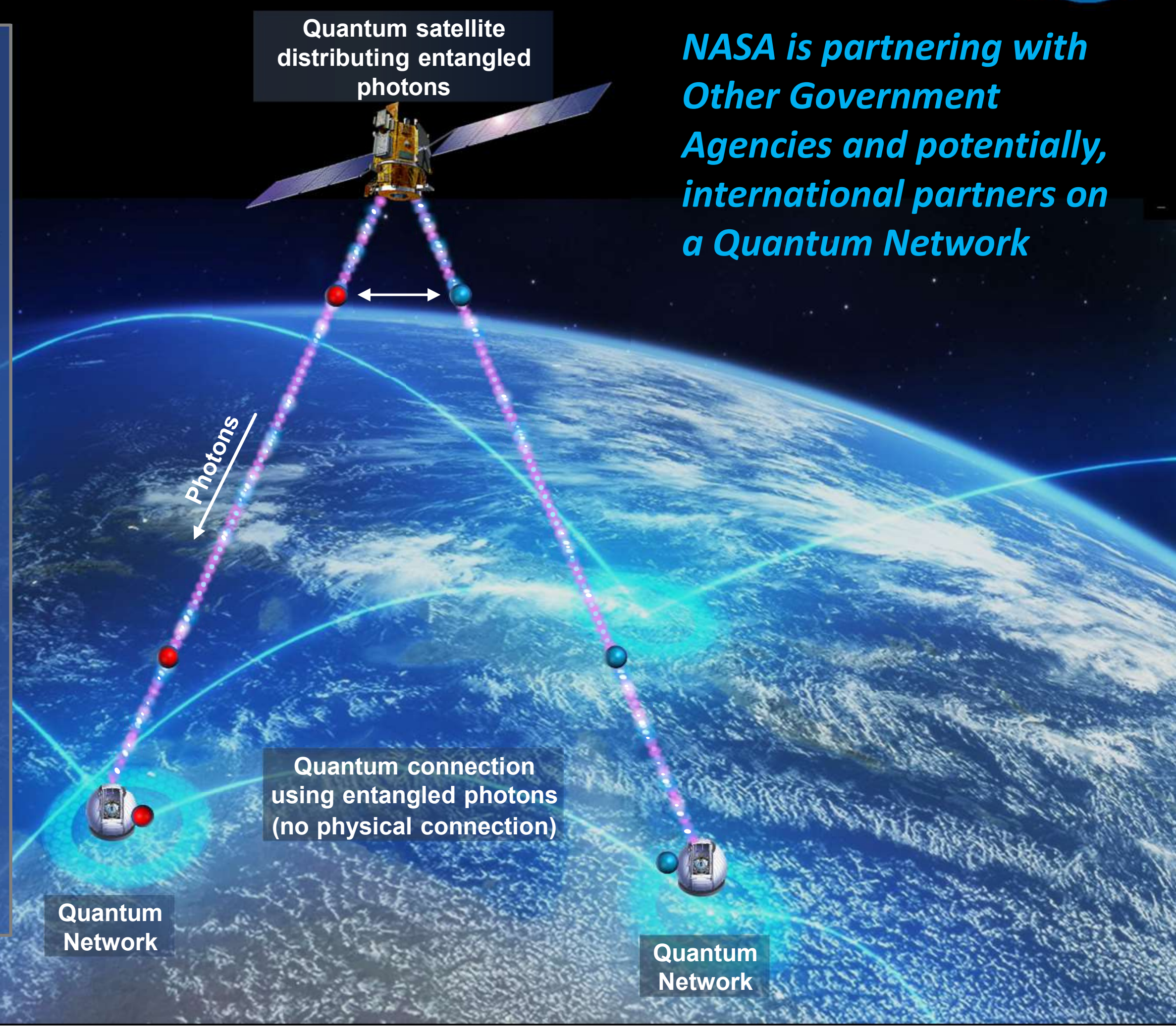
Quantum Communications

Communications is no longer based on 1's and 0's but represented by multi-state quantum bits referred to as qubits

- Entangled Photons can interact with each other at any distance
- By having a satellite distribute pre-entangled photons via optical links to stations on Earth, those stations can "talk" to each other via quantum communication without needing to be connected to each other

- Benefits:
  - Improved energy efficiency for optical communications
  - Improved bandwidth efficiency for optical communications
  - Quantum data (qubits) link two ground stations without a physical connection between them

NASA is partnering with Other Government Agencies and potentially, international partners on a Quantum Network



X-Rays as Communication Medium

Abundant applications of Modulated X-ray Source (MXS) continue to unfurl in, near Earth and deep space communications. Known as XCOM, this new form of sending information could achieve better power efficiency than radio or laser systems in the vacuum of space, since X-rays have shorter wavelengths.

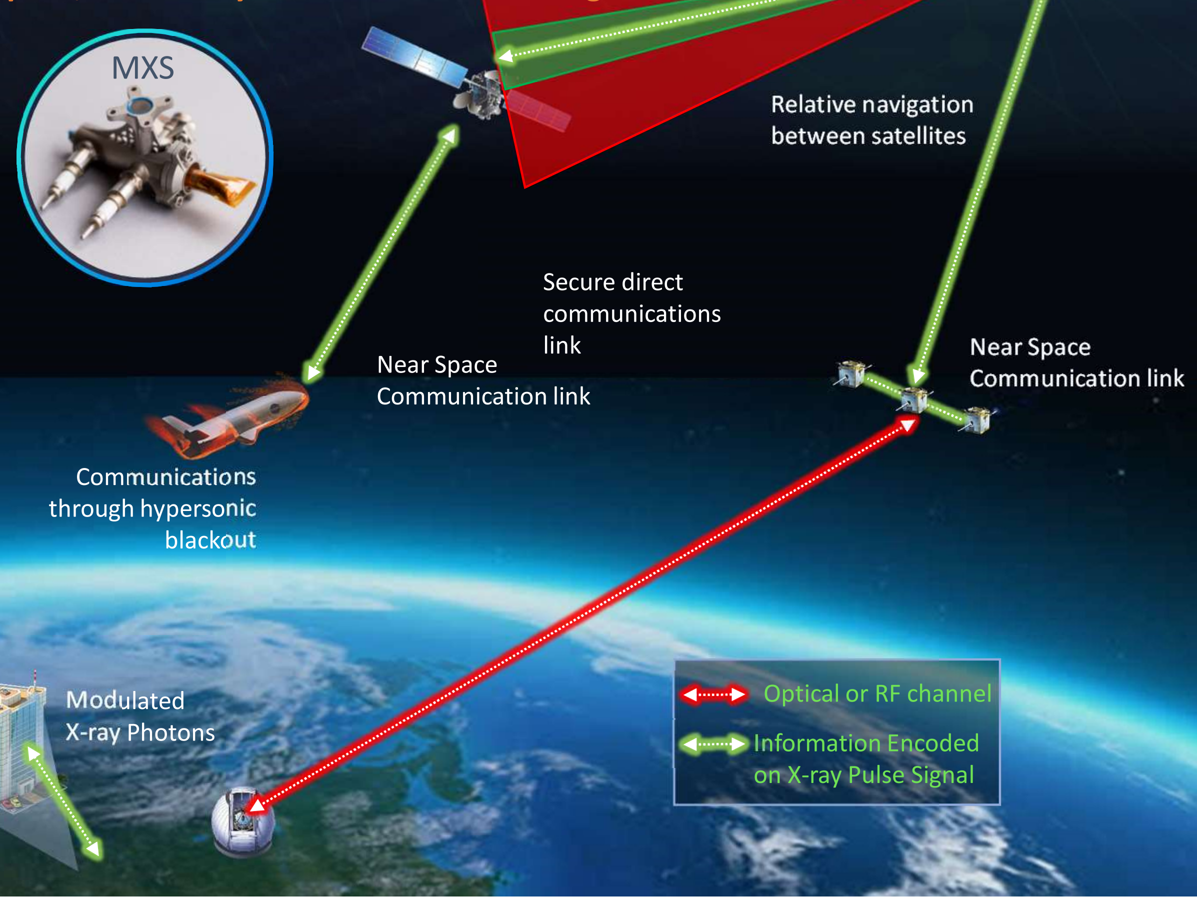
GSFC developed *Modulated X-ray Source* (MXS)

(NASA's 2019 Government Invention of the Year)

- Modulated with sub-nanosecond transitions

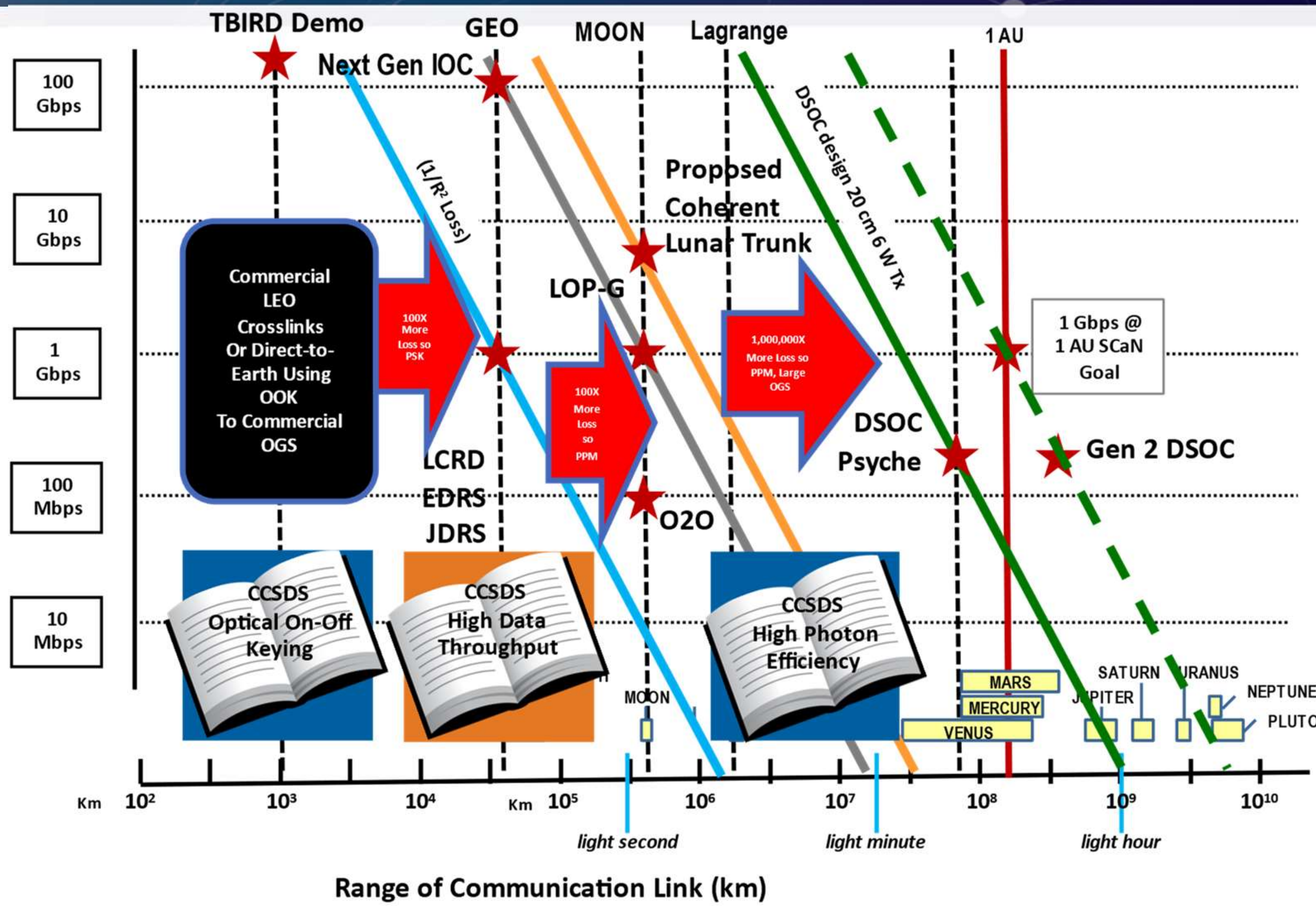
MXS opens up X-ray time domain, advantages:

- **Tight beams due to diffraction limit at low energies (<10 keV) have multiple advantages**
  - Least power required for LONG distance communication
  - Extremely secure point to point communication at *shorter distance (GEO-to-LEO)*
    - IR laser spot size <1 km
    - XCOM spot size ~2 m
- **Penetration at high energies (>100keV) of:**
  - Buildings
  - Plasma Shrouds around hypersonic vehicles



BACKUP

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



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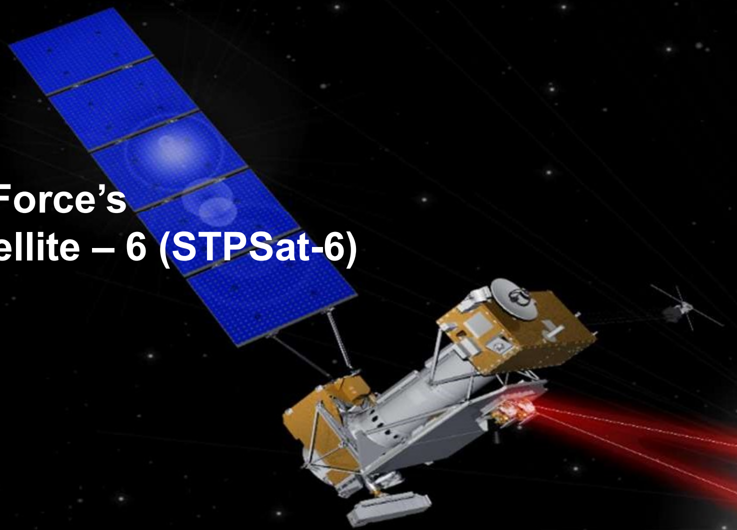
2021 Laser Communications Relay Demonstration (LCRD)

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**

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 Goddard · 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)

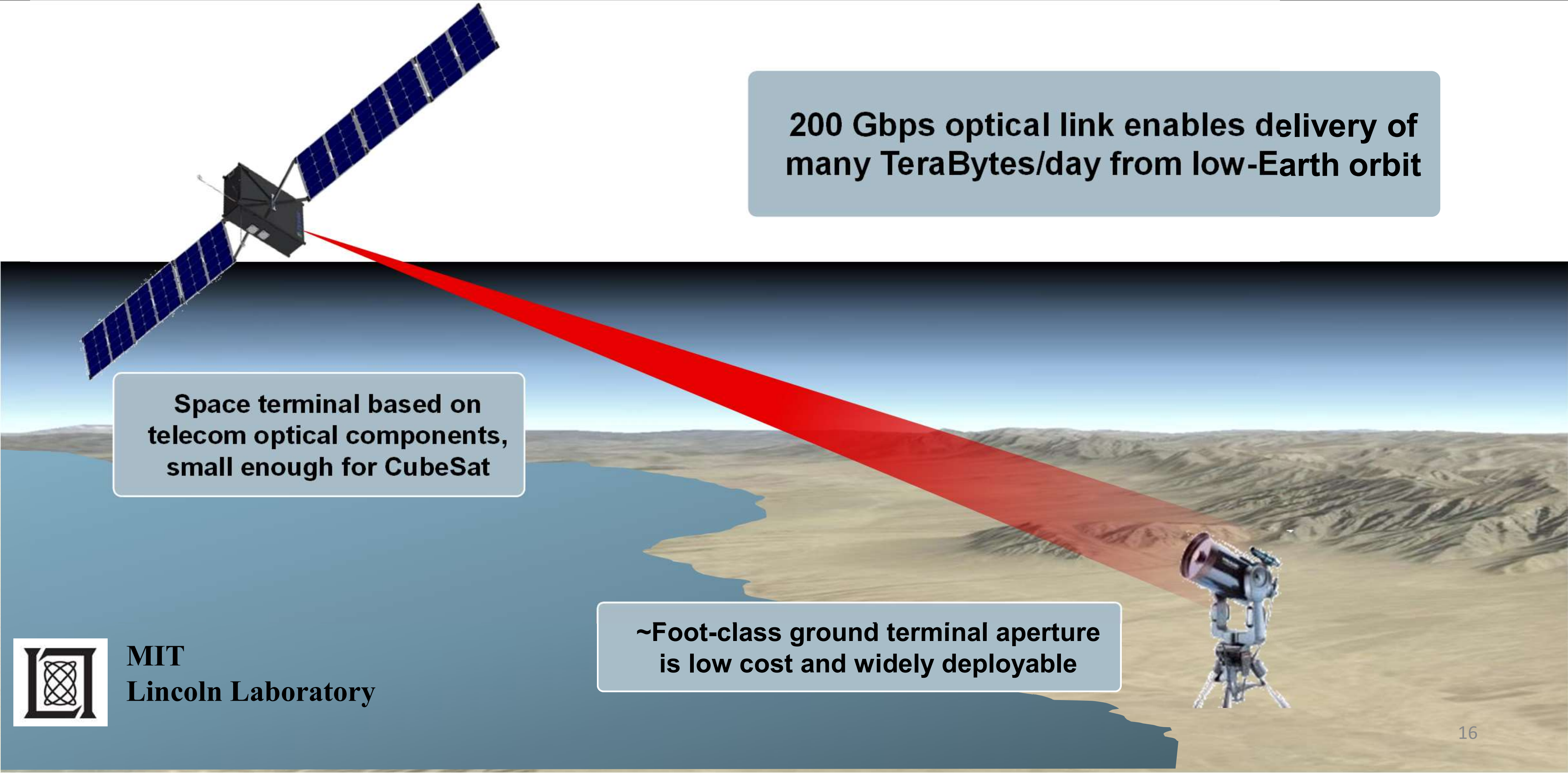
October 2022 Delivery to KSC

2024 Launch on Orion/SLS

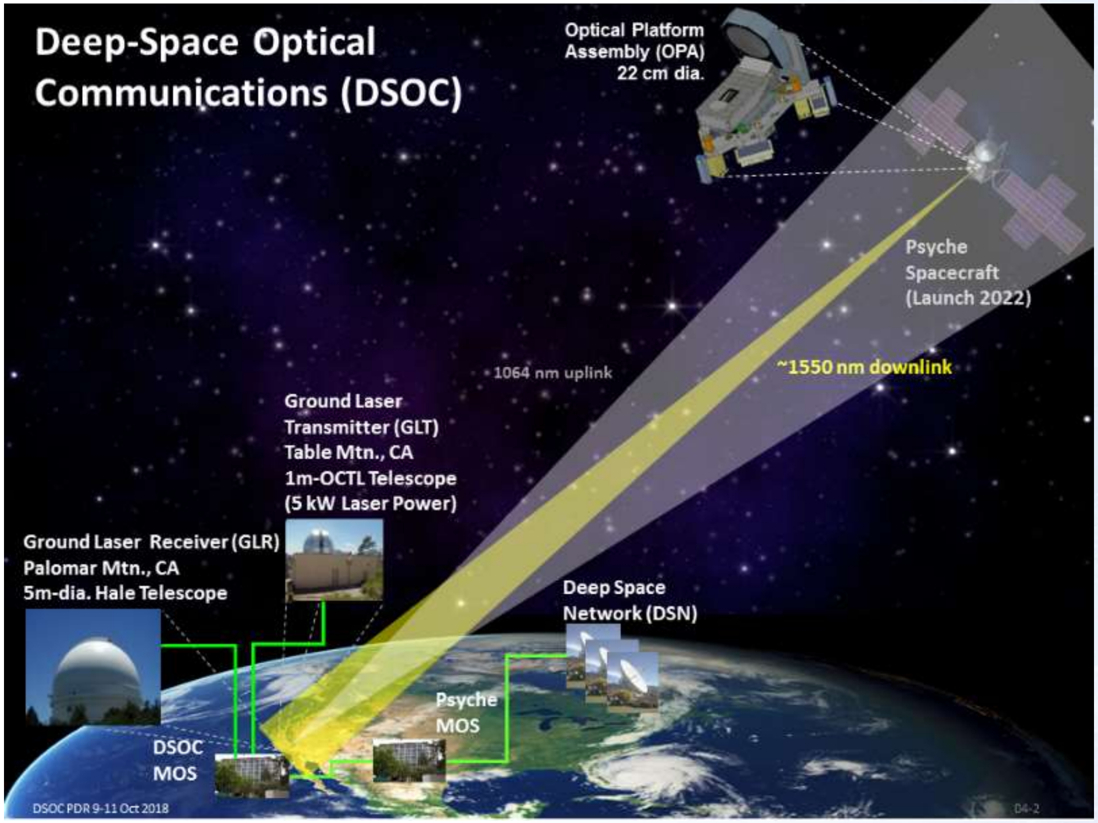
8 – 21 Day Mission

NASA Goddard · Lockheed Martin · NASA Johnson Space Center · NASA Marshall Space Flight Center · JPL

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



Deep Space Optical Communications (DSOC)



Level 1 requirements (Phase A Starting FY17)

- **DSOC-PROG-1: DSOC shall demonstrate on the ground a deep-space optical communications link demonstrating the data rates for the simulated distances defined in table 1A:**
- **DSOC-PROG-3: DSOC shall demonstrate a deep-space optical communication downlink from space for data rates and distance as defined in table 1B:**
- **DSOC-PROG-4: DSOC shall demonstrate optical communication uplink data rates to space of 1.6 kbps for multiple ranges between 0.25 and 1 AU**
- **DSOC-PROG-5: The DSOC flight terminal shall operate in space for at least one year**

FY17-FY23 Key Milestones:

FY17 **Complete WSi detector array fabrication** √
FY18 **SRR/MDR, End-to-end signaling testbed** √
FY19 **System PDR** √
FY20 **Ground PDR, System CDR** √
FY21 **Integration & Test of GLR and GLT** √
FY22 *Operations Readiness Review (May 11–12)*
FY22-23 Operations for Technology Demo

TABLE 1A

Downlink Data Rates	Simulated Distance
132 Mbps	0.25 AU
> 200 kbps	2.8 AU

TABLE 1B

Downlink Data Rates	Simulated Distance
> 132 Mbps	D < 0.25 AU
> 14 Mbps	0.25 < D < 1 AU
> 2 Mbps	1 AU < D < 2 AU
> 200 kbps	2.0 AU < D < 2.7 AU