

National Aeronautics and
Space Administration



Optical Communications to Enhance Science & Exploration

Bernard L. Edwards

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

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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.

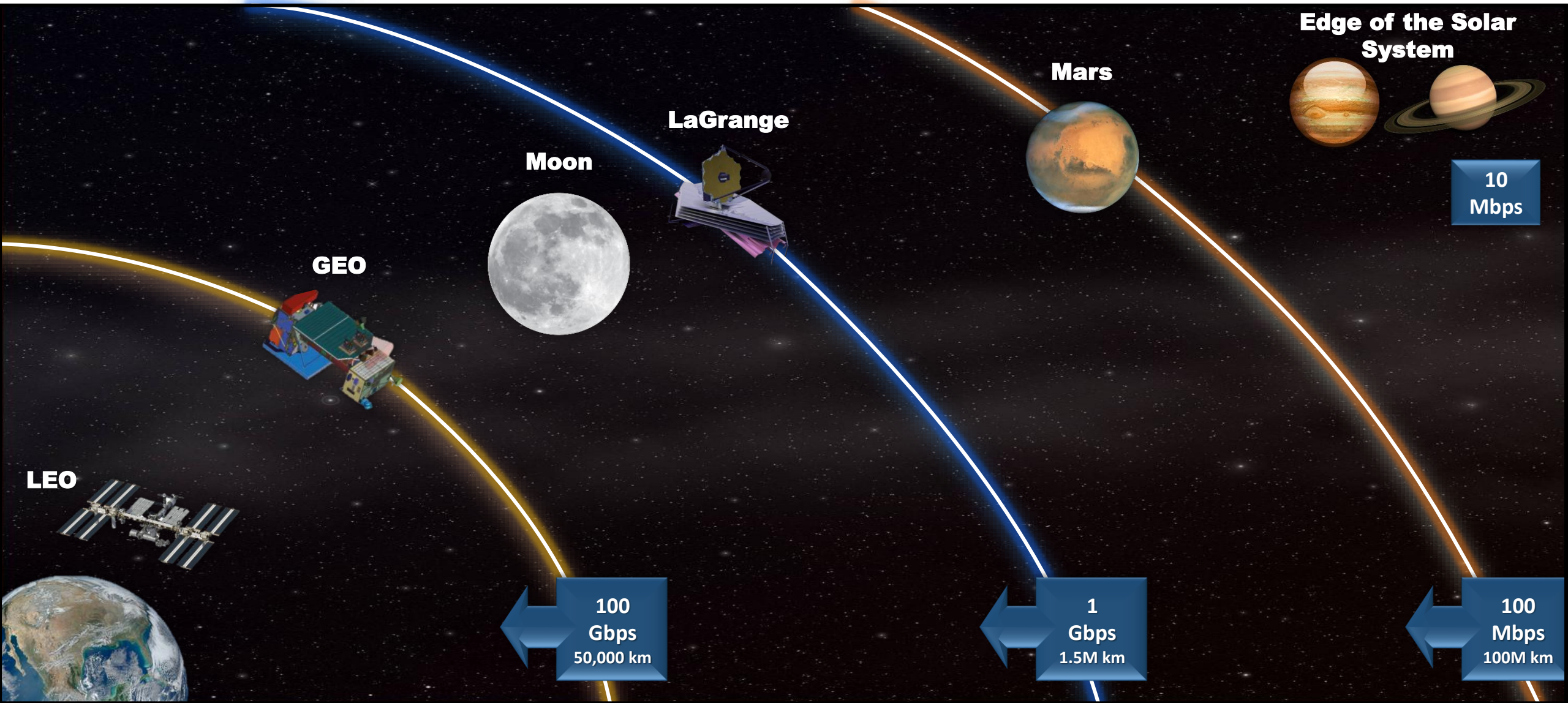
This is accomplished with limited resources and a need for balanced portfolios across various technologies.

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

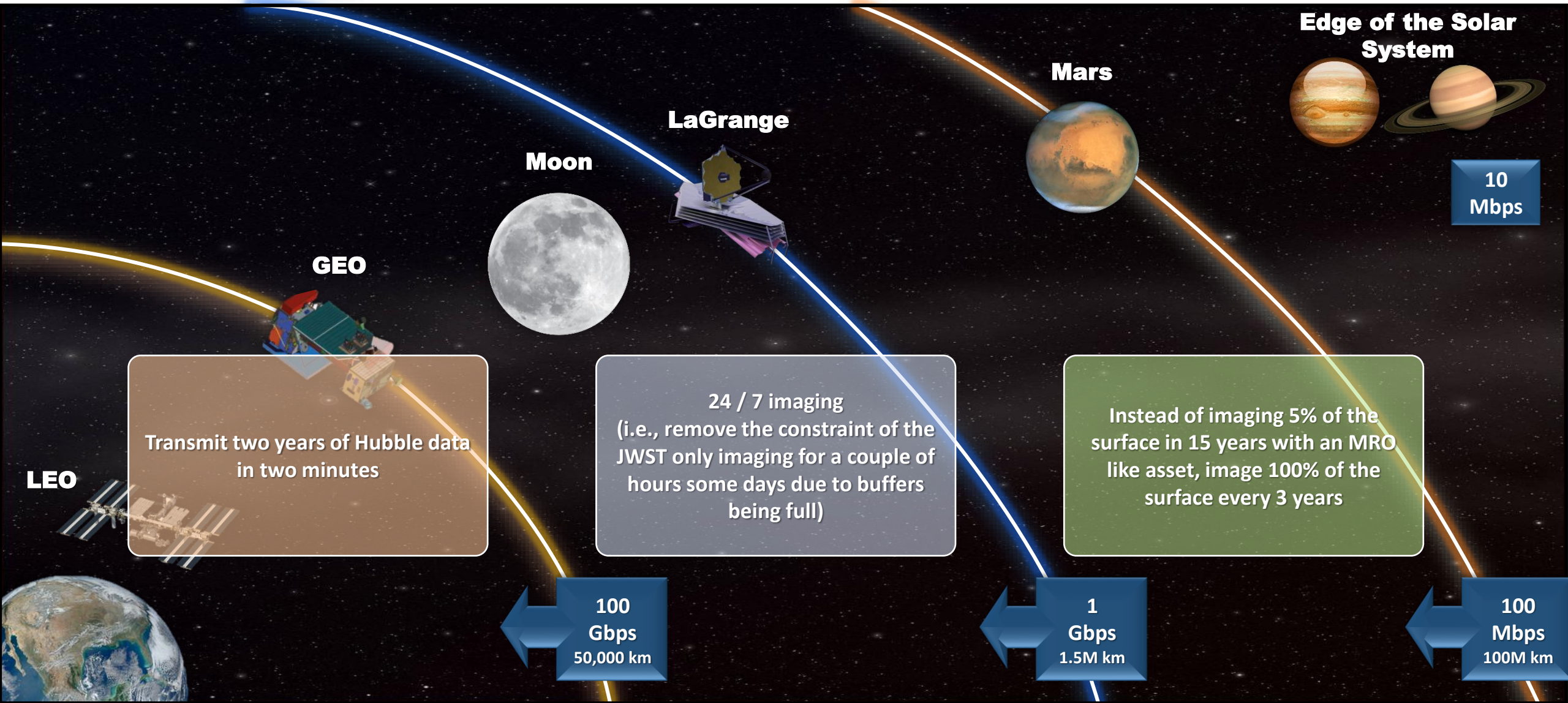
- In-Situ Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications
- High-Rate Communications Across the Lunar Surface
- Deep Space Autonomous Navigation
- High-Rate Deep Space Communications



A Vision for NASA Communications *Contour Map for the Solar System*



Notional Examples of the Impact of Achieving the Communications Vision



ADVANTAGES OF OPTICAL COMMUNICATIONS



- Extremely narrow beams with small apertures

- Small, low power terminals
 - S-band, 20 kW, 34m = 8 GW EIRP
 - Optical, 0.5W, 10cm = 8 GW EIRP
- Security
 - Anti-jam
 - Low Probability of Detection
 - Low Probability of Interception

Beam Size From Moon

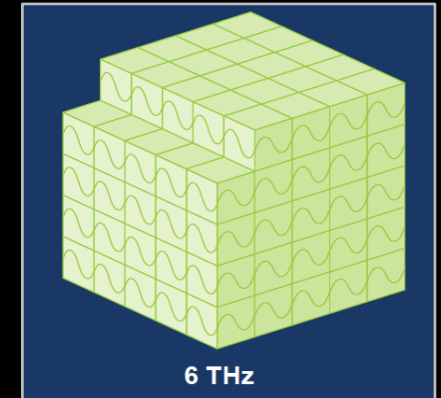


- Unlimited, unregulated spectrum

- Enables high data rates
- Enables shorter contact times
- Enables the delivery of large data volumes over the duration of mission

Optical Spectrum (1530-1580 nm)

RF Spectrum



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 (3 rd 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 standards 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

Commercial Optical Communications 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

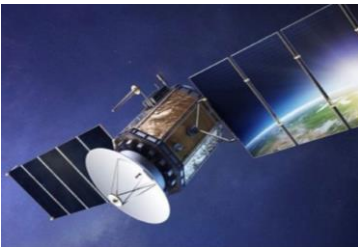
Inmarsat

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



Kuiper Government Solutions

- 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



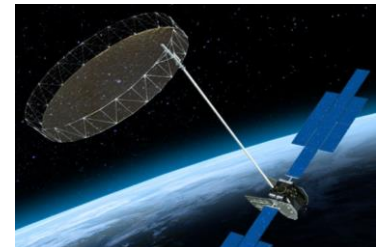
Telesat U.S. Services

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

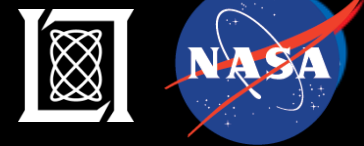


Viasat

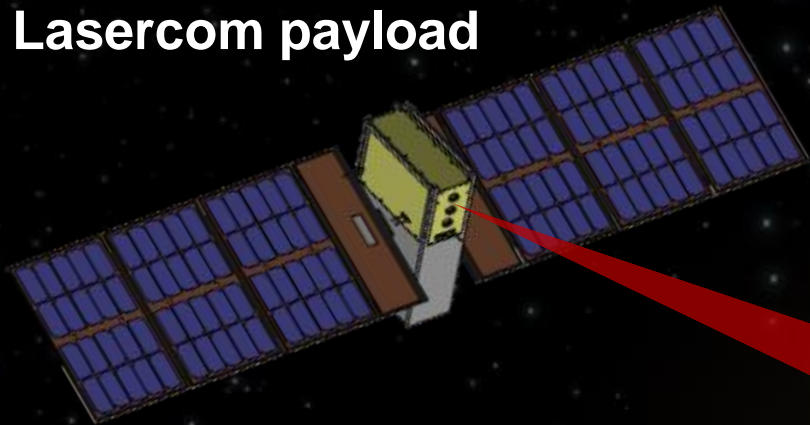
- GEO Ka-band relay network
- High- and low-rate communications services
- Routine launch and mission support



Terabyte Infrared Delivery (TBIRD) Demonstration



6U CubeSat in LEO
3U Lasercom payload



Flight payload developed by MIT Lincoln Laboratory

200 Gbps downlink

- Leverage fiber telecom equipment for 200 Gbps burst delivery (TBs per pass)
- Downlinked 4.8 TB error-free in a single pass of ~ 5 Minutes (A Guinness World Record)
- Body pointed with payload pointing feedback
- Launched in May 2022; Ended in September 2024



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



2021 Laser Communications Relay Demonstration (LCRD)

Launched December 2021

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
- SOMD/Space Communications and Navigation

Flight payload:

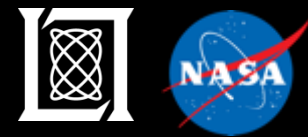
- Two 10.8 cm Optical Modules and Controller Electronics Modules
- Two software-defined DPSK Modems with 2.88 Gbps data rate (1.244 Gbps coded user rate) that can also support PPM
- 622 Mbps Ka-band RF downlink
- New High Speed Switching Unit to interconnect the three terminals

Guest investigators welcome!

URL: <https://esc.gsfc.nasa.gov/projects/LCRD>

Email: lcrd-experiments@nasa.onmicrosoft.com

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

November 9, 2023 Launch
on SpaceX-29

Ended July 2024



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

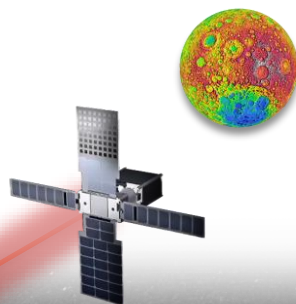
2025 Launch on Orion/SLS



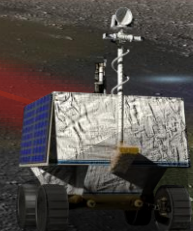
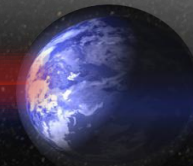
Potential Optical Communications for Future Artemis Missions



Relay-Enabled Lunar Network
*High-rate, low-latency data with
positioning, navigation and timing*



Coherent Optical Data Trunk
20+ Mbps Forward
5 Gbps Return



Lunar Surface
100 Mbps – 2.1 Gbps
*e.g., low-latency tele-robotics;
In-situ analysis*

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

Deep Space Optical

Deep Space Optical Communications is a Reality TODAY!

Deep Space Optical Communications (DSOC) on Discovery Psyche Mission

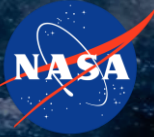
- Launched in Oct 2023
- Purpose: Demonstrate deep space optical links on outbound trajectory to 2.6 AU (Mars-far-like distance)
- Collaboration between STMD, SMD, and SCA

RF/Optical Hybrid Antenna Technology Development

- A concept 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



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

Psyche/DSOC Optical User Terminal

Launch: Oct 2023

RF/Optical Hybrid Antenna

(Ready to Support)

Optical Ground Terminals

Deep Space Optical Architecture

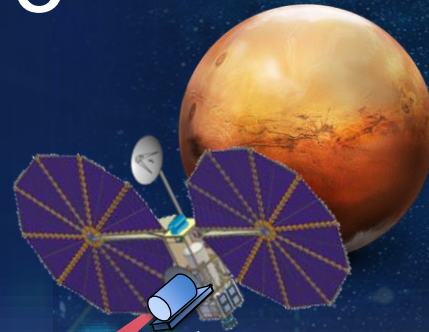
Array of low cost small apertures to achieve an effective large aperture



DSN Hybrid RF/Optical Antennas:

Maximally leverages existing DSN infrastructure. An option for large, 8m, ground terminals. Two can be arrayed for 11.3m aperture.

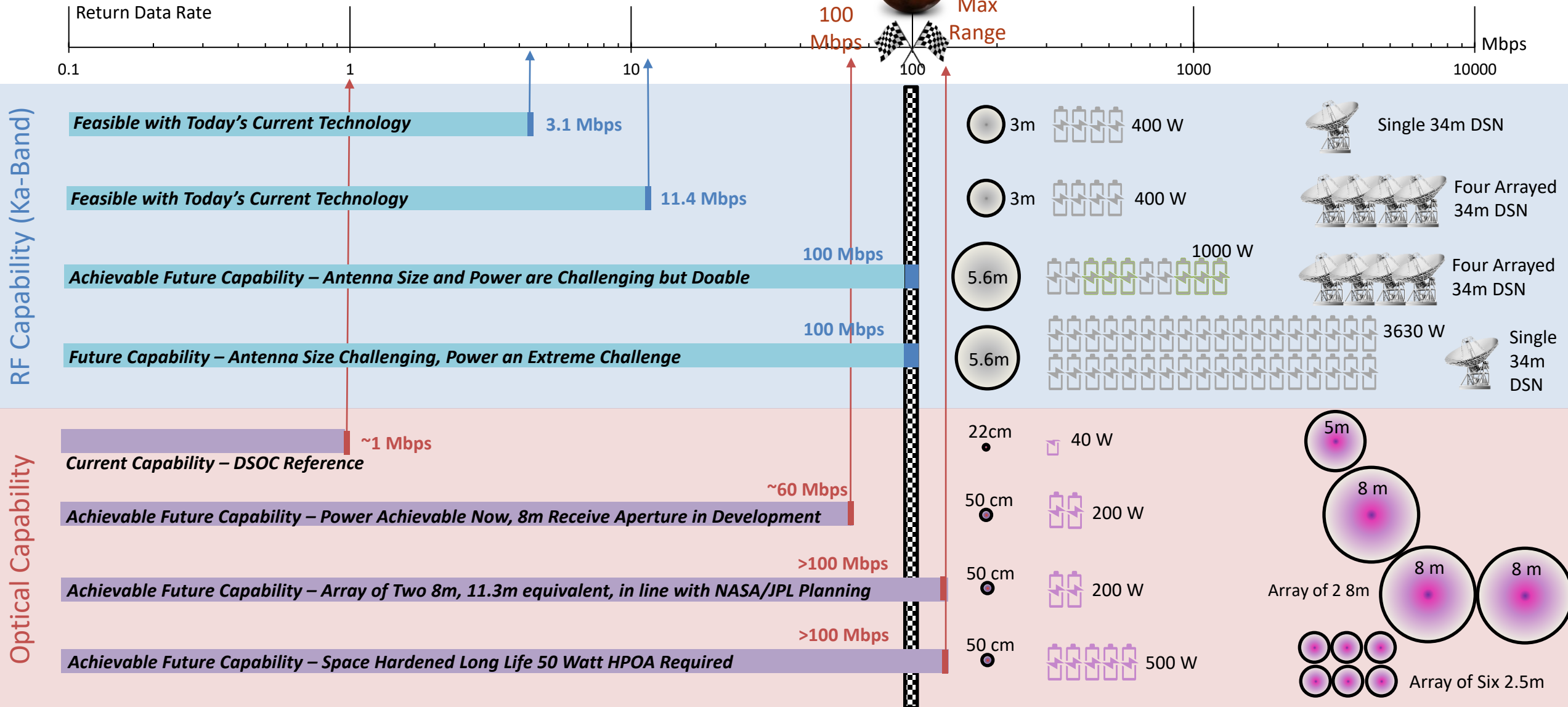
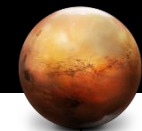
Dedicated Comm Relays
Extend the Internet to Mars and enable public engagement



DSOC Gen-1 User Terminal

DSOC on Discovery Psyche Asteroid Mission
267 Mbps / 1.6 kbps maximum
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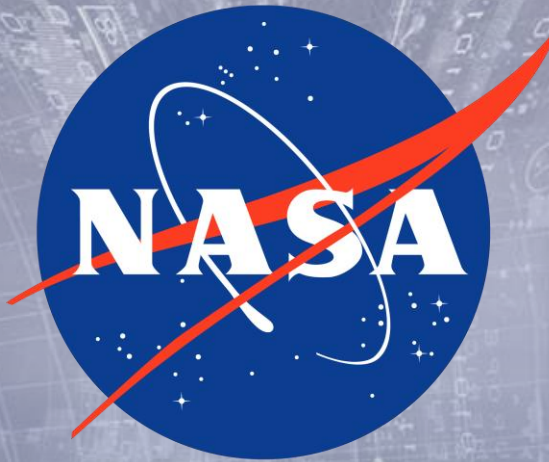
Mars Direct to Earth Example



CONCLUSION



- A critical technology shortfall is High-Rate Deep Space Communications
 - Optical communications will be critical to in closing this shortfall
 - Data rates on the order of 10 Gbps from the Moon and 100 Mbps from Mars are not unrealistic (Today, the highest data rate to a single 34m Deep Space Network terminal at maximum Mars range is 500 Kb/s).
 - Relevant NASA Optical Communications Demonstrations:
 - Deep Space Optical Communications (2023)
 - Lunar Laser Communications Demonstration (2013)
 - Orion Artemis II Optical Communications System (O2O) (TBD)
- STMD leverages NASA expertise and industry partners to advance needed technologies
 - Future feedback opportunities will include international participants
 - Review the integrated ranked shortfall list and participate in future feedback opportunities:
nasa.gov/civilspaceshortfalls



Questions?

Please feel free to contact:

Bernie Edwards

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Space Technology Mission Directorate

Bernard.L.Edwards@NASA.gov



BACKUP

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 m² 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

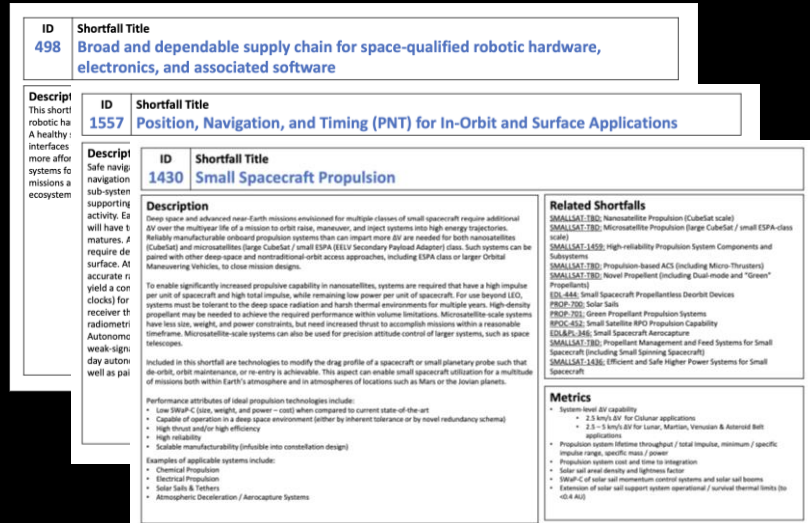


Winner of the National Space Club's Nelson P. Jackson Award for 2015

Revolutionary capability for space users

Civil Space Shortfalls

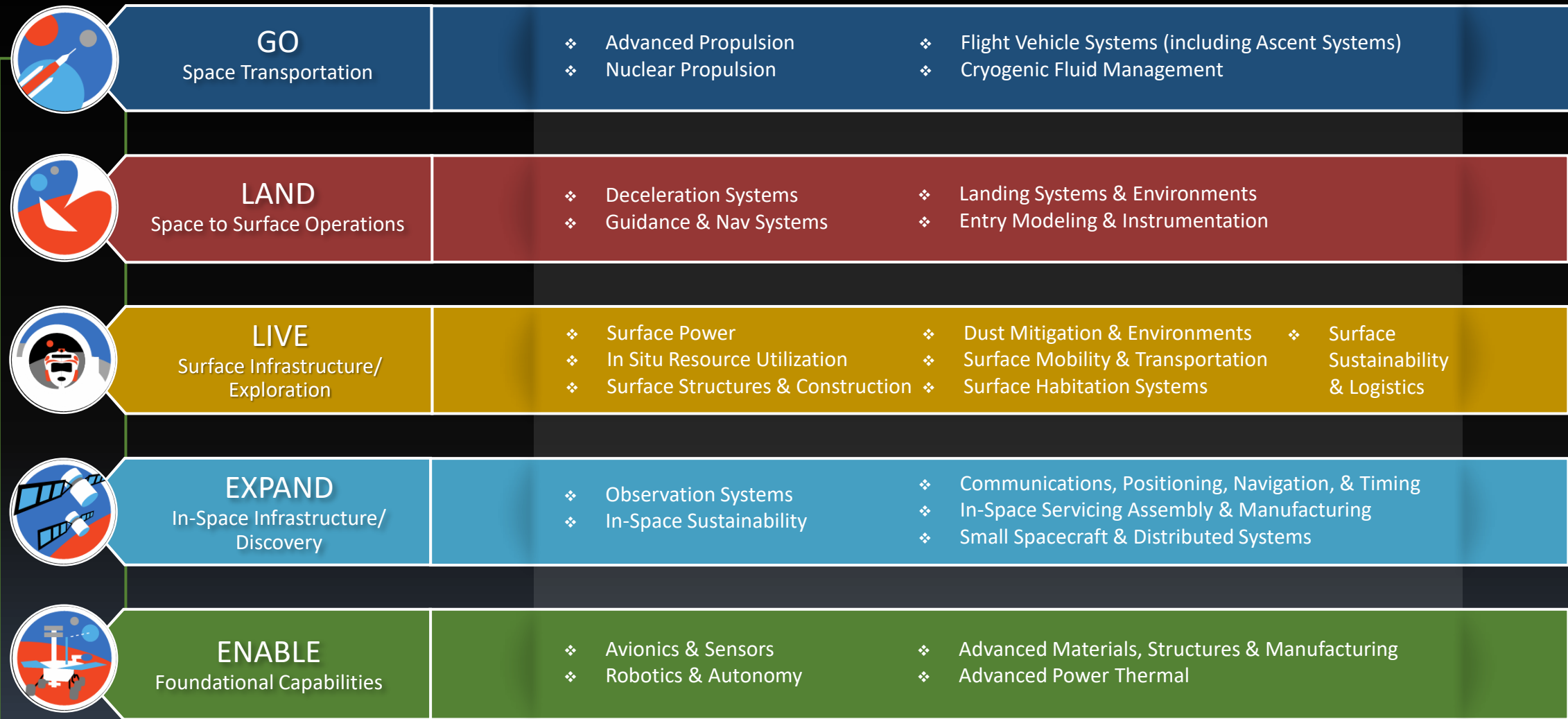
- NASA compiled an initial list of **187 shortfalls** organized into **20 capability areas**
- The shortfall description document and feedback form were organized accordingly



NASA identified an initial list of 187 shortfalls and invited the community to give input on your critical technology needs 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

Tech Base Functional Domains



❖ Capability Portfolio

<p>CATALYSTS Innovative Mechanisms</p>	<ul style="list-style-type: none"> • NIAC/CIF/ECI • STRG 	<ul style="list-style-type: none"> • PCC • Tech Transfer 	<ul style="list-style-type: none"> • SBIR/STTR • Flight Opportunities 	<ul style="list-style-type: none"> • TP/ACO • Inclusive Innovation
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