



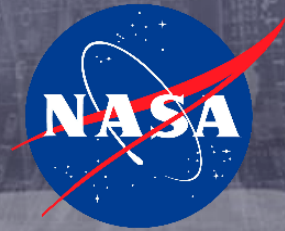
COMMUNICATIONS AND NAVIGATION FOR ARTEMIS AND BEYOND

Panelists:

- **Badri Younes**, Deputy Associate Administrator for Space Communications and Navigation (SCaN), NASA
- **Philip Baldwin**, SCaN Network Operations Manager, NASA
- **Dr. Jason Mitchell**, Director, Advanced Communications and Navigation Technology, NASA
- **Greg Heckler**, Director, Commercial Communications Services Division, NASA

November 15, 2021

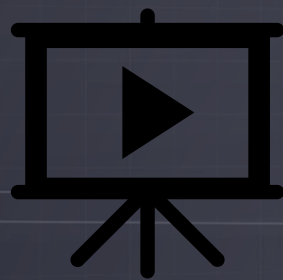
Artemis Overview



Badri Younes

Deputy Associate Administrator for
Space Communications and
Navigation (SCaN), NASA

“We are SCaN” Video



Artemis Landing Humans on the Moon



Lunar Reconnaissance Orbiter: Continued surface and landing site investigation



Artemis I: First human spacecraft to the Moon in the 21st century



Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st Century



Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost



Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



Early South Pole Robotic Landings
Science and technology payloads delivered by Commercial Lunar Payload Services providers

Volatiles Investigating Polar Exploration Rover
First mobility-enhanced lunar volatiles survey

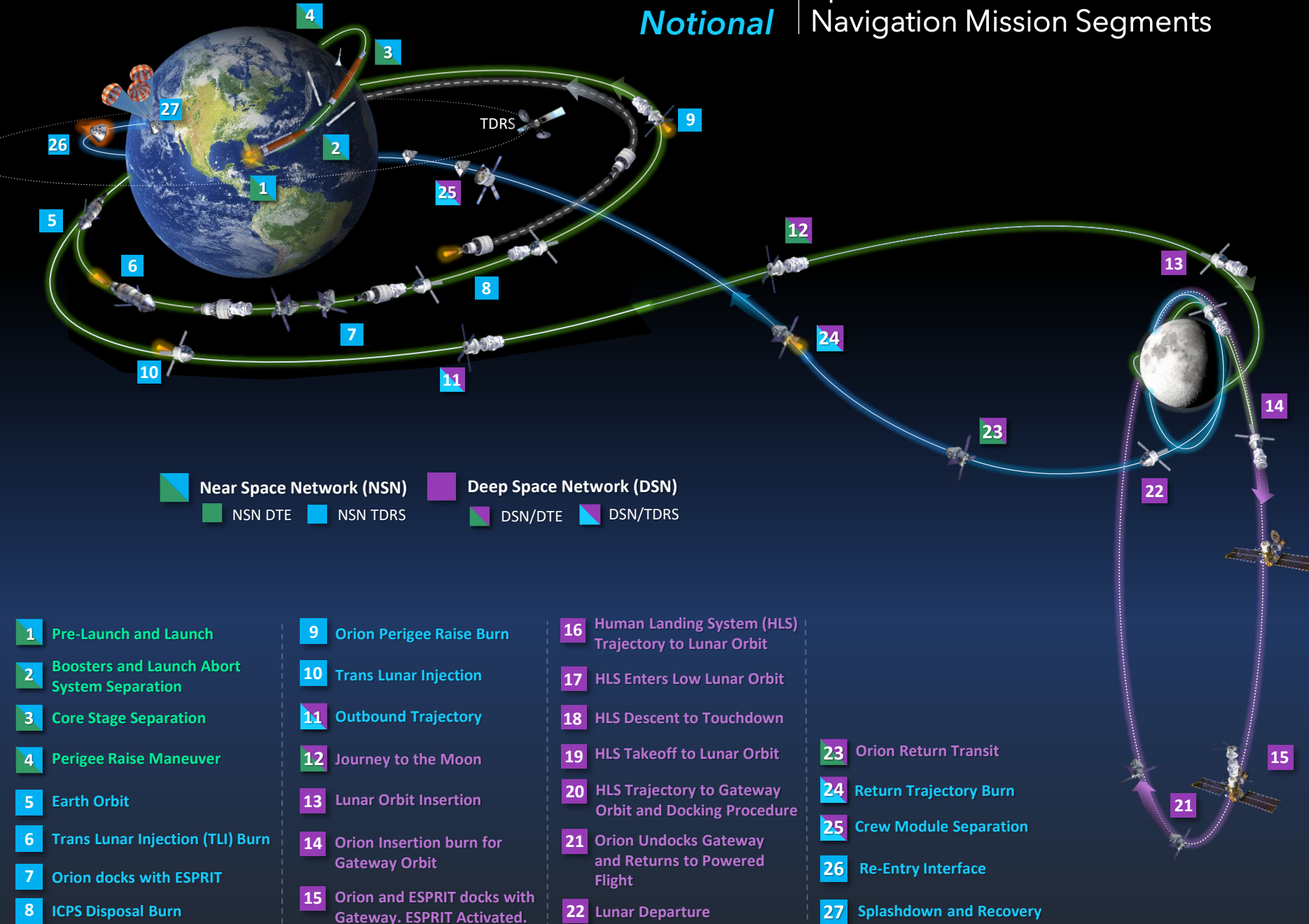
Uncrewed HLS Demonstration

Humans on the Moon - 21st Century
First crew expedition to the lunar surface

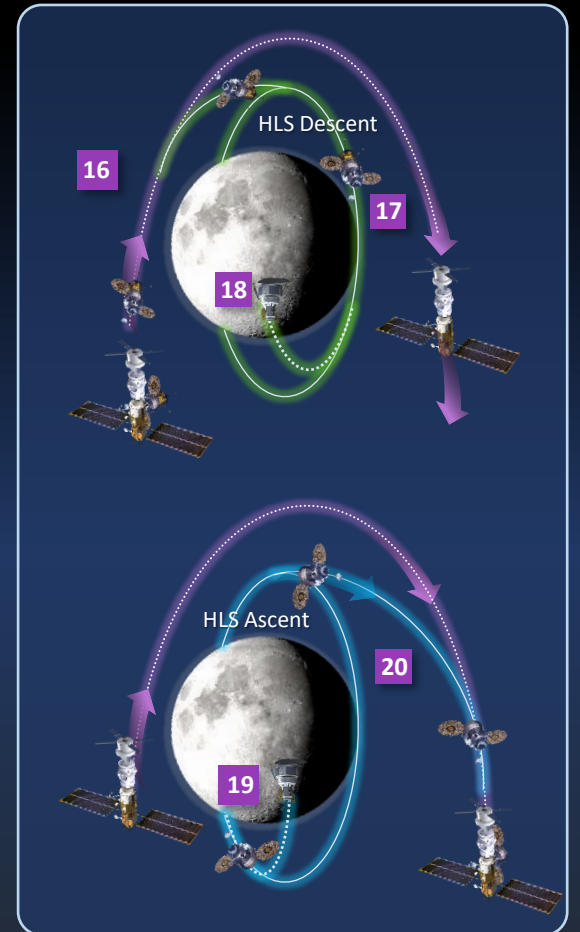
LUNAR SOUTH POLE TARGET SITE

ARTEMIS Notional

Space Communications and Navigation Mission Segments

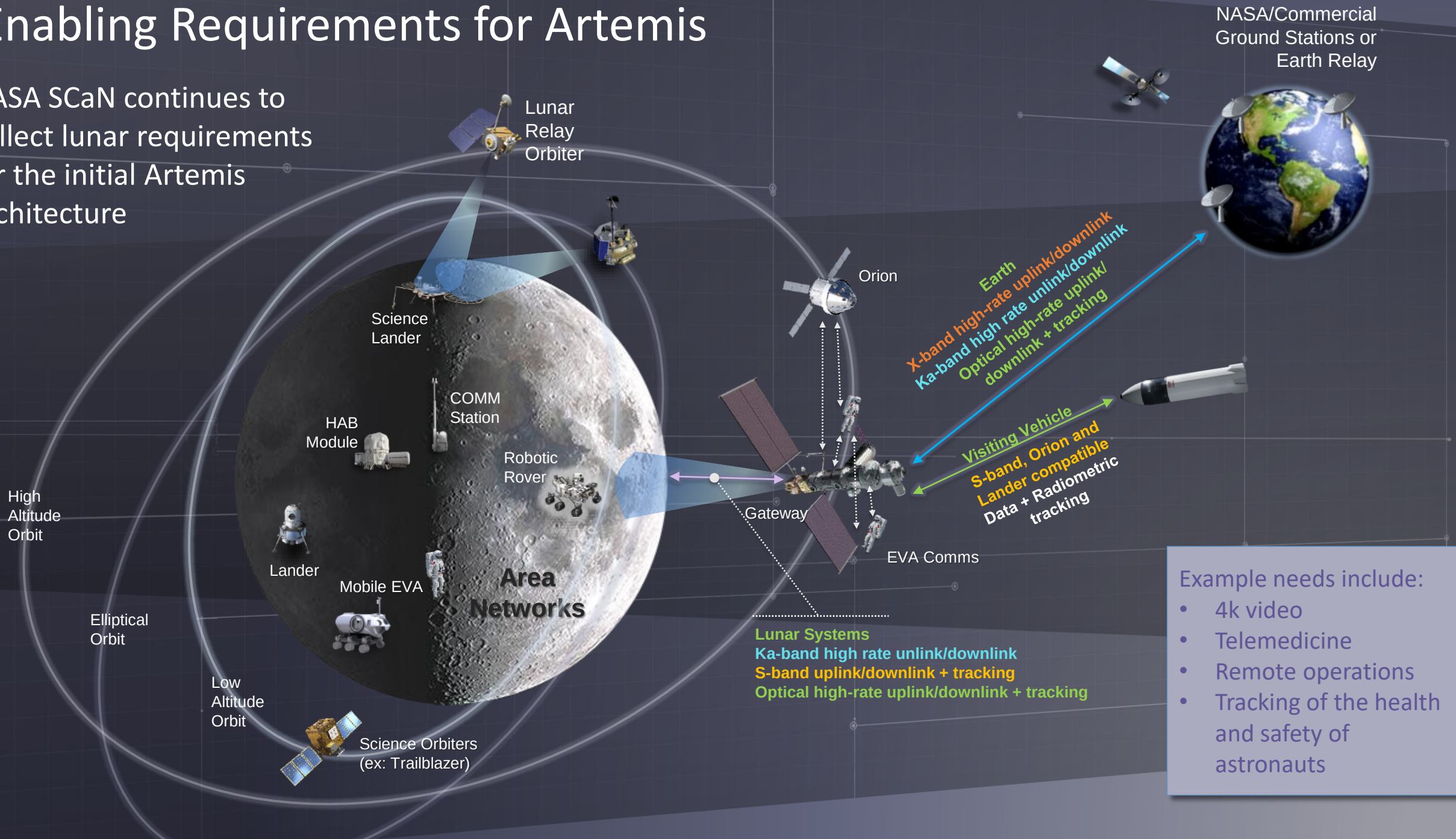


Notional Lunar Landing Details



Enabling Requirements for Artemis

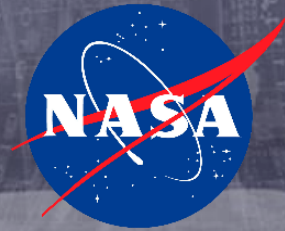
NASA SCaN continues to collect lunar requirements for the initial Artemis architecture



Example needs include:

- 4k video
- Telemedicine
- Remote operations
- Tracking of the health and safety of astronauts

SCaN Network Operations Perspective and Plans



Philip Baldwin
SCaN Network Operations
Manager, NASA

NASA's Communications Networks

-  NASA Near Space Network (NSN)
-  NASA Deep Space Network (DSN)
-  Commercial Stations Supporting NSN
-  Optical
-  Future Upgrades



Artemis Plan Communications Approach

**Deep Space Network
(DSN) 34-Meter Antenna
Upgrades**



**Lunar Exploration
Ground Sites (LEGS) –
18-meter Class Antenna
Subnet**



**Lunar Relay and
Interoperable Lunar
Network**



Deep Space Network Upgrades

- Upgrades to DSN's 34-m subnet represent a low-risk option to help meet Artemis program and Lunar science needs
- **Modifications will be made to two antennas at each DSN complex – total of six antennas**

Simultaneous Operations

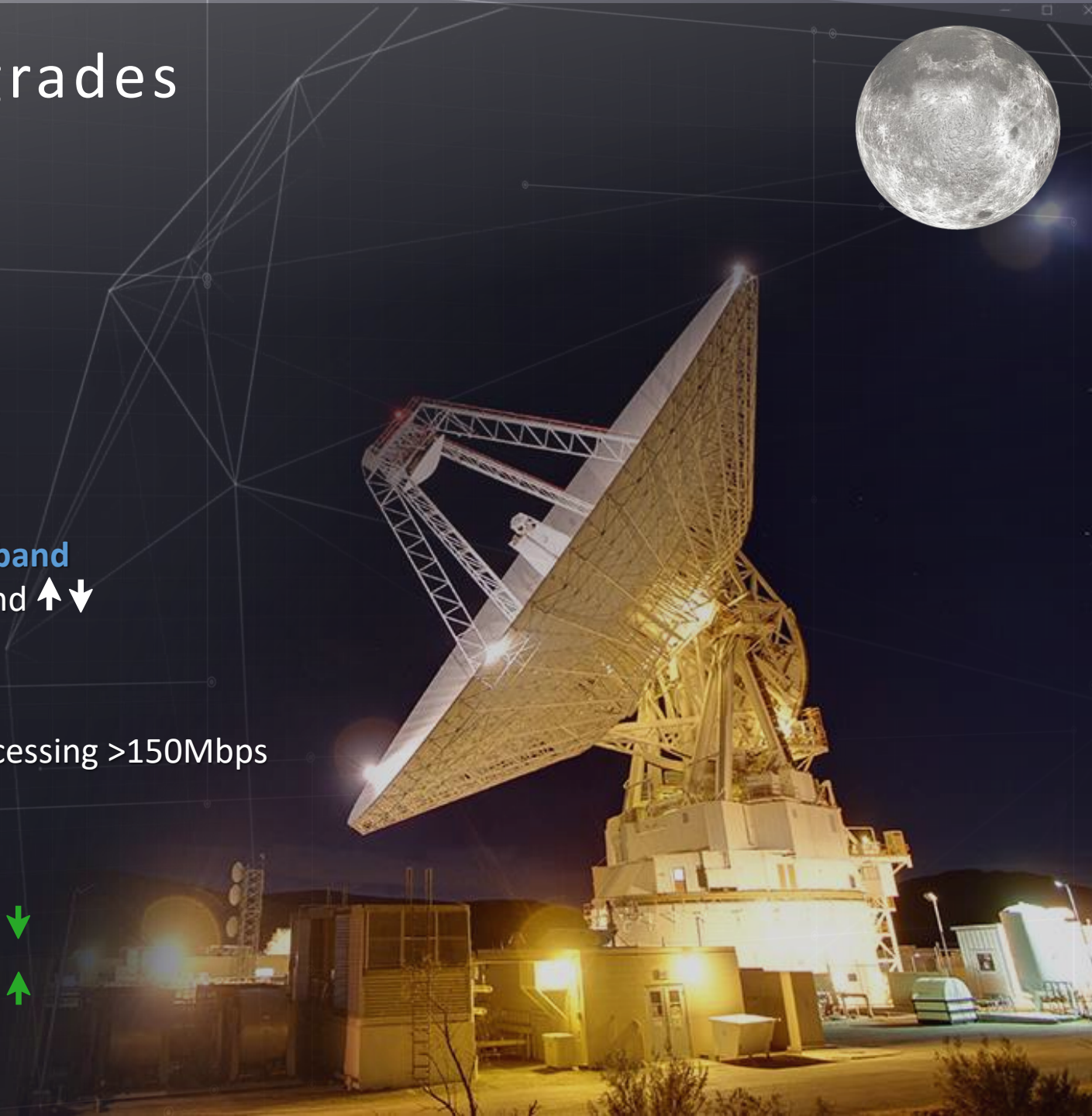
S+Ka-band or **X+Ka-band**
Simultaneous Ka-band ↑↓

LOW Latency data processing >150Mbps

HIGHER DATA RATES

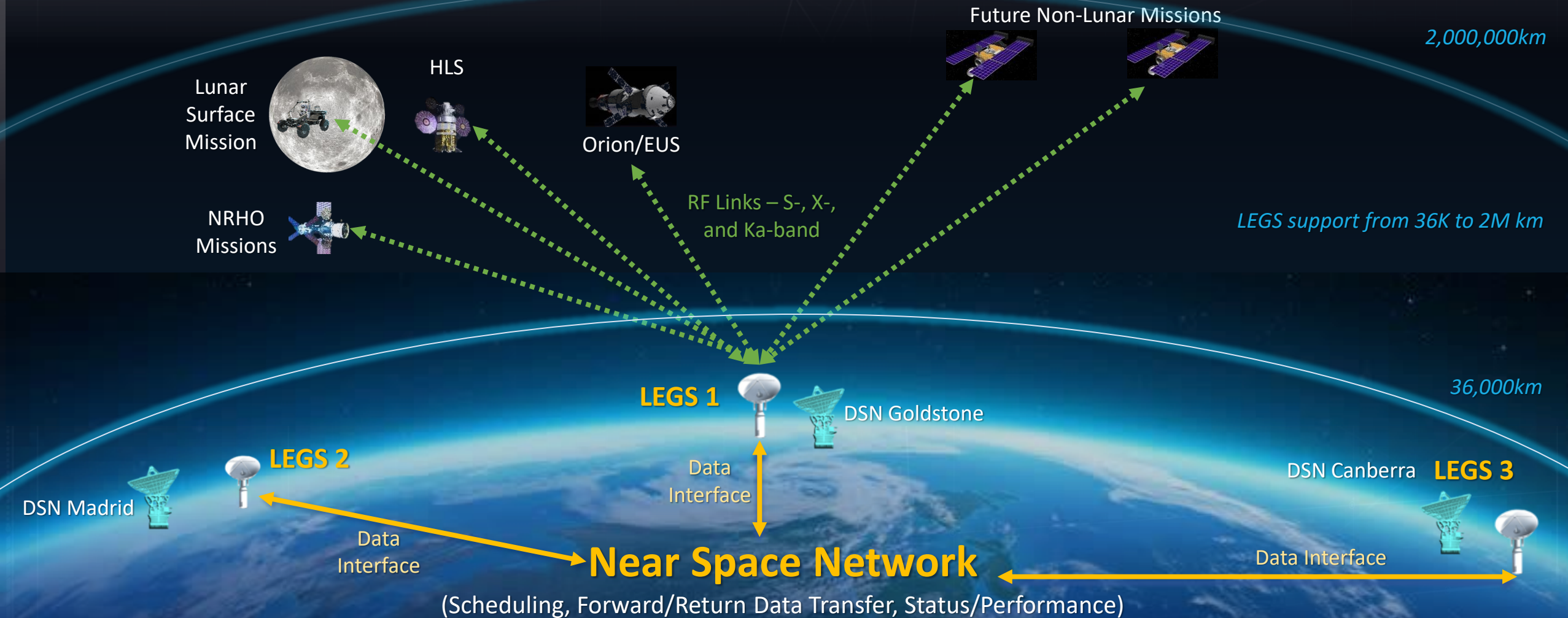
Ka-band
>100Mbps ↓
>20Mbps ↑

X-band
>2Mbps ↓
>5Mbps ↑

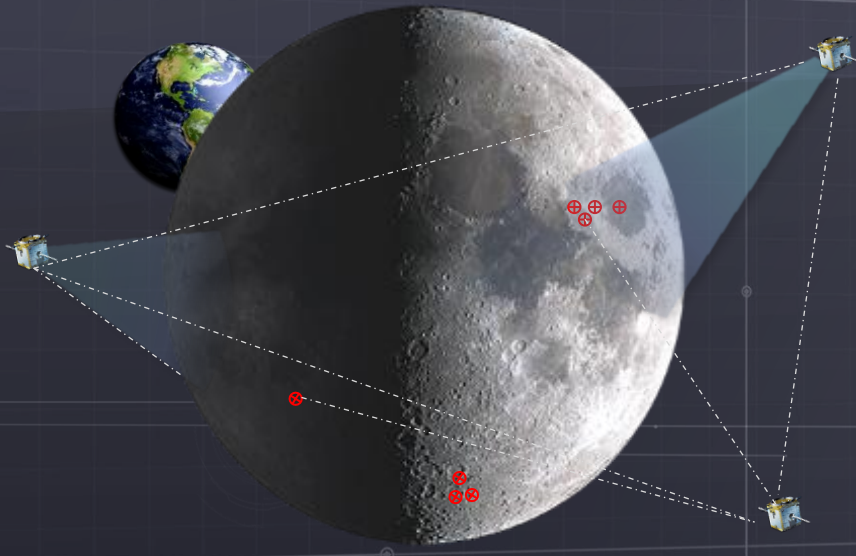


Lunar Exploration Ground Sites Overview

- Lunar Exploration Ground Sites (LEGS) will provide Direct to Earth (DTE) RF comms to users ranging from Earth GEO orbit cis-Lunar space and to Sun-Earth-Lagrange orbits
- Minimum of three sites located around the Earth to provide continuous coverage
- Ability to add further assets as demand grows



Critical Need For Lunar Relay and An Interoperable Lunar Network – LunaNet



Lunar Relay services needed as early as 2024 to support key missions and spacecraft

- Solves mission communications for scenarios with limited Missions DTE visibility
- Missions without line-of-sight visibility issues also benefit from relay

“LunaNet” is a scalable, extensible, and reusable network architecture framework

- Initial focus on lunar vicinity comms
- Framework is extensible to Mars and beyond



Other Core Capabilities

Delay/Disruption Tolerant Networking:

- DTN protocol enables efficient data transmissions
- **More DTN nodes = more data pathways**
- Reusable interoperable solutions

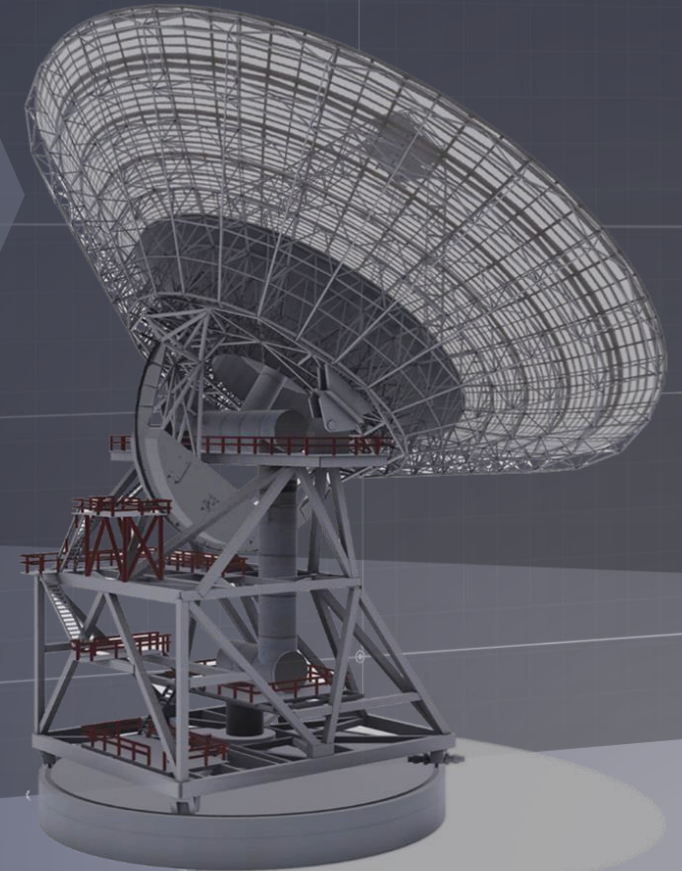
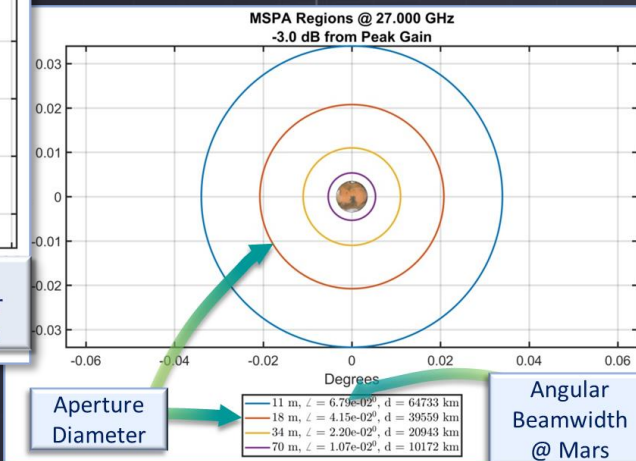
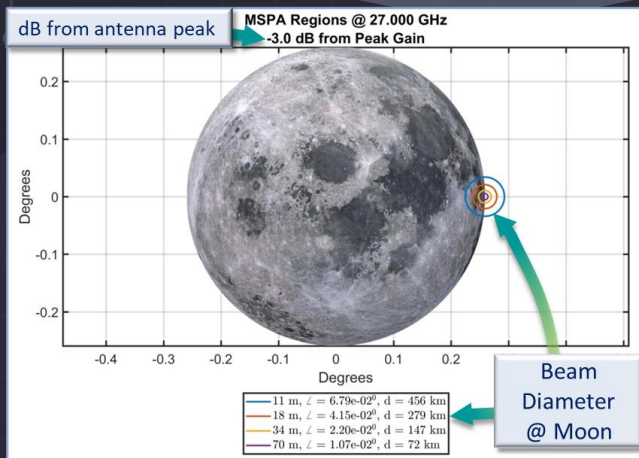


Multiple Spacecraft Per Aperture:

- MPSA antenna receives data simultaneously from multiple spacecraft → **more efficient use of each DSN asset**

Simultaneous Frequency Communications:

- DSN dichroic mirrors / mirror configuration updated for simultaneous comm. in **multiple bands**



Timeline and Evolution

Now to 2024

2024 to 2028

2028 and Beyond

Deep Space Network Upgrades

First upgrades in 2022 completed in 2024



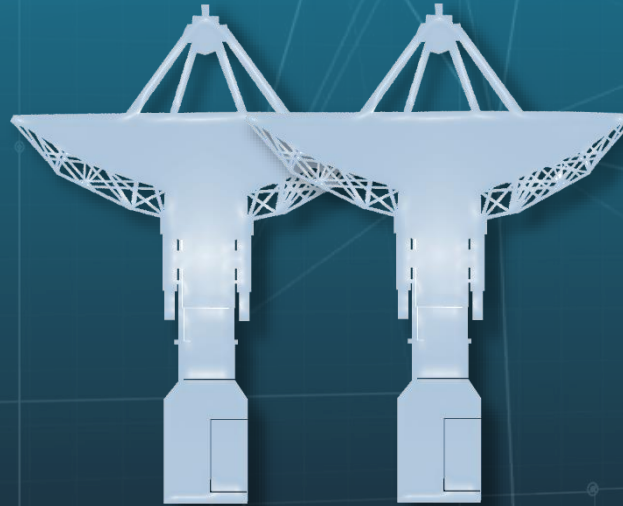
LEGS 1

First Lunar Exploration
Ground Site 2024



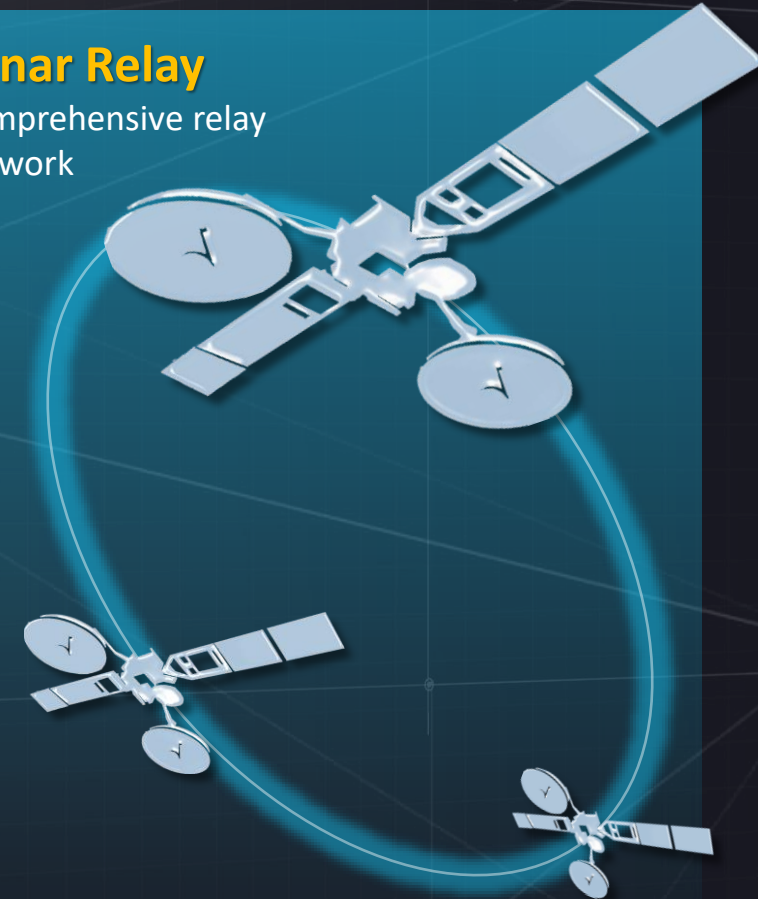
LEGS 2 & 3

Expansion of Lunar Exploration
Ground Sites by 2026



Lunar Relay

Comprehensive relay
network



Lunar Relay

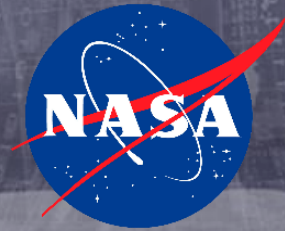
One or more Relays
Developed by 2024

- *LunaNet Compatibility*



- *Evolution Infrastructure*
- *Infusion of New Technology*
- *Surface Comm & Nav Assets*
- *Full LunaNet Services*

Technology Enabling C&N Capability at the Moon and Beyond



Dr. Jason Mitchell
Director, Advanced
Communications and Navigation
Technology, , SCaN Program, NASA

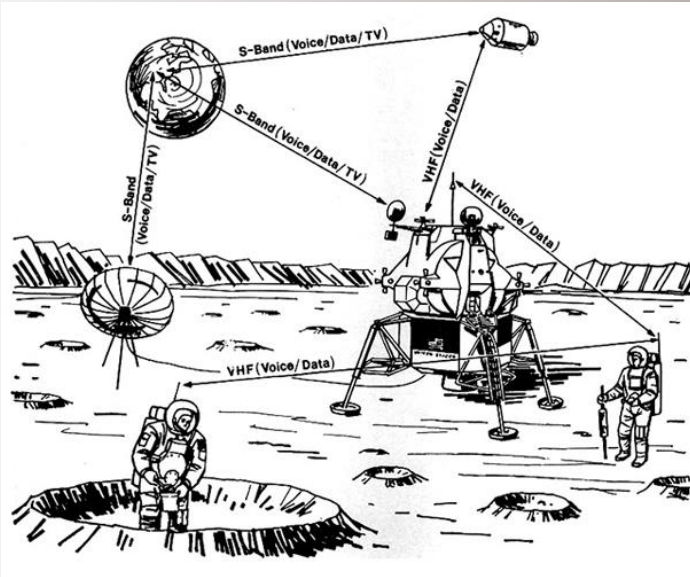
Autonomy Drives Technology Needs

The new era of lunar exploration is a departure from Apollo

- Volume of missions and assets – complexity of ops
- Greater precision for science and ops
- Greater autonomy required to perform, and prep for Mars
- High-rate data aggregation to reduce user burden

Elements of our Technology Portfolio:

- **Lunar Global Navigation Satellite System (GNSS) capability**
- **Deep Space Atomic Clocks**
- **Autonomous Navigation**
- **Optical trunk links supporting LunaNet**

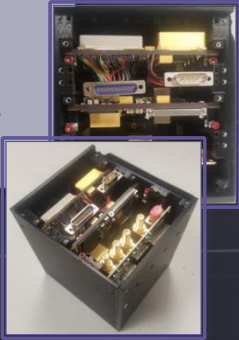


GNSS at the Moon and High-Rate Data Aggregation

Global Navigation Satellite System (GNSS) reception in cislunar environment dramatically **reduces network burden** and **enables autonomous operations**

NavCube3-mini (NC3m) multi-GNSS receiver

- <2U, 2 kg, ~12 W
- Onboard navigation filter
- TRL6 targeting mid-2022



Space Service Volume (SSV) (3,000 to 36,000 km)

GNSS Orbit

Near-Earth GNSS Sidelobe Signals

High-Rate Trunkline Link

Cislunar GNSS Sidelobe Signals

LunaNet Node 1

LunaNet Node 2

LunaNet Node 4

LunaNet Node 3

LunaNet Node n

User A

User B

User C

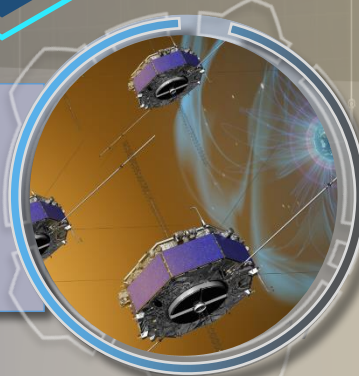
User D

Surface Beacons

Crosslinks

Lunar relay services address far-side access

Build on experience with successful high-altitude GPS application: Magnetospheric Multi-Scale Mission (MMS) demonstrated success at 29.3 Earth radii (50% of lunar distance)



Deep Space Atomic Clock (DSAC)

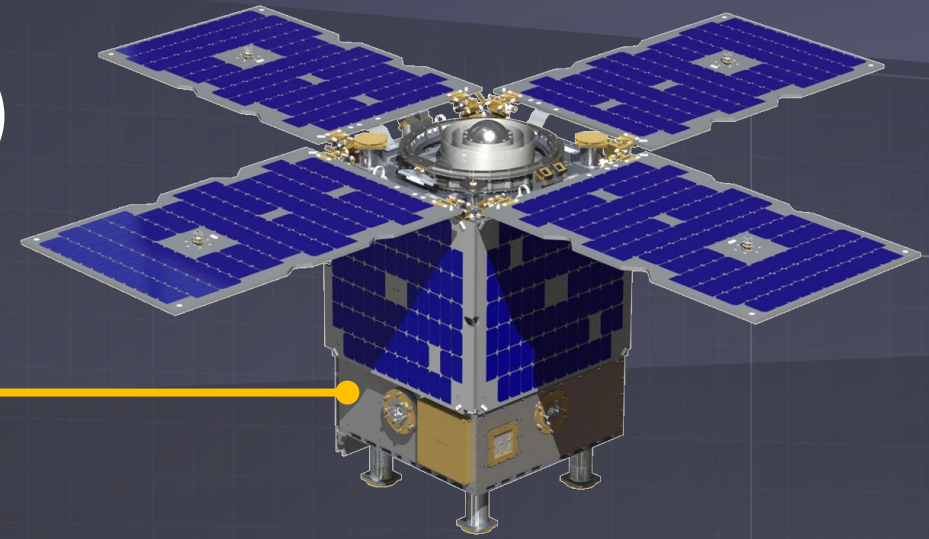
DSAC is a **mercury ion (Hg⁺)** atomic clock demonstration that recently set the record for long-term stability in space

Provides **more than 50x** better long-term stability over current atomic frequency standards

1-day STABILITY = $3e-15$

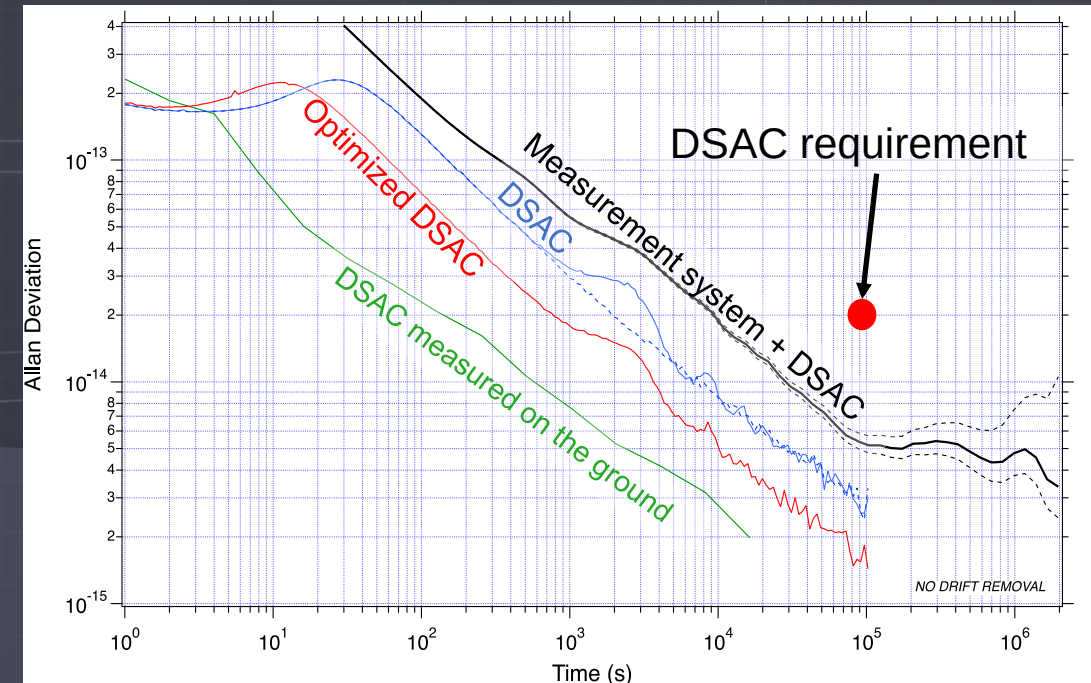
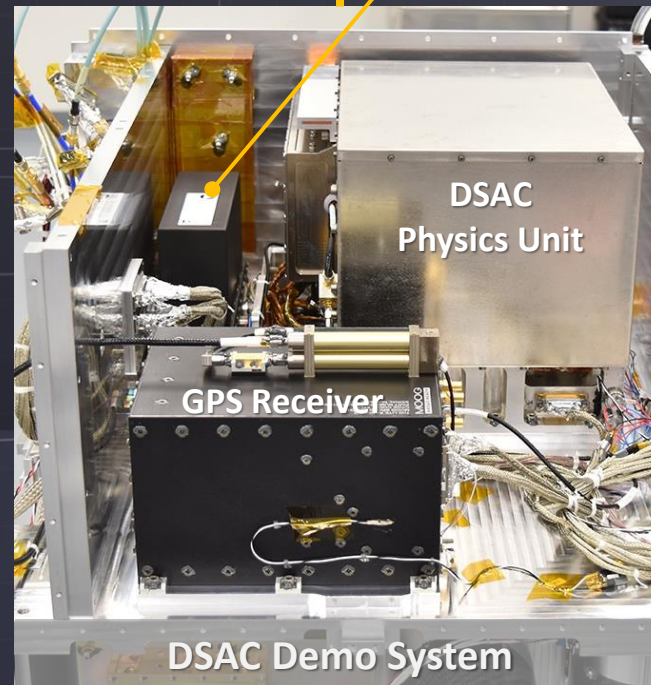
DRIFT = $3e-16$ /day

Enhances autonomous navigation performance
DSAC2 is smaller and requires less power— will fly on **VERITAS**



Ultra-Stable Oscillator (USO)

DSAC Allen Deviation



Autonomous Navigation

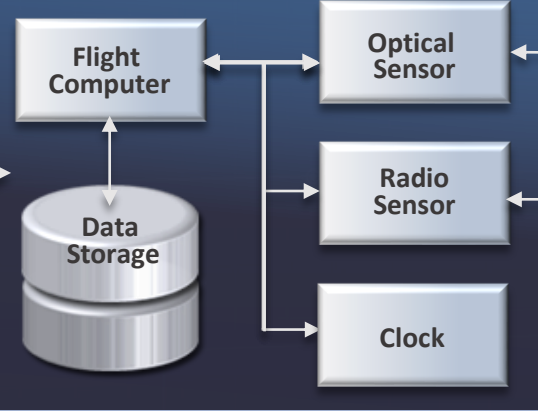
Fusion of a diverse set of measurements will enable spacecraft autonomy

INTERFACES:

Position,
Velocity,
Time,
Attitude,

Maneuver,
Epoch, Vector
and Duration,
Commands,
Telemetry,
Power

FLIGHT SOFTWARE



Angles

Target Body
Centroid or
Landmarks

Doppler,
Range

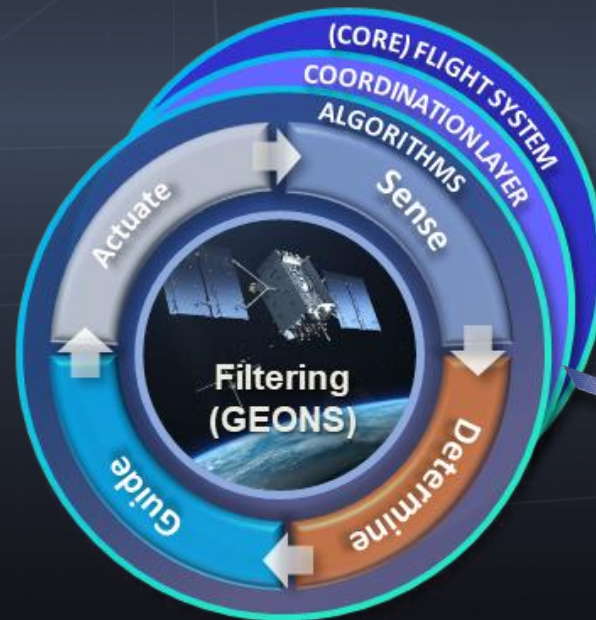
Radio
Beacon:
Earth-based
Or In-Situ

Image-based Example
Approach: Combine
Celestial and Terrain-
Relative Navigation

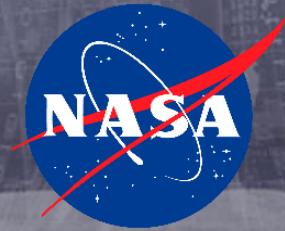
Optical Triangulation in
Cruise: Target body,
asteroids, and stars

Approach

Maneuver
Computed
On Spacecraft

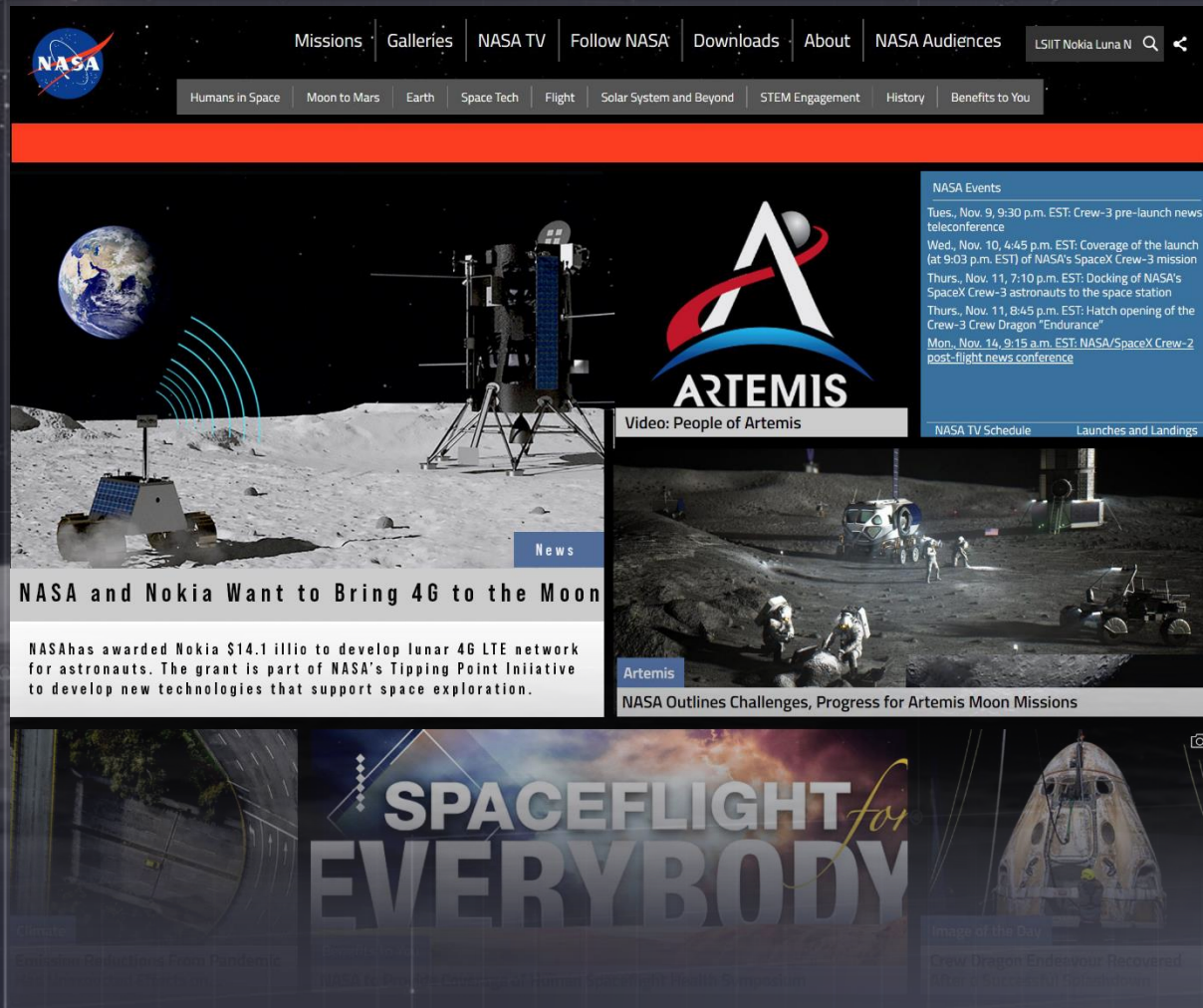


SCaN Commercialization Opportunities



Greg Heckler, Director,
Commercial Communications
and Services Division, SCaN
Program, NASA

What Could Commercial Service at the Moon Look Like?



The screenshot shows the NASA website with the following elements:

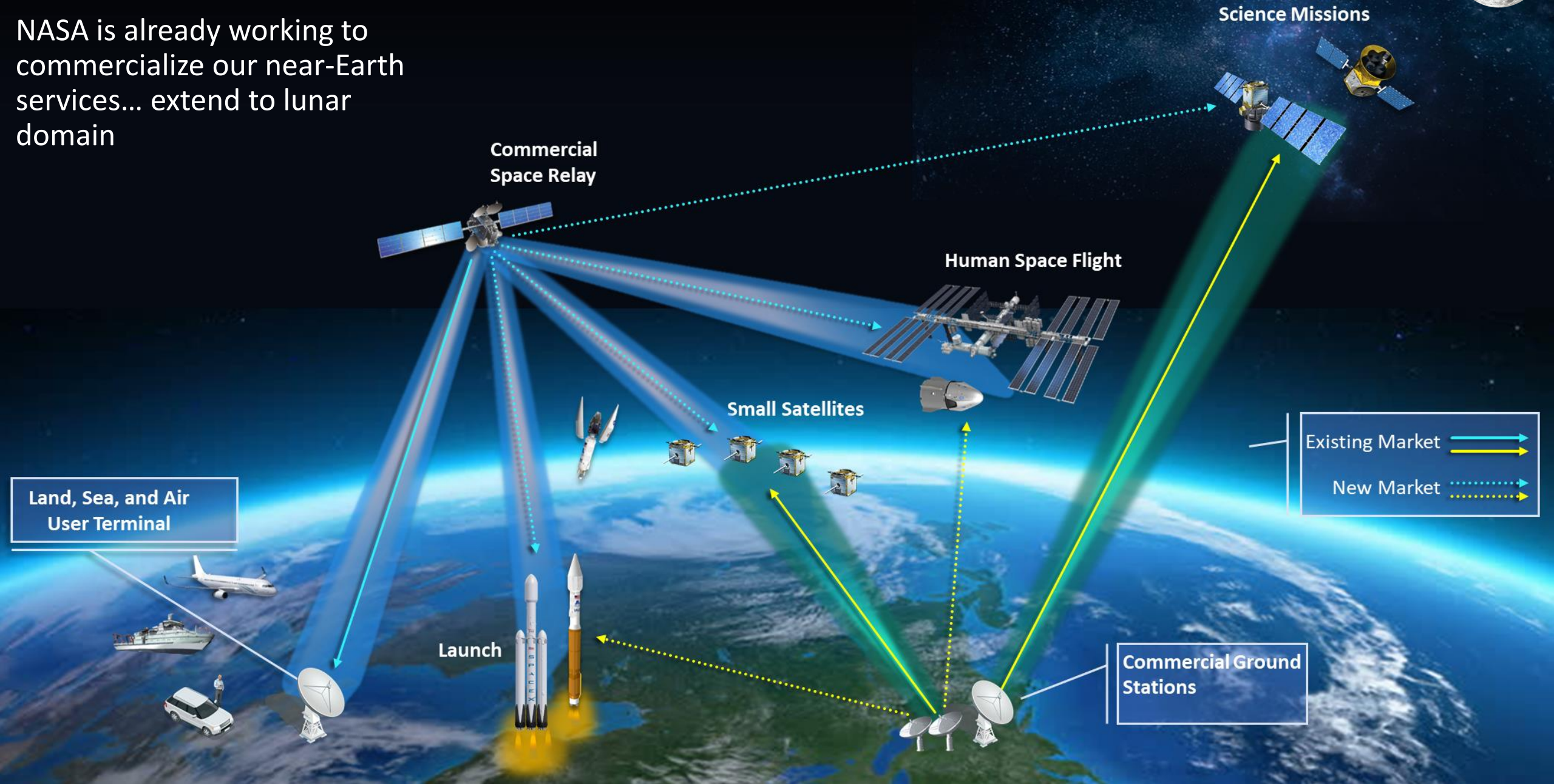
- Top Navigation:** Missions, Galleries, NASA TV, Follow NASA, Downloads, About, NASA Audiences, LSIIT Nokia Luna N.
- Secondary Navigation:** Humans in Space, Moon to Mars, Earth, Space Tech, Flight, Solar System and Beyond, STEM Engagement, History, Benefits to You.
- Main Content Area:**
 - Left Column:** A large image of a lunar lander on the moon surface with the Earth in the background. Below it is a "News" tag and the headline "NASA and Nokia Want to Bring 4G to the Moon". The text below the headline states: "NASA has awarded Nokia \$14.1 million to develop lunar 4G LTE network for astronauts. The grant is part of NASA's Tipping Point Initiative to develop new technologies that support space exploration."
 - Center Column:** The Artemis logo with the text "Video: People of Artemis" below it. Below the video is an "Artemis" tag and the headline "NASA Outlines Challenges, Progress for Artemis Moon Missions".
 - Right Column:** A "NASA Events" section listing several upcoming events with dates and times.
- Bottom Section:** A banner for "SPACEFLIGHT for EVERYBODY" with a background image of a rocket launch. Below the banner are two smaller images: "Image of the Day" showing a Crew Dragon Endeavour and a "Crew Dragon Endeavour Recovered After a Successful Mission".

- Bringing near-Earth commercial capability to the lunar environment
- Lunar surface use cases are analogous to terrestrial use cases that are supported by 4G/LTE standards
- First steps... NASA awarded a Lunar Surface Innovation Initiative Technology Demonstration to Nokia, partnering with Intuitive Machines to demonstrate a 4G/LTE base station and user radio on the moon

Commercialization Underway



NASA is already working to commercialize our near-Earth services... extend to lunar domain

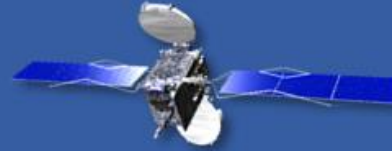


How We Get There



Vision for Satellite ("Non-Terrestrial Network" (NTN))

- Integrated/hybrid terrestrial NTN
- Multi-beam
- Internet of Space Things
- Cognitive terrestrial-NTN



- SDN/NFV based NTN
- Network slicing in NTN
- Edge computing-based NTN
- NOMA based terrestrial-NTN

Can space missions be a 5G NTN user in Near Earth?

And...then can we extend these same capabilities and standards to the moon?



- Orbital users – connecting MOCs and spacecraft
- TT&C services
- Science data transfer



- Fixed and mobile backhaul alternative
- Professional mobile
- Automotive
- eHealth



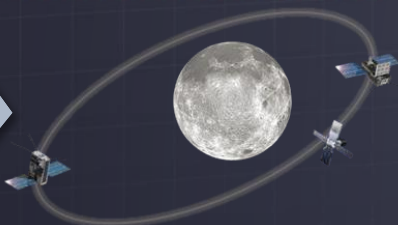
- Connectivity alternative
- Mobile network backhaul
- Disaster relief



- Highly distributed networks
- Isolated connectivity
- Emergency and safety



- Aeronautical broadband
- Maritime broadband
- Maritime safety



Outreach and Engagement



NASA is actively encouraging the commercial industry to participate in lunar efforts for communication and navigation on LEGS and Relay services

Outreach beginning in the summer of 2020 has led to a recent Source Sought Notice (September 2021). Planned Requests for Proposals (RFPs) in 2022 will span services:

- DTE for near-earth
- Lunar DTE communications
- Lunar relay communications and navigation

The logo for ASCEND, featuring a stylized white 'A' with a small triangle pointing right, followed by the letters 'SCEND' in a bold, sans-serif font. The logo is set against a dark blue rectangular background.

ASCEND

COMMUNICATIONS AND NAVIGATION
FOR ARTEMIS AND BEYOND

QUESTION AND ANSWER

Contact us at scan@nasa.gov