National Aeronautics and Space Administration

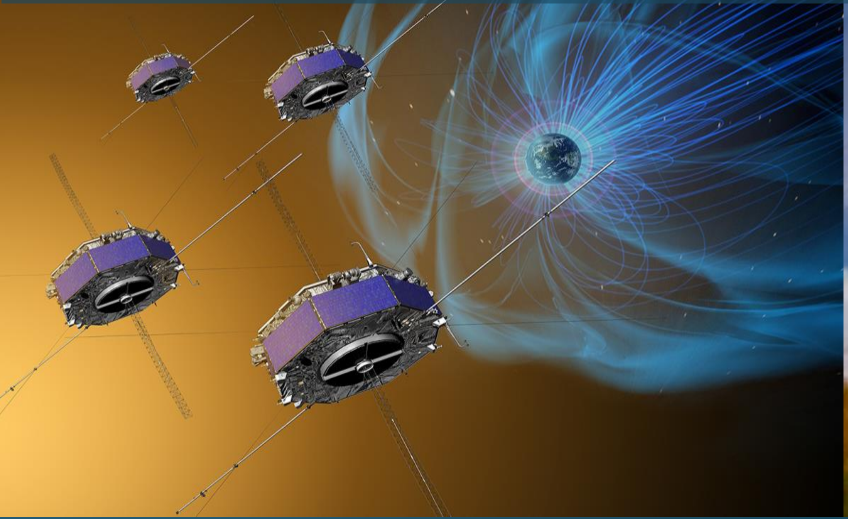
NASA Advancements using GNSS for Space Operations and Science

Joel J. K. Parker

Technology Strategist, NASA Space Communications and Navigation (SCaN)

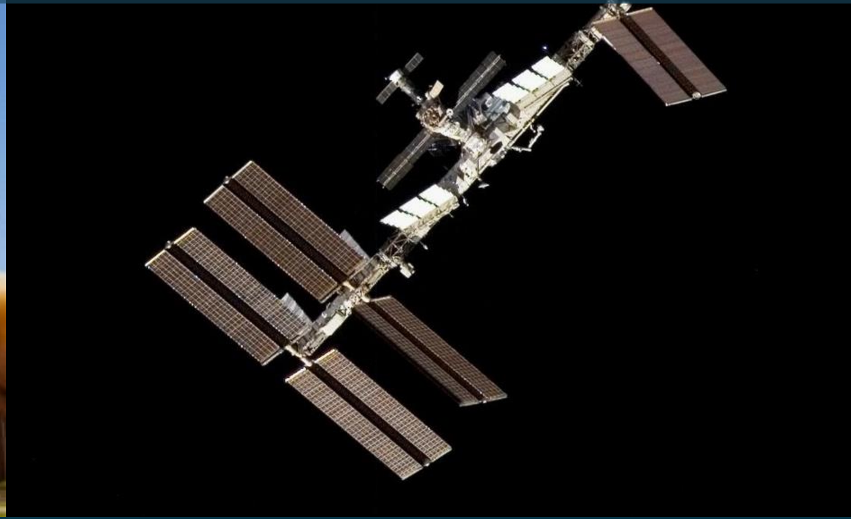
April 21, 2026

Real-Time On-Board PNT



Launch Vehicle Range Ops

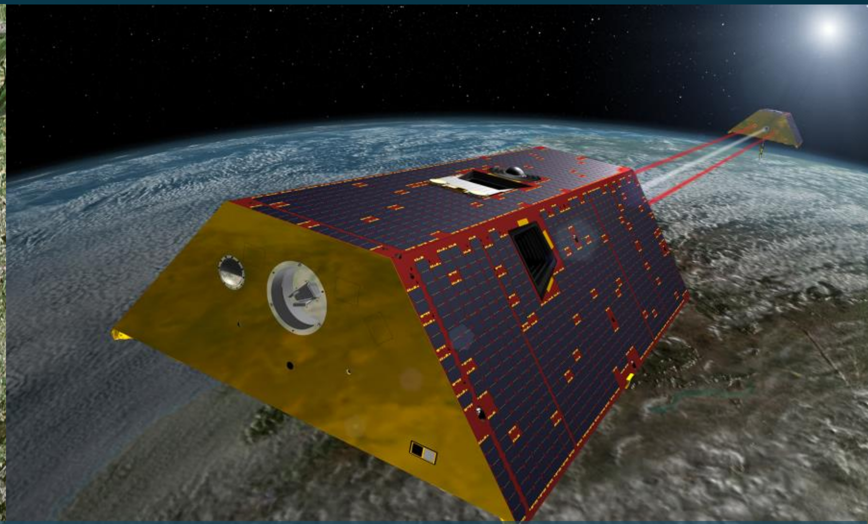
Attitude Determination



Active Space Uses of GNSS at NASA

Time Synchronization

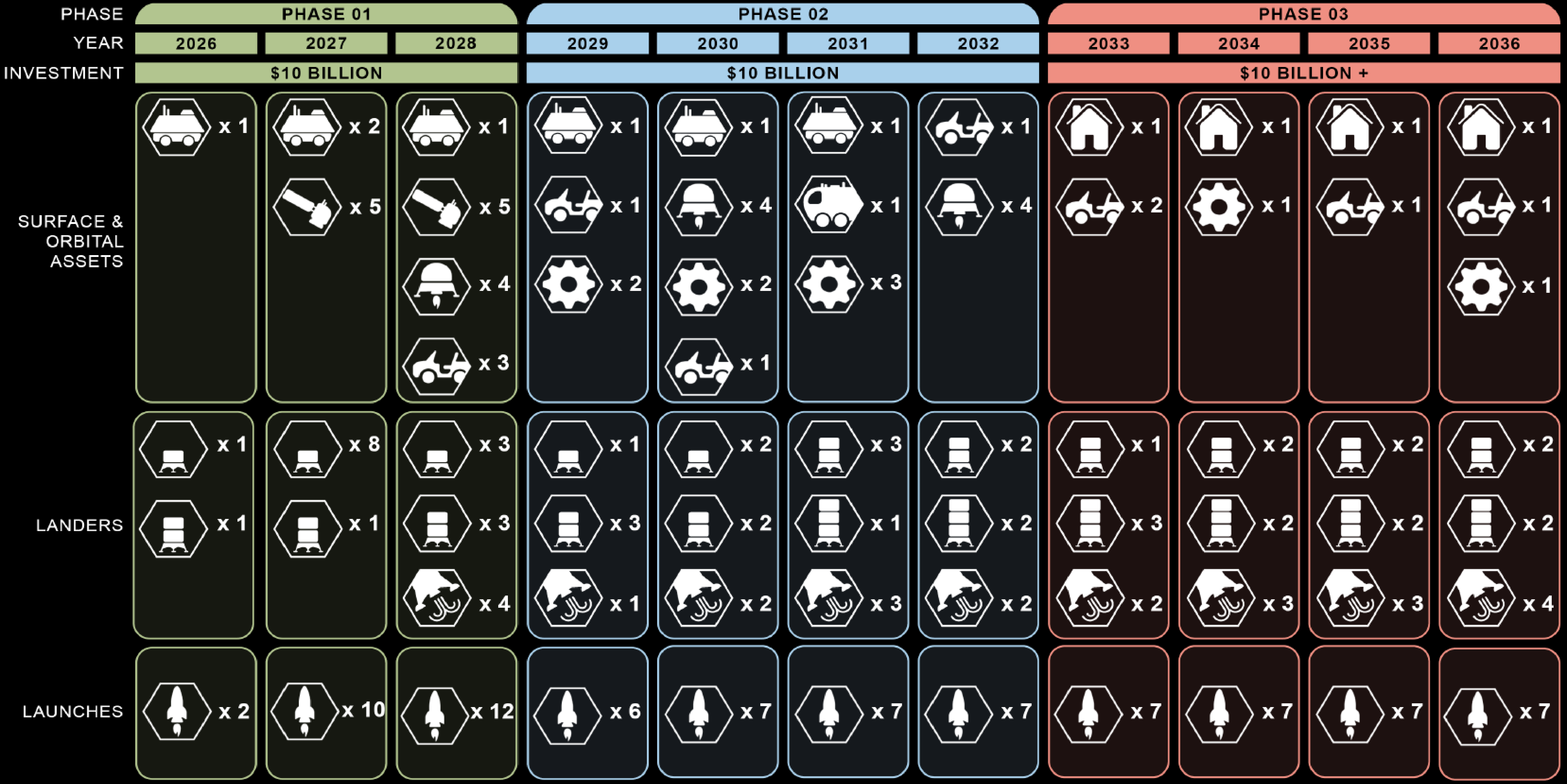
Earth Sciences



Precise Orbit Determination

Source: NASA Ignition, Mar 24, 2026

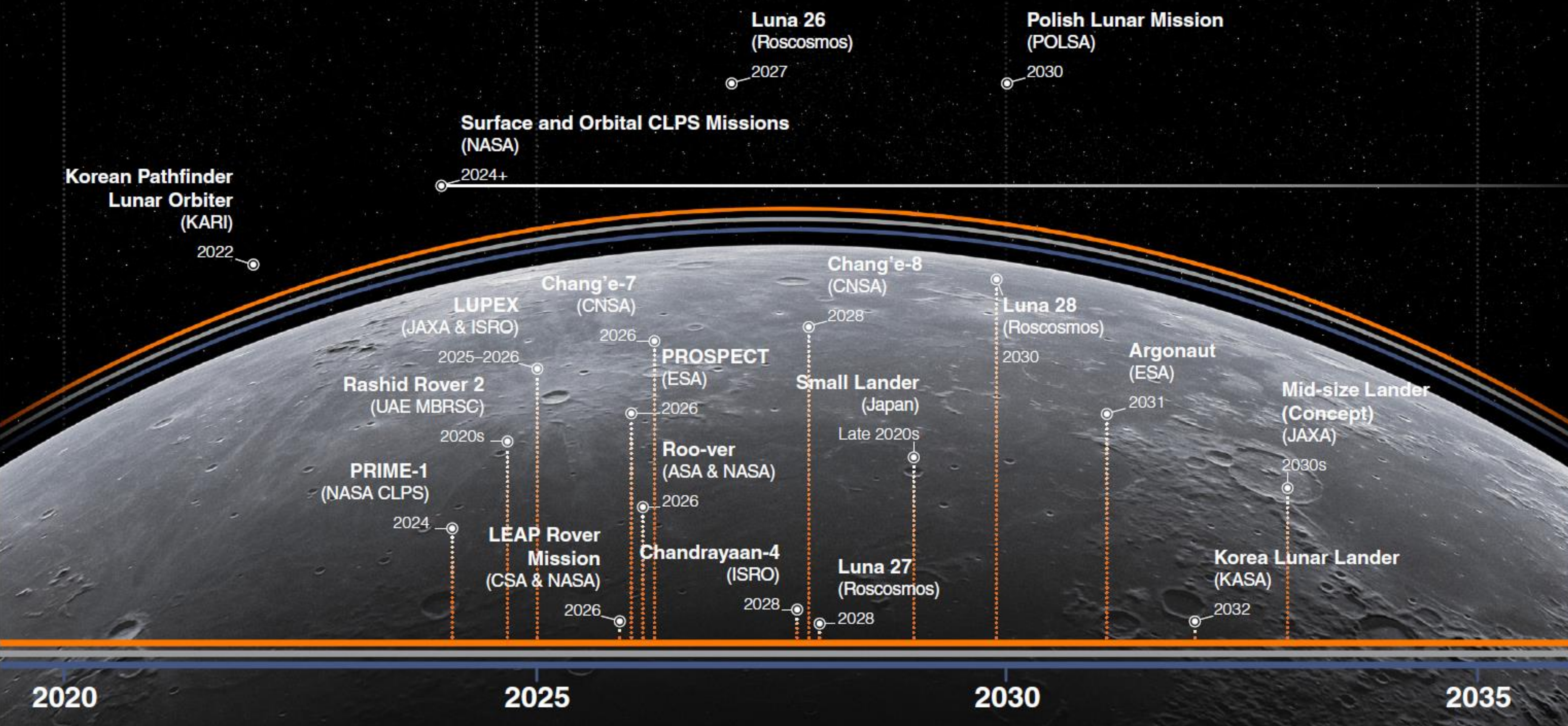
MOON BASE



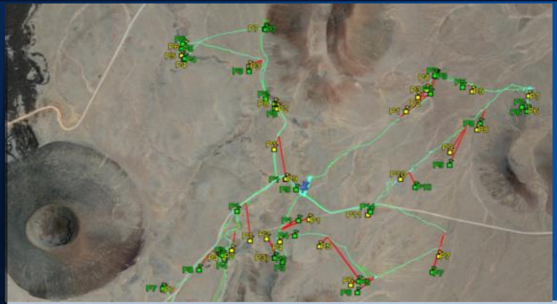
Operational and Planned Lunar Robotic Missions

Source: Global Exploration Roadmap, Aug 2024

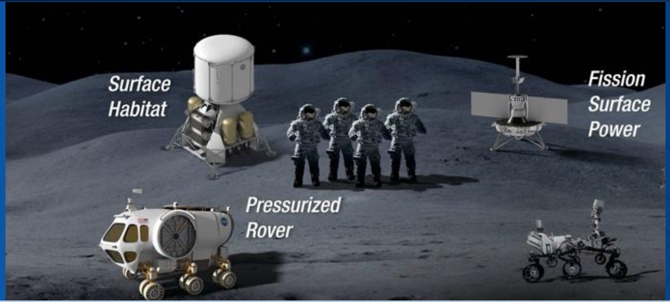
Note: Not to scale; positioning in graphic does not indicate landing location.



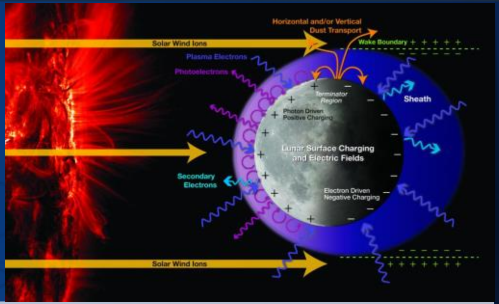
Lunar PNT **Challenges**



Orienteering Accuracy

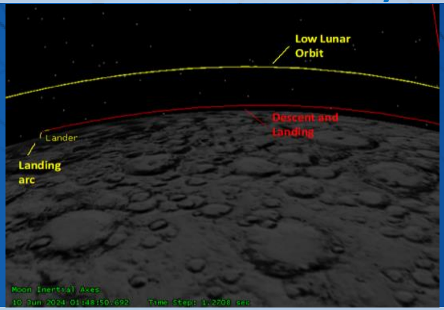


Power / Mass / Volume – Constrain what users can carry for nav



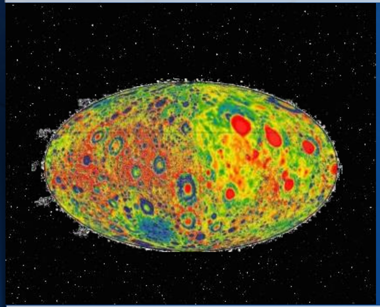
Surface Environment

Reference Time



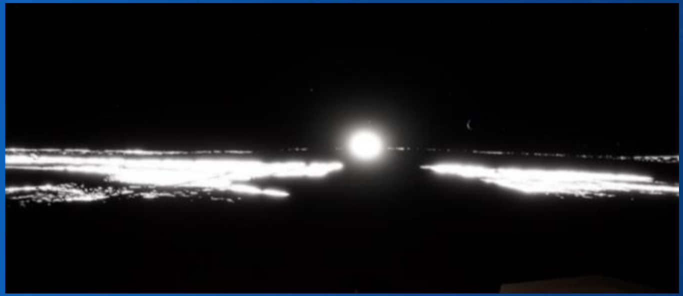
Dynamic Conditions – descent/ascent trajectories

Data/Sensor Fusion



Reference Geodetics

Interference

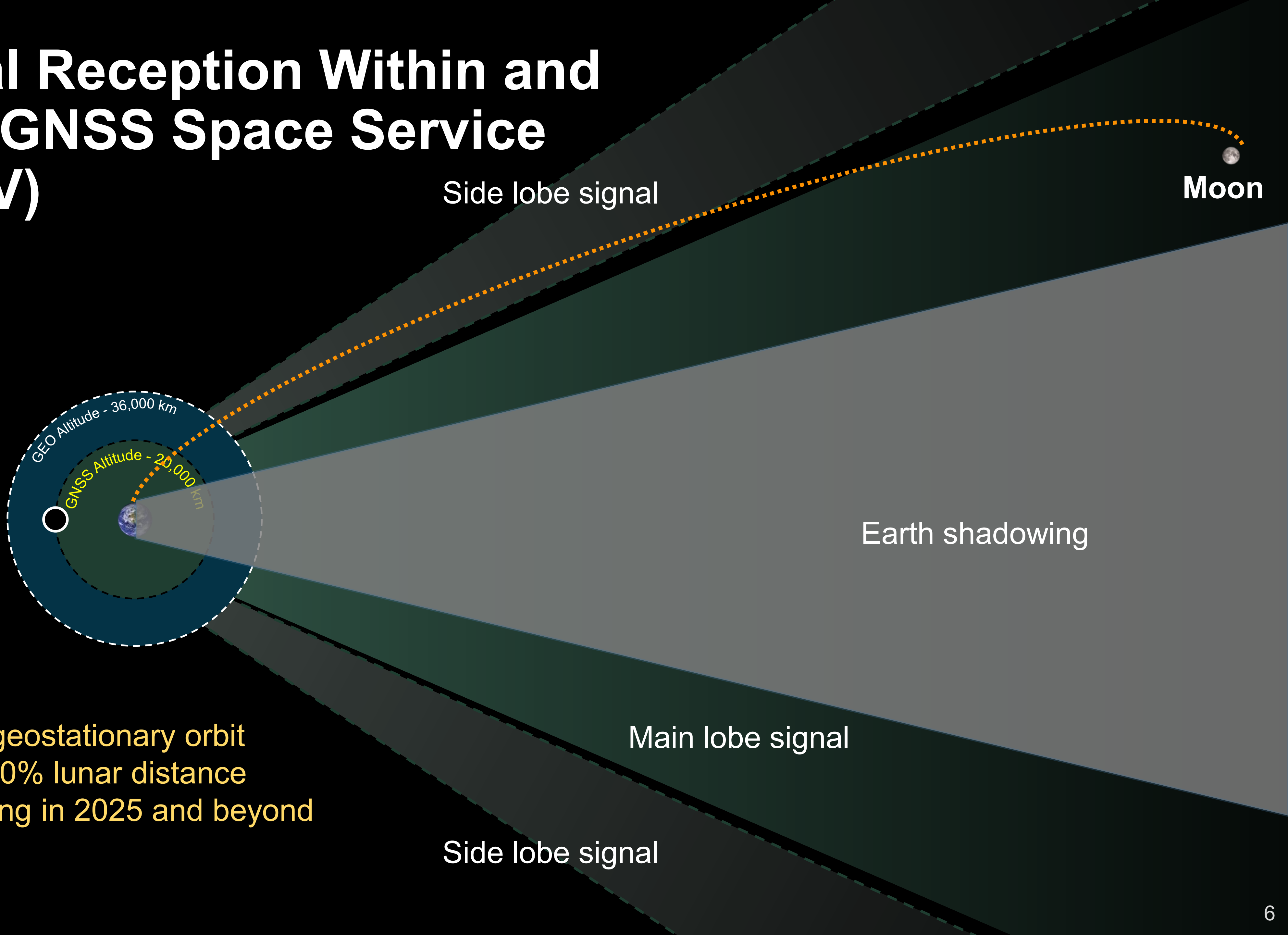


Stark Lighting – difficult for traditional cameras

Earth Occultation – limits Earth-based tracking

Fault tolerant autonomous systems providing PVT knowledge + situational awareness will be needed

GNSS Signal Reception Within and Beyond the GNSS Space Service Volume (SSV)



Utilization:

- Broad utilization in geostationary orbit
- Active users up to 50% lunar distance
- Lunar users launching in 2025 and beyond

Phased Expansion of Lunar PNT

GNSS-only demonstra → GNSS Lunar Operations → GNSS + Lunar PNT Service Demos → Broad Infusion

Relative use of signal sources

Terrestrial GNSS

Lunar PNT Services (e.g. LunaNet)

Today — **Time** →

Transit use of GNSS and Lunar PNT Services

Lunar PNT Services (e.g. LunaNet)

GNSS Use

Lunar PNT Use

← Transit Distance →

Use of GNSS and lunar PNT services are considered as a key part of the broader navigation ecosystem including ground-based on on-board sources.

Lunar GNSS Receiver Experiment (LuGRE)

LuGRE
LUNAR GNSS RECEIVER EXPERIMENT

Payload objectives

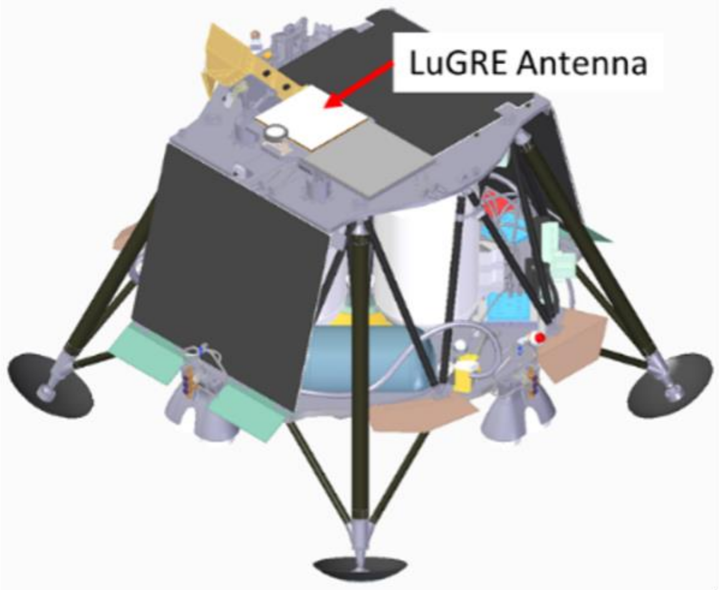
1. Receive GNSS signals at the Moon. Return data and characterize the lunar GNSS signal environment.
2. Demonstrate navigation and time estimation using GNSS data collected at the Moon.
3. Utilize collected data to support development of GNSS receivers specific to lunar use.

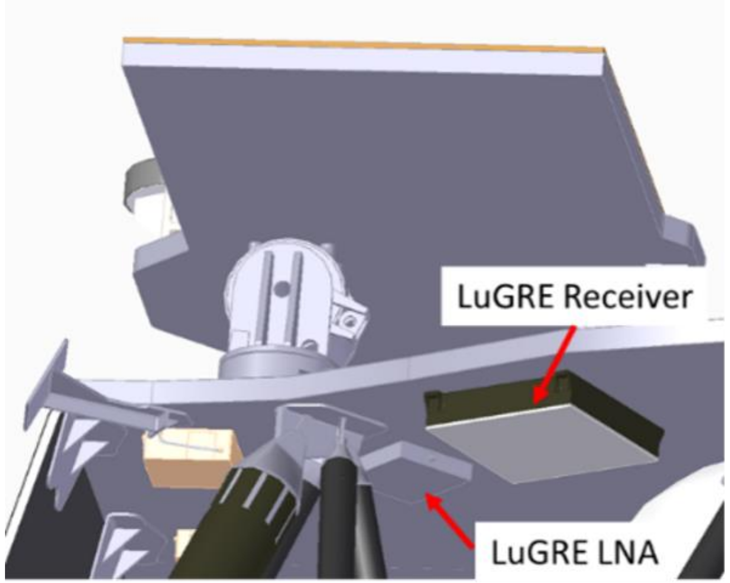
Measurements

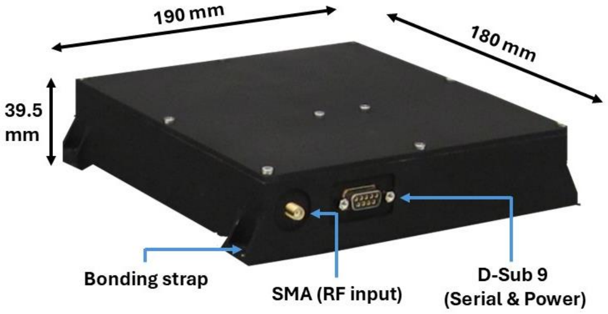
- GPS+Galileo, L1/L5 (E1/E5)
- Observables: pseudorange, Doppler, carrier phase
- Onboard navigation products: multi-GNSS point solutions, filter solutions
- Raw baseband I/Q samples

Payload

- Three components:
  HGA → LNA → Receiver
- Integrated separately onto lander
- Total mass: 4.64 kg
- Total peak power: 14 W

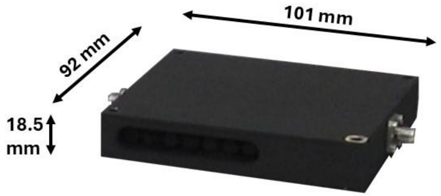






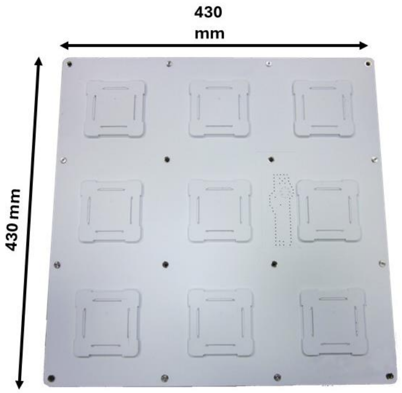
QN400-Space Receiver:

- GPS L1 C/A + L5; Galileo E1BC + E5a
- Mass: 1.3 kg, power: <14 W
- Two cold-redundant receivers
- VCTCXO clock
- Manufactured by Qascom S.r.l.



Low Noise Amplifier:

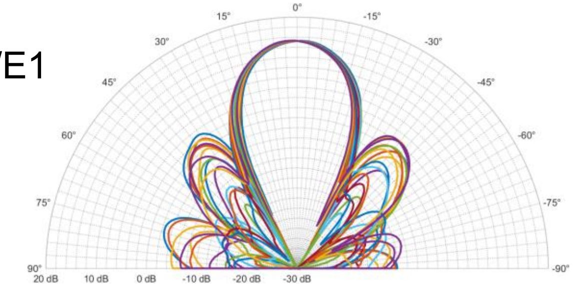
- 40 dB Gain
- ~1 dB Noise Figure
- Manufactured by dB Microwave



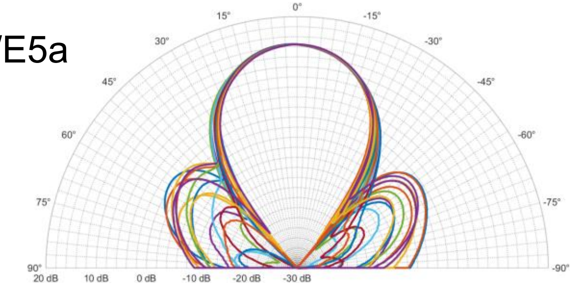
High Gain Antenna:

- L1/E1: 15.35 dB, 12° HPBW
- L5/E5a: 14.56 dB, 16° HPBW
- Manufactured by Haigh Farr

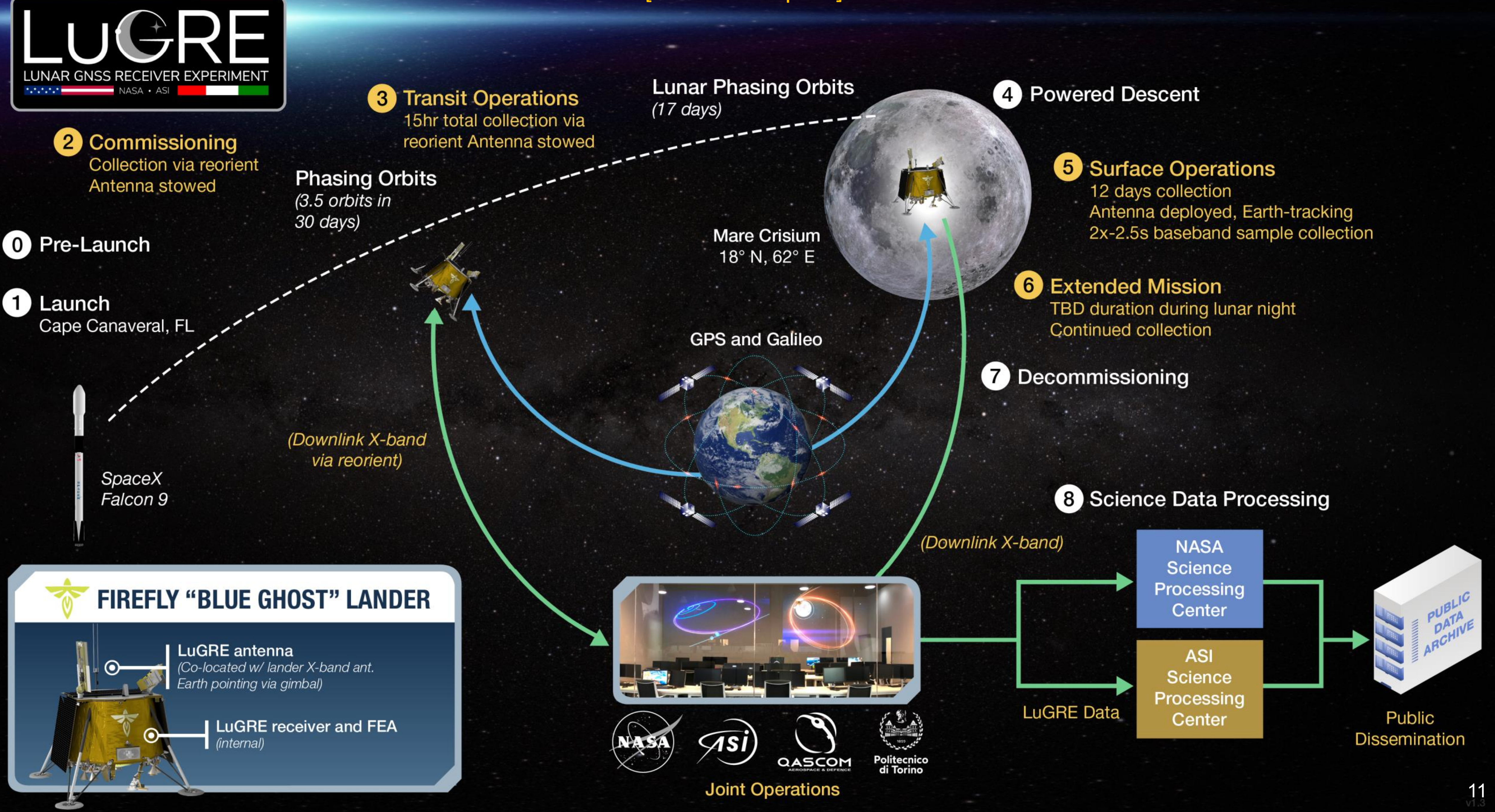
L1/E1



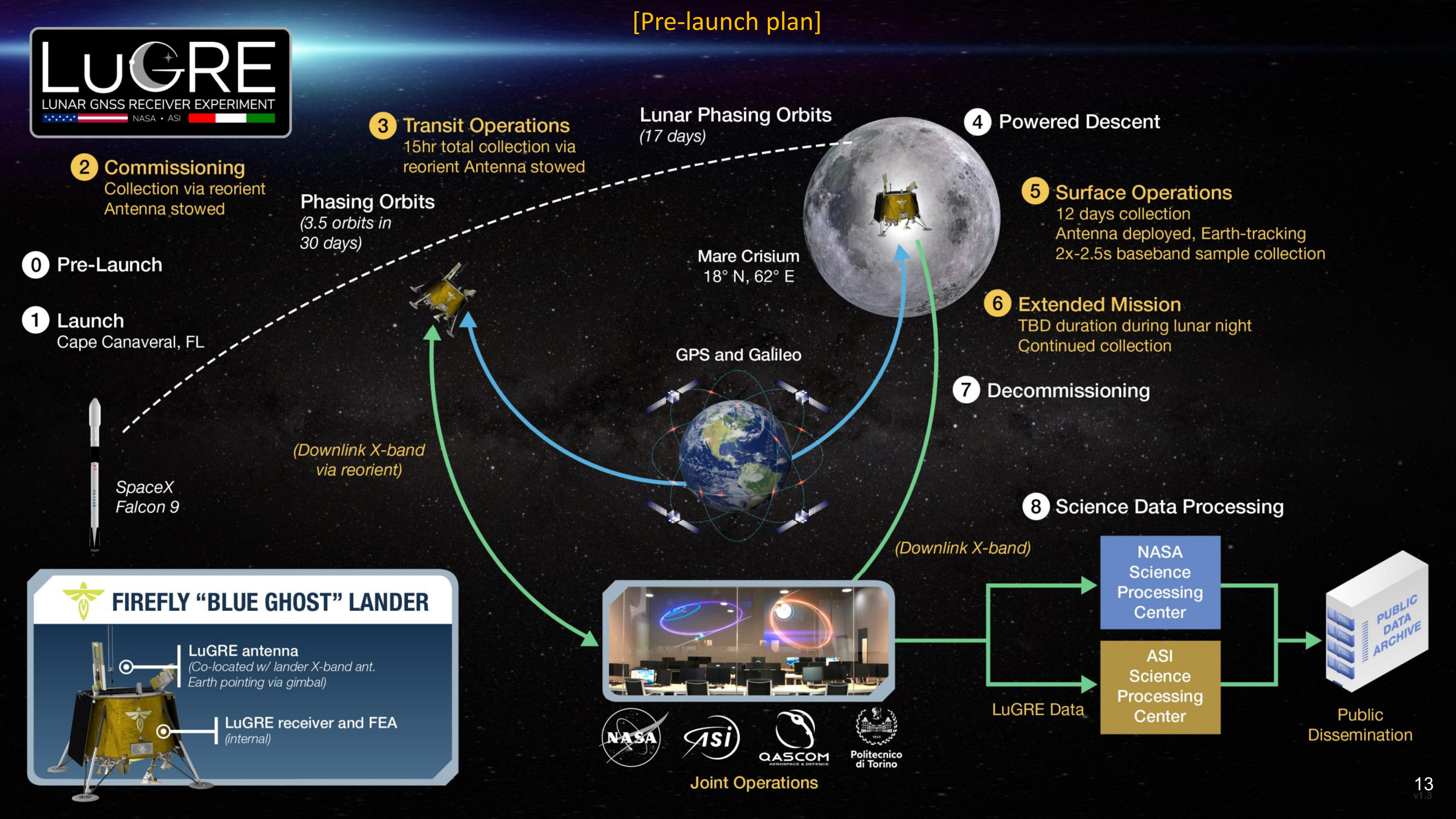
L5/E5a



[Pre-launch plan]



March 2, 2025


[Pre-launch plan]
LuGRE
LUNAR GNSS RECEIVER EXPERIMENT
NASA • ASI
0 Pre-Launch
1 Launch
Cape Canaveral, FL
SpaceX
Falcon 9
2 Commissioning
Collection via reorient
Antenna stowed
Phasing Orbits
(3.5 orbits in
30 days)
3 Transit Operations
15hr total collection via
reorient Antenna stowed
Lunar Phasing Orbits
(17 days)
4 Powered Descent
5 Surface Operations
12 days collection
Antenna deployed, Earth-tracking
2x-2.5s baseband sample collection
6 Extended Mission
TBD duration during lunar night
Continued collection
7 Decommissioning
Mare Crisium
18° N, 62° E
GPS and Galileo
(Downlink X-band
via reorient)
(Downlink X-band)
8 Science Data Processing
LuGRE Data
NASA
Science
Processing
Center
ASI
Science
Processing
Center
PUBLIC
DATA
ARCHIVE
Public
Dissemination
FIREFLY "BLUE GHOST" LANDER
LuGRE antenna
(Co-located w/ lander X-band ant.
Earth pointing via gimbal)
LuGRE receiver and FEA
(internal)
NASA
ASI
QASCOM
Politecnico
di Torino
Joint Operations

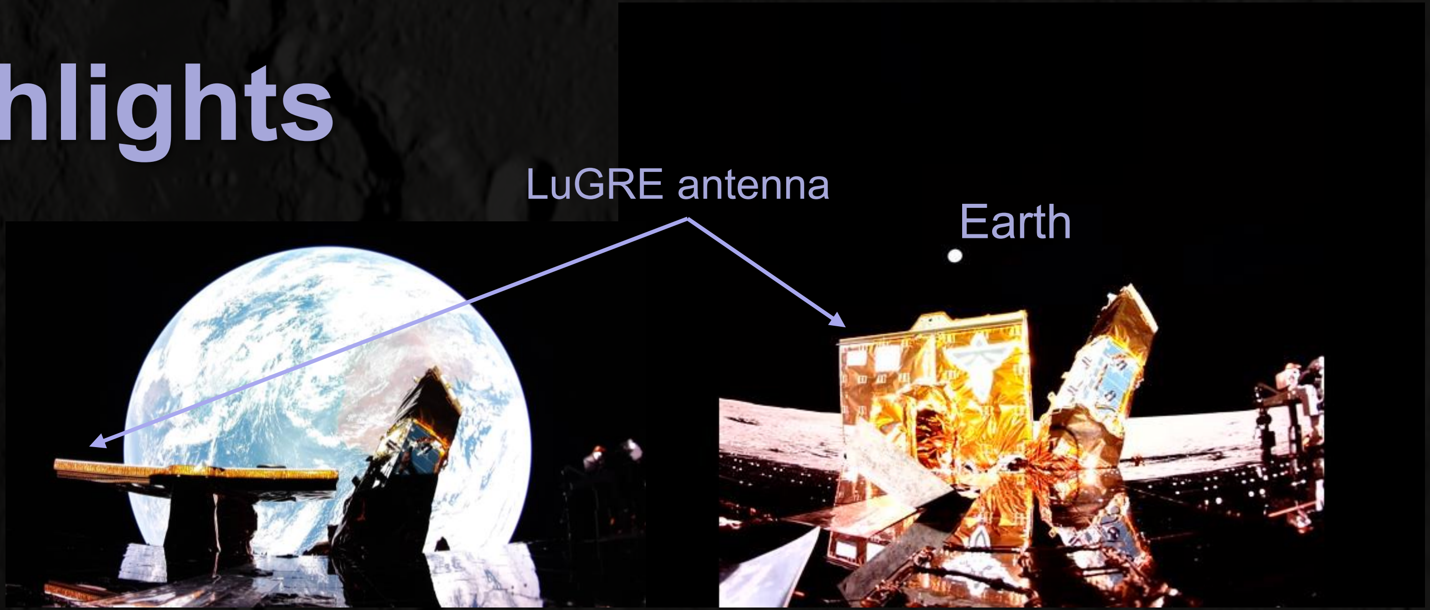
LuGRE Mission Highlights

TOTAL OPERATION TIME: >111 hours,
- Operation time on surface: >95 hours (>85%)

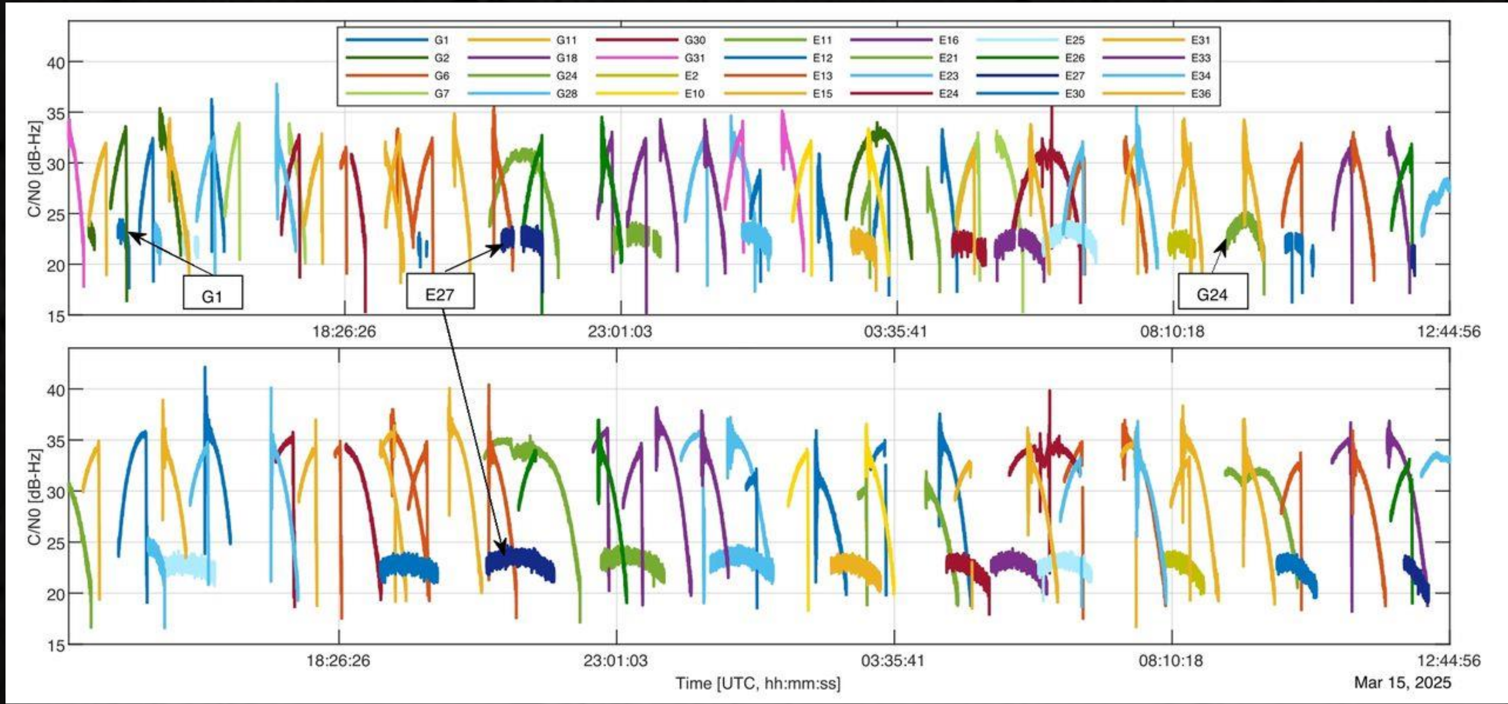
TOTAL DATA VOLUME COLLECTED
- Approximately 12s of IQ sample batches
- More than 106 hours of GNSS measurements in real-time processing mode.

16 TOTAL OPERATIONS IN TRANSIT
- 2 during the commissioning phase
- 9 during the Earth-centered phasing loops
- 5 in lunar orbit
- 14 with IQS sample batch collections
- 14 with real-time measurements

SURFACE TIME: 95+ hours
Nearly 93 hours were spent in real-time processing mode.



In transit   On lunar surface



C/N_0 received on lunar surface, first ~24 hr, GPS+Galileo, L1+L5

Data Release

- Open dataset now available
- Contents include raw telemetry for acquisition, measurements, PVT solutions, IQ samples, and ancillary data.
- Publication in journal NAVIGATION: *"GNSS Reception at the Moon: First Results of the Lunar GNSS Receiver Experiment (LuGRE)"* https://doi.org/10.33012/navi.756
- Link to data: https://doi.org/10.5281/zenodo.16411686

ID	Level[a]	Description	Coverage
TLM_ACQ	L0	Receiver ACQ (acquisition) message, in raw binary and text forms.	All real time processing (RTP) operations, 1 Hz rate
TLM_RAW	L0	Receiver RAW (measurements) message, in raw binary and text forms.	All real time processing (RTP) operations, 1 Hz rate
TLM_NAV	L0	Receiver NAV (least-squares PVT solutions) message, in raw binary and text forms.	All real time processing (RTP) operations, 1 Hz rate
IQS_L1	L0	In-phase/quadrature sample capture binary data, L1 and E1 bands	All sample capture (SC) operations, (variable parameters)
IQS_L5	L0	In-phase/quadrature sample capture binary data, L5 and E5a bands	All sample capture (SC) operations, (variable parameters)
OPTABLE	Ancillary	Detailed operations table	Full mission
ICD	Ancillary	Binary data format ICD	N/A

LuGRE initial data products

LuGRE successfully demonstrated GNSS-based PNT at the Moon.
Legacy: Data and results shared with all to enable the future of lunar GNSS.

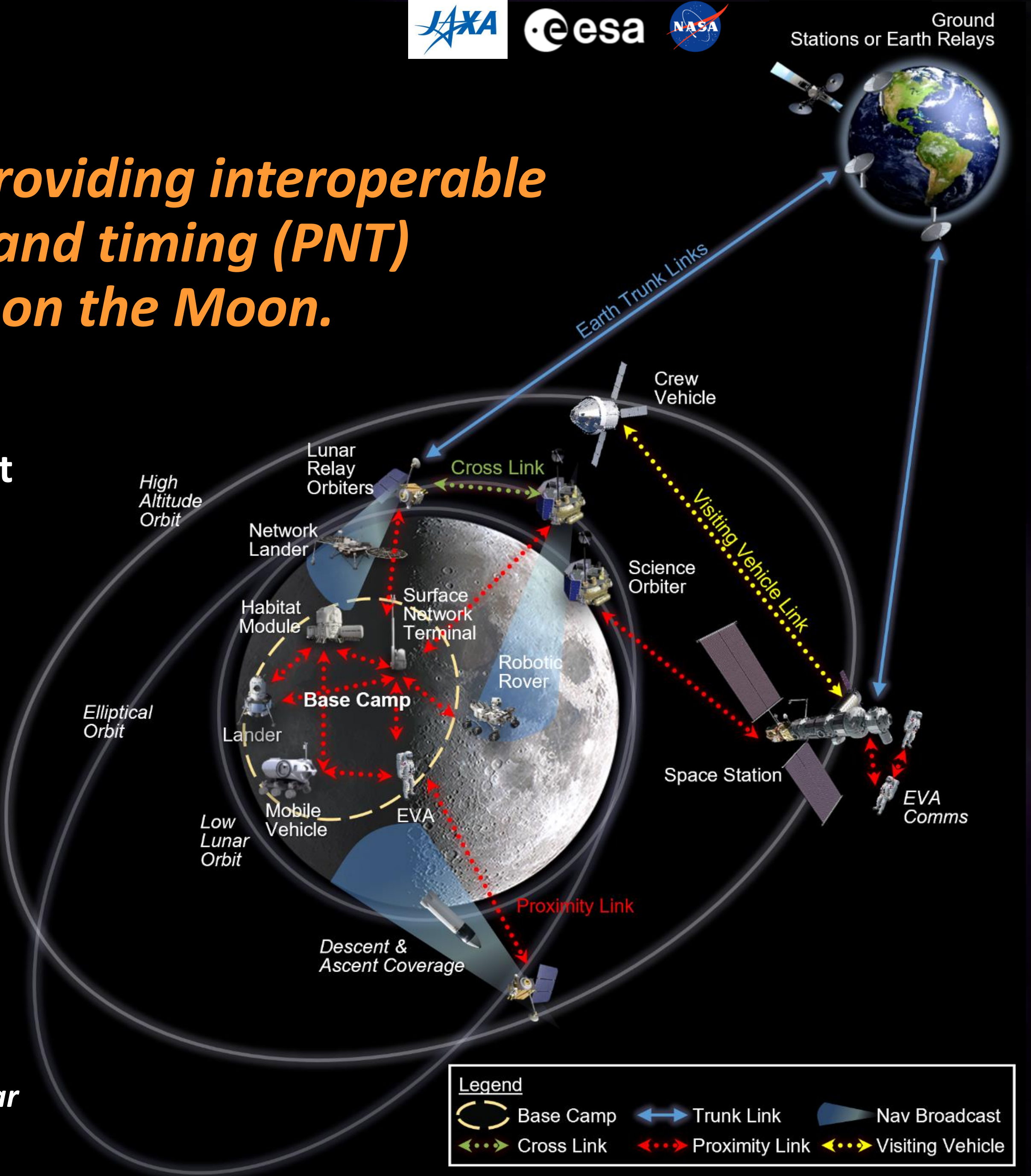
LunaNet

What is LunaNet?

LunaNet is a set of cooperating networks providing interoperable communications and position, navigation, and timing (PNT) services for users in transit to, around, and on the Moon.

- **Based on a framework of mutually agreed-upon standards, protocols, frequency bands, and interface requirements that enable interoperability.**
- **Allows many lunar mission users to engage the services of diverse commercial and government service providers in an open and evolvable architecture.**
    - **Service-Oriented**
    - **Scalable**
    - **Open**
    - **Resilient**
    - **Secure**
    - **Extensible**

LunaNet consists of Earth Ground Stations (for Direct with Earth links), lunar orbital relays (lunar proximity and Earth trunk links), and surface assets.



Lunar Comm & PNT Systems Relationships

LunaNet

Framework for Standardized Interoperable Services, umbrella under which many providers collectively work. Interoperability defined in a set of *specifications.**

Lunar Comm. Relay and Navigation System (LCRNS)

NASA's instantiation of LunaNet Lunar Relay Services– a LunaNet Service Provider (LNSP)

Currently scoped for Initial Operating Capability

Moonlight

Lunar Communications and Navigation System (LCNS)

ESA's instantiation of Lunar Relay Services

Lunar Navigation Satellite System (LNSS)

Japan's instantiation of Lunar Relay Services

Ground Stations for Lunar Missions

e.g. NASA's Lunar Exploration Ground Segment

Others

e.g. other orbiting systems, surface comm and/or PNT systems (future), ground systems, 3GPP

Lunar Reference System(s) Components (includes Time)

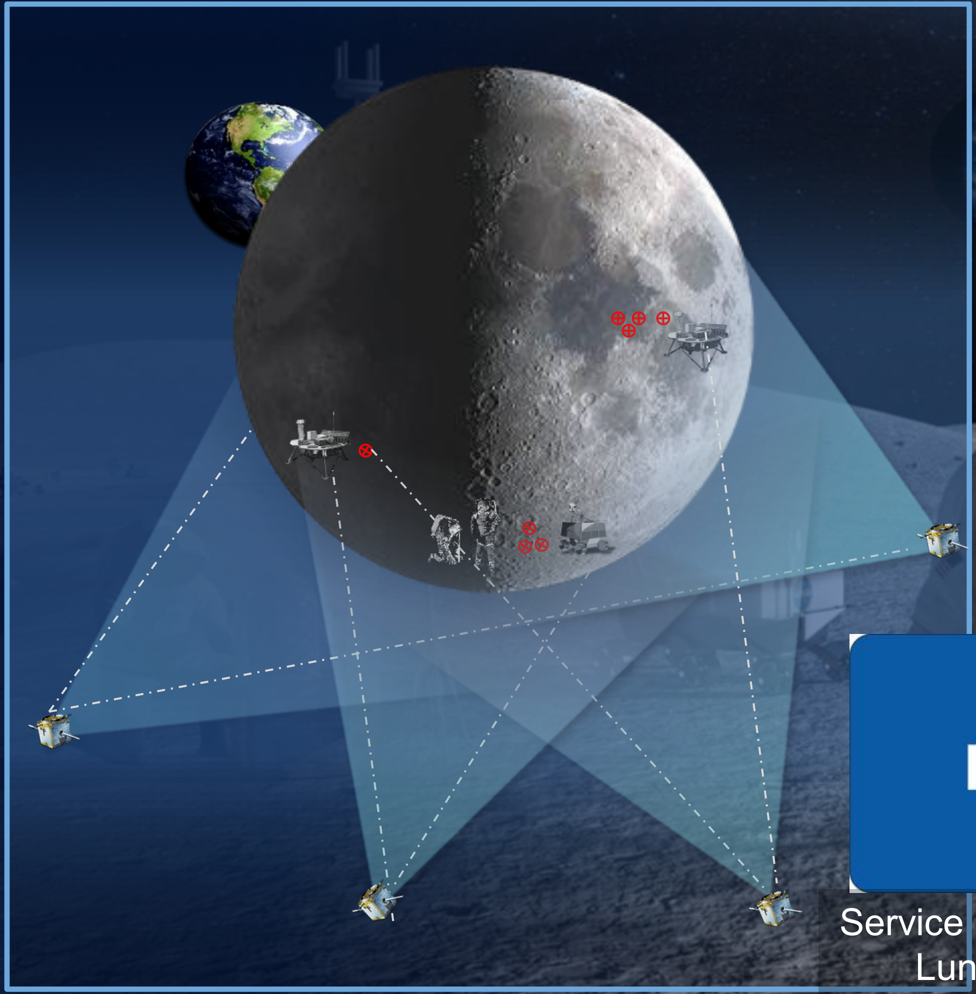
A canonically defined set of components for consistent, accurate, and safe navigation.

Interoperability defined in Applicable Document 5 (AD5).

*Latest version: LunaNet Interoperability Specification v5

Lunar Communications Relay and Navigation System (LCRNS)

- NASA's service-based Initial Operating Capability is expected to consist of three distinct phases over a period of approx. 5 years:
  - Phase Alpha, with a minimum of one Augmented Forward Signal (AFS) expected to broadcast over the South Pole region.
  - Phase Bravo, with a minimum of two AFS expected over the same South Pole region.
  - Phase Charlie, with an expected minimum of four AFS in view (forms LANS*) in an expanded service volume (for a limited portion of each Earth day). Additionally meeting a requirement for Geometric Dilution of Precision (GDOP).
  - Also offers S-band Peer-to-Peer 2-way radiometrics and 1-way Doppler reference services
- The LCRNS AFS is expected to comply with the LunaNet Interoperability Specification.
- LCRNS orbit(s) are defined by the service provider and relays are expected to meet the Signal-in-Space-Error in the LCRNS SRD.
- Service delivery is reliant on defined lunar reference system and lunar time.



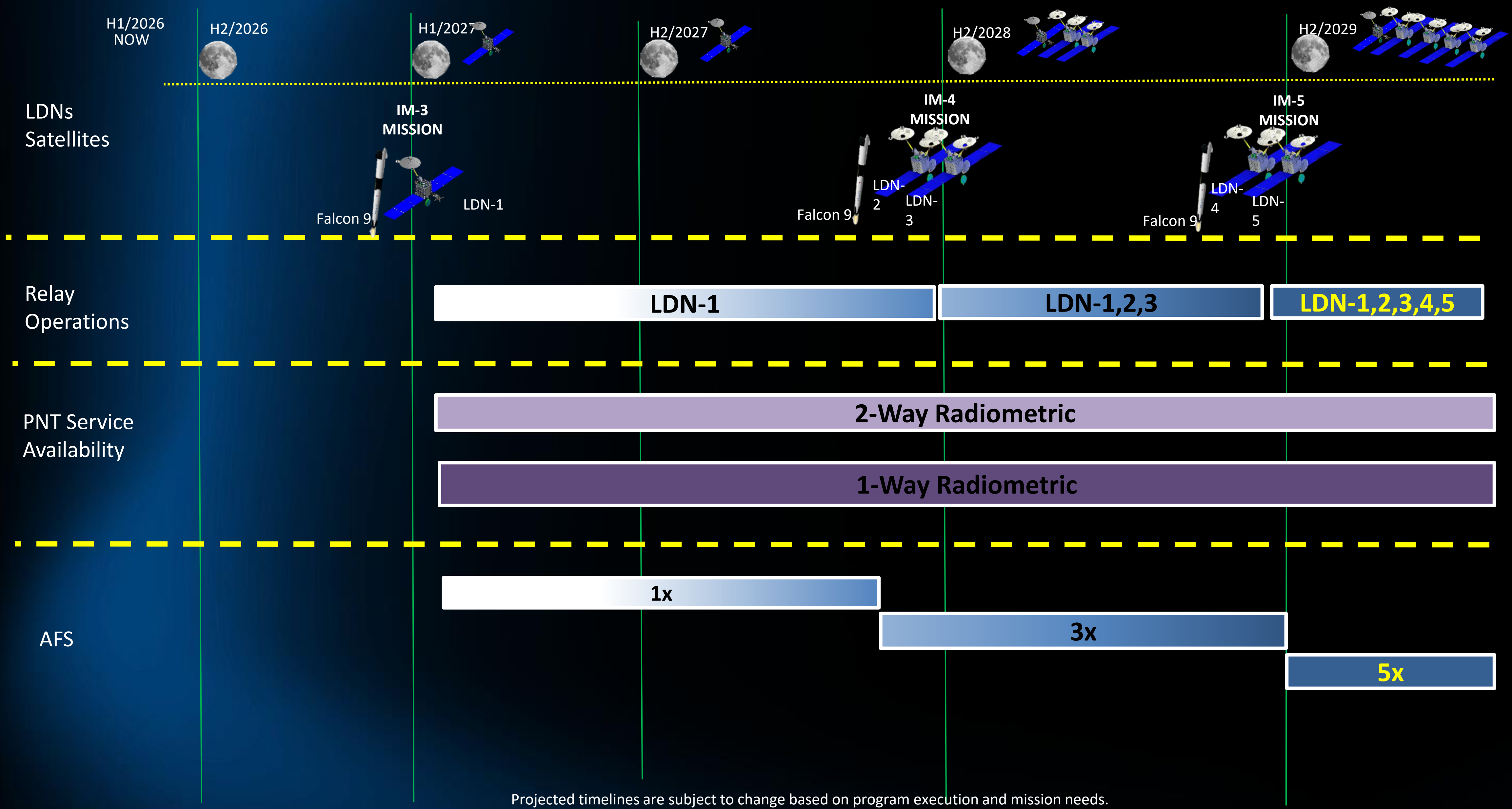
*LANS = Lunar Augmented Navigation Service

Service Provider: Intuitive Machines
Lunar Data Network (LDN)

https://esc.gsfc.nasa.gov/projects/LCRNS

Presented by Intuitive Machines, Cislunar PNT Workshop, 10 Feb 2026

INTUITIVE MACHINES LUNAR ARCHITECTURE AND SERVICES



Projected timelines are subject to change based on program execution and mission needs.

Conclusions

- NASA uses GNSS **across the agency** – for operations and science, from the launch pad into cislunar space.
- US and global exploration of the Moon is planned to **increase rapidly in coming decade**, and PNT will be needed to support these missions in the challenging lunar environment.
- The NASA/ASI LuGRE mission for the first time **demonstrated GNSS-based PNT near the Moon and on the lunar surface** as a stepping-stone to purpose-build lunar PNT systems.
- NASA, ESA, and JAXA are **developing LunaNet** as a set of cooperating networks providing interoperable communications and PNT services for users in transit to, around, and on the Moon.
- Intuitive Machines is developing the Lunar Data Network (LDN) to provide lunar communications and PNT services to users including NASA and will form the initial instantiation of LunaNet.

SPACE OPERATIONS MISSION DIRECTORATE

SPACE COMMUNICATIONS & NAVIGATION

scan@nasa.gov | nasa.gov/SCaN