NASA Advancements using GNSS for Space Ops & Science

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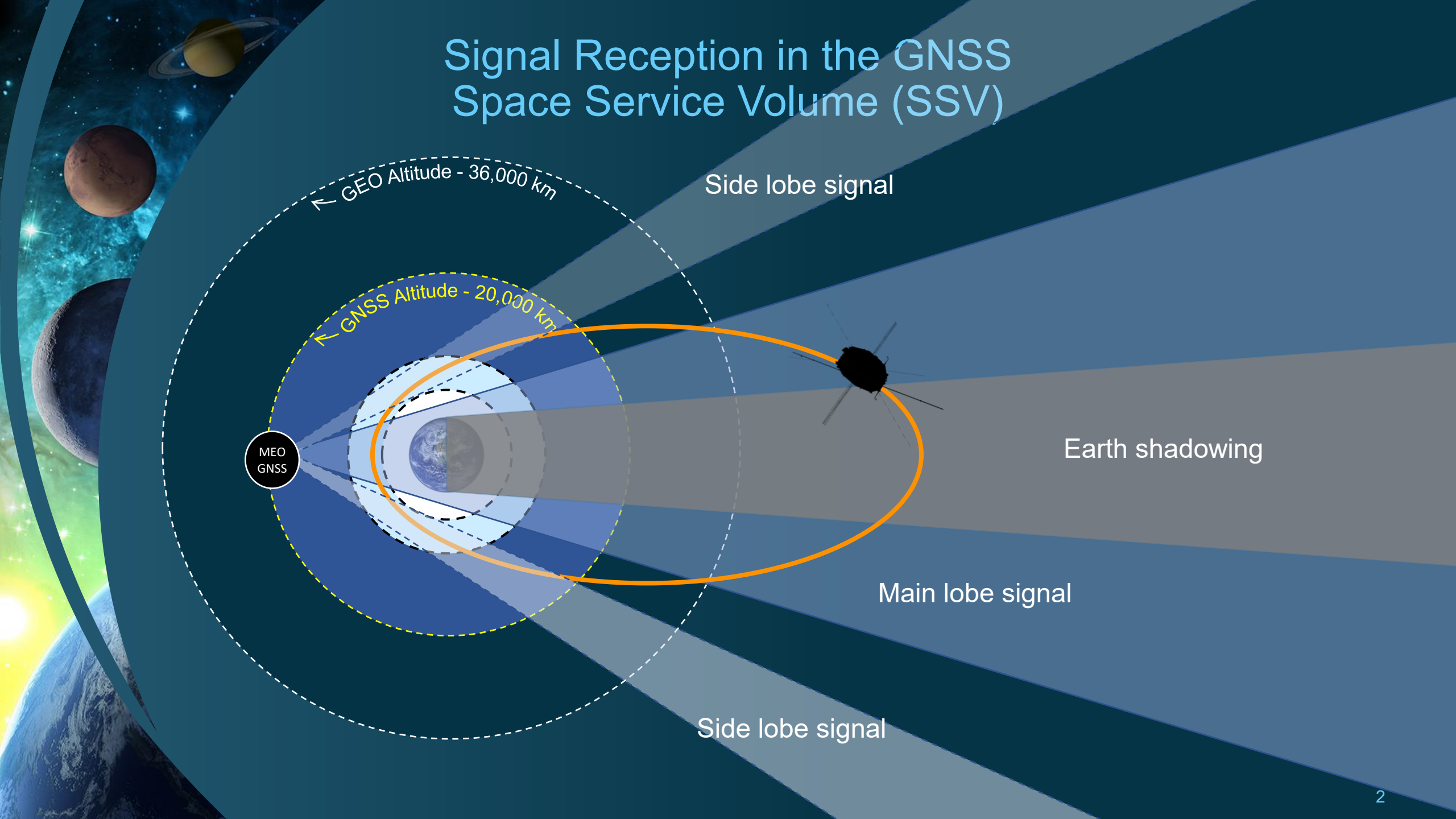
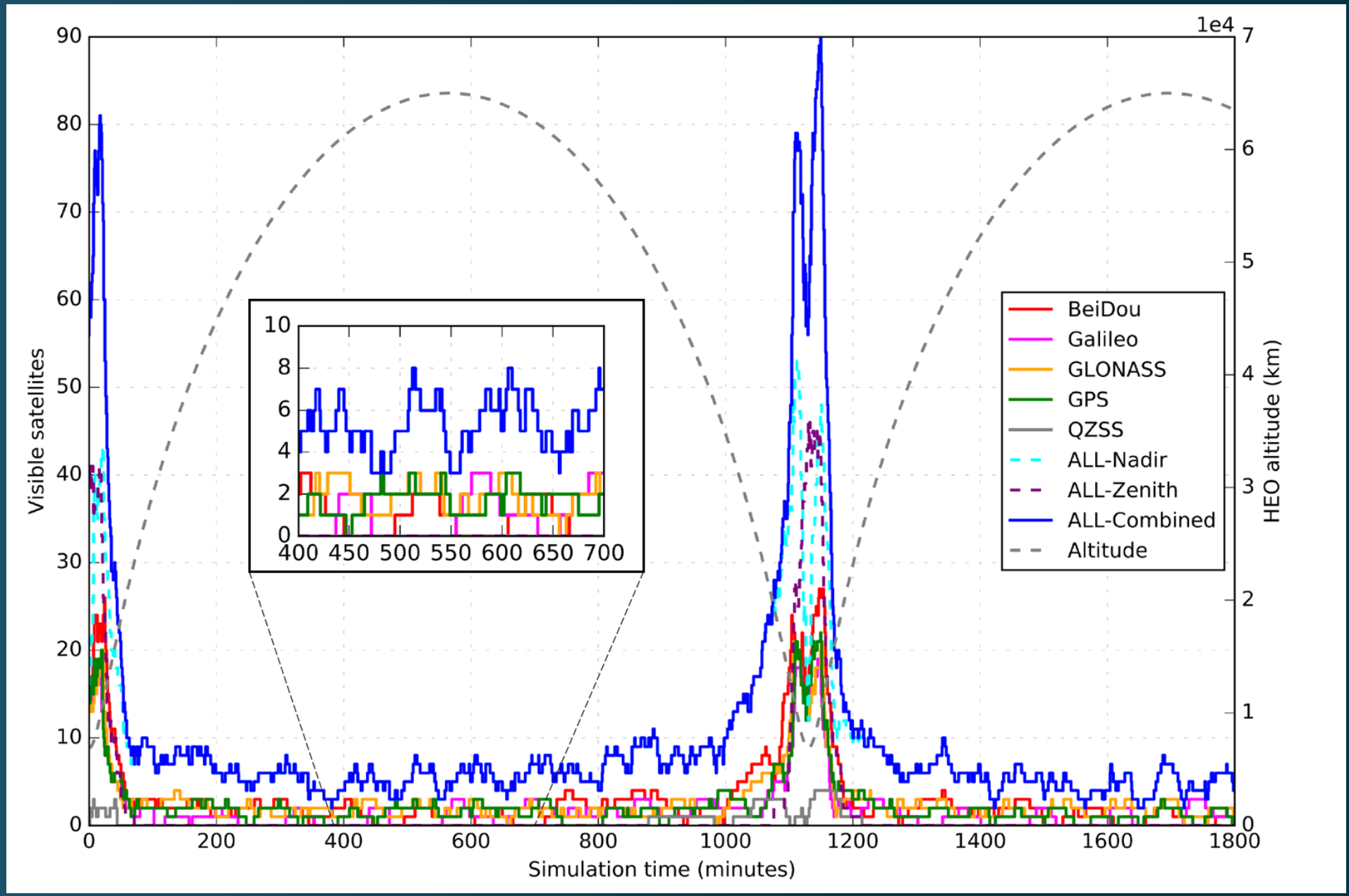
64th Meeting of the CGSIC
September 17, 2024

Signal Reception in the GNSS Space Service Volume (SSV)



Multi-GNSS in the SSV

- Signal visibility simulation for spacecraft in highly elliptical orbit, extending above geostationary orbit
- Visibility of signals is maximized by use of multiple GNSS constellations together
- Details available from UN ST/SPACE/75*, ICG publication on Multi-GNSS SSV



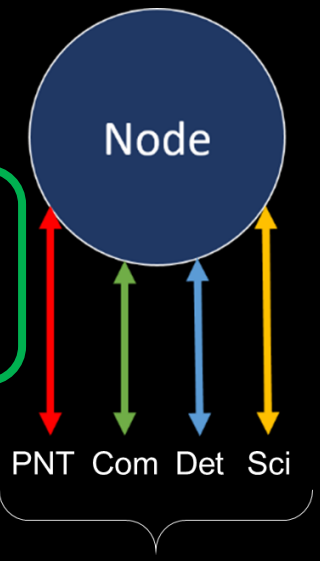
*https://undocs.org/ST/SPACE/75/REV.1

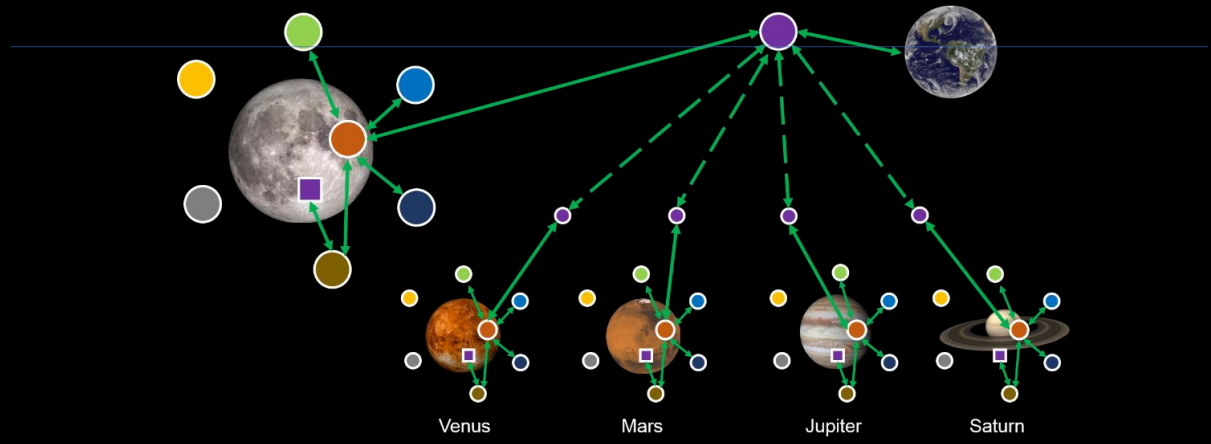
LunaNet Overview

- 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 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 and promotes 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 GNSS have transformed our lives on Earth, LunaNet will transform lunar science and exploration.

Phased Expansion of Lunar PNT

GNSS-only Lunar demonstrations → 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

GNSS Use

Lunar PNT Use

Lunar PNT Services (e.g. LunaNet)

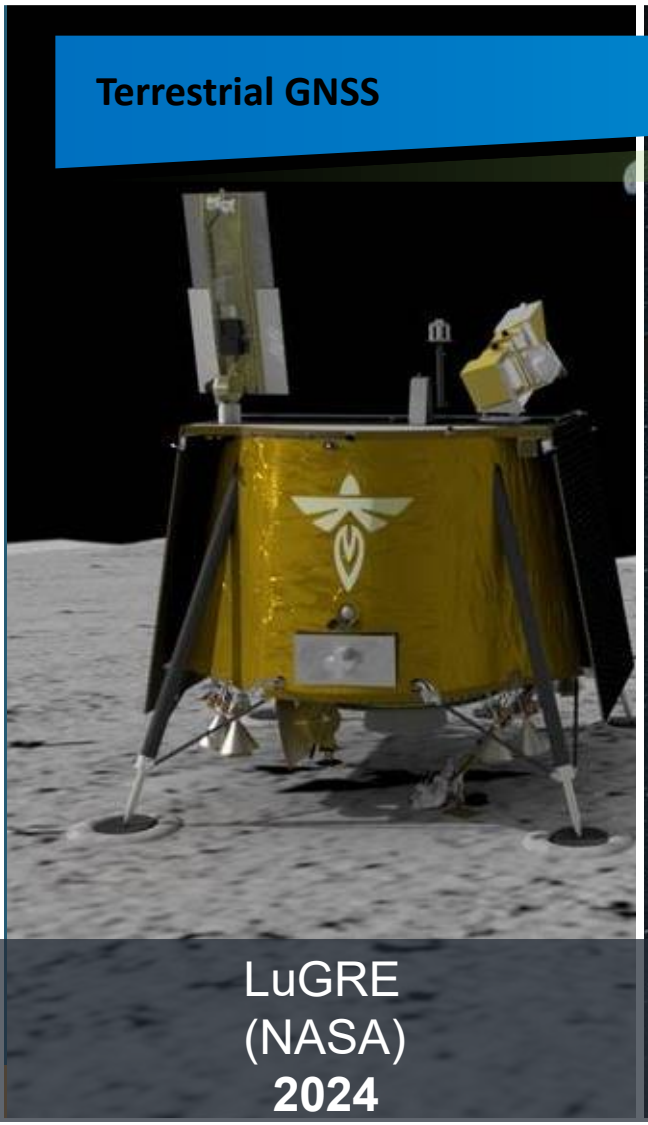
Transit Distance

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.

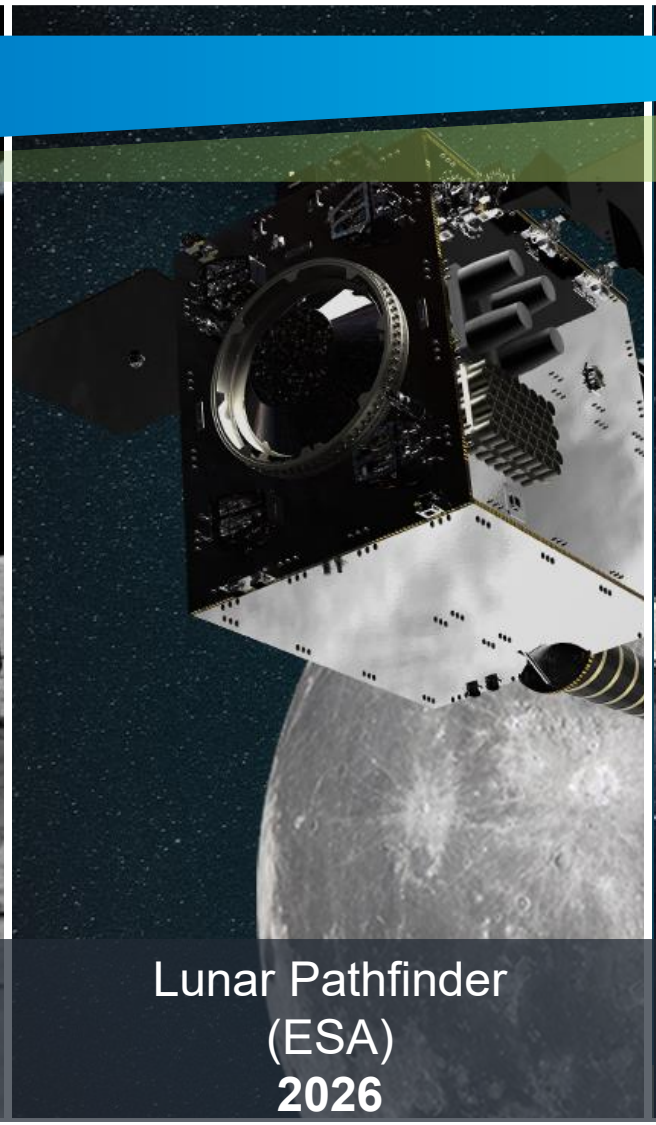
Evolutionary Milestones in Lunar PNT

Terrestrial GNSS

Lunar PNT Services (e.g. LunaNet)

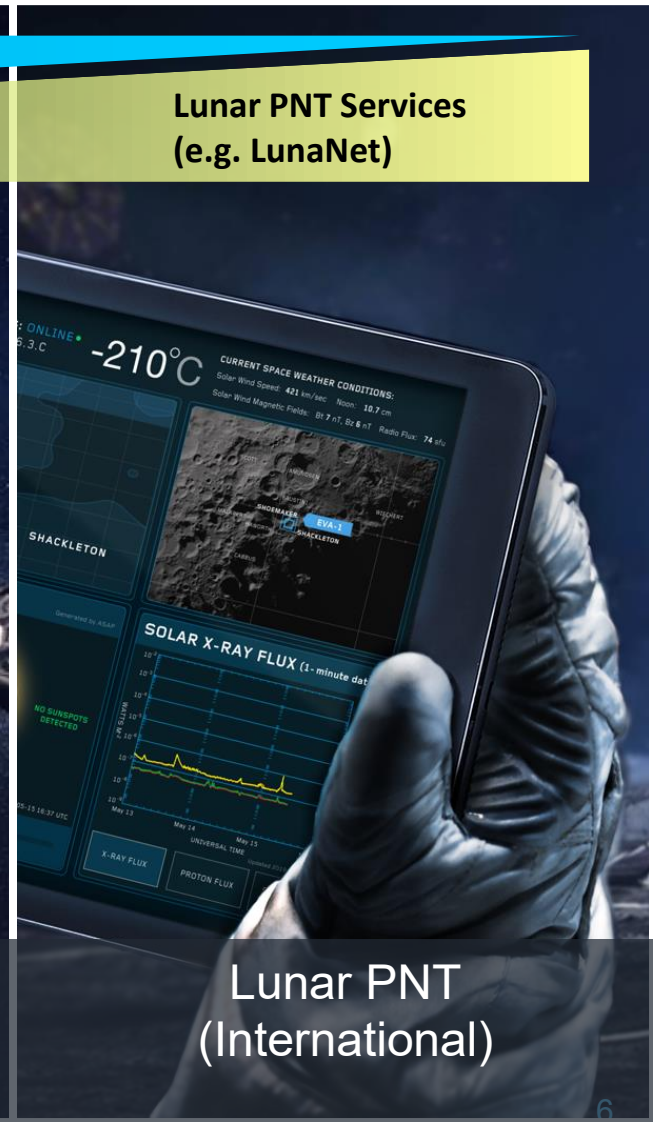


LuGRE (NASA) **2024**



Lunar Pathfinder (ESA) **2026**

Gateway (International)



Lunar PNT (International)

LuGRE
LUNAR GNSS RECEIVER EXPERIMENT
NASA • ASI

NASA

0 **Pre-Launch**

1 **Launch**
Cape Canaveral, FL

SpaceX
Falcon 9

2 **Commissioning**
Collection via reorient
Antenna stowed

3 **Transit Operations**
15hr total collection via
reorient Antenna stowed

Phasing Orbits
(3.5 orbits in 30 days)

Lunar Phasing Orbits
(17 days)

4 **Powered Descent**

Mare Crisium
18° N, 62° E

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**

GPS and Galileo

(Downlink X-band via reorient)

(Downlink X-band)

8 **Science Data Processing**

FIREFLY "BLUE GHOST" LANDER

LuGRE antenna
(Co-located w/ lander X-band ant.
Earth pointing via gimbal)

LuGRE receiver and FEA
(internal)

NASA Science Processing Center

ASI Science Processing Center

LuGRE Data

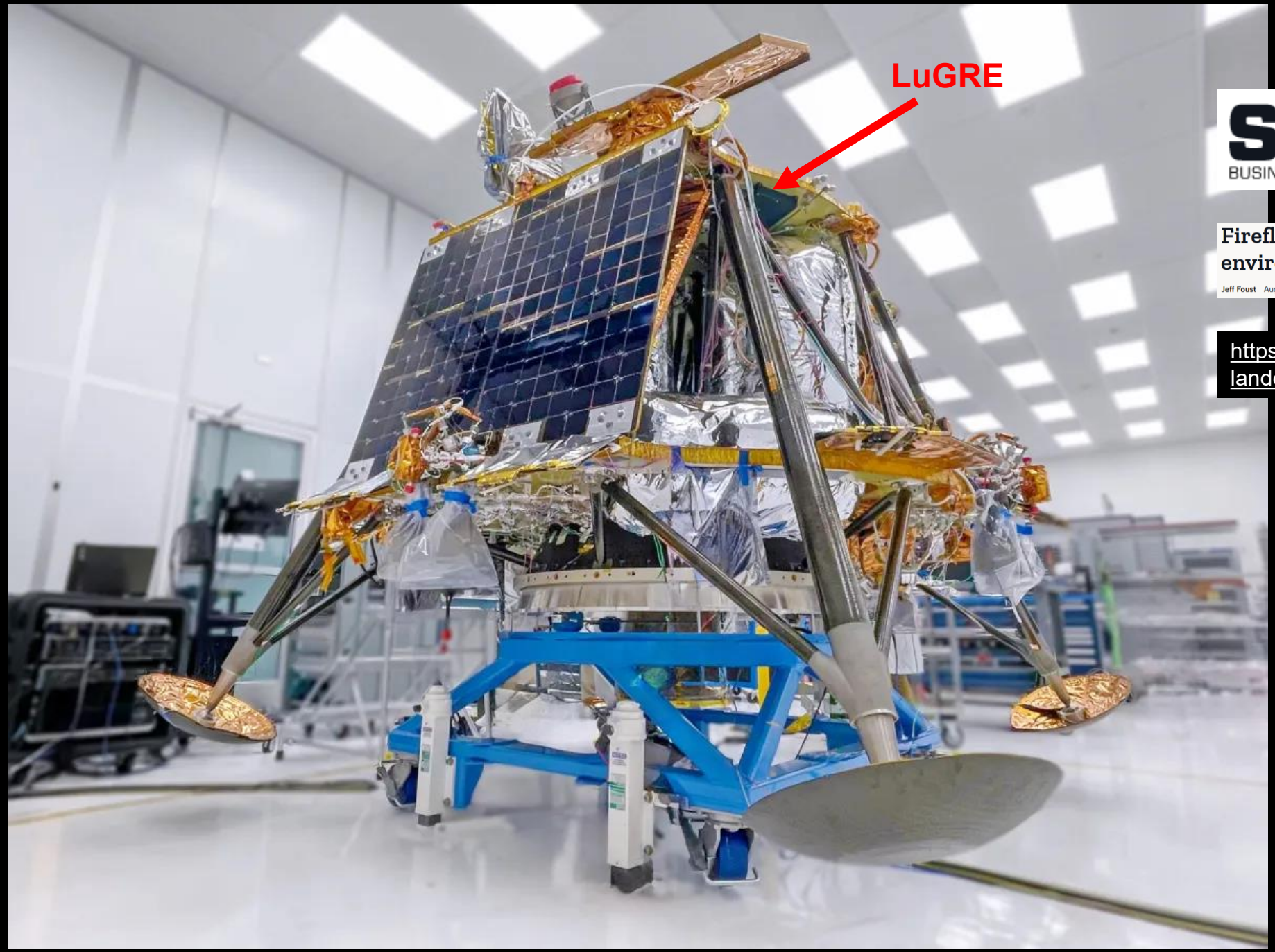
PUBLIC DATA ARCHIVE

Public Dissemination

NASA ASI

Joint Operations

v1.2



SPACENEWS
BUSINESS | POLITICS | PERSPECTIVE

Firefly Aerospace's lunar lander begins pre-launch environmental tests

Jeff Foust August 26, 2024

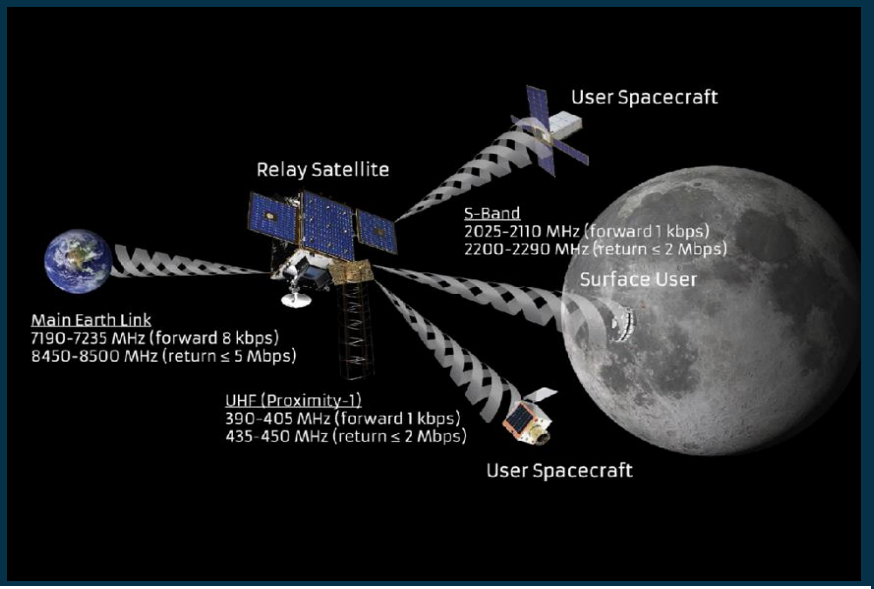
https://spacenews.com/firefly-aerospaces-lunar-lander-begins-pre-launch-environmental-tests/

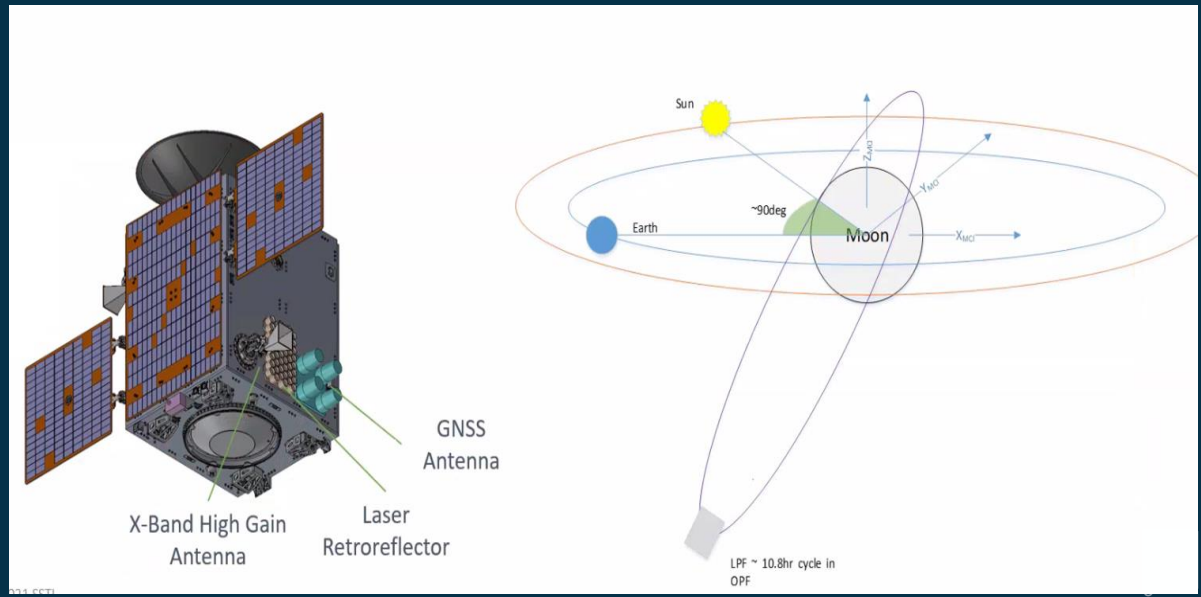
Lunar Pathfinder – GNSS/SLR POD Experiment

- **Mission Objectives**
  - Provision of data relay services
  - Demonstration of GNSS Navigation technologies
    - Galileo/GPS receiver
  - NASA Laser reflector experiment
- **POD Experiment**

Demonstrate Precise Orbit Determination concepts and algorithms based on combined processing of GNSS and SLR data for a spacecraft in lunar orbit

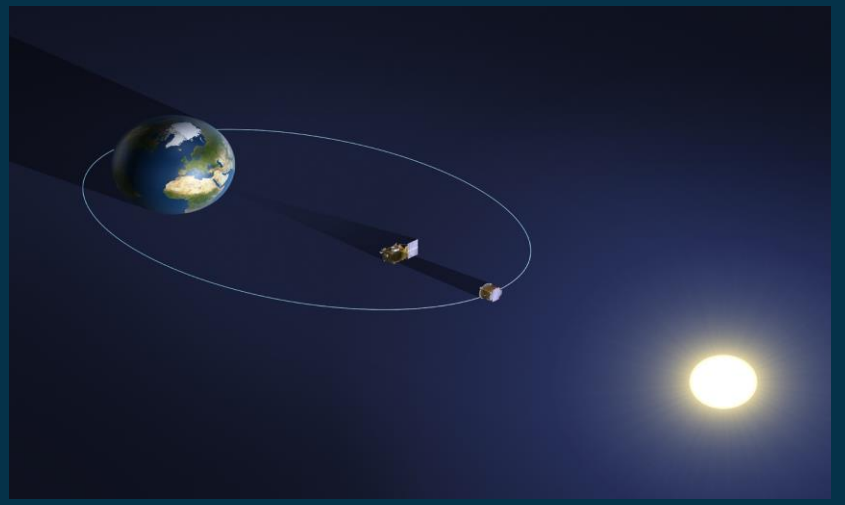
- **Launch Date: Dec 2025**





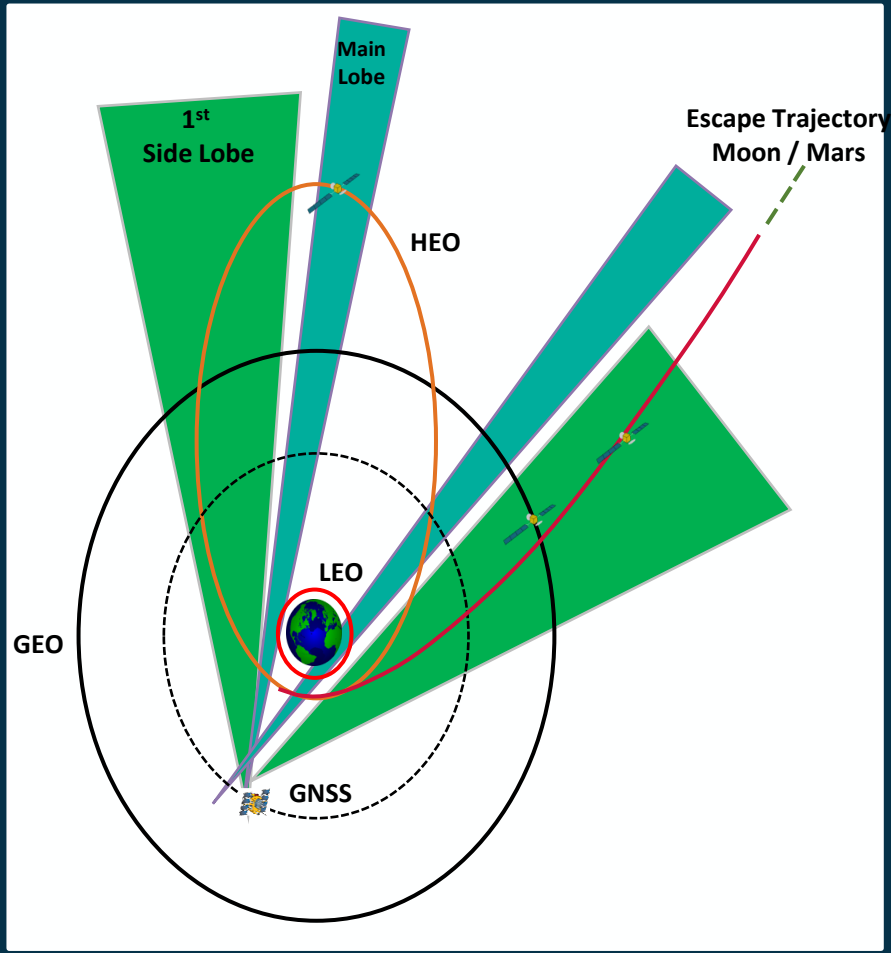
PROBA-3 Mission Overview

- ESA's PROBA-3 mission is a Technology Demonstration Mission for formation-flying of a pair of satellites in an HEO orbit with new developed technologies and high degree of on-board autonomy.
- During nominal operations, the PROBA-3 spacecraft pair will fly divided between periods of accurate formation flying, when payload observations will not be possible, and periods of free flight. In the nominal phase, the GNSS receiver will only be turned on for a limited time and only GPS measurements will be used.
- The operational orbit is a high excentric orbit (e = 0.811) with an inclination of 59 deg, an altitude at apogee of 60524 km and an altitude at perigee between 600 BOL to 900 km and falling down again.
- The Launch of Proba-3 is foreseen for 29 November 2024.



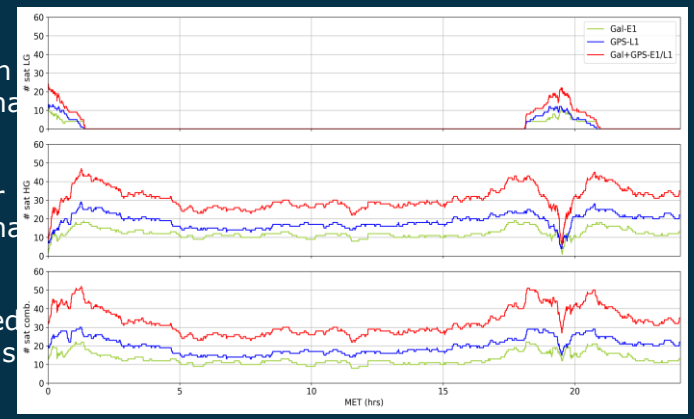
PROBA-3 GNSS POD Experiment

- Beside the nominal operations, it is also foreseen to conduct a GNSS POD experiment
- The GNSS receiver on-board of Proba-3 is capable of tracking Galileo and GPS signals – E1/L1, E5a and L2
- **Main Objectives of the GNSS POD experiment**
  - Analysis of GNSS signal performance
  - In space measurement of the Galileo transmitting antenna pattern, focus on **side lobes**
  - Demonstrate the benefits of GNSS interoperability
  - Test new Precise Orbit Determination Algorithms (absolute and relative) for Formation Flying satellites

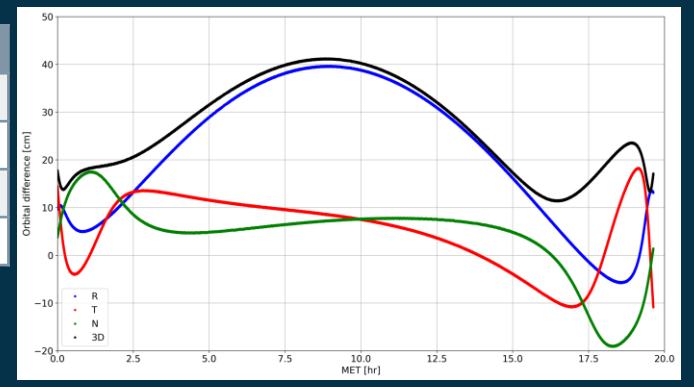


PROBA-3 GNSS POD Experiment

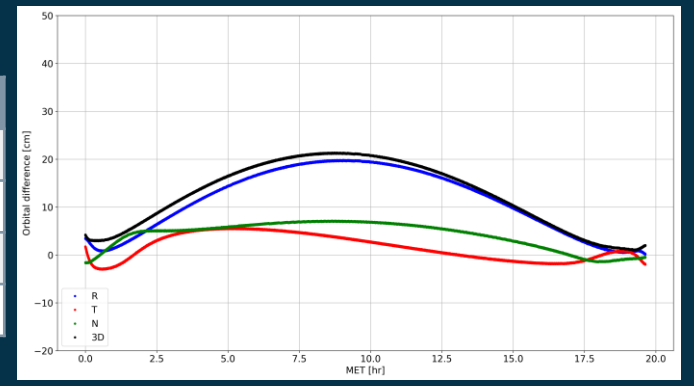
- In 2019, simulations were conducted taking into account the GNSS equipment (GNSS receiver characteristics, user antennas, cables), the antenna pattern of the GNSS satellites and also the attitude of the spacecraft
- **The results of these simulations can be summarised as:**
  - Combining the measurements from the two antennas (nadir and zenith), continuous visibility > 20 of GNSS (Galileo + GPS) satellites
  - The level of POD accuracy (absolute), achieved with ESOC's operational POD SW was between 29 cm and 14 cm (3D RMS) depending on the processing method.
  - Areas of further improvements have also been identified



RMS (cm)	
R	25.8
T	8.9
N	9.1
3D	28.8



RMS (cm)	
R	13.1
T	3.1
N	5.0
3D	14.3

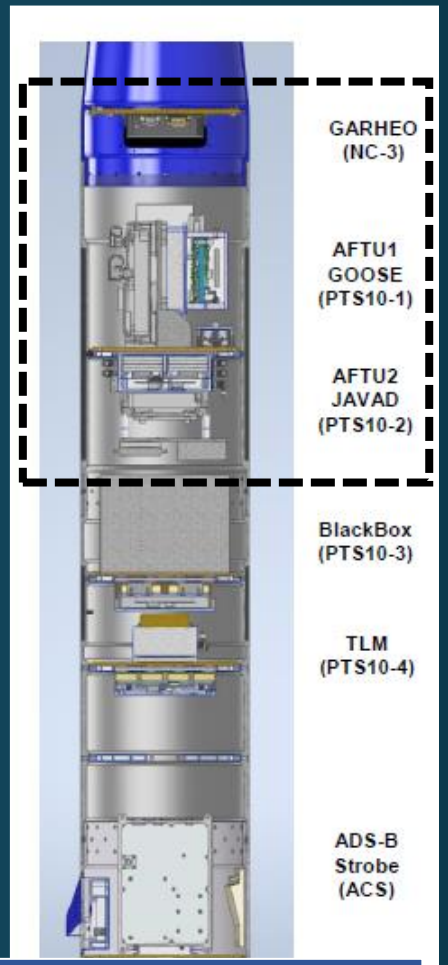


SL-15 Launch with Multi-GNSS

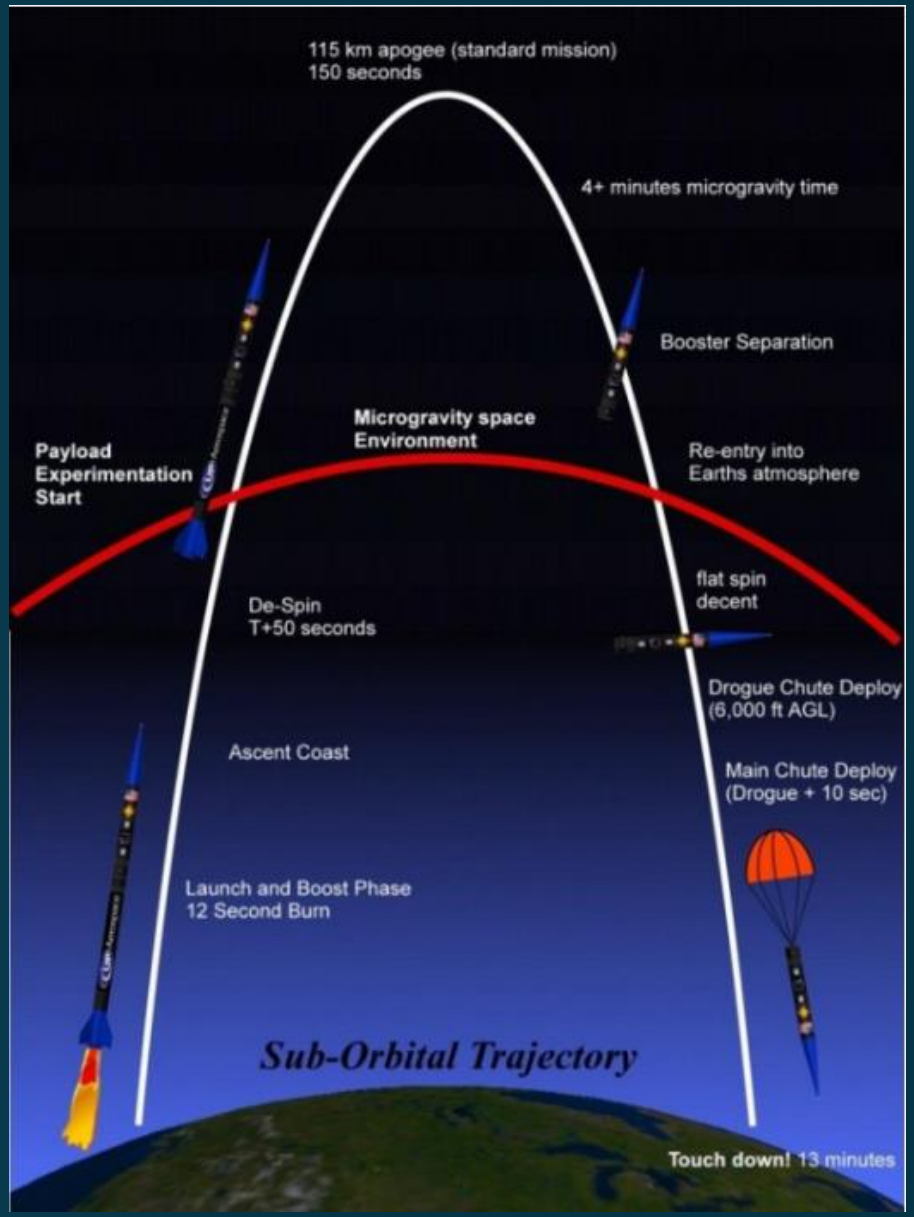
- NASA agreement with the Italian Space Agency (ASI) and with the European Space Agency (ESA) to fly two GPS-Galileo receivers on a sounding rocket
- Builds on the success of the SL-14 launch
- **Objective:** Assess GPS-Galileo performance in a highly dynamic environment, including potential to augment GPS in Autonomous Flight Termination System (AFTS) range safety system

- SL-15 Mission provided by NASA's Flight Opportunities Program:
  - Scheduled for Oct 2024 launch on UP Aerospace sounding rocket
  - Experiment includes two GPS-Galileo receivers
  - Utilizing L1/E1/L2/E5a

- Mission profile
  - Launch and boost phase (12 s)
  - Ascent coasting until 100 km Apogee
  - Descent, re-entry, and landing
  - Total duration: 13 minutes
  - Maximum speed: 1400 m/s
  - Maximum acceleration: 13.5 G
  - Maximum Spin rate: 7 Hz



Launching Oct 1, 2024!



ICG Working Group B Space Use Subgroup (SUSG)

- Founded at ICG-13, Nov 2018, in Xi'an, China to serve as the focal point for representing the needs of the space GNSS user community within the ICG.
- Notable recent activities:
  - **Oct 2023 (ICG-17)**: Announcement of release of Galileo Reference Antenna Pattern*
    - Provides public full-coverage EIRP patterns for Galileo FOC satellites
    - Responds to ICG recommendation
  - **Oct 2023 (ICG-17)**: Adoption of Recommendation on "*Joint ICG-IOAG organization of multilateral workshop on cislunar PNT*"
  - **Jun 2024**: Joint Working Group Session on Lunar PNT
    - Topics: Lunar PNT Systems, Spectrum, Reference Frames, Timing, GNSS Lessons Learned, Lunar PNT within ICG
    - 14 presentations, including from China, Europe, India, Japan, US, SFCG

ICG International Committee on Global Navigation Satellite Systems

NASA esa European Space Agency ROSCOSMOS CASC JAXA इसरो isro

*https://www.gsc-europa.eu/electronic-library/programme-reference-documents

Conclusions

- High-altitude space use of GNSS is an important emerging user segment with unique needs. The Moon is the next frontier for space use of GNSS.
- The first lunar GNSS demonstrations, such as LuGRE and Lunar Pathfinder, are around the corner.
- International collaboration is advancing space use of GNSS through flight demonstrations, data sharing, and multilateral technical and policy coordination.
- Lessons learned from GNSS will form a model for coordination of compatibility, interoperability, and availability of emerging lunar PNT systems.

Joint ICG-IOAG Multilateral Cislunar PNT Workshop

11-13 February 2025, Vienna, Austria and broadcast

Registration now open

https://www.unoosa.org/oosa/en/ourwork/icg/working-groups/b/CislunarPNT2025.html