15 July 2026 - Japan Aerospace eXploration Agency, (JAXA)

GNSS at the Moon: LuGRE Results, Open Data, and Lessons for Future Lunar PNT

Navigation Signal Analysis and Simulation Research Group

Dr. Andrea **Nardin**

Contents and material by Dr. Andrea Nardin, the NavSAS team, and the LuGRE team

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Department of Electronics and Telecommunications

Polytechnic University of Turin's **Japan Hub**

A gateway for Italy-Japan engineering, research, and innovation collaboration

- Provides a low-friction interface to build **academic and industrial partnerships** with Japan.
- Built around shared Italy-Japan **challenges**: sustainability, technology development, environmental risk, ageing society and cultural heritage.
- Coordinates activities in education, research & technology transfer, public engagement & knowledge dissemination.

01
Education

- Strengthen outgoing and incoming mobility
- Launch joint curricula with strategic universities
- Develop teaching opportunities at Japanese universities

02
Research & Technology Transfer

- Increase professor mobility and joint JP/IT publications
- Join competitive project calls with Japanese partners
- Develop research contracts with industrial partners, involving Japanese research groups

03
Reputation

- Organize symposia/workshops in both Italy and Japan to expand the network
- Promote PoliTO Japan Hub as a national best practice for Italy–Japan academic relations.
- Strengthen existing agreements at institutional level and develop new implementation agreements.

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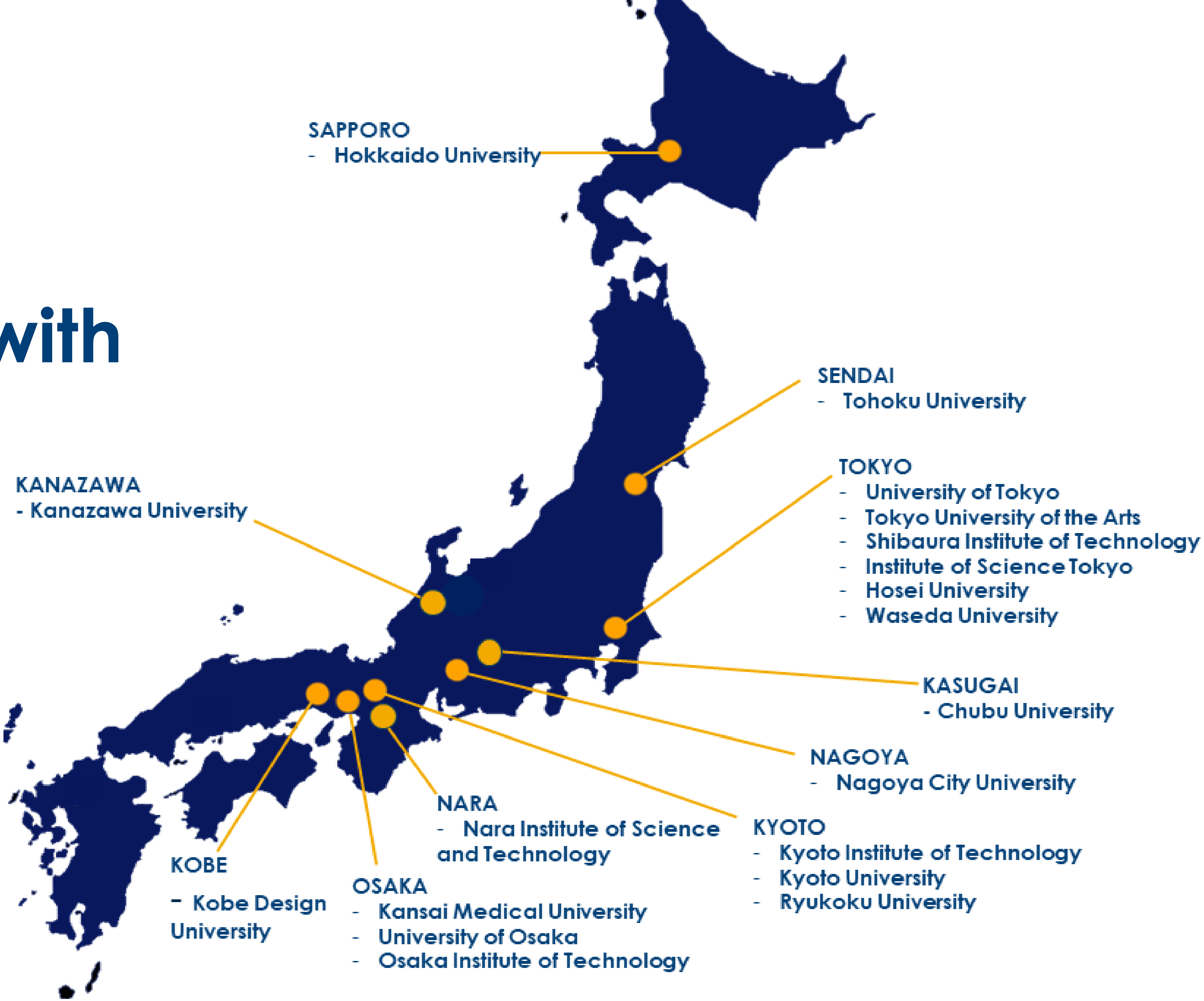
Relationships with academic partners



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Outline

1. GNSS on the Moon
2. The Lunar GNSS Receiver Experiment (LuGRE)
3. The Blue Ghost Journey
4. LuGRE Highlights & Initial Results
5. LuGRE Legacy:
   Open Dataset, Processing Tool, Lessons Learned

GNSS ON THE MOON

01

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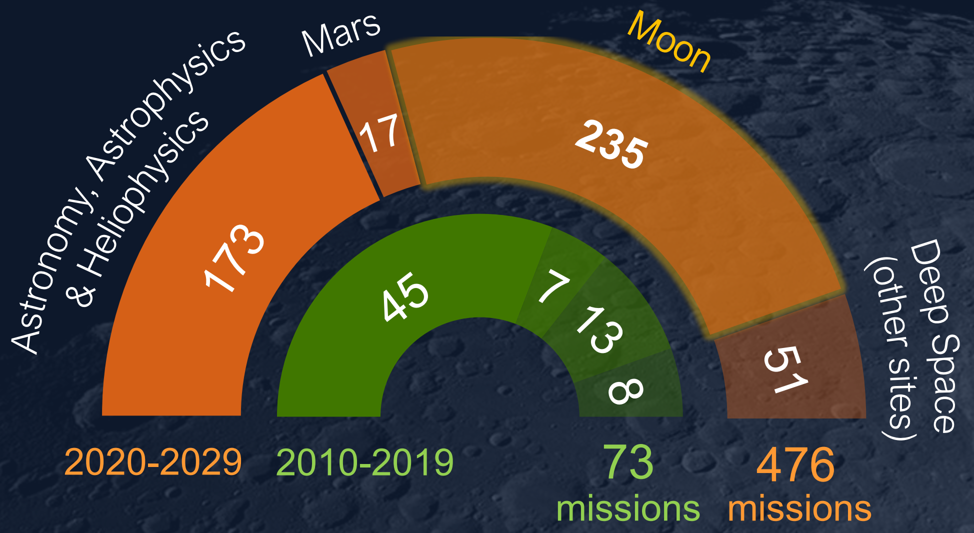
Towards a crowded cislunar environment

Moon is a recognized stepping-stone for interplanetary exploration missions

- Testing and Refining Technologies for Deep-Space.
- Human-tended infrastructure development (e.g., in-orbit gateway and surface outposts).
- Continued science investigations, and crewed visits.



Credit: "Prospect for Space Exploration" Report

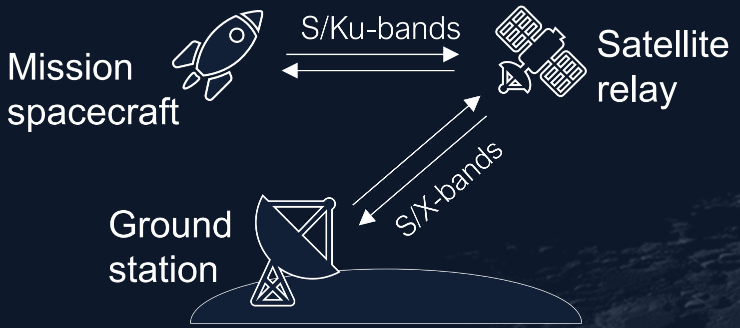
MISSION LAUNCHES

- Moon missions will contribute to the 40% share of this decade
- About 26% growth from previous decade
- Including SmallSats, 250+ outlook in the next 10 years

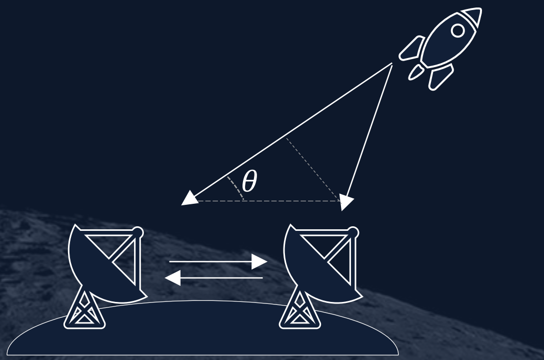
Lunar PNT: approaches to date

Operational services for cislunar Orbit Determination & Time Synchronization (ODTS) employ ground-based networks with Direct-To-Earth (DTE) links and space network

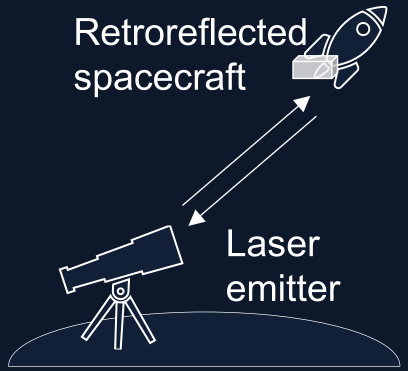
ONE/TWO-WAY (SPACE-RELAYED) RADAR TRACKING



(VERY) LONG BASELINE INTERFEROMETRIC TRACKING



LASER-BASED TRACKING



However, current model lacks efficiency and scalability

- Limited contact time and Coverage
- Scalability and Resource constraints
- Delayed Responsiveness and Limited Data Throughput

Enhanced Autonomy in ODTS has become a pressing need

(Cis)Lunar GNSS: A Major Opportunity

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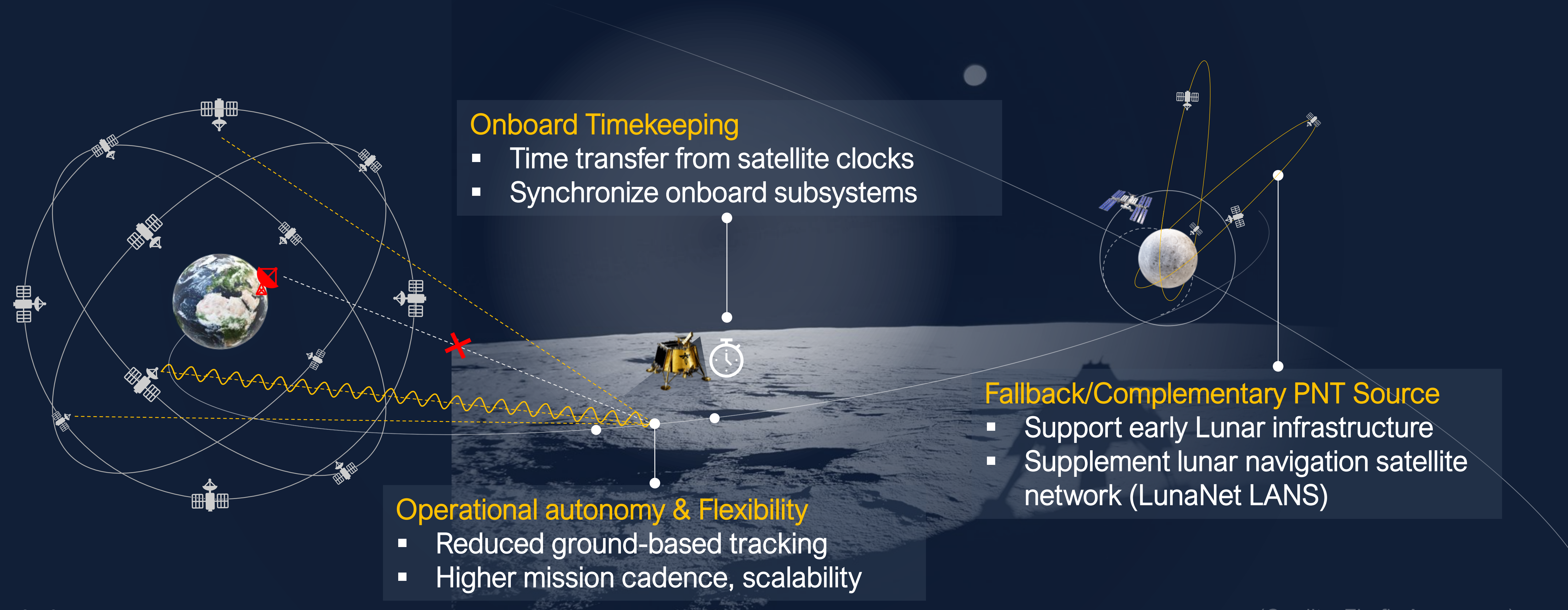
GNSS may offer a **mature** and operationally proven PNT solution for space users.

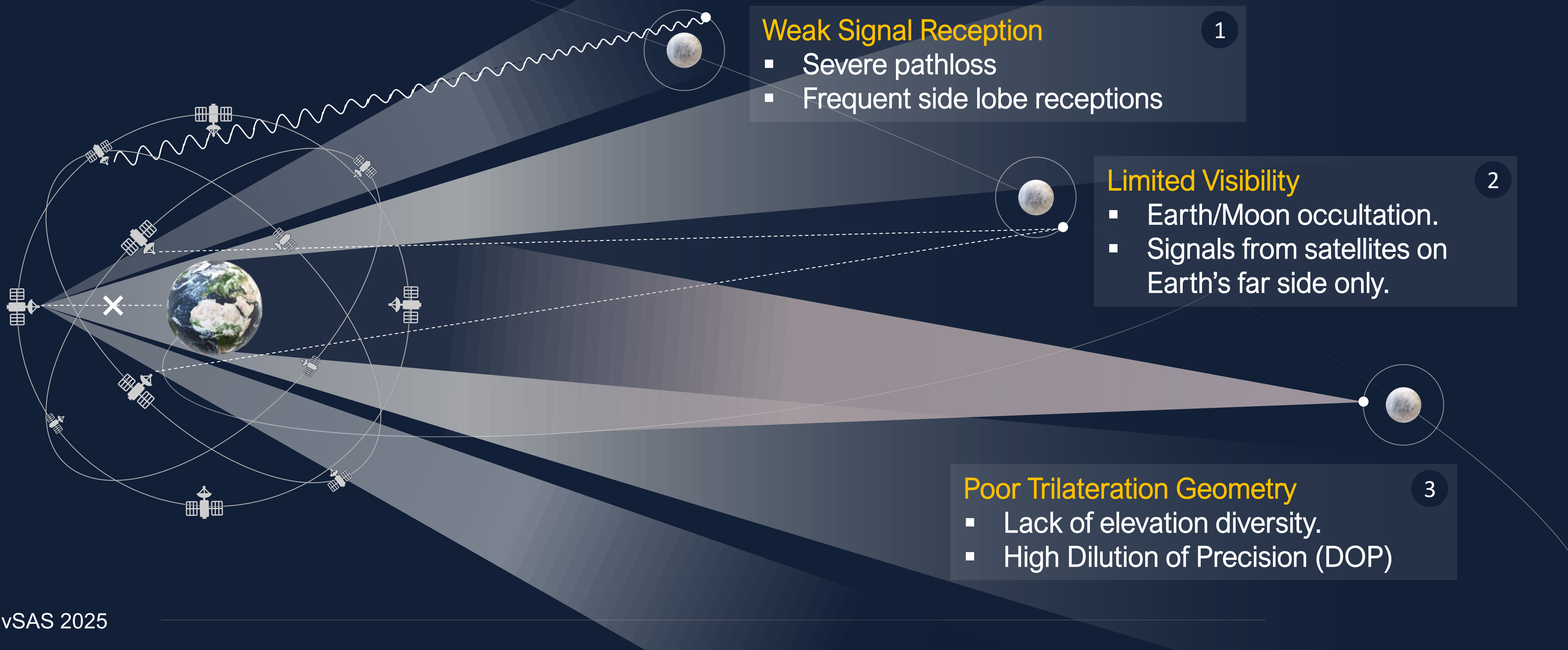
- Extending GNSS into cislunar space opens the door to **autonomous navigation**, the key challenge for future lunar missions.



(Credits: Firefly Aerospace)

Challenges for (Cis)Lunar GNSS

Beyond Earth's orbits, GNSS faces its most challenging environment yet.



Weak Signal Reception (1)

- Severe pathloss
- Frequent side lobe receptions

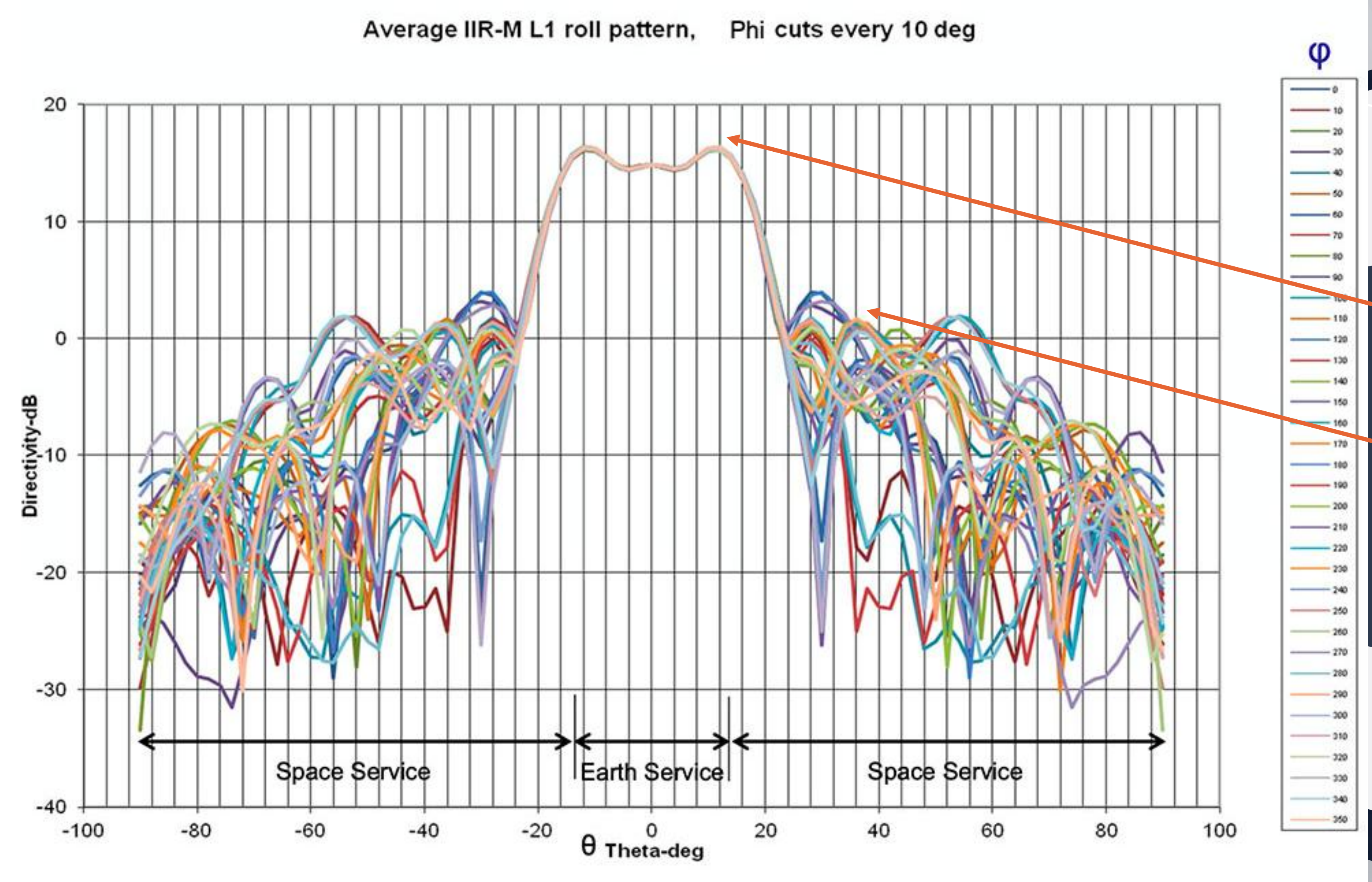
Limited Visibility (2)

- Earth/Moon occultation.
- Signals from satellites on Earth's far side only.

Poor Trilateration Geometry (3)

- Lack of elevation diversity.
- High Dilution of Precision (DOP)

GNSS at lunar distances: critical issues

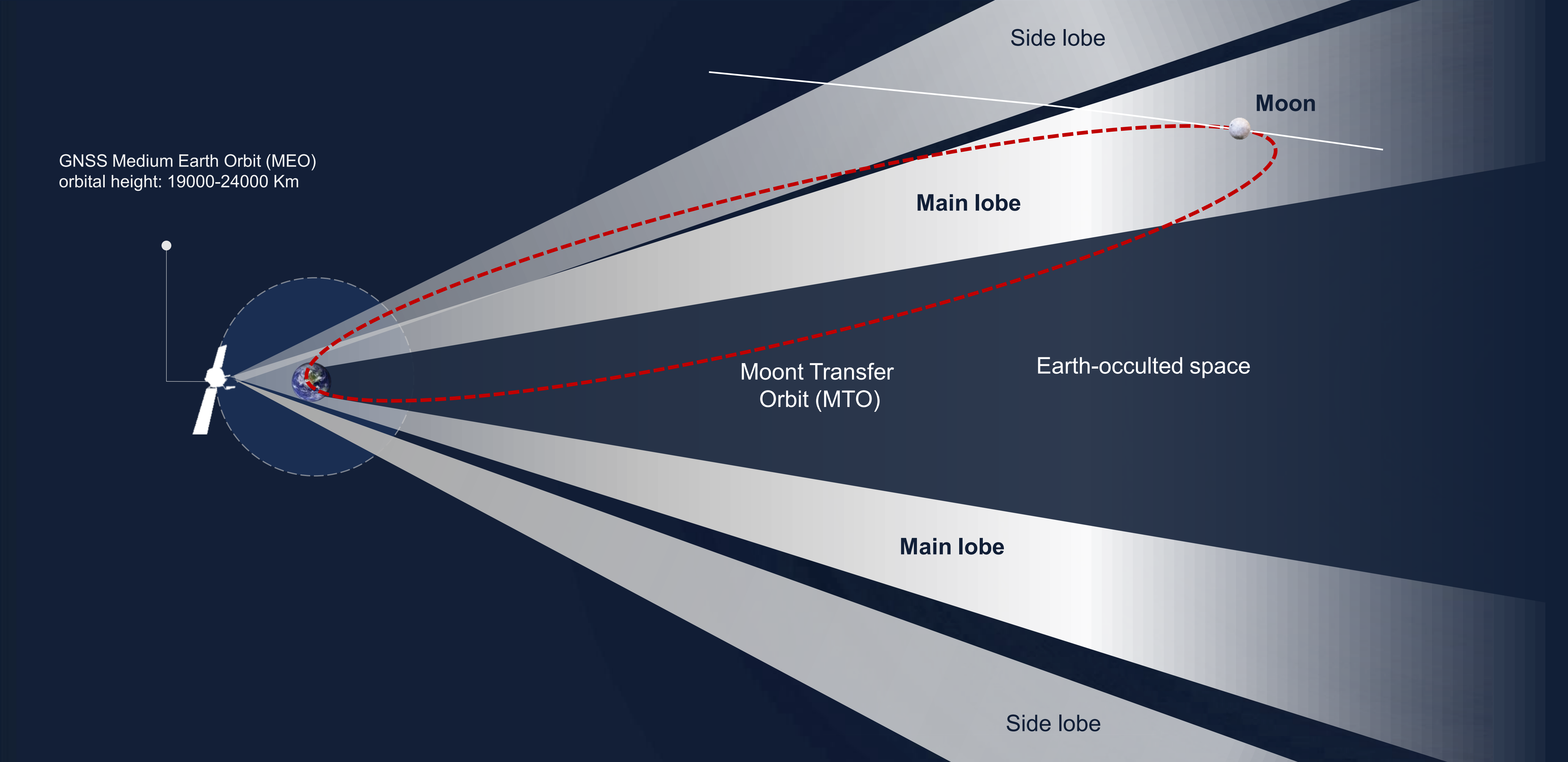


U.S. Space Force and Lockheed Martin Space have released the GPS IIR/IIR-M satellite antenna patterns for worldwide public use

Higher gain at the boundaries of the main lobe

Sidelobes: spillover of power… that can be used for navigation in space

GNSS at lunar distances: critical issues



Challenges for (Cis)Lunar GNSS

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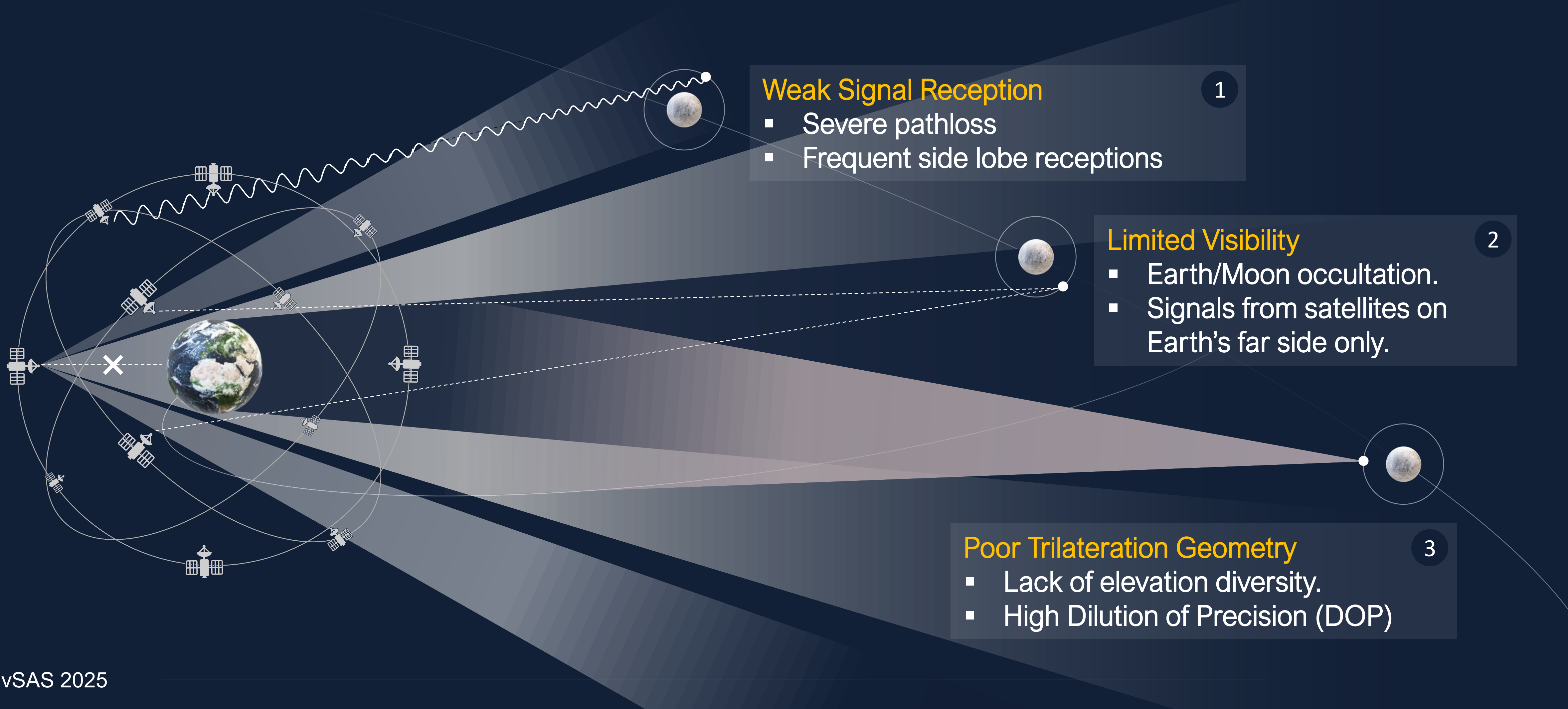
Beyond Earth's orbits, GNSS faces its most challenging environment yet.



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Challenges for (Cis)Lunar GNSS

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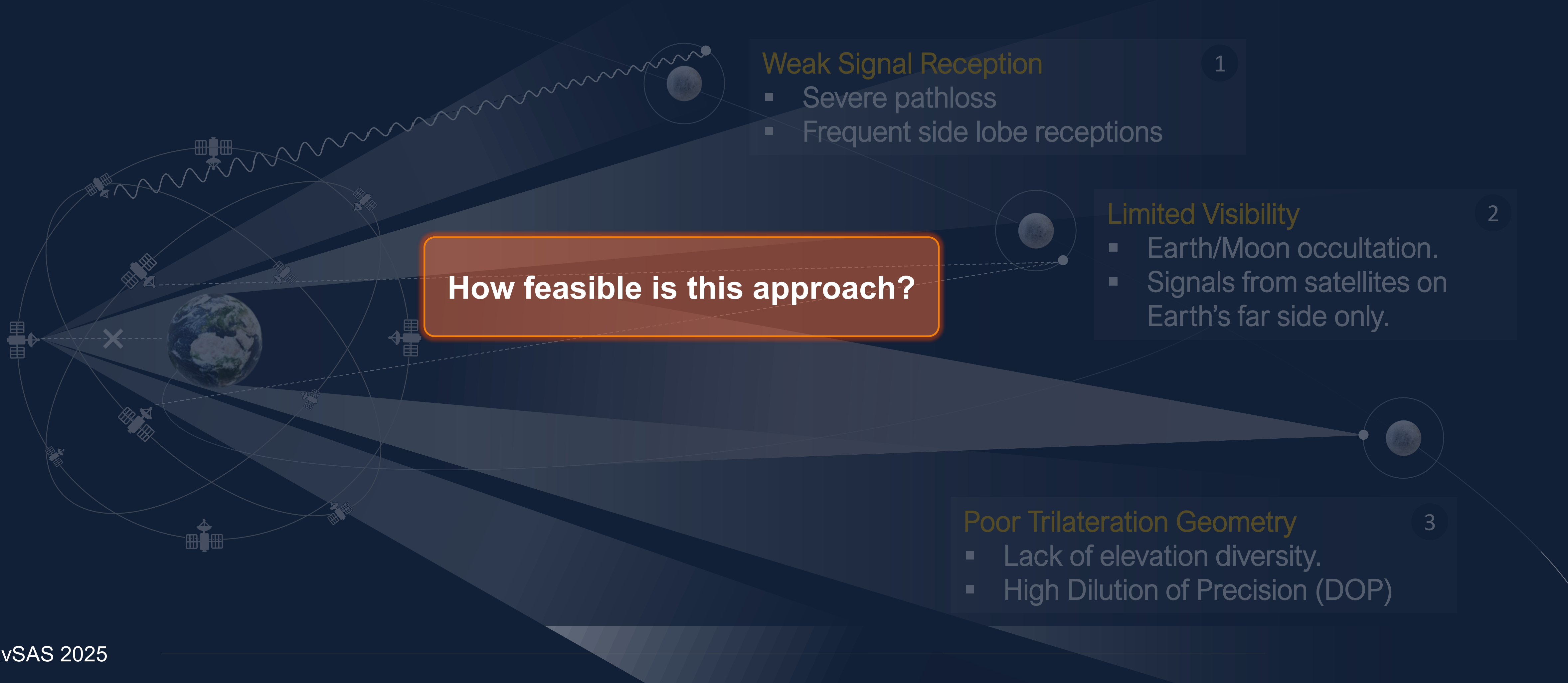

04

THE LUNAR GNSS RECEIVER EXPERIMENT (LuGRE)

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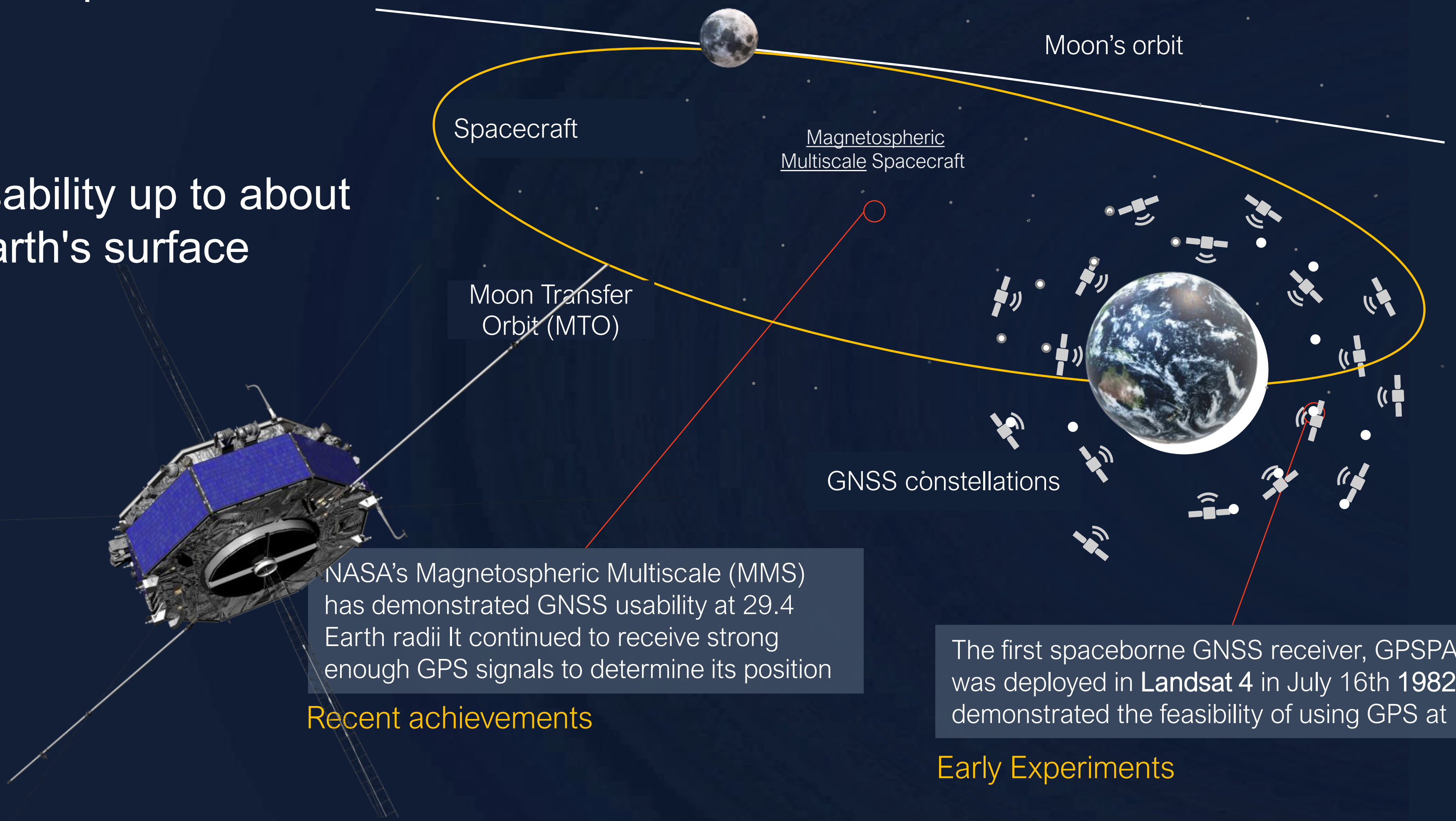
GNSS beyond terrestrial applications

Can GNSS support autonomous navigation (manned or unmanned) in space?

NASA has proven its usability up to about 190 000 km from the Earth's surface



NASA's Magnetospheric Multiscale (MMS) has demonstrated GNSS usability at 29.4 Earth radii It continued to receive strong enough GPS signals to determine its position

Recent achievements

The first spaceborne GNSS receiver, GPSPAC, was deployed in **Landsat 4** in July 16th **1982**. It demonstrated the feasibility of using GPS at LEO

Early Experiments

LuGRE

LUNAR GNSS RECEIVER EXPERIMENT

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ASI
Agenzia Spaziale Italiana

Qascom
Trust is Nice, Control is Better.

FIREFLY AEROSPACE

NASA

NASA • ASI
LUNAR GNSS RECEIVER EXPERIMENT
LuGRE
QASCOM

LuGRE Lunar GNSS Receiver Experiment

NASA CLPS Commercial Lunar Payload Services

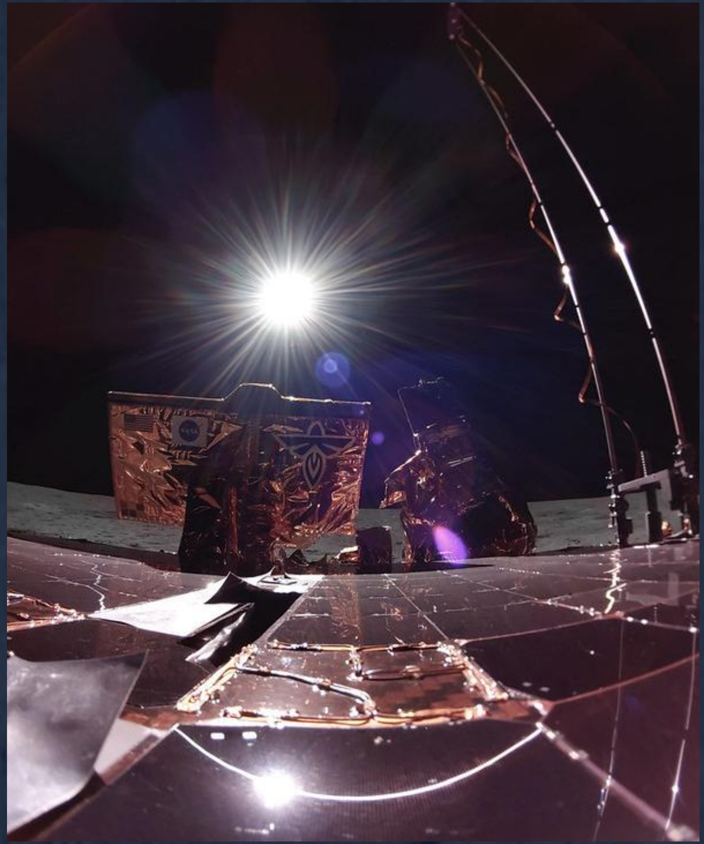
The Lunar GNSS Receiver Experiment (LuGRE) was a bilateral project involving ASI (the Italian Space Agency) and NASA

A GNSS receiver developed by the Italian company Qascom was launched onboard Firefly's BlueGhost M1 (BGM1) lander and successfully delivered to the Moon in March 2025.

LuGRE has been part of the **CLPS program**, an initiative where NASA partners with private companies to deliver science and technology payloads to the Moon, enabling rapid development and cost-effective lunar exploration

Qascom: Software-defined radio (SDR) technology receiver

Politecnico di Torino, Department of Electronics and Telecommunications (NAVSAS): Scientific support for the GNSS data analysis and experiments implementation



The project assessed the usability of a spaceborne GNSS receiver to support cislunar and lunar standalone navigation through multi-frequency, multi-constellation GNSS.

LuGRE Lunar GNSS Receiver Experiment

LUNAR GNSS RECEIVER EXPERIMENT

NASA CLPS
Commercial Lunar Payload Services

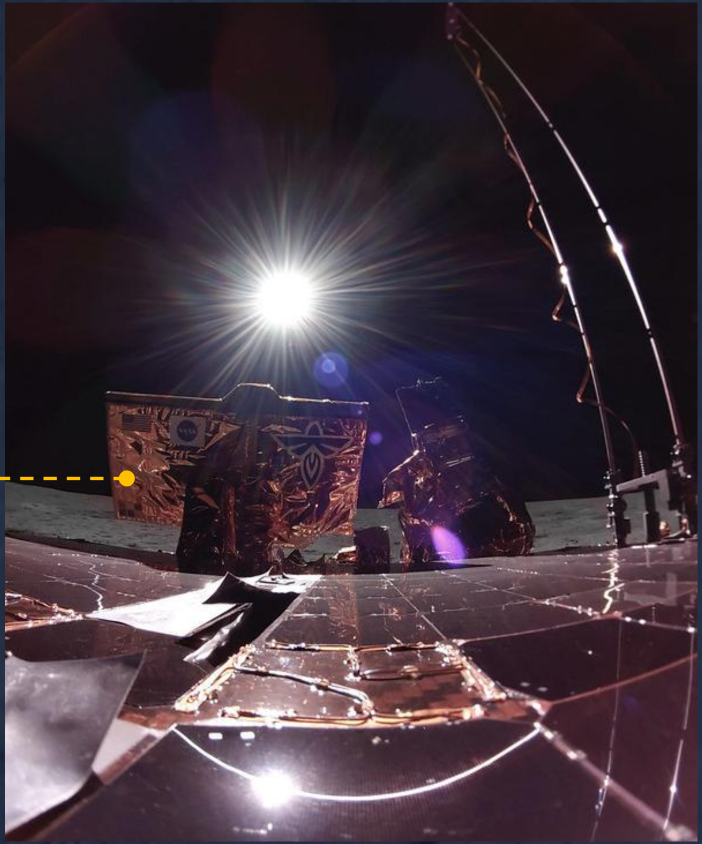
Payload objectives

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.

LuGRE GNSS Payload

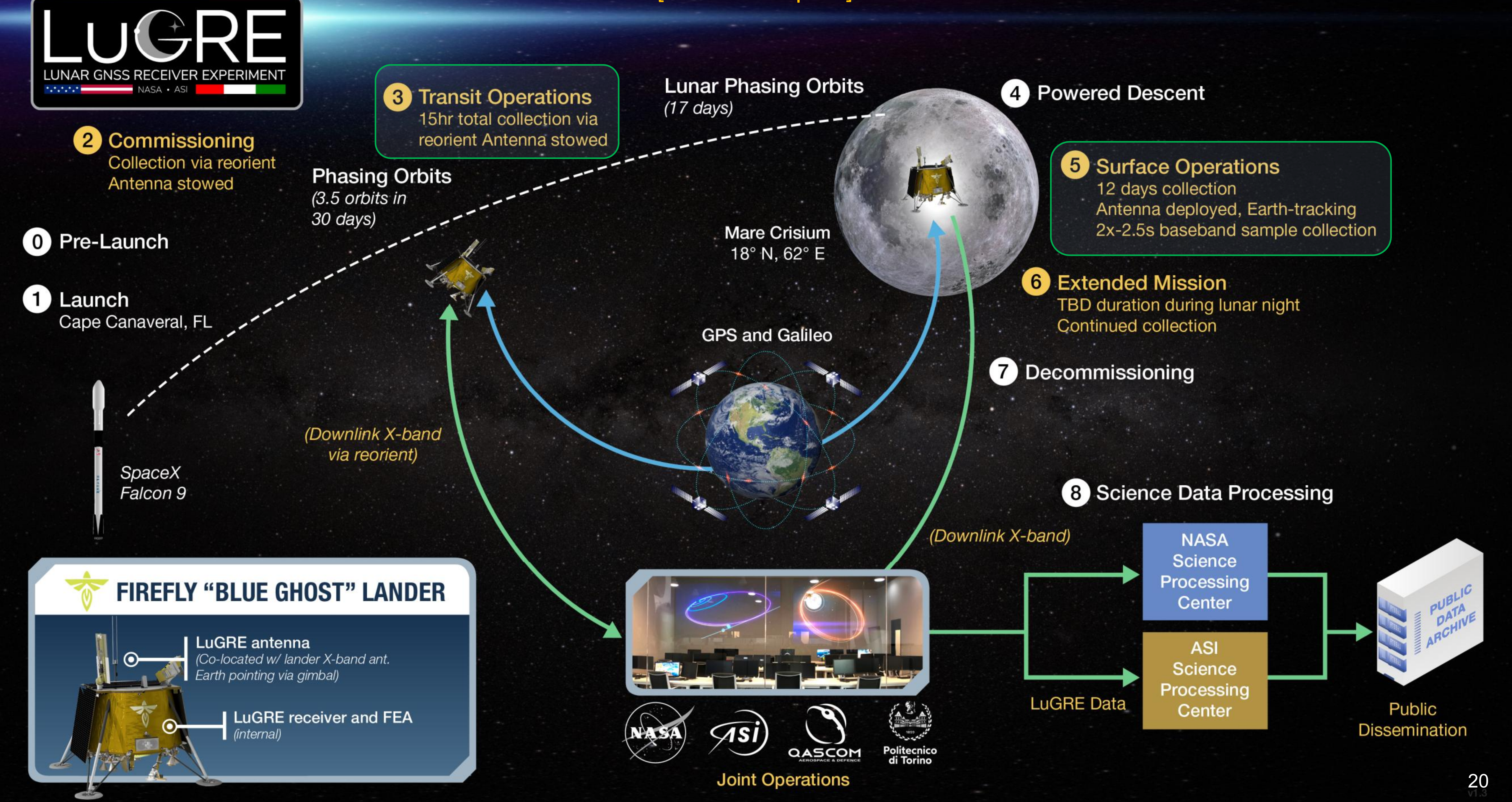
Navigation Early Investigation on Lunar surface (NEIL) receiver with software-defined radio (SDR) technology

QASCOM AEROSPACE & DEFENCE



The first ever GNSS-only PNT demonstration in transit to the Moon and on the Lunar surface

[Pre-launch plan]



LuGRE data collected

Essential view of the GNSS observables, navigation and raw-signal data returned by the Lunar GNSS Receiver Experiment

111+ h	95+ h	106+ h	~12 s	GPS + Galileo
total operations	surface operations	real-time processing	I/Q sample batches	L1/E1 and L5/E5a

Real-time processing mode (RTP)

O 1. GNSS Observables

- ACQ: acquired satellites, Doppler and correlation information
- RAW: C/N0, pseudorange, Doppler and carrier phase
- 1-Hz products for all real-time processing operations

N 2. Navigation solutions

- NAV: onboard least-squares PVT solutions
- POD: navigation-filter solutions in Earth-inertial frame
- Used to demonstrate real-time lunar GNSS navigation

Sample capture mode (SC)

S 3. Digital signal captures

- IQS: baseband in-phase/quadrature samples
- Captured in L1/E1 and L5/E5a GNSS bands
- Enable post-processing, acquisition tests and spectral analysis

Public data release products

TLM_ACQ	Acquisition
TLM_RAW	Measurements
TLM_NAV	PVT solutions
IQS_L1	L1/E1 I/Q
IQS_L5	L5/E5a I/Q
OPTABLE	Operations table
ICD	Binary format

All payload telemetry is provided in raw form and packaged in standard formats to support rapid scientific use; ancillary products document operations and binary formats.

Source: Parker et al., NAVIGATION (2026), LuGRE paper, Sections 2, 4 and 8 / Table 7.

04

THE BLUE GHOST JOURNEY

Payload Operations Center (POC)
NASA GSFC
Greenbelt, MD, USA

Remote Science Processing Center (RSPC)
Politecnico di Torino
Torino, IT

Earth-Moon Transfer

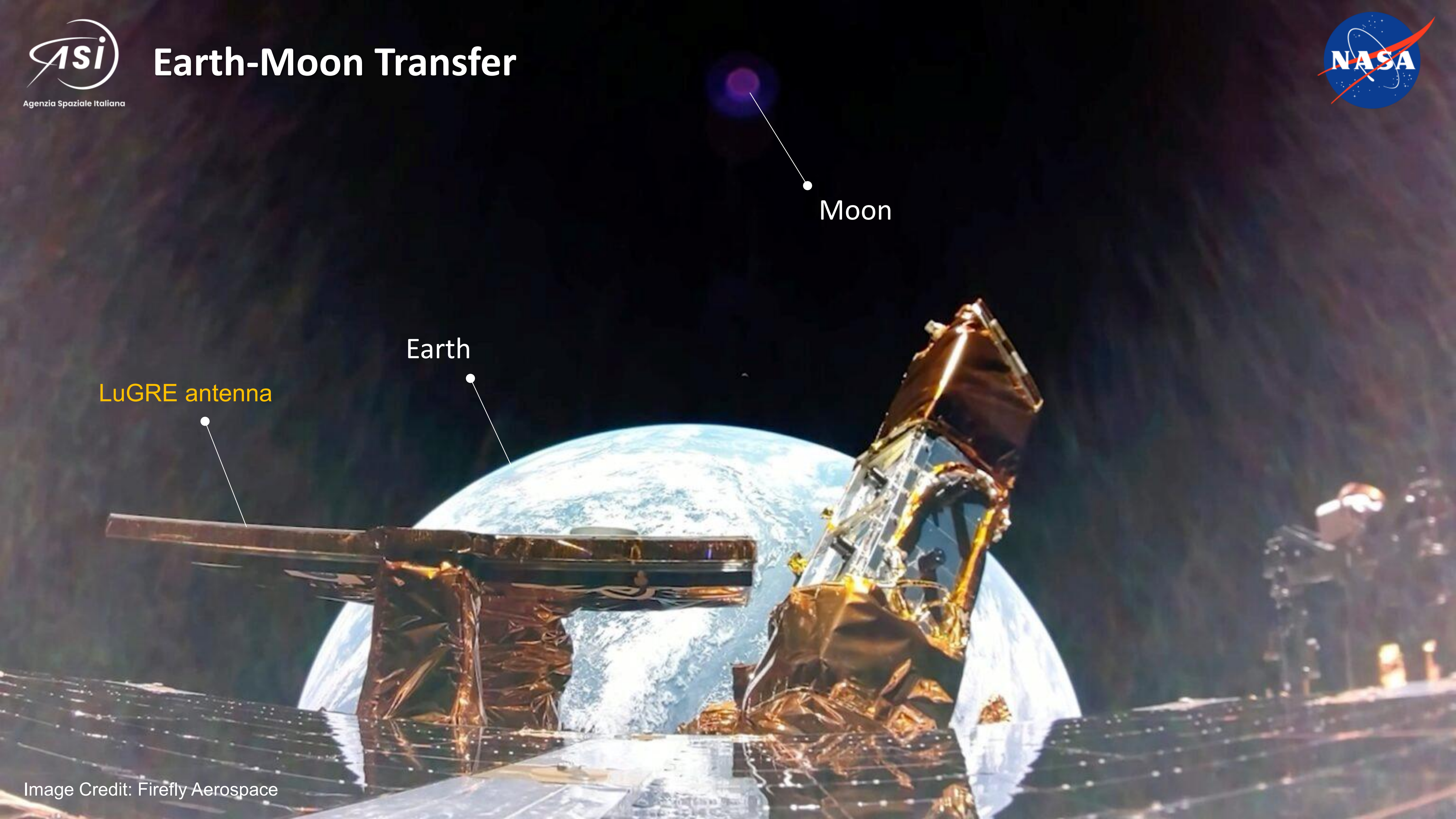
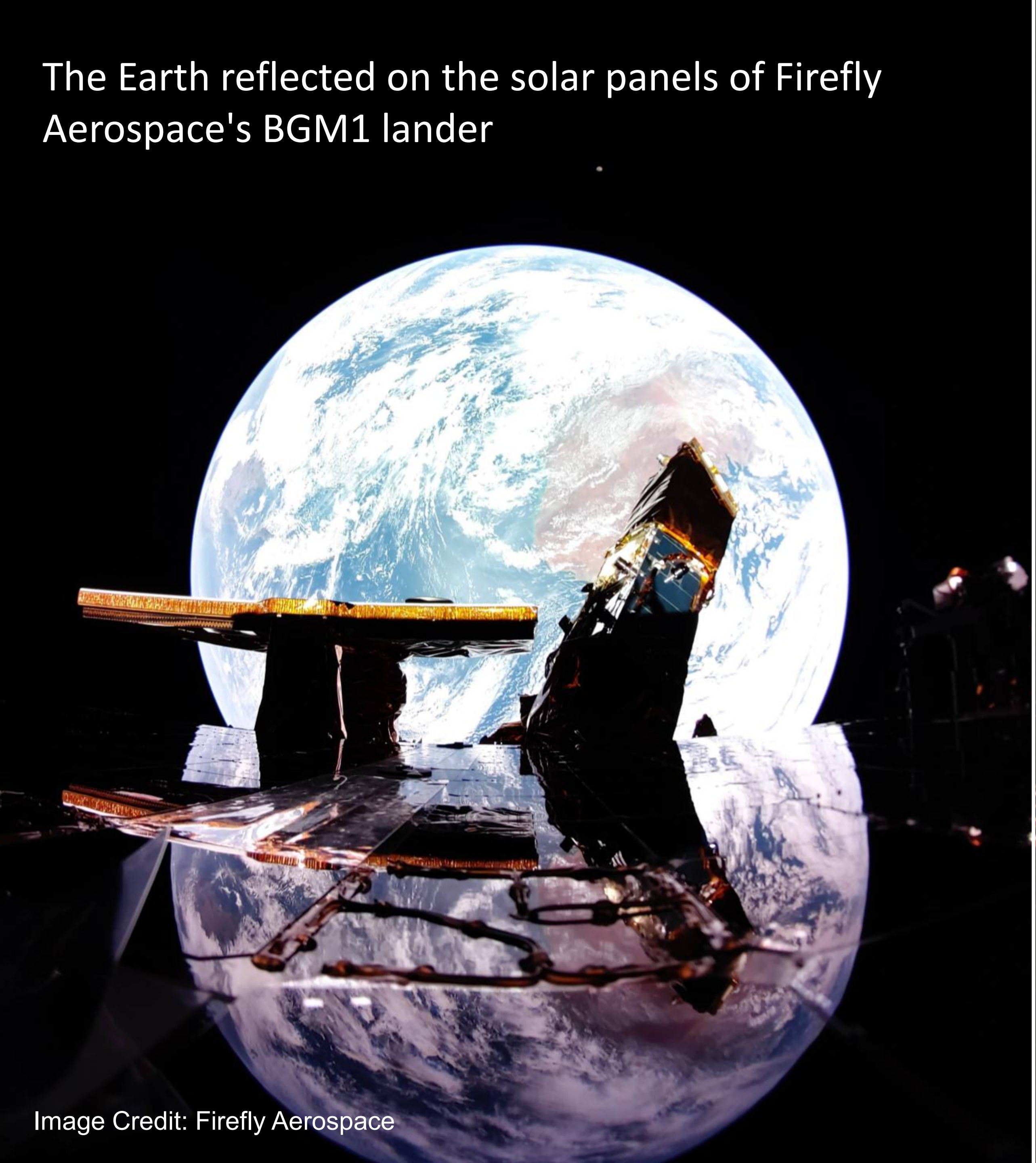


Image Credit: Firefly Aerospace

Image Credit: Firefly Aerospace


The Earth reflected on the solar panels of Firefly Aerospace's BGM1 lander
Image Credit: Firefly Aerospace

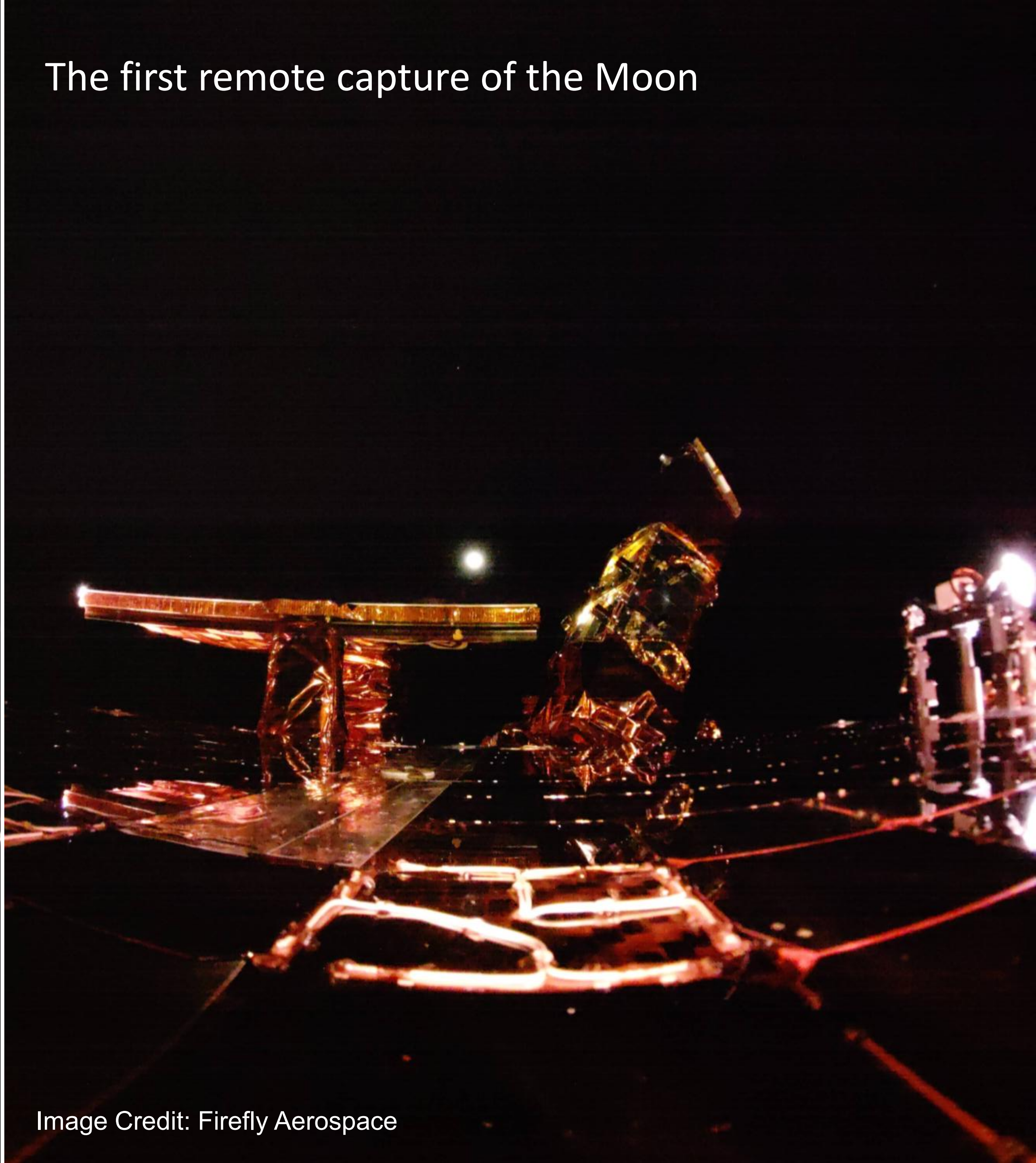
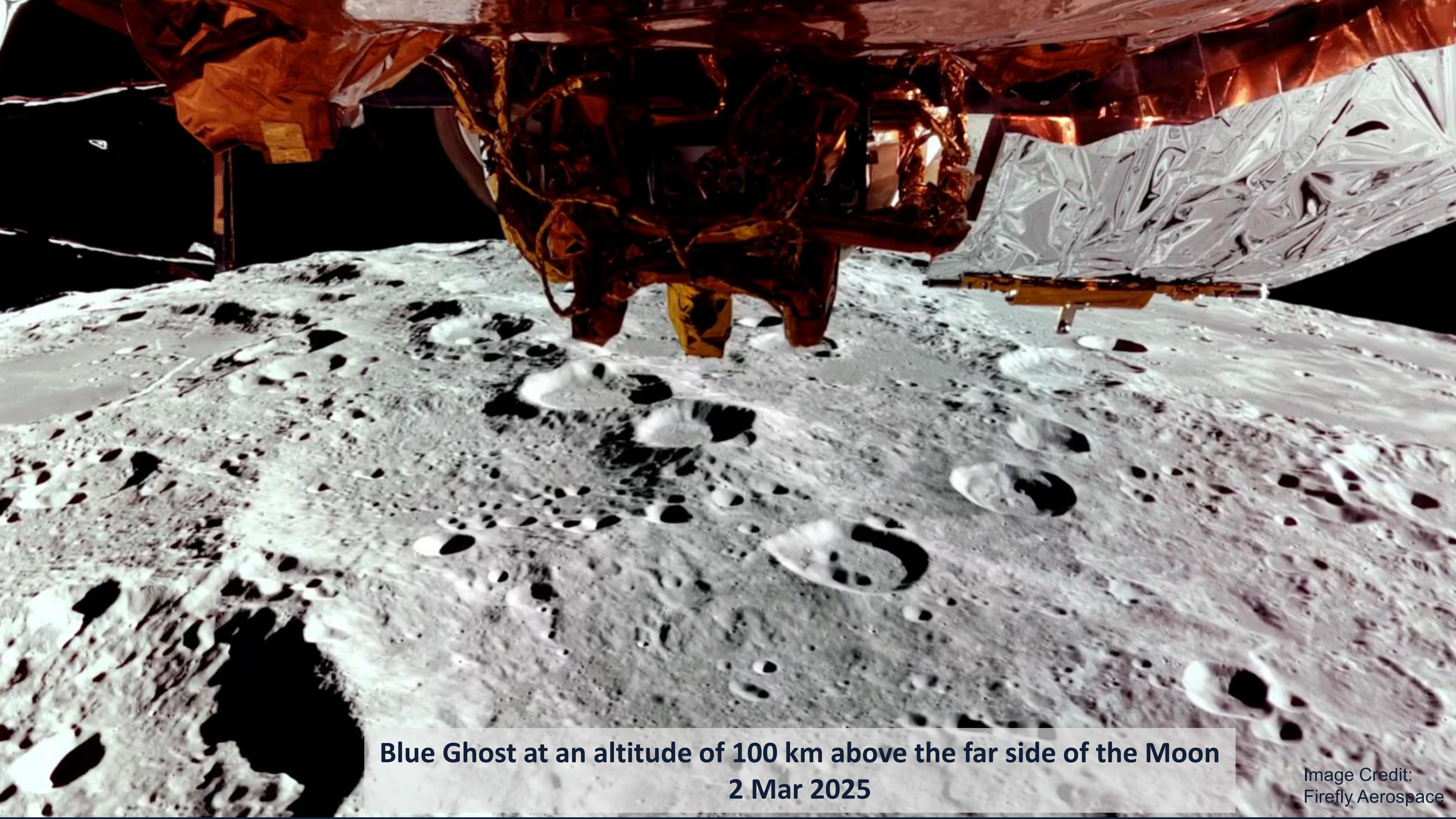

The first remote capture of the Moon
Image Credit: Firefly Aerospace

Image of the Lunar South Pole
14 Feb 2025

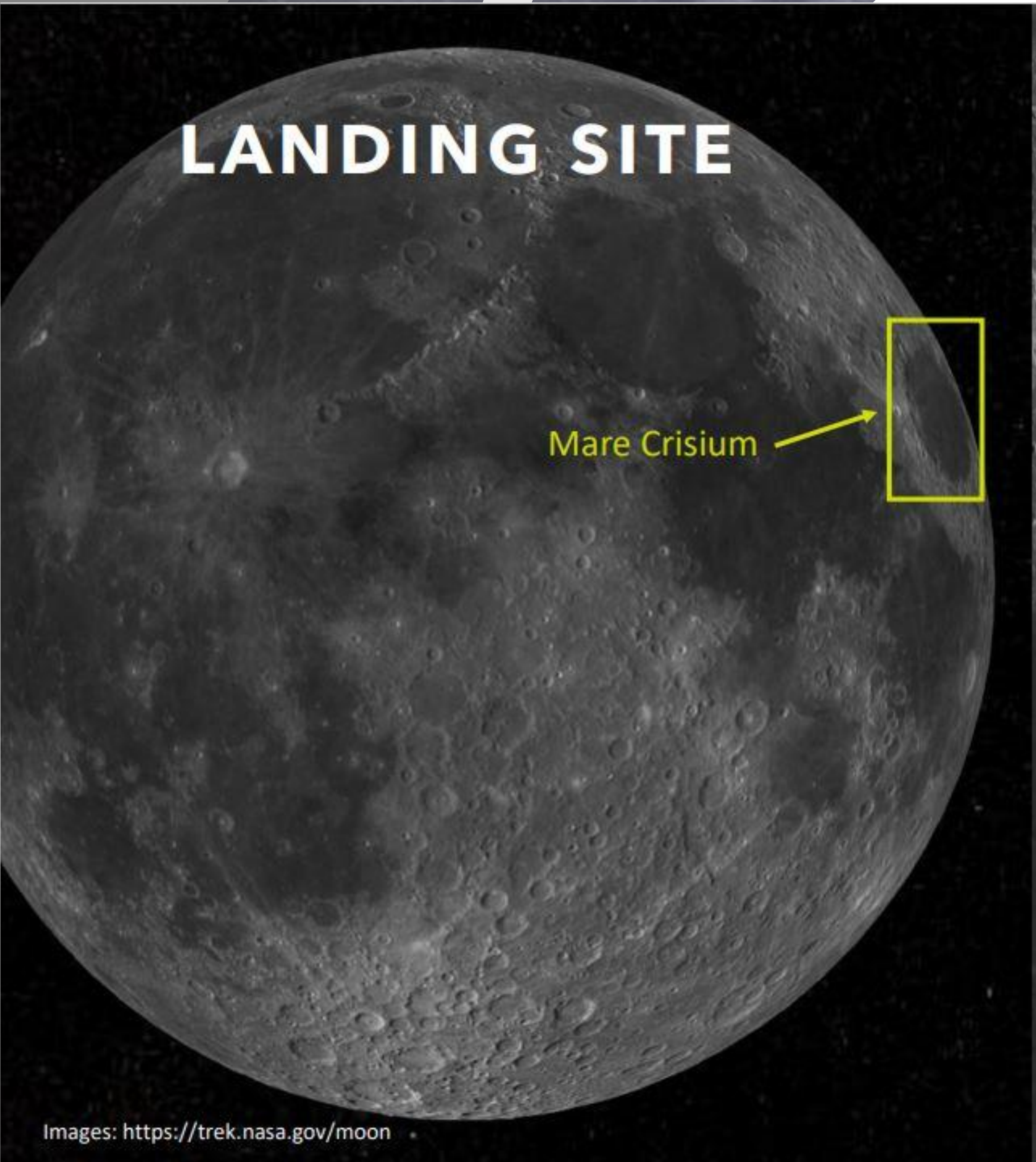
Image Credit: Firefly Aerospace

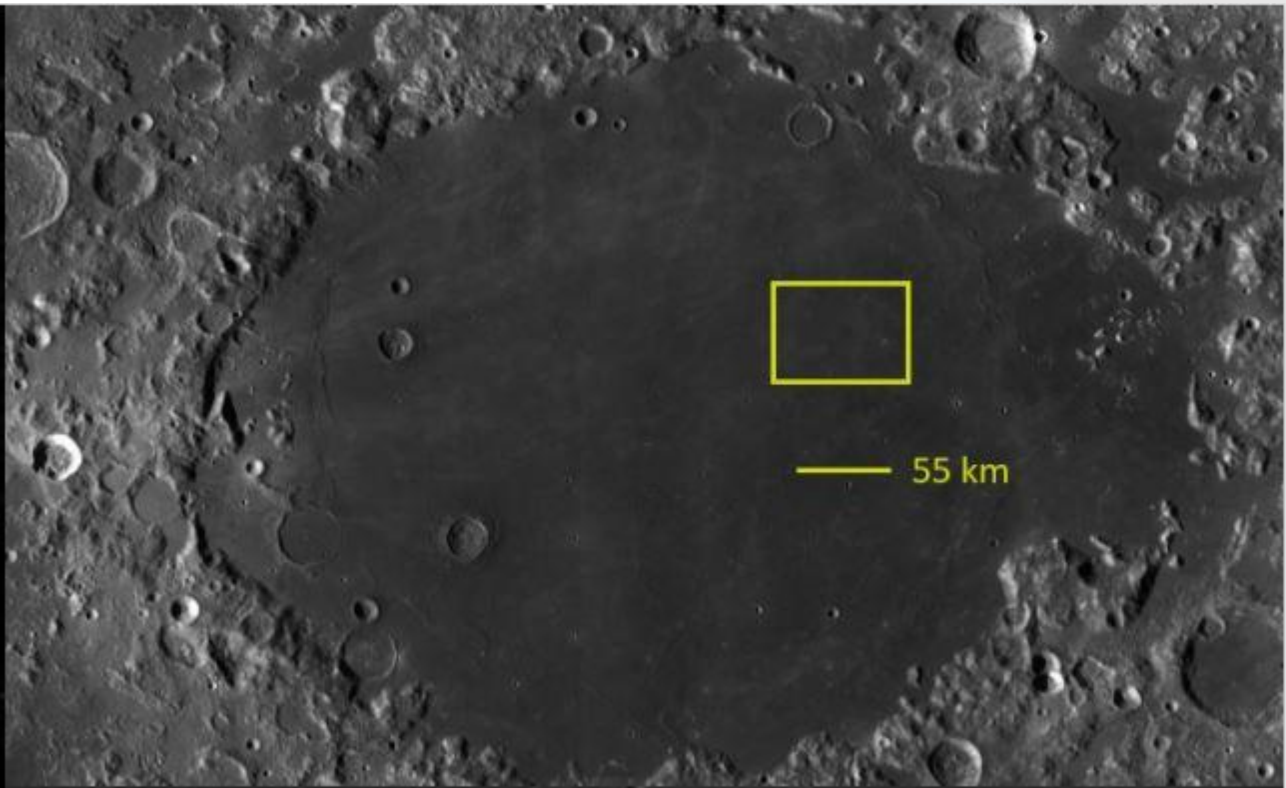


Blue Ghost at an altitude of 100 km above the far side of the Moon
2 Mar 2025

Image Credit:
Firefly Aerospace

LANDING SITE





Images: https://trek.nasa.gov/moon

Shadow of BGM1 on the lunar surface.
2 Mar 2025

Image Credit: Firefly Aerospace

Total solar eclipse observed by Mare Crisium, with re-emergence of the Sun.
14 Mar 2025

Image Credit: Firefly Aerospace


Sunset observed from the Moon.
16 Mar 2025

LUGRE HIGHLIGHTS & INITIAL RESULTS

05

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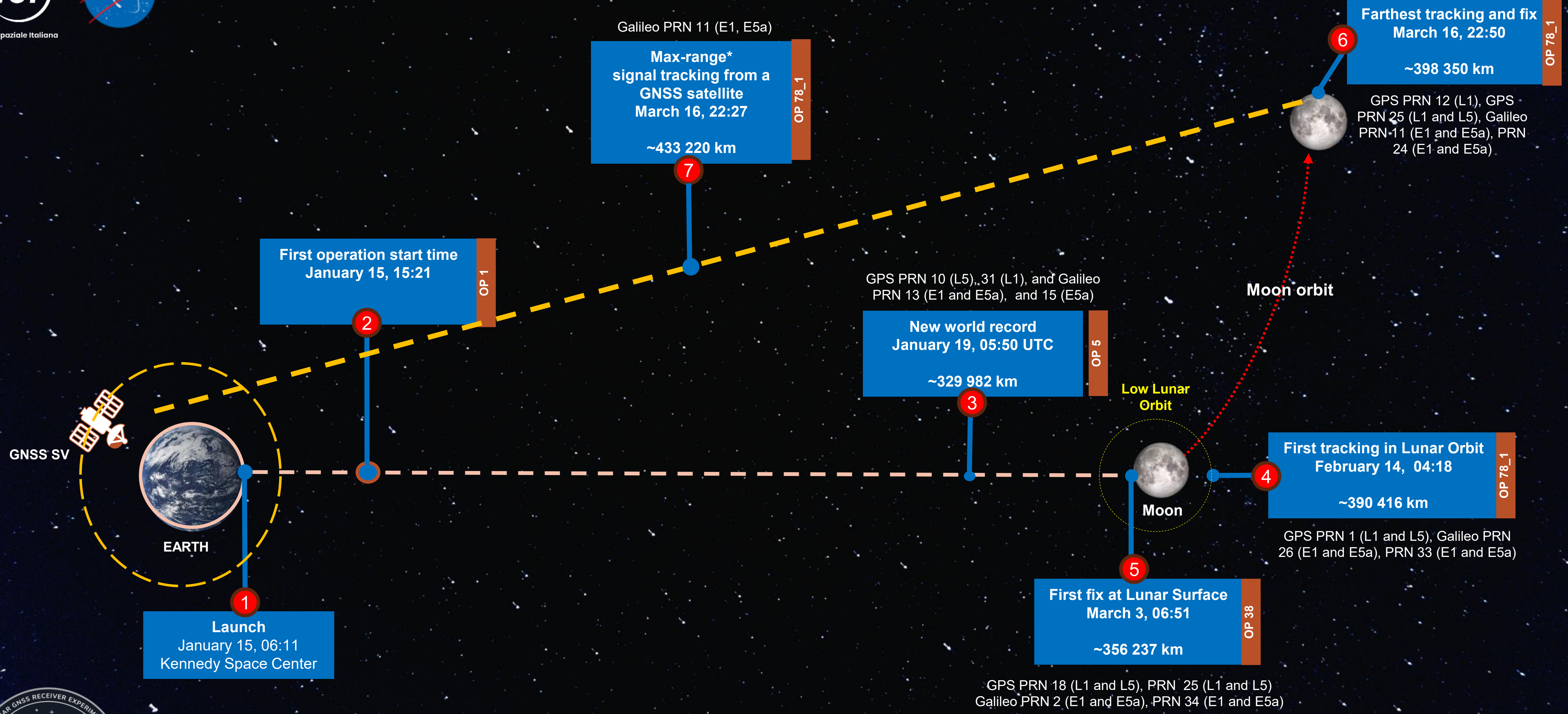

NOTES: diagram not to scale
All times are expressed in UTC; distances are altitude from Earth geoid
*The max range is computed from the Galileo GSAT0101 position to the Lander location
PRN = pseudo-random noise
SV = space vehicle

LuGRE Highlights

Payload Operations

- 16 in-flight operations (Earth-Moon transit + lunar orbit)
- 111+ hours total activity, incl. 95+ hours on the Moon
- 106+ hours in real-time processing (RTP);
- 12 s of IQ samples collected

Technical Performance

- Tracked GPS & Galileo (L1, L5, E1, E5a)
- Operated with both redundant receivers; demonstrated switching
- Maintained <1° Earth-pointing accuracy during ops

Tracking Achievements & PVT Records

✓ Record tracking distance: 433,220 km (Galileo PRN 11)
✓ First-ever GNSS fix in lunar orbit
✓ First GNSS fix on lunar surface
✓ Farthest GNSS fix: 398,350 km from Earth

Received: d month yyyy | Revised: d month yyyy | Accepted: d month yyyy
DOI: 10.1109/xxx.xx.xxxx

ION

REGULAR PAPERS

GNSS Reception at the Moon: First Results of the Lunar GNSS Receiver Experiment (LuGRE)

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[5]Agenzia Spaziale Italiana (ASI), Rome, Italy

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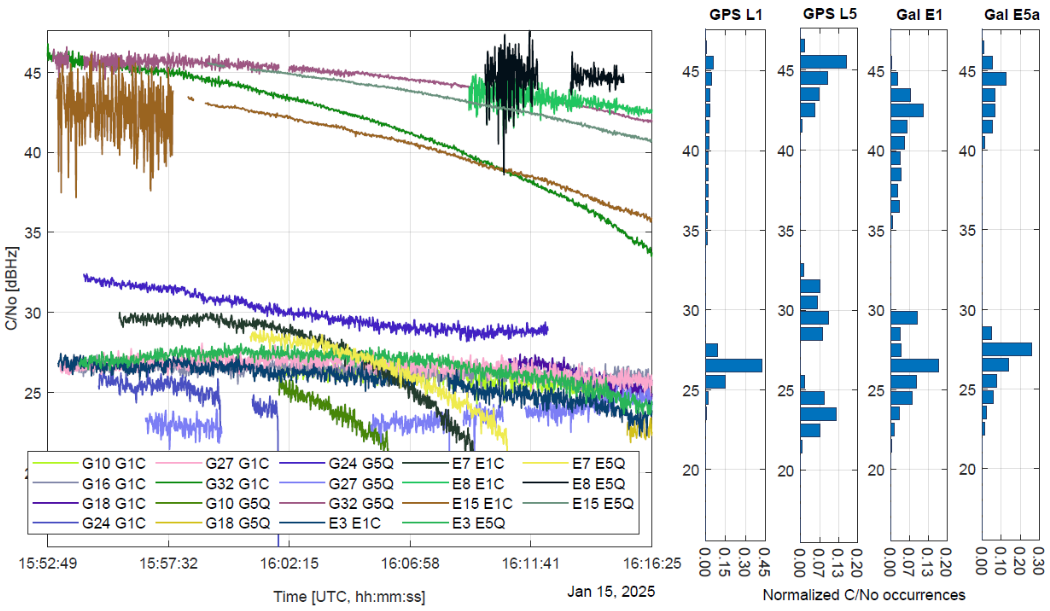
Abstract
This article presents a comprehensive overview of the successful execution of the Lunar GNSS Receiver Experiment (LuGRE), the first known demonstration of GNSS signal acquisition, tracking, and navigation near and on the Moon. A general overview of the mission, payload, and ground system is provided. The as-flown mission profile is described in detail across Earth-Moon transit, low lunar orbit, and lunar surface phases. A description of the high-level results of the mission are presented, including an evaluation of the C/N_0; the quality of the pseudorange and carrier phase measurements; the signal availability; the results of real-time least-squares position, velocity, and time estimation by the on-board receiver; and an evaluation of the in-phase and quadrature samples captured during the mission. Finally, key observations for future lunar GNSS users are discussed. The article also serves as a reference guide to the unique open dataset released by the project.

Keywords
Lunar GNSS Receiver Experiment (LuGRE), GNSS, GPS, Galileo, Firefly Aerospace, Blue Ghost Mission 1 (BGM1), Commercial Lunar Payload Services (CLPS), Lunar PNT, Lunar navigation, Space service volume

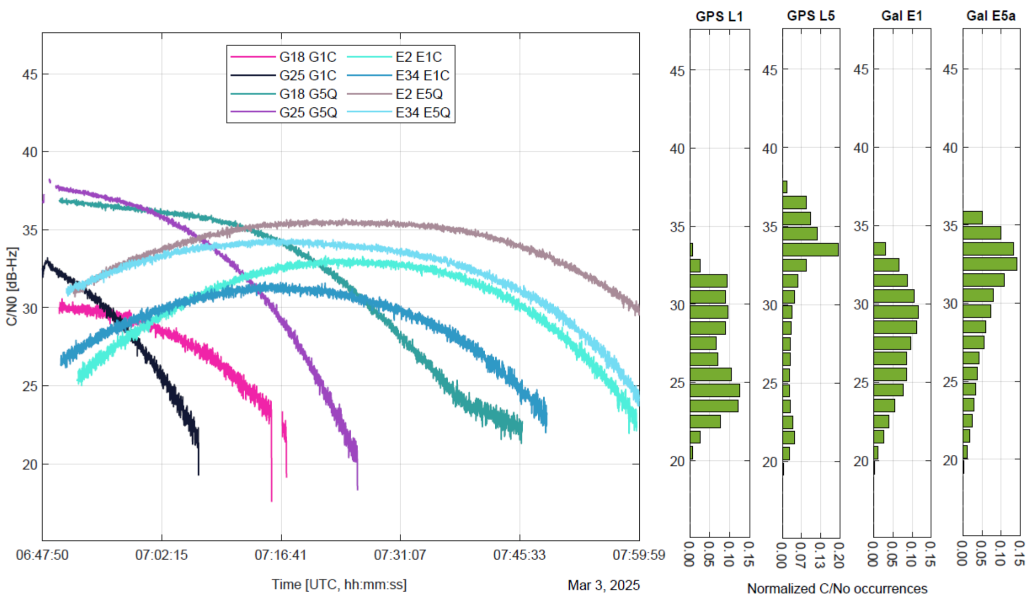
LuGRE Reference Paper

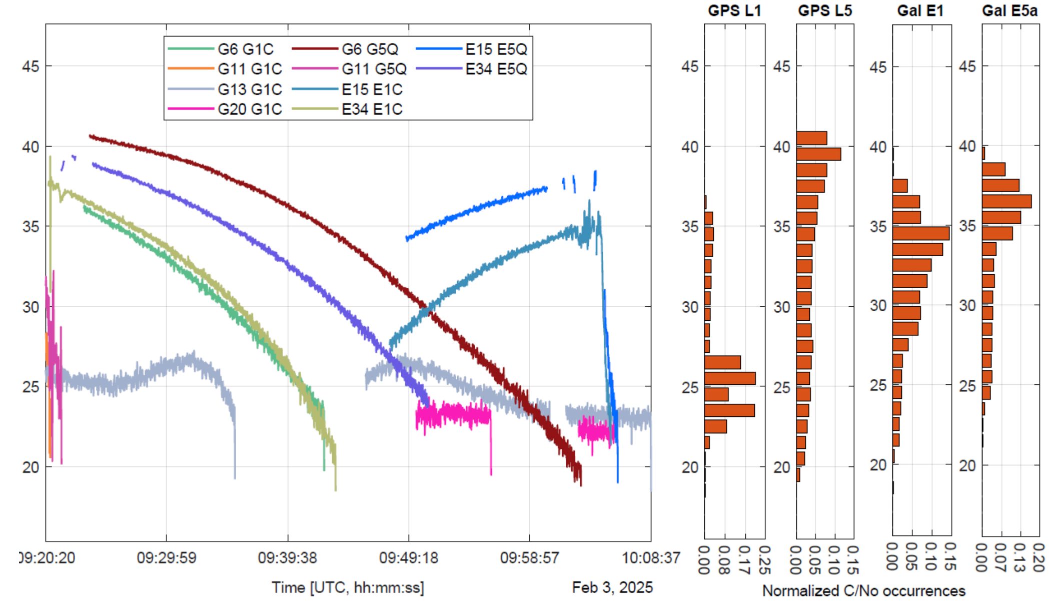
Parker, J. J. K., Dovis, et al. (2026). *GNSS reception at the Moon: First results of the Lunar GNSS Receiver Experiment (LuGRE).* Institute of Navigation Mar 2026, 73 navi.756; DOI: 10.33012/navi.756

Results: Received Signal Strength (C/N_0)



Transit
OP1_0
Altitude: 15RE





Transit
OP17
Altitude: 45RE

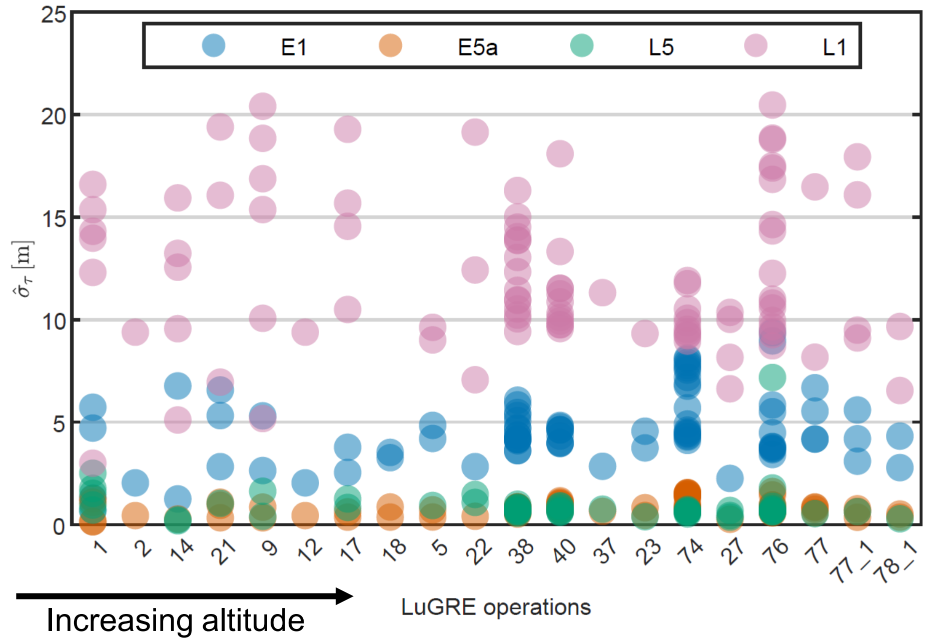
Lunar surface
Altitude: 55RE
(OP38, first 72 min)

- Plots show received C/N_0 at three example operations
- Mixture of GPS, Galileo, L1/E1, L5/E5a in all cases
- Distinct separation between **main lobes** and **sidelobes**
- Only main lobes present in OP38 example; sidelobes tracked occasionally on lunar surface

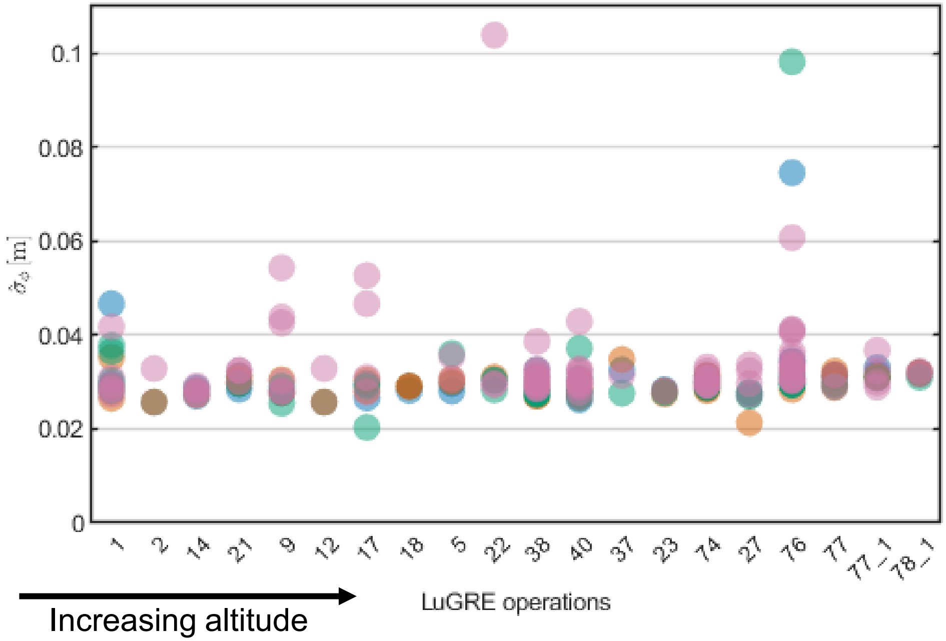
Results: Measurement Quality

- Standard deviation of detrended code and carrier-phase measurements to isolate short-term variations due to receiver noise
- Statistics accumulated for each PRN over full operation window.
- In general, results show measurement quality in all mission phases comparable to typical terrestrial receivers
- Measurement noise behavior is as expected
  - L5/E5a measurements show lower measurement noise than L1/E1
  - Carrier-phase noise two orders of magnitude less than code measurement noise

Code measurements

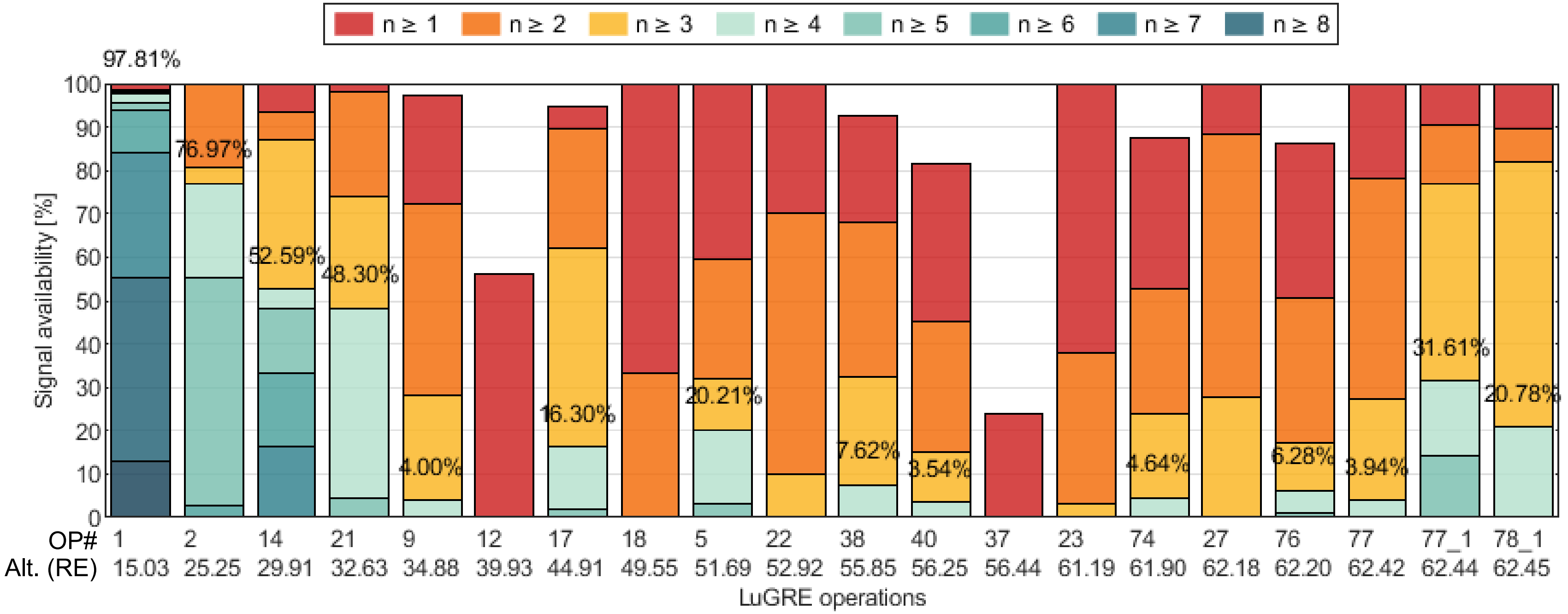


Carrier-phase measurements



Results: Signal Availability (multifreq., multiconst.)

- High degree of availability of at least one signal across full altitude range
- least-squares solution availability (4+ unique signals) decreased with altitude, but remained even during long-duration lunar surface operations
- L5/E5a contributed to PVT availability: 1–5% increase in long-duration lunar surface operations
- Limited availability (e.g., OP12, OP22 and OP37 was conditioned by poor geometrical visibility



PVT availability (4+ unique signals)

Lunar surface operations

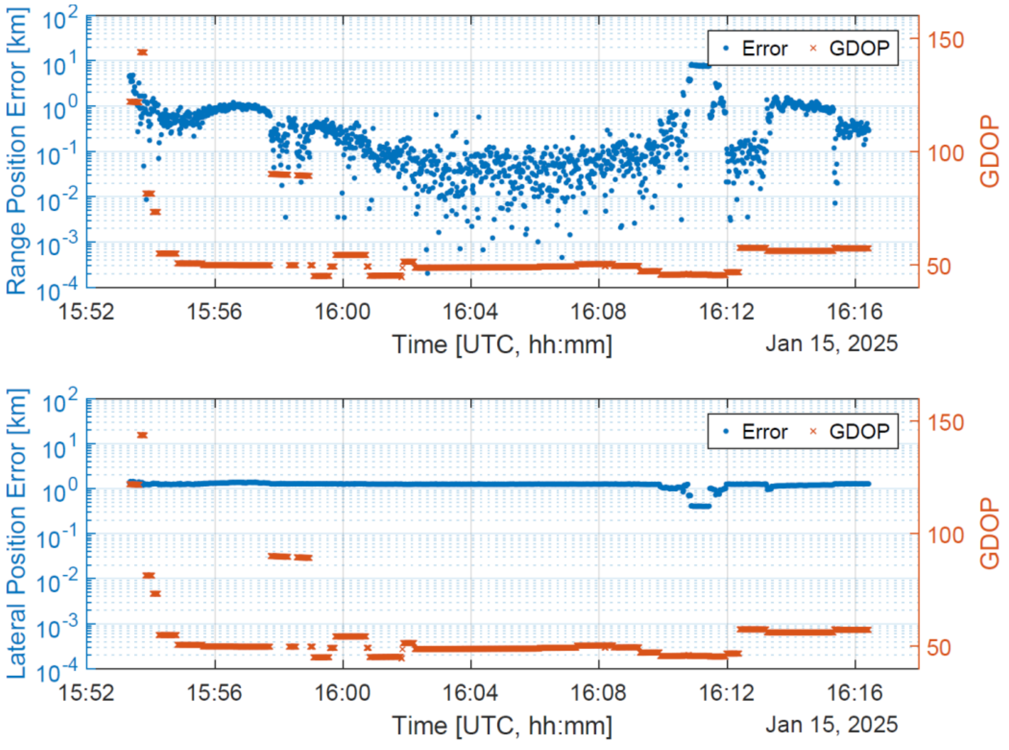
Metric / OP ID	1	2	14	21	12	17	5	23	74	27	76	77	77_1	78_1
L1/E1 (%)	97.81	61.35	0.00	3.70	52.59	0.00	13.10	1.44	1.43	1.43	0.87	3.00	4.09	20.48
L1/E1+L5/E5 (%)	97.81	76.97	20.21	4.00	52.59	16.30	48.30	7.62	3.54	4.64	5.94	3.94	31.61	20.78
Gain (%)	0.00	15.62	20.21	0.30	0.00	16.30	35.20	6.18	2.11	3.21	5.07	0.94	27.52	0.30

Results: State Estimation (PVT)

15RE altitude (OP1)

Range position error

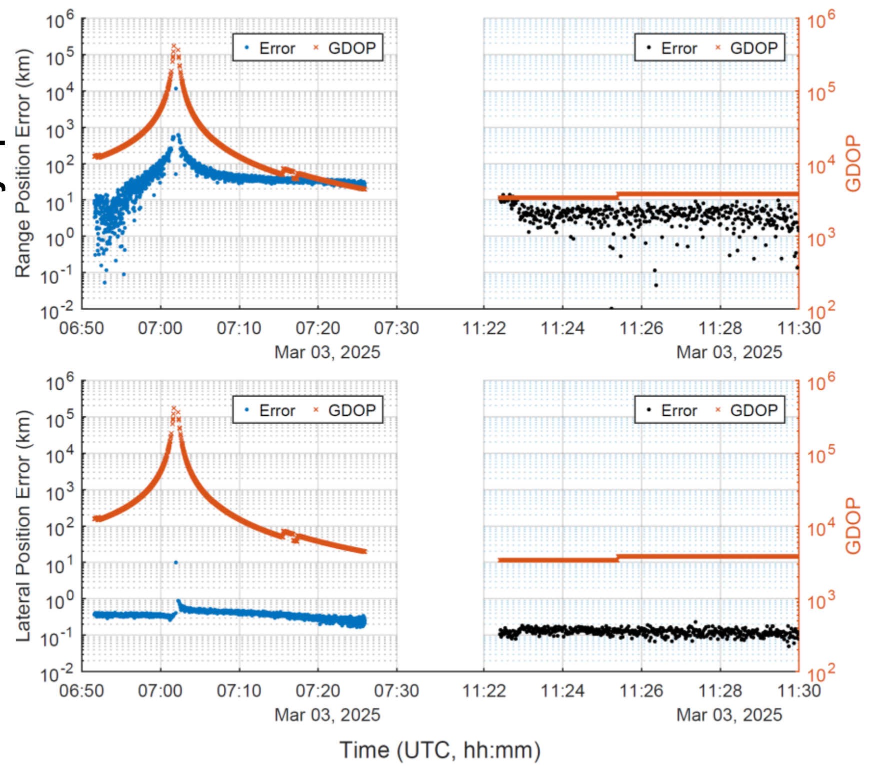
Lateral position error (RSS)



Lunar surface (OP38, two PVT instances)

Asymptotic

Stable



- LuGRE receiver calculated both least-squares PVT and Kalman filter POD multiconstellation solutions.
- Plots describe PVT solution position error with respect to Firefly definitive ephemeris and GDOP
- At 15RE, behavior is as expected – GDOP near 50, position errors around 1km in all directions
- On lunar surface, both an asymptotic and a stable DOP case are shown.
  - asymptotic case is caused by temporary alignment of GNSS planes as seen by receiver – DOP discontinuity causes highly elevated range position error.
  - Stable case shows effect of correlation between range and clock bias states – range error ~10km, lateral error ~100m

05

LUGRE OBSERVATIONS AND LESSONS LEARNED

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Observations

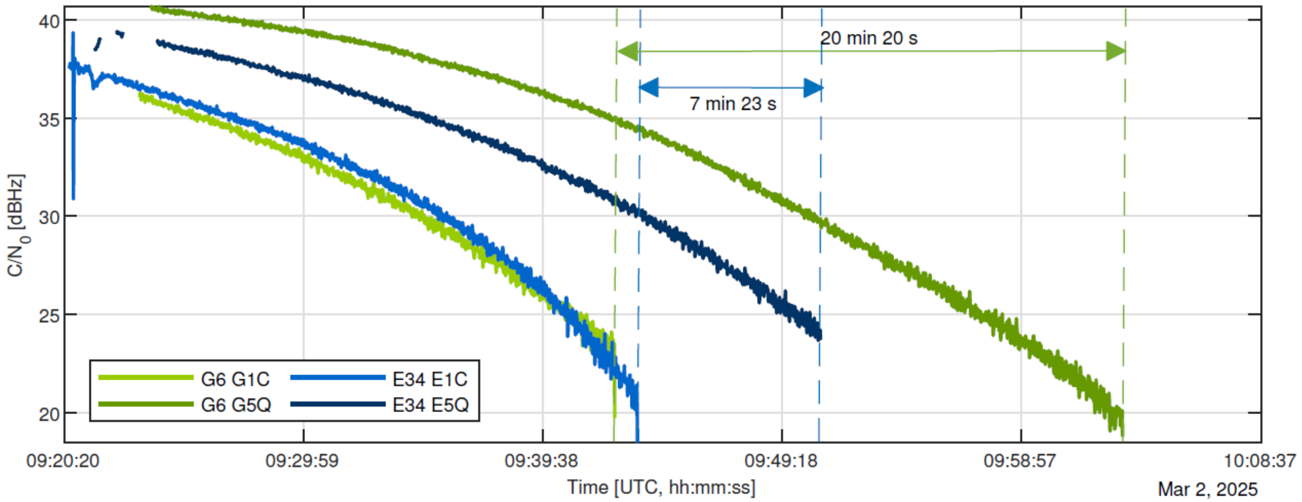
Overall remarks

- GPS and Galileo L1/E1 and L5/E5a signals can be acquired, tracked, and used for navigation at the Moon – using both main lobes and side lobes.
- Measurements quality vs. est. C/N0 is consistent with measurements from typical terrestrial receivers.

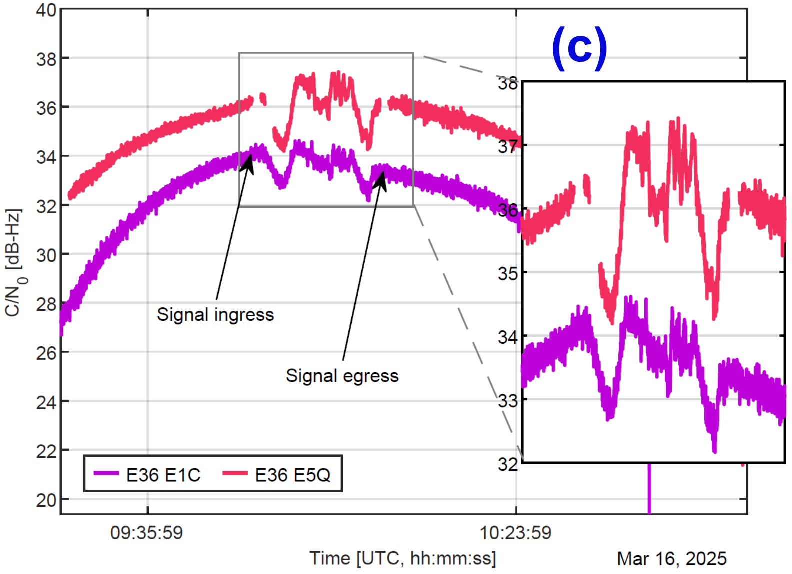
Peculiar observations (details on next slides)

- L5/E5a offers better C/N0 and longer trackable signals than L1/E1. **(a)**
- Phasing significantly affects main lobe visibility, esp. for Galileo. **(b)**
- Ionospheric signature visible in C/N_0. **(c)**

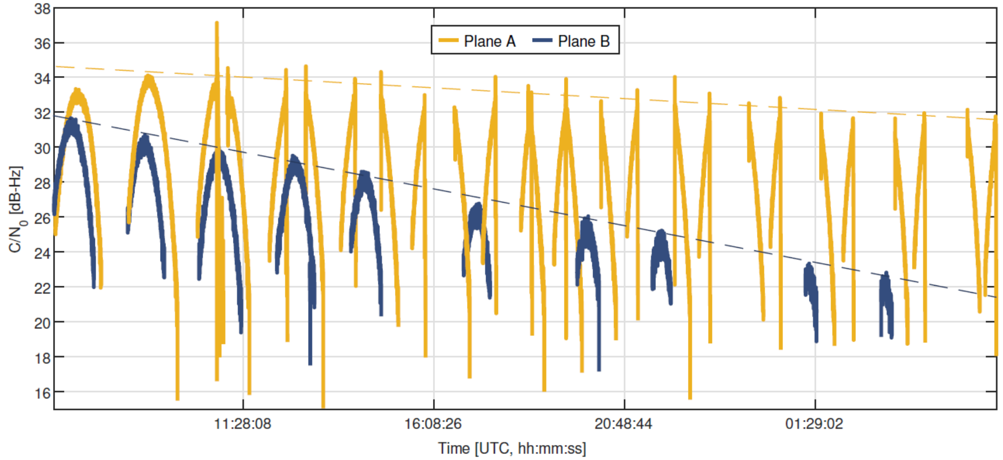
(a)



(c)

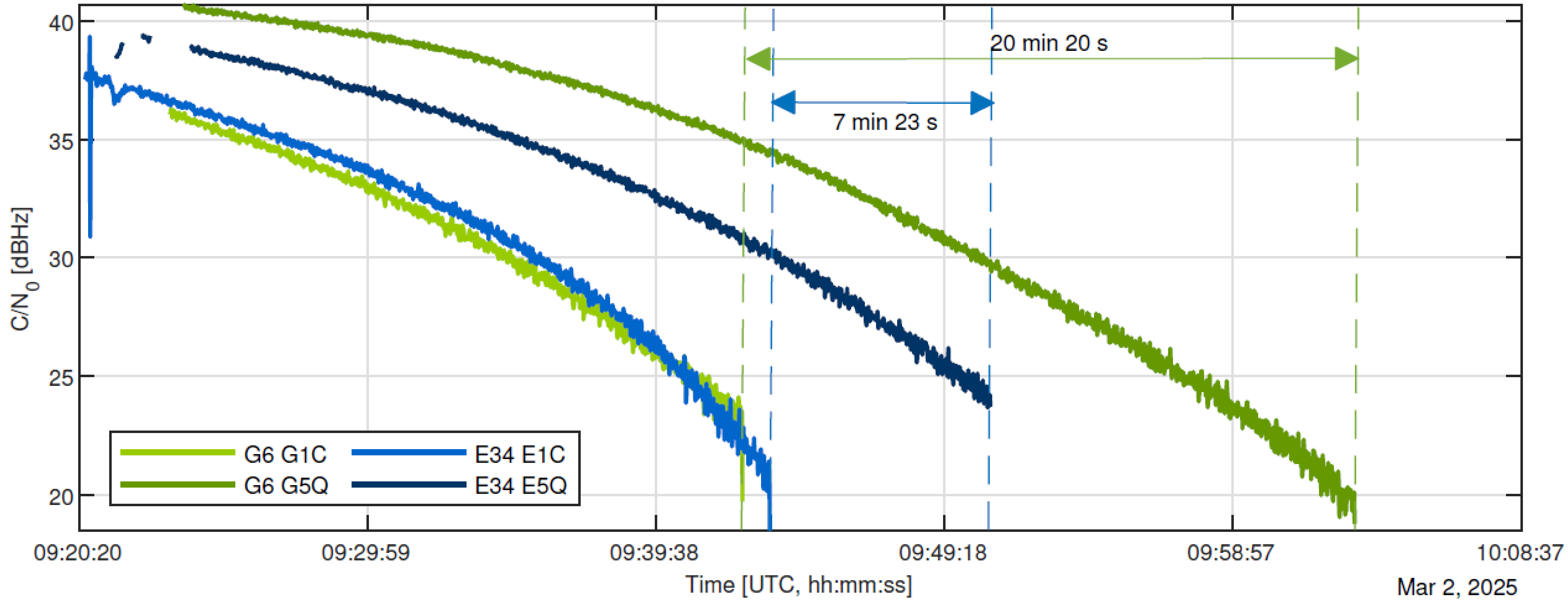


(b)



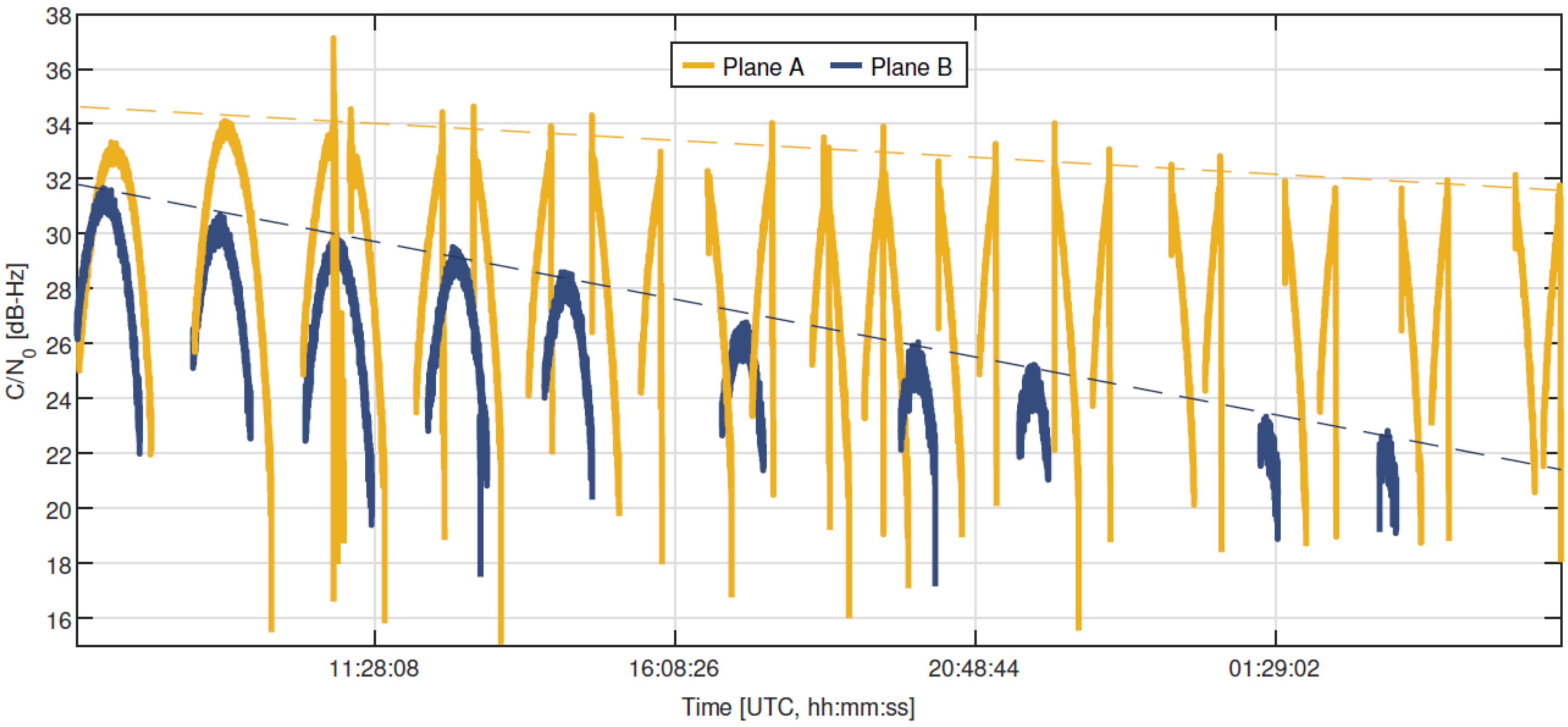
Observations (a)

- GPS and Galileo L1/E1 and L5/E5a signals can be acquired, tracked, and used for navigation at the Moon – using both main lobes and side lobes.
- Measurements show good stability over time (except when Earth limb/ionosphere occultation is experienced) and low standard deviation, consistent with measurements from typical terrestrial receivers.
- L5/E5a offers higher C/N_0 and longer trackable signals than L1/E1. This has a direct impact on signal and least squares solutions availability



Observations (b)

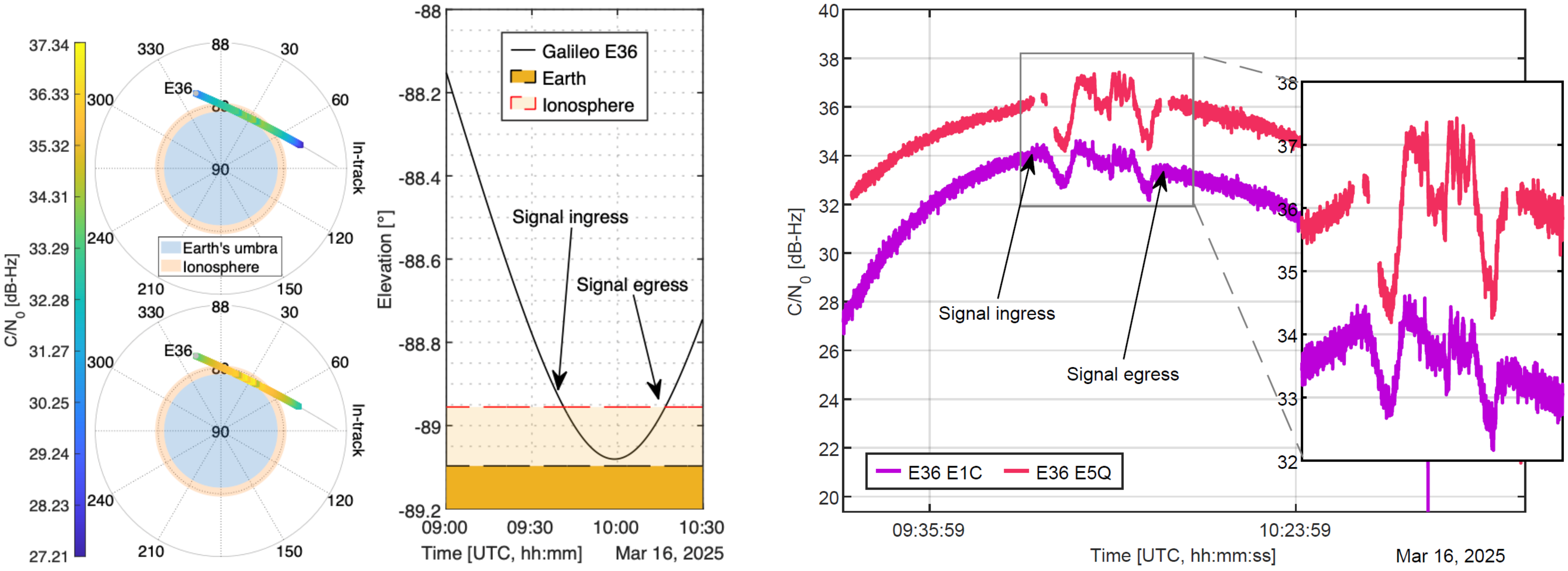
- GNSS satellite phasing due to orbital planes design significantly affects main lobe visibility, esp. for Galileo.
- Unprecedented experimental assessment (previously observed in different simulation scenarios)
- This partly contribute to a limited signal and least square solution availability on lunar surface



- Dashed curves highlight the decreasing trend over time by linearly interpolating peak C/N_0 observations
- Linear decrement (in dB scale) of C/No experienced over time
- Difficult to observe over short timespan

Observations (c)

- Ionospheric signature visible on C/N_0 time series (multi-frequency example in figure)
- Signal propagation transitions due to ionosphere were observed in several OP from transit to surface phase
- Signal tracking was kept stably by LuGRE payload, especially on L1/E1 band, but measurements reliability may be reduced



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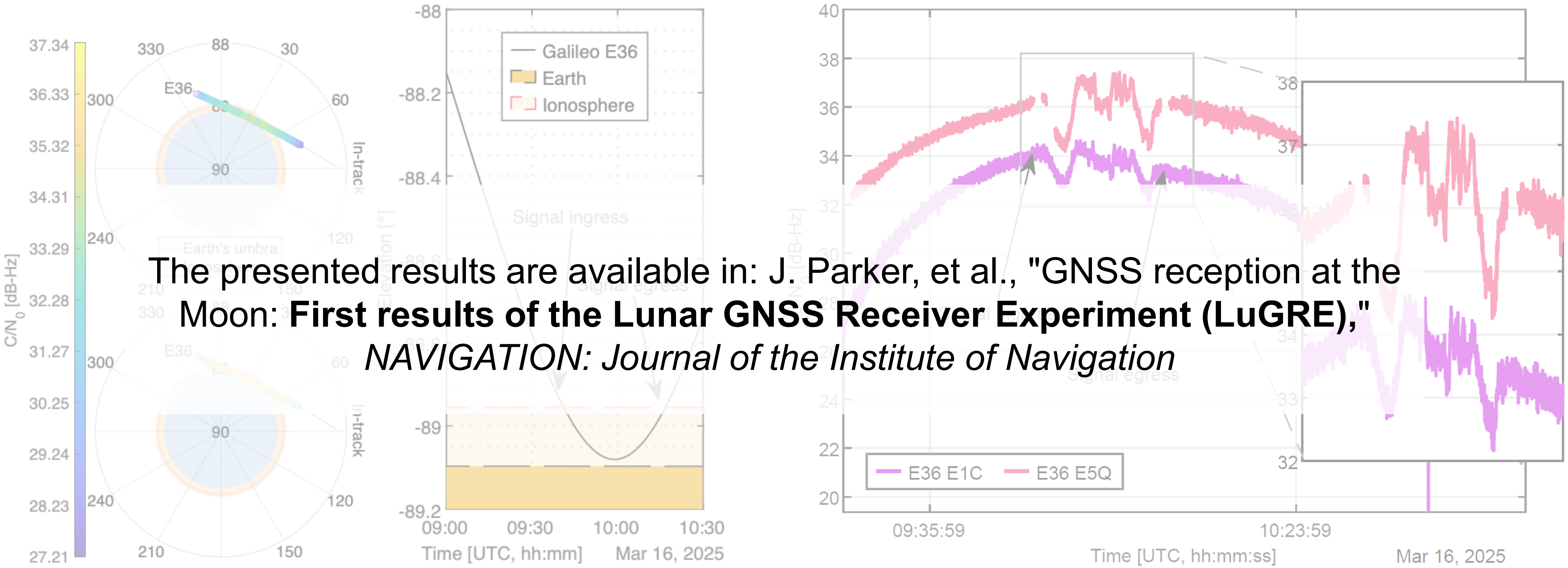


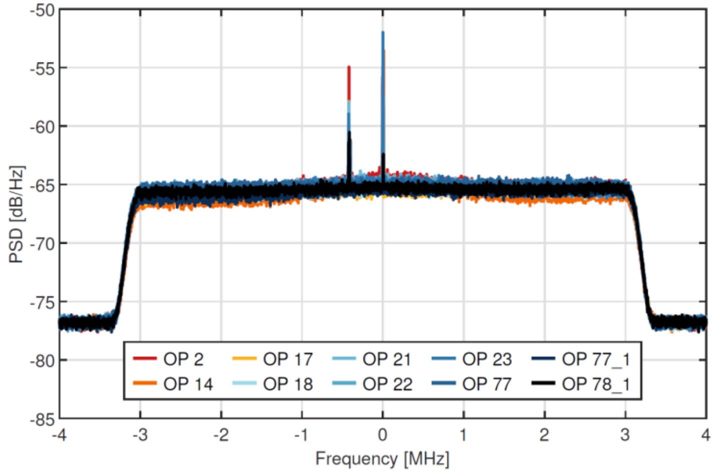
The presented results are available in: J. Parker, et al., "GNSS reception at the Moon: **First results of the Lunar GNSS Receiver Experiment (LuGRE),"** *NAVIGATION: Journal of the Institute of Navigation*

Post-processing IQ: Spectral Density

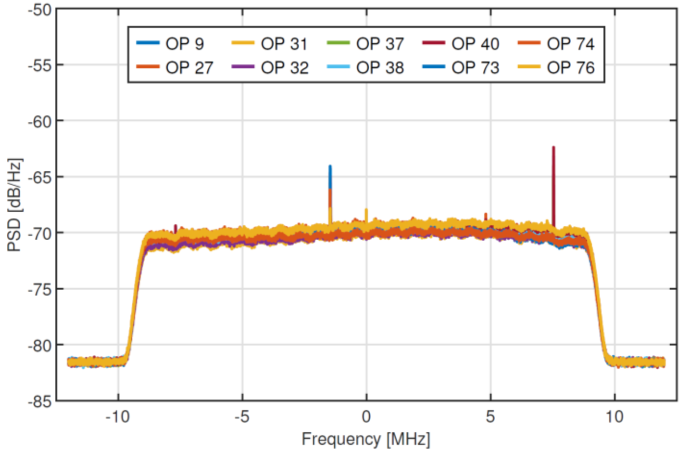
- LuGRE captured IQ samples during nearly all operations – 12s of samples total
- Configurable parameters:
  - Bands: L1/E1 only, L5/E5a only, dual-band
  - Sample rate: 8–12 Msps (L1/E1), 24 Msps (L5/E5a)
  - Quantization: 4–8 bits/sample
  - Duration: 200–800 ms (transit+surface) + 2000 ms (2x on surface)
- Executed immediately before or after real-time processing experiment
- Welch plots show spurious peak in both frequencies, likely caused by EMI
- Addition of cascading notch filter in postprocessing to exclude peak results in acquisition C/N_0 increase of <0.2 dB – shows that this peak does not significantly affect overall signal strength seen during operations.

IQS batches are part of public dataset

L1/E1



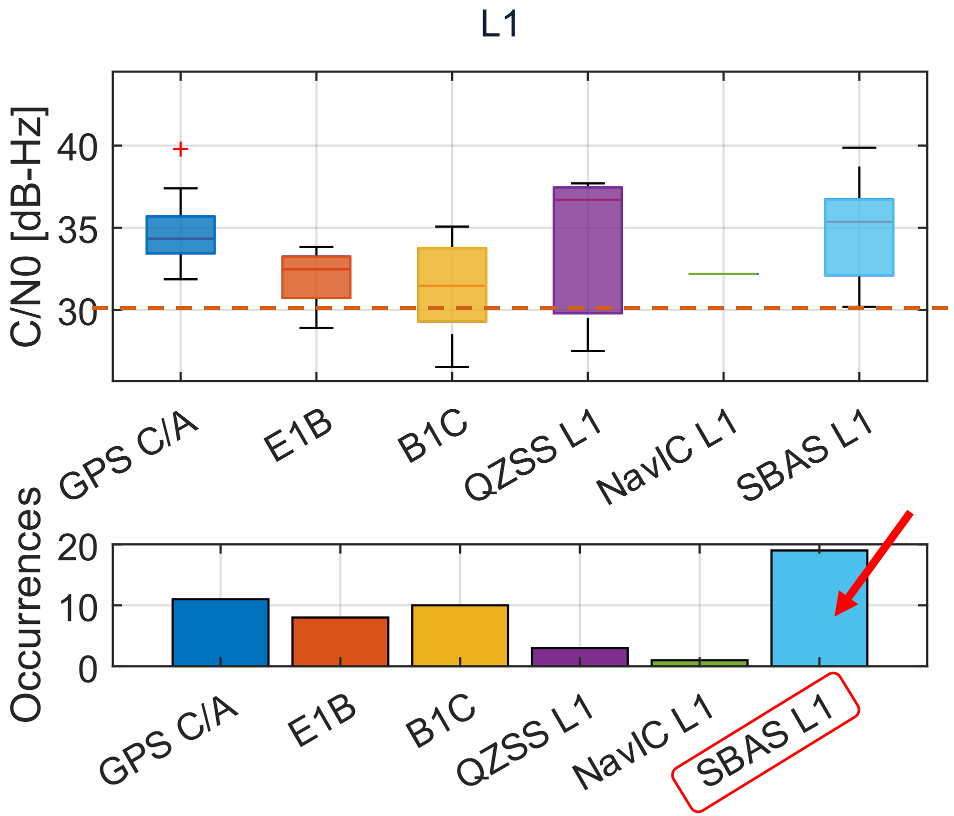
L5/E5a

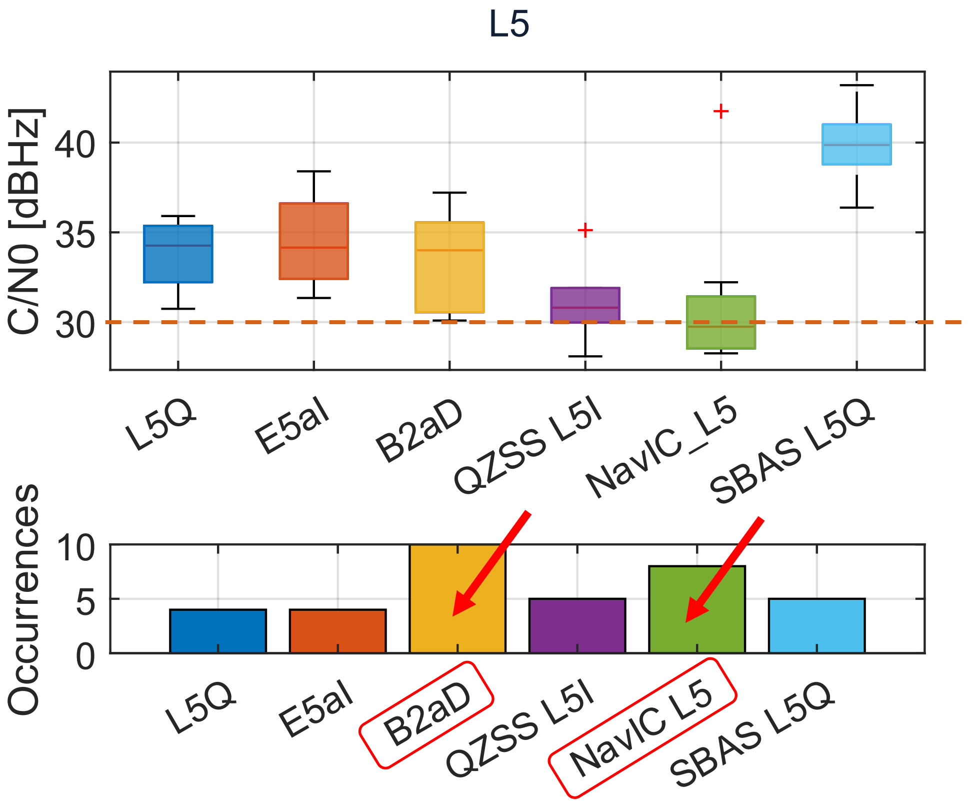


EMI peak can be removed via cascading notch filter; shows EMI has little impact on C/N_0

Signal, PRN	Est. C/N_0 (dB-Hz)			Doppler Shift (kHz)			C/N_0 Increase due to Filtering (dB)
	IQS	ACQ	Filtered IQS	IQS	ACQ	Filtered IQS	
GPS L1 C/A, 18	39.21	40.81	39.30	-10.800	-12.448	-10.800	0.09
GPS L1 C/A, 24	37.03	40.63	37.19	-3.100	-4.7477	-3.100	0.16

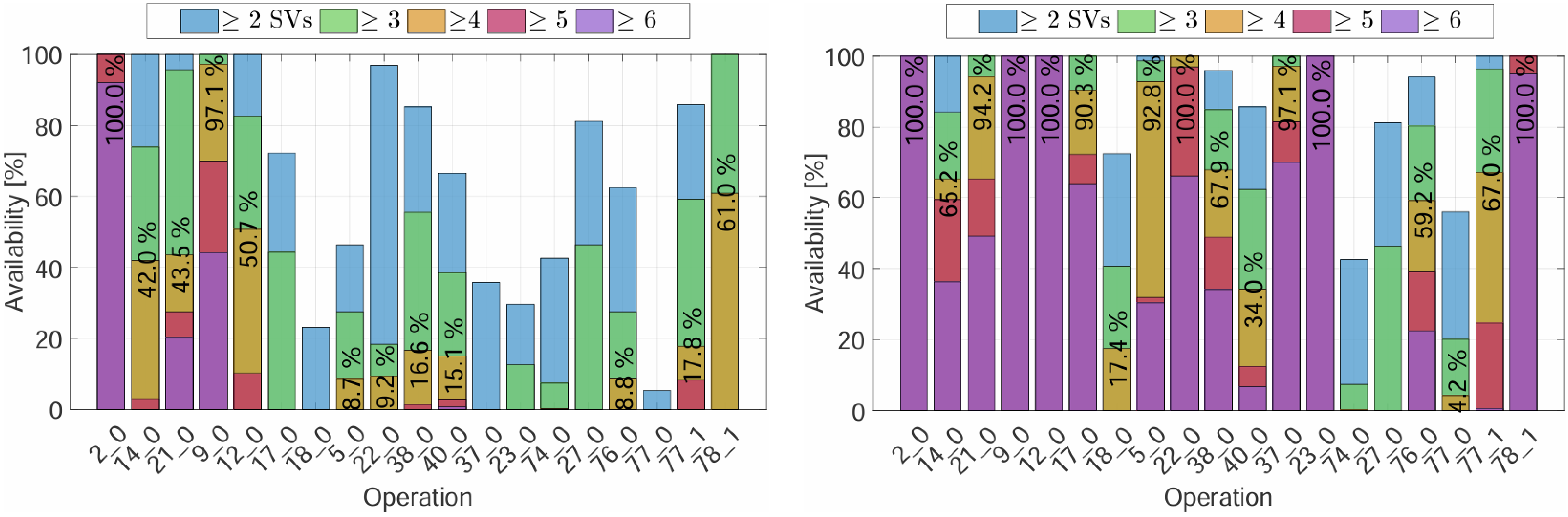
Post-processing IQ: Signals Acquisition





- Over all Ops, relatively strong signals from all the tested systems
- Statistical characterization of C/N_0 is still weak due the limited occurrences of signals and data (insufficient statistics)
- SBAS L1, B2aD, and NavIC L5 showed a remarkable number of occurrences.

Post-processing IQ: Signals Acquisition

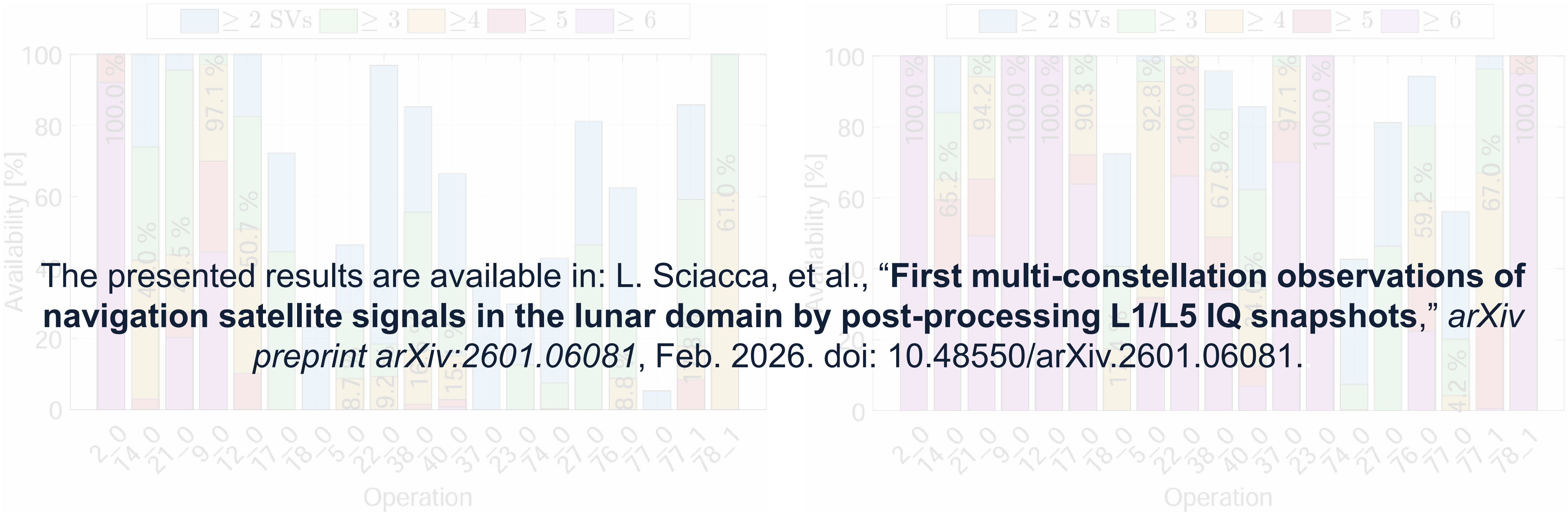


(a) GPS + Galileo

(b) GNSS + RNSS + SBAS

- Availability of signals from distinct GNSS satellites above the C/N0 threshold. **Percentages are shown for *n*≥4.**
- Expanding the no. of constellations is proved to have a **remarkable impact on availability**

Post-processing IQ: Signals Acquisition



(a) GPS + Galileo

(b) GNSS + RNSS + SBAS

The presented results are available in: L. Sciacca, et al., “**First multi-constellation observations of navigation satellite signals in the lunar domain by post-processing L1/L5 IQ snapshots**,” *arXiv preprint arXiv:2601.06081*, Feb. 2026. doi: 10.48550/arXiv.2601.06081.

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- Expanding the no. of constellations is proved to have a **remarkable impact on availability**

LuGRE: Lessons Learned

From first lunar GNSS demonstration to operational lunar PNT design

01	**Signals are usable**	GPS and Galileo L1/L5 were acquired and tracked at lunar distance and on the surface; side-lobes improve availability and continuity.
02	**Design for availability**	Multi-constellation and multi-frequency reception is a major gain; L5/E5a offers better C/N0, wider main-lobes , and frequency diversity.
03	**Protect the link budget**	At lunar distance, small C/N0 losses can remove signals. Build margin, calibrate the full payload link, and investigate discrepancies.
04	**Aiding and timing matter**	Robust time, spacecraft ephemeris and GNSS ephemeris aiding speed acquisition; high-stability clocks become critical for demanding accuracy.
05	**Long Operations + Robust Filters**	Long-duration operations help warm-up, clock stability, tracking arcs and filter convergence; sparsity-robust navigation filters and up-to-date Earth-orientation parameters are essential.
	Operational heuristics	Warm up hardware when possible | acquire L5/E5a directly | reject grazing/outlier measurements | fuse GNSS with complementary navigation sources

Bottom line

GNSS at the Moon works but robust use depends on link margin, availability, aiding and filtering.

Source: Parker et al., NAVIGATION, 2026, Sec. 6 Discussion.

(Credits: Firefly Aerospace)

06

LUGRE LEGACY

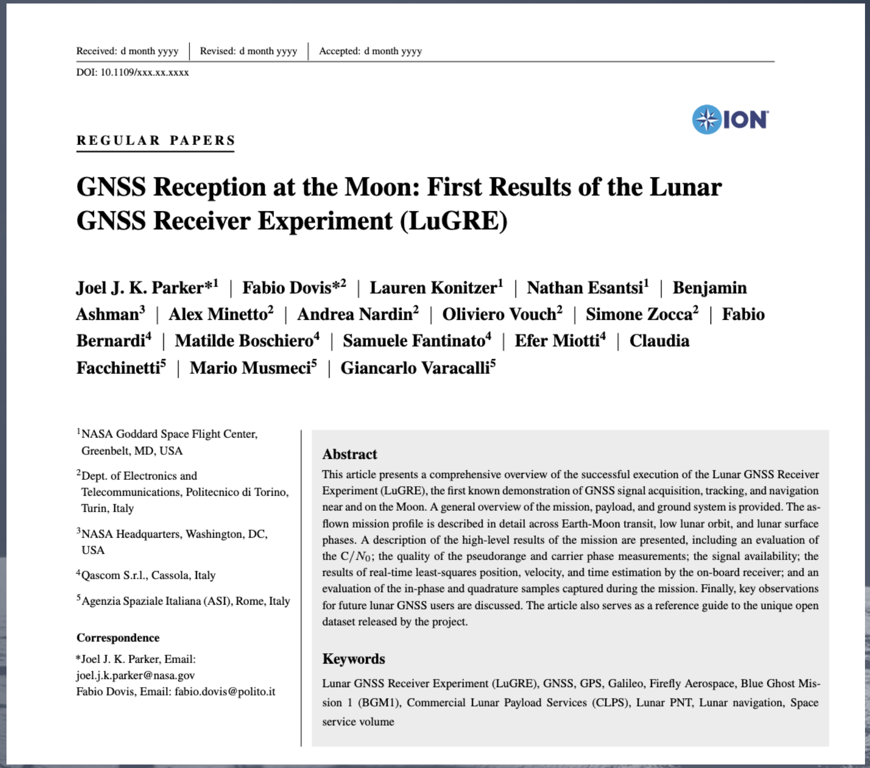
OPEN DATASET AND PROCESSING TOOL

Politecnico di Torino
Department of Electronics and Telecommunications

LuGRE Overview and Results Paper

Most of the results, observations, and lessons learned described before can be found in the LuGRE reference paper.

Find it here:



Received: d month yyyy | Revised: d month yyyy | Accepted: d month yyyy

DOI: 10.1109/xxx.xx.xxxx

REGULAR PAPERS

GNSS Reception at the Moon: First Results of the Lunar GNSS Receiver Experiment (LuGRE)

Joel J. K. Parker*[1] | Fabio Dovis*[2] | Lauren Konitzer[1] | Nathan Esantsi[1] | Benjamin Ashman[3] | Alex Minetto[2] | Andrea Nardin[2] | Oliviero Vouch[2] | Simone Zocca[2] | Fabio Bernardi[4] | Matilde Boschiero[4] | Samuele Fantinato[4] | Efer Miotti[4] | Claudia Facchinetti[5] | Mario Musmeci[5] | Giancarlo Varacalli[5]

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Abstract

This article presents a comprehensive overview of the successful execution of the Lunar GNSS Receiver Experiment (LuGRE), the first known demonstration of GNSS signal acquisition, tracking, and navigation near and on the Moon. A general overview of the mission, payload, and ground system is provided. The as-flown mission profile is described in detail across Earth-Moon transit, low lunar orbit, and lunar surface phases. A description of the high-level results of the mission are presented, including an evaluation of the C/N_0; the quality of the pseudorange and carrier phase measurements; the signal availability; the results of real-time least-squares position, velocity, and time estimation by the on-board receiver; and an evaluation of the in-phase and quadrature samples captured during the mission. Finally, key observations for future lunar GNSS users are discussed. The article also serves as a reference guide to the unique open dataset released by the project.

Keywords

Lunar GNSS Receiver Experiment (LuGRE), GNSS, GPS, Galileo, Firefly Aerospace, Blue Ghost Mission 1 (BGM1), Commercial Lunar Payload Services (CLPS), Lunar PNT, Lunar navigation, Space service volume

What it contains

- It brings together the mission context and profile, payload architecture, ground operations, collected data, signal-strength results, measurement quality, signal availability, onboard PVT performance, I/Q sample characterization, and lessons learned for future lunar GNSS users.

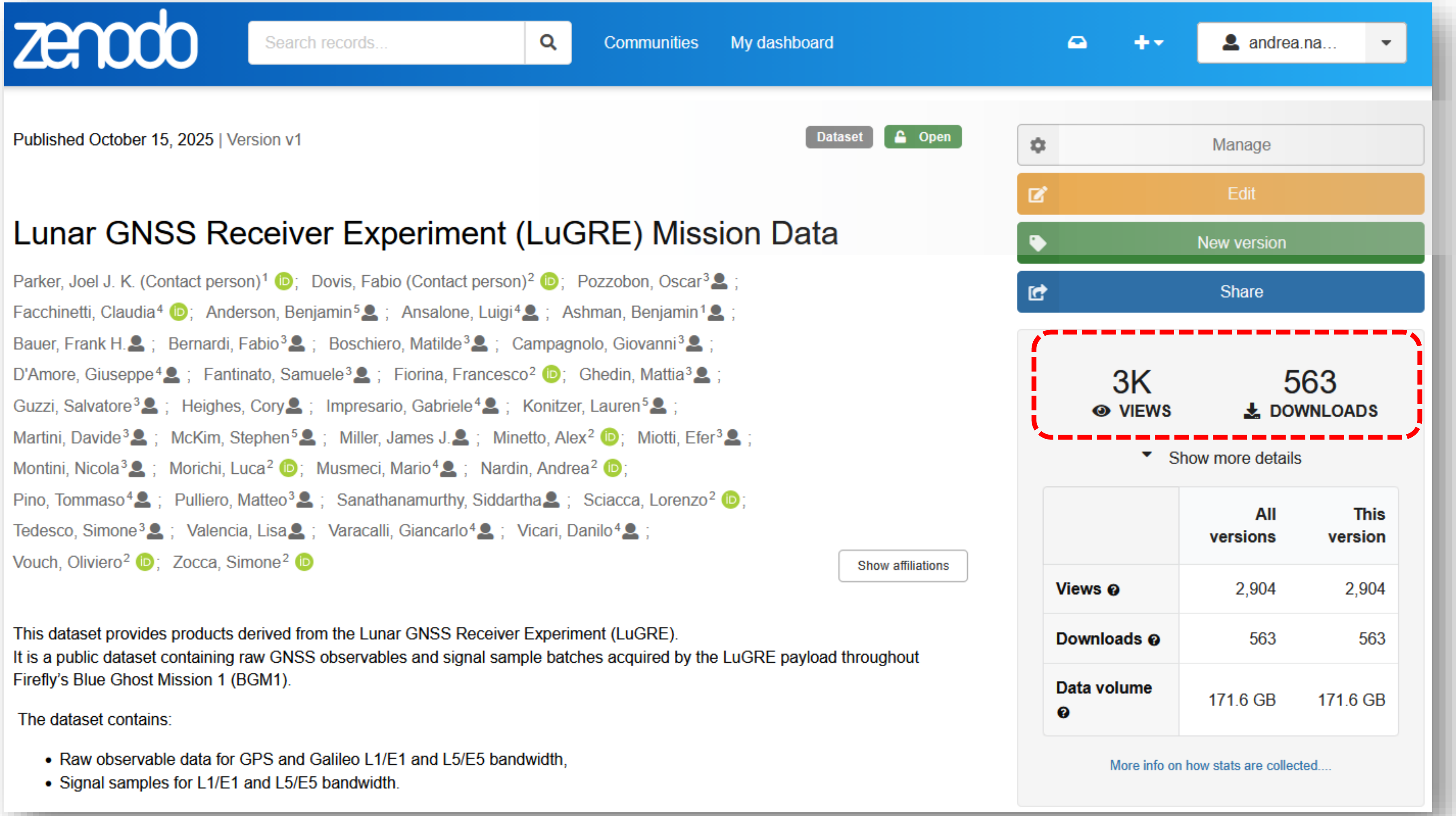
Value for the community

- It serves as both a first-results paper and a guide to the LuGRE open data set, enabling researchers to reproduce and build on the mission results for future cislunar and lunar PNT studies.

LuGRE Reference Paper

Parker, J. J. K., Dovis, et al. (2026). *GNSS reception at the Moon: First results of the Lunar GNSS Receiver Experiment (LuGRE).* Institute of Navigation Mar 2026, 73 navi.756; DOI: 10.33012/navi.756

LuGRE Data (Released on Oct. 15 2025)



This dataset provides products derived from the Lunar GNSS Receiver Experiment (LuGRE).
It is a public dataset containing raw GNSS observables and signal sample batches acquired by the LuGRE payload throughout Firefly's Blue Ghost Mission 1 (BGM1).

The dataset contains:

- Raw observable data for GPS and Galileo L1/E1 and L5/E5 bandwidth,
- Signal samples for L1/E1 and L5/E5 bandwidth.

	All versions	This version
Views	2,904	2,904
Downloads	563	563
Data volume	171.6 GB	171.6 GB

More info on how stats are collected....

Open Dataset Contains:

TLM: ACQ, EPH, NAV, RAW, CLK

IQS

1. Raw GNSS observables (tracking)
2. Acquisition observables
3. Navigation Solutions (least-squares PVT)
4. I/Q digital signal samples

Find them here:

LuNART Open Project

The tool that produced most of these plots is available
as open-source project on GitHub!

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1859
Department of Electronics and Telecommunications

- Quick GNSS experiments and reporting capability
- Probing of LuGRE open data for GNSS scientists, young engineers and students
- New experiments can be easily included by the community (modularity)
- Educational-oriented for training students on GNSS use in space
- Open framework for technical/scientific assessment of raw GNSS observables and I/Q data

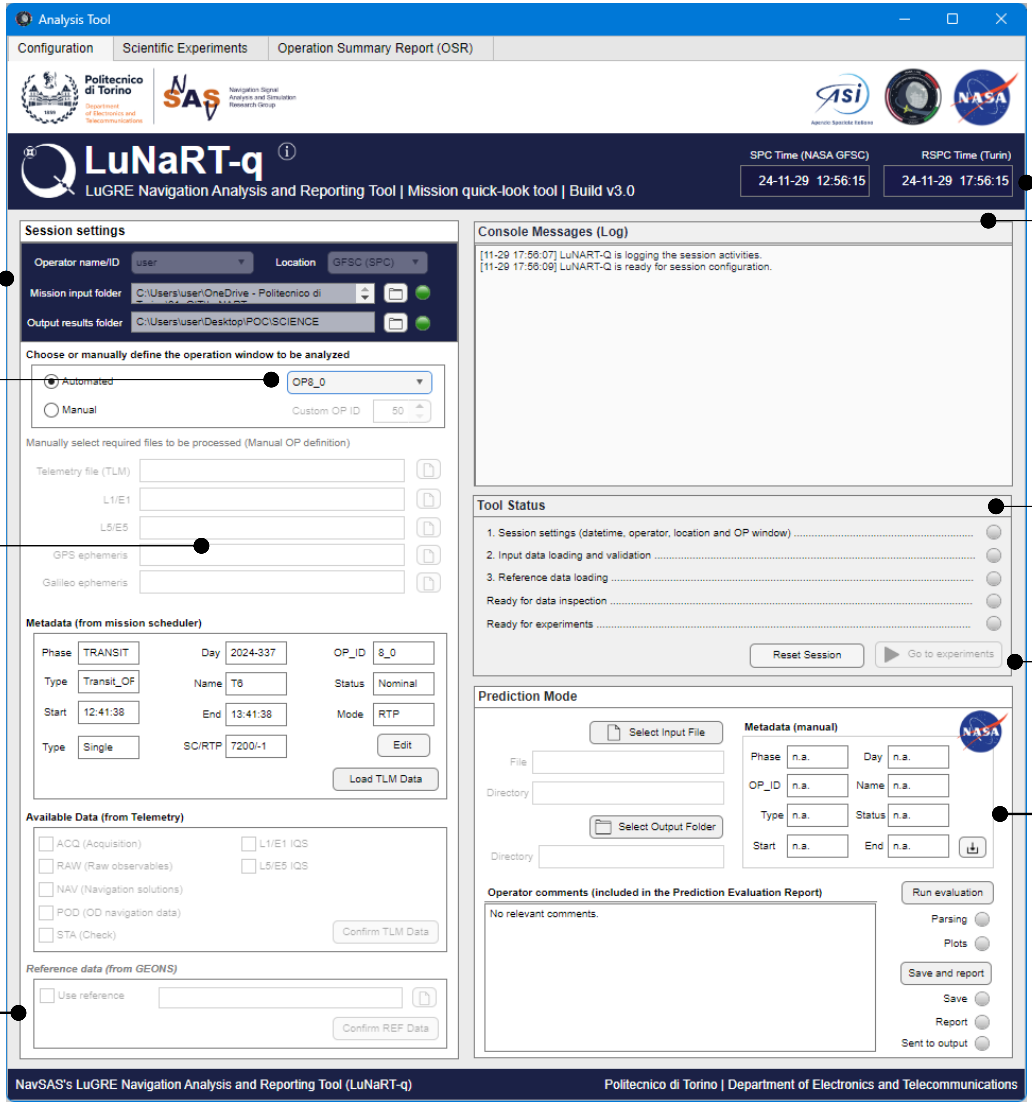
git + GitHub

LuNART-q

Find it here:

LuGRE

LuNART Session Configuration Tab



Session settings

Operations List (automated from mission scheduler)

Custom operation Files paths (manual)

GEONS preference data

Real-time reference clocks (SPC and RSPC)

Real-time log panel

Tool readiness status

Reset and experiment

Prediction Evaluation Mode (NASA only)

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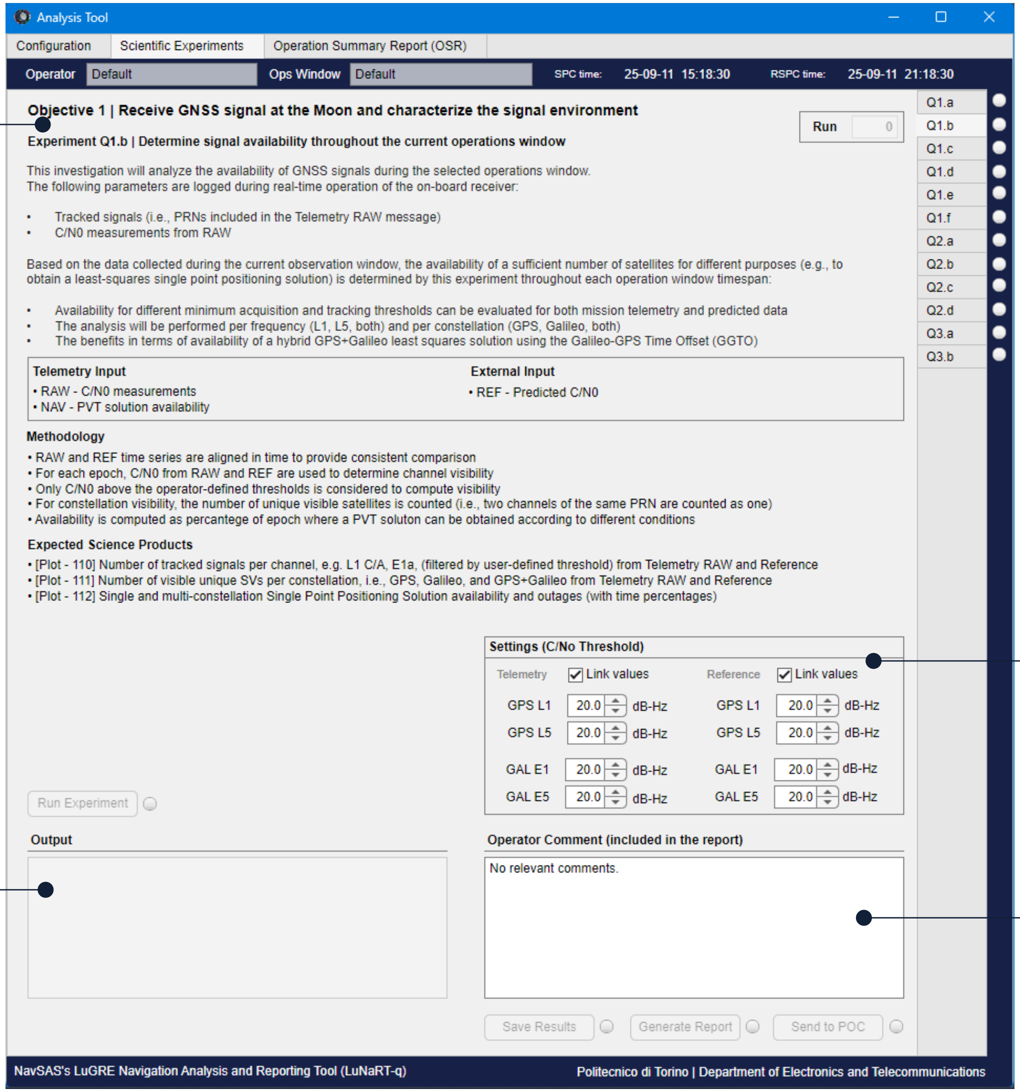
Quick Experiments Tab(s)

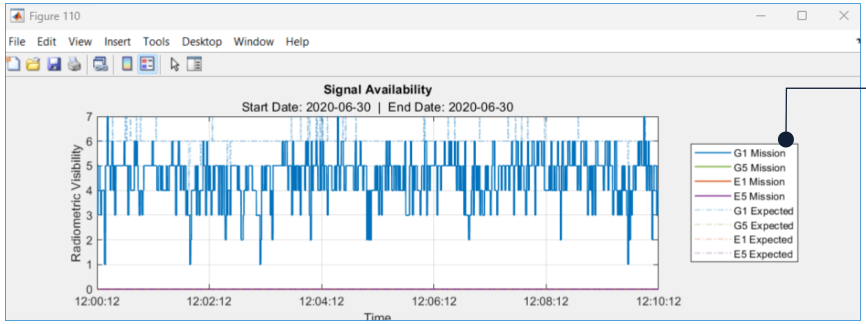


Experiment briefing

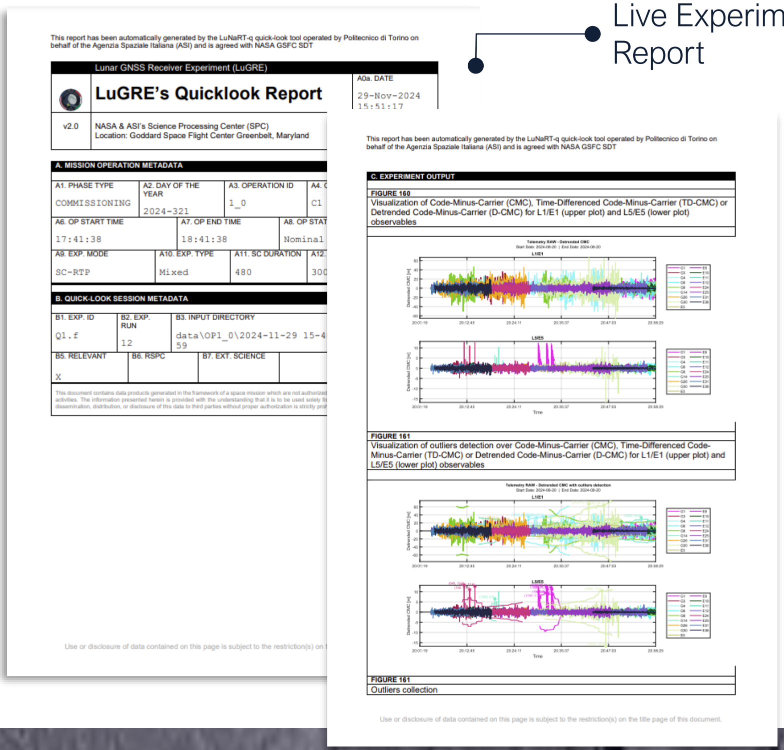
Output of the software routines

Configuration panel (if required)

Comments of the science team operator



Output results



Live Experimental Report

LuGRE Data & Code Access

There's still so much to explore: dive into the data and code and build on this work!

LuGRE White Paper

Parker, J. J. K., Dovis, et al. (2025). *GNSS reception at the Moon: First results of the Lunar GNSS Receiver Experiment (LuGRE).*

https://doi.org/10.33012/navi.756

LuGRE Open Dataset

zenodo

https://doi.org/10.5281/zenodo.16411686

Dataset Processing Tool: LuNaRT-q

git

https://github.com/NavsasPolito/LuNART

Read → **Download** → **Code**

The Fantastic LuGRE team

Credit: Firefly Aerospace

Shadow of BGM1 on the lunar surface
2 Mar 2025

Andrea **NARDIN**, Ph.D.

Researcher & Assistant Professor

E-mail: andrea.nardin@polito.it

Politecnico di Torino

Dept. of Electronics and Telecommunications

Thank you for your attention

Image Credit: Firefly Aerospace

Backup

LuGRE Bibliography

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