NASA & ESA Space User Update: Advancing GNSS Interoperability for Space Use and Lunar PNT

Frank H. Bauer, FBauer Aerospace Consulting Services (FB-ACS)
Werner Enderle, Head of ESA /ESOC's – Navigation Support Office

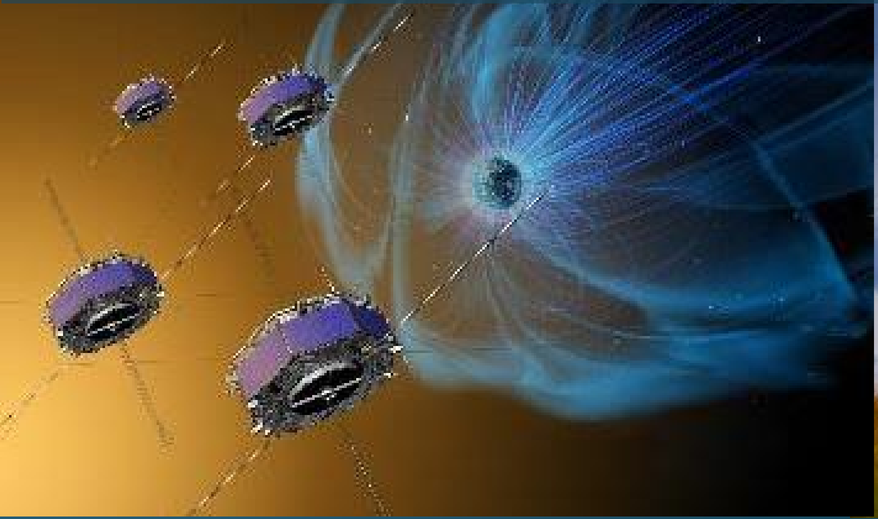
62nd Meeting of the CGSIC
September 20, 2022

Lunar Exploration

- The Moon is again a top space exploration priority
- Current lunar exploration efforts more diverse and collaborative
  - >80 national space agencies
  - numerous private companies and partnerships
- Over 20 nations have signed the Artemis Accords to coorperate in the exploration and use of the Moon
- International Space Exploration Coordination Group (ISECG) currently comprised of 27 international space agencies
  - Global Exploration Roadmap (GER) identified 14 planned Moon missions
  - 100-m performance target for precision landing
- International space agencies are developing lunar PNT capabilities **NOW**; need to ensure these are interoperable, compatible and available to all
- GNSS will play a meaningful role in Lunar PNT

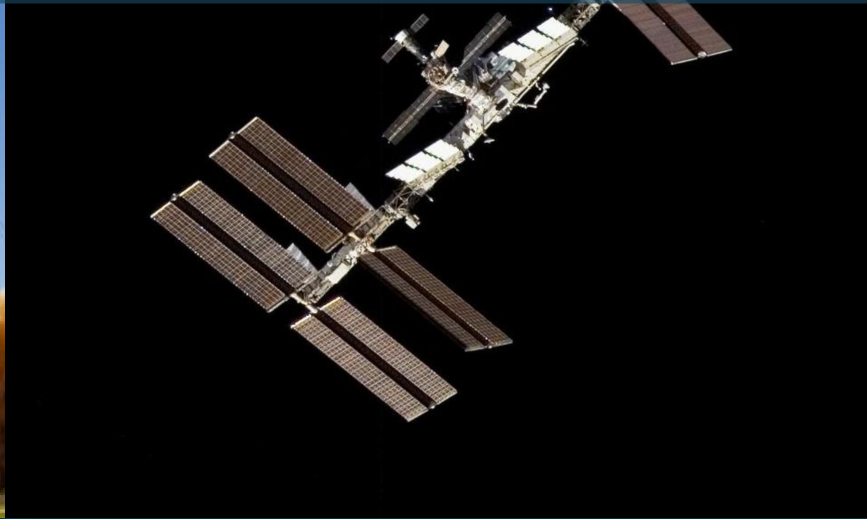
Advancing Interoperability: Enabling Lunar PNT via GNSS

Real-Time On-Board Nav



Launch Vehicle Range Ops

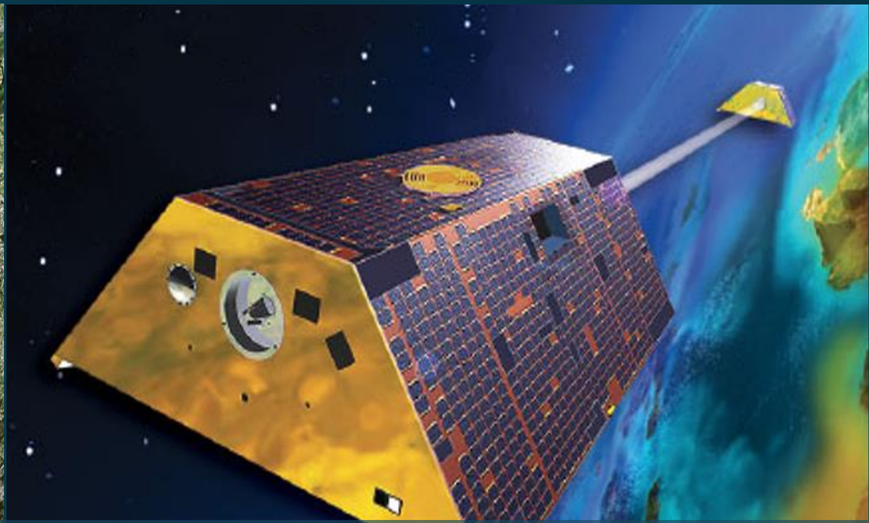
Attitude Determination



Active Space Uses of GNSS at NASA

Time Synchronization

Earth Sciences

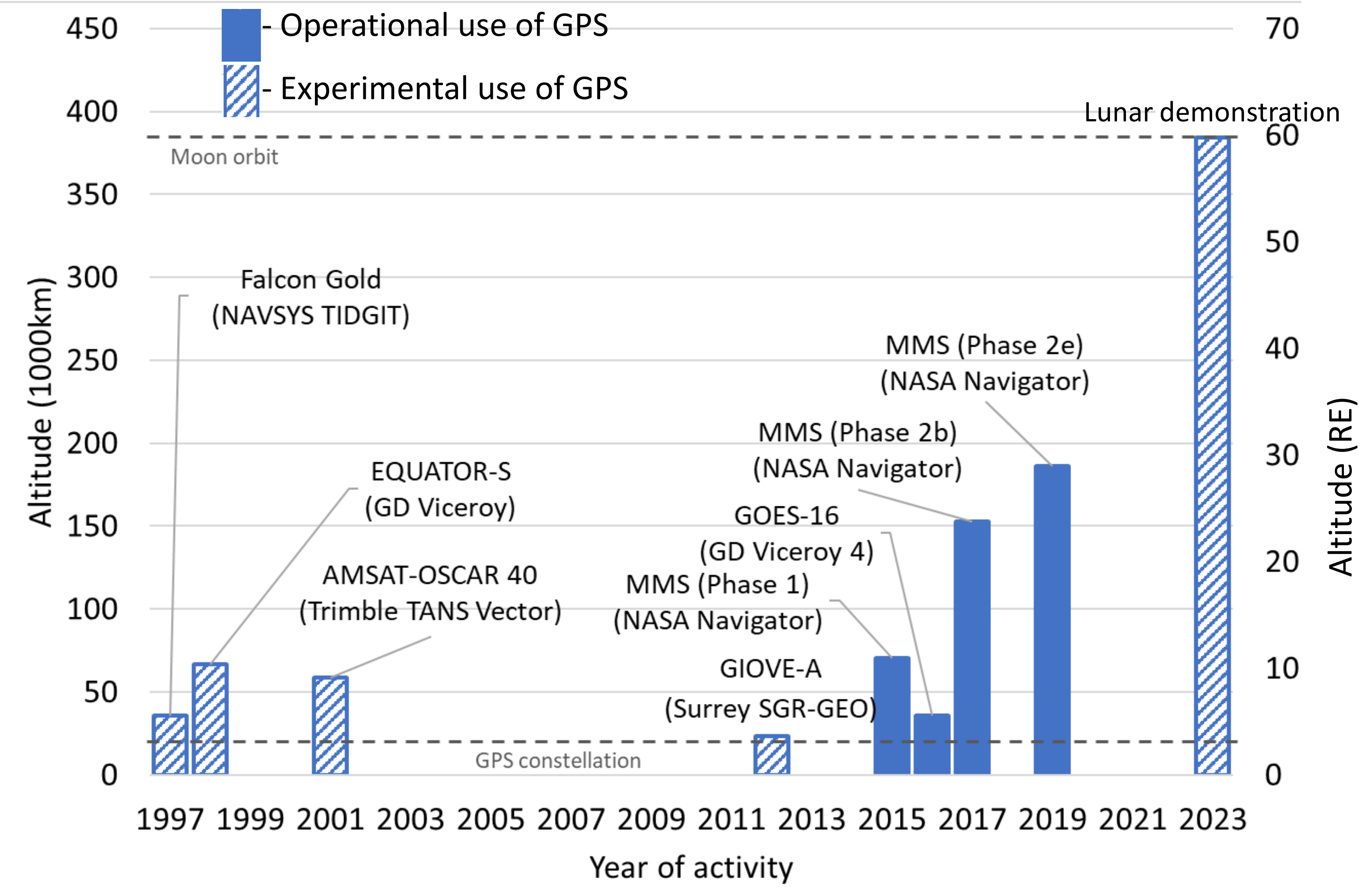


Precise Orbit Determination

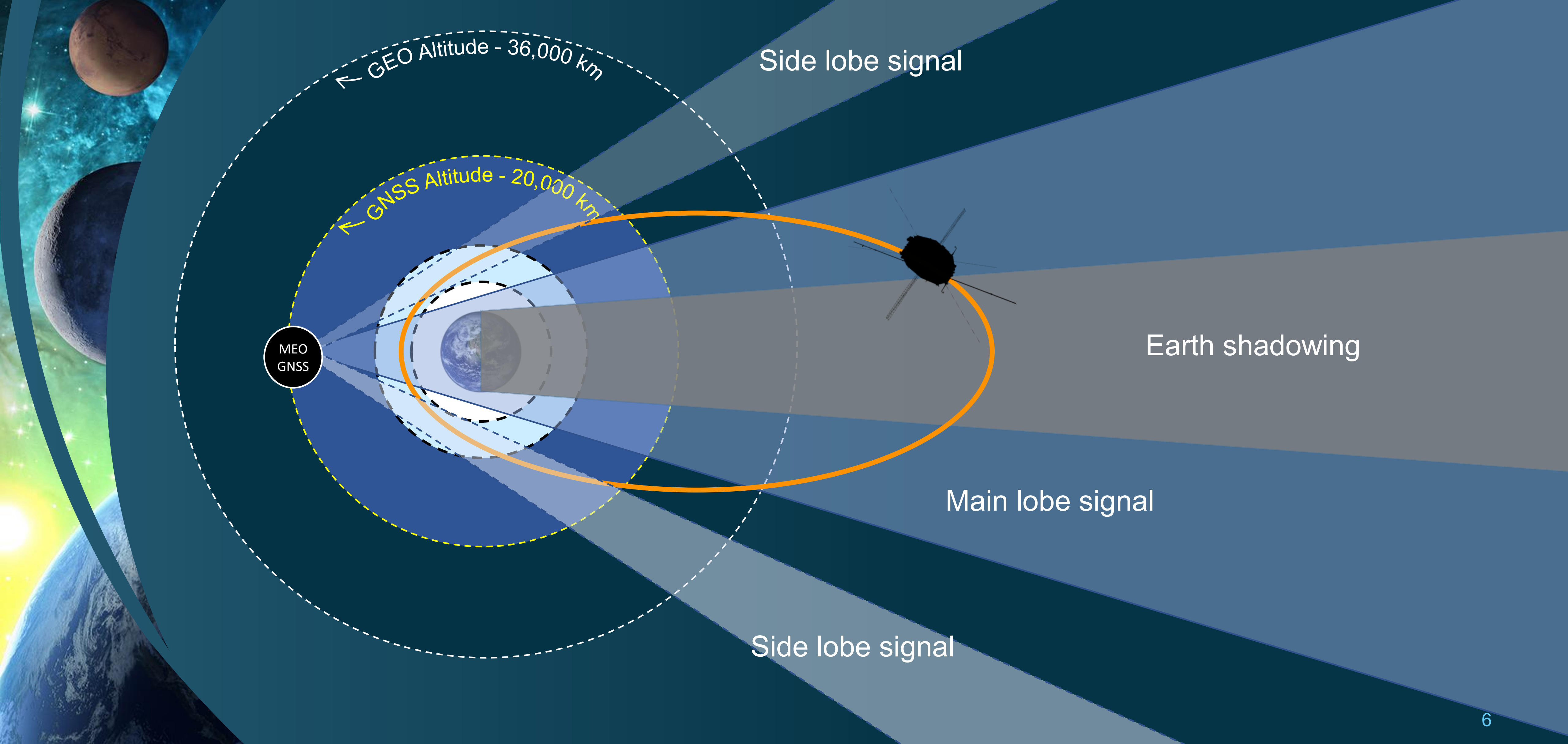
Development of High Altitude GNSS

Transition from experimentation to operational use, and move into cislunar space:

- **1990s**: Early flight experiments—Equator-S, Falcon Gold
- **2000**: Reliable GPS at GEO w/ bent pipe architecture
- **2001**: AMSAT OSCAR-40 mapped GPS main and sidelobe signals
- **2015**: MMS employed GPS operationally at 76,000 km
- **2016–Present**: GOES-16/17/18 employs GPS operationally at GEO
- **2019**: MMS apogee raise to 50% lunar distance
- **2024: Lunar demonstration**



Signal Reception in the GNSS Space Service Volume (SSV)



Lunar Role of GNSS

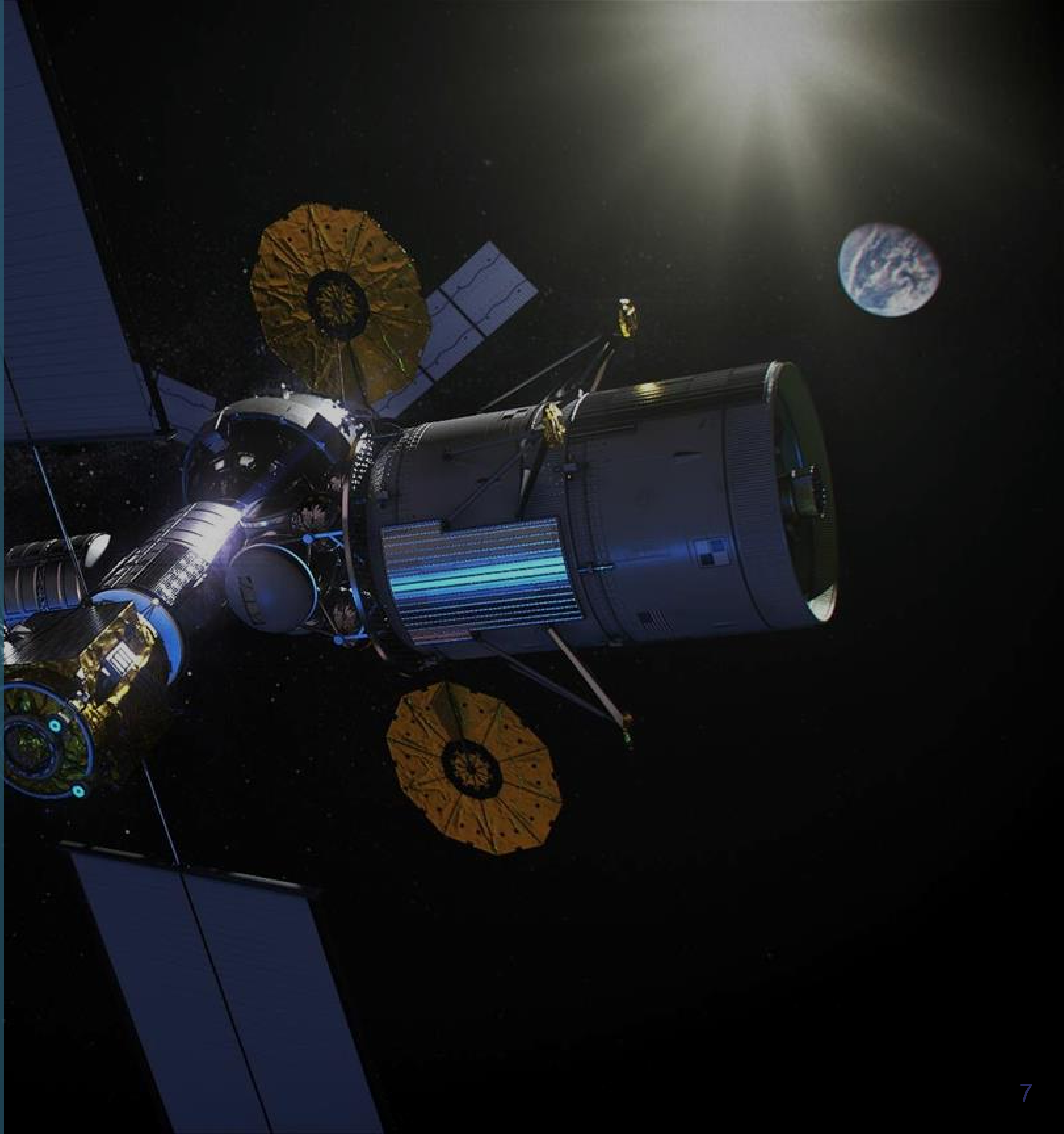
Critical technology gaps identified in the Global Exploration Roadmap:

- Autonomous Rendezvous & Docking, Proximity Operations, Target Relative Navigation
- Beyond-LEO crew autonomy

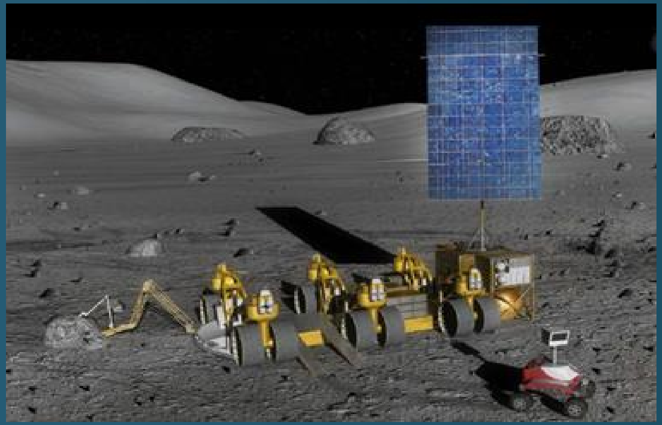
GNSS on lunar missions would:

- enable autonomous navigation
- reduce tracking and operations costs
- provide a backup/redundant navigation for human safety
- provide timing source for hosted payloads
- reduce risk for commercial development

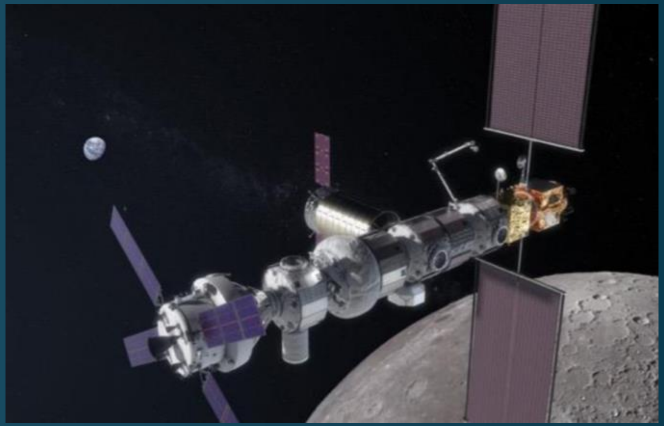
Recent advances in high-altitude GNSS can benefit and enable future lunar missions



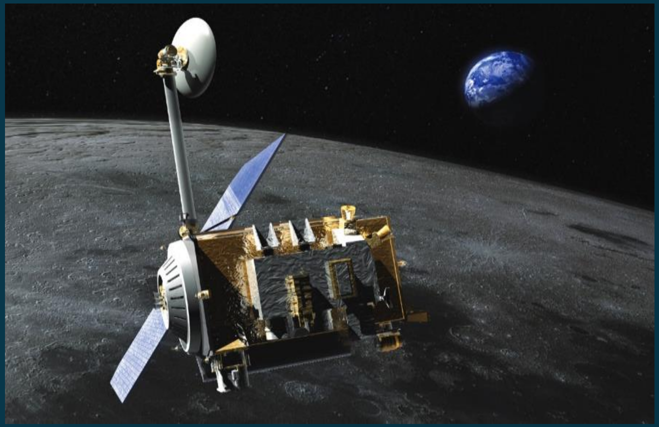
Lunar Exploration: Roles for GNSS



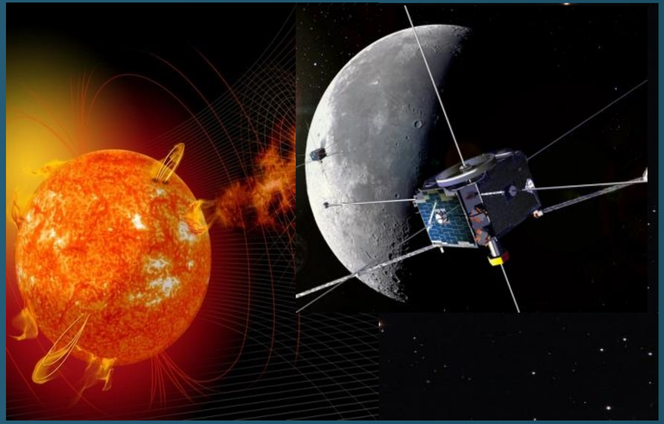
Lunar Surface Operations, Robotic Prospecting,& Human Exploration



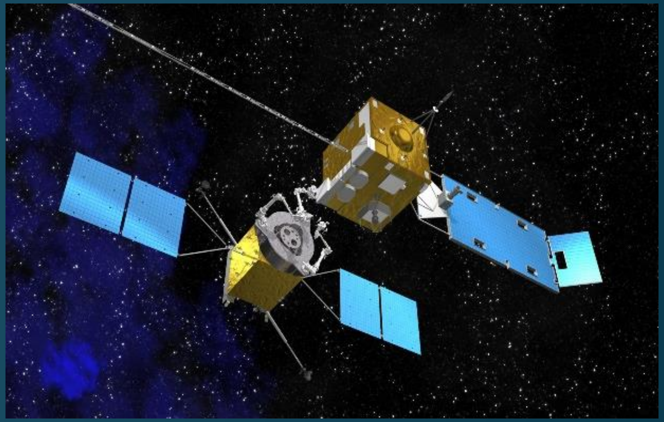
Human-tended Lunar Vicinity Vehicles (Gateway)



Robotic Lunar Orbiters, Resource & Science Sentinels



Earth, Astrophysics, & Solar Science Observations

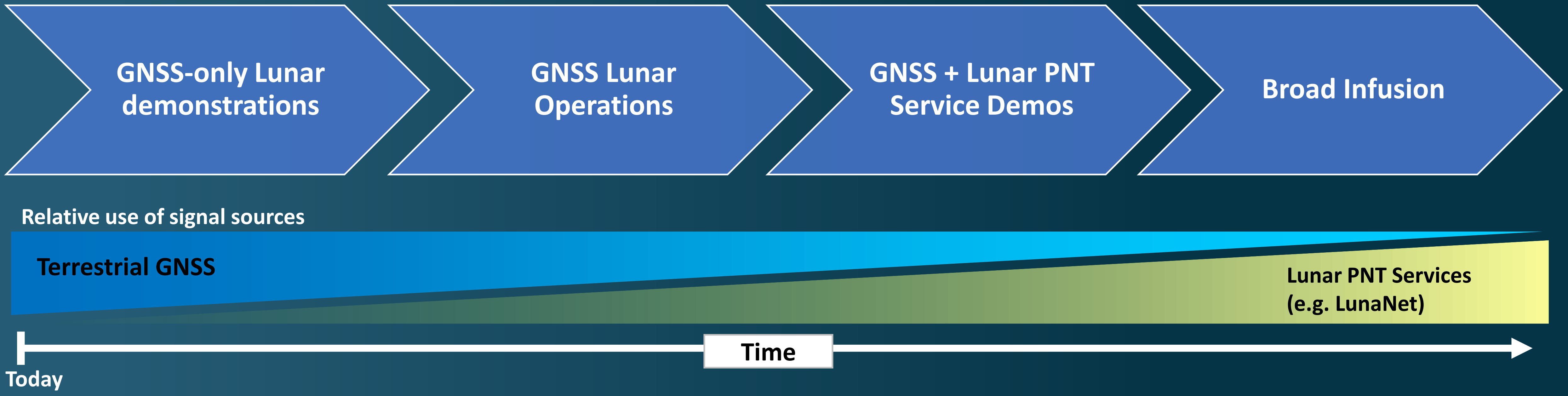


Satellite Servicing

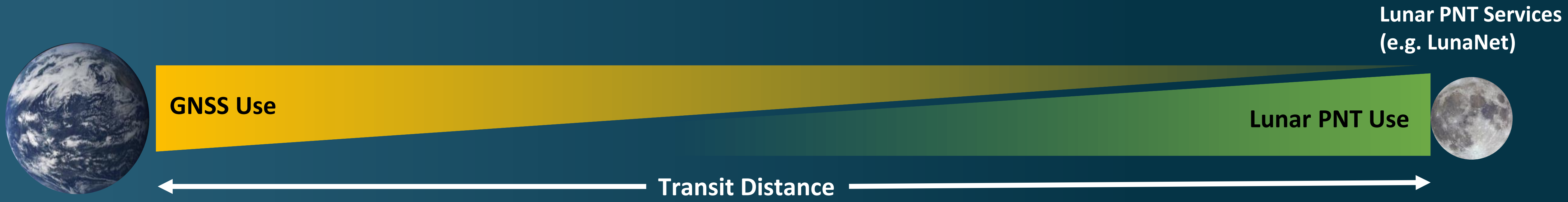
Lunar Exploration Infrastructure

Lunar PNT: From Terrestrial GNSS to an Earth-Moon PNT System of Systems

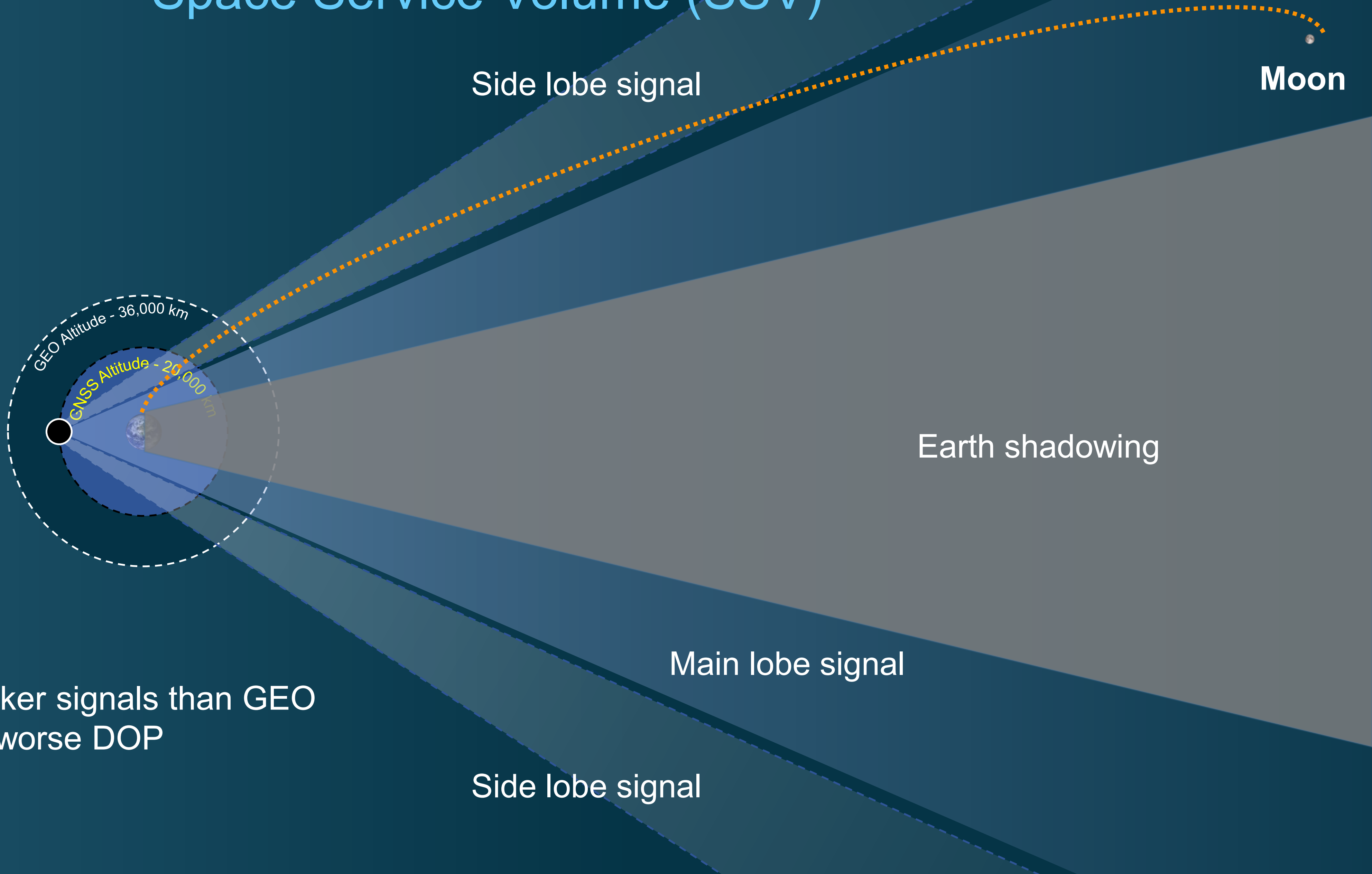
Phased Expansion of Lunar PNT



Transit use of GNSS and Lunar PNT Services



Signal Reception **beyond** the GNSS Space Service Volume (SSV)

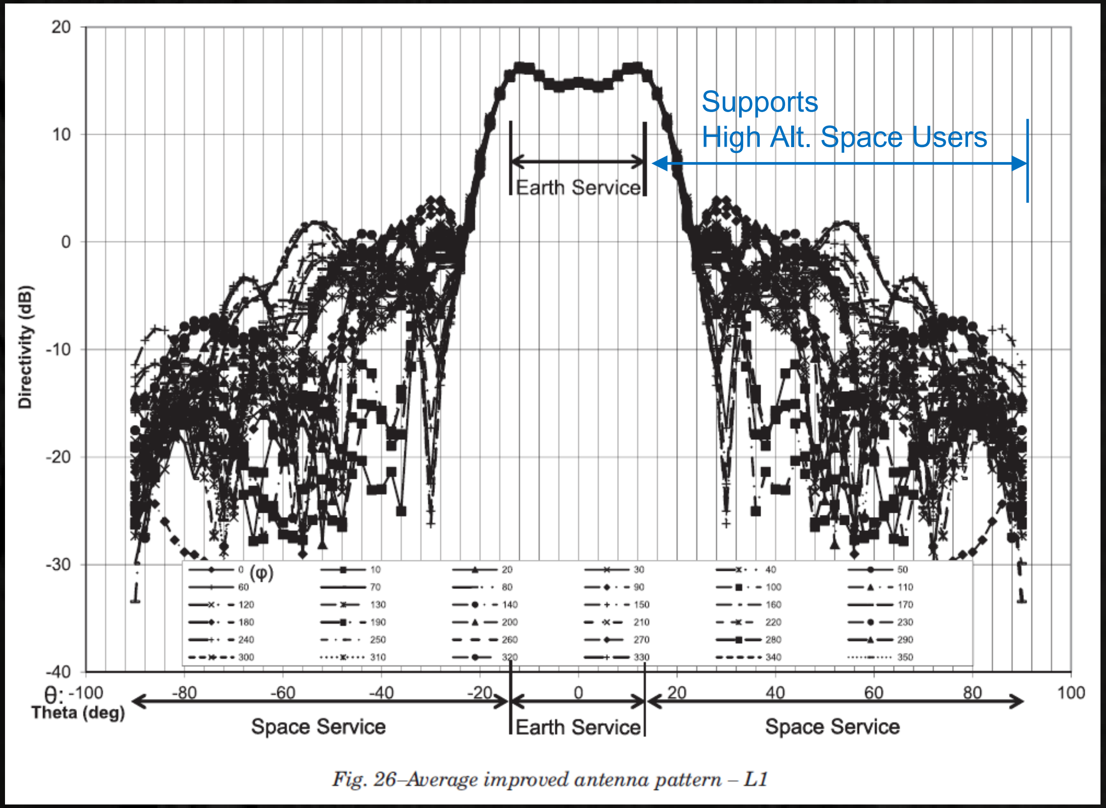


Challenges:

- >30x weaker signals than GEO
- 10–100x worse DOP

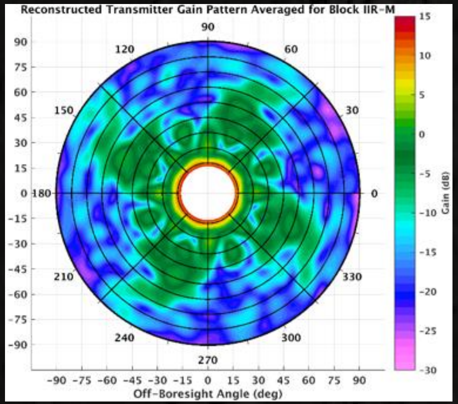
Enabling Lunar PNT:
GPS Initiatives

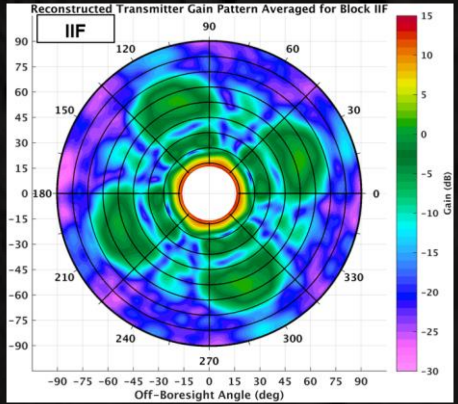
- **GPS III Space Service Volume**
  - Stabilized main lobe signal with spillover to support high-alt. users
- **NASA-USAF Memorandum of Understanding**
  - Signed in 2017 to ensure SSV signal continuity for future space users
  - Provides for release of antenna data + NASA representative in the GPS IIIF procurement cycle
- **GPS data availability**
  - 2001: AO-40 initial gain pattern measurements
  - 2015: Initial IIR/IIR-M antenna gain pattern data release
  - 2018: GPS ACE flight-measured patterns released by NASA
  - Late 2020: IIR/IIR-M antenna gain pattern data (re-release)
  - Late 2020: GPS III SVN 74-77 phase center, group delay, and inter-signal bias data



Average L1 antenna pattern, GPS Block IIR-M

Source: Marquis, W.A., and Reigh, D.L. (2015) The GPS Block IIR and IIR-M Broadcast L-band Antenna Panel: Its Pattern and Performance. J Inst Navig, 62:329–347. doi: 10.1002/navi.123.





NASA GPS ACE Reconstructed Patterns for Block IIR-M (left) and IIF (right)

Source: https://doi.org/10.1002/navi.361

Enabling Lunar PNT: International Committee on GNSS (ICG)—A GNSS Interoperability Powerhouse

The United Nations ICG consists of the GNSS Service Providers Forum and four Working Groups (WG-S, WG-B, WG-C and WG-D).

WG-S
Systems, Signals and Services

Major Topics
- Spectrum compatibility
- Interference detection & mitigation
- Service interoperability
- Performance standards & monitoring

WG-B
Enhancement of GNSS
Performance, New Services and Capabilities

Major Topics
- Development of interoperable, multi GNSS SSV
- GNSS hosted search and rescue payloads
- Space weather and atmosphere modelling

Applications Subgroup

Space Use Subgroup (SUSG)

The WG-B SUSG is the body dedicated to representing needs of space users within ICG, including lunar
Work Plan includes
Work Packages WP1–WP5.

WG-D
Geodetic Reference, Time Reference and Applications

Major Topics
- ITRF, geodetic reference frame
- Time standards & multi constellation time offsets
- High Accuracy applications (PPP)

WG-C
Information Dissemination and Capacity Building

Major Topics
- Training and Seminars
- Information Material

(Subgroups of WG-S, WG-D, WG-C not shown.)

Enabling Lunar PNT: ICG WG-B Space Use Subgroup (SUSG) Terms of Reference

- As adopted 15 Apr 2021

  Objectives of Space Use Subgroup:
  - *Lead evolution of the Interoperable Multi-GNSS Space Service Volume including the use of GNSS for missions beyond the existing SSV (e.g. lunar).*
  - *Encourage developments of space-based user equipment and emerging user community.*
  - *Encourage coordination with Interagency Operations Advisory Group (IOAG) and International Space Exploration Coordination Group (ISECG).*
  - *Encourage development of new services and augmentations beneficial to space users.*
  - *Promote space user community needs within ICG.*

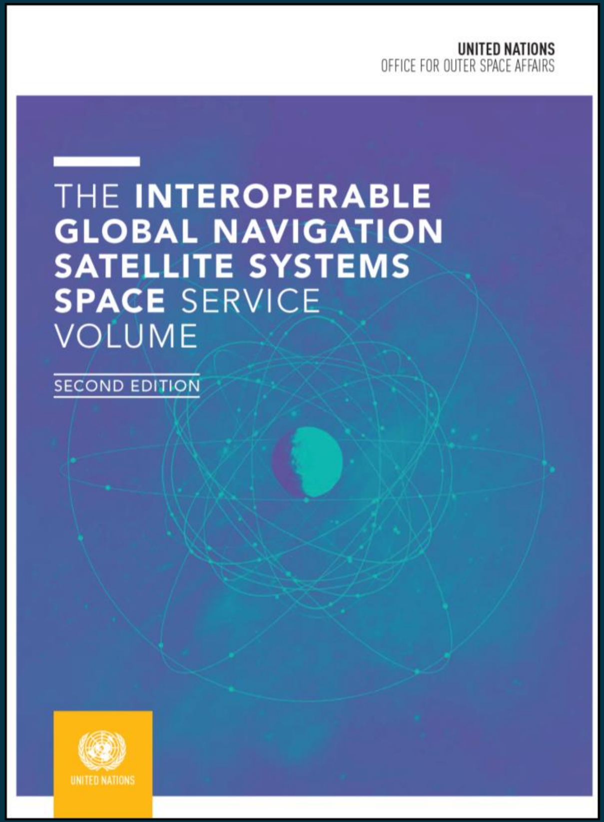
- The Space Use Subgroup operates within the scope of the overall ICG Terms of Reference.

https://www.unoosa.org/documents/pdf/icg/2021/ICG15/ICG_ToR2021amended.pdf

Enabling Lunar PNT:
Interoperable SSV Characterization & Documentation

ICG SSV Booklet 2nd Edition

- -Full revision and update of all chapters
- -New content:
  - -GNSS constellation updates
  - -Flight Experiences chapter featuring five real-world missions
- -Available at: https://undocs.org/ST/SPACE/75/REV.1



ICG SSV Video

- –Four minute video, developed as an outreach tool to:
  - –Explain utility and benefits of a multi-GNSS SSV
  - –Show how it will transform navigation use in space, and
  - –Describe how it will impact humanity—in space and on Earth
- –Co-Sponsors: NASA and National Coordination Office for Space-based Positioning, Navigation and Timing
- –Available at: https://youtu.be/-1ngun6OfgQ

Space Use Subgroup Work Plan 2021-2022

Adopted 24 Sep 2021 at ICG-15

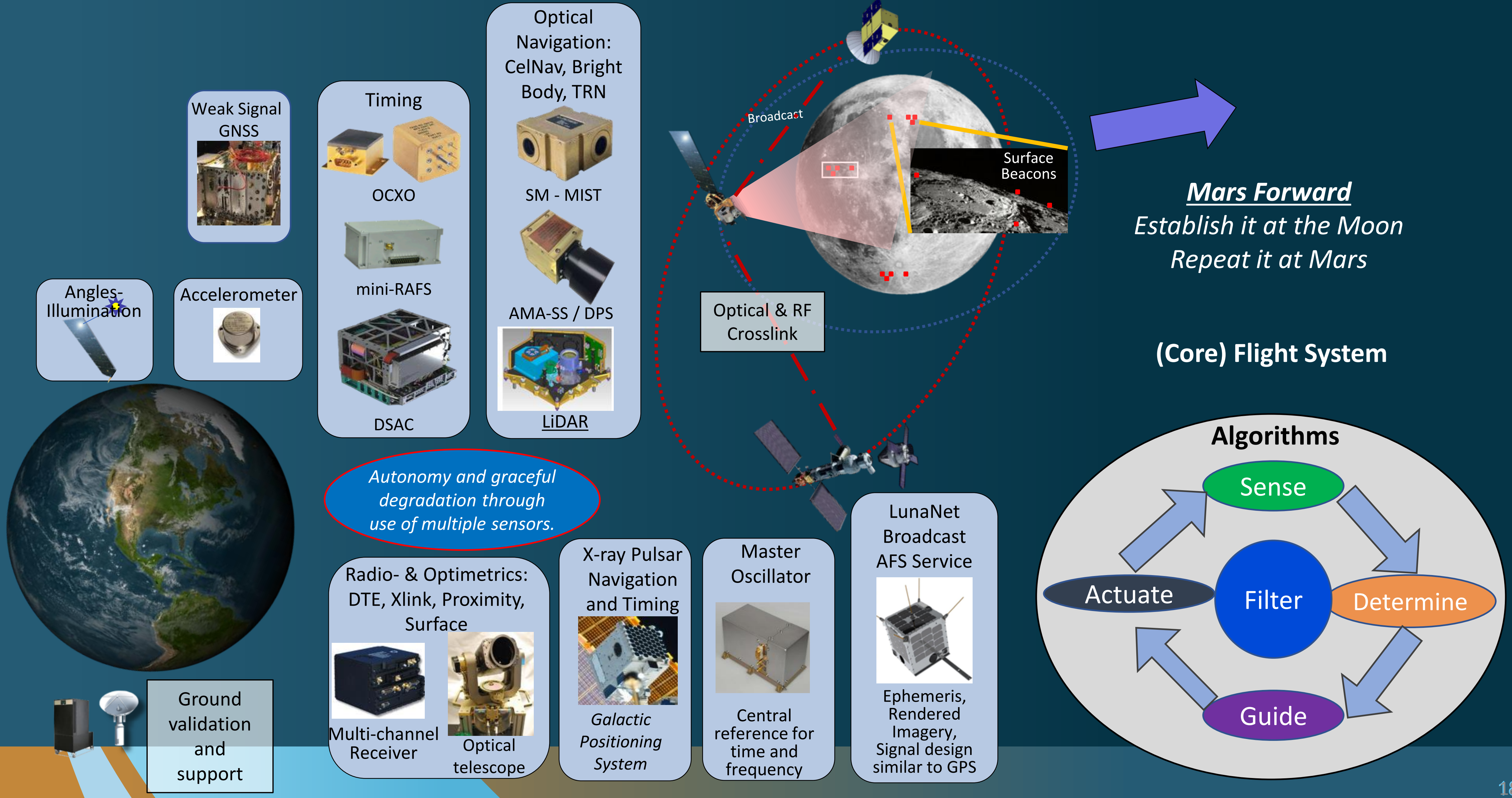
WP#	Activity	Lead	Participation
1	Public availability of provider antenna/signal technical data and requisite models	India	China Japan Europe USA
2	GNSS space user mission data and profile	China	USA Europe
3	GNSS space user timing requirement analysis and space user operations recommendations	Europe	USA China Japan India
4	Expansion of GNSS SSV to Support Lunar Operations	USA	Russia China Japan Europe
5	GNSS space user Standards	Europe	Russia USA China India

Enabling Lunar PNT: ICG Space Use Subgroup (SUSG) Work Package-4: Expansion of GNSS SSV to Support Lunar Ops

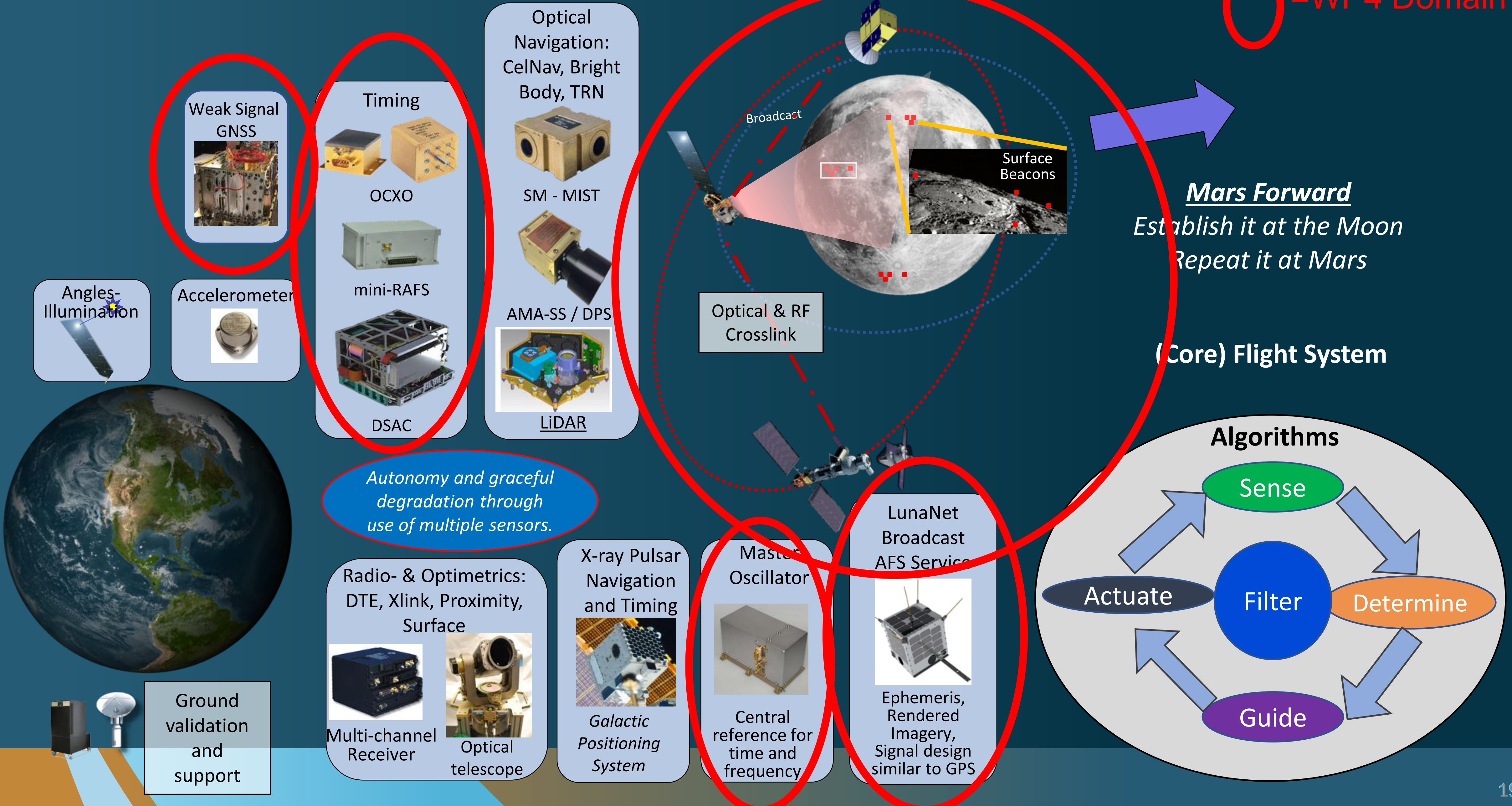
Work Package-4 (WP-4) Initiatives:

- Establish necessary liaison roles with Space Frequency Coordination Group, ISECG, etc.
- Collect and document lunar use cases that require lunar GNSS or PNT
- Encourage and consolidate results of lunar flight experiments employing GNSS and lunar PNT systems
- Study and make recommendations to maximize compatibility, interoperability and availability of combined GNSS + lunar PNT “system of systems”, including:
  - Coordination of frequencies and codes
  - Service volume definitions
  - Combined GNSS-lunar PNT architectures
  - Signal interoperability, compatibility and availability
  - Reference frames and timing

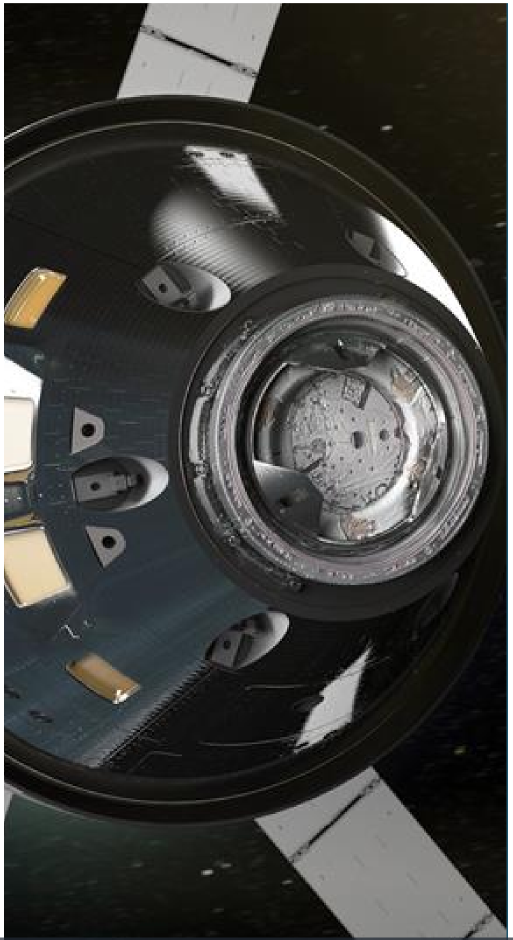
Lunar PNT Architectural Elements



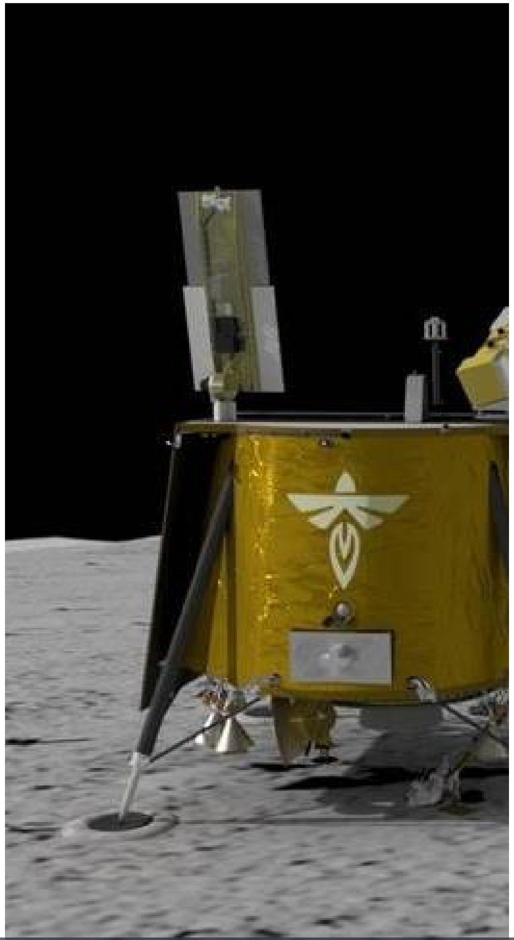
Lunar PNT Architectural Elements



Evolution from Demonstrations to Flight Operations

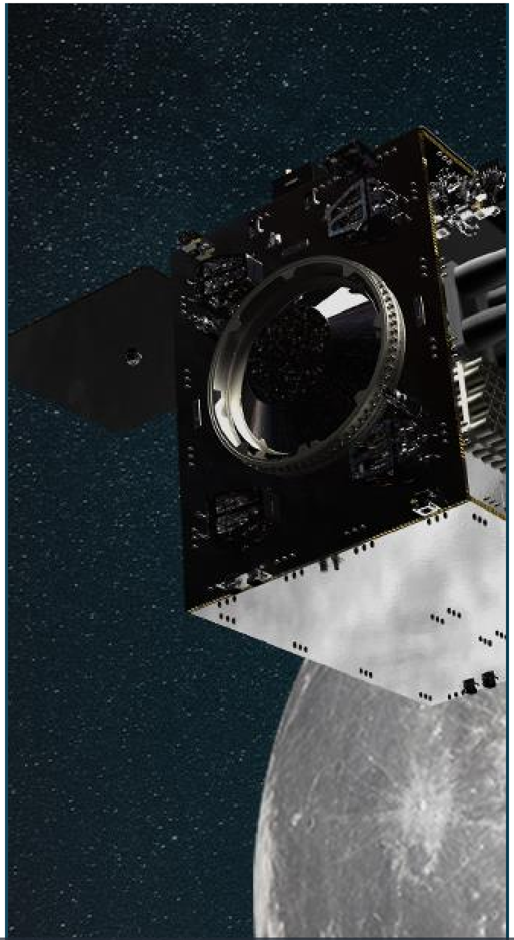


Artemis-1
(LEO receiver)
2022



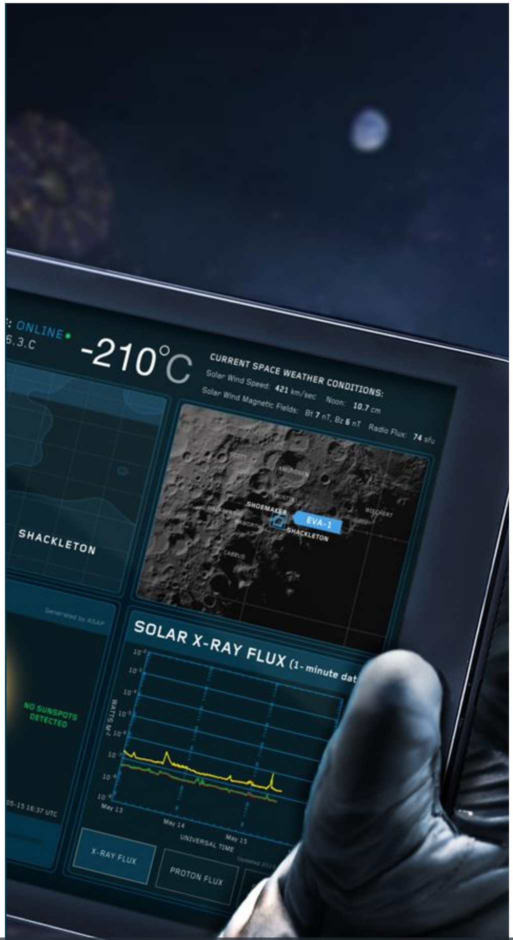
LuGRE

2024

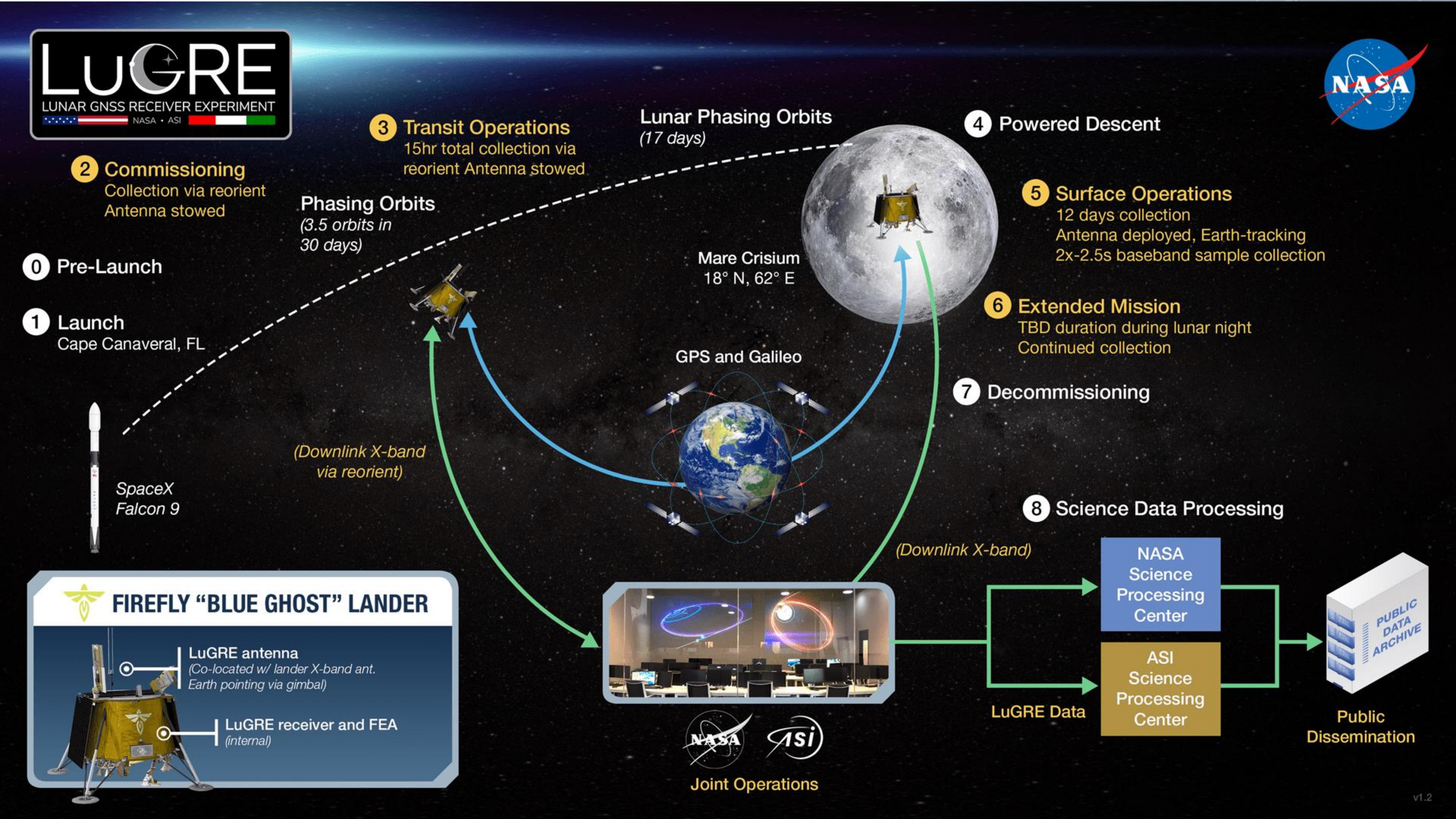


Lunar Pathfinder
(ESA)
2024

Gateway Payloads



LunaNet



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
Phasing Orbits
(3.5 orbits in
30 days)
3 Transit Operations
15hr total collection via
reorient Antenna stowed
Lunar Phasing Orbits
(17 days)
Mare Crisium
18° N, 62° E
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
GPS and Galileo
(Downlink X-band
via reorient)
(Downlink X-band)
8 Science Data Processing
NASA
Science
Processing
Center
ASI
Science
Processing
Center
LuGRE Data
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
Joint Operations
v1.2

LuGRE Overview

Mission

- NASA HEOMD payload for CLPS “19D” flight
- Joint NASA/Italian Space Agency mission
- “Do No Harm” class
- Firefly Blue Ghost commercial lander
- Transit + surface observation campaign
- Expected surface duration: one lunar day (~12 Earth days)

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.

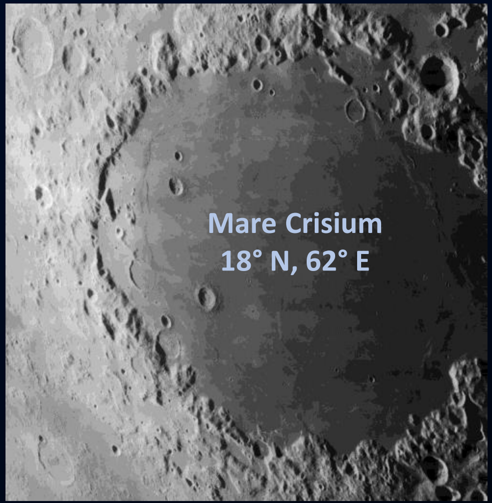
Measurements

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

Utilization

- Data + lessons learned for operational lunar receiver development
- Potential collaborative science: heliophysics, lunar geodesy
- Lunar human and robotic real-time onboard PNT

NASA
CLPS
Commercial Lunar Payload Services



CLPS Draft RFP Jul 2020

CLPS Final RFP Oct 2020

LuGRE Checkpoint A Mar 2021

LuGRE Checkpoint B (SRR) May 2021

LuGRE Checkpoint C Step-1 EPR Aug 6

LuGRE Checkpoint C Step-2, CDR Sept 13-14,30

LuGRE Checkpoint C Programmatic Sep 30, 2021

ETU Delivery Perf Test Start Sep 30 2021

EQM Testing In Italy Jan/Feb, 2022

EQM w/.9 beta SW Delivery Mar 7, 2022

EQM beta 1.1 SW delivery June 21, 2022

Checkpoint- D FM TRR (May 31, 2022)

FM Testing (Jun-Sept 2022)

Payload Delivery to Firefly Dec. 2022

Lander IRR, TRR, Ops Dry-runs, Launch rehearsal, etc. 2023-2024

Launch+Ops 2024

Analysis Late 2024

Coming up on

LuGRE Outcomes

Characterize the GNSS signal environment → Characterize navigation performance → Share collected data → Facilitate adoption of capability

Characterize the GNSS signal environment

- GPS+Galileo, L1+L5, E1+E5a
- Signal availability
- DOP
- C/N_0
- Observables
  - Pseudorange
  - Carrier phase
  - Doppler
- Raw baseband I/Q samples
- Transmit antenna patterns
- Multipath, surface environment

Characterize navigation performance

- Point solutions
- Onboard Kalman filter states
- Time to first position fix
- Formal errors, convergence
- Comparison to independent sources (lander, LRR)
- Application of GGTO

Share collected data

- GNSS receiver developers
- LuGRE science partners
- NASA missions (Artemis, Gateway, science)
- Commercial landers
- International space agencies
- GNSS community
- Science community
- Public

Facilitate adoption of capability

- Raw data availability
- LuGRE team reports + papers
- Calibration of lunar GNSS simulation models
- Application to future mission navigation studies
- Lessons learned to GNSS hardware and software developers

*Specific investigations are coordinated via LuGRE Science Team

Lunar Gateway

- Joint NASA/ESA performance study. NASA GPS-only results summarized here.
- Assumptions: MMS-like navigation system with Earth-pointed high-gain antenna (~14 dBi) and Goddard Enhanced Onboard Navigation System (GEONS) flight filter software
- Calibrated with flight data from MMS Phase 2B; Employs GPS ACE-derived antenna patterns, IGS yaw model, solar noise model
- L2 southern Near Rectilinear Halo Orbit (NRHO), 6.5 day period
- Cases for both crewed and uncrewed perturb. models:
    - GPS only with Rubidium Atomic Frequency Standard (RAFS)
    - DSN only without atomic clock
    - GPS + DSN

Ground tracking assumptions

- Three contacts per orbit (uncrewed) or continuous (crewed)
- Data Cutoff (DCO) 24 hrs before orbit maintenance maneuvers

Ground tracking sim. parameters

Noise/Bias Type	Value
Measurement Rate	10 s
Range Noise	1.0 m (1-sigma)
Range Bias	2.5 m (1-sigma)
Doppler Noise	0.33 mm/s (1-sigma)

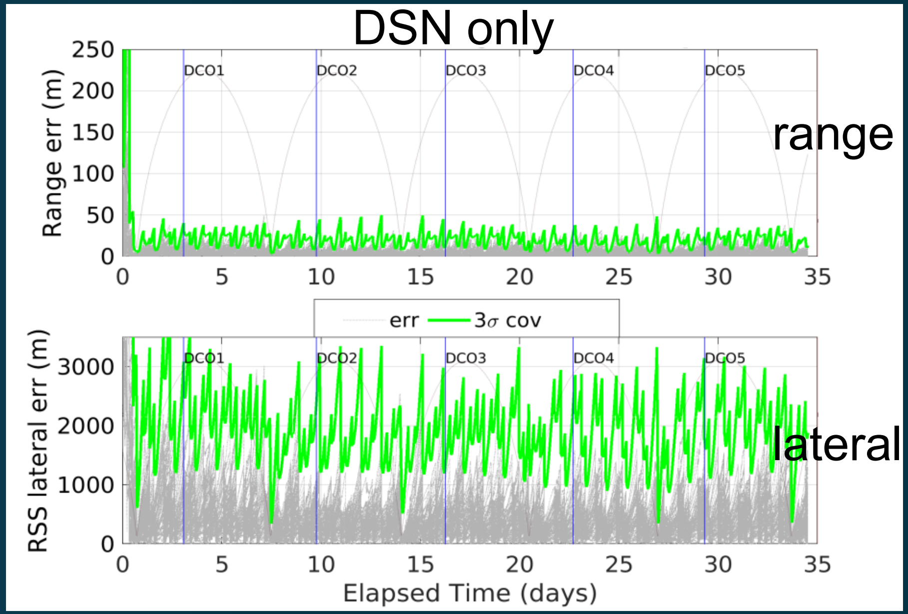
Lunar Gateway Study – Sep 2020

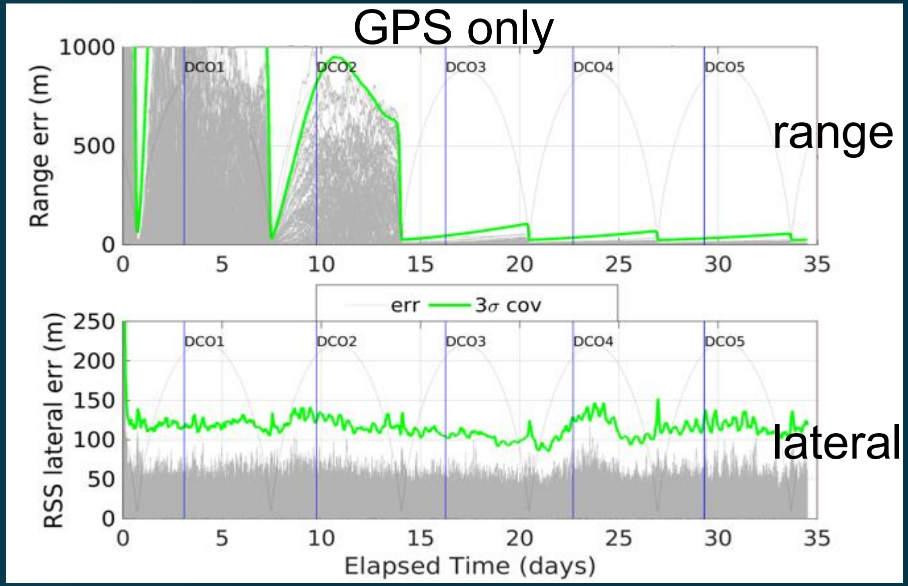
GPS Expected Performance

- Update to Feb 2019 preliminary study
- Position and velocity goals: 10 km and 10 cm/s, respectively
- Analyzed max OD error at the Data Cutoff (DCO) and at the final two perilunes and apolunes
- Observations:
  - GPS can provide greatly improved performance vs. DSN
  - GPS is real-time, on-board, without reliance on ground-based assets.

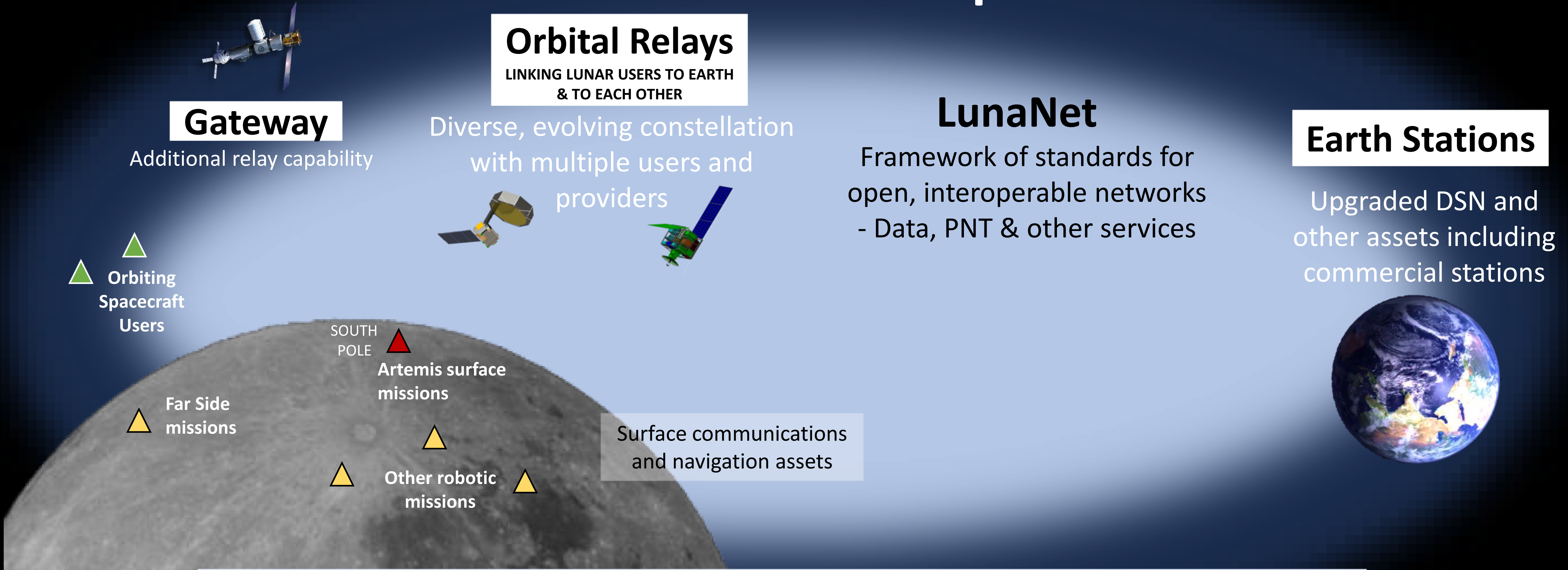
Max steady-state errors, crewed assumptions

	Case	DCO	Apolune	Perilune	All
Position [m]	**DSN**	1469.7	1326.4	319.8	2353.6
	GPS	**60.4**	**84.5**	**73.0**	**118.7**
	DSN+GPS	57.7	81.7	107.0	117.4





Early Lunar Communications and Navigation Architecture Concept



Communication and navigation infrastructure lowers the barriers to entry for new missions and capabilities and supports expanding robotic and human activities on the Moon.

Lunar Communications & Navigation Evolution

Near-Term

NEEDS
- Far Side science mission
- South Pole human exploration
- PNT services

IMPLEMENTATION
- Existing ground networks
- Initial relay capabilities
- LunaNet compatibility

Medium-Term

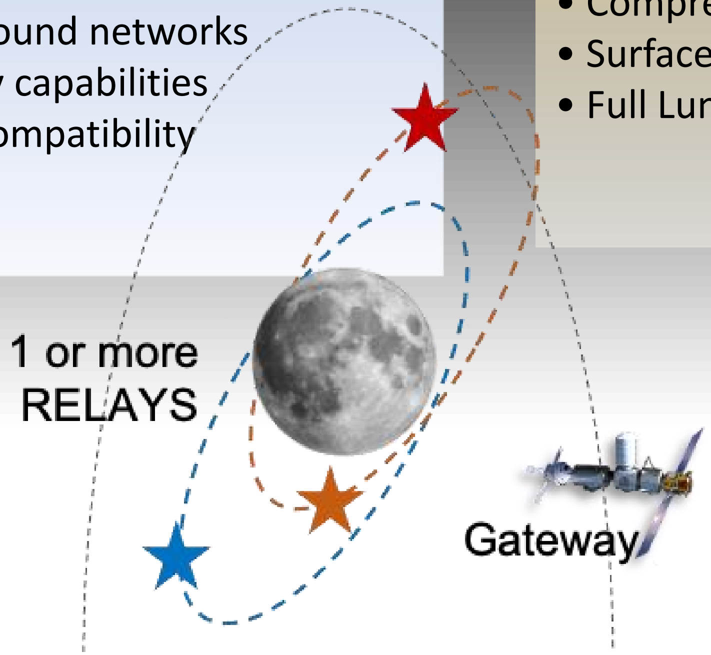
NEEDS
- Global coverage
- Longer, more complex missions, greater mobility

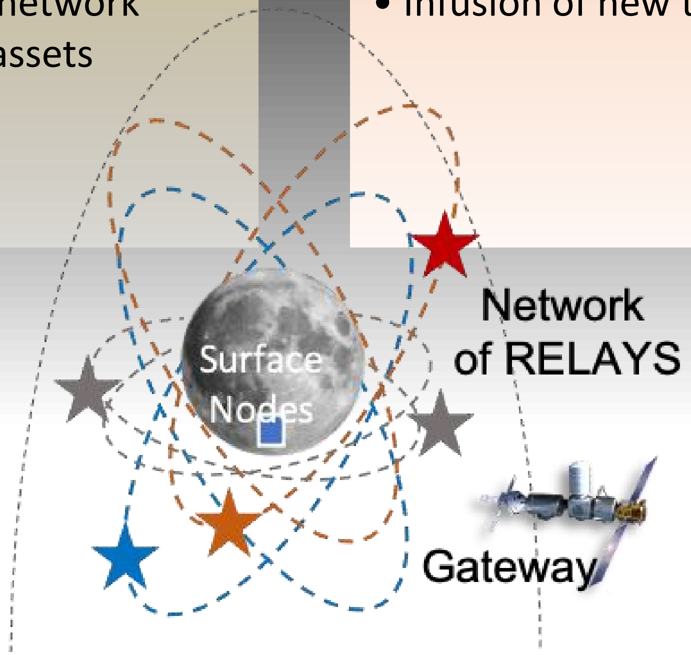
IMPLEMENTATION
- Comprehensive relay network
- Surface comm & nav assets
- Full LunaNet services

Far-Term

NEEDS
- Sustained surface and orbital presence

IMPLEMENTATION
- Evolution of infrastructure
- Infusion of new technology





LunaNet Services

Networking Services
(Data Transmission)

Data transmitted to Earth in real time or aggregated and transmitted in store-and-forward mode

Data exchange among lunar users (avoid transfer to and from Earth)

Multiple relays used interchangeably, as needed

PNT Services
(Position, Navigation, Timing)

LunaNet nodes generate and exchange PNT information

Nodes can share PNT data to support and enhance their operations

Messages, Alerts, Radio/Optical Science

LunaNet nodes can host sensors and disseminate space weather alerts conjunction alerts and science measurements

Lunar Communications and Navigation Interoperability Standards

In collaboration with other agencies, international partners and private companies, NASA is seeking to define a framework of mutually agreed-upon standards to be applied by lunar users and service providers in a set of cooperating networks.

The framework would apply to communication transmission services for science, exploration and commercial operations, distribution of navigation and timing references, and sharing of information. These standards can be introduced as part of the earliest missions and accommodate expansion as new commercial and government users and service providers join in an open and evolving architecture.

An initial version of proposed Lunanet standards has been drafted and can be found at the link below.
https://go.nasa.gov/3BQrCOk

Lunanet articles of note:
https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4773&context=smallsat
https://doi.org/10.1109/AERO47225.2020.9172509

Lunar Pathfinder – Overview

Lunar Pathfinder will provide communication services to missions in Cislunar space through a spacecraft in an elliptical orbit around the Moon

Primary payload

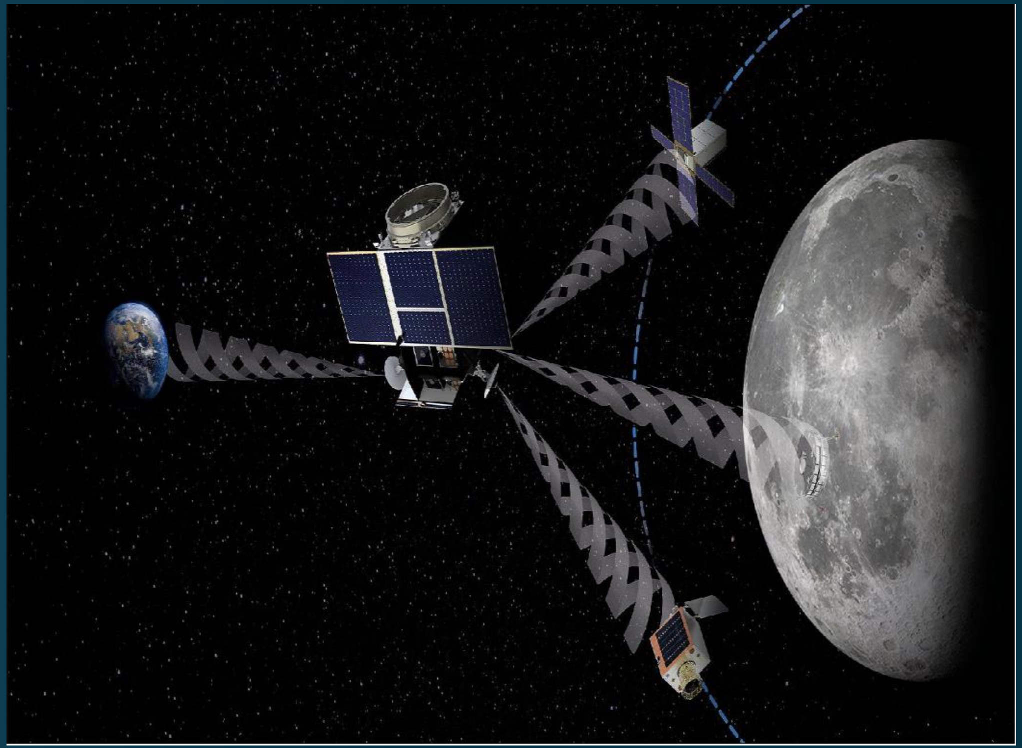
- Moonlink communication-relay payload providing data relay communications between Earth and Lunar
- 2 simultaneous channels of communication to lunar assets (S-band and UHF)
- Communications relayed back to Earth ground station in X-band

Experimental payloads

- Navigation IoD payload (GNSS receiver & antenna) - ESA
- Radiation Monitor payload - ESA
- Laser Retro-Reflector (LRR) payload - NASA

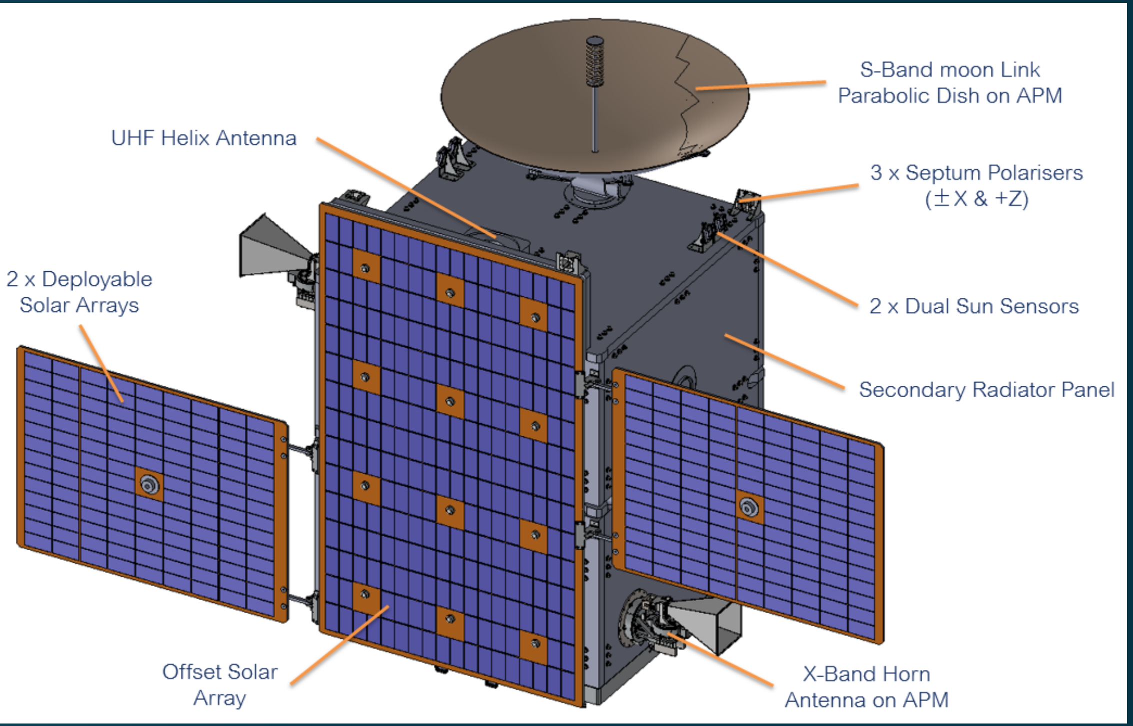
Tentative launch date : Q4 2024

ESA-NASA cooperation – General Agreement signed



Lunar Pathfinder – Spacecraft Characteristics (Preliminary)

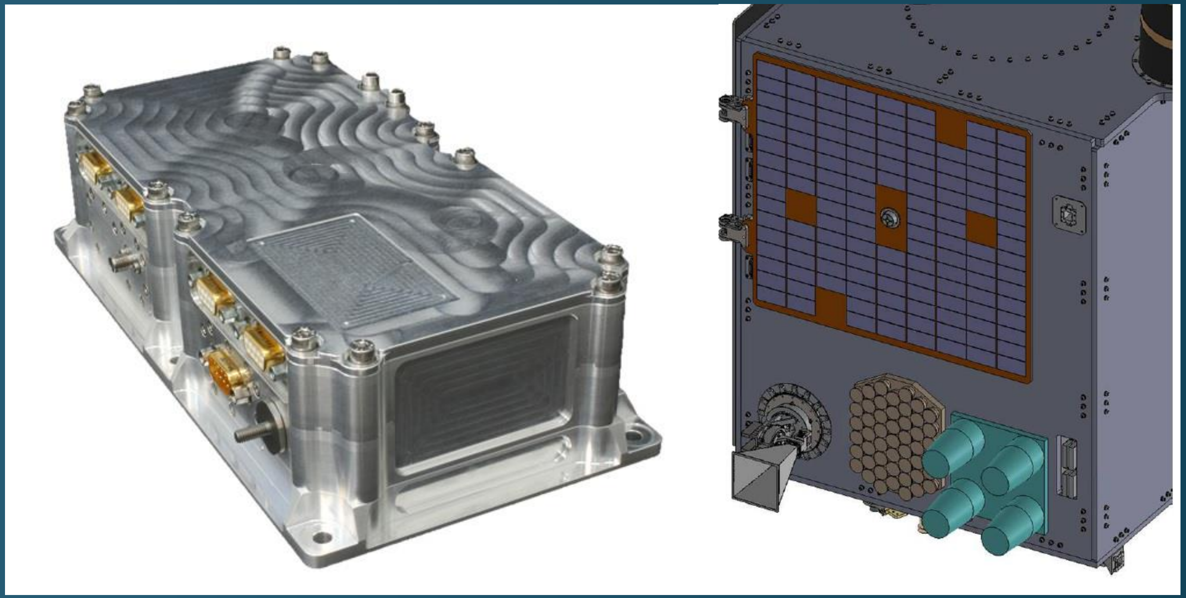
PLATFORM	
Operation orbit	Aposelene height (km) 7500 Periselene Height 500 Eccentricity 0.61 Inclination (deg) 57.8 RAAN (deg) 61.5 Argument of Pericenter (deg) 90 Epoch: 1 Dec 2022 00:00:00
Life time	8.5 years (0.5 y transfer; 8 y Comms service)
Wet Mass	291.6 kg
Power	Solar Array cells Azure 3G30C, battery 2x SAFT 8S3P
Earth Link (Xband)	Orbiter to Earth (RTN) LGA 51 kbps Orbiter to Earth (RTN) HGA 5000 kbps Earth to Orbiter (FWD) LGA low 2 kbps Earth to Orbiter (FWD) LGA medium 31 kbps
Moon Link (S band and UHF)	Orbiter to Moon (FWD) Sband/UHF 124 kbps (Rover) Moon to Orbiter (RTN) Sband/UHF 248 kbps (EIRP 13) Moon to Orbiter (RTN) Sband 1986 kbps (EIRP 21.5)
Ranging	Based on 2 GS (different hemispheres), 6 hrs/15 days 20 km position knowledge
Propulsion	RCS based on 8 1N thrusters blown down mode, 28.6 kg hydrazine (75% fill ratio)
AOCS	Constrained Sun/Nadir pointing Normal mode, STIM Gyro- Sodern Auriga STR-Bison SS, SSW-200 Wheels and RCS
Redundancy	CoreDHS, AOCS, Earth link Transponder, BCM, RCS, Moon Link Transponder
Platform Avionics used	PIU/CHIMP, LEO avionics (SSTL & external supplier) based on CoreDHS
Rideshare Provider	NASA
MOON LINK PAYLOAD	
Moon Link Payload	Moon Link Data handling (HSRDX data recorder HW and SW) , Moon Link Comms (Proximity-1 transponders, RF front End, UHF and Sband antennas)



Launch date (planned): Q4 2024

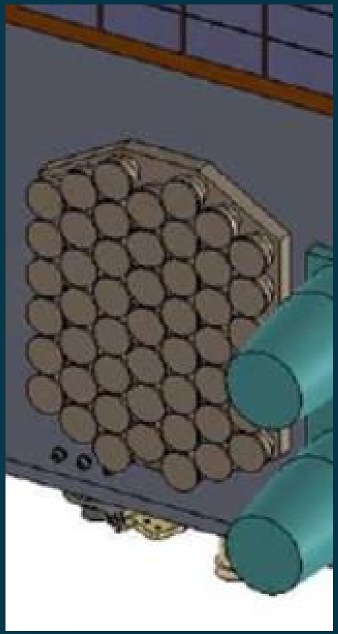
Lunar Pathfinder – Navigation Experiments Payloads

ESA



GNSS Receiver

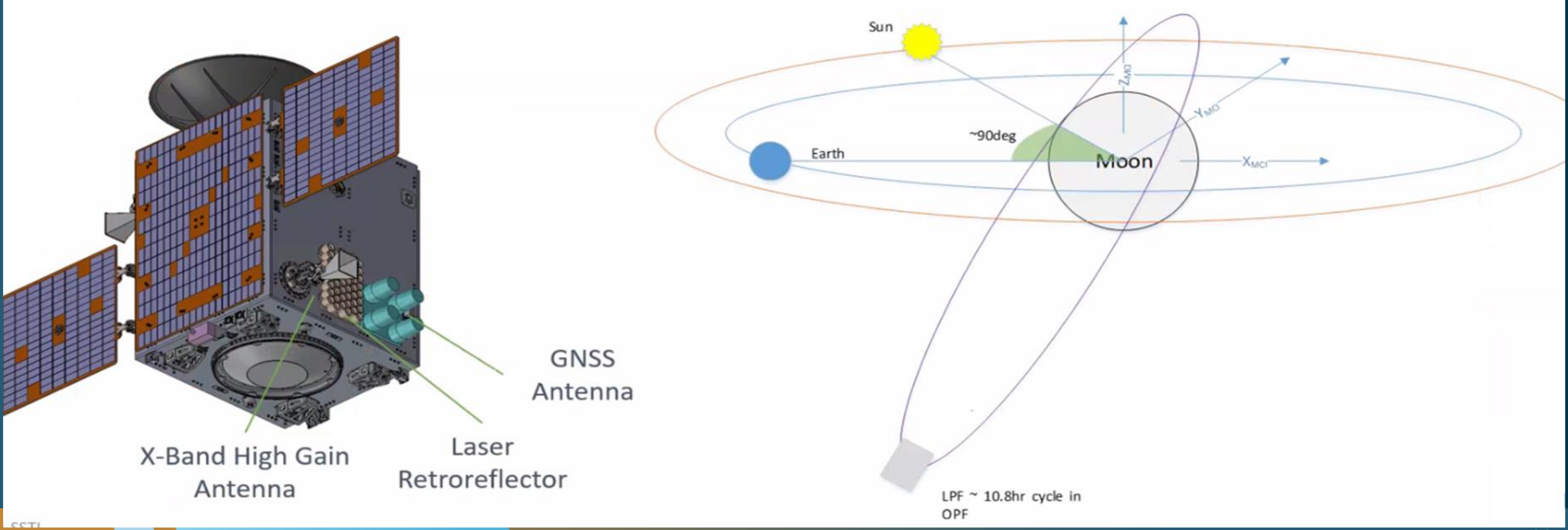
NASA



Laser Retro-Reflector

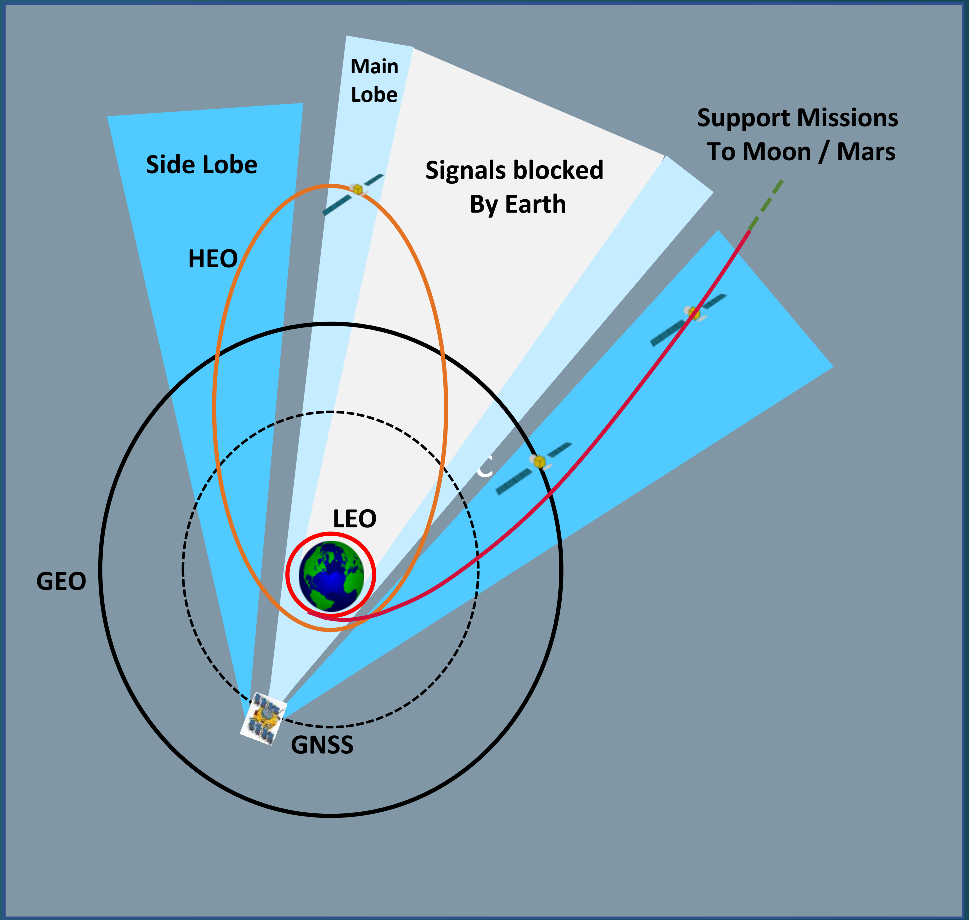
Lunar Pathfinder – Precise Orbit Determination Concept

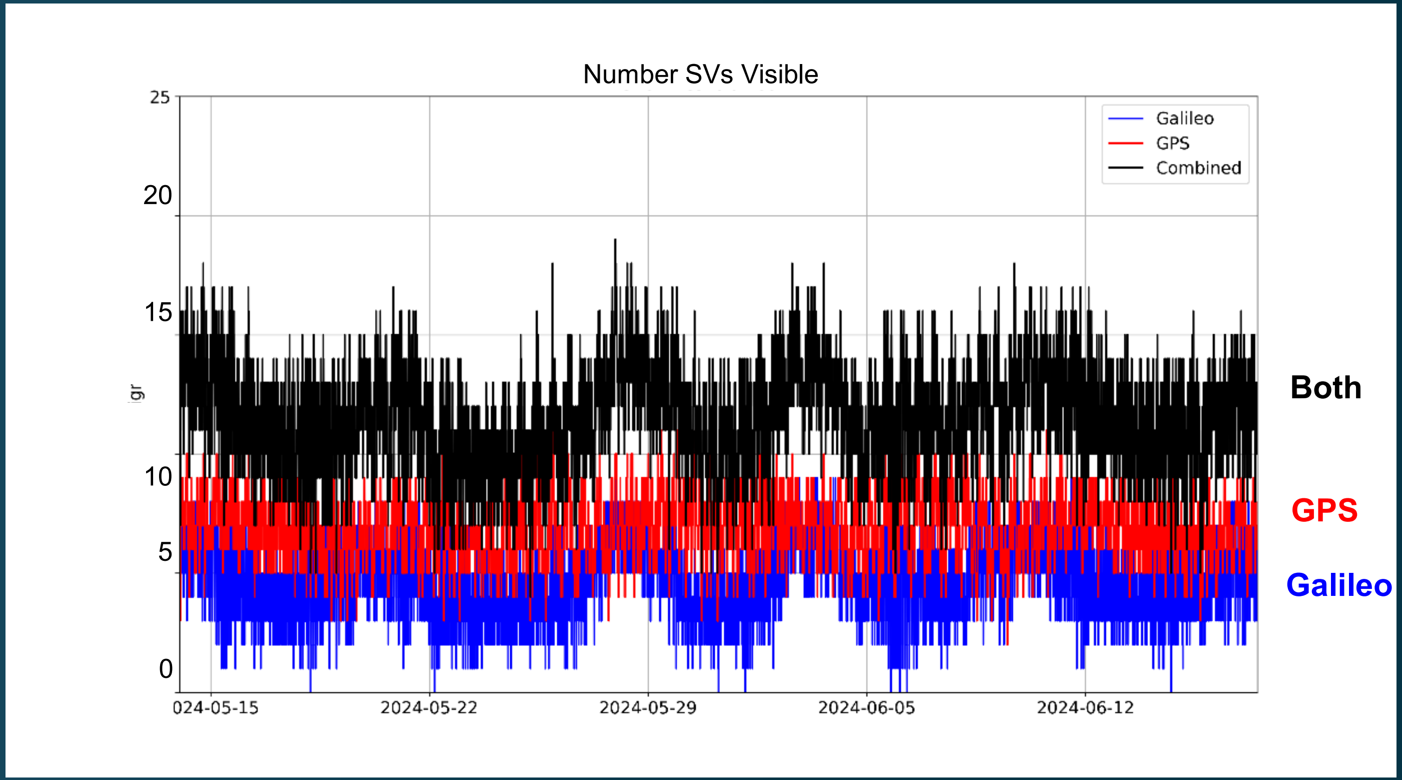
Joint ESA/NASA NAV/LRR in-orbit demonstration - 1st time ever that a mission to the Moon is equipped with GNSS and LRR for OD/POD



Lunar Pathfinder – GNSS Visibility

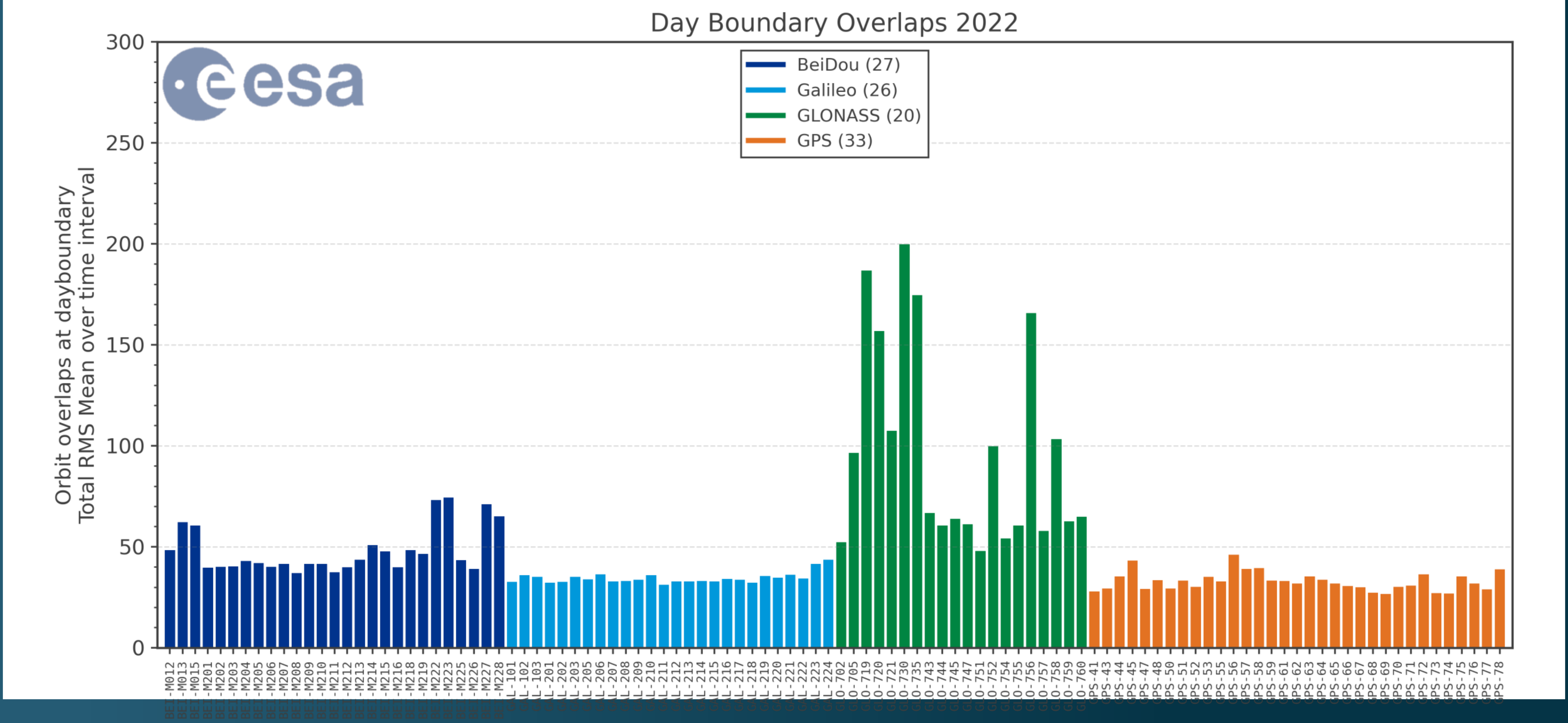
Impact of GNSS Side Lobes Signals for Mission to the Moon (Lunar Pathfinder, Gateway etc.)





Predicted Gateway GPS/Galileo visibility
(20 dB-Hz; ESA/ESOC)

ESA/ESOC MGNSS Final Products



Lunar Pathfinder – GNSS Orbit Determination

- Demonstration of GNSS signal reception and usage for different Orbit Determination concepts
- Testing of Orbit Determination (OD) and Precise Orbit Determination (POD)
  - On-board PVT
  - Precise Orbit Determination (POD) on-ground – batch processing based on
    - Galileo and GPS (GNSS) multi frequency, multi signal observations
- Validation of GNSS POD results based on Laser Ranging POD results
- POD based on combined processing of GNSS and Laser ranging data
- Testing of new OD and POD algorithms
- Validation of dynamical models based on GNSS and Laser Ranging observations

Lunar Pathfinder – LRR Objectives

- Demonstration of 2-way laser ranging in support of precision orbit determination (POD) of lunar orbiters
    - Builds upon the successful use of 1-way laser ranging to the LRO for improved POD
    - Future lunar orbiter missions will require enhanced POD beyond what was performed on LRO and GRAIL (Gravity Recovery and Interior Laboratory)
- Validation Global Navigation Satellite System (GNSS) positioning measurements of lunar orbiter
    - Optical laser ranging as an independent and higher-precision measurement technique supports validation of traditional radio tracking and GNSS-based positioning
- Improve tie between Terrestrial Reference Frame & Lunar Reference Frame
    - Advances capabilities that will be vital for geolocation of lunar science measurements and to the National Geospatial-Intelligence Agency (NGA) lunar geodesy objectives
- Demonstrate use of lunar orbiter for improved determination of Universal Time (Earth’s rotation angle)

ESA's GNSS Experiment 'EXPOL' on NASA's SL-15

Background

- NASA's Flight Opportunities Program provides the capability to fly payloads on launch vehicles.
- NASA and ESA have a mutual interest in cooperating on the flight test of NASA's Autonomous Flight Termination System (AFTS) and ESA's GPS/Galileo receiver on board NASA's SpaceLoft 15 (SL-15) sounding rocket mission

SL-14 Launch in 2019
Picture – Up Aerospacec

Objective

- The SL-15 GNSS Experiment 'EXPOL' is an element of an ESA/NASA cooperation for the demonstration of the benefits of GNSS Interoperability for space users

ESA's GOOSE Receiver
From Fraunhofer IIS

Status

- ESA's GNSS receiver 'GOOSE' is currently undergoing environmental tests
- Launch is scheduled for 30 Nov 2022

Conclusions

- The Moon is the next frontier for in space use of GNSS and other PNT services
- NASA and ESA are pursuing multiple open, collaborative PNT capabilities to open-up cislunar space for government and commercial exploration and use
- The first lunar GNSS demonstrations, such as LuGRE and Lunar Pathfinder, are around the corner
- New lunar PNT architectures, like Lunanet and Moonlight are being devised
- NASA and ESA are working within the ICG and IOAG to enhance the use of GNSS services in the lunar environment and to develop and expand lunar PNT capabilities that are **available** to all users and **interoperable and compatible** with all region-developed PNT systems

Backup

International Committee on GNSS (ICG)

- The ICG emerged from 3rd UN Conference on the Exploration and Peaceful Uses of Outer Space in July 1999
- The ICG brings together all six GNSS providers (United States–GPS, European Union–Galileo, Russia–GLONASS, China–BeiDou, India–NavIC and Japan–QZSS), as well as other members and observers to:
  - *Promote the use of GNSS and its integration into infrastructures*
  - *Encourage compatibility and interoperability among global and regional systems*
- Observers: International organizations and associations (BIPM, IOAG, ITU, IGS, etc.,)

https://www.unoosa.org/oosa/en/ourwork/icg/icg.html

ICG SUSG Work Plan 2021-2022

WP#	Activity	Lead
1	Public availability of provider antenna/signal technical data and requisite models	India
2	GNSS space user mission data and profile	China
3	GNSS space user timing requirement analysis and space user operations recommendations	Europe
4	Expansion of GNSS SSV to support lunar operations	USA
5	GNSS space user standards	Europe

WP4: Expansion of GNSS SSV to support lunar operations

Objective: Expand interoperable GNSS SSV to support Lunar transit, surface, Earth-Moon Lagrange points and orbital operations (cis-lunar region); develop a formal definition of the expanded SSV

Approach:

1. Lunar frequency and code signal coordination
2. User needs assessment
3. Draft lunar SSV definition
4. Recommend/support lunar GNSS flight experiments; publish results and lessons learned
5. Leverage publicly available trade studies and performance analyses; if necessary, perform narrow analyses/trades via ICG region study team(s)
6. Recommend updated provider requirements and/or augmentations as needed
7. Publish results in future editions of SSV Booklet, technical journals and press articles
8. Lunar Reference Frame development and coordination