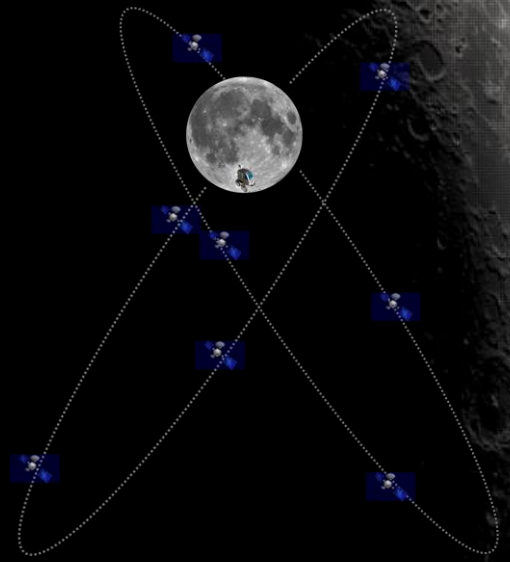
Japan

Lunar Navigation Satellite System



9th Cislunar PNT Conference

Lunar PNT and LEO PNT Update

23rd January, 2025

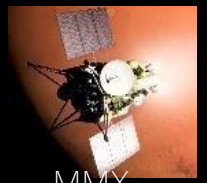
Masaya Murata (Japan Aerospace Exploration Agency)

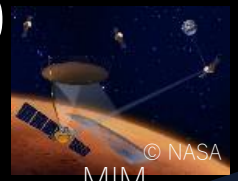
Overview of JAXA Roadmap from LEO to Moon/Mars

2020 2030 2040

Expanding Human Presence

MARS


MMX



MIM

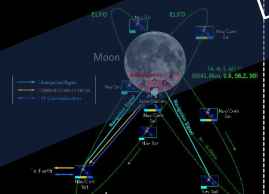
Robotic Tech Demo → Crewed Missions


Kaguya

Landed!


SLIM


LUPEX



LNSS/LANS demo


HTV-XG


Cargo Lander

MOON

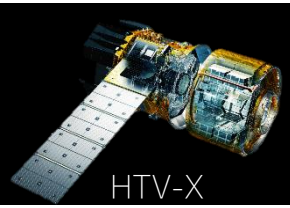
Gateway

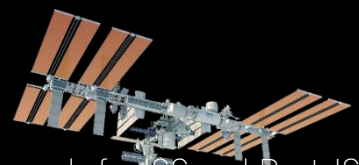
Pressurized Crew Rover


Fuel-Plant (demo)


Lunar Base

Robotic Missions → Crewed Missions → Surface Infrastructure → Sustainable Exploration


HTV-X


Resupply for ISS and Post-ISS


Concept study of Japanese Module

LEO

ISS Operations → Sustainable LEO Commercializing Space Activities

Lunar Surface: Pin-point Landing and South Pole Exploration

Smart Lander for Investigating Moon (SLIM)

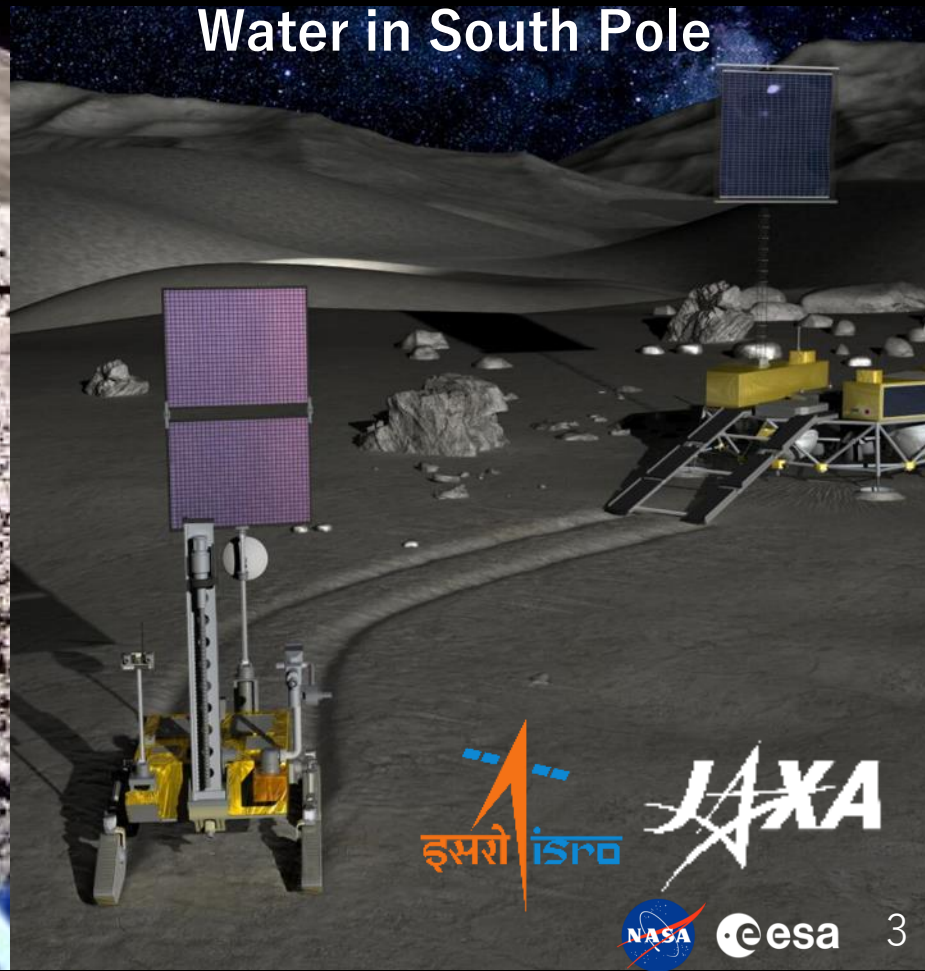
- Launch: on Sept. 7, 2023
- Moon Landing: Jan. 20, 2024

- **Pinpoint Landed !!**
  Landed 55m East from Targeted Site
- **Survived 3 Lunar Nights !!**
- **Observation of Lunar Rocks with Multi-Band Camera**

Lunar Polar Exploration (LUPEX)

- Target Launch: 2025-2026

In-situ Observation of Water in South Pole



Japan's Contribution to the Gateway and Beyond

Habitation Functions

ECLSS for I-HAB

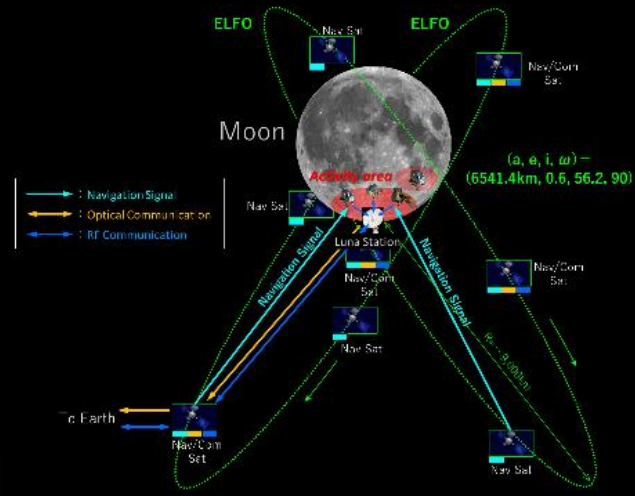
- Environment Control and Life Support Capability in I-HAB
- Batteries for HALO

Logistics Module

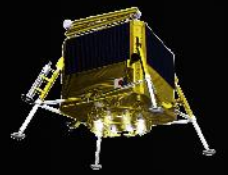
HTV-X (HTV-XG)

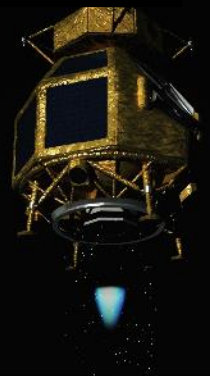
- Logistic Resupply capability
- 4,000kg of pressurized cargo to Gateway within 30 days

Lunar Comm & Nav (CPNT) system



Small Lander





Medium Cargo Lander

The Pressurized Rover

- Expected to take key role in Artemis missions - Launch target: 2031

- **World first mobility system on the Moon boarded without EVA suit.**
- **Expands the exploration range on lunar surface**
- **Provides both crewed/uncrewed operation modes**

Signing of IA
(MEXT-NASA)
April 2024

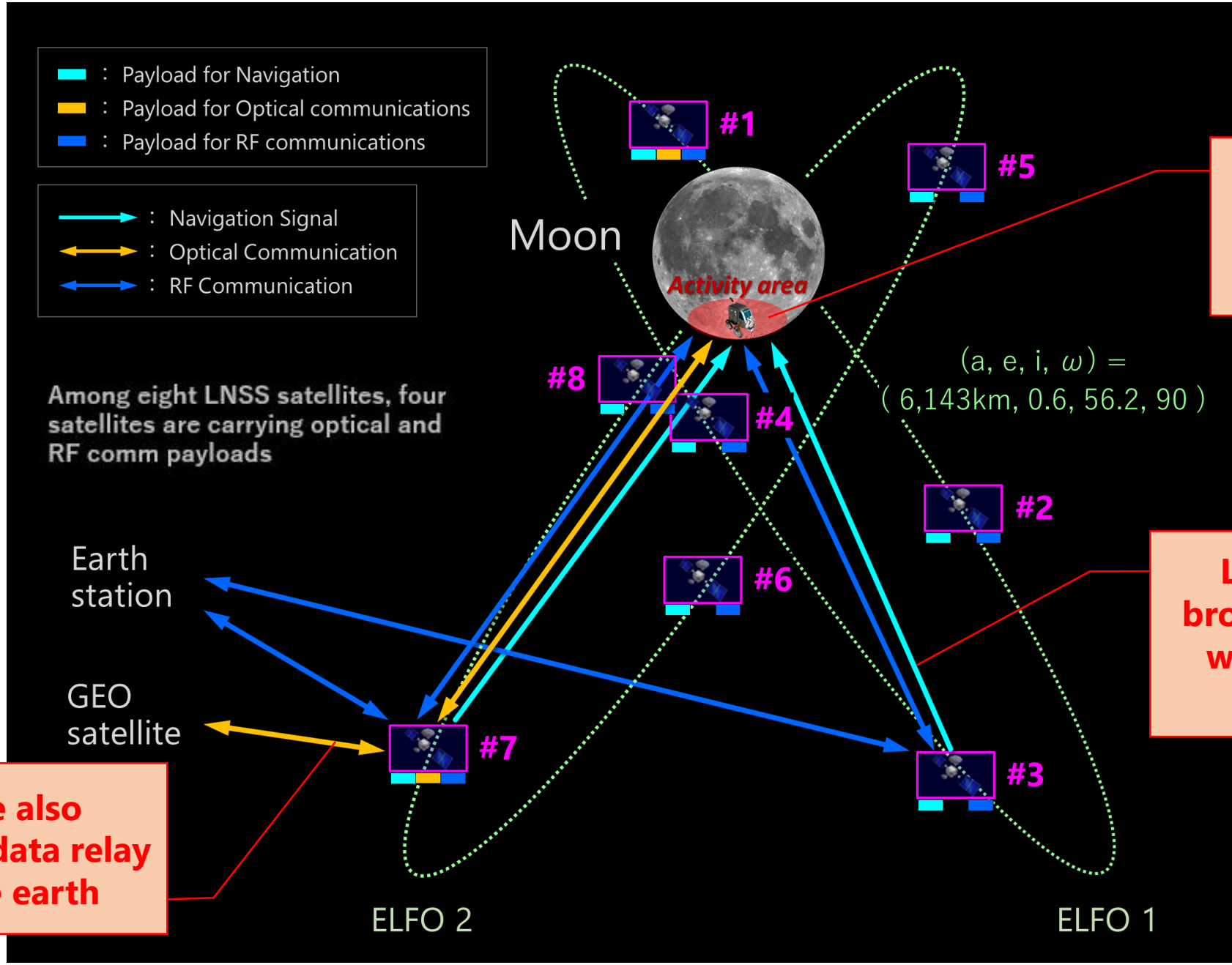
✓ **Provision of a Pressurized Rover** by Japan

✓ **2 opportunities for Japanese astronauts** on the Moon's surface for exploration missions.

JAXA's plan

LNSS is GPS-like satellite constellation for the Moon designed by JAXA

LNSS: Lunar Navigation Satellite System

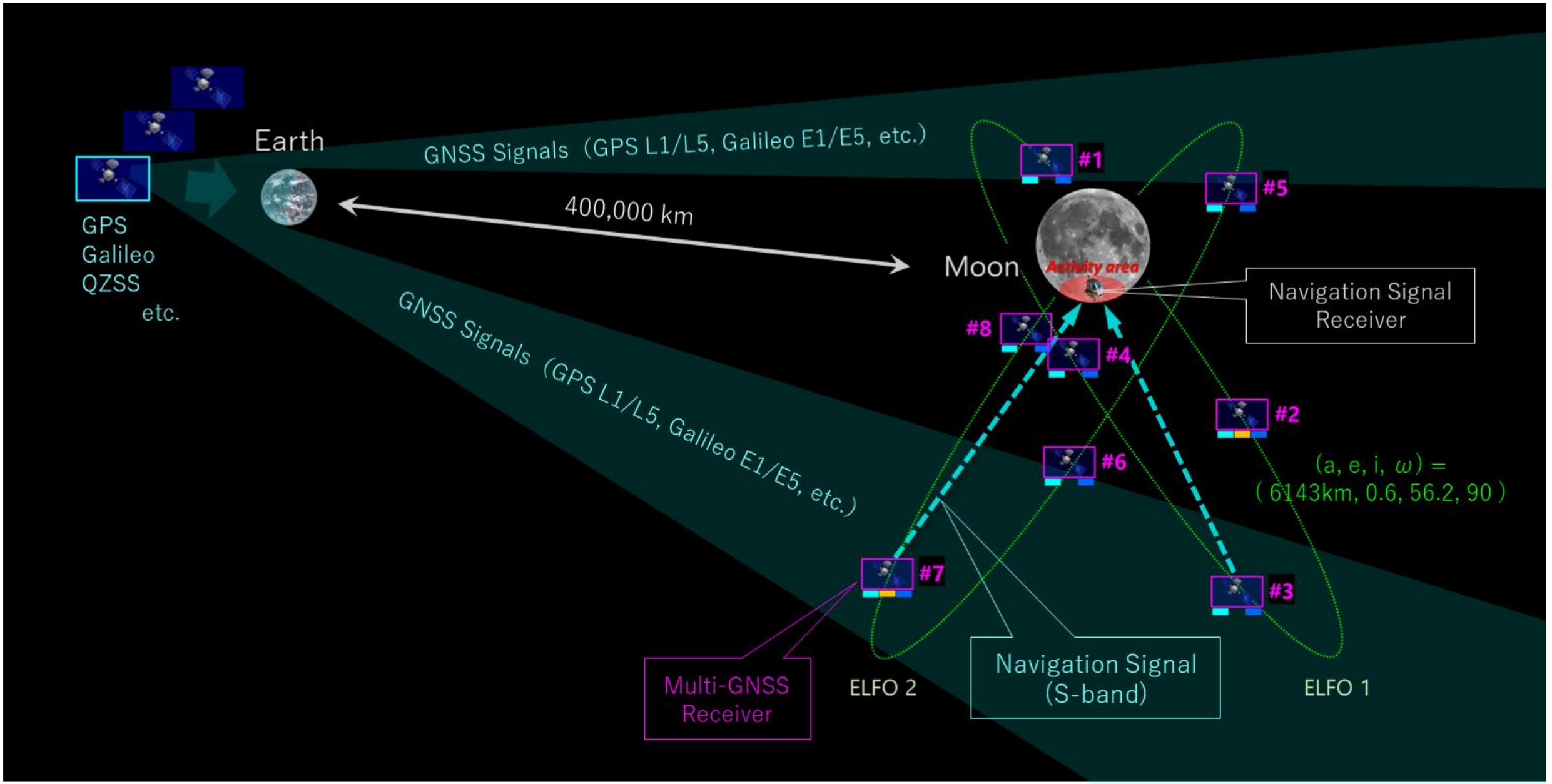


Target: South Pole region

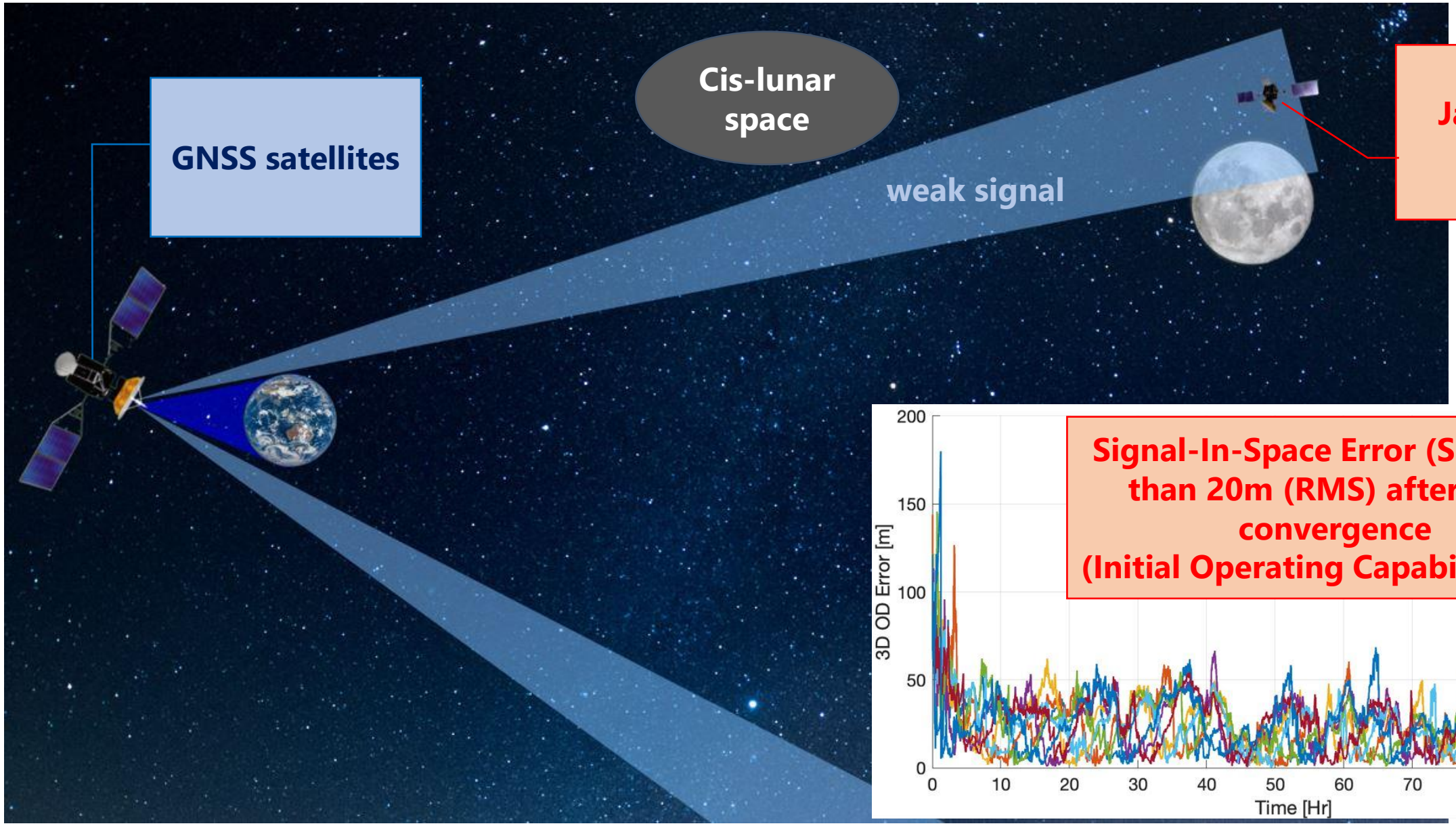
LNSS satellite broadcasting one-way navigation signal

LNSS satellite also functioning as a data relay satellite to the earth

GNSS weak signal navigation for LNSS satellites, making the lunar PNT autonomous



GNSS weak signals drive our LNSS, 20m SISE (RMS) at IOC, 10m SISE (RMS) at FOC



Signal-In-Space Error (SISE) less than 20m (RMS) after filter convergence (Initial Operating Capability, IOC)

Typical LNSS PNT accuracy for fixed and moving receivers at the South Pole

Fixed

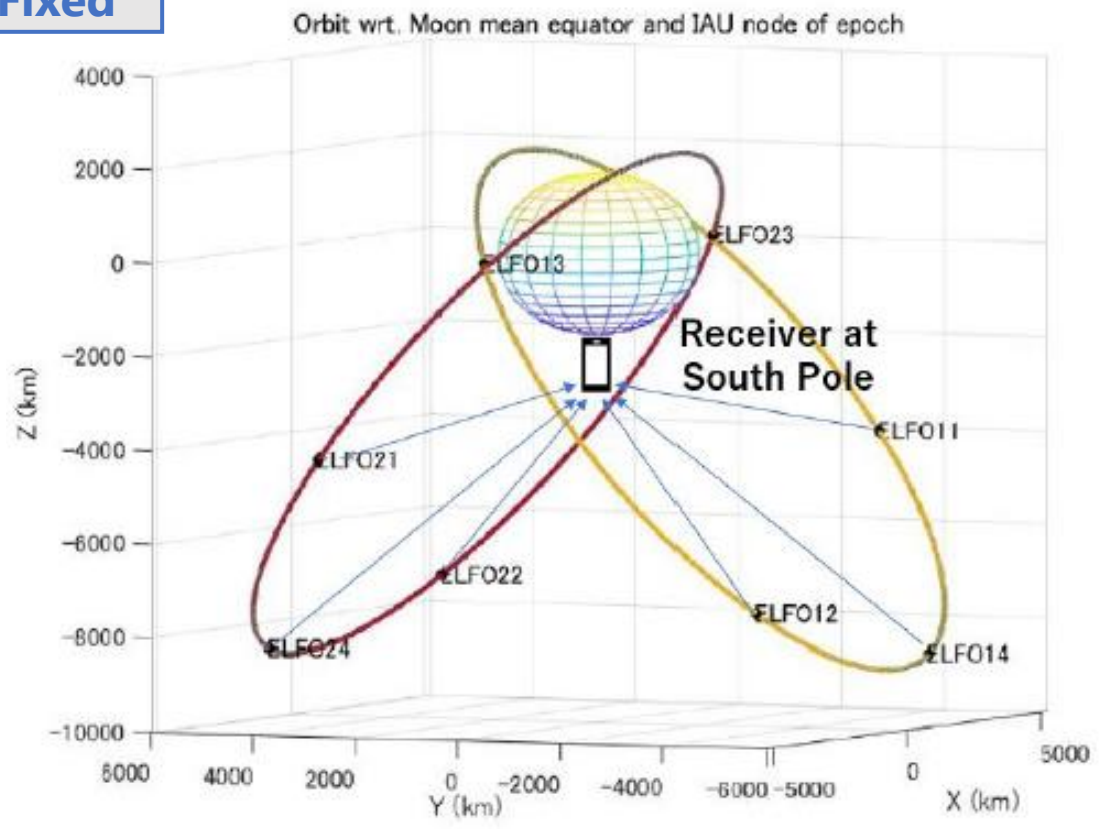


Figure 2: LNSS satellite constellation and receiver at South Pole.

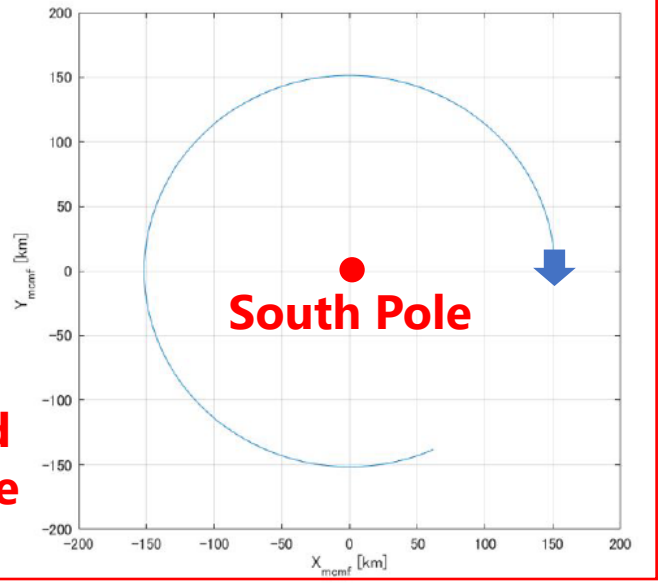
- **Average SSP errors:**

3D position 37.7m,
2D position 13.8m,
Vertical 32.8m,
Clock bias 6.6E-08s

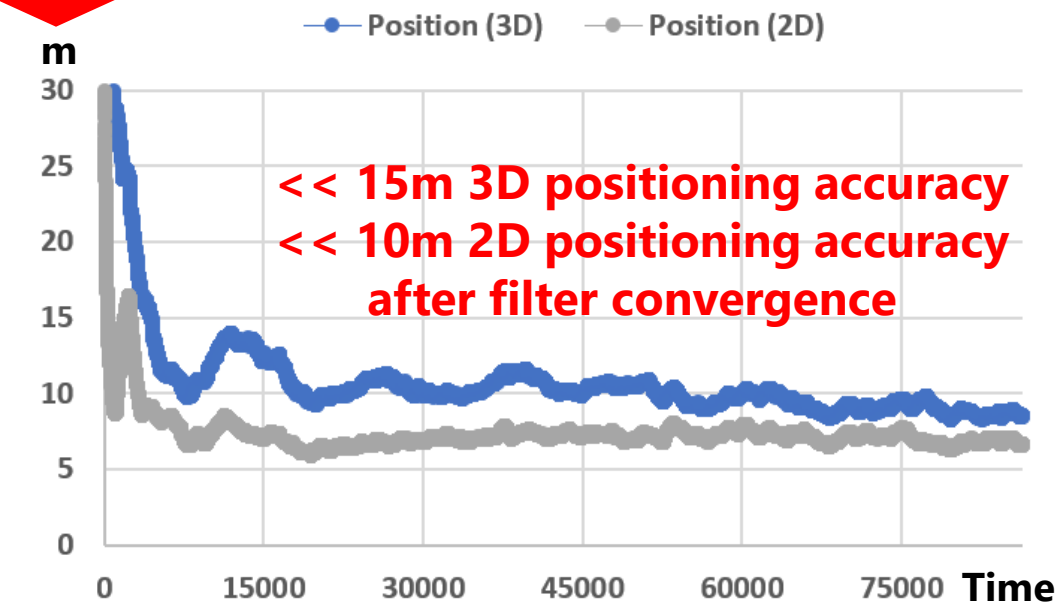
Our LNSS was designed to achieve the high 2D (horizontal) PNT accuracy

Moving

Assumed circular movement with velocity of 3 m/s at south altitude of 85 degrees



Applying onboard filtering technique (EKF)



Collaboration with ESA and NASA and LunaNet Interoperability Specification (LNIS)

Lunar Comm & Nav (CPNT) systems by US, Europe, Japan

ESA Moonlight LCNS (2028～)

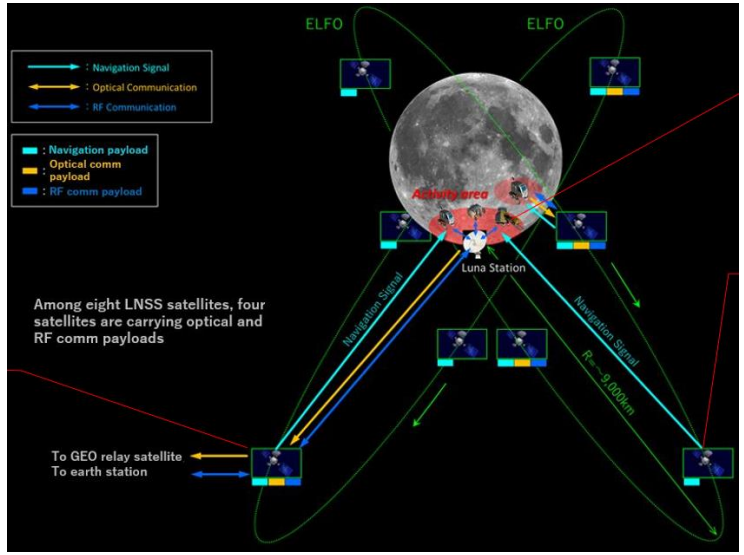
Contractor: Telespazio

NASA LCRNS (2026～)

Contractor: Intuitive Machines

Japan LNSS (2028/2029～)

ArkEdge Space was recently selected
※PNT only



LCNS:
Lunar Communications and Navigation Services

LCRNS:
Lunar Communications Relay and Navigation Systems

LNSS:
Lunar Navigation Satellite System

LunaNet Overview

This slide available at Space For Inspiration (2024) HP
https://bsgn.esa.int/space-for-inspiration-5th-edition-from-4-5-december-2024-in-luxembourg/

- Set of **coorporating** networks
- Providing interoperable **communication** and **navigation** services
- Based on a framework of **mutally agreed-upon standards**
- Enabling **interoperability**.

Service Oriented

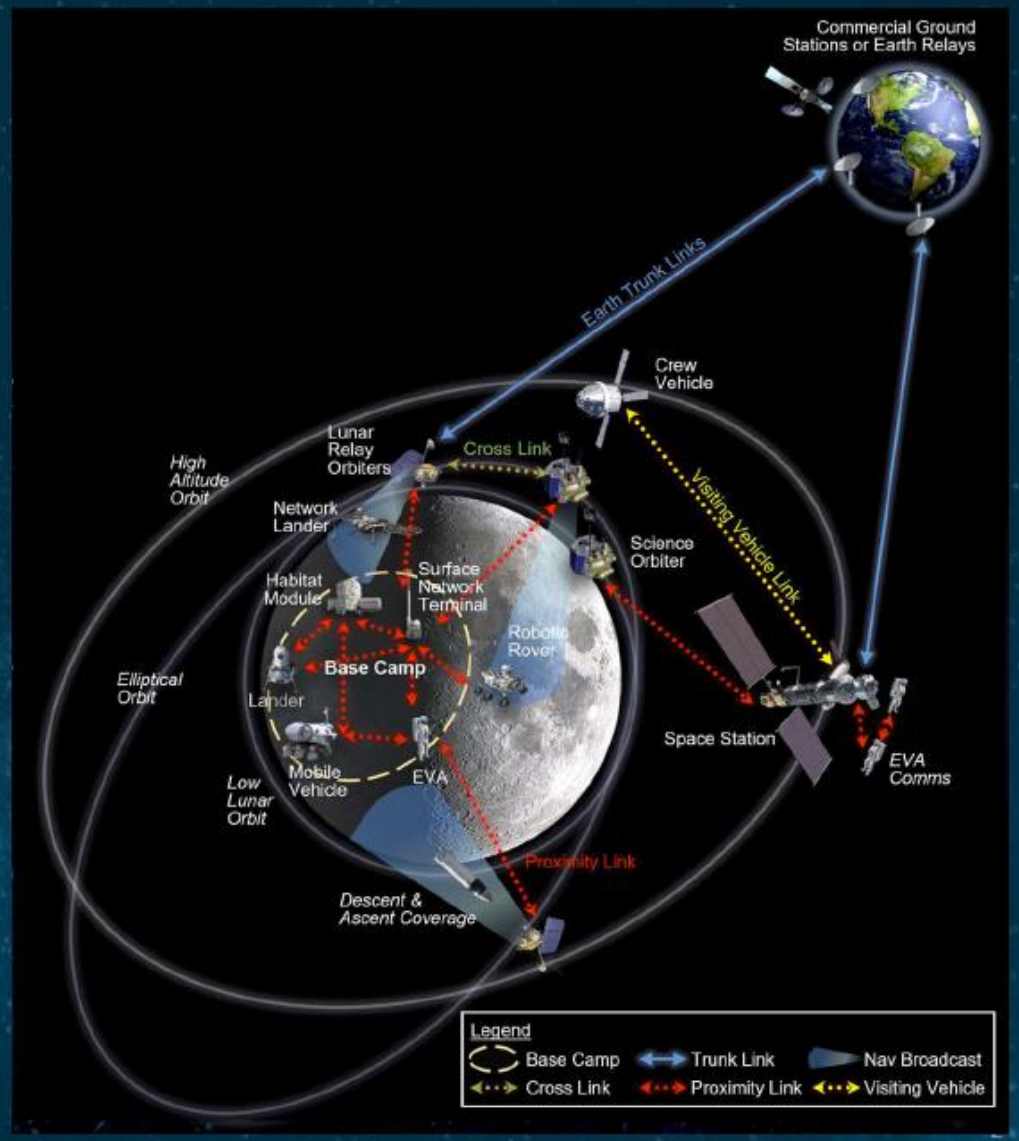
Open

Scalable

Extendable

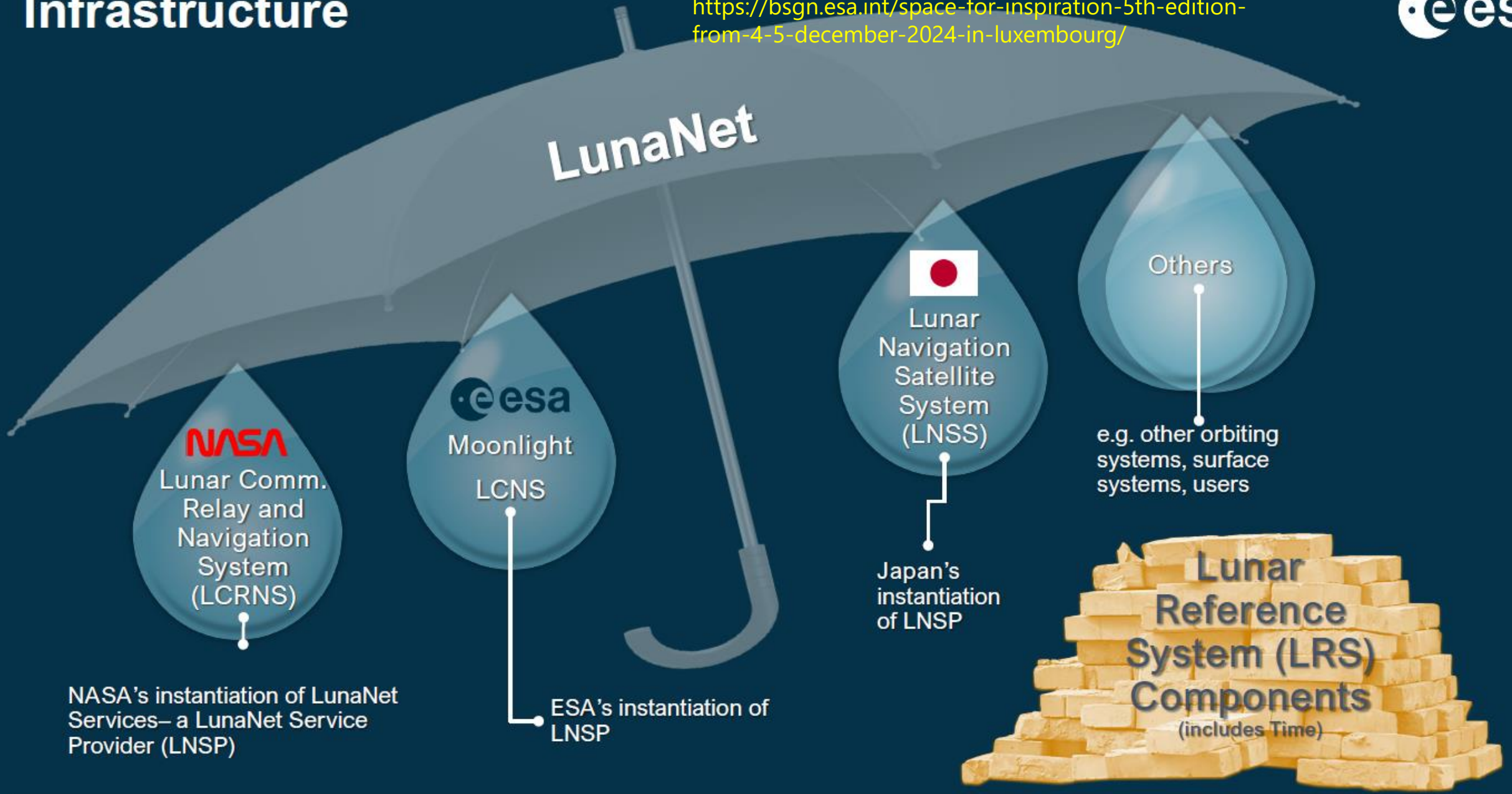
Resilient

Secure



Infrastructure

This slide available at Space For Inspiration (2024) HP
https://bsgn.esa.int/space-for-inspiration-5th-edition-from-4-5-december-2024-in-luxembourg/



LunaNet: Lunar CPNT International Framework

Ensuring interoperability among lunar CPNT systems from the get-go

Joint establishment of "moon GNSS" called LANS

LunaNet: Bringing terrestrial internet capabilities to astronauts, rovers, and orbiters.
NASA / Reese Patillo

Towards the establishment of 'Moon GNSS' called LANS

The concept of interoperable lunar PNT system of systems (Lunar Augmented Navigation Service (LANS))

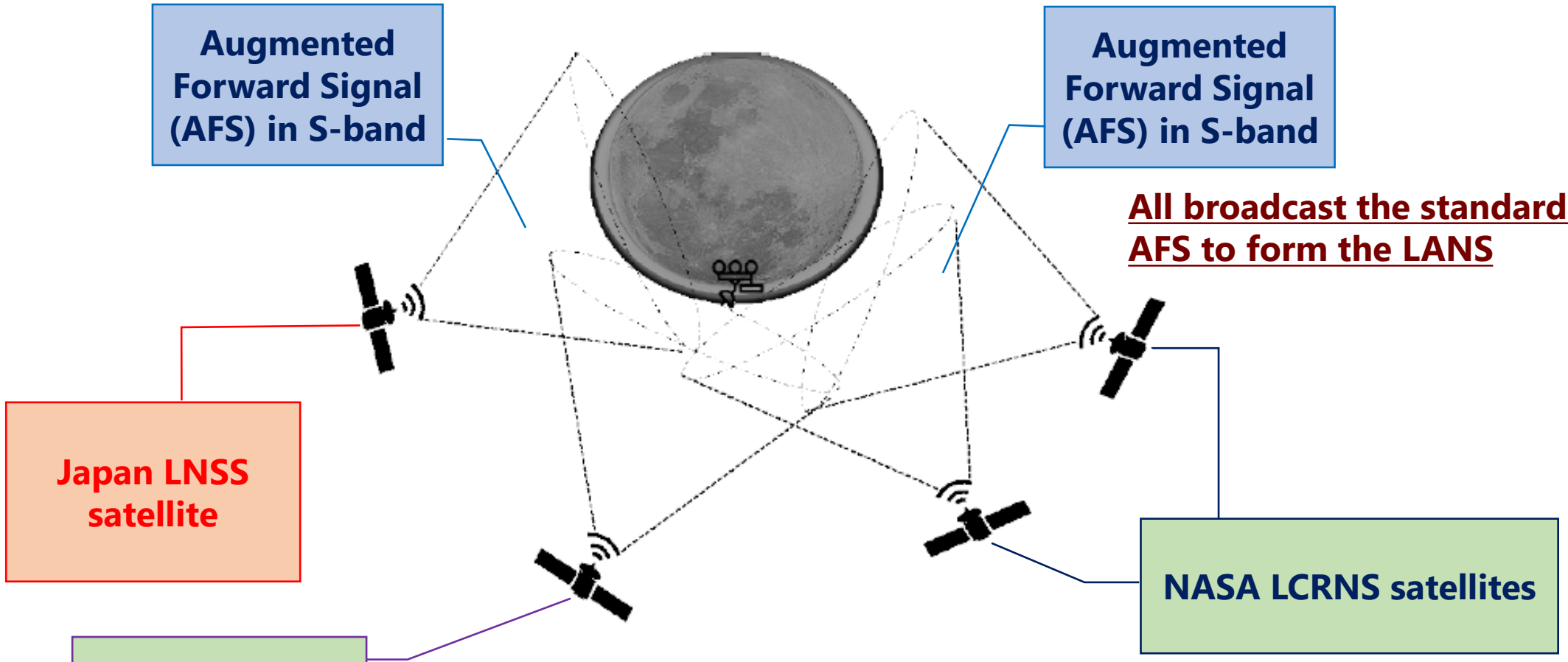


Figure 10 - LANS PNT Concept Provided by LunaNet Nodes

This figure was copied from the LunaNet Interoperability Specification (LNIS)

※LNIS is the standardization document for the LunaNet

LunaNet Interoperability Specification (LNIS)

Set of **mutually agreed-upon** specifications

This slide available at Space For Inspiration (2024) HP https://bsgn.esa.int/space-for-inspiration-5th-edition-from-4-5-december-2024-in-luxembourg/

Being developed with international partners through the **LNIS working group**

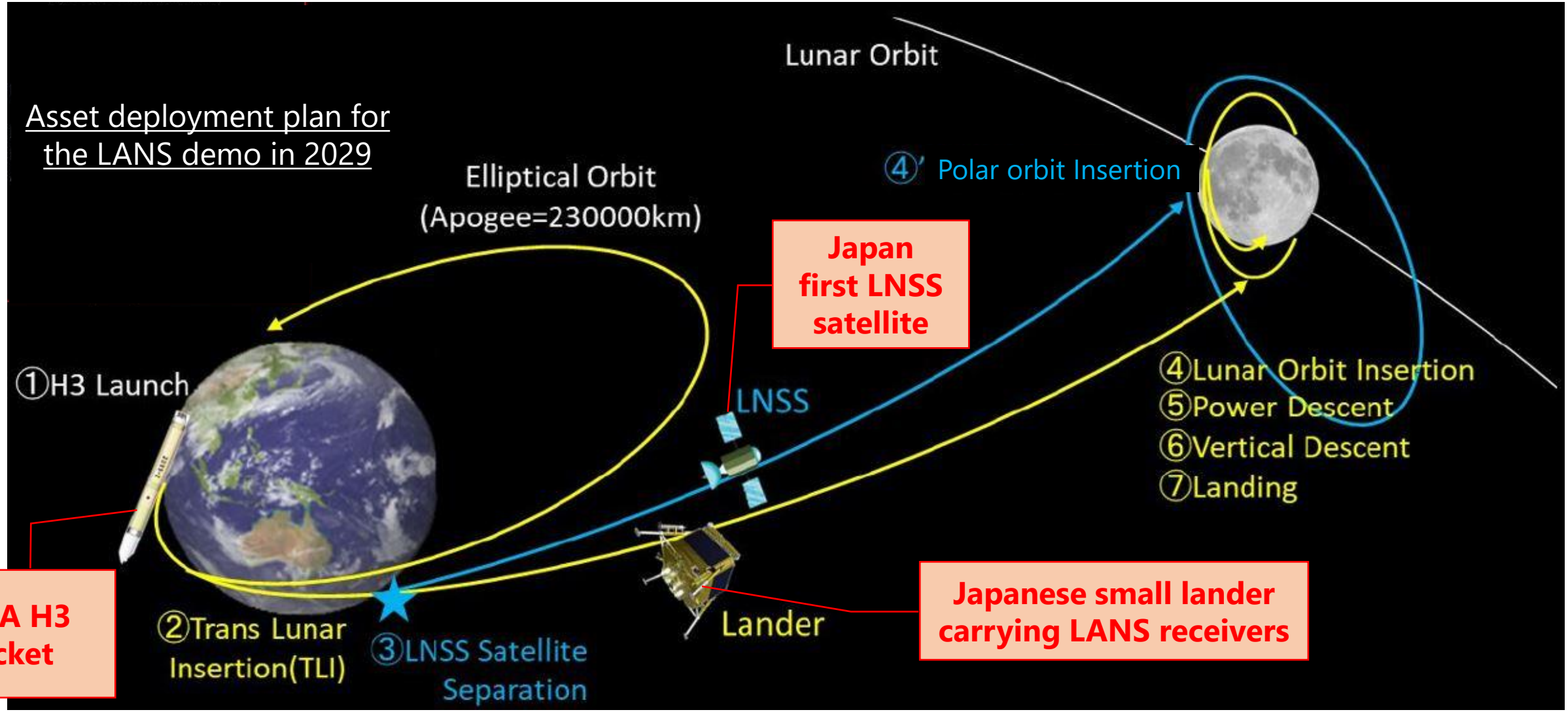
Includes a set **of Applicable Documents** (in development):

- AD1 Volume A LunaNet Signal-In-Space Recommended Standard (LSIS) Augmented Forward Signal (AFS)
- AD1 Volume B LunaNet Signal-In-Space Recommended Standard (LSIS) Point-to-Point Signals
- AD2 LunaNet Measurement Schema and Parameters
- AD3 LunaNet Detailed Message Definition Document
- AD4 LunaNet Location Services for Users
- AD5 Lunar Reference System and LunaNet Reference Time System Standard
- AD6 LunaNet Data Services Document
- AD7 LunaNet LunaSAR Definition Document
- AD8 LunaNet Interoperability Security Specifications

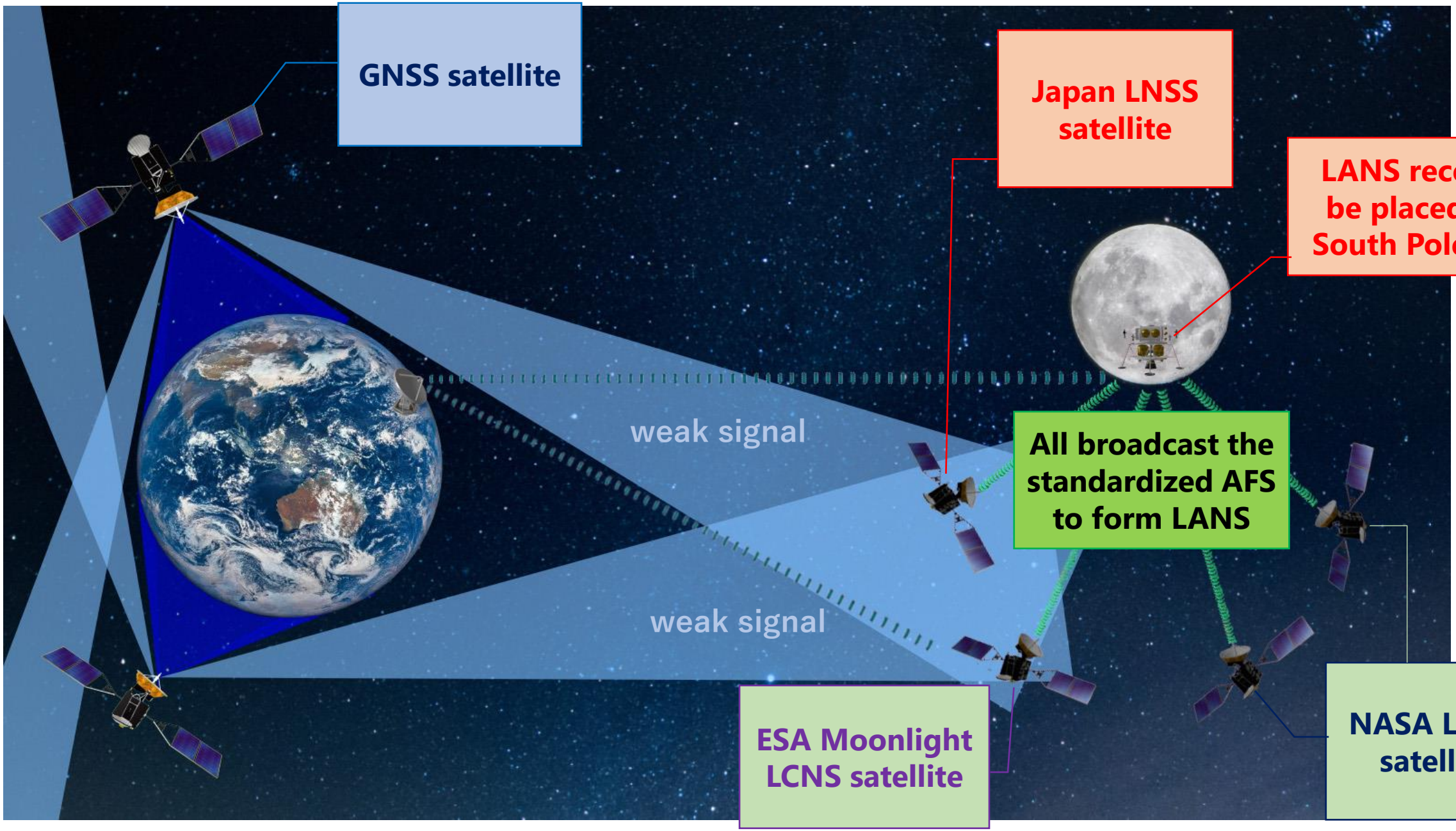
Soon Available

Plan of LANS interoperability and PNT demonstration mission targeting in 2029

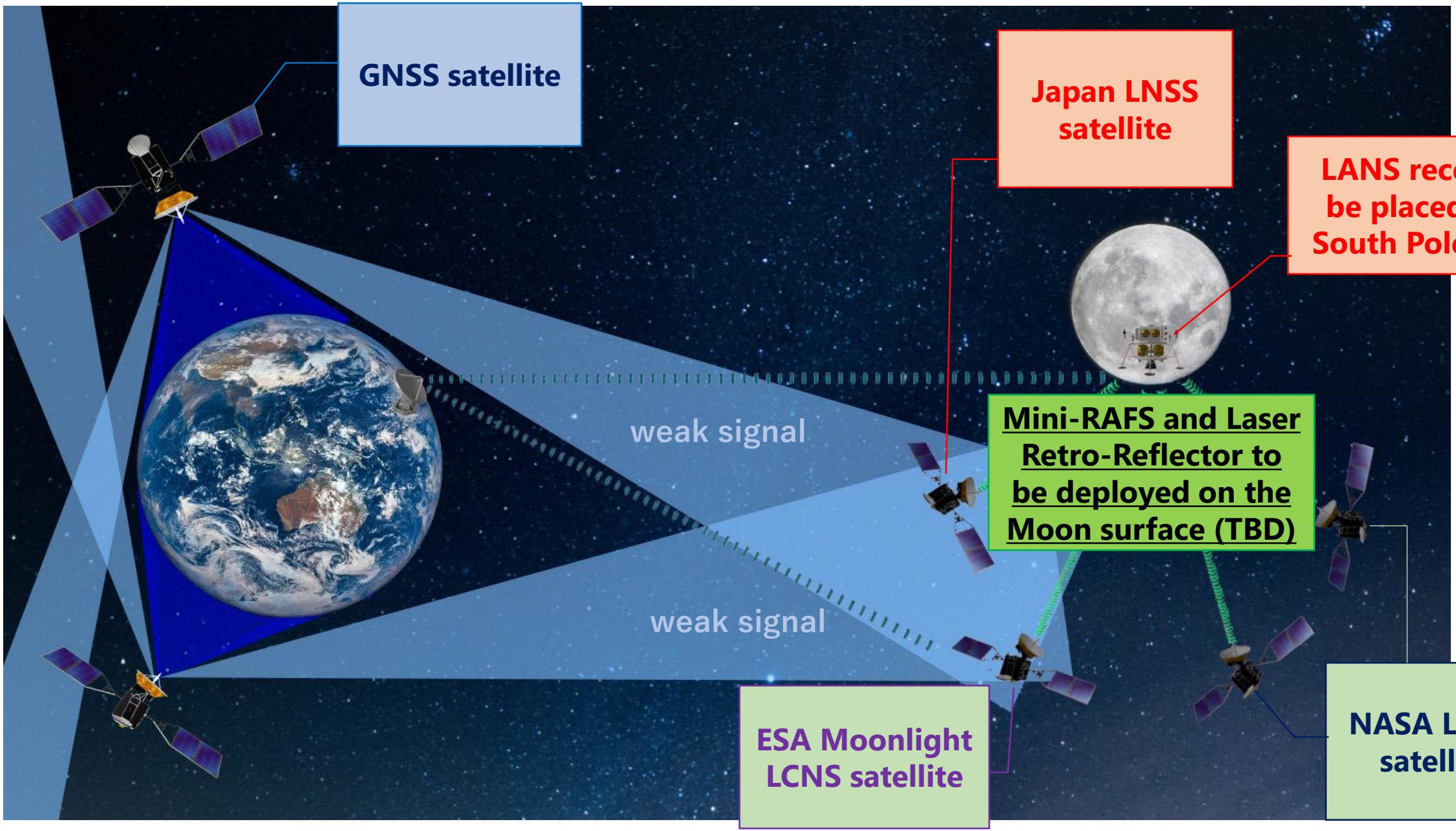
JAXA is proposing the first-ever ESA-NASA-JAXA LANS interoperability demonstration



LANS receiver to be placed at the South Pole region will receive all broadcasted AFSs

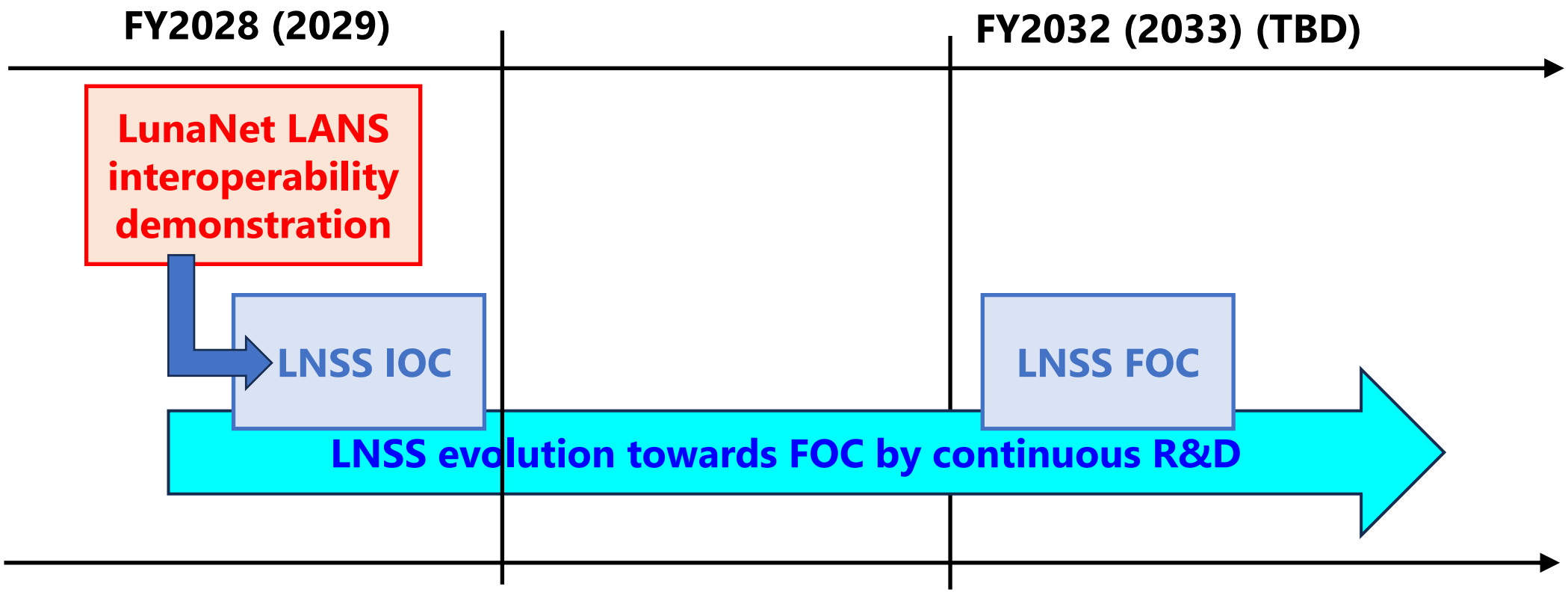


The SISEs for satellites forming the LANS and LANS PNT accuracy will be evaluated



JAXA's plan

Towards the LNSS Full Operating Capability (FOC) in 2032-2033 timeframe



- **Our feasibility study (FS) towards FOC has started from this year**
  - **LNSS SISE enhancement by using GNSS precise measurements and etc.**
  - **LNSS augmentation by using moon surface assets such as surface beacons**
  - **Development of LANS receiver PNT algorithm (combined navigation algorithm)**
  - **Service region expansion (satellite constellation design for entire moon surface)**

GPS WORLD
GNSS POSITIONING NAVIGATION TIMING

NASA and Italian Space Agency demonstrate lunar GNSS payload

January 16, 2025 - By Jesse Khalil

NASA and the Italian Space Agency (ASI) are collaborating on the Lunar GNSS Receiver Experiment (LuGRE), which seeks to demonstrate the viability of providing positioning, navigation and timing capabilities on the moon using GPS and Galileo signals.

2025/1/15
NASA and ASI launched the first-ever GNSS receiver to be placed on the Moon surface (landing scheduled this March)

This slide available at Space For Inspiration (2024) HP
https://bsgn.esa.int/space-for-inspiration-5th-edition-from-4-5-december-2024-in-luxembourg/

SSTL LUNAR

Lunar Pathfinder Capabilities

User return data-rates:

- Earth Link
  - 5Mbps X-band
- Moon Link*
  - 2 x 2.7Mbps S-band

Schedule for launch at the end of 2025. The first-ever GNSS reception in the lunar orbit (ELFO)

*depending on location

X-Band Earth Link

S-Band High-Gain Moon Link

S-Band Wide-Beam Moon Link

Communications

Laser Retro Reflector

GNSS Weak Signal Detection

Radiation Monitor

Hosted Payloads

Takeaways on Japan Lunar PNT

- LNSS first satellite launch expected in 2028/2029 to do the LANS interoperability and PNT accuracy demonstration with ESA and NASA

- Our feasibility study towards the LNSS FOC is ongoing, aiming for continuous accuracy enhancement and service region expansion (entire moon surface)

- <u>We continue working with our international partners to realize lunar PNT system of systems</u>

New working group on lunar PNT (WG-L) established at ICG last year!

Joint ICG-IOAG Multilateral Cislunar PNT Workshop

11-13 February 2025, Vienna, Austria and broadcast

Registration for online participants has started!

(Registration for in-person participants already closed)

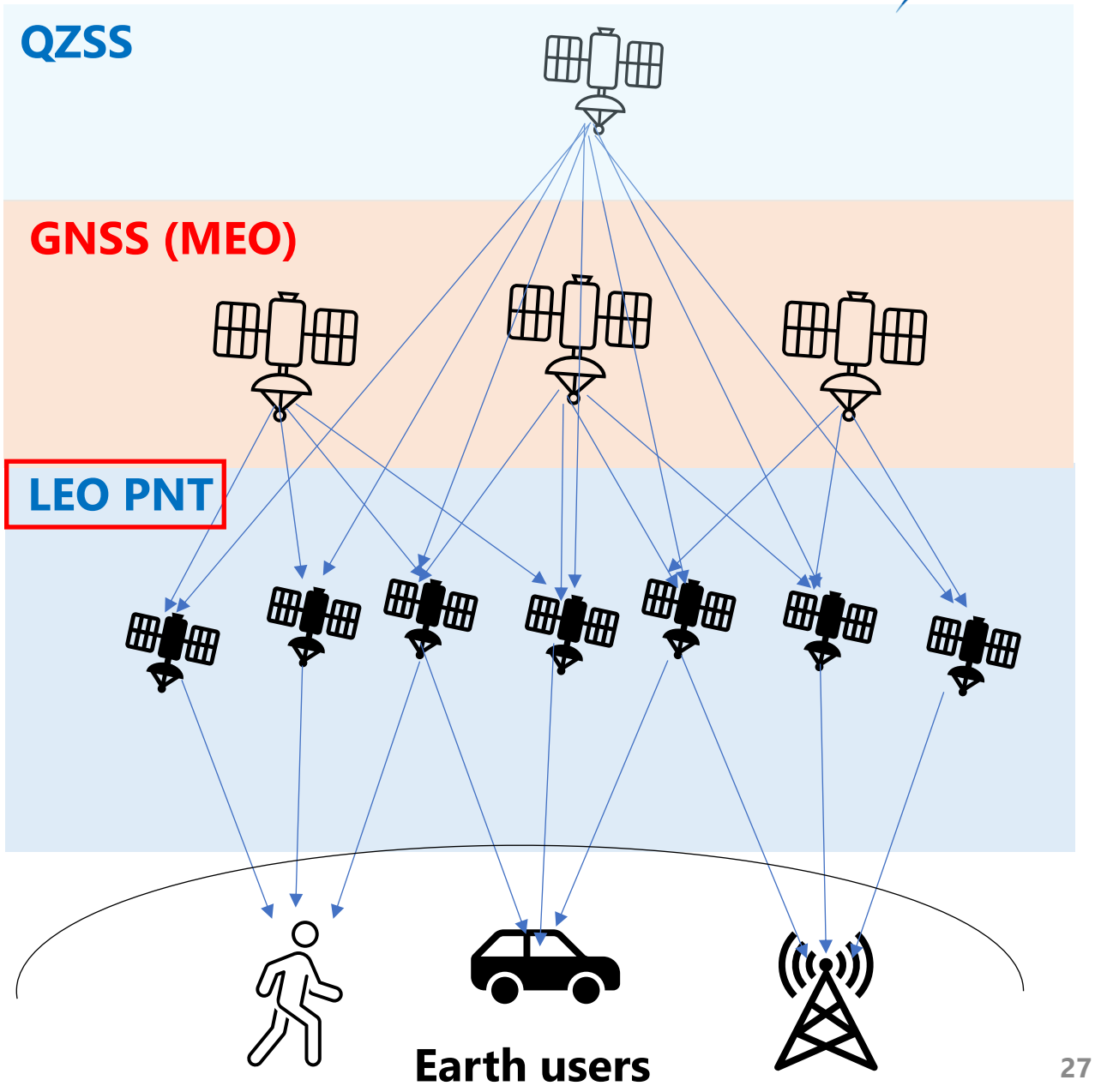
https://www.unoosa.org/oosa/en/ourwork/icg/working-groups/b/CislunarPNT2025.html

JAXA LEO PNT

Masaya Murata (JAXA)

Why LEO (Low Earth Orbit) PNT is so hot now?

- LEO PNT augmentation for the existing GNSS
  - Realizing ultra-rapid PPP convergence service
- Stronger navigation signal emitted from the LEO
  - Strong against the existing GNSS jamming/spoofing
- And global PNT service for applications requiring higher, faster, and more robust PNT performance



Planned LEO PNT systems from USA, China, and Europe

- USA
  - Xona Space
    258 satellites
    L1, L5 bands
  - TrustPoint
    288 satellites
    S, C1 bands
- China
  - CentiSpace
    190 satellites
    L1, L5 bands
  - China Satellite Network Group
    504 satellites
    L1, L5 bands
- Europe
  - European Space Agency (ESA)
    10 demo satellites
    L1, L5, S, C1-C4 bands

Deployment of navigation satellites at low earth orbits (LEO) to realize multi-layered GNSS

Initial Operational Capability (IOC) Plans

- USA
  - Xona Space
    16 satellites
    in 2026
  - TrustPoint
    100+ satellites
    in 2027
- China
  - CentiSpace
    190 satellites
    in 2026
  - China Satellite Network Group
    168 satellites
    in 2025
- Europe
  - European Space Agency (ESA)
    10 demo satellites
    in 2027

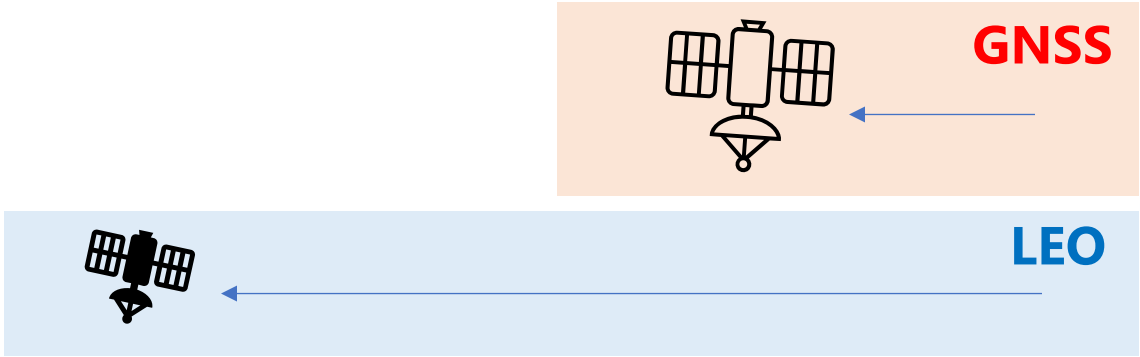
2025/1/13

Chinese sea launch sends 10 navigation enhancement satellites into orbit for CentiSpace

https://spacenews.com/chinese-sea-launch-sends-10-navigation-enhancement-satellites-into-orbit/

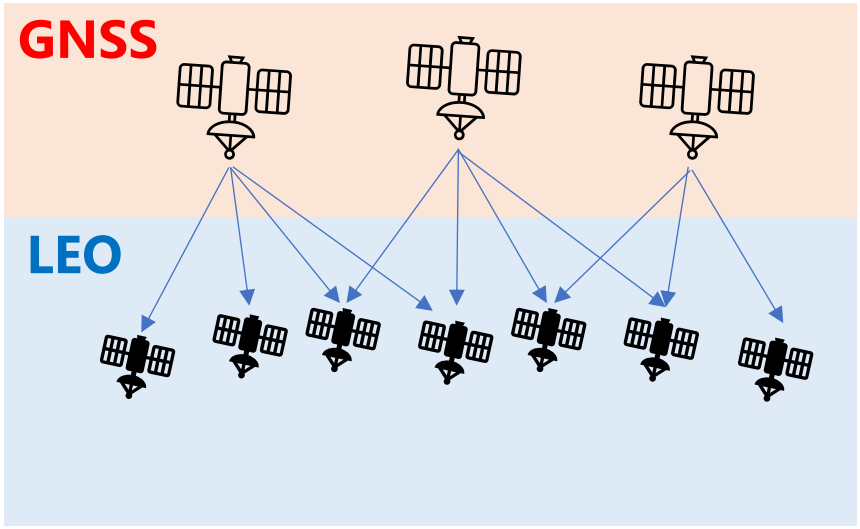
Acceleration of PPP Convergence by LEO PNT

1.



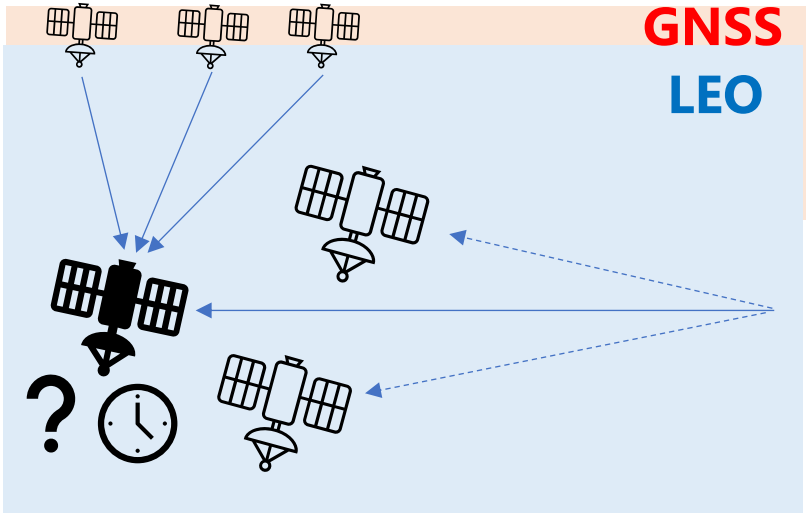
・Much faster satellite movement than GNSS, yielding temporally diversified measurements

2.



・Much larger number of satellites than GNSS, yielding spatially diversified measurements

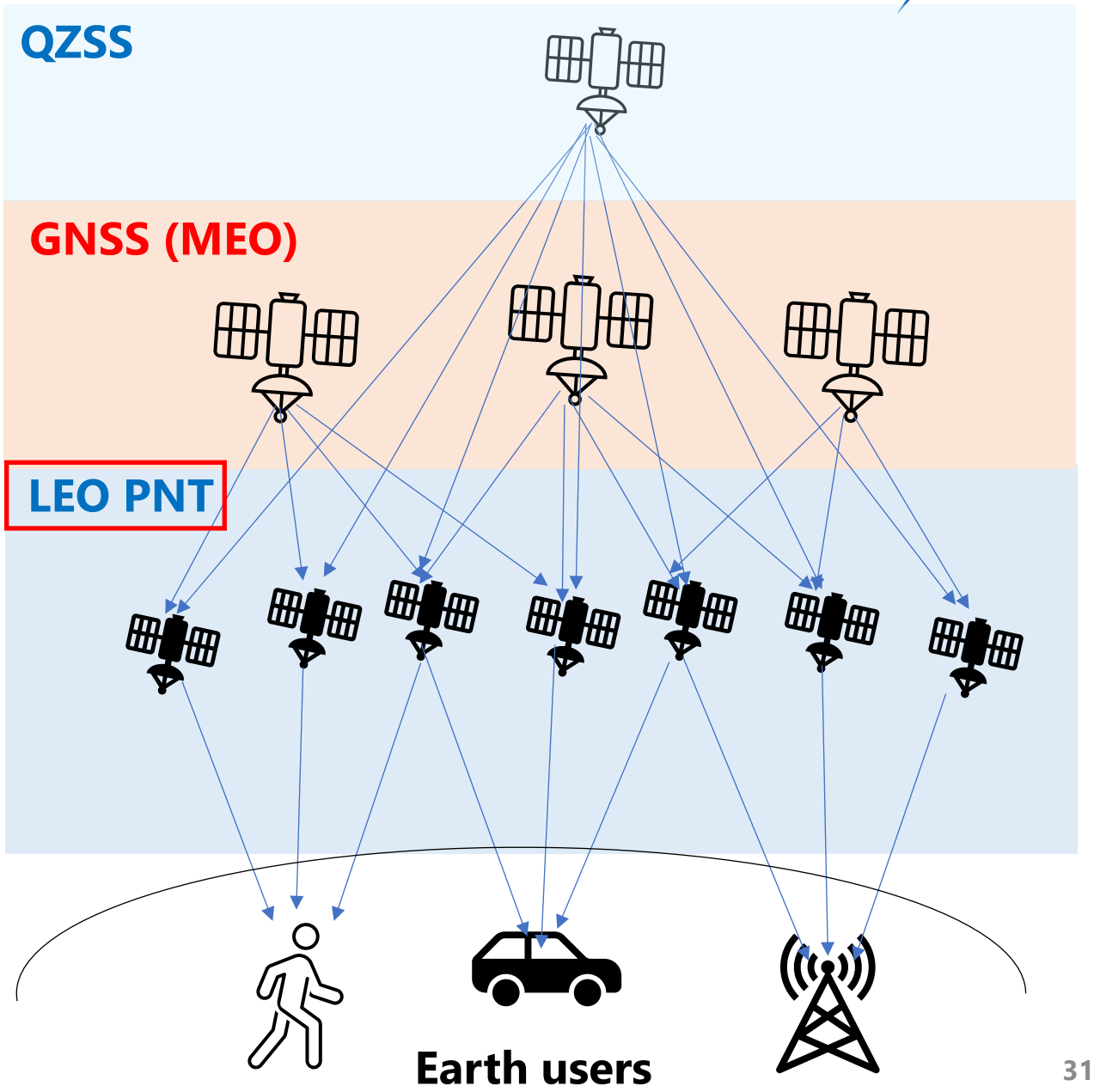
3.



・Real-time low SISE (Signal-In-Space Error) for LEO sats thanks to precise GNSS measurements

JAXA LEO PNT Concept

- LEO PNT augmentation for the existing GNSS
- Enabling ultra-rapid global PPP convergence service for Earth users
- Highly autonomous LEO PNT system driven by onboard GNSS navigation for LEO sats
- No harm against the existing GNSS by utilizing new C1-C4 bands (5010-5250 MHz)

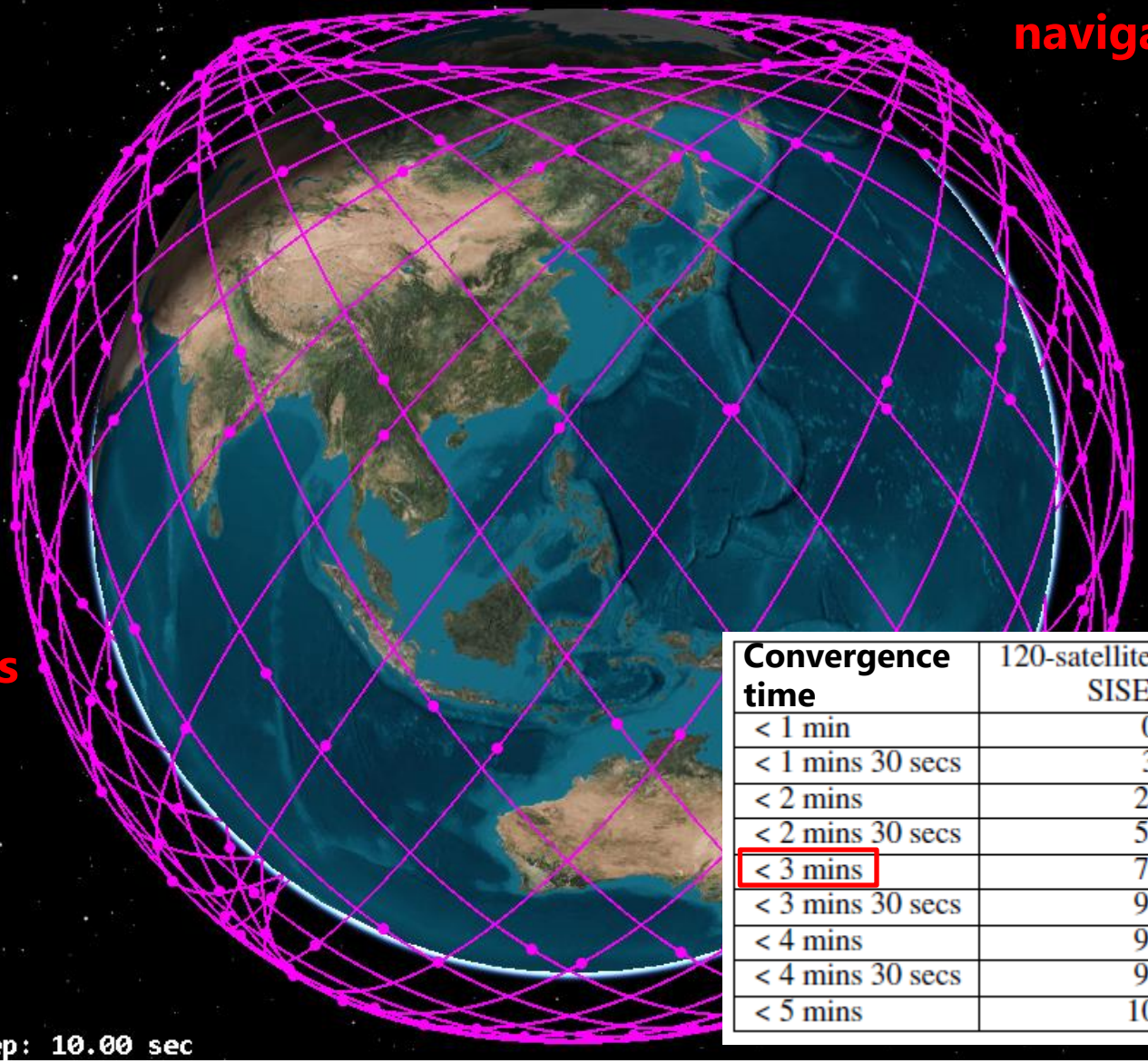


Phase I (2030)

Our LEO PNT Constellation Plan Using 240 Satellites

Walker 55° :240/24/1 (Altitude = 975km)

SISE of 20cm (RMS) by GNSS navigation for LEO satellites



LEO PNT navigation signal in C1-C4 bands (5010-5250 MHz)

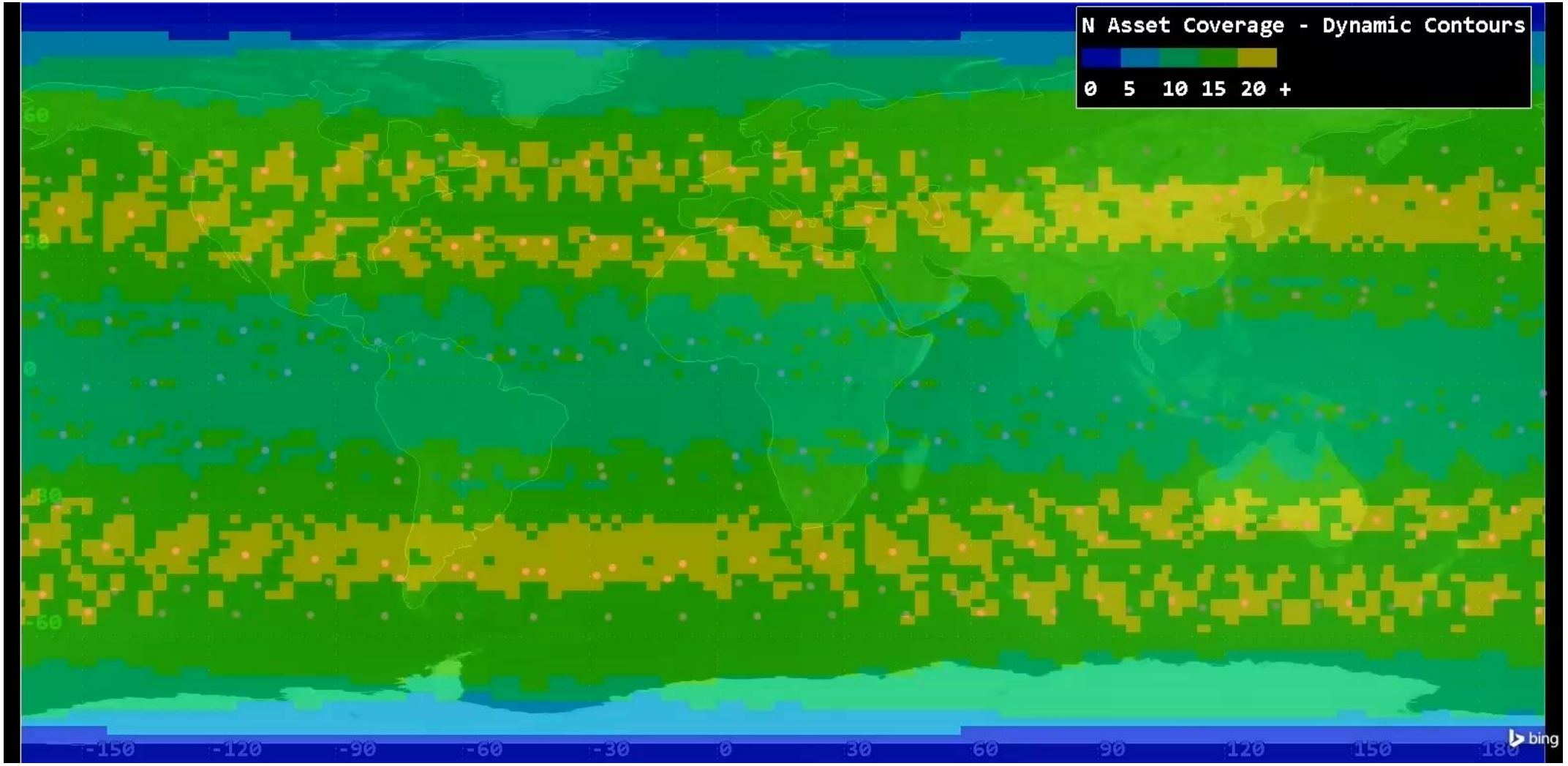
10cm-level horizontal PPP convergence less than three minutes

Convergence time	120-satellite constellation, SISE=20cm	240-satellite constellation, SISE=20cm
< 1 min	0%	1%
< 1 mins 30 secs	3%	22%
< 2 mins	23%	67%
< 2 mins 30 secs	57%	96%
< 3 mins	78%	99%
< 3 mins 30 secs	90%	100%
< 4 mins	96%	100%
< 4 mins 30 secs	99%	100%
< 5 mins	100%	100%

Phase I (2030)

240-Satellite Constellation: Satellite Visibility Analysis

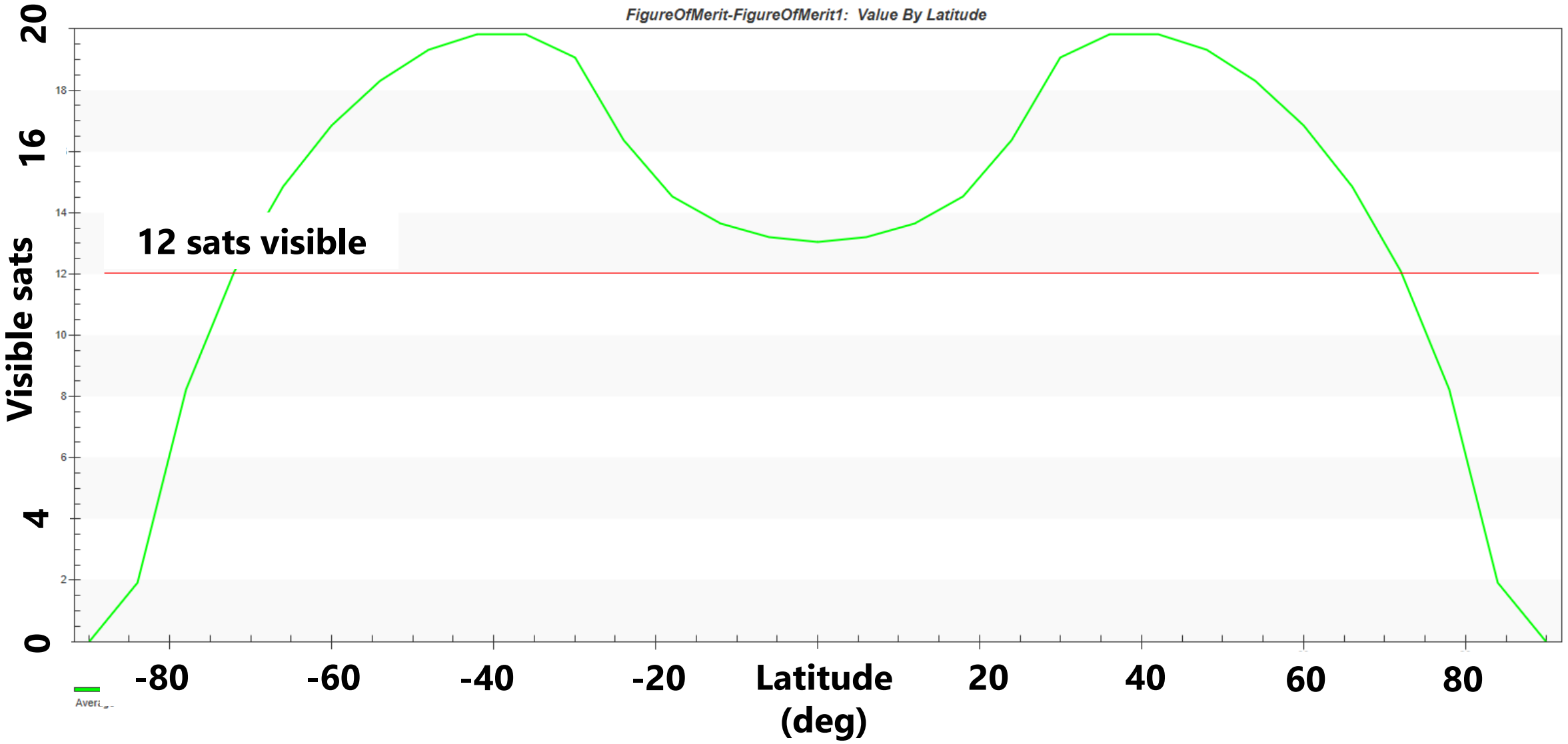
Walker 55° :240/24/1 (Altitude = 975km)



Phase I (2030)

240-Satellite Constellation: Average Visible Sats vs. Latitude

Walker 55° :240/24/1 (Altitude = 975km)

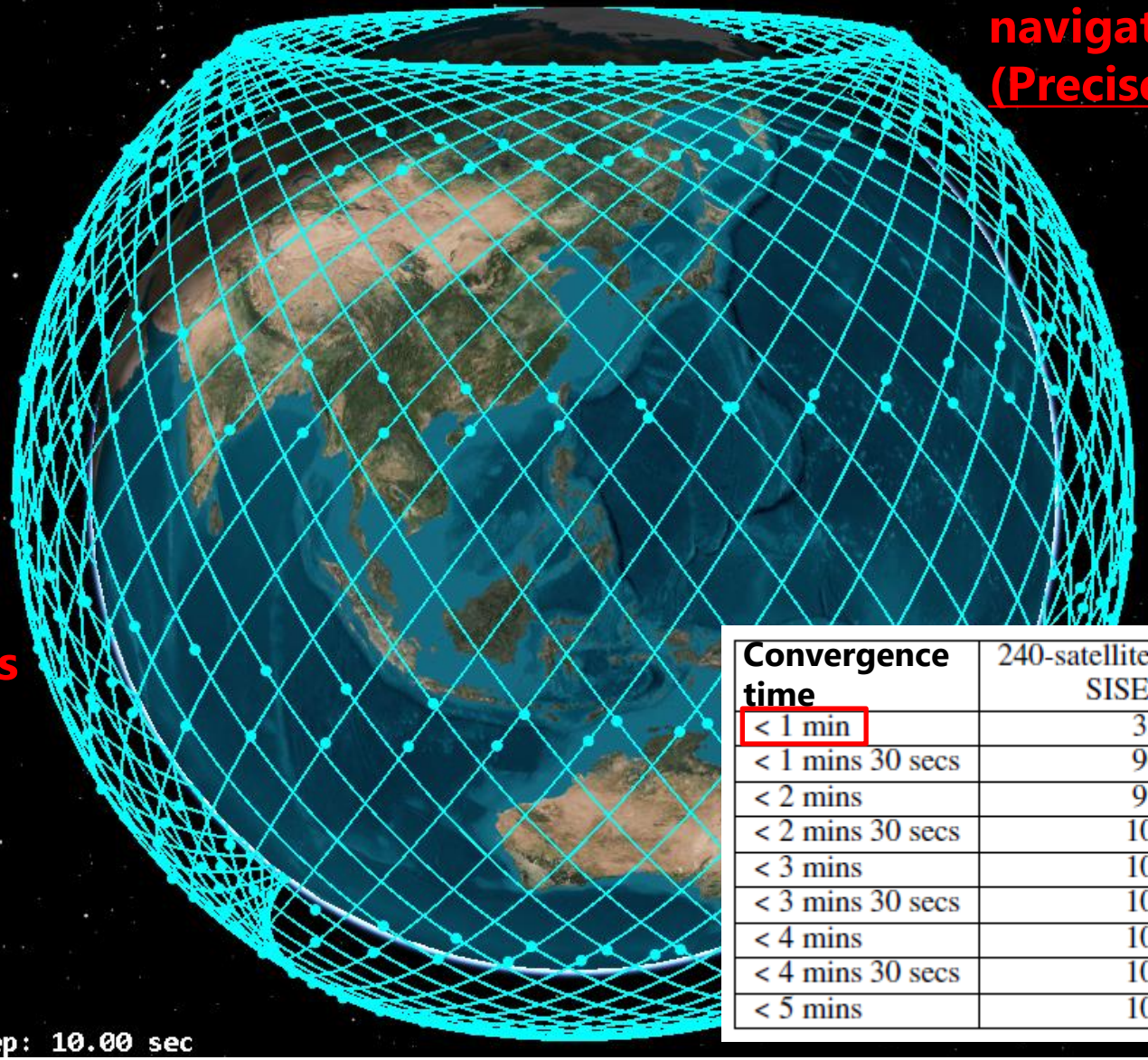


Phase II (2035)

Our LEO PNT Constellation Plan Using 480 Satellites

Walker 55° :480/48/1 (Altitude = 975km)

SISE of 10cm (RMS) by GNSS navigation plus on-ground POD (Precise Orbit Determination)



LEO PNT navigation signal in C1-C4 bands (5010-5250 MHz)

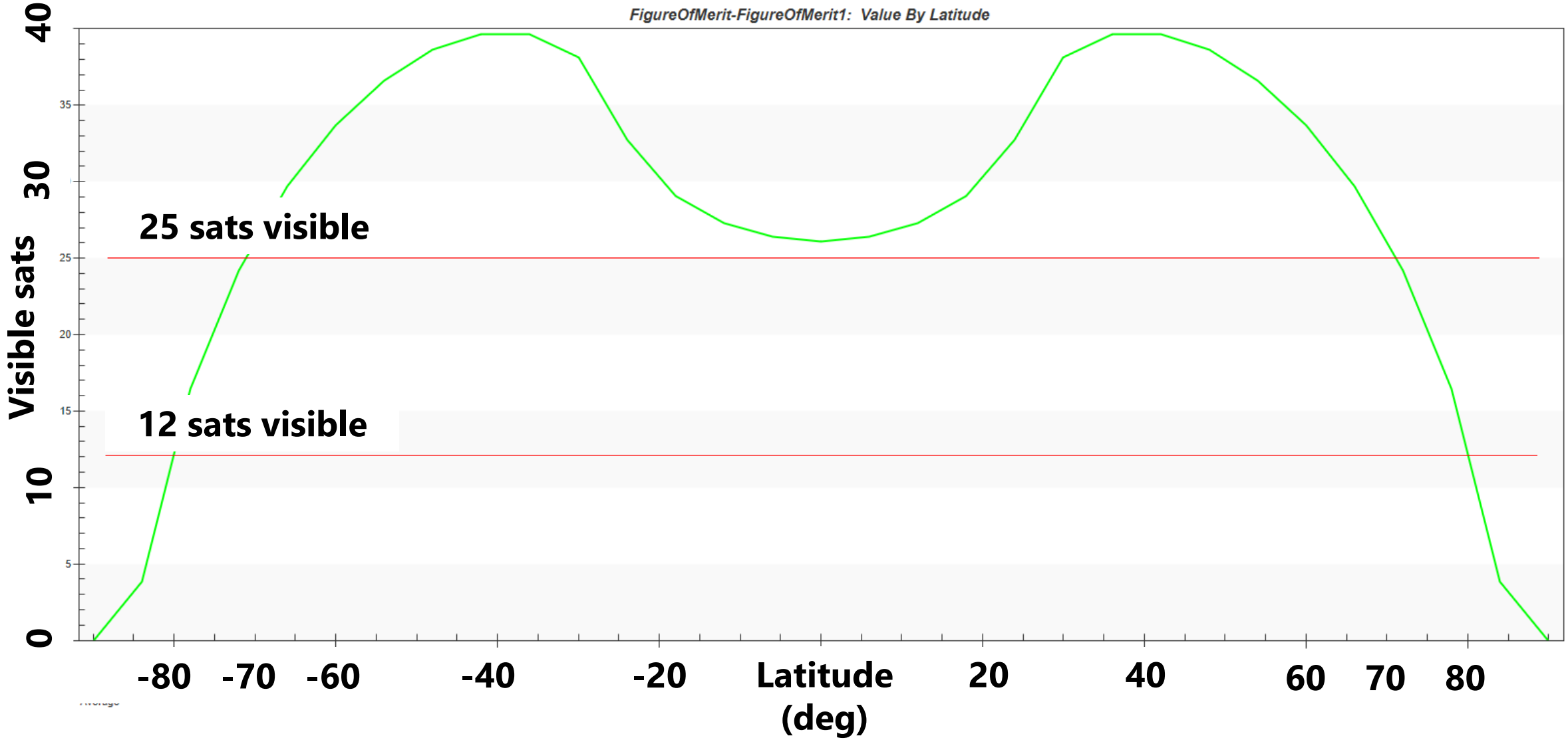
10cm-level horizontal PPP convergence less than one minute!

Convergence time	240-satellite constellation, SISE=10cm	480-satellite constellation, SISE=10cm
< 1 min	33%	77%
< 1 mins 30 secs	90%	99%
< 2 mins	99%	100%
< 2 mins 30 secs	100%	100%
< 3 mins	100%	100%
< 3 mins 30 secs	100%	100%
< 4 mins	100%	100%
< 4 mins 30 secs	100%	100%
< 5 mins	100%	100%

Phase II (2035)

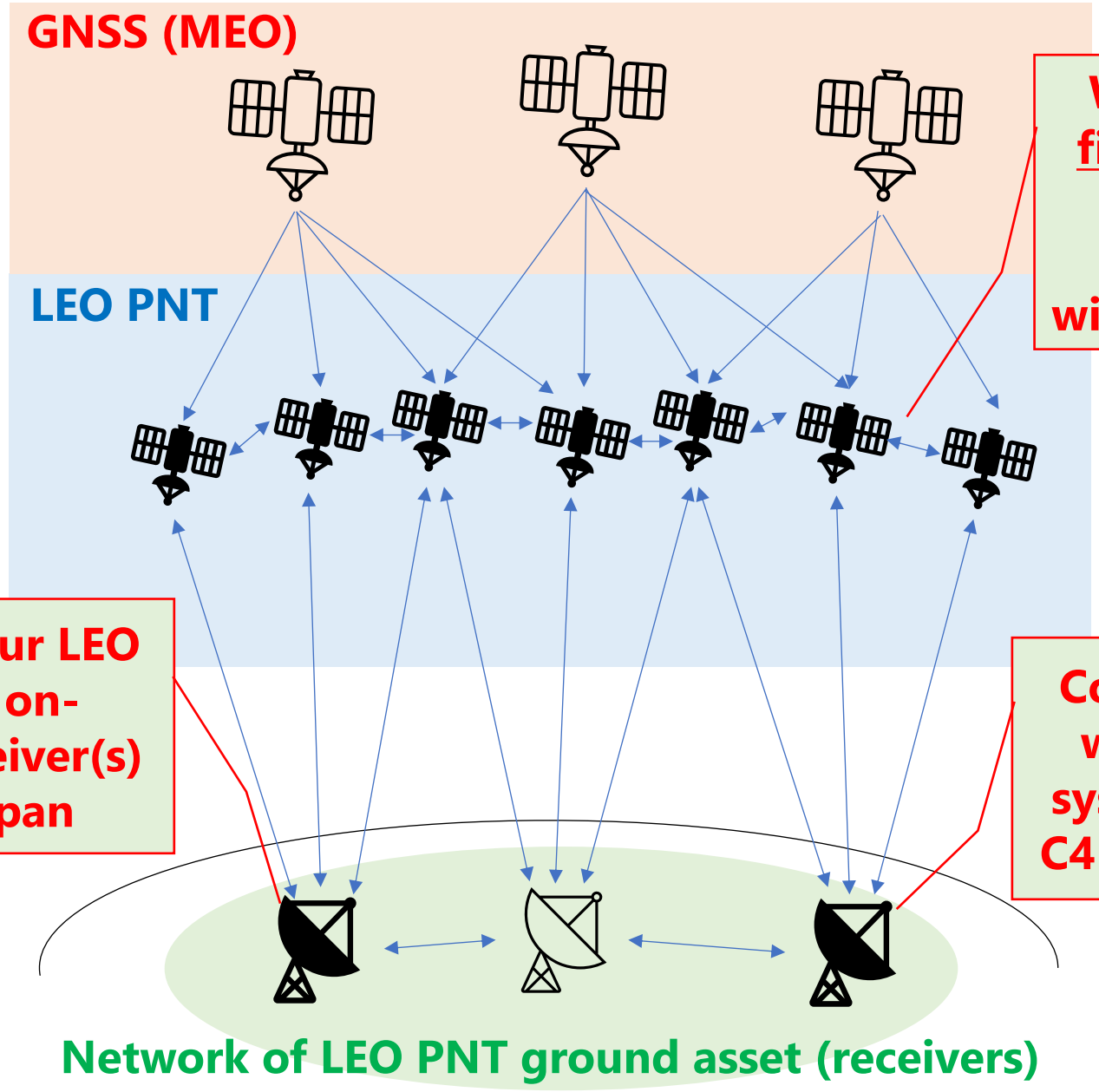
480-Satellite Constellation: Average Visible Sats vs. Latitude

Walker 55° :480/48/1 (Altitude = 975km)



Demonstration Mission (2027)

Our LEO PNT Demonstration Under Planning



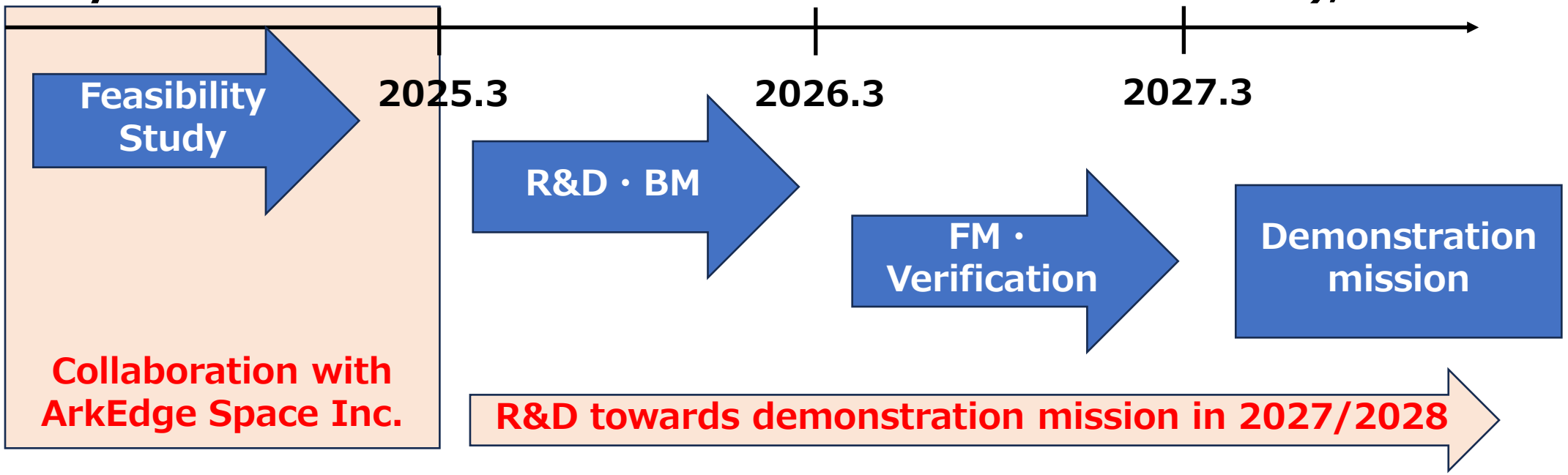
We plan to propose the first-ever multi-LEO PNT constellation demo through collaboration with international partners

SISE evaluation for our LEO PNT signals using on-ground LEO PNT receiver(s) to be placed in Japan

Compatibility verification with the other LEO PNT systems for using new C1-C4 bands (5010-5250 MHz)

JAXA has initiated the LEO PNT FS

1. LEO PNT system, satellite constellation trade-off study
2. Evaluation of GNSS navigation accuracy for LEO navigation satellite
3. PPP convergence time evaluation by LEO PNT (horizontal accuracy of less than 10 cm within three minutes)
4. Trade-off evaluation on LEO PNT signal format and frequency
5. Satellite concept design and cost evaluation for demonstration mission
6. Activity at ITU for extended C-band（collaboration with ESA), etc.



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Our LEO PNT activity has attracted many interests from overseas

Civil

ArkEdge Space wins JAXA position, navigation and timing contract

Debra Werner October 17, 2024

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Business Launch Civil VC/PE Military Polaris Payload Pioneers 2024

INTERNATIONAL • SATCOM

JAXA Selects ArkEdge to Study LEO PNT System

By Douglas Gorman October 18, 2024

The 15th

Multi-GNSS Asia Annual Conference

4th - 7th Mar. 2025

4 - 7 March | @Phuket, Thailand

Registration Opening Soon

Programme at a Glance

4th Mar	1. Exhibition Opening 2. MGA Grand Opening : Opening session -JP-TH 10 years & Phuket Tsunami Memorial 20 -MGA Grand Opening Sponsors Talk -RPD Challenge Award Ceremony
5th Mar	Diamond Sponsor Session System Provider session
	Emerging System session -LEO-PNT -Lunar PNT
6th Mar	Application session -Disaster and Environmental problem mitigation & -GNSS service for mass market -GNSS x EO application

We are now organizing the LEO PNT panel at the MGA2025 conference to be held on 4th-7th this March (we also held the same panel at the MGA2024)

Reference: LEO PNT panel at MGA2024

)-12:30 (ICT)
Room 516

Low Earth Orbit PNT

Moderator

Dr. Masaya Murata
JAXA

- *Mr. JJ Miller, NASA*
- *Mr. Pietro Giordano, ESA*
- *Dr. Tyler Reid, Xona Space Systems*
- *Mr. Joshua Critchley-Marrows, ArkEdge Space*
- *Dr. Xu Mingliang, Centispace*
- *Dr. Masaya Murata, JAXA*

Takeaways on JAXA LEO PNT

- JAXA LEO PNT aims for global fast-convergence PPP service
  - Making the PNT strong against the L-band jamming/spoofing as well

- We are now doing the LEO PNT feasibility study with the ArkEdge Space, designing the future Japan LEO PNT system
  - We will take a full consideration on avoiding collision with the other systems under planning and minimizing the risk of debris occurrence

- We are now preparing for the contribution to the ITU study in accordance with Resolution 684 on using the C2-C4 bands (5030-5250MHz) for our LEO PNT system

- We plan to perform the first-ever multi-LEO PNT constellation demo in 2027. <u>International collaboration is the key of success</u>