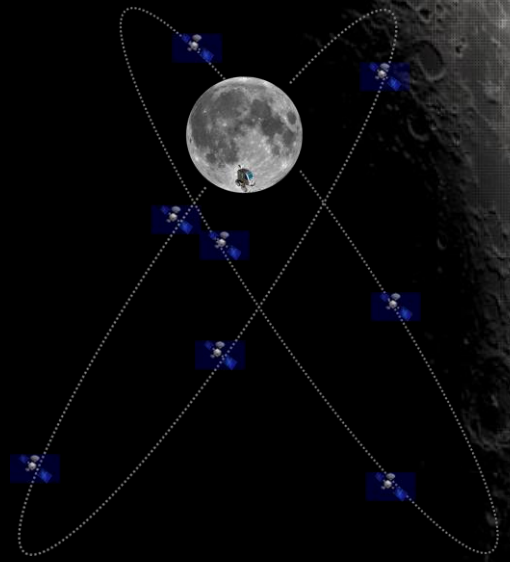
Joint ICG-IOAG Multilateral Cislunar PNT Workshop

Session1: Overview of Lunar PNT Frameworks & Systems (Part II)

Japan

Lunar Navigation Satellite System



Japan Lunar Navigation Satellite System (LNSS) and Its Contribution Towards LANS

11th February, 2025

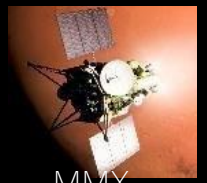
Masaya Murata (Japan Aerospace Exploration Agency)

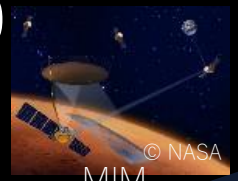
Overview of JAXA Roadmap from LEO to Moon/Mars

2020 2030 2040

Expanding Human Presence

MARS


MMX



MIM

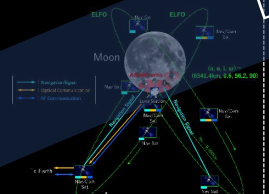
Robotic Tech Demo → Crewed Missions


Kaguya

Landed!


SLIM


LUPEX



LNSS/LANS demo


HTV-XG


Cargo Lander

MOON

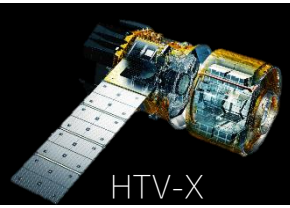
Gateway

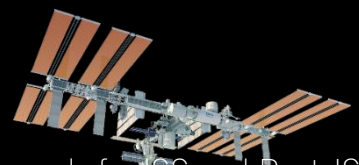
Pressurized Crew Rover


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)

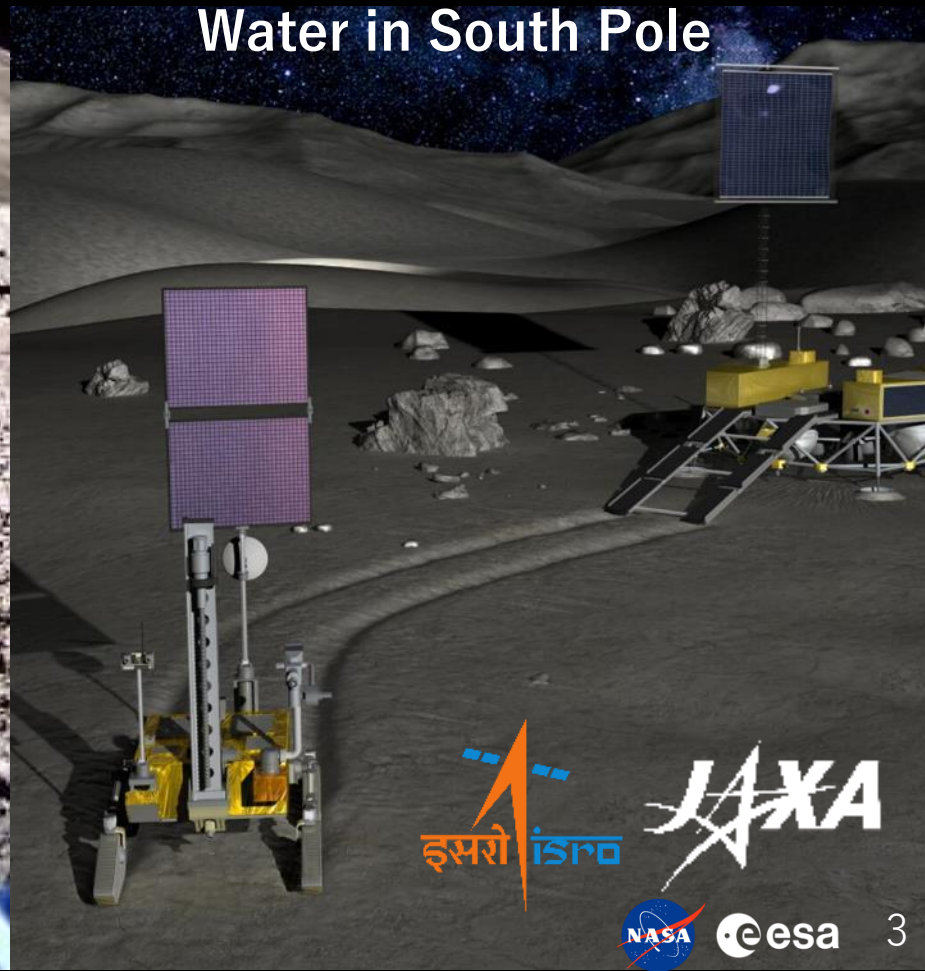
- Launch: on Sept. 7, 2023
- Moon Landing: Jan. 20, 2024

- **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

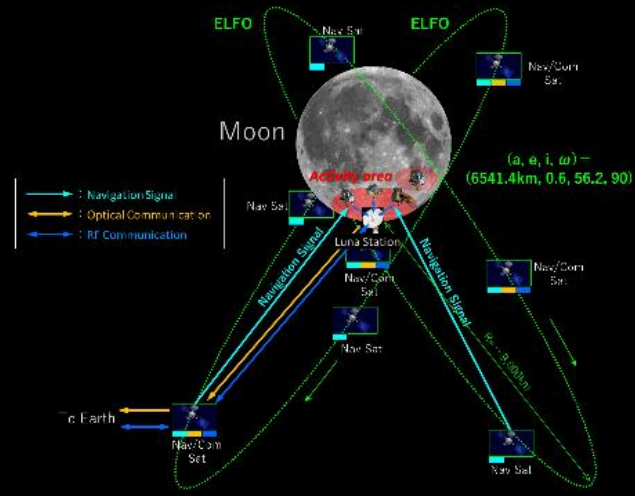
- Environment Control and Life Support Capability in I-HAB
- Batteries for HALO

Logistics Module

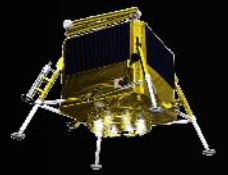
HTV-X (HTV-XG)

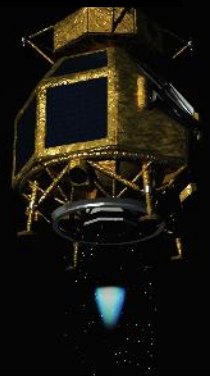
- Logistic Resupply capability
- 4,000kg of pressurized cargo to Gateway within 30 days

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

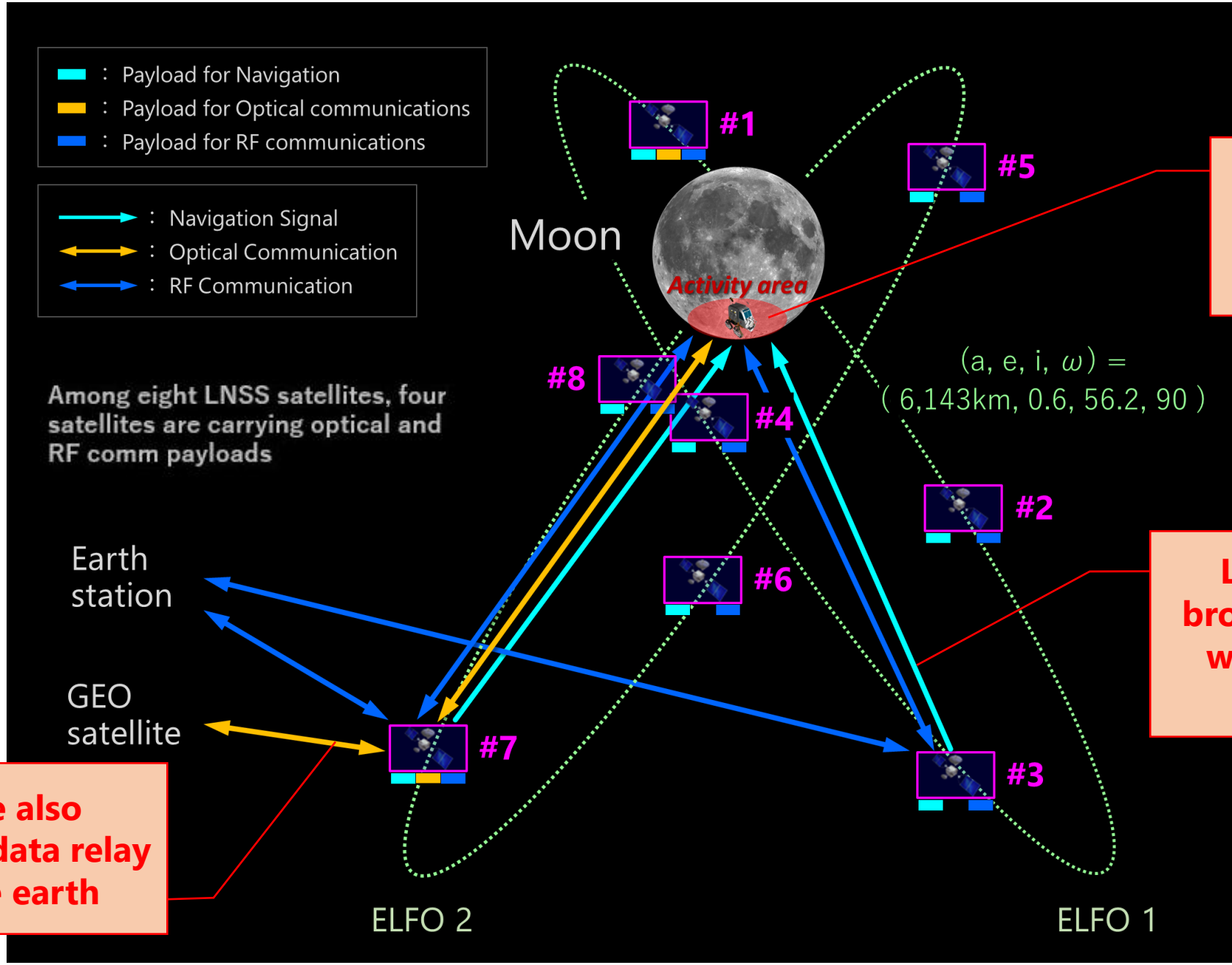
✓ **Provision of a Pressurized Rover** by Japan

✓ **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

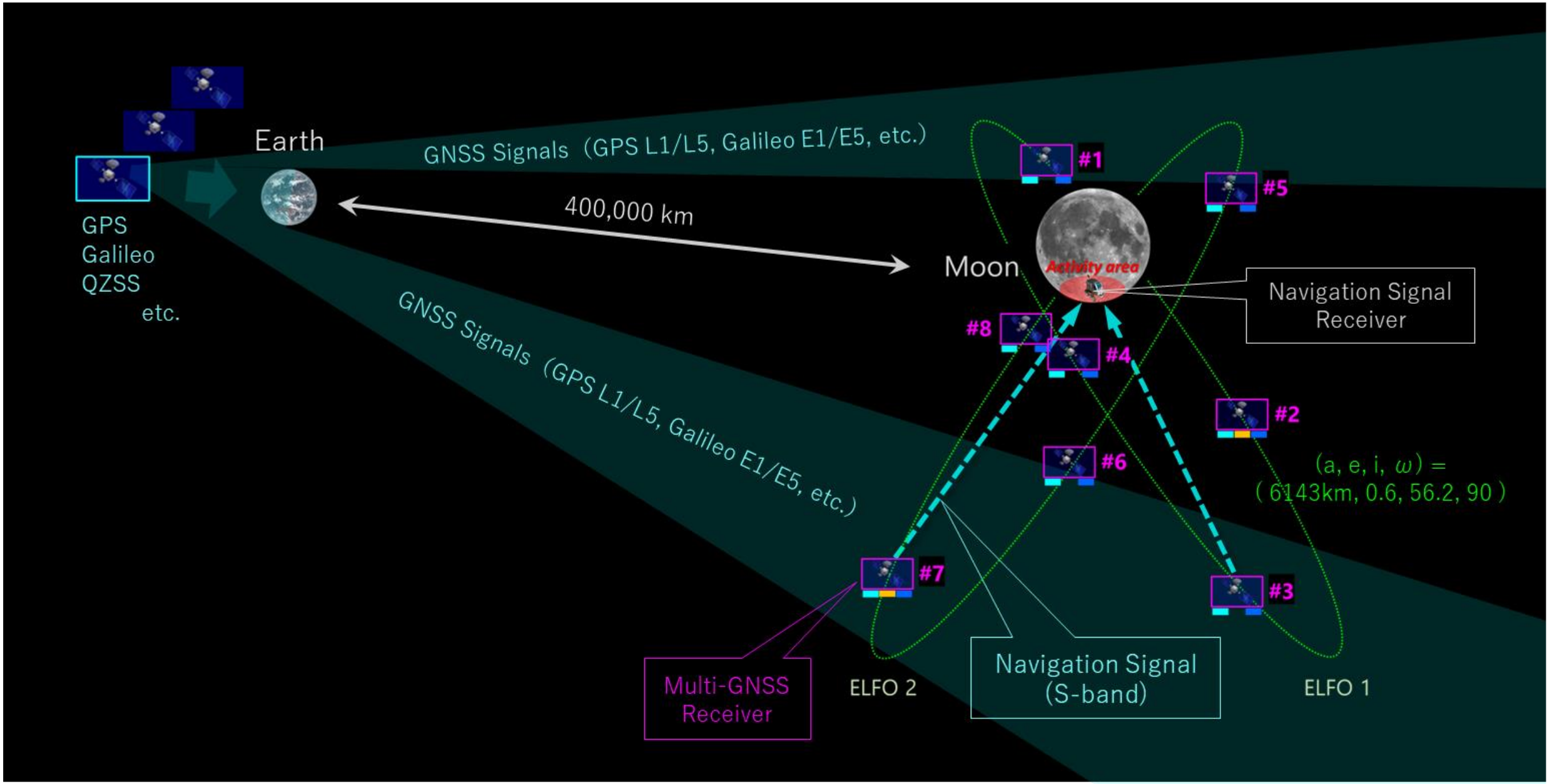


Target: South Pole region

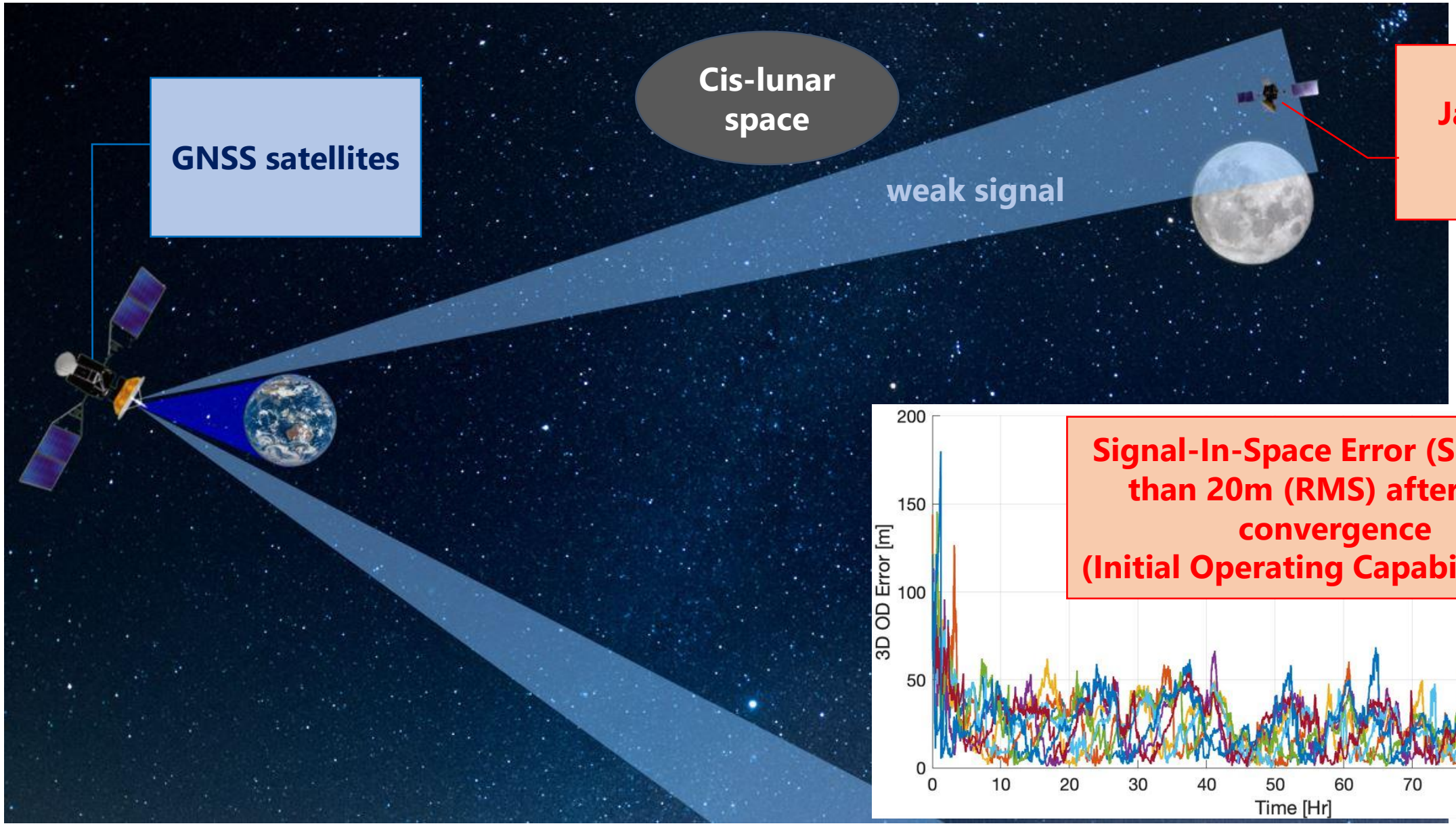
LNSS satellite broadcasting one-way navigation signal

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

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

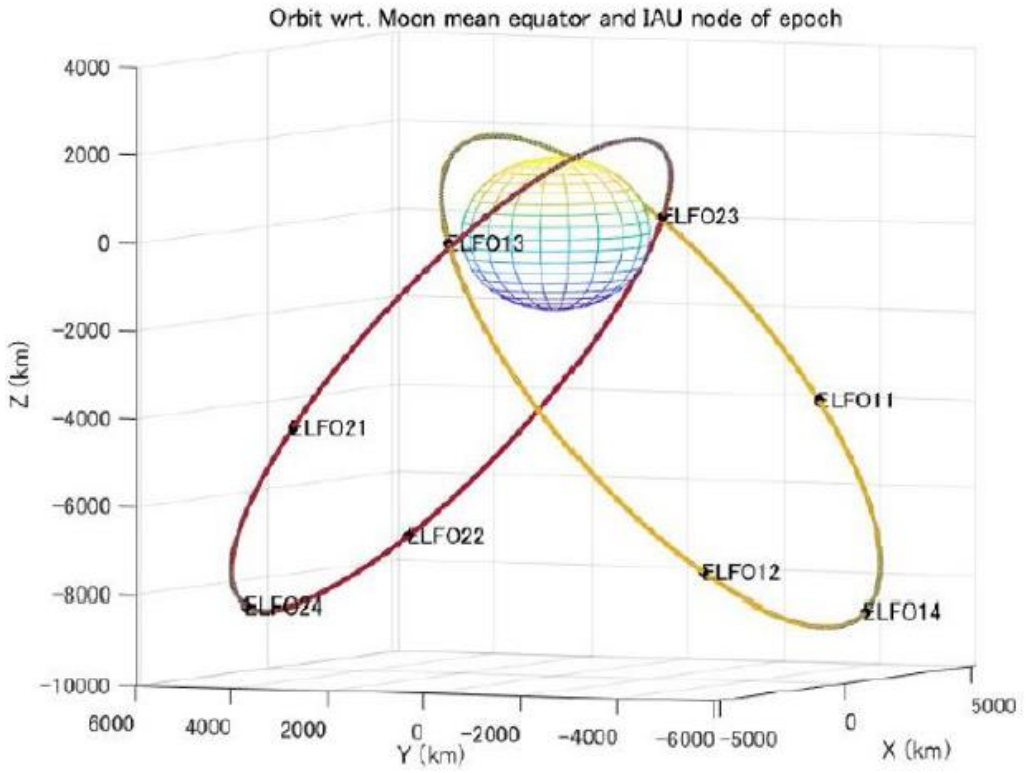


GNSS weak signals drive our LNSS, 20m SISE (RMS) at IOC, 10m SISE (RMS) at FOC

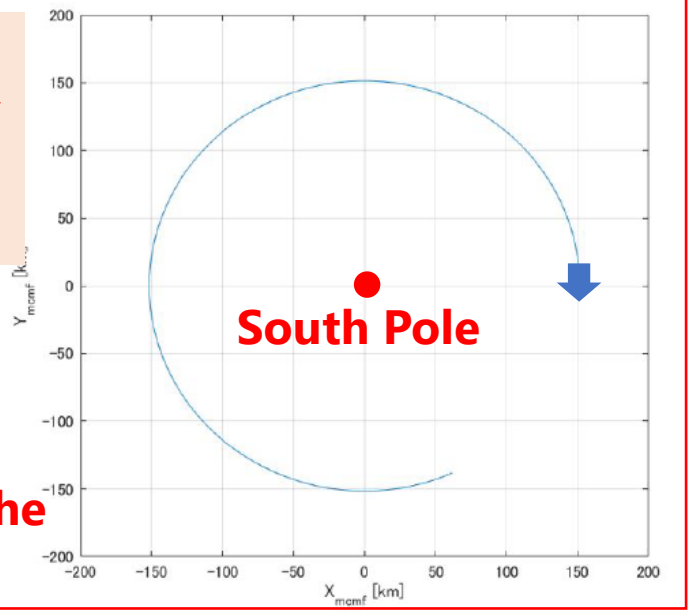


Signal-In-Space Error (SISE) less than 20m (RMS) after filter convergence (Initial Operating Capability, IOC)

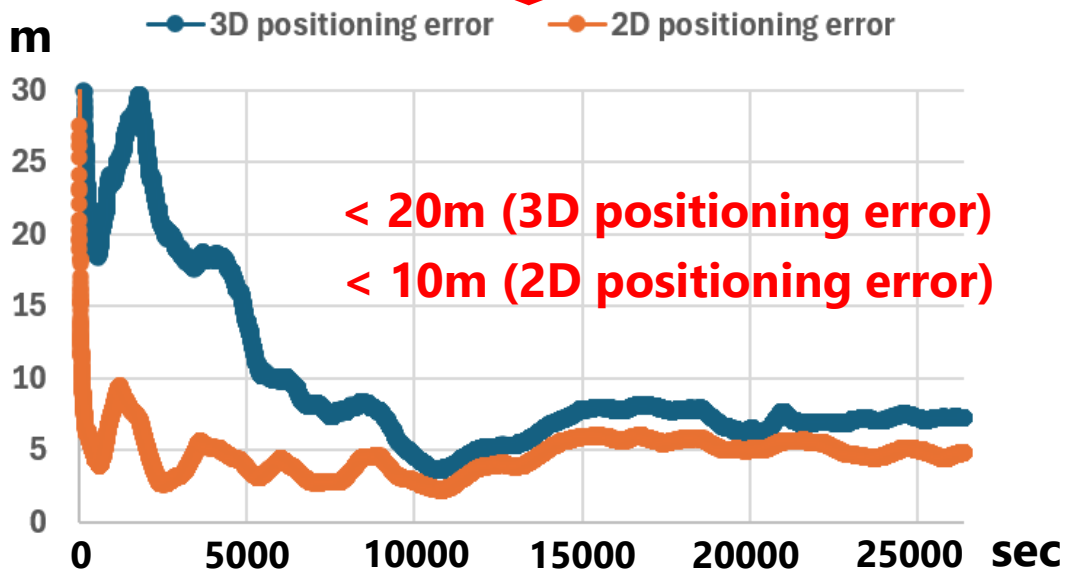
Typical LNSS PNT accuracy for a moving object (receiver) at the South Pole region



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



The onboard filter (EKF) processing the LNSS measurements showed the following performance:



LNSS orbital elements in earth orbit plane frame (Ely, 2005)

SV	A[km]	E	I[deg]	RAAN[deg]	AP[deg]	MA[deg]
ELFO11	6540	0.6	56.2	0	90	0
ELFO12	6540	0.6	56.2	0	90	180
ELFO13	6540	0.6	56.2	0	90	90
ELFO14	6540	0.6	56.2	0	90	270
ELFO21	6540	0.6	56.2	180	90	0
ELFO22	6540	0.6	56.2	180	90	180
ELFO23	6540	0.6	56.2	180	90	90
ELFO24	6540	0.6	56.2	180	90	270

Collaboration with NASA and ESA for LunaNet

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

ESA Moonlight LCNS (2028～)

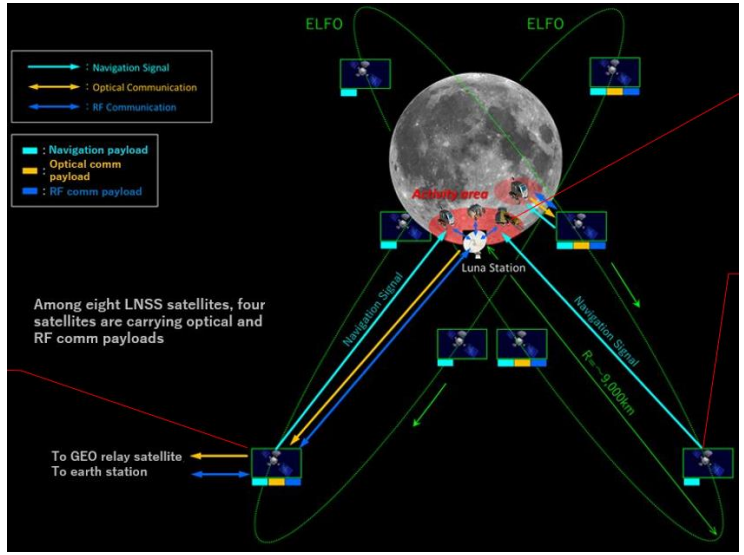
Contractor: Telespazio

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

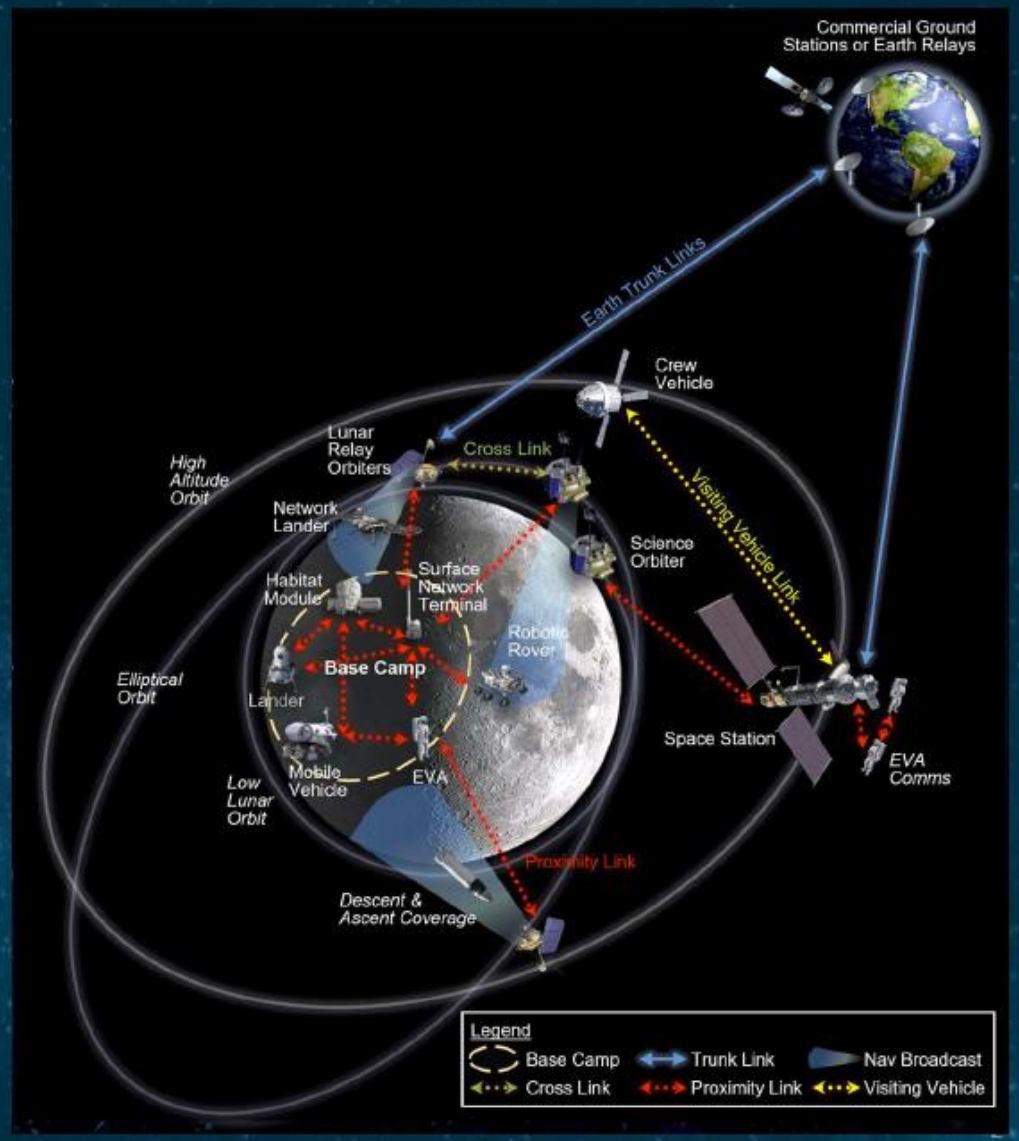
Open

Scalable

Extendable

Resilient

Secure



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))

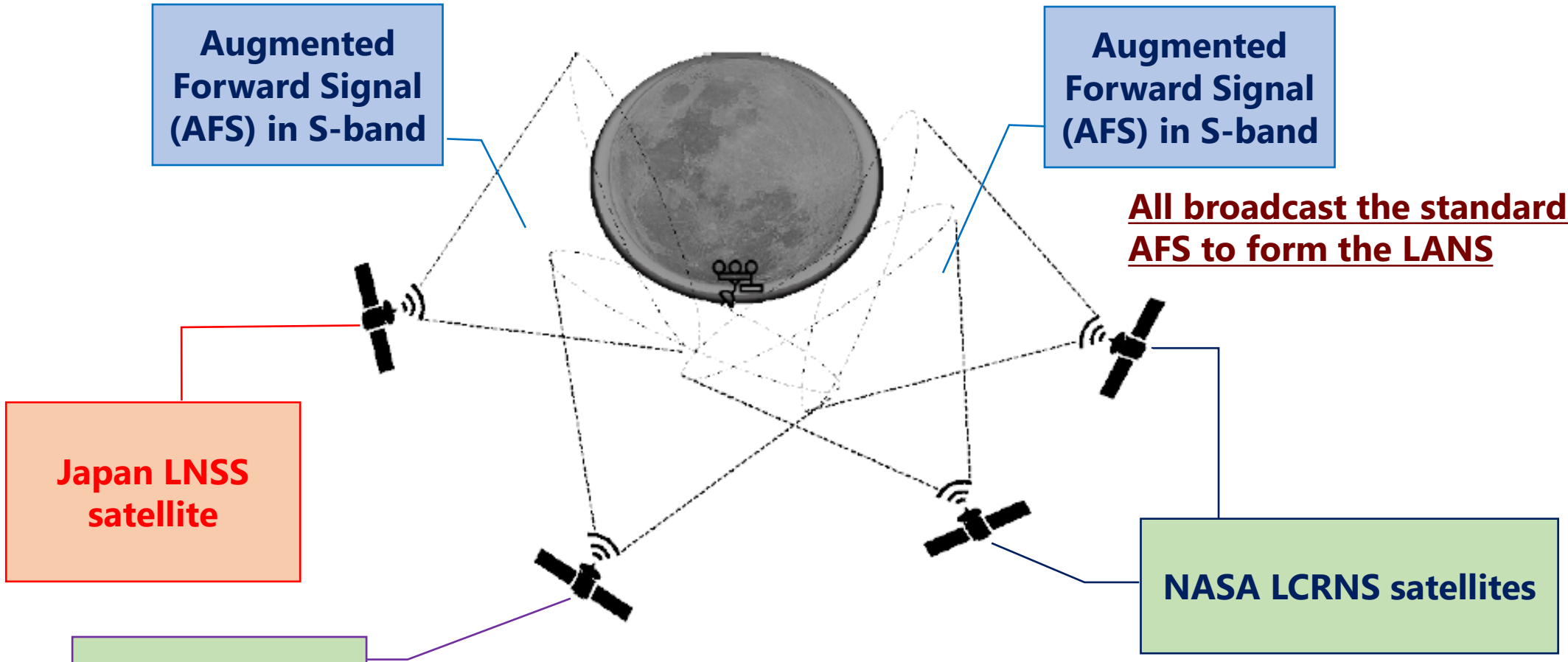
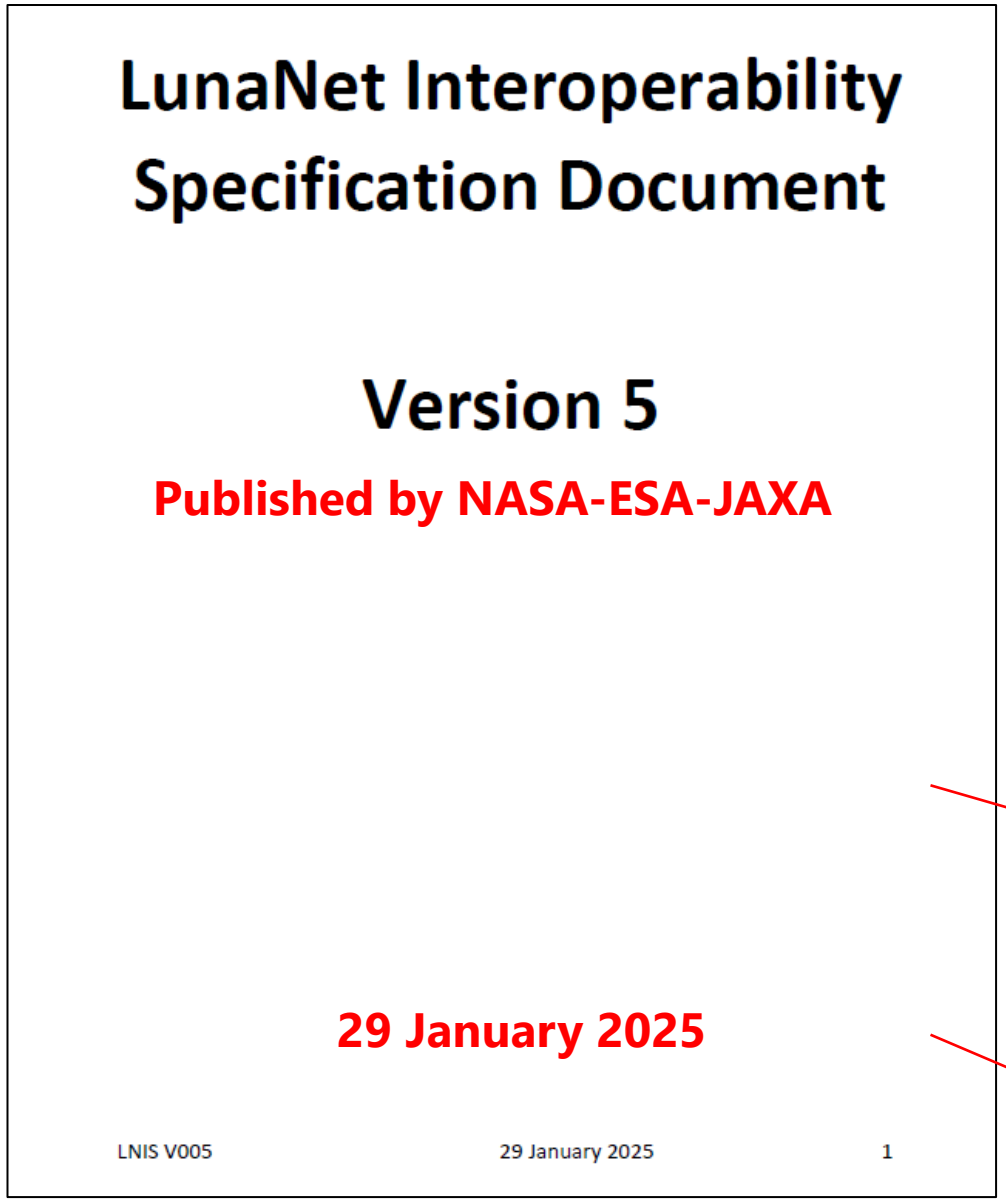


Figure 10 - LANS PNT Concept Provided by LunaNet Nodes

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

※LNIS is the standardization document for the LunaNet

LunaNet Interoperability Specification (LNIS) Version 5 now available on the internet



The LNIS and its applicable document includes:

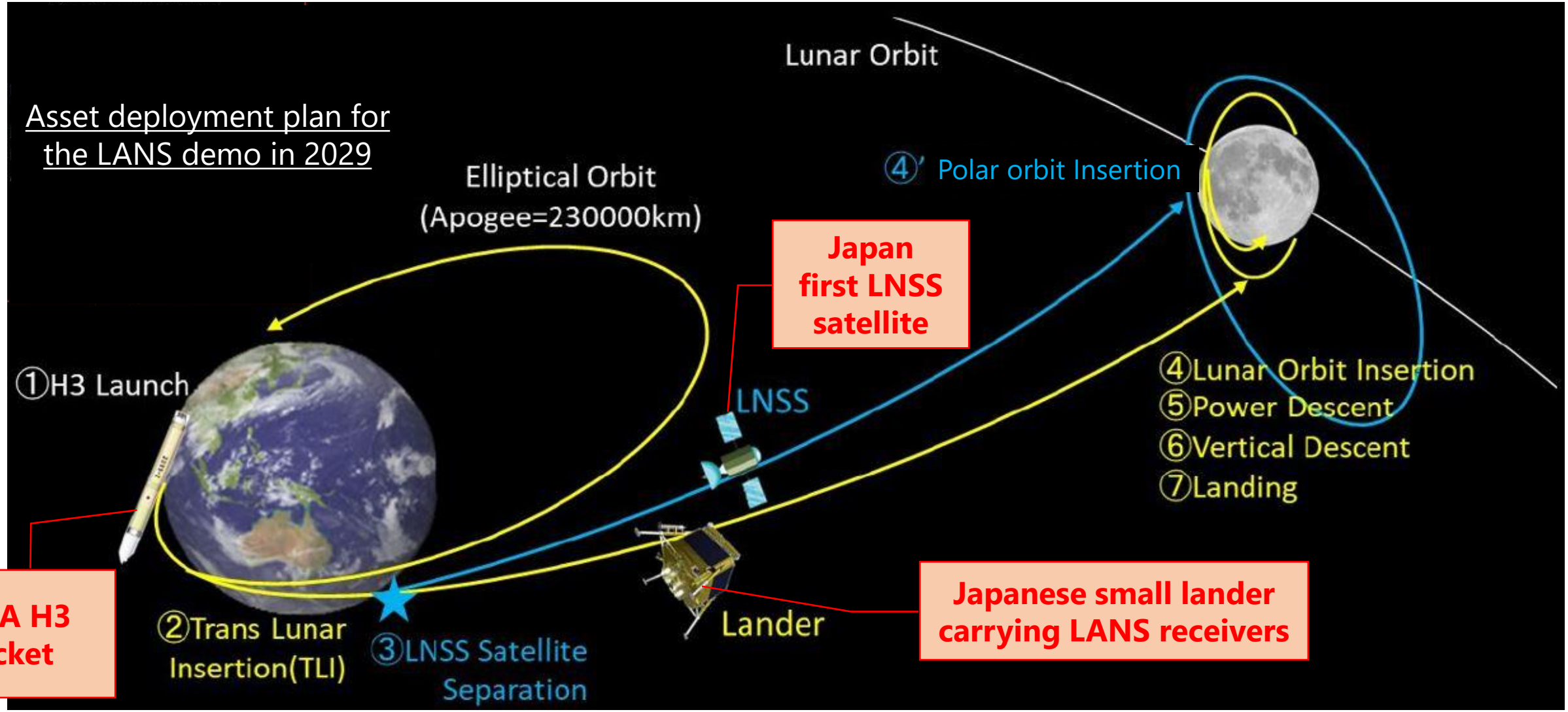
- **Concept of the LANS, message format of the Augmented Forward Signal (AFS), signal frequency, power, etc.**
- **Signal-In-Space-Error (SISE) requirement for LunaNet Service Providers (LNSPs)**
- **Lunar Reference System and Lunar Time System Standard**

The Japan LNSS complies with the LNIS to become interoperable and comparable with the other LNSPs

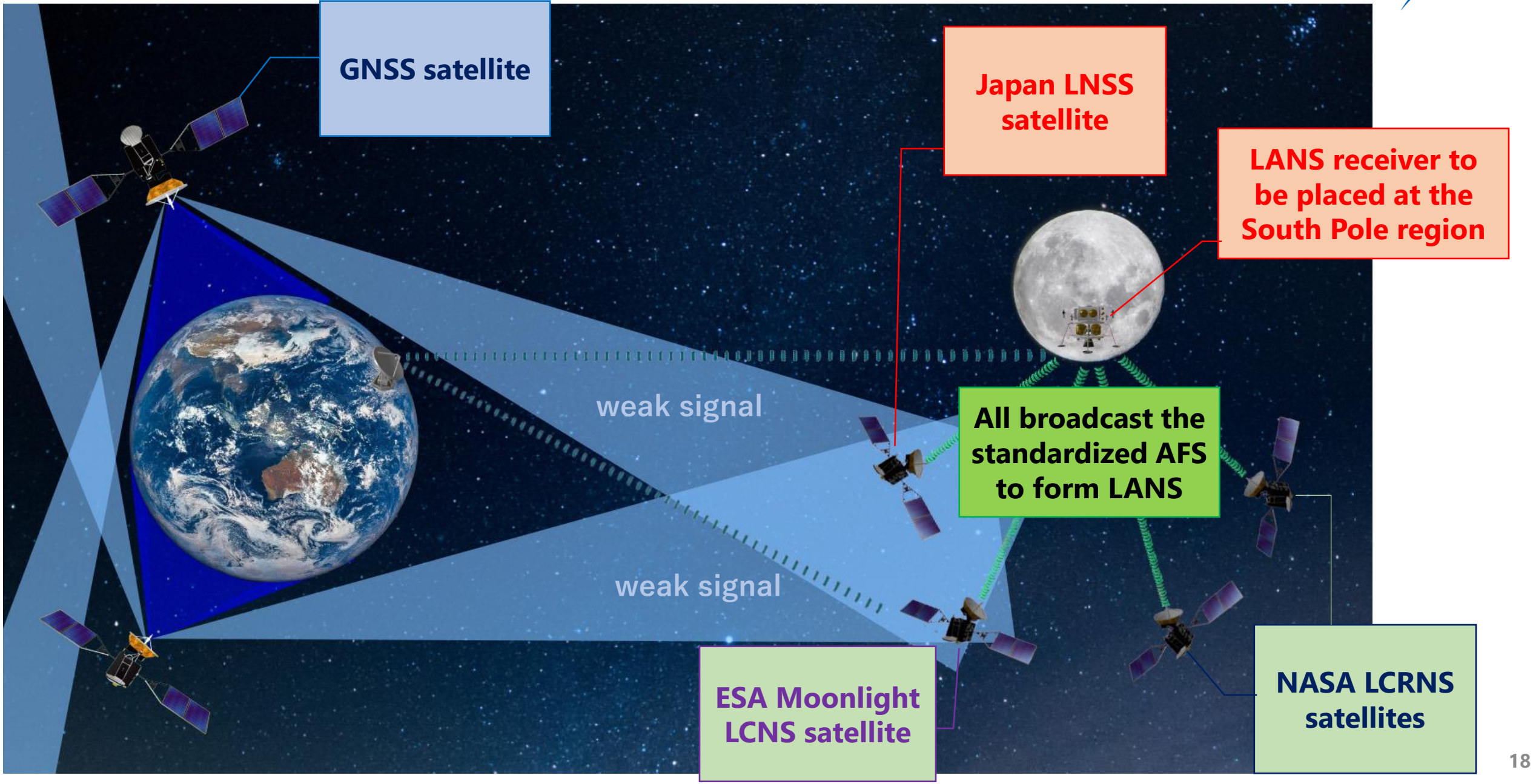
Together with NASA and ESA, JAXA continues contributing to the development of the future LNIS documents and the success of the LANS concept

Towards LANS interoperability demonstration mission targeting in 2029

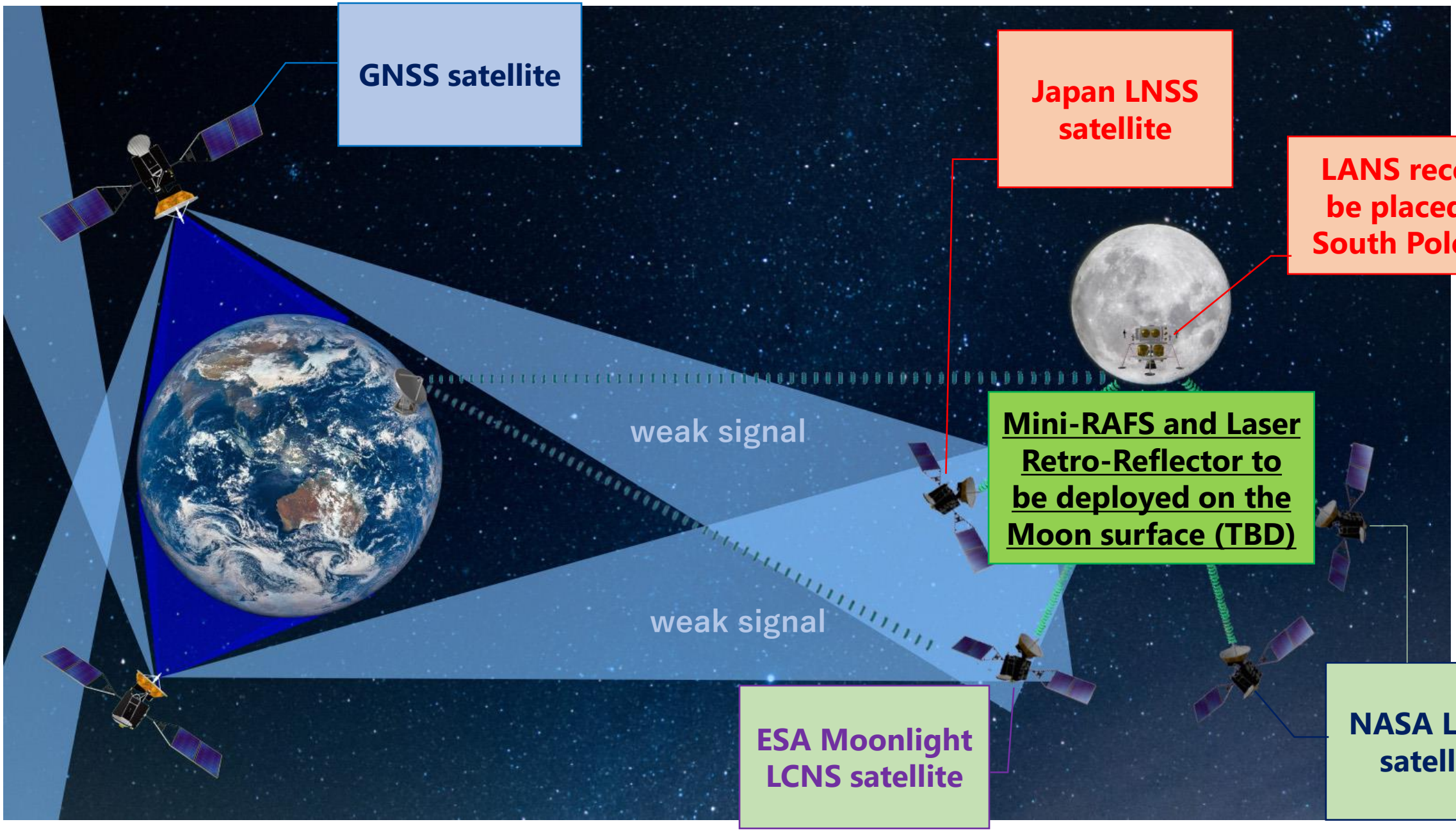
JAXA is proposing the first-ever ESA-NASA-JAXA LANS interoperability demonstration



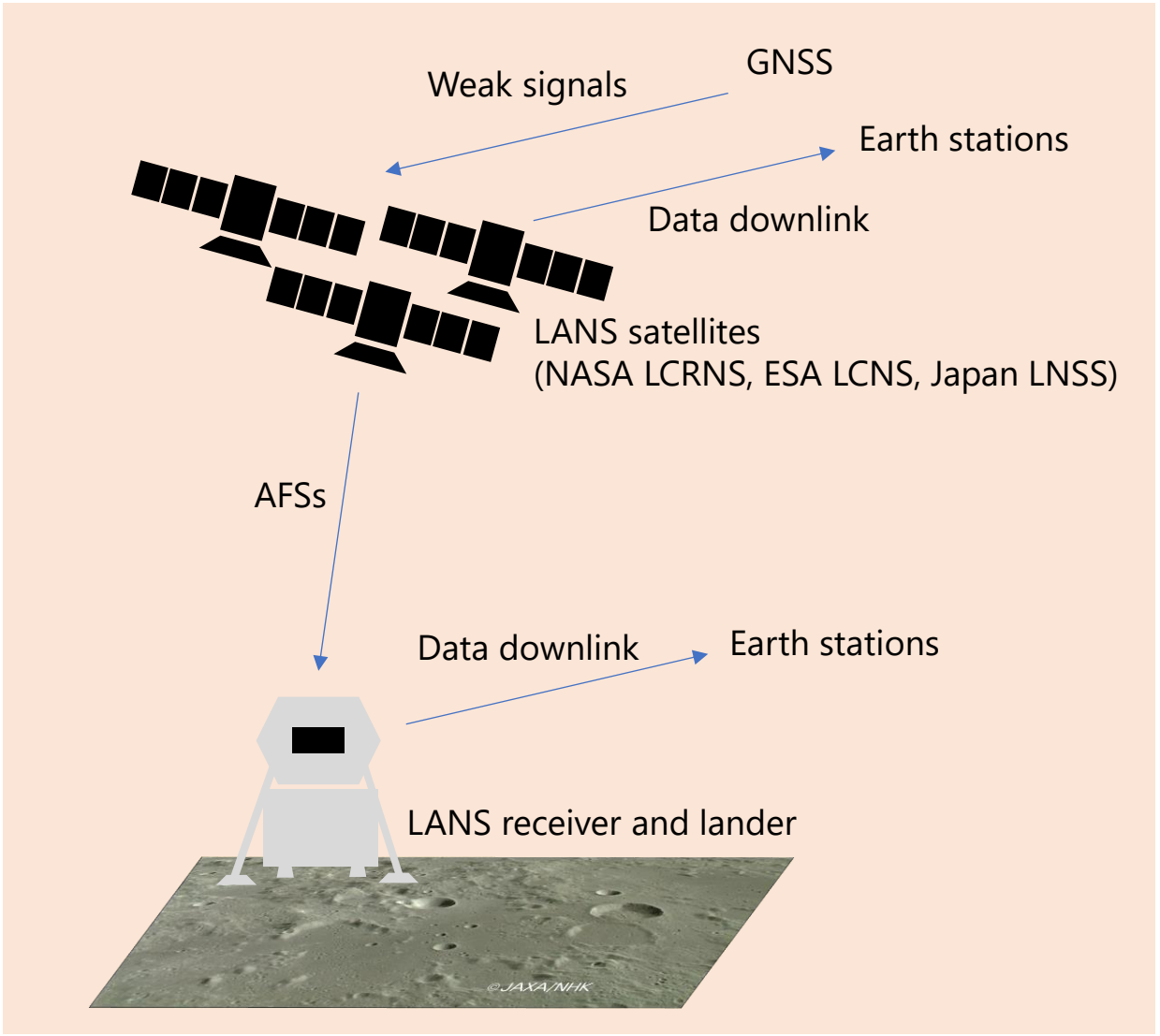
LANS receiver to be placed at the South Pole region will receive all broadcasted AFSs

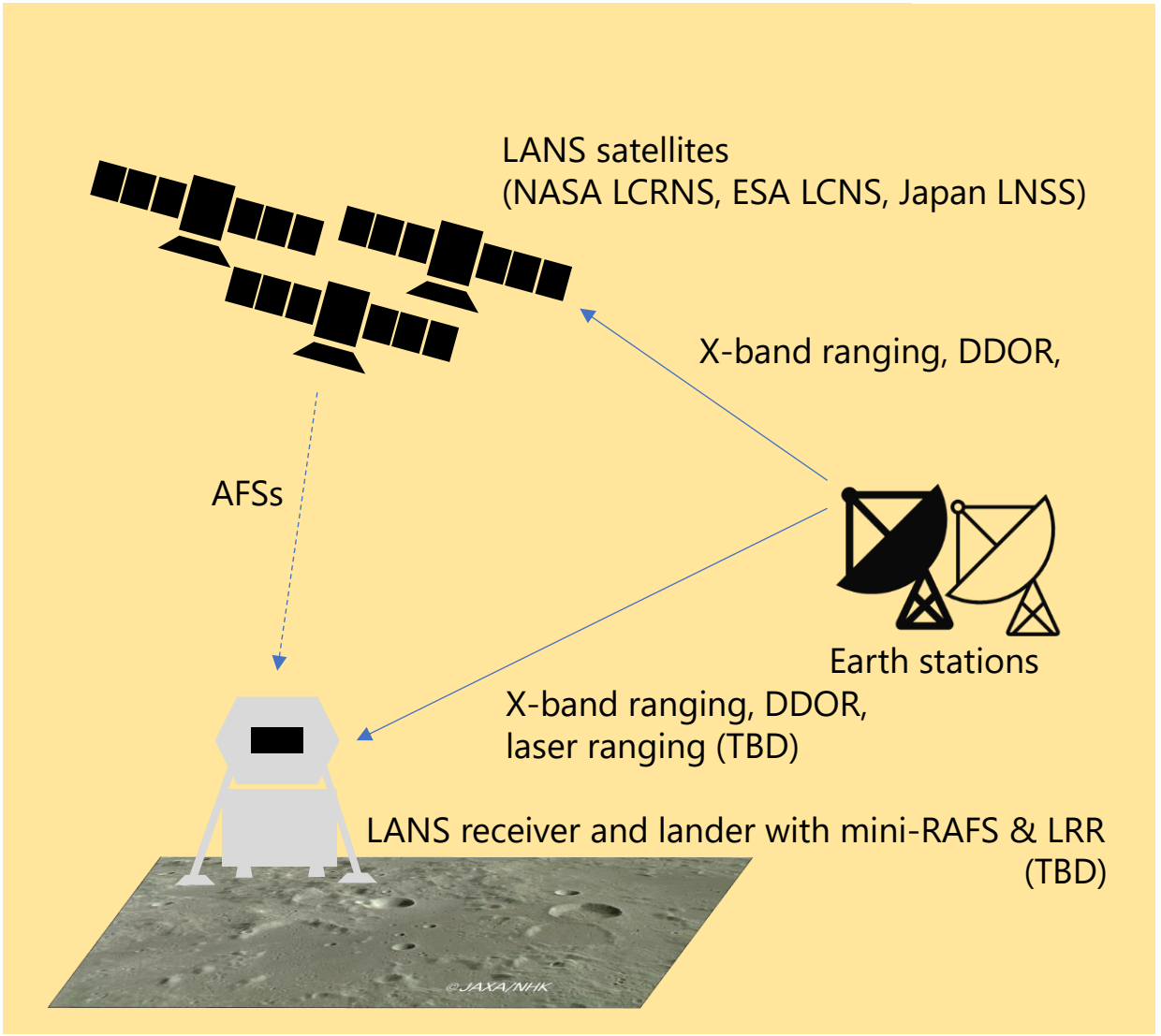


The SISEs for satellites forming the LANS and LANS PNT accuracy will be evaluated



Mission data acquisition and ground-truth data calculation





Acquisition of the LANS AFSs, LANS receivers' PNT solutions, and GNSS weak signals

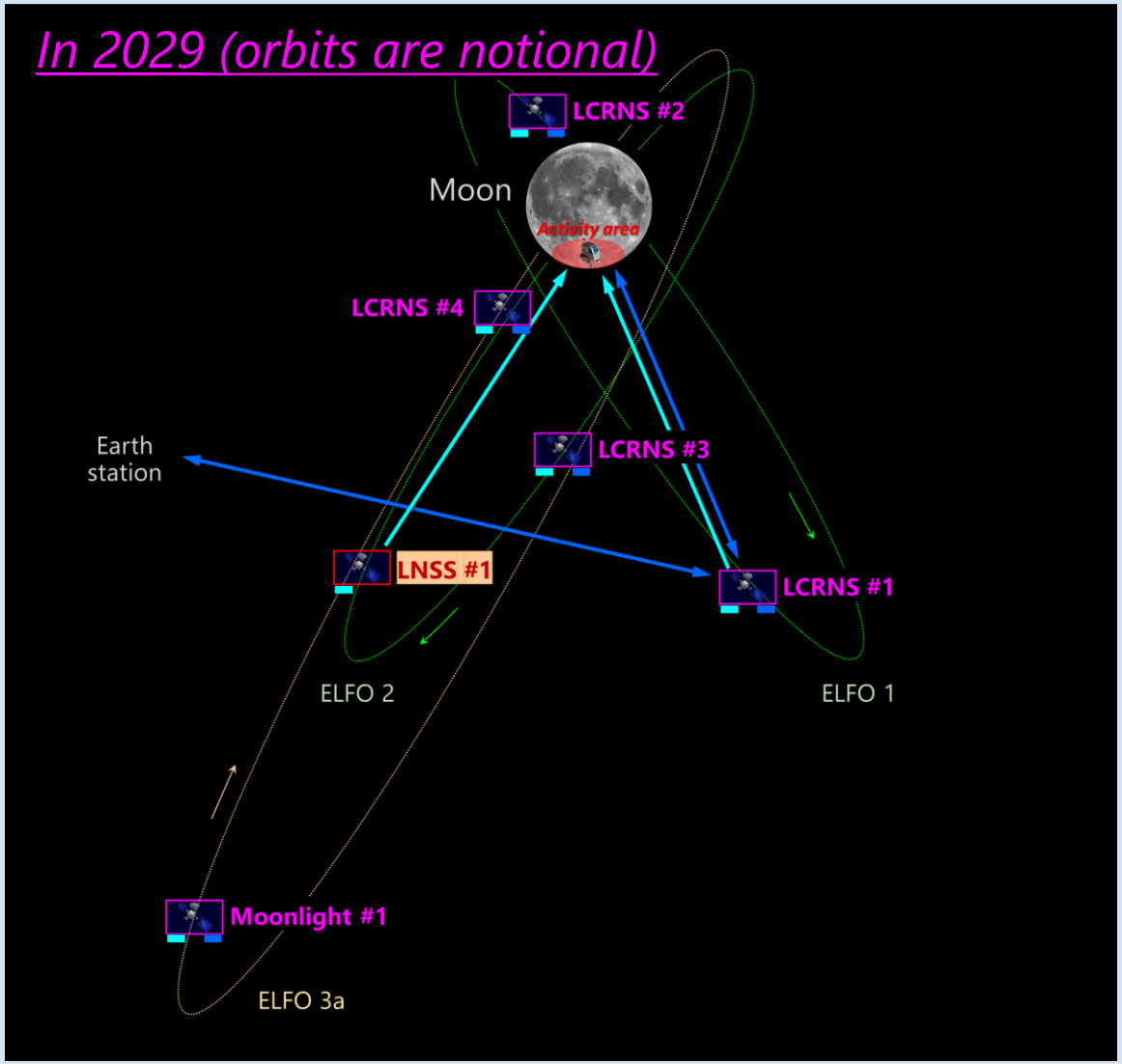
Calculation of the precise satellite orbits and clocks, precise receiver positions and clocks

SISE and PNT accuracy evaluation

SISE evaluation

1. Compare the LANS satellite ephemerides with the ground-truth LANS satellite orbits and clocks

2. Compare the LANS pseudo ranges with the ground-truth ones to identify unknown error sources (satellite hardware and Moon environment delays)



PNT accuracy evaluation

1. The LANS receiver at the lunar South Pole region calculates its PNT solutions

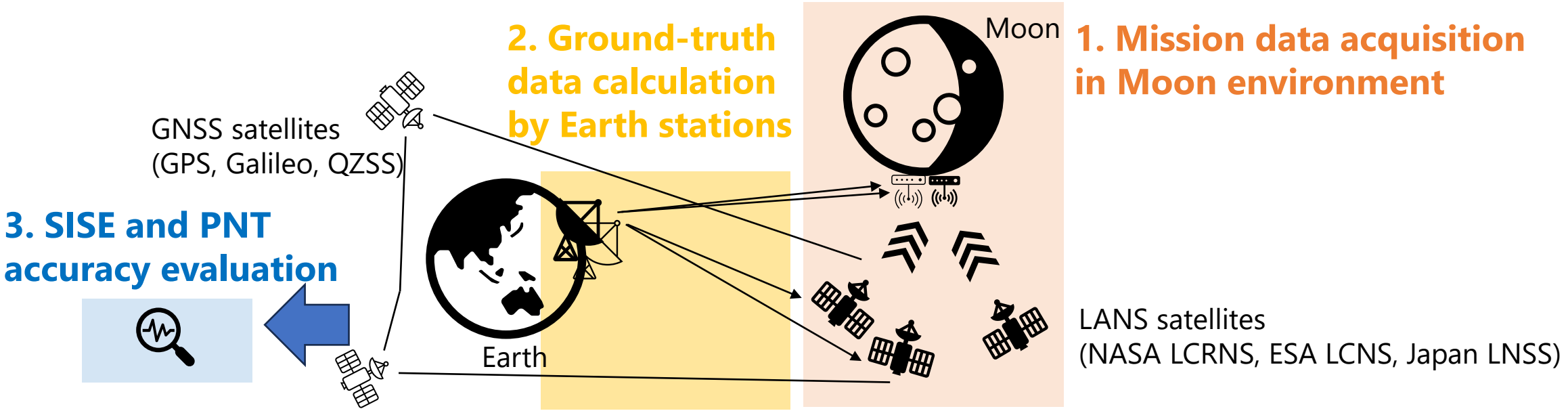
2. Compare the receiver's PNT solutions with the ground-truth receiver position and clock

※The PNT solutions can be the combined solution with the Digital Elevation Map (DEM)

LANS interoperability and PNT demonstration – concept of operation

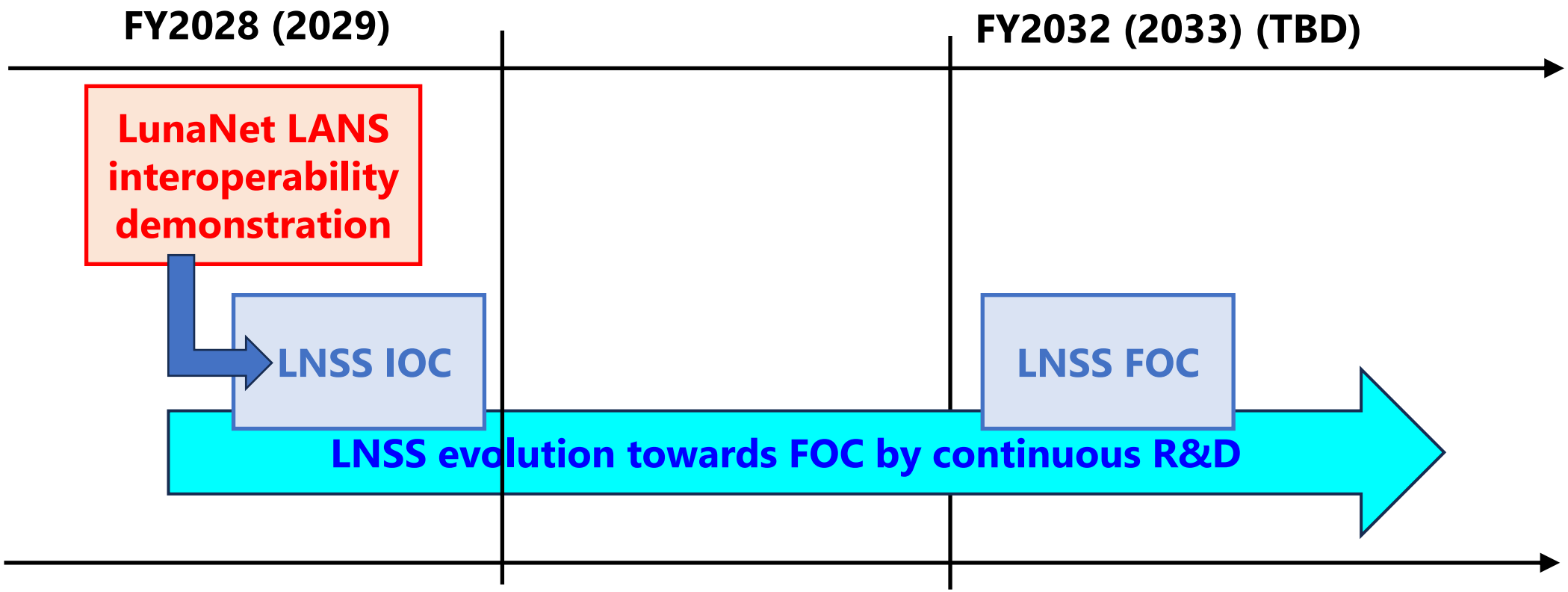
☐ Three major steps for the demonstration

1. Acquisition of mission data (AFSs, LANS receivers' PNT solutions, GNSS weak signals) in Moon environment
2. Calculation of ground-truth data (precise LANS satellite orbits and clocks, precise LANS receiver positions and clocks) by Earth stations
3. Evaluation of SISEs for LANS satellites and LANS PNT accuracy by comparing the acquired mission data with the calculated ground-truth data



JAXA's plan

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



- **Our feasibility study (FS) towards the LNSS FOC is currently ongoing**
  - **LNSS SISE enhancement by using GNSS precise measurements and etc.**
  - **LNSS augmentation by using moon surface assets such as surface beacons**
  - **LANS receiver PNT algorithm (combined navigation algorithm with DEM)**
  - **Service region expansion (satellite constellation design for entire moon surface)**

Takeaways on Japan Lunar PNT

- The 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!