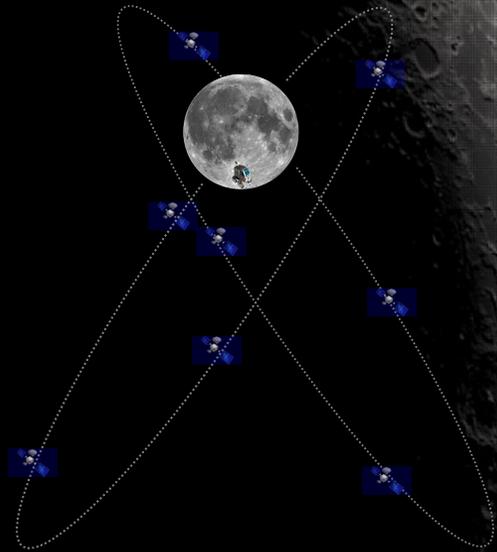


2nd Joint ICG-IOAG Multilateral Cislunar PNT Workshop@Vienna

Japan

Lunar Navigation Satellite System



Japan Lunar Navigation Satellite System (LNSS) and Towards LunaNet Lunar Augmented Navigation Service (LANS) Interoperability Demonstration

10th February, 2026



Masaya Murata (Japan Aerospace Exploration Agency)

- Overview LunaNet Service Providers and LNSS
- Lunar Augmented Navigation Service
- Demonstration Objectives
- Demonstration Architecture
- Analysis
- Future Plans



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



ESA Moonlight LCNS (2028~)

Contractor: Telespazio



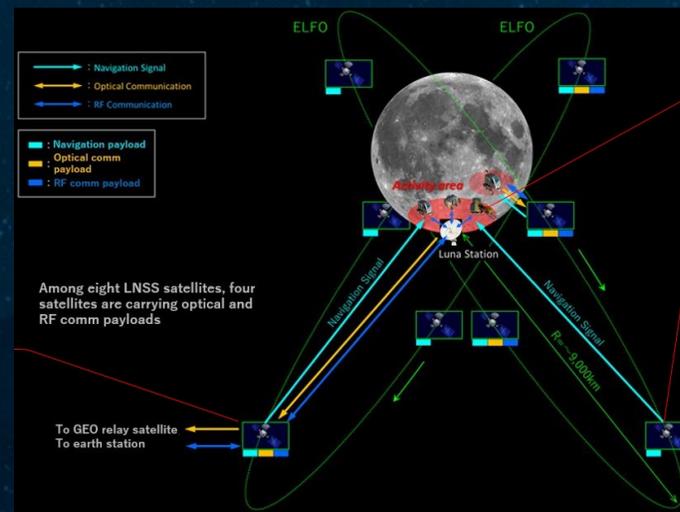
NASA LCRNS (2026~)

Contractor: Intuitive Machines



Japan LNSS (2029~)

Contractor: ArkEdge Space



LCNS: Lunar Communications and Navigation System

LCRNS: Lunar Communications Relay and Navigation Systems

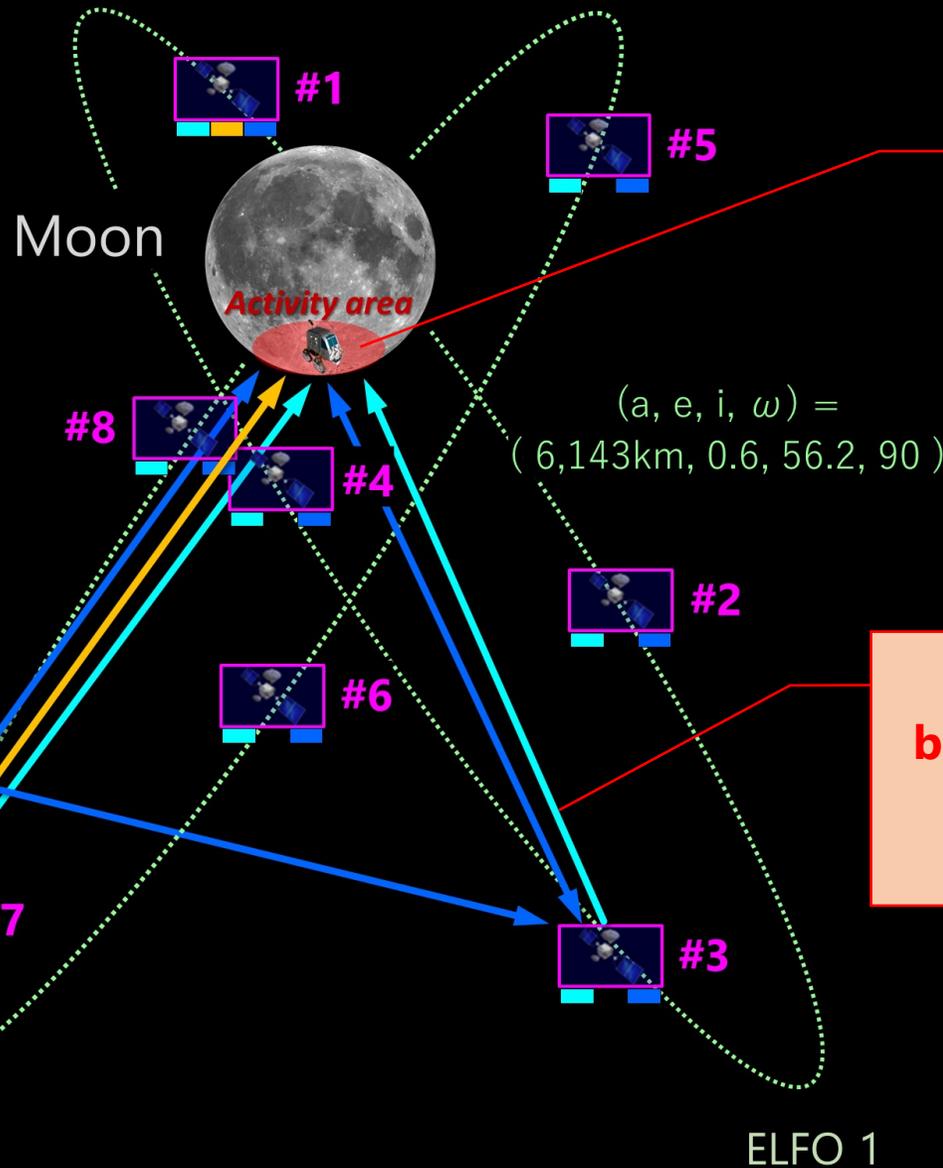
LNSS: Lunar Navigation Satellite System

**LNSS:
Lunar Navigation
Satellite System**

- : Payload for Navigation
- : Payload for Optical communications
- : Payload for RF communications

- : Navigation Signal
- : Optical Communication
- : RF Communication

Among eight LNSS satellites, four satellites are carrying optical and RF comm payloads

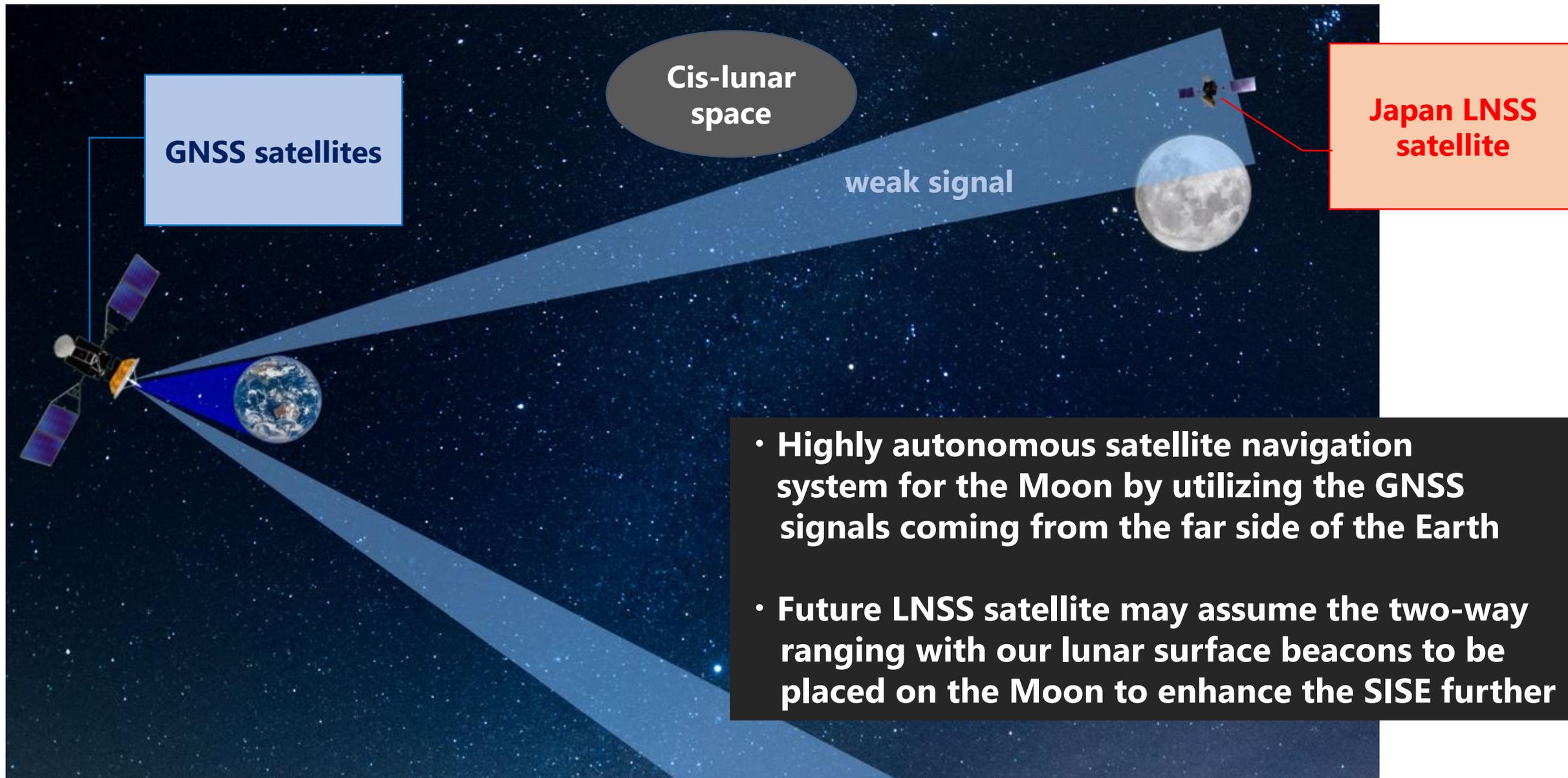


**Target:
South Pole
region**

**LNSS satellite
broadcasting one-
way navigation
signal**

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

GNSS weak signals drive our LNSS, 20m SISE (2σ) at IOC, 10m SISE (2σ) at FOC

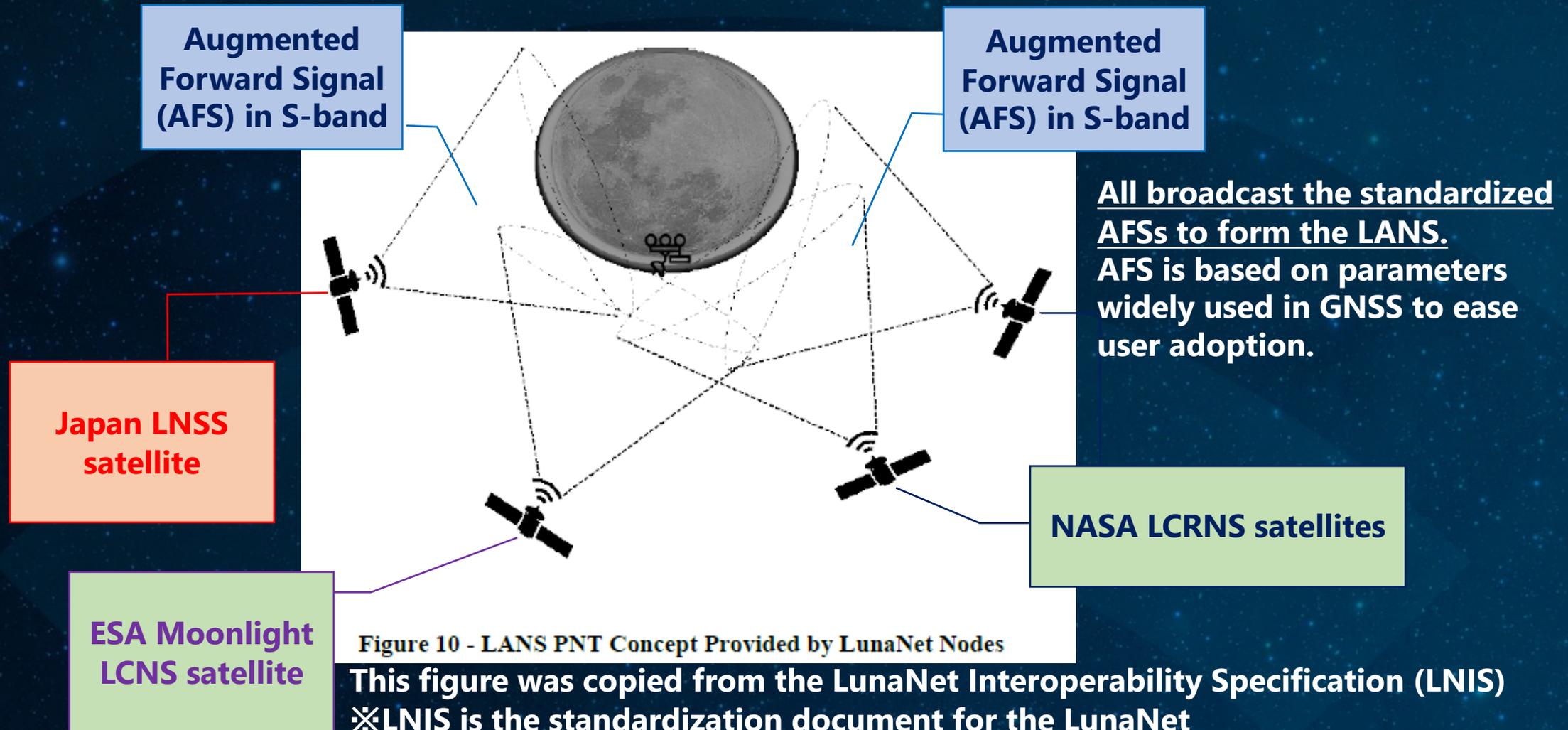




LunaNet LANS Regional Lunar "GNSS"



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



LNSS long-term timeline (subject to change)

FY2029

FY2031

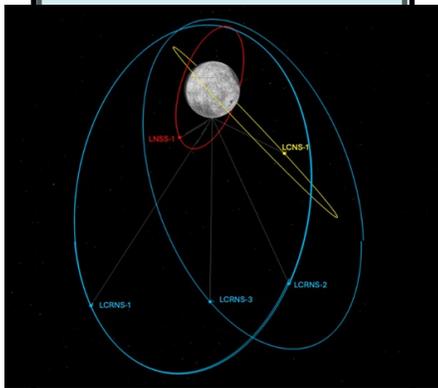
FY2033

FY2040~

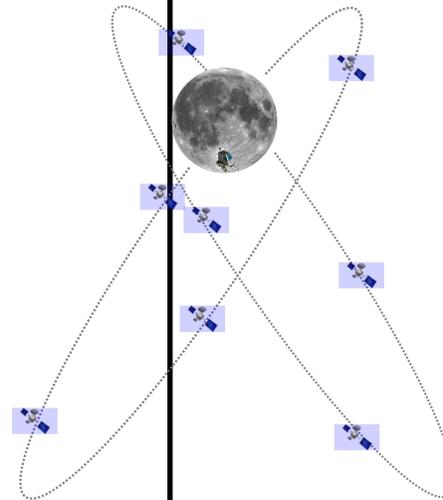
LNSS demo satellite development

LANS receiver development

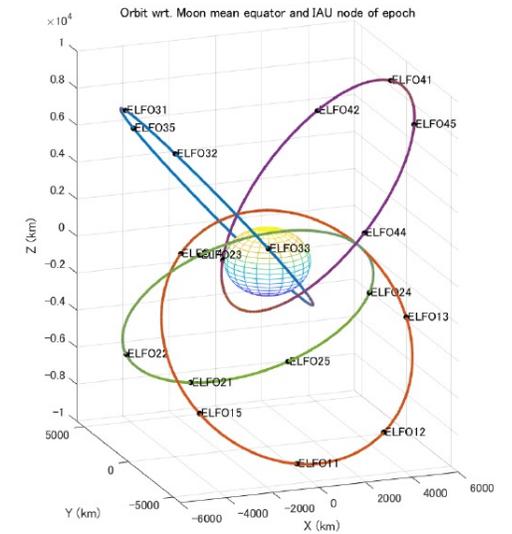
LANS demo mission (2029 (TBD))



LNSS FOC#1 (South Pole region)



LNSS FOC#2 (entire Moon surface)



LANS (LCRNS IOC-C, LCNS FOC, LNSS IOC)

Collaboration with ESA NovaMoon



© ESA

LANS reference and monitoring stations

LNSS long-term timeline (subject to change)

FY2029

FY2031

FY2033

FY2040~

LNSS demo satellite development

LANS receiver development

Interoperability demonstration

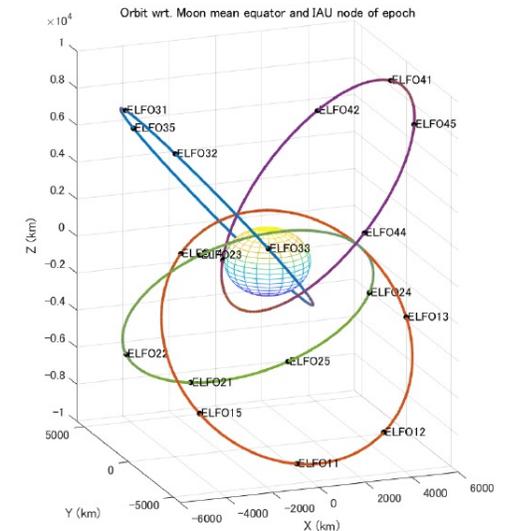
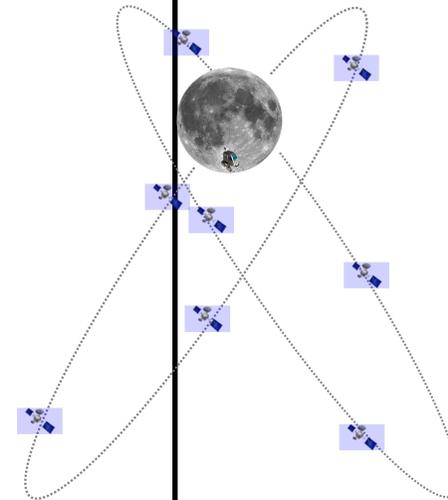
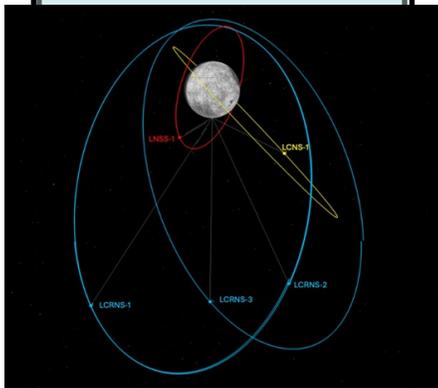
LANS demo mission (2029 (TBD))

LANS (LCRNS IOC-C, LCNS FOC, LNSS IOC)

Collaboration with ESA NovaMoon

LNSS FOC#1 (South Pole region)

LNSS FOC#2 (entire Moon surface)



LANS reference and monitoring stations



© ESA



Interoperability is Critical to LANS



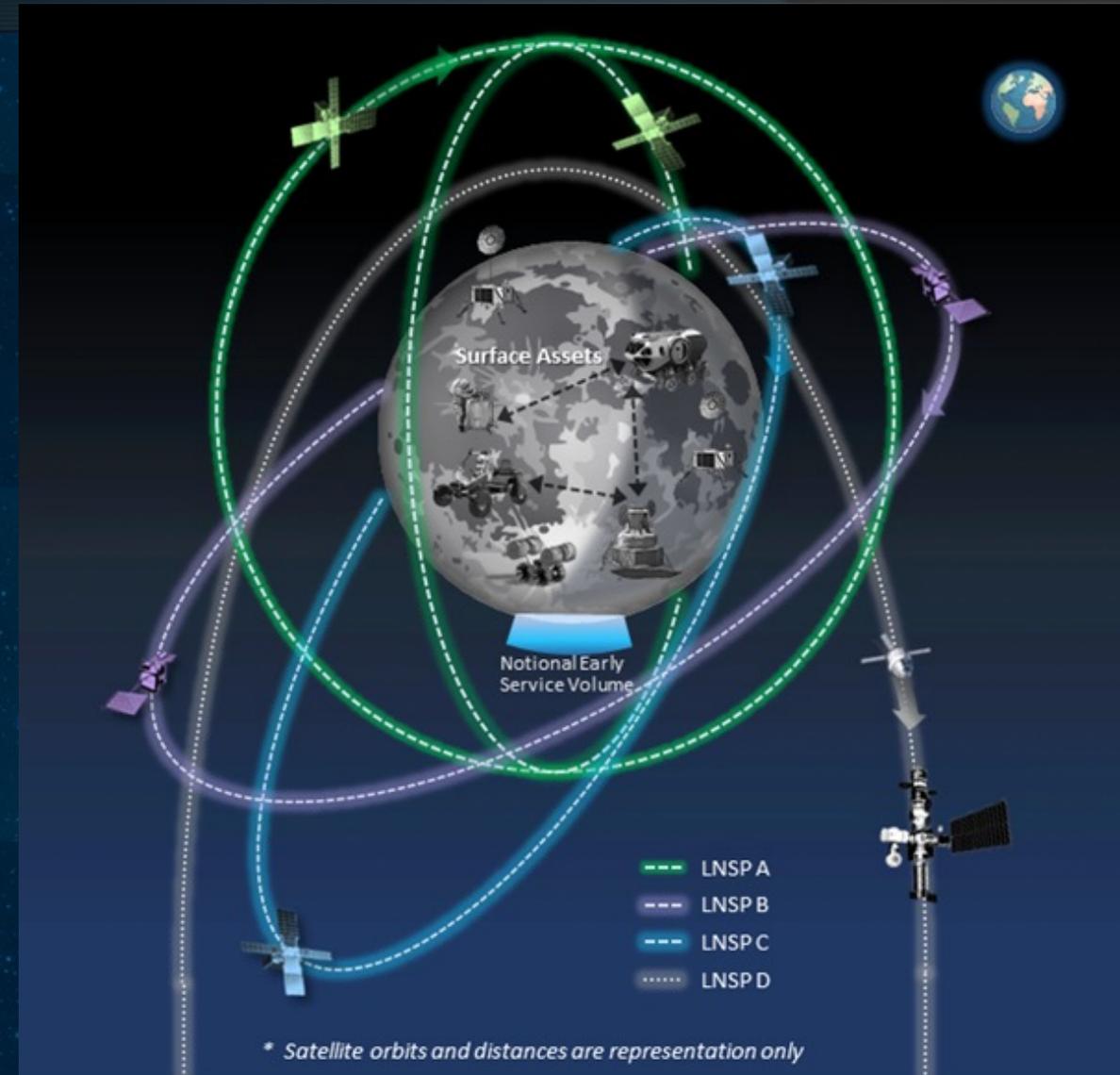
Current concept is to combine different LunaNet Service Provider (LNSP) space vehicles to create a constellation of AFS broadcasters for LANS. (Lunar Augmented Navigation Service)

➤ **Interoperability is critical to achieve this.**

LANS Interoperability¹: each service provider that claims to be LunaNet compliant (becoming a LunaNet Service Provider, LNSP) for the LANS service, must:

- Comply with a common signal and message structure (Augmented Forward Signal, AFS).
- Comply with the Signal In Space Error requirements.
- Assure compliance with the Received Power at the Lunar Surface requirement.

¹ ICG SSV booklet: "(interoperability is defined as) the ability of global and regional navigation satellite systems, and augmentations and the services they provide, to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system"





LANS Interoperability Demonstration Objectives



OBJ-1 - To **receive AFS** from each LNSP node, check the **received power** and **measurement consistency**, and assess the **signal quality**

OBJ-2 - To compute and **validate** the **Signal In Space Error** (SISE) for each LNSP node the **User Equipment Error** (UEE) evaluation for the LANS receivers

OBJ-3 – To validate the **achieved** user Position, Velocity, and Time (**PVT**) knowledge from **combined LANS**

OBJ-4 – To validate the **LunaNet Time** and **Reference** Frame



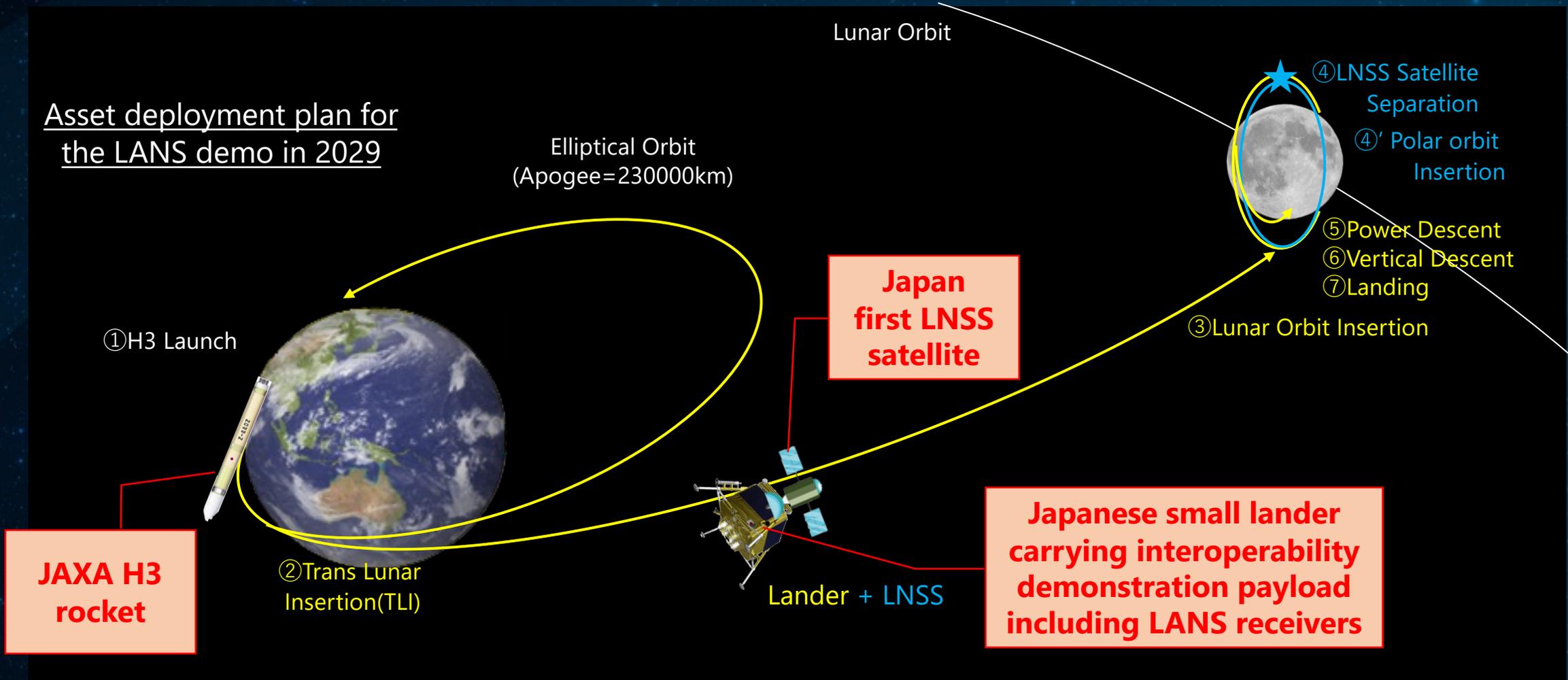
Bringing LANS interoperability demonstration payloads to the Moon



Asset deployment plan for the LANS demo in 2029

Elliptical Orbit
(Apogee=230000km)

Lunar Orbit

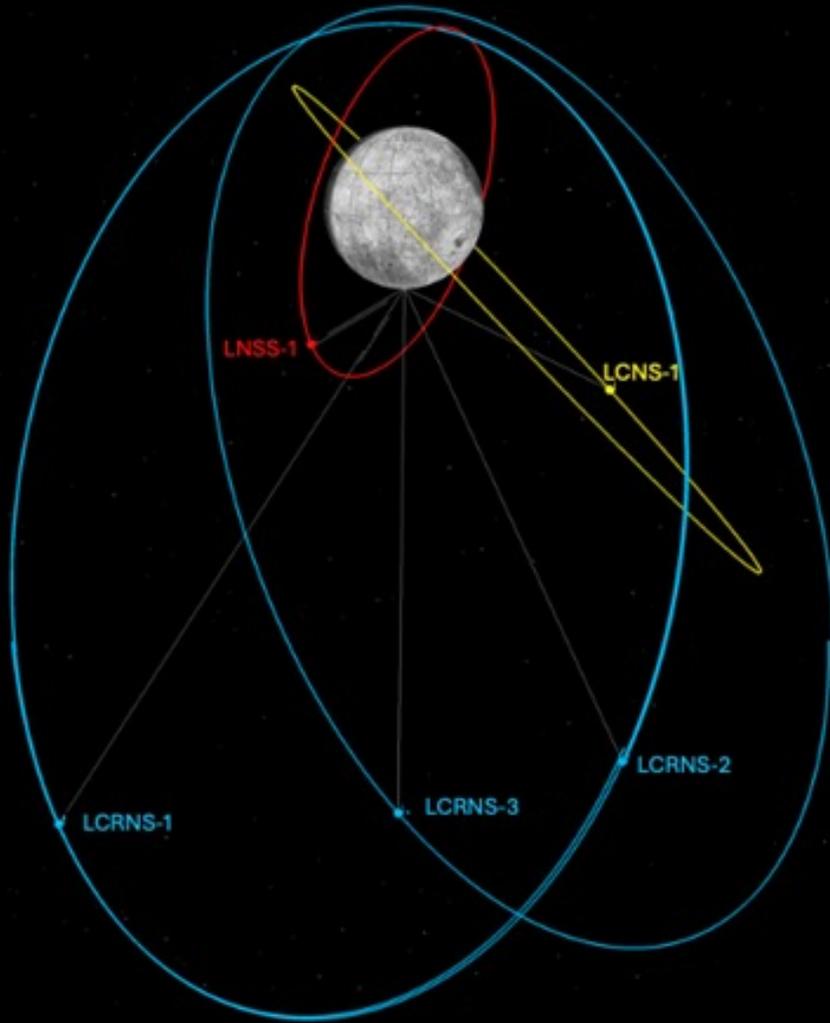




Expected LANS constellation in 2029 (two or three LCRNS, one LCNS, one LNSS)



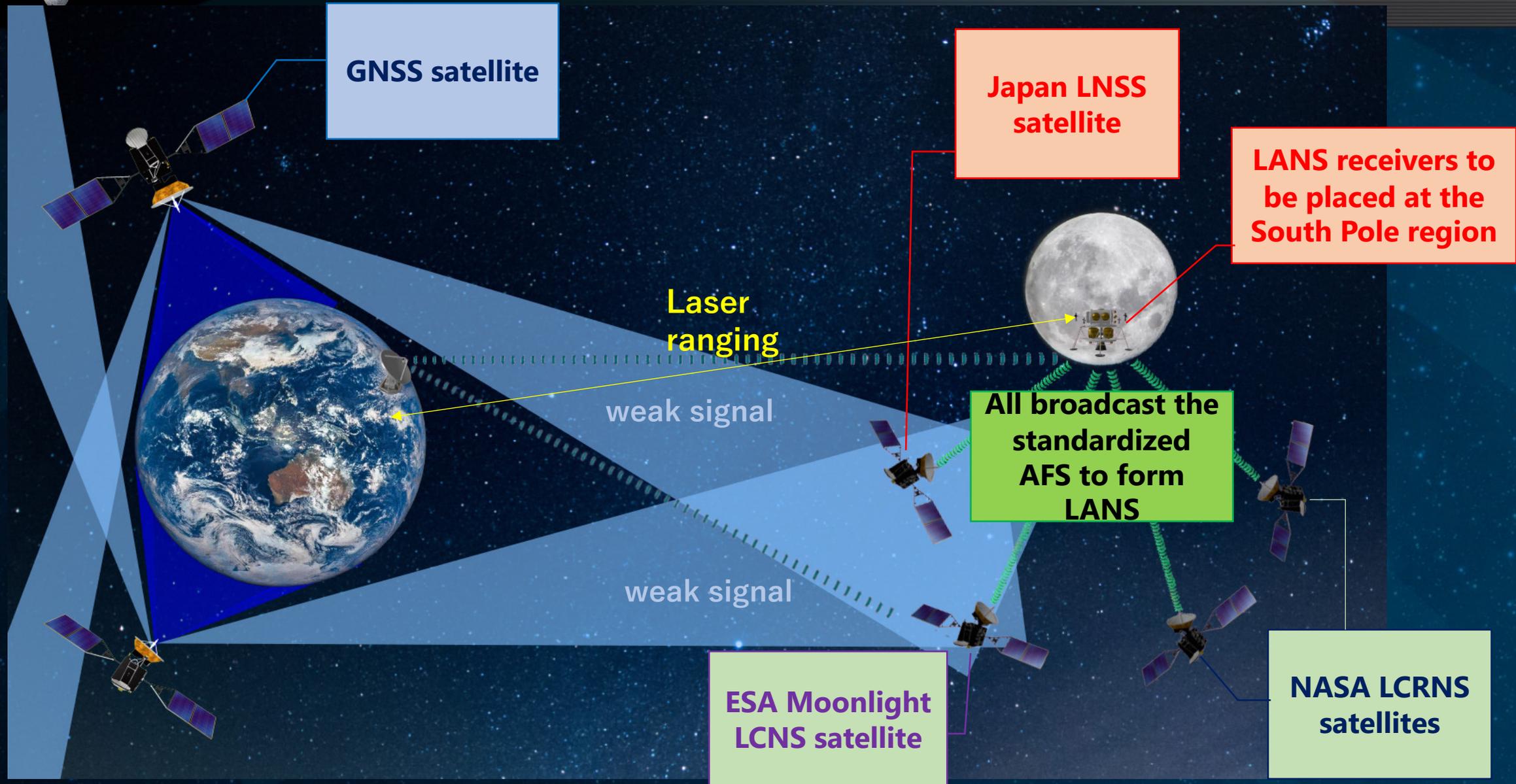
Lunar position, navigation, and timing services jointly provided by international LNSPs (ESA's LCNS, NASA's LCRNS, and Japan's LNSS)



Analyzed orbital and SISE features:

	ESA LCNS	Japan LNSS	NASA LCRNS #1	NASA LCRNS #2	NASA LCRNS #3
Orbital Period	24 hrs (ELFO)	6 hrs (Circular)	32.8 hrs (ELFO)	32.8 hrs (ELFO)	32.8 hrs (ELFO)
Eccentricity	0.7	0	0.678	0.678	0.678
SISE-pos	20 m (2-sigma)	20 m (2-sigma)	13.43 m (3-sigma)	13.43 m (3-sigma)	13.43 m (3-sigma)

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

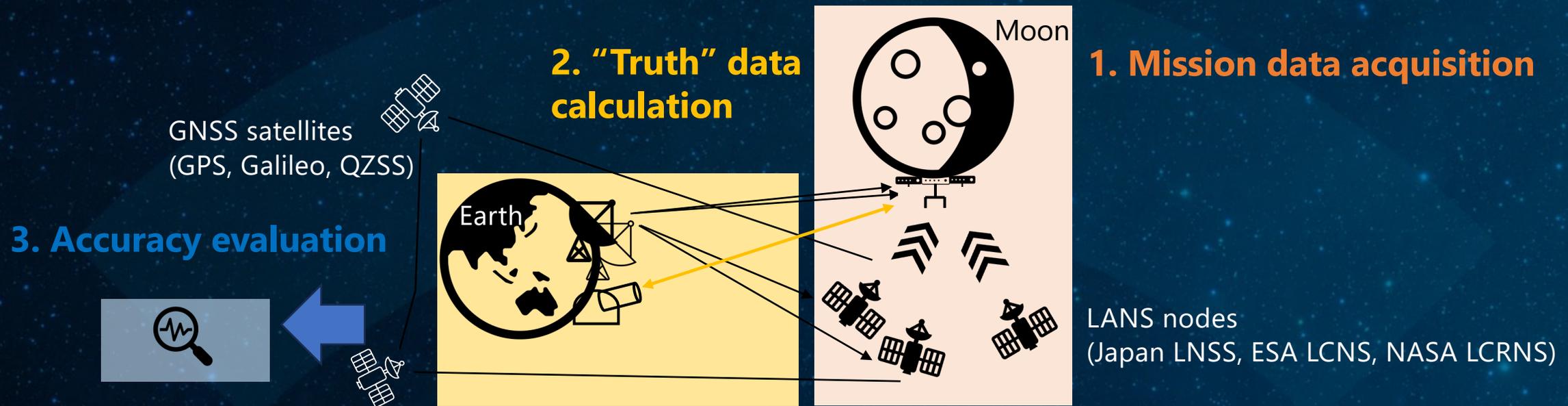




LANs interoperability and PNT demonstration – Three major steps



1. Acquisition of mission data (observations from the AFSs and terrestrial GNSS, LANS receiver PVT solutions) in Moon's environment
2. Calculation of "truth" data (precise LANS satellite orbits and clocks, precise LANS receiver positions and clocks) by Earth stations and laser stations
3. Evaluation of SISEs for LNSP nodes and LANS PVT accuracy by comparing the acquired mission data with the calculated "truth" data

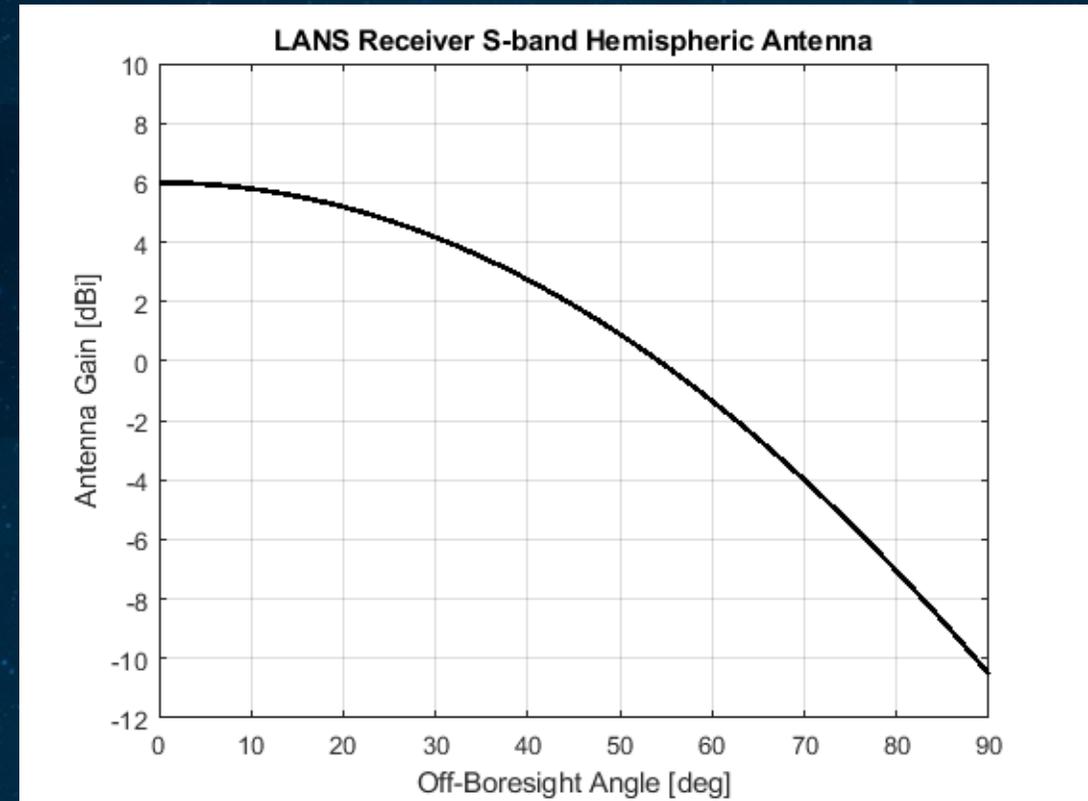




Preliminary Analysis - Assumptions



- **Static** lander (-87° N, 20° E)
- Equipped with **OCXO** (Oven Controlled Cristal Oscillator) and **MiniRAFS** (atomic clock)
- State-of-the-art AFS receiver (based on GNSS technology) with omnidirectional antenna and external **LNA**
- Height provided by digital elevation model (**DEM**)
- Accurate error modelling, accounting for receiver **thermal noise** and satellite clock and orbit errors (through **SISE**)
- Orbits are **phased** to realize **optimal visibility** (not geometry)



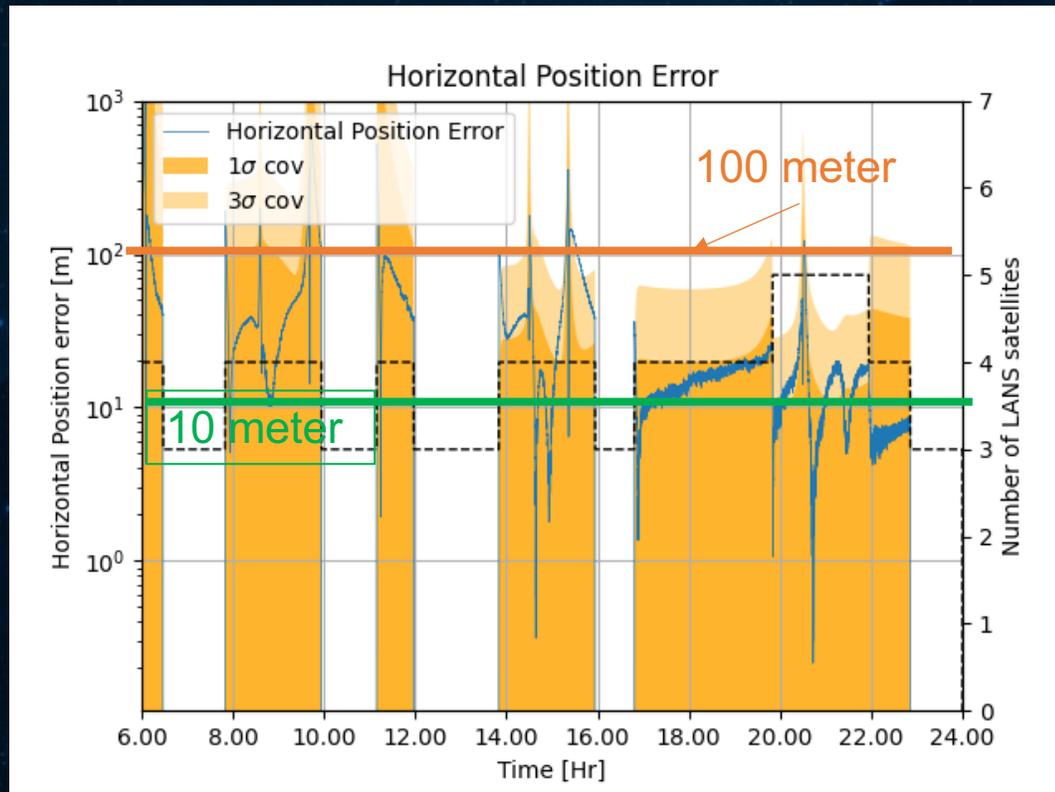
LANS Receiver Antenna
(hemispherical)



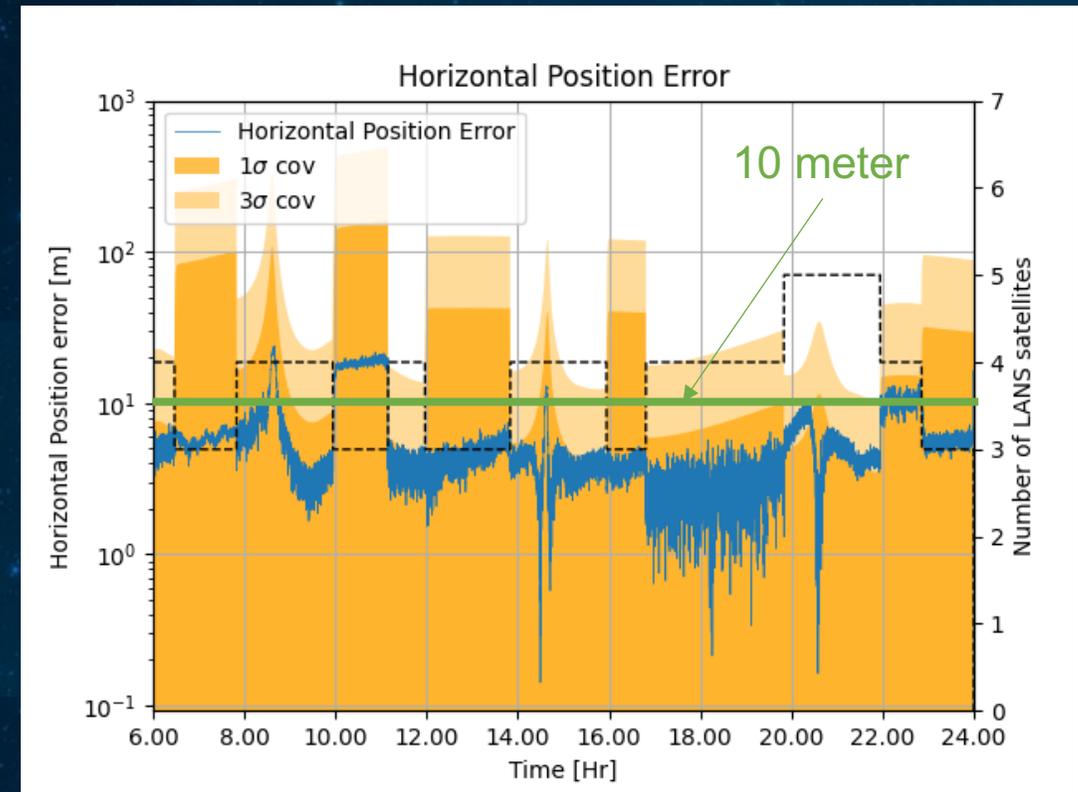
Preliminary Analysis – User Horizontal Error



No Height Constraint
(only using the LANS AFSs)



With Height Constraint by DEM
(Digital Elevation Map)



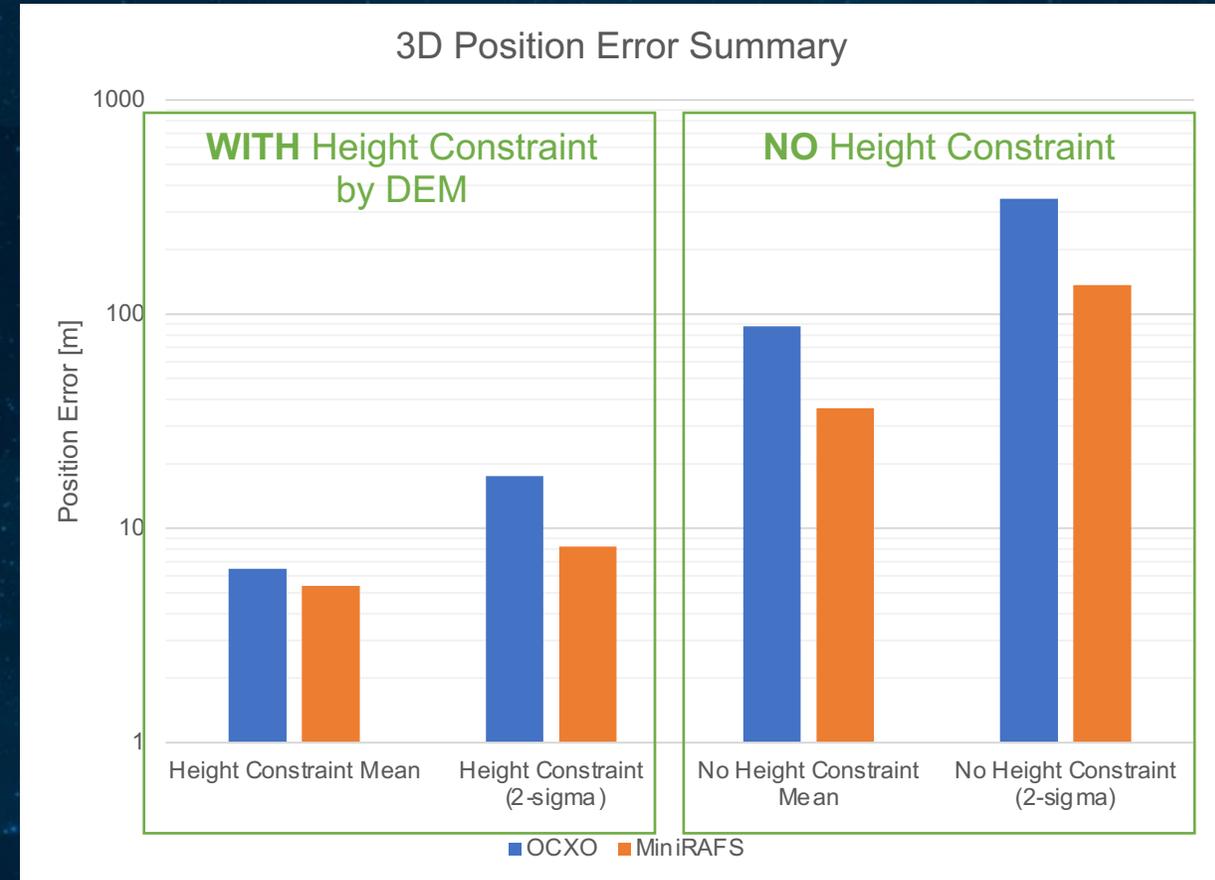
- Impact of **high DOP** on position error is clearly visible
- **With DEM**, the horizontal position error is **less than 10 meter** most of the time (> 68%)



Preliminary Analysis – User Performance Summary



- Availability of **height constraint** results in **improvement of PVT** accuracy.
- An **accurate clock** (i.e., atomic clock) at user level can result in **better PVT** accuracy.
- **Optimization of relative phasing** may further **enhance PVT** accuracy (by **reducing spikes in DOP** resulting in poor geometry)





Future Endeavors



- **NASA LCRNS** will reach **Initial Operating Capability-Charlie** increment, for a total of **5 LNSP nodes**
- **ESA Moonlight LCNS** will reach **Full Operating Capability** with **3 additional LNSP LANS nodes**
- **JAXA** plans to enter into the development phase of **LNSS Full Operating Capability**