Moonlight Navigation Services

Towards a new paradigm in Lunar exploration

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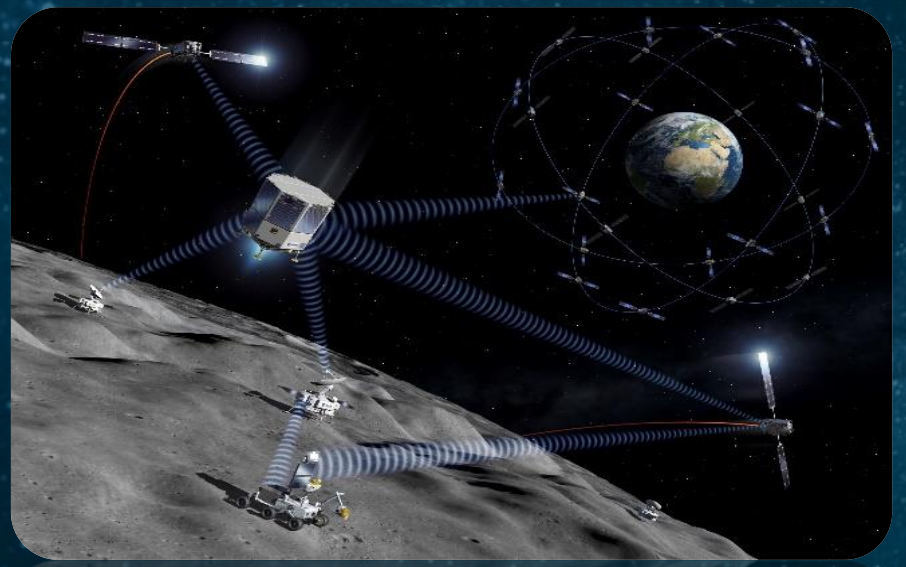
Moonlight Approach: Services

Service development Approach: ESA supporting infrastructure development and acting as Anchor customer



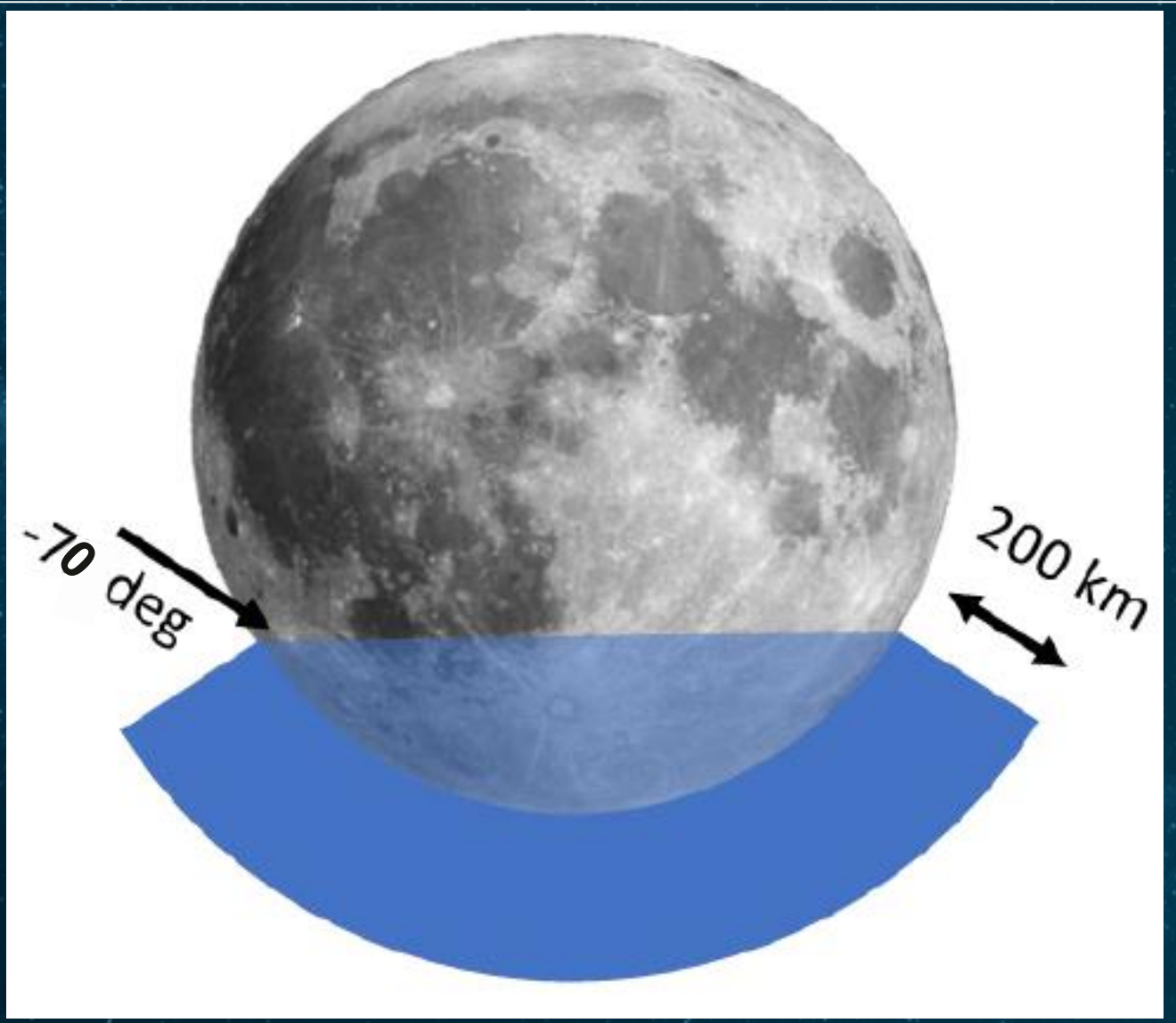
- Data transport
- Tele-operations
- Audio/Video streaming
- Absolute Position
- Absolute Velocity
- Universal time

PNT Services

- Third-party payloads
- Over-the-top Services
- Alert & Information
- Search and Rescue

- Public-Private Partnership: Private sector as service provider
- A dedicated constellation of satellites around the Moon

FOCUSING ON THE SOUTH POLE



Moonlight LCNS High-level Service Requirements

High DataRate (KBand)
Upto 200Mbps/user

Low Datarate (Sband)
Upto 1Mbps/user

Security functions

Slotted Real time services

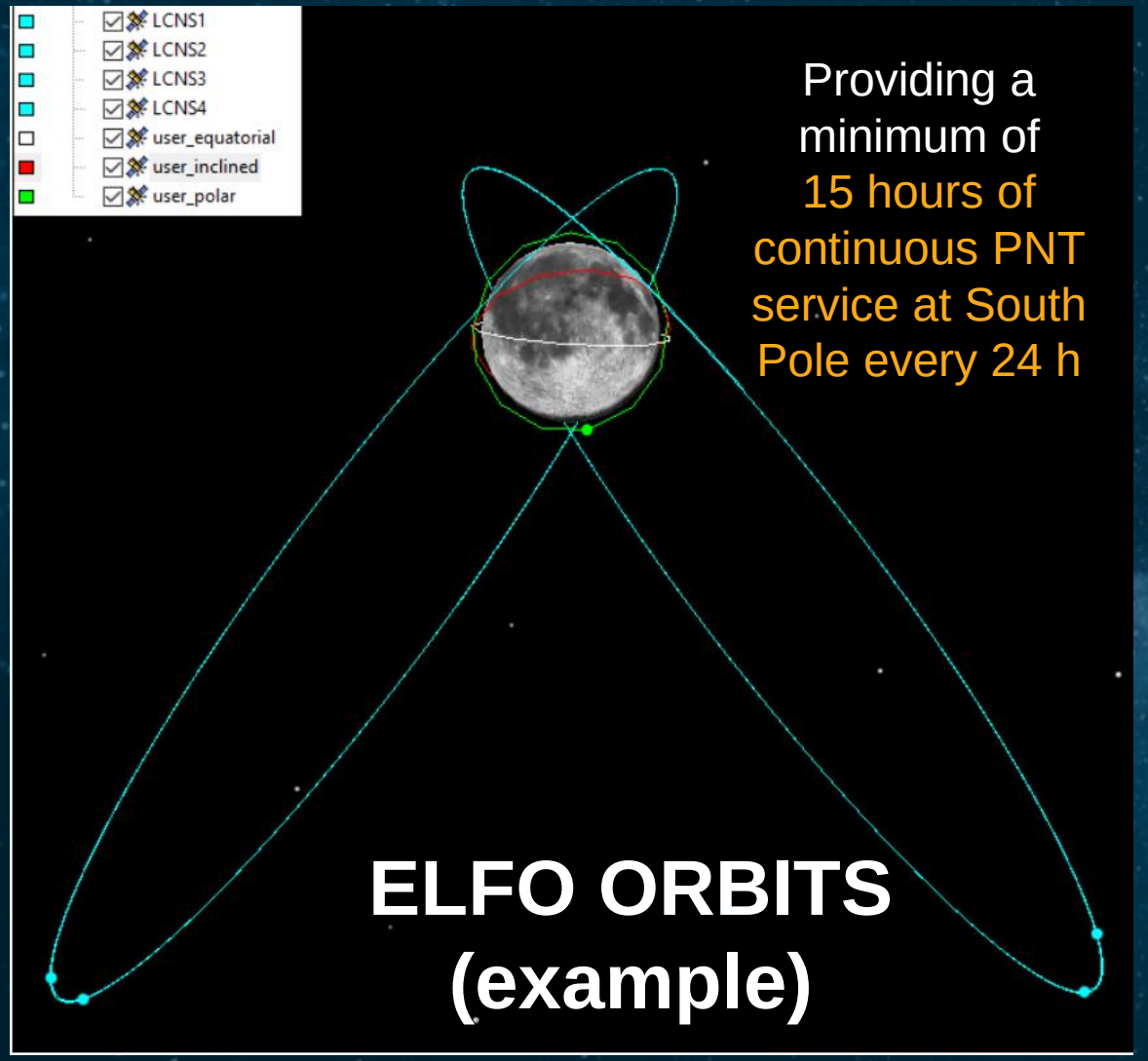
Based on GNSS technologies

Precise timing (sub µs)

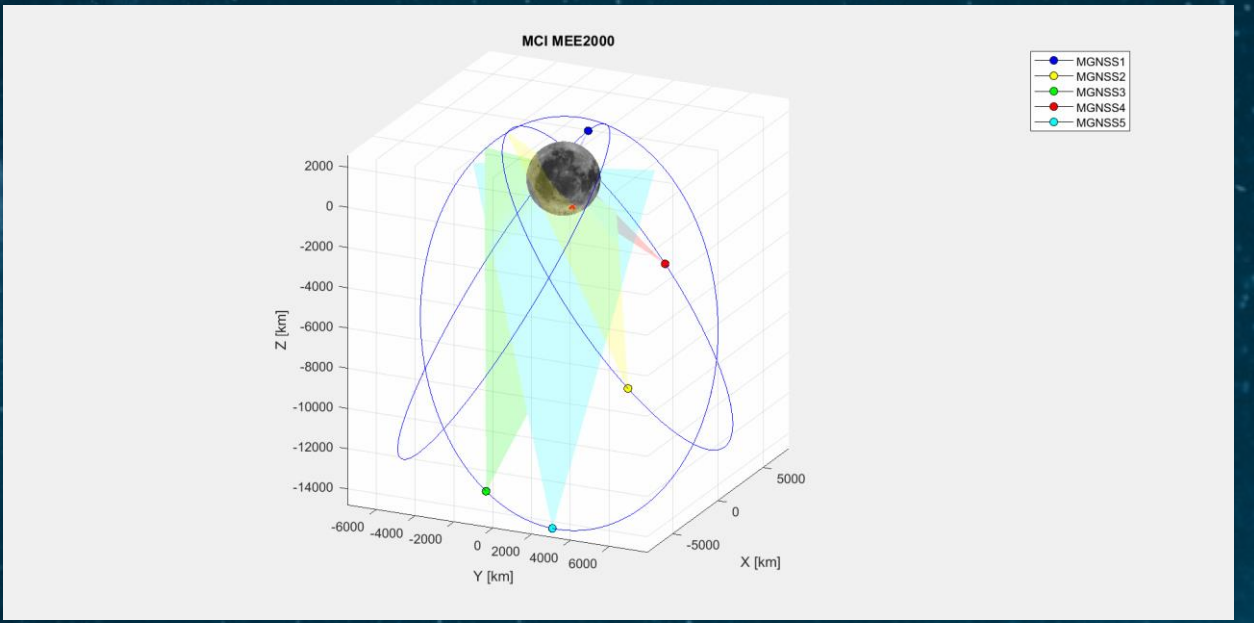
One Way Ranging
SISE ODTS (95%)
IOC: 20 m
FOC: 10 m

Position accuracy (95%)
Orbiters: 100m
Landing: 50m
Surface: 10m

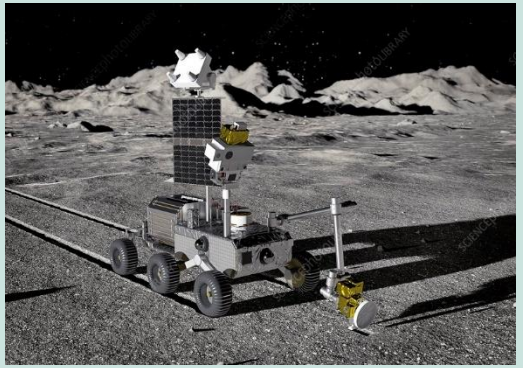
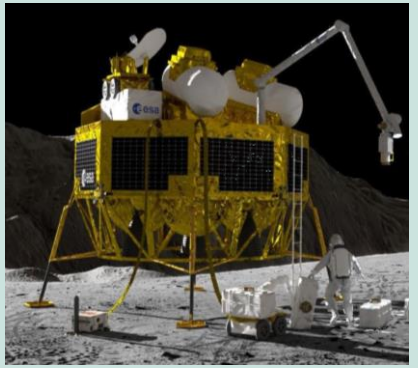
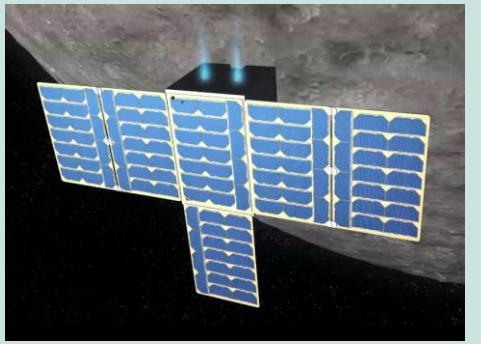
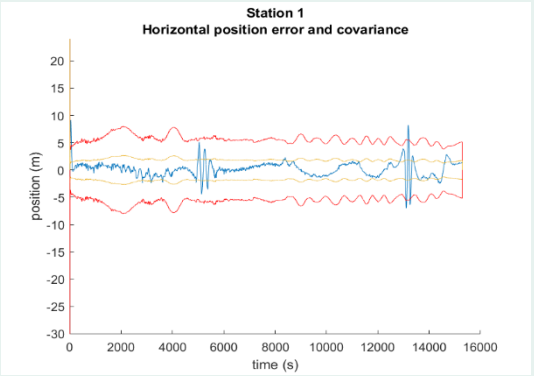
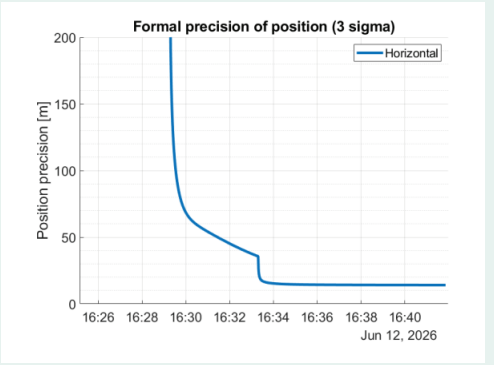
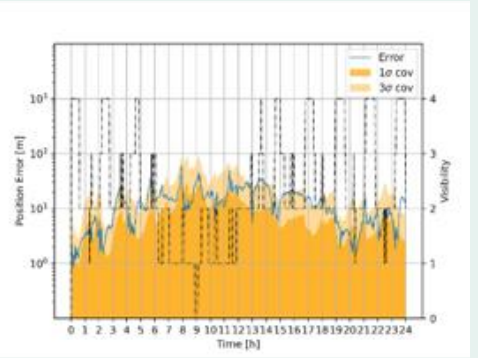
Moonlight NAV services:
A GNSS-like system on lunar orbit consisting of 4 nodes



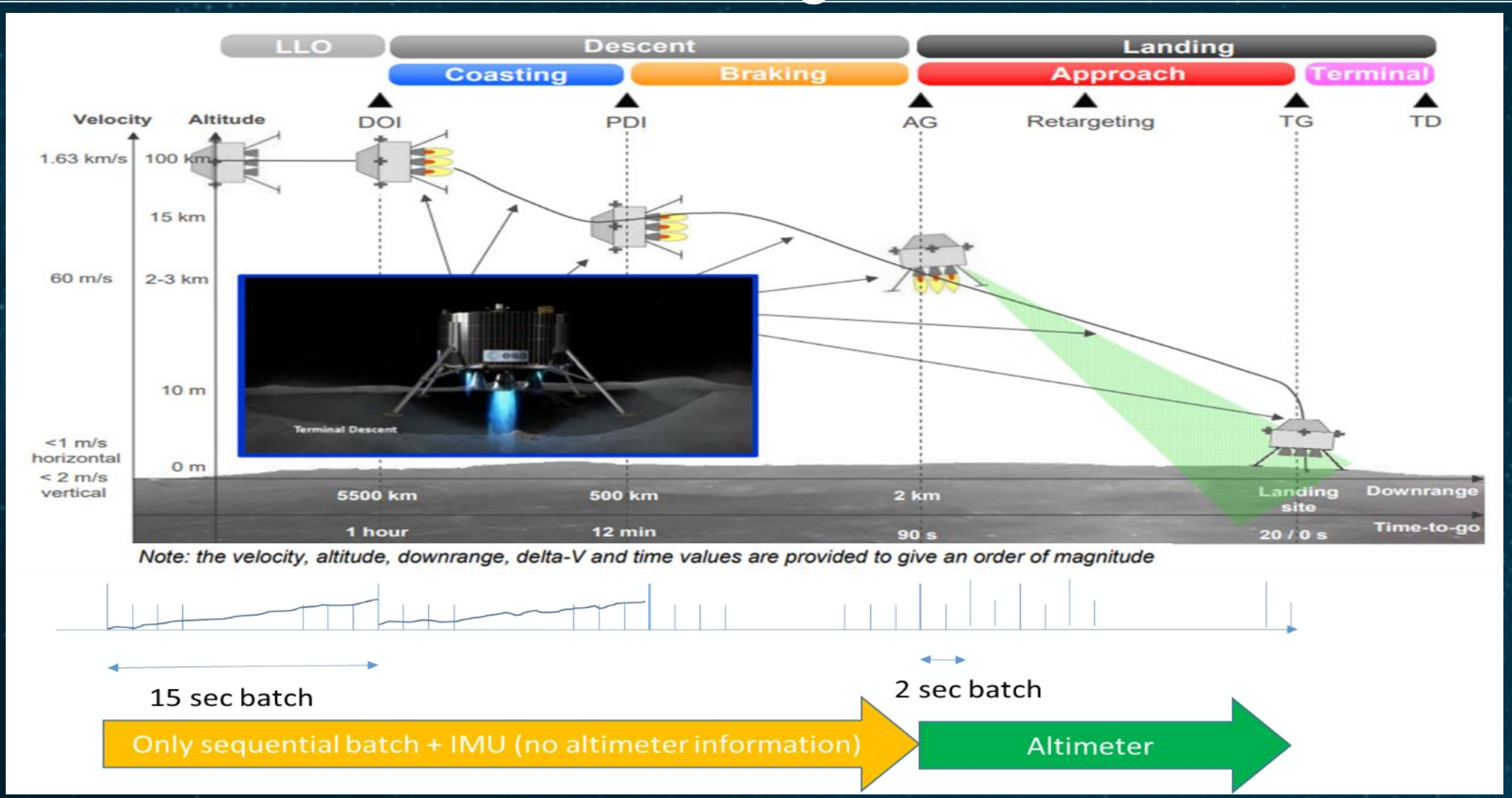
Satellite Id	1	2	3	4
Semi-Major Axis (km)	9750.73	9750.73	9750.73	9750.73
Eccentricity	0.6383	0.6383	0.6383	0.6383
Inclination (°)	54.33	54.33	61.96	61.96
Argument of pericenter (°)	55.18	55.18	121.7	121.7
RAAN (°)	277.53	277.53	59.27	59.27
True Anomaly (°)	123.42	0	180	0



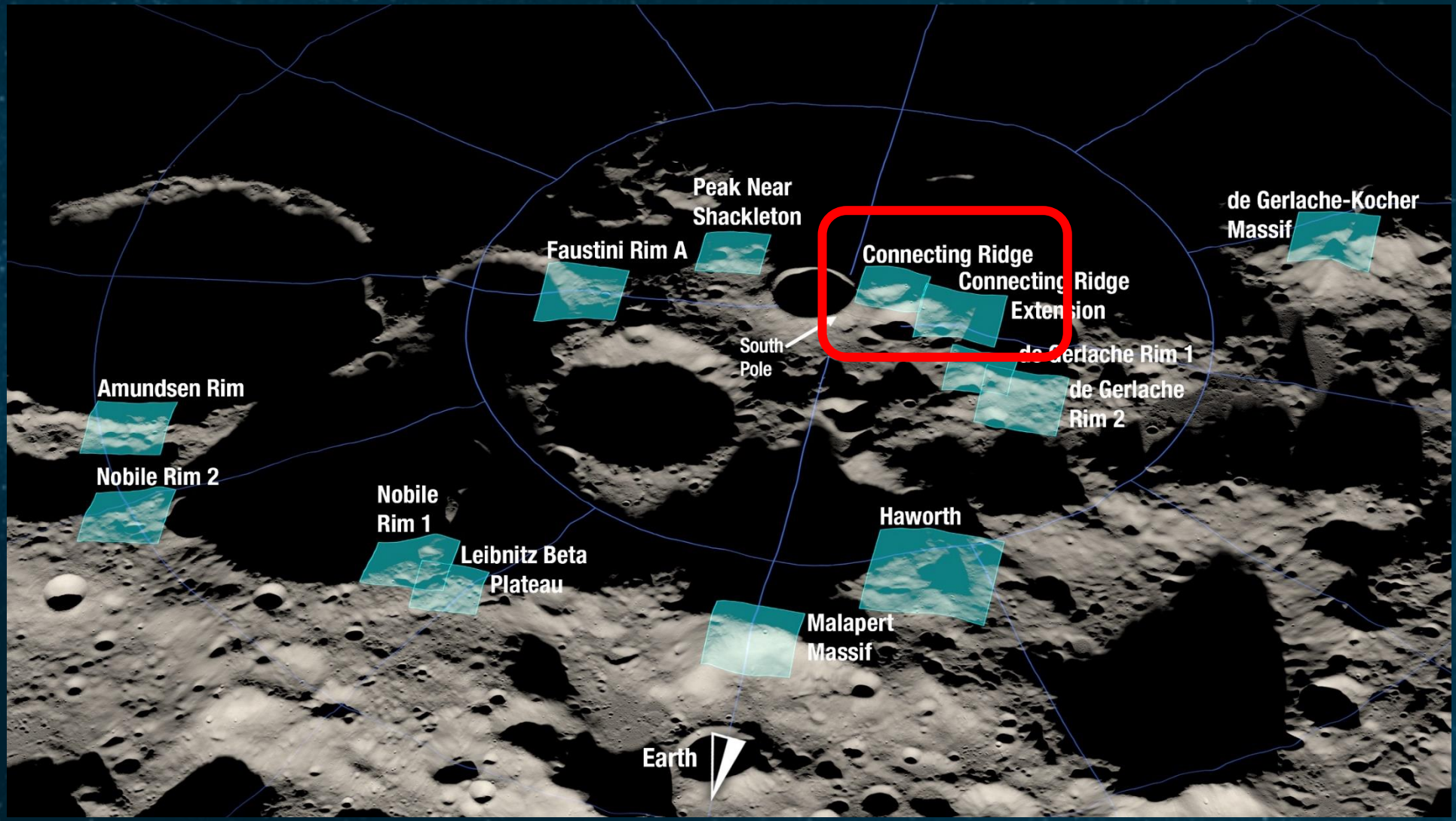
Moonlight performance estimations are excellent !
Extensive ESA and industrial simulations & analysis performed

Surface Rover	Lunar Lander	Lunar Orbiter
		
Real time < 10 m (95%) Post-processing < 3 m (95%	< 50 m (95%) Landing accuracy	Real time < 100 m (95%) LLO accuracies
		
3-5 meters	~20 meters	30-60 meters
Ref: Navigation Performance of a Lunar Surface Rover Using LCNS Positioning Assuming Realistic ODTS Performances, EUROPEAN NAVIGATION CONFERENCE 2023	Ref: Positioning and Velocity Performance Levels for a Lunar Lander using a Dedicated Lunar Communication and Navigation System, Navigation Journal 2022	Ref: Navigation performance of Low Lunar Orbit satellites using a Lunar Radio Navigation Satellite System, ION-GNSS 2023

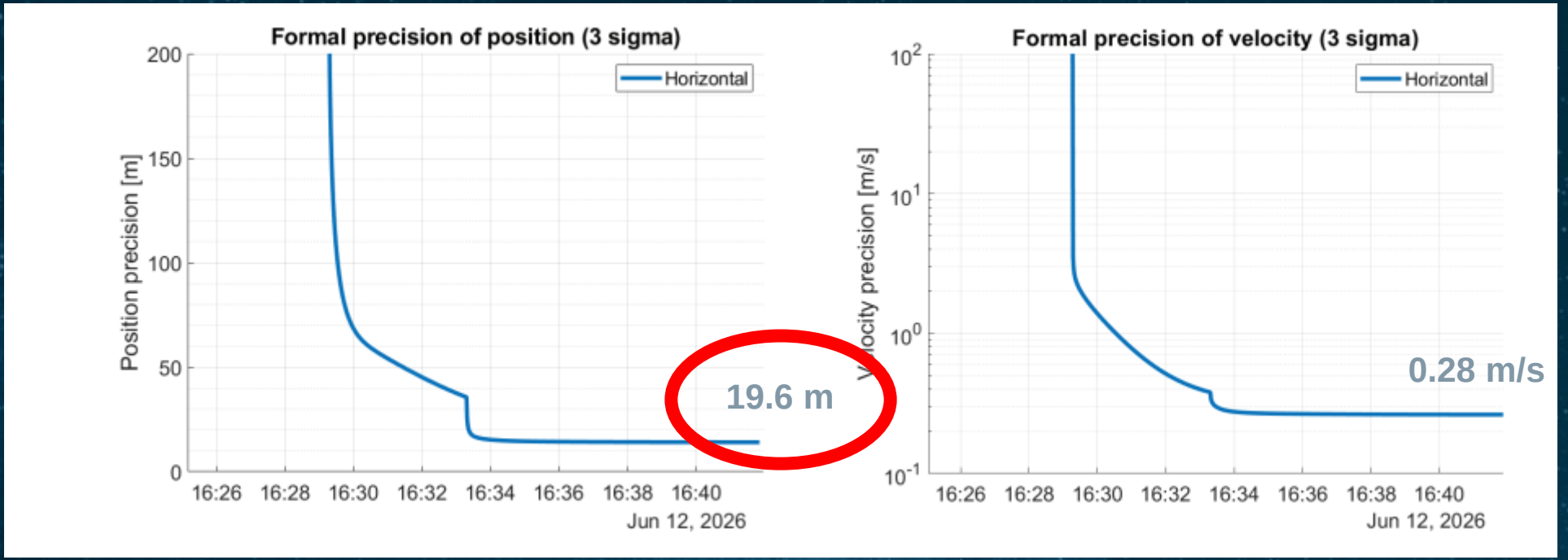
Example of potential Moonlight Performances for Moon landing



Lunar Landing locations proposed for Artemis 3



Landing performances assuming ODTS orbit errors (x,y,z) (15, 15 , 15) m and clock errors of 10 m (all values 1 sigma) – conservative values



Combining LCNS signals with a simple IMU and a simple altimeter the achieved final landing horizontal precision is below 20 m 3-sigma !!

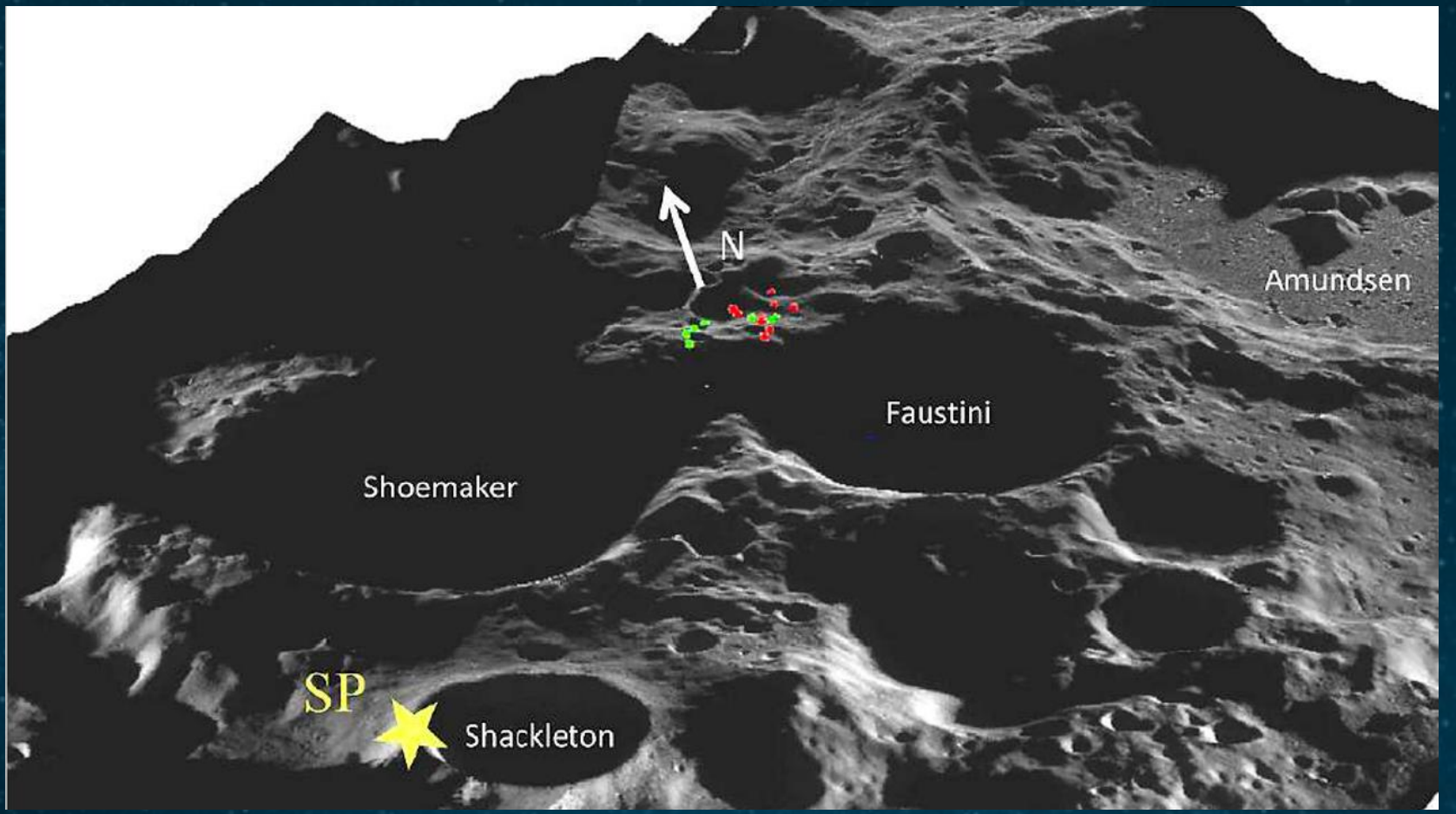
Note: Details published at "*Positioning and Velocity Performance Levels for a Lunar Lander using a Dedicated Lunar Communication and Navigation System*" ION Navigation Journal 2022

Landing on Permanent Shaded Regions (PSRs)

Areas on some craters near the Moon's poles where sunlight never shines (permanently shadowed)

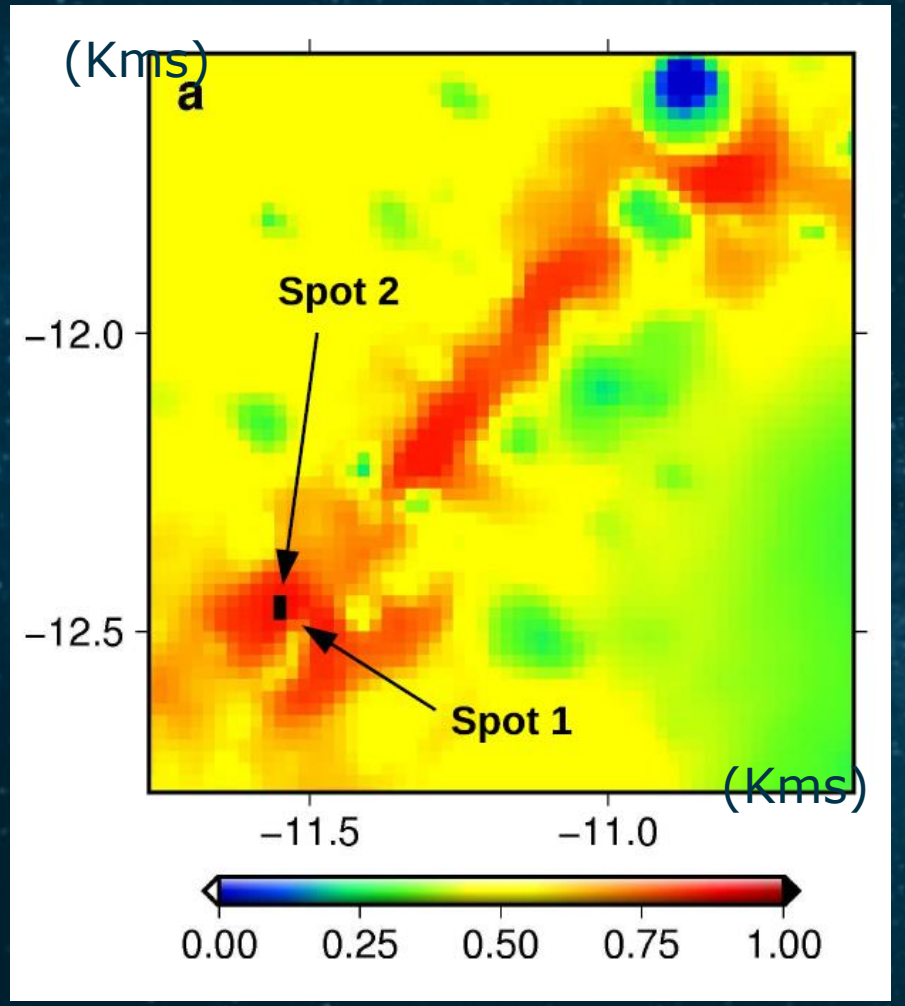
These are of high interested because they preserve water ice and other minerals.

Key to support sustainable exploration, of high scientific interest and may also lead to commercial opportunities.



Landing on these sites is challenging due to the difficulty to use optical/visual navigation sensors !

Landing at Peaks of Eternal Light (PELs) require very high landing accuracies



Over 20 years, the longest continuous periods in darkness are typically only 3-5 days .

Source: EPSC Congress

Areas wit extended periods of sunlight exposition, on some crater rims near the poles

Example Connecting Ridge-1 (89.4 South, 222.6 East). connecting the Gerlache and Shackleton craters.

PELs are of very high interest since they potentially allow the exclusive use of solar panels over long mission durations.

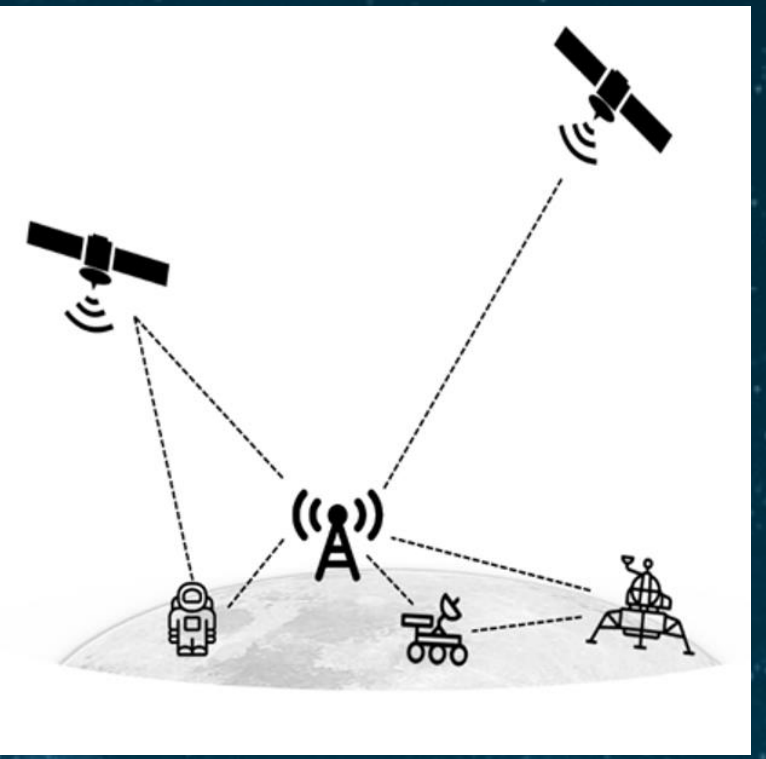
PELs are key for sustainable lunar exploration and for future lunar Base settlements.

Landing accuracies required 50 to 100 metres !!

Moonlight PNT Capabilities: On-going R&D

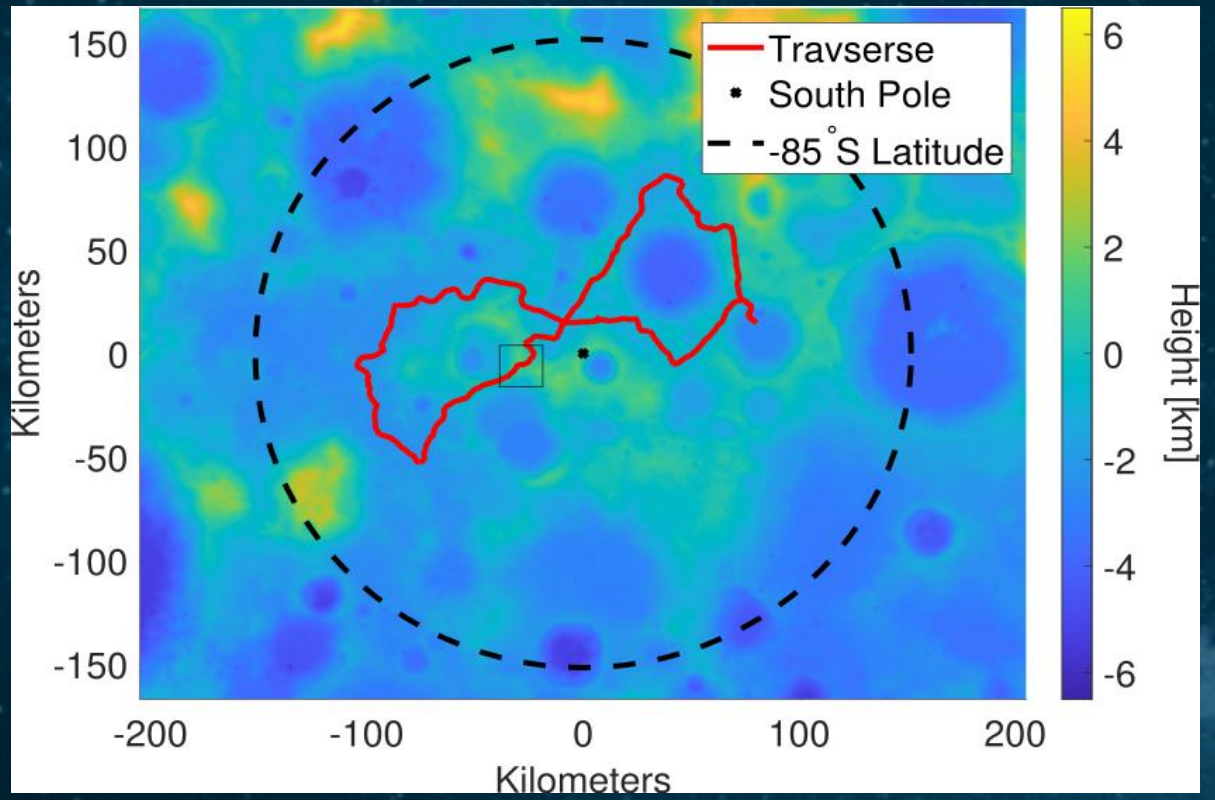
Optimal combination of Moonlight Navigation signals with landing sensors (enhanced GNC system)

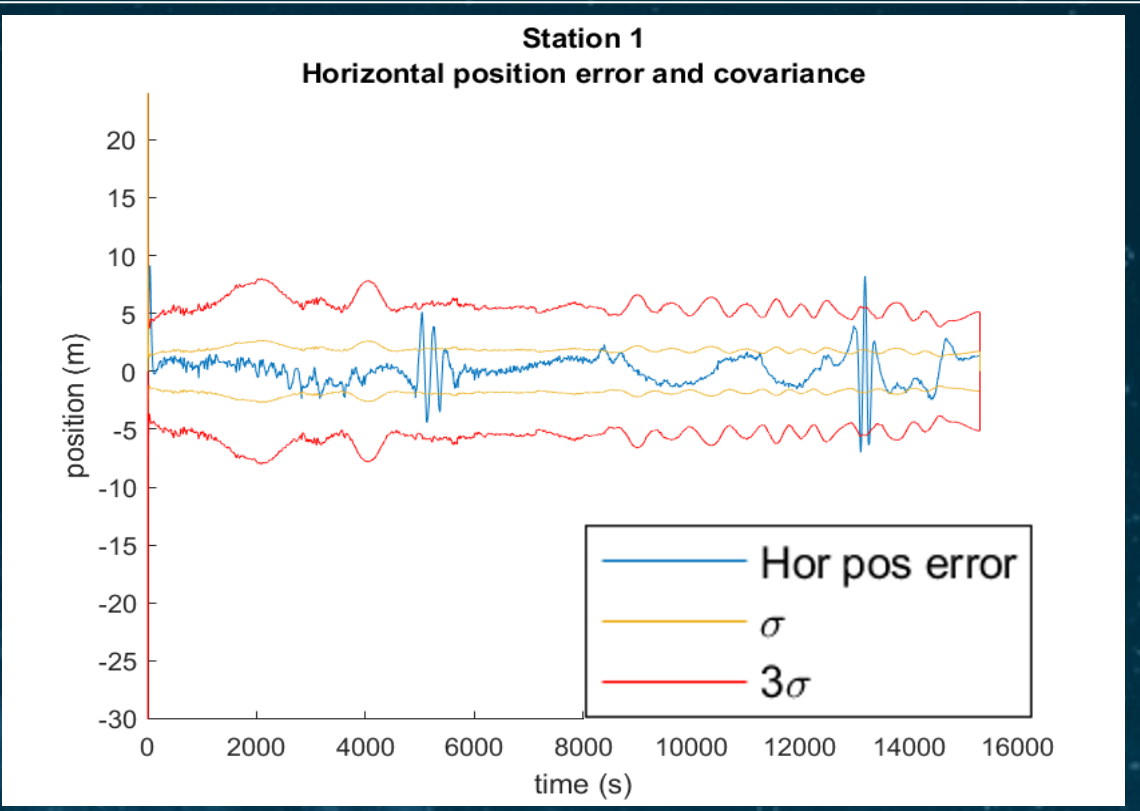
Combining Moonlight Navigation signals with rover sensors



Lunar Local Differential Navigation systems based on Moonlight System

Combining Moonlight ranging signals with Digital Elevantion Models (DEM) information (~5 m/px)





Performances obtained when combining Moonlight with local DEM information:
Position errors 3-5 meters (3 sigma) shown to be at reach and in real time !

Note: Details at "*Navigation Performance of a Lunar Surface Rover Using LCNS Positioning Assuming Realistic ODTS Performances*", ENC Conference May 2023.

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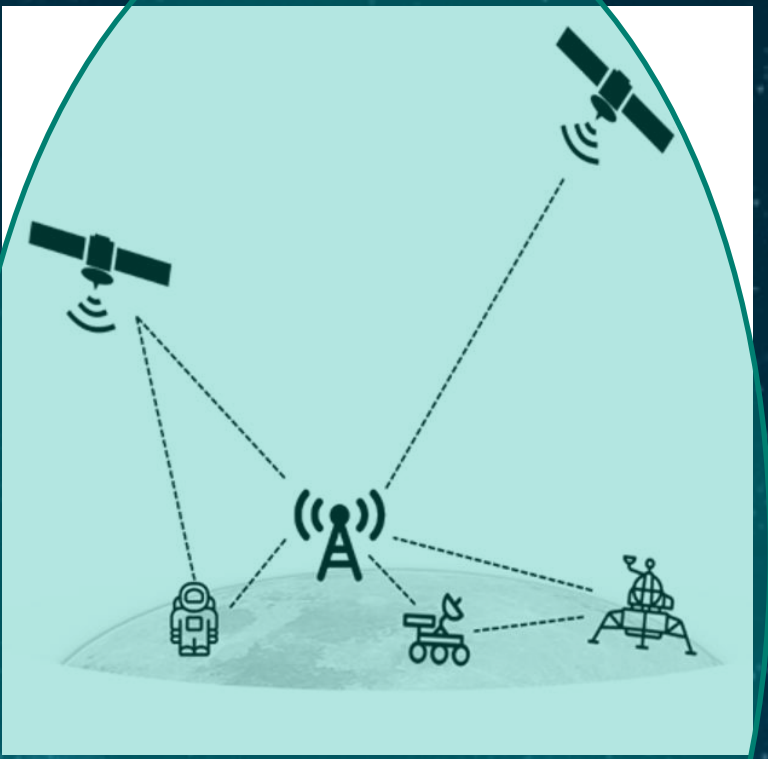
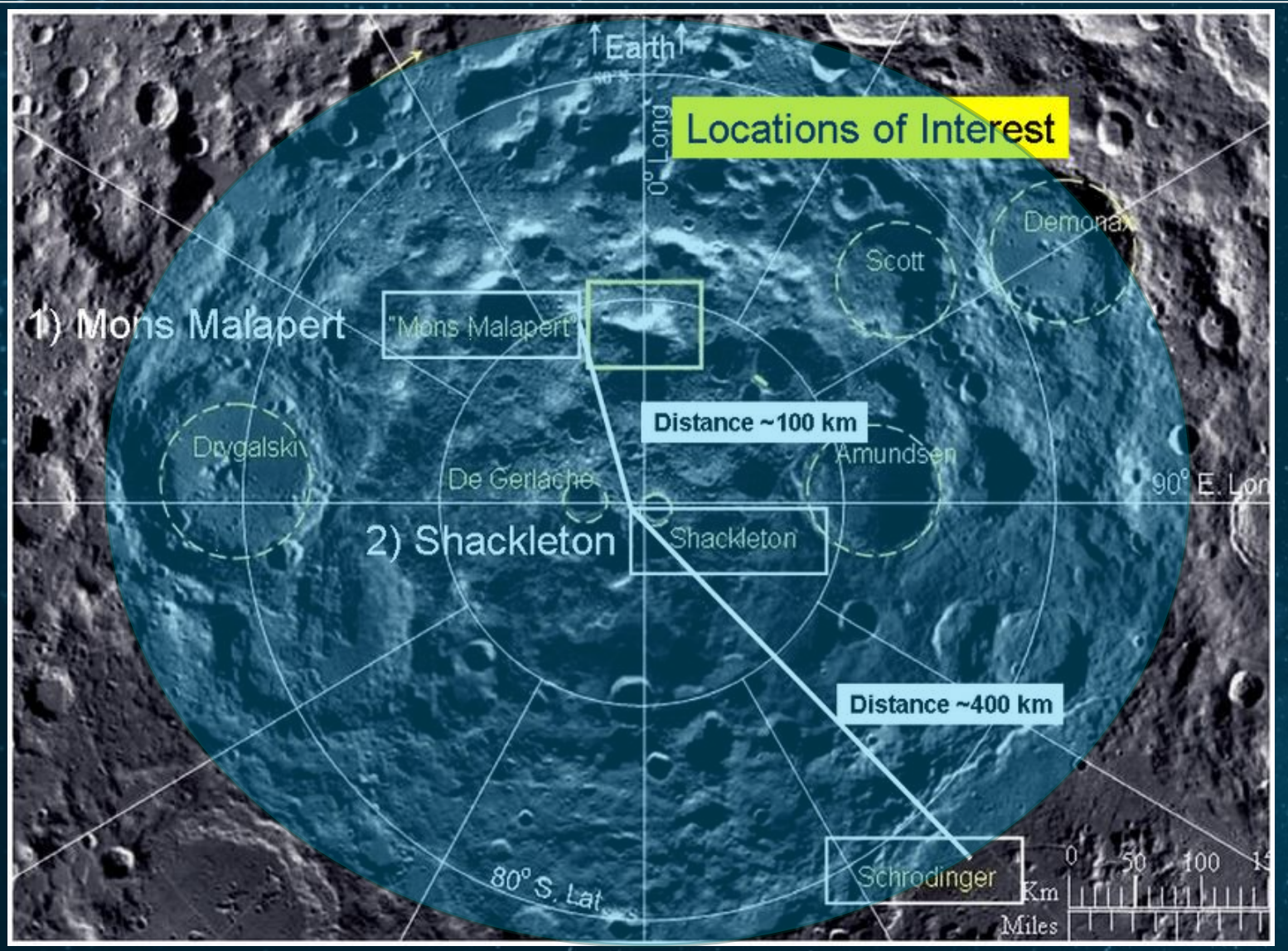


Lunar Local Differential Navigation systems based on Moonlight System

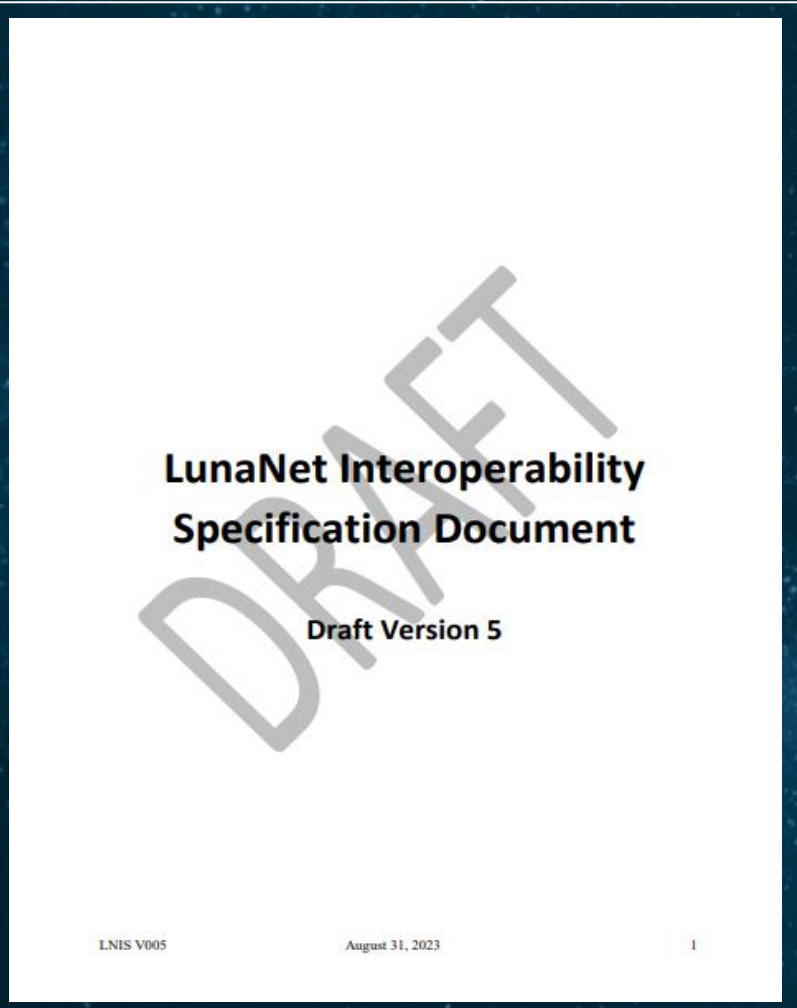
Complementing Moonlight with a Local Differential Station

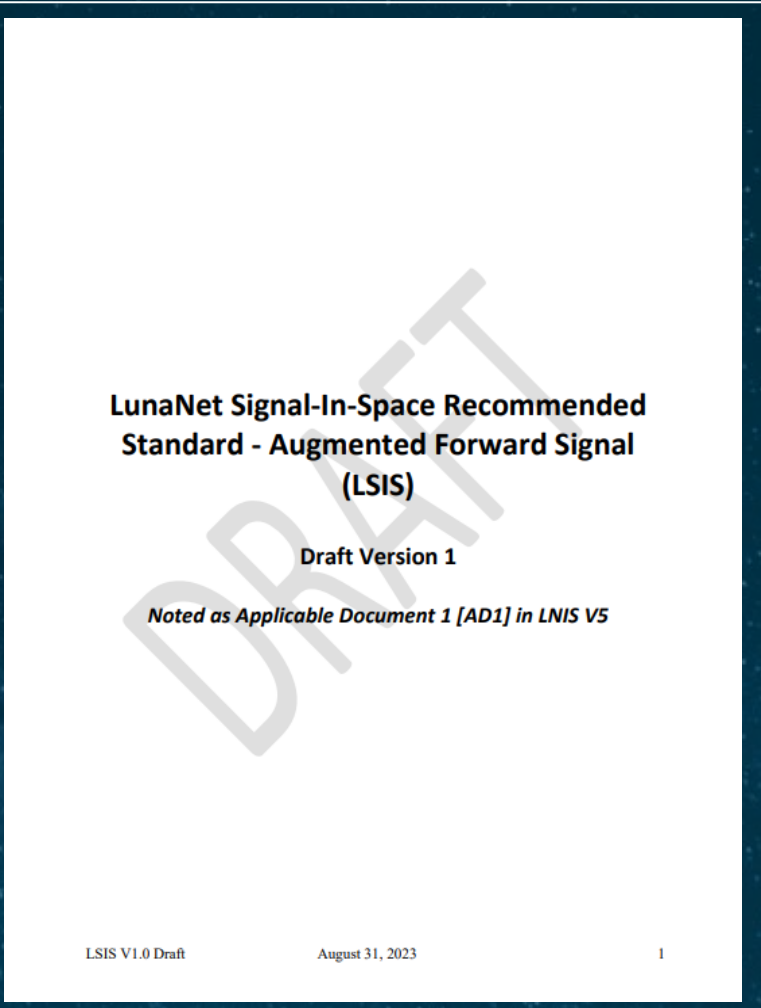


Our simulations show that a single well-placed Moonlight Differential Station could serve the whole of the South Pole enhancing Moonlight accuracies to ~1m accuracies in real time for dynamic users.

INTERNATIONAL COOPERATION

MOONLIGHT LunaNet Interoperability Specifications updated (published in Sept 2023)





Joint NASA, ESA and JAXA cooperation defining future Lunar Communication and Navigation interoperability Standards

AD1: LunaNET PNT Signal-in-Space ICD Document (well advanced)

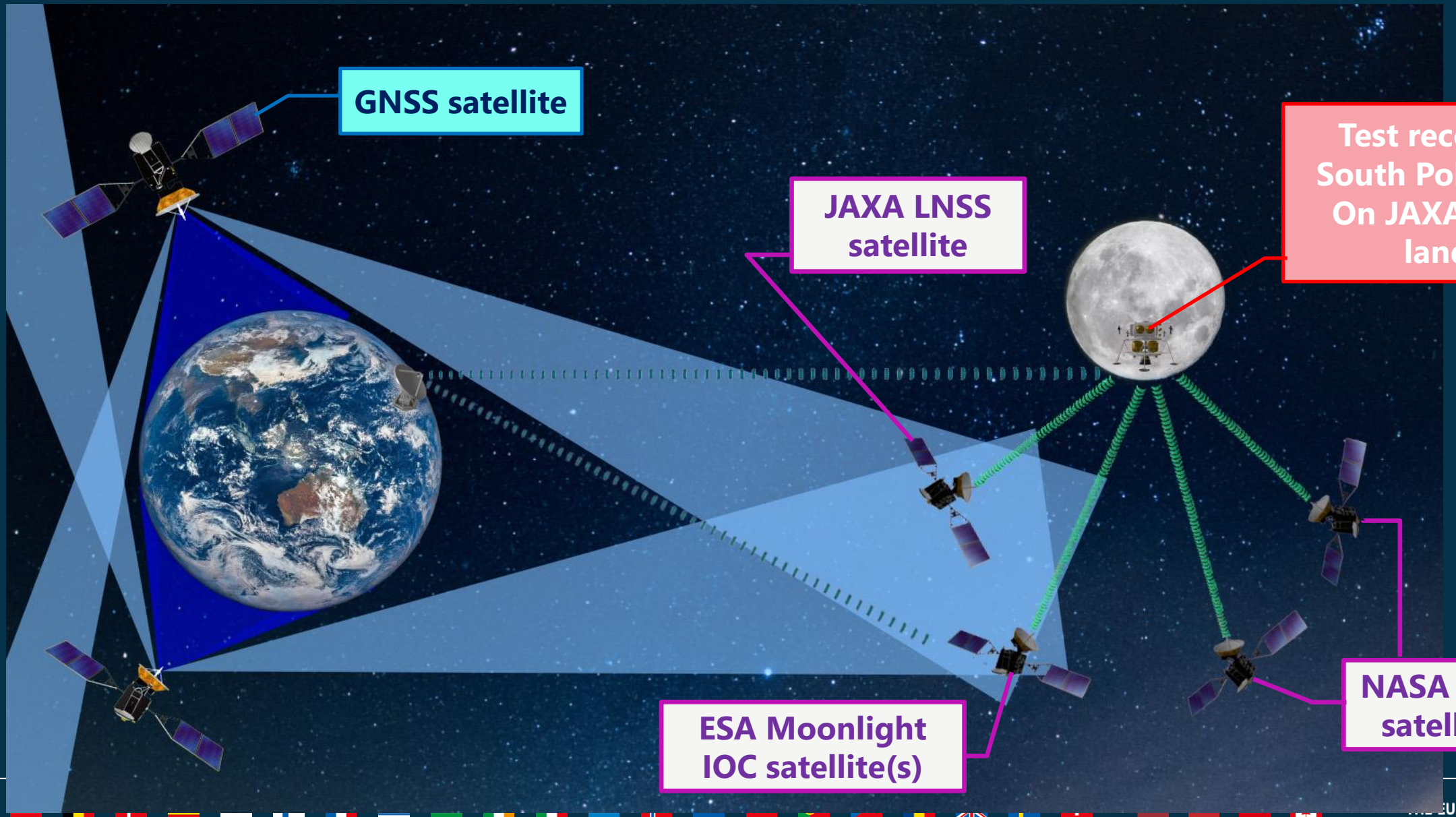
RF signal specifications

Navigation message format specifications

Message and data content specifications

LunaNet PNT compatible receivers may now start to be developed !

First-ever lunar PNT interoperability demonstration planned for 2028
ESA / NASA / JAXA: Towards an international LANS System



Thank you!