ICG International Committee on Global Navigation Satellite Systems

ICG Intercessional Meeting
Joint Working Group Session on Lunar PNT

Moonlight: LCNS, and Lunar Pathfinder

European contribution to lunar Communication and Navigation Services

Dr Javier Ventura- Traveset
Moonlight-Navigation Manager
European Space Agency

The case for cislunar Communication and Navigation services

Towards a new paradigm in lunar exploration

A dedicated cislunar **COM and NAV infrastructure** serving many moon missions

For a more efficient return to the Moon

Opportunity to kick start **new services**…

… and contribute to Moon economy

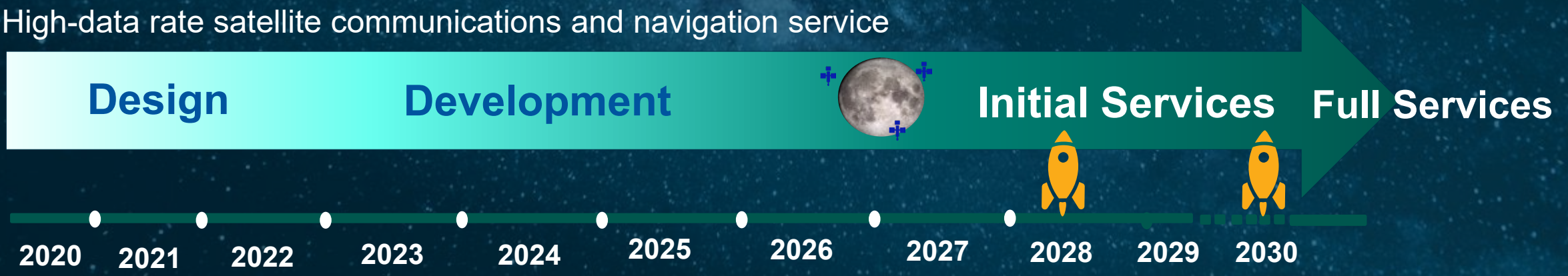
European Roadmap under coordination with ESA

STEP 1: LUNAR PATHFINDER

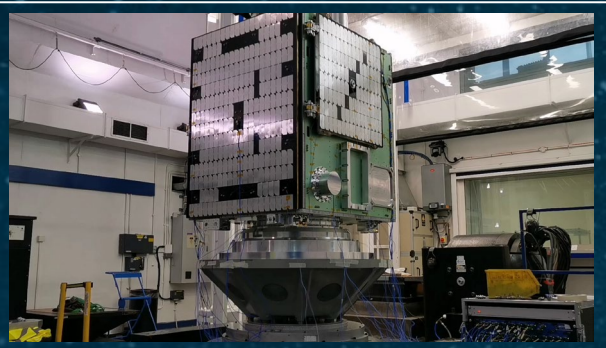
Low-rate satellite communications service + Moon GNSS Receiver

STEP 2: MOONLIGHT LCNS CONSTELLATION

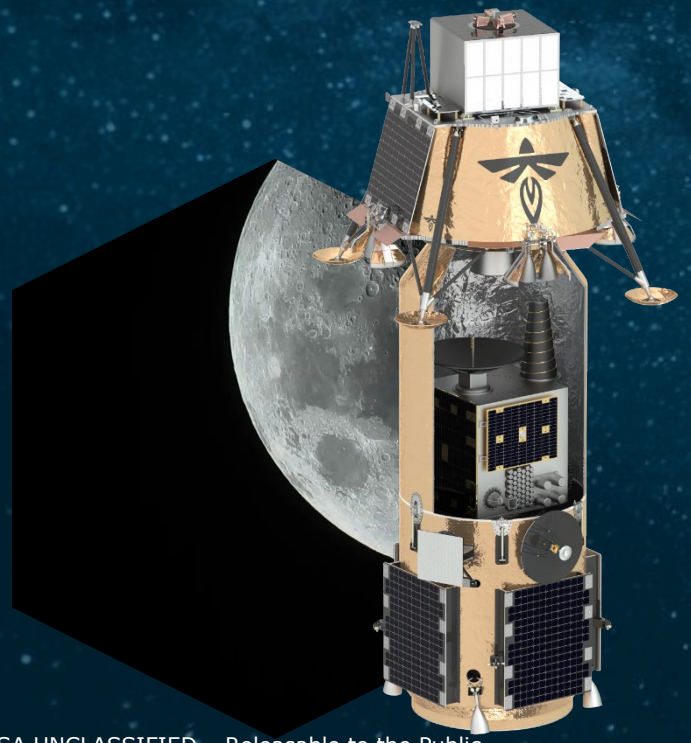
High-data rate satellite communications and navigation service



Moonlight – Lunar Pathfinder – Quick facts



Lunar Pathfinder Structure under test



Provides data relay services as of Q1 2026

- ✓ Flight-patchable SBand Prox1 link, follows SFCG 42-1
- ✓ Adaptative Communication Rates [1;4096] ksps
- ✓ Designed to maximize interoperability with LunaNet (follows LNISv5 subset)

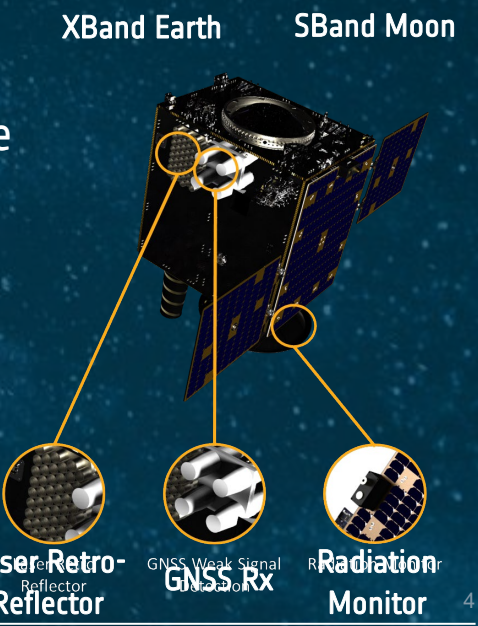
ESA Partnership with SSTL, strategic partnership with NASA:

- ✓ Launch date: Dec 2025 (Firefly's Blue Ghost)
- ✓ Exploitation phase (8 years): Q1 2026 up to Q3 2034
- ✓ Will provide DTE to US LuSEE-NIGHT mission from lunar far side

Demonstrates Navigation technologies

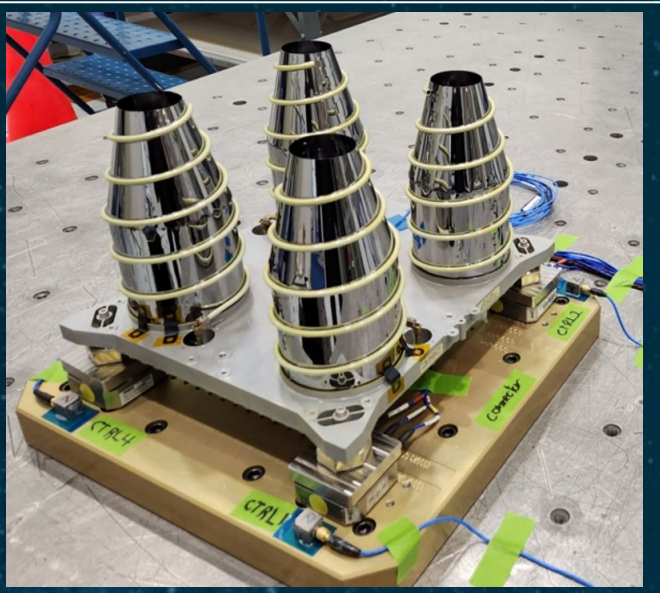
- ✓ First ever GPS/GALILEO reception on lunar orbit
- ✓ NASA Laser Retro-Reflector experiment

Hosts a radiation monitor

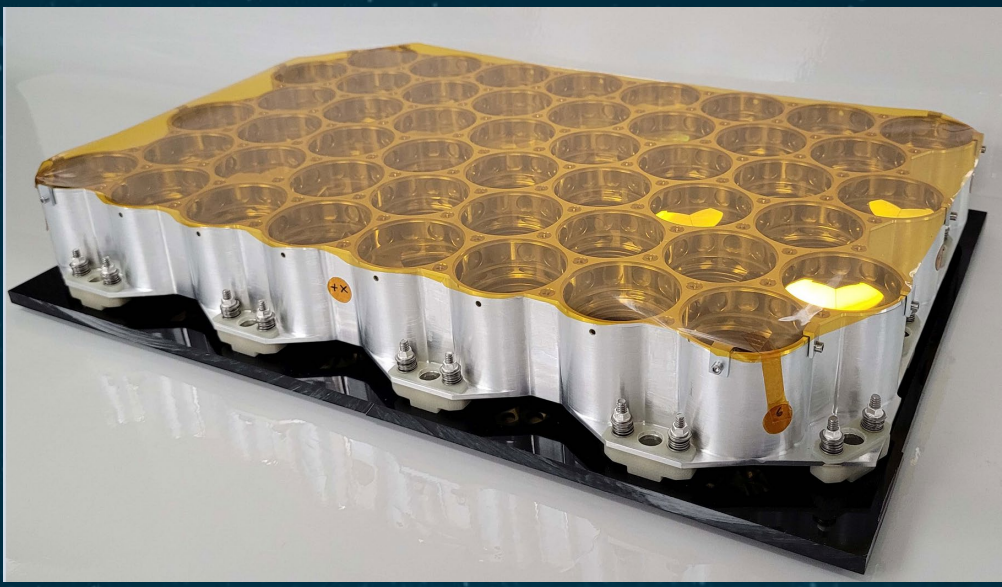


Lunar Pathfinder will also test First ever GPS/GALILEO reception on lunar orbit and precise autonomous Lunar orbit determination (cooperation with NASA)

GNSS High-sensitive receiver
Flight unit



GNSS High-gain Antenna
Flight unit



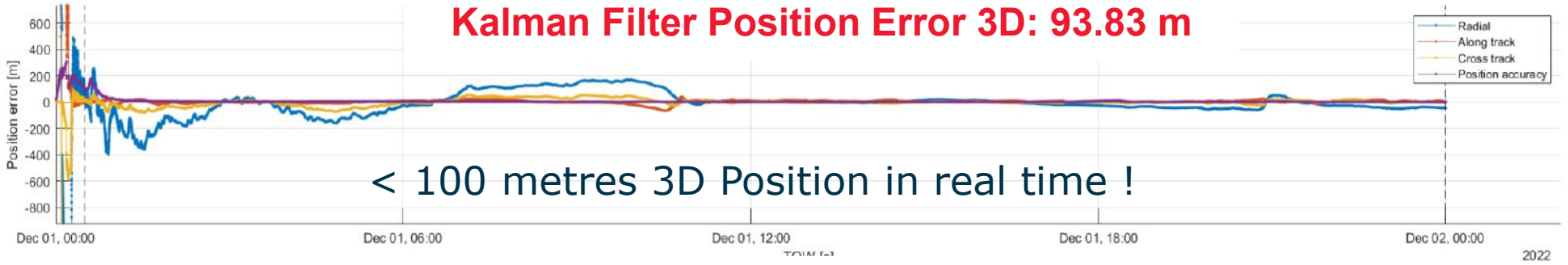
Laser Retroreflector
Flight unit (NASA)

Demonstration of GPS/Galileo PNT on a Lunar orbiting satellite

First time ever three ranging techniques (GNSS, Laser and X-band ranging) are used simultaneously on lunar orbit

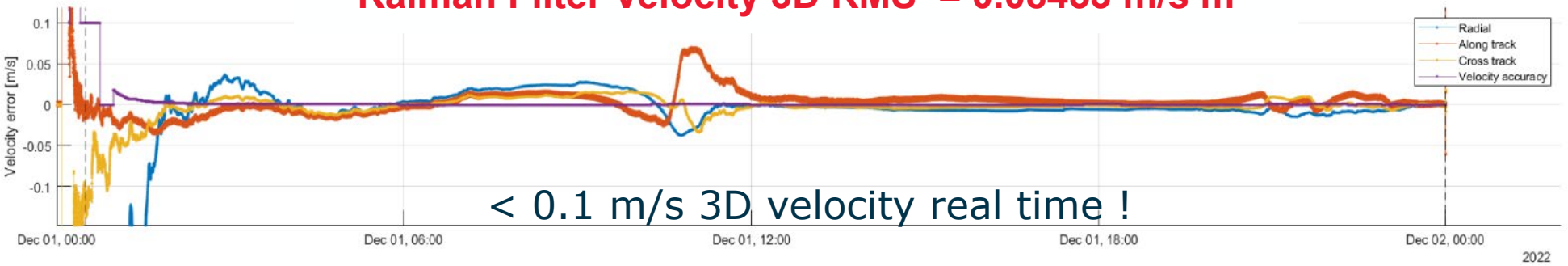
Lunar Pathfinder – Hardware-in-the-loop Test

Kalman Filter Position Error 3D: 93.83 m

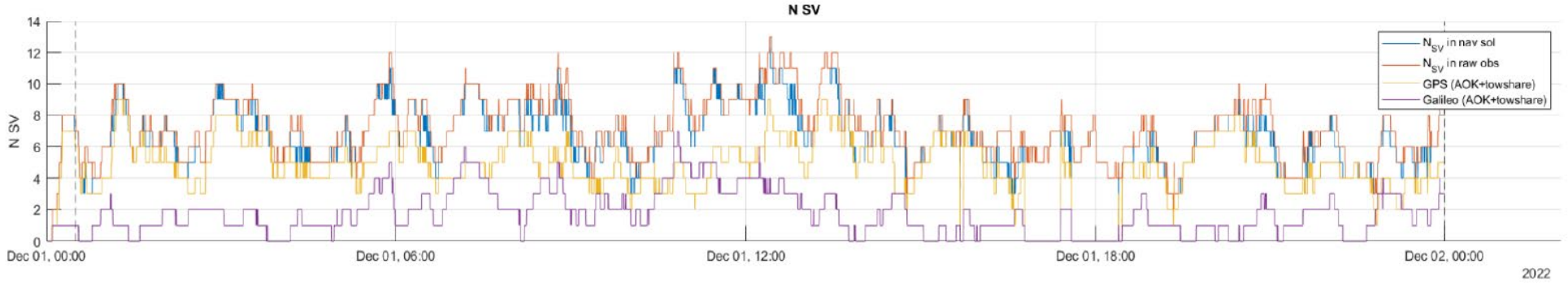


< 100 metres 3D Position in real time !

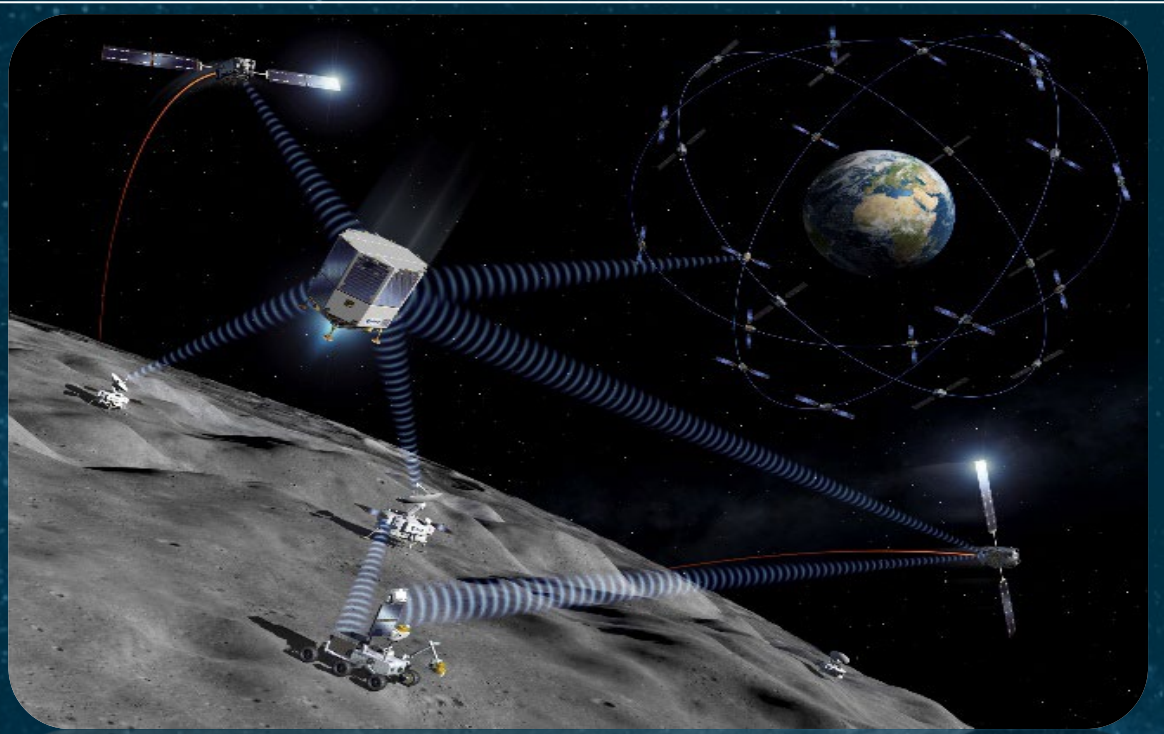
Kalman Filter Velocity 3D RMS = 0.08453 m/s m



< 0.1 m/s 3D velocity real time !



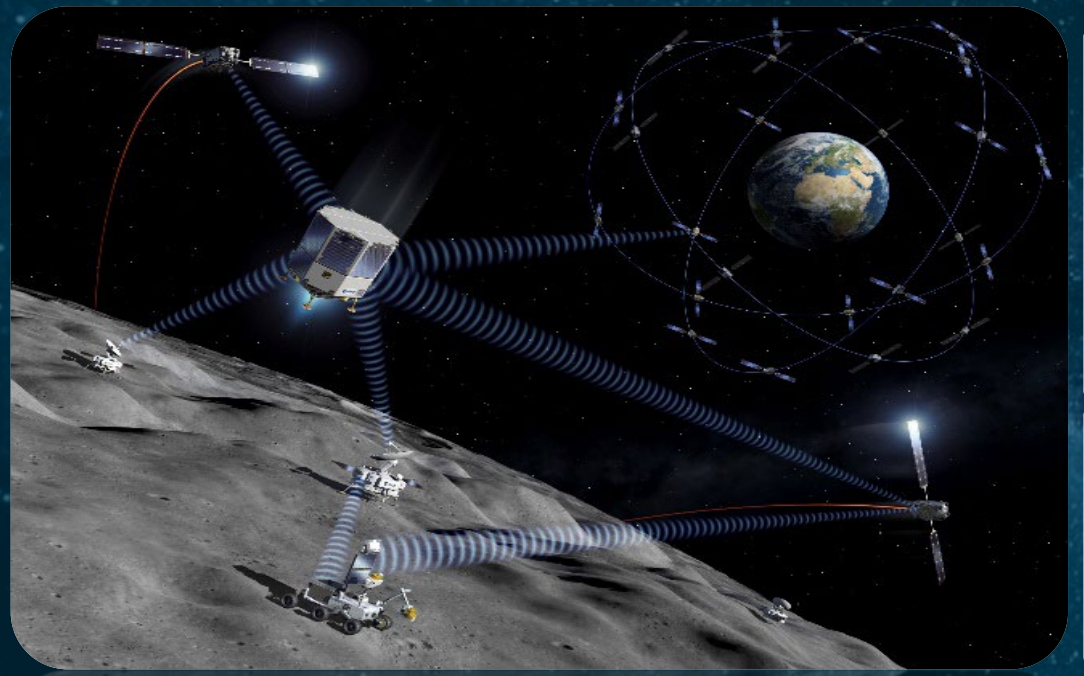
Moonlight Vision



To enable the delivery of interoperable Communications and Navigation Services that will support the current and next generations of institutional and commercial Lunar explorers

Moonlight Approach & Services

Public-Private Partnership: Private sector as service provider
ESA supporting infrastructure development and acting as Anchor customer



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

Direct To Earth Service	Post-processing PVT
Over-the-top Services	LunaSAR return link

- A dedicated constellation of satellites around the Moon providing commercial lunar communication and navigation services in two steps IOC (2028) and FOC (2030).

Moonlight LCNS High-level Mission and Service Drivers

Supporting Commercial & Institutional Missions

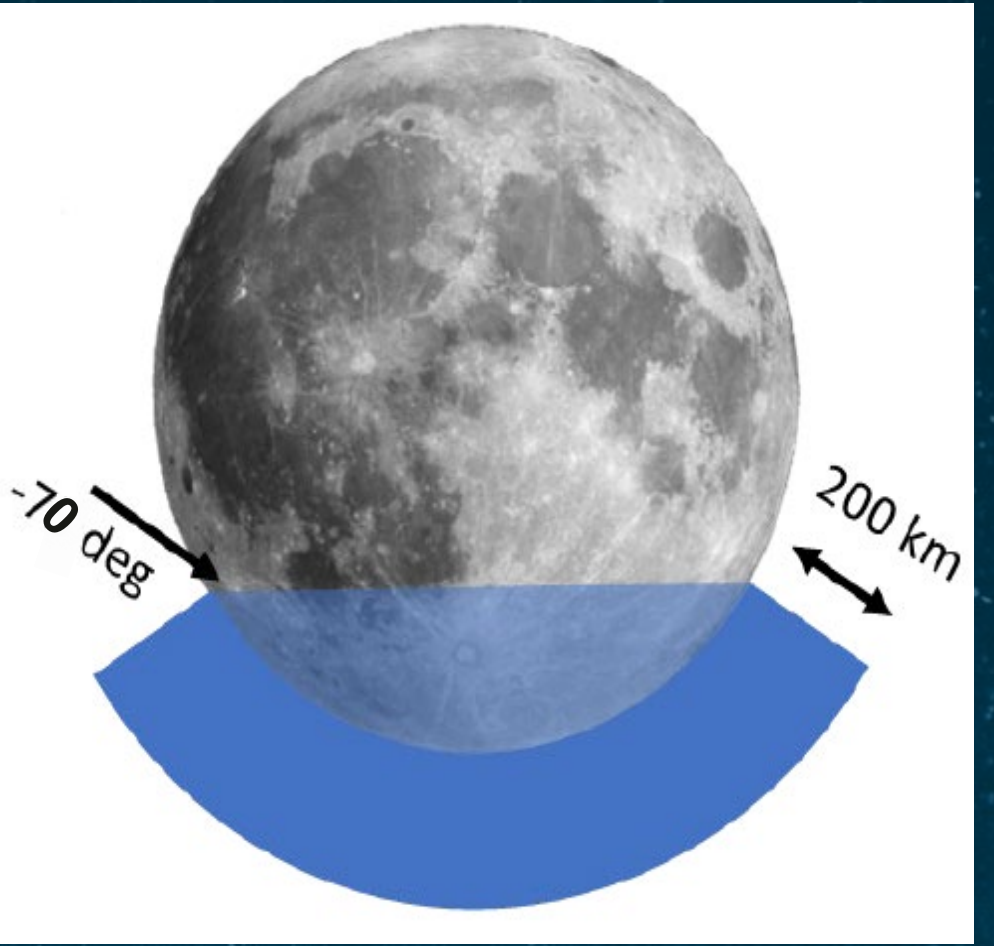
Interoperable LunaNET

IOC in 2028
FOC in 2030
Evolutions 2030+

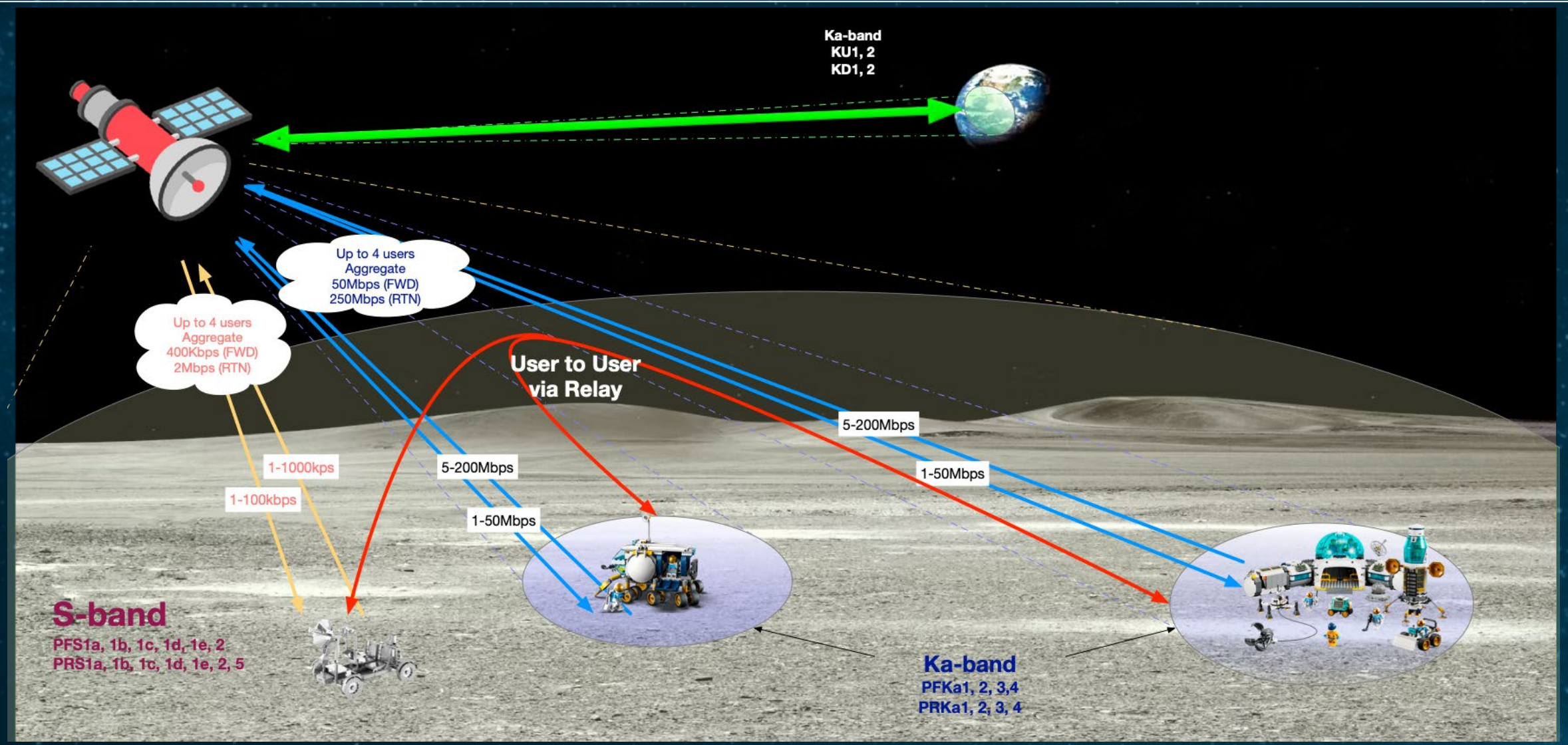
A Scalable System

Supporting all Mission Phases

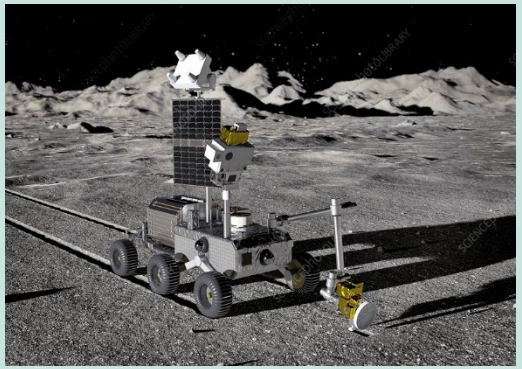
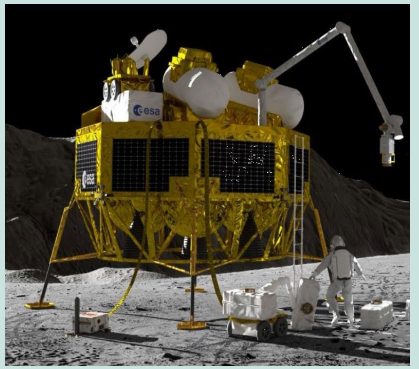
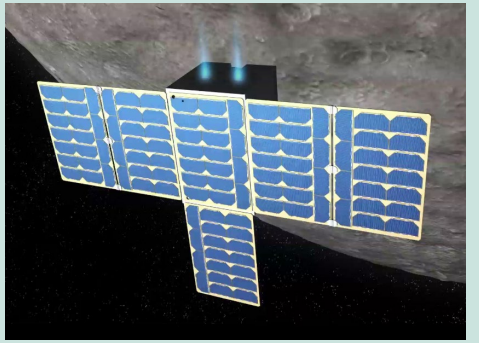
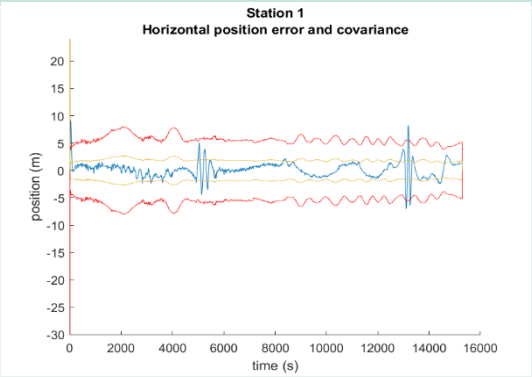
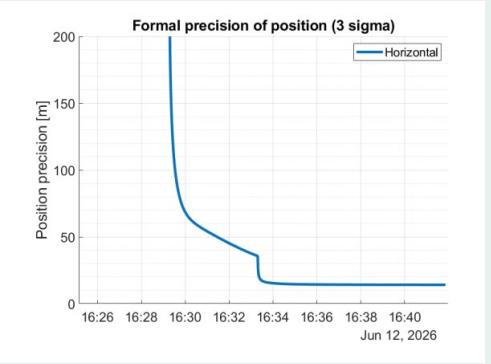
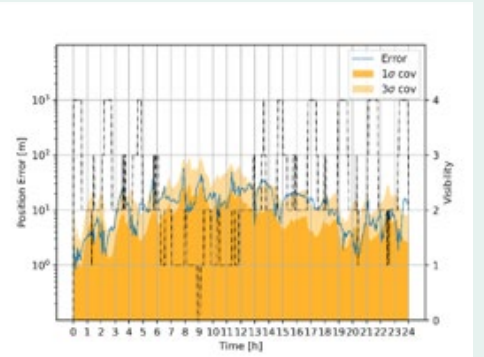
Optimised For South Pole services [70-90° South]



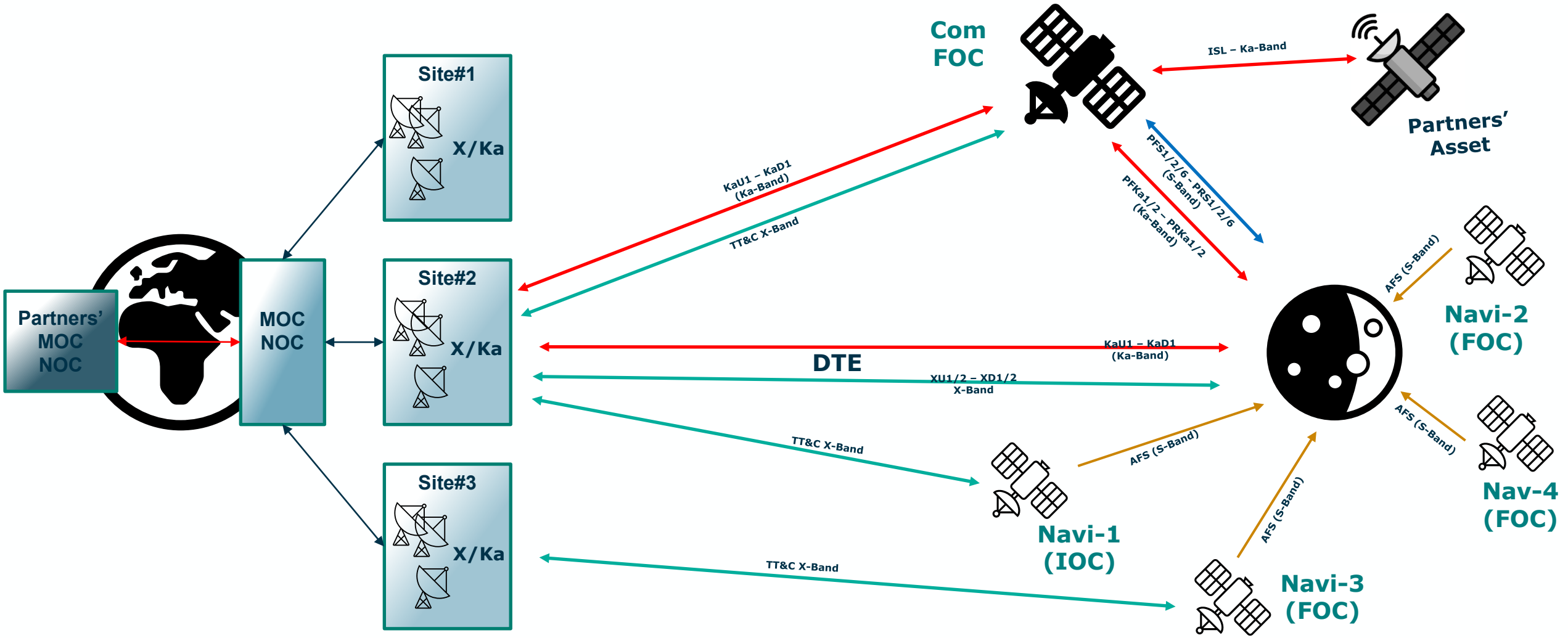
Moonlight LCNS High-level Mission and Service Drivers



Moonlight LCNS High-level Mission and Service Drivers

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

Moonlight: Mission Architectural Concept (notional)

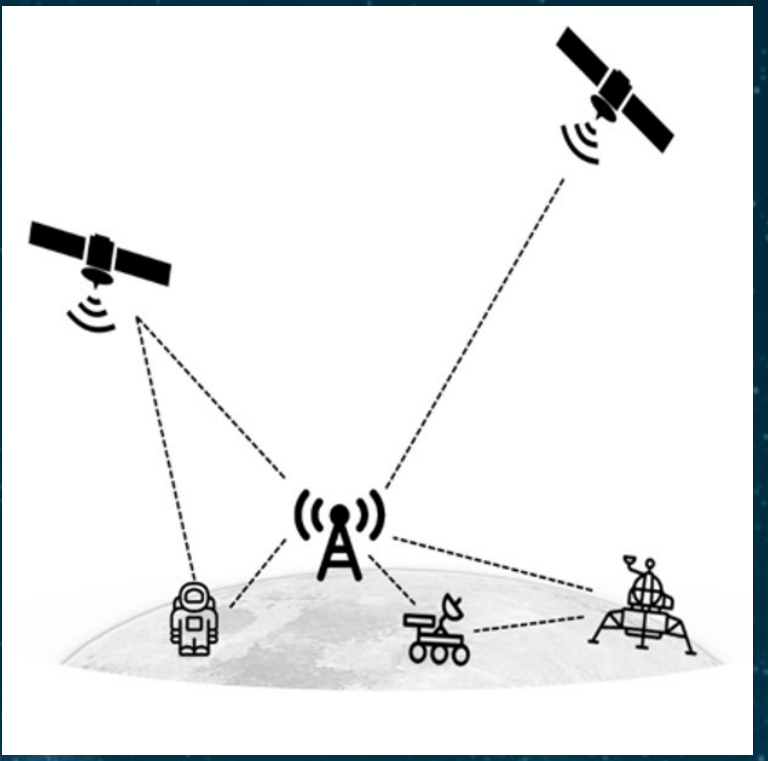


Links are named in-line with LunaNet spec

Moonlight PNT : Performance Analysis

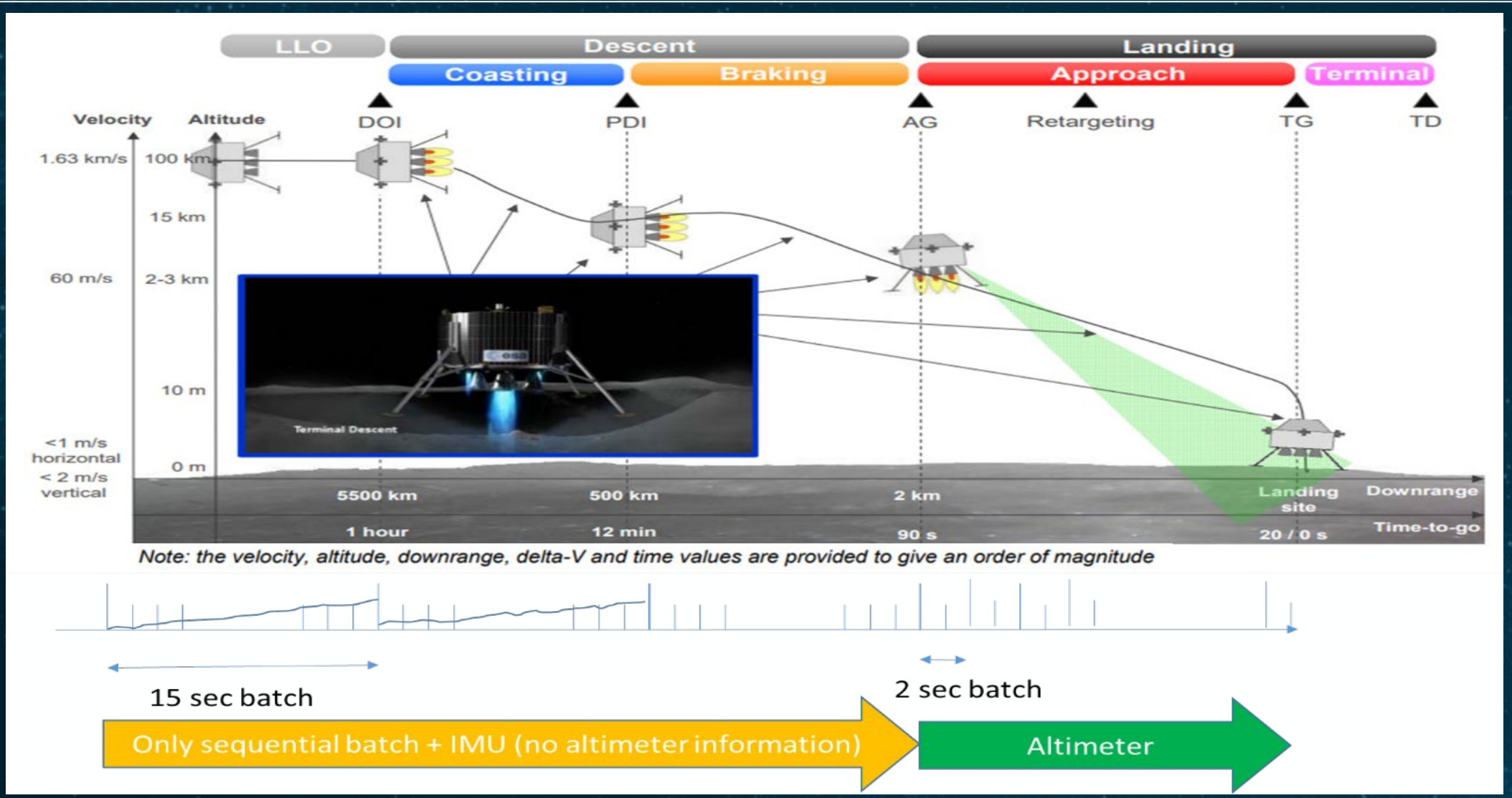
Optimal combination of Moonlight Navigation signals with landing sensors (enhanced GNC system)

Combining Moonlight Navigation signals with rover sensors

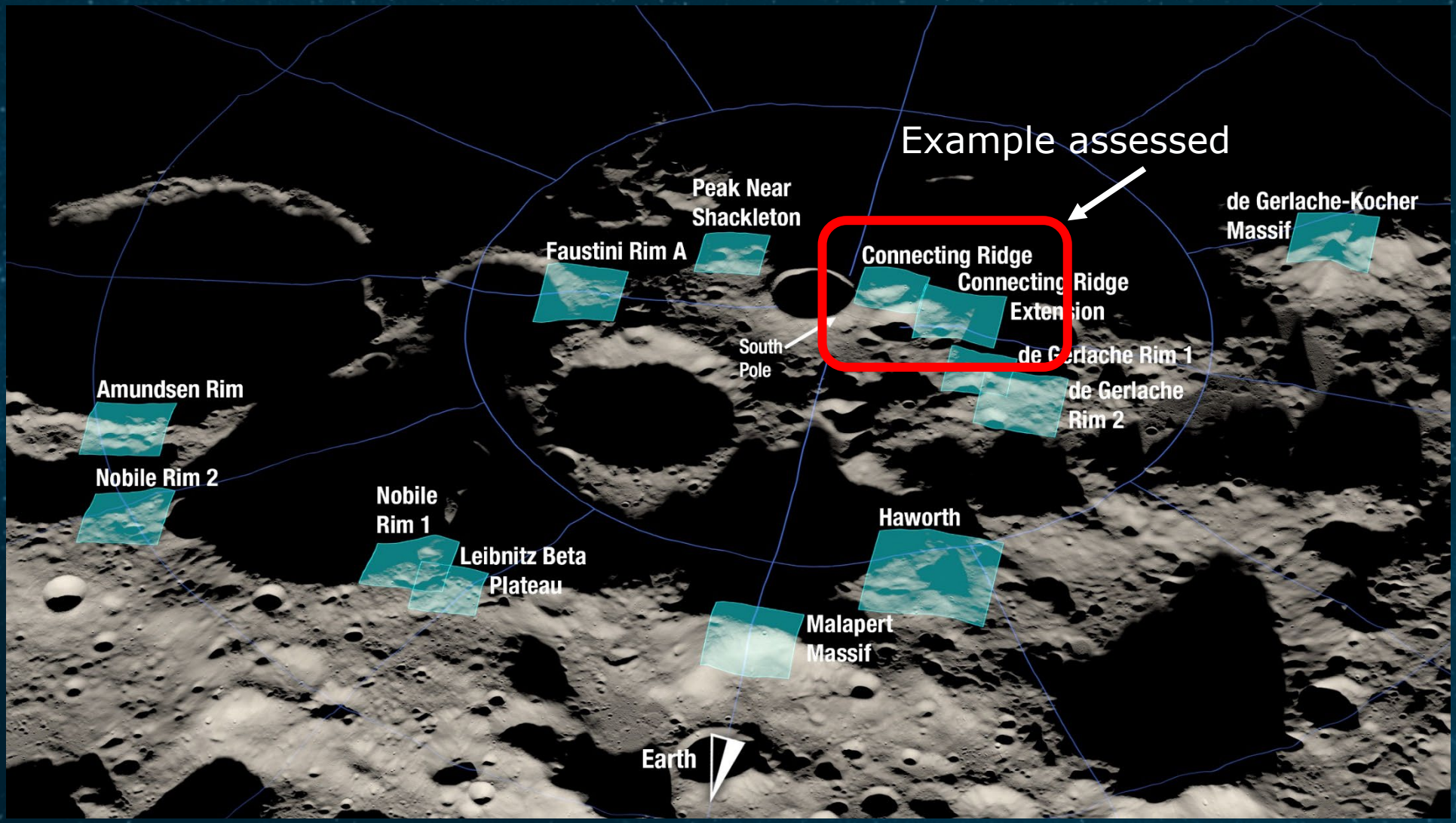


Lunar Local Differential Navigation systems augmenting Moonlight LNCS System

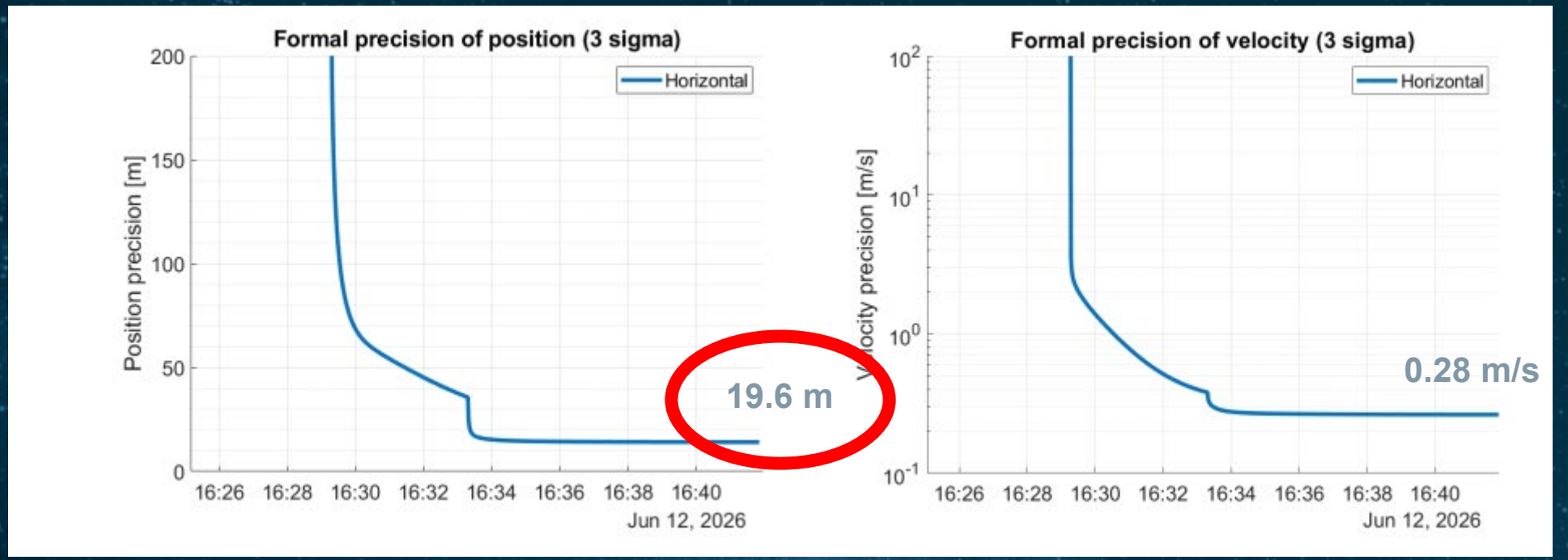
Example Moon landing profile with Moonlight LCNS



Potential Artemis Lunar Landing areas



End-to-end Analysis of Moonlight LCNS landing performances

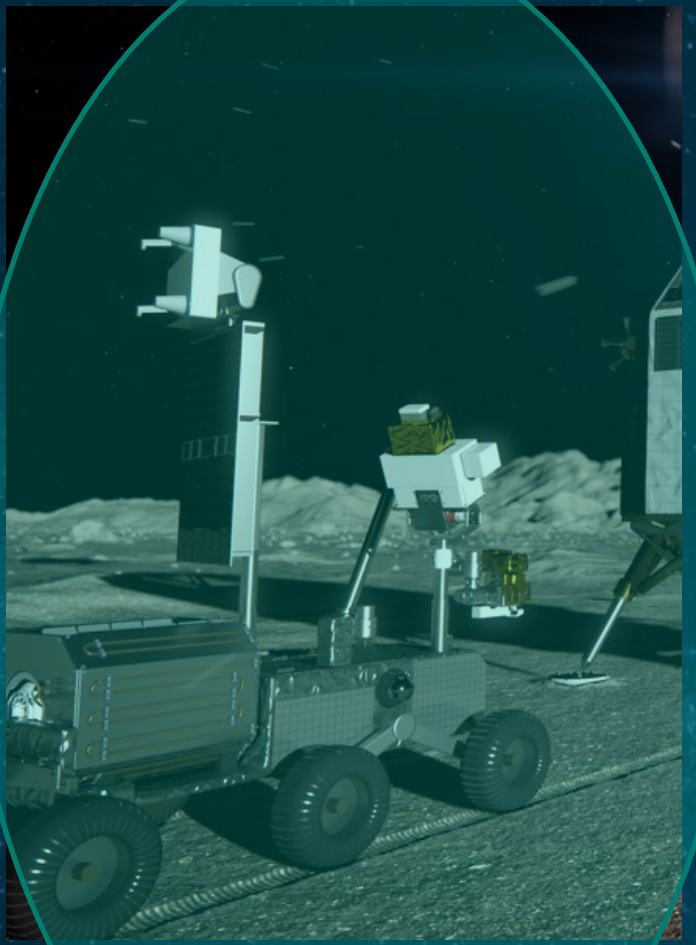


Combining Moonlight LCNS signals with a simple IMU and altimeter the achieved final landing horizontal precision obtained is around 20 m !! (bellow 50 m Spec)

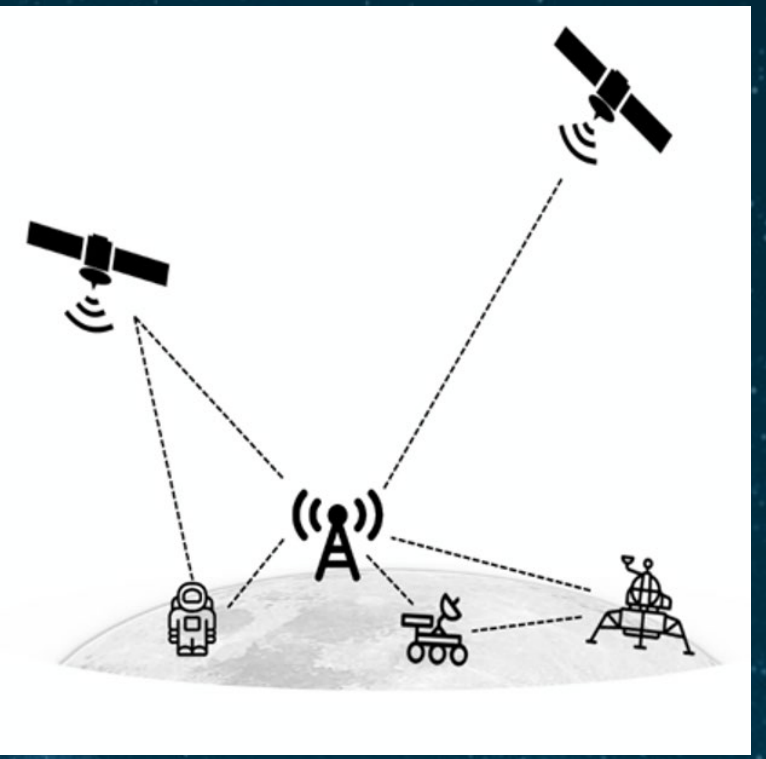
Note: Details published at "*Positioning and Velocity Performance Levels for a Lunar Lander using a Dedicated Lunar Communication and Navigation System*" ION Navigation Journal 2022

Moonlight PNT : Performance Analysis

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

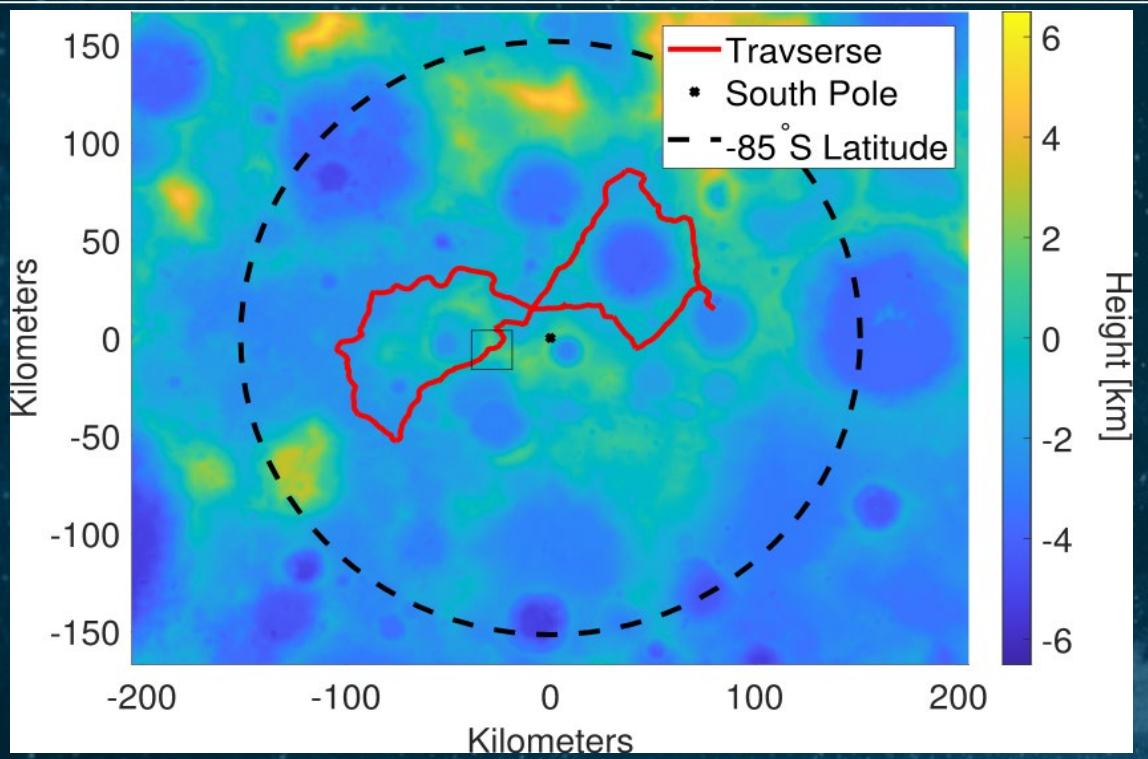


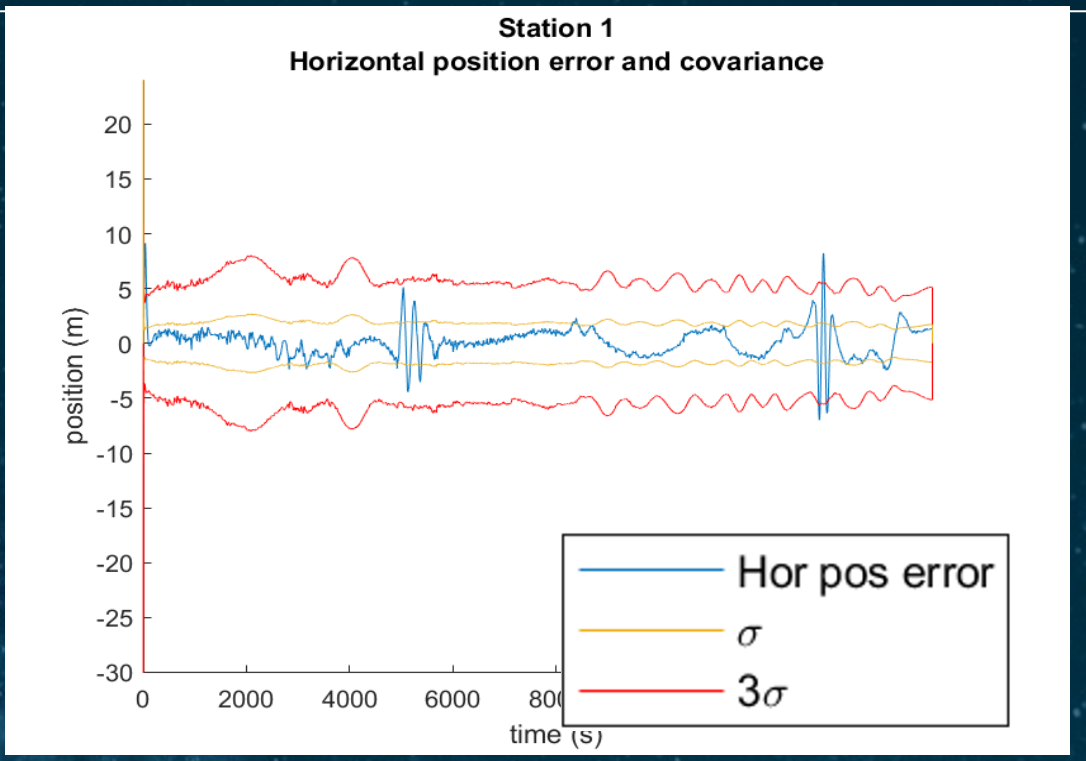
Combining Moonlight Navigation signals with rover sensors



Lunar Local Differential Navigation systems augmenting Moonlight LNCS System

Combining Moonlight One-Way Ranging signals with available Lunar DEM information (~5 m/px)





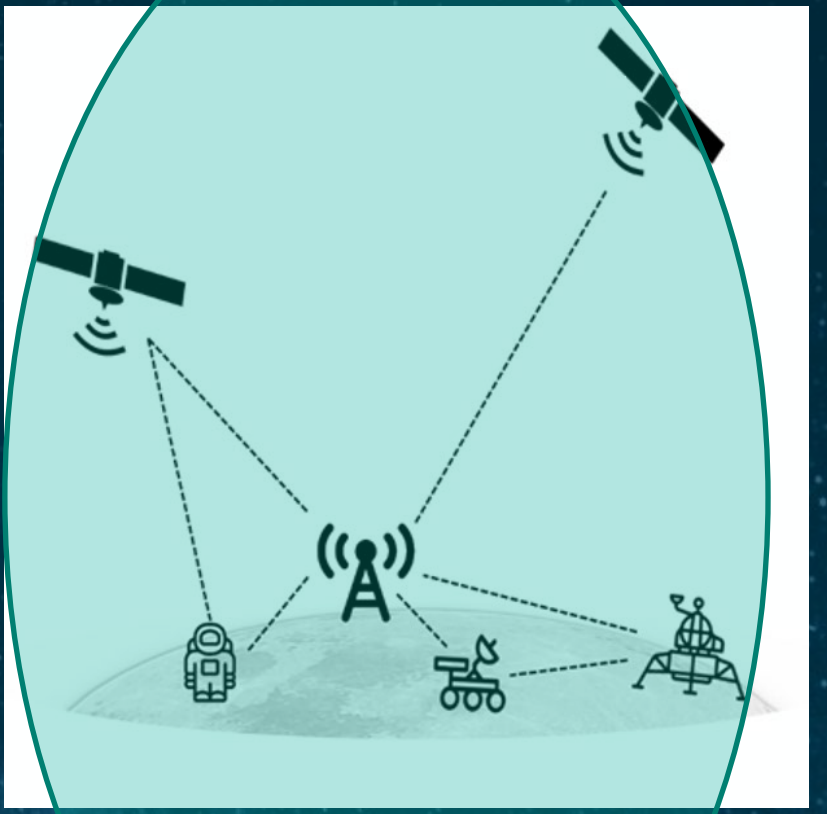
Combining Moonlight LCNS signals with Digital Elevation model (DEM) information Position errors obtained are around 5 meters (3 sigma) - below 10 m spec !

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

Moonlight PNT : Performance Analysis

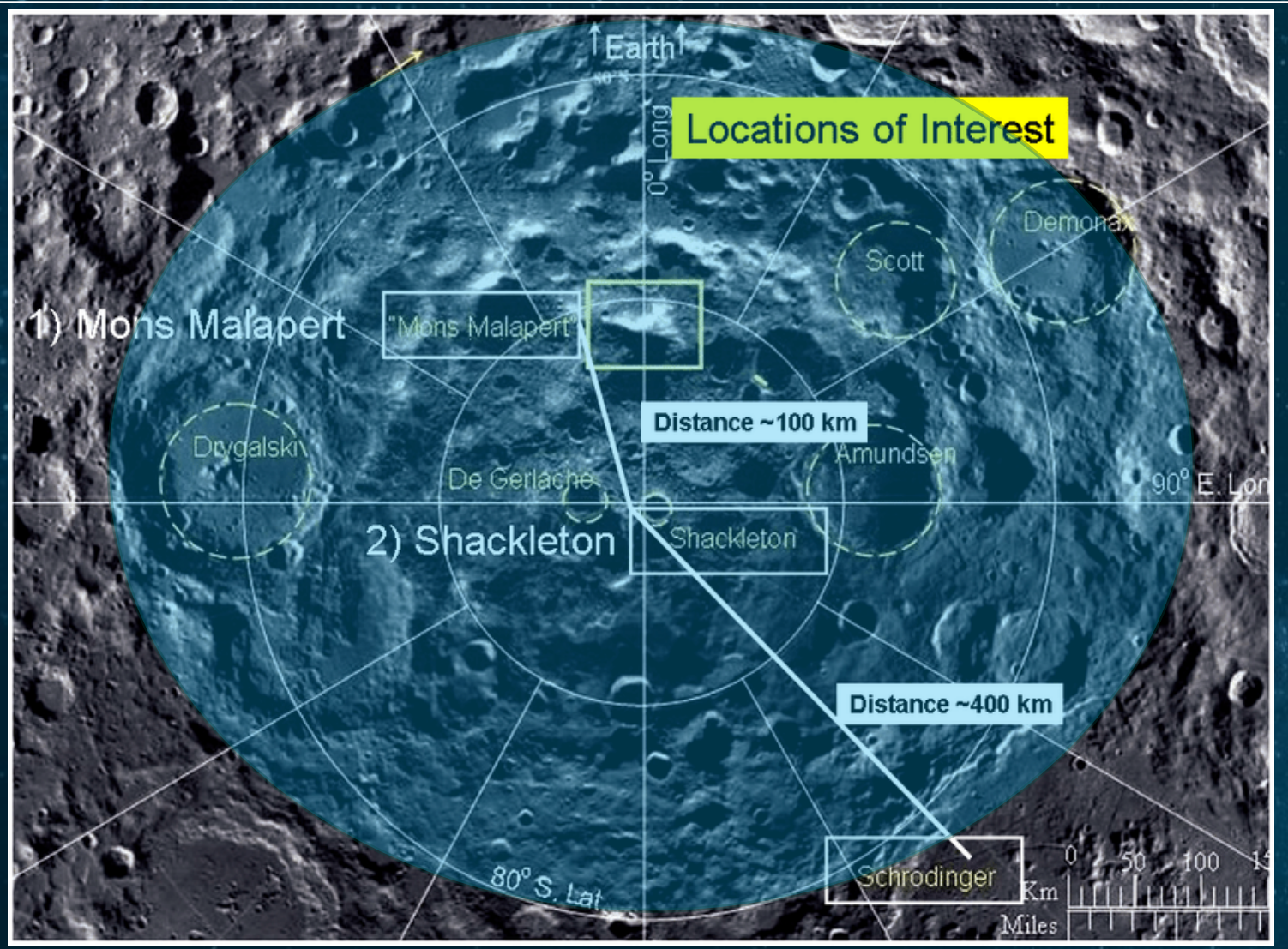
Optimal combination of Moonlight Navigation signals with landing sensors (enhanced GNC system)

Combining Moonlight Navigation signals with rover sensors



Lunar Local Differential Navigation systems augmenting Moonlight LNCS System

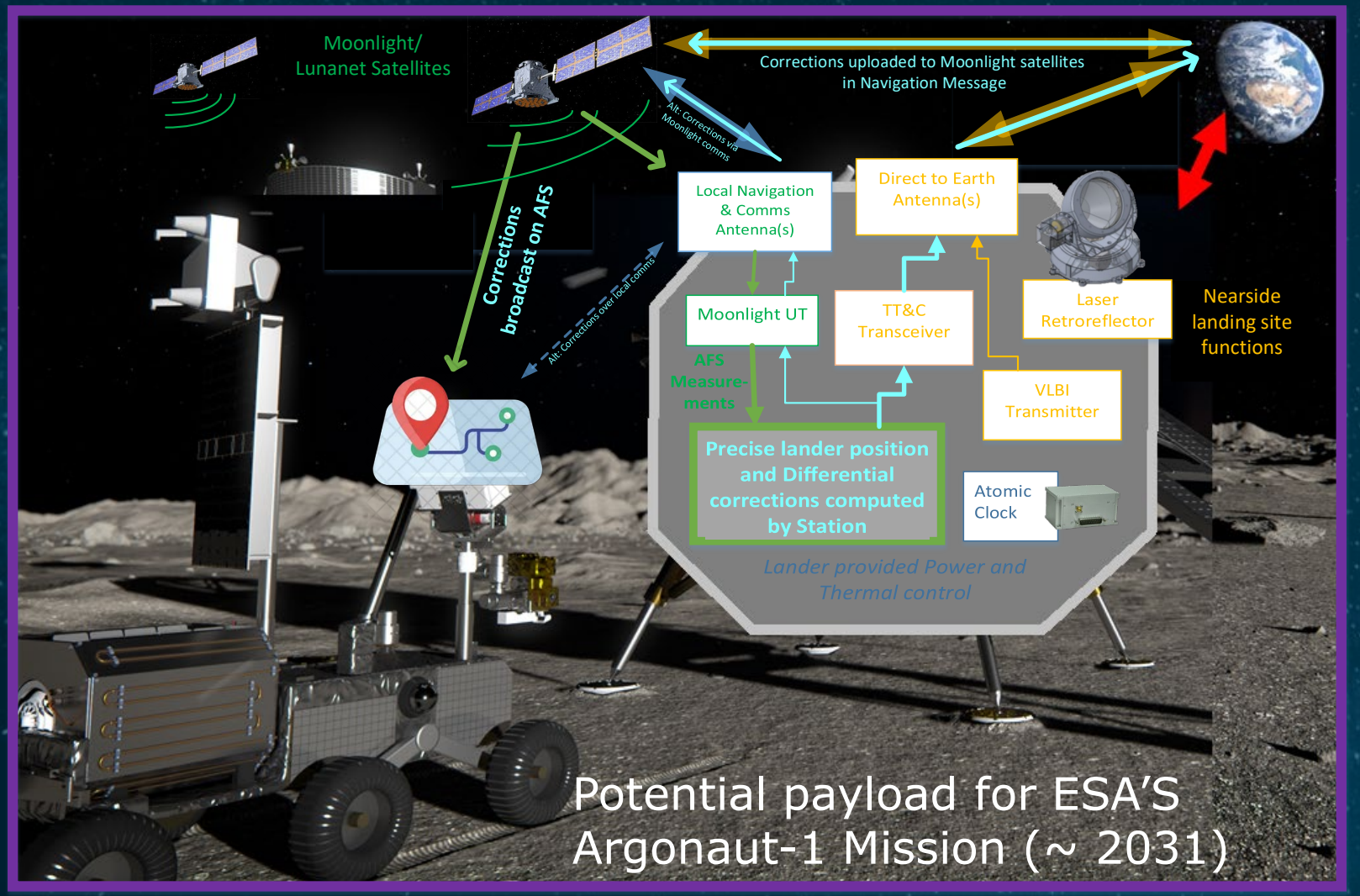
Complementing Moonlight with a Local Differential Station (R&D on-going)



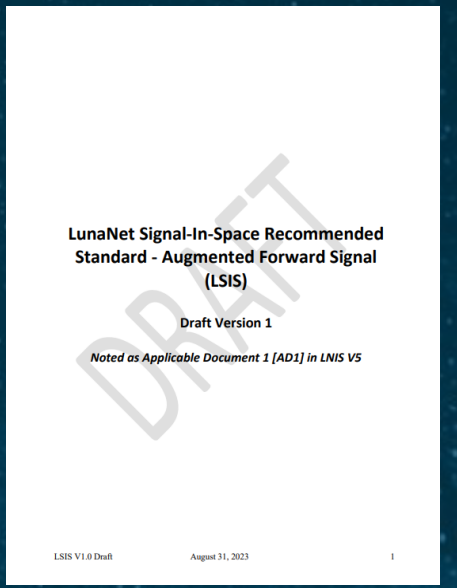
A well-placed single Moonlight LCNS Differential Station could serve all South Pole area allowing sub-metre accuracies in real time.

Moonlight LCNS could be used to send the lunar differential station corrections back to Earth and then sent to the lunar users via LunaNET AFS message. An elegant and practical solution for users.

NOVAMOON: Moonlight LCNS Local differential station proposed for ESA's Argonaut Mission – under assessment



Moonlight LCNS compatible


LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LSIS)

Draft Version 1

Noted as Applicable Document 1 [AD1] in LNIS V5

DRAFT

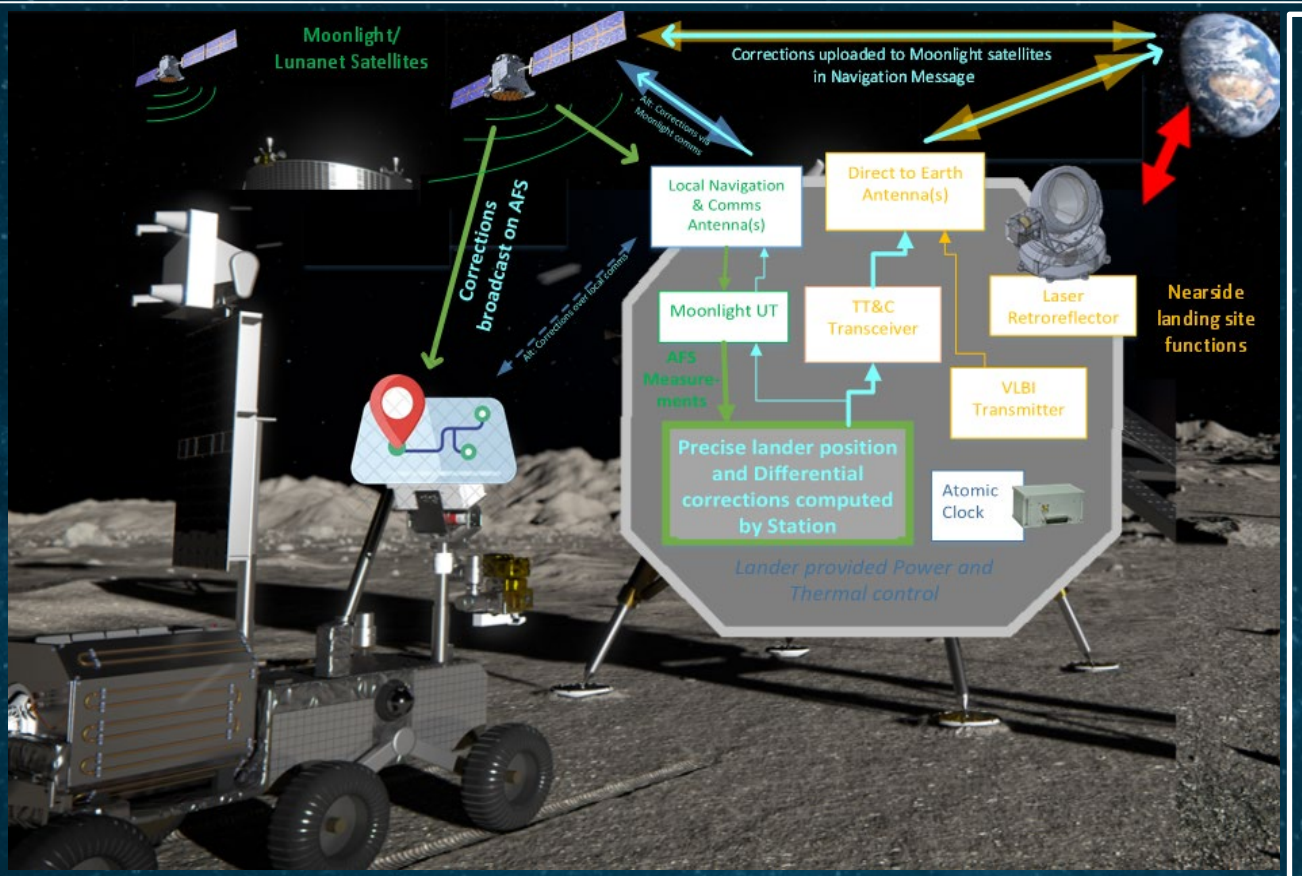
LSIS V1.0 Draft August 31, 2023 1

LunaNet standards compatible

NOVAMOON – First ever Lunar differential and Selenodetic station

1. Install **the first-ever reference local differential station on the lunar surface**

This station proposed to be placed on ESA's Argonaut-1 lander will compute Moonlight NAV satellite pseudorange error corrections and broadcast these via the Moonlight PNT Channel allowing **decimeter level** navigation accuracies over the whole Lunar South Pole (ARTEMIS service area) to standard LunaNet users.



2. Install **the first-ever International "geodetic" Reference station on the lunar surface**

Co-locating 4 geodetic techniques: GNSS/Moonlight, VLBI tx, last generation laser retroreflector and Two way DTE ranging allowing to locate the Argonaut lander station at **cm-level** accuracy on the lunar surface

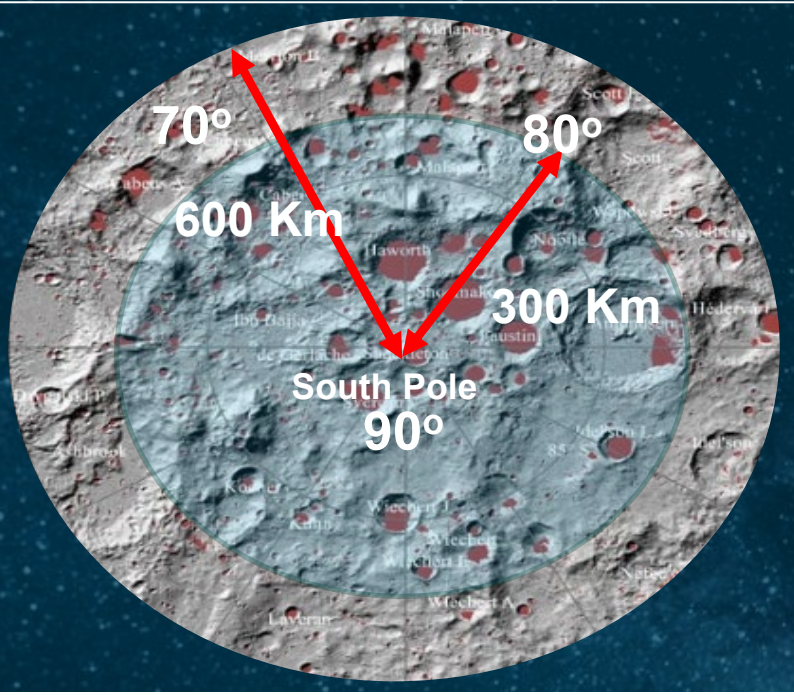
Setting the international standard station for Lunar Refence Frame realisation

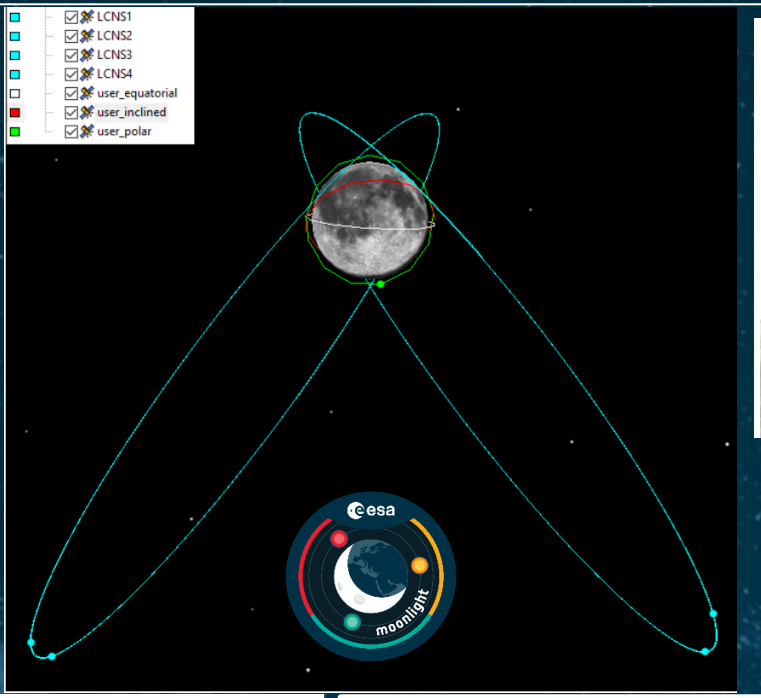
3. Install **the first-ever "Lunar Time-reference" Laboratory**

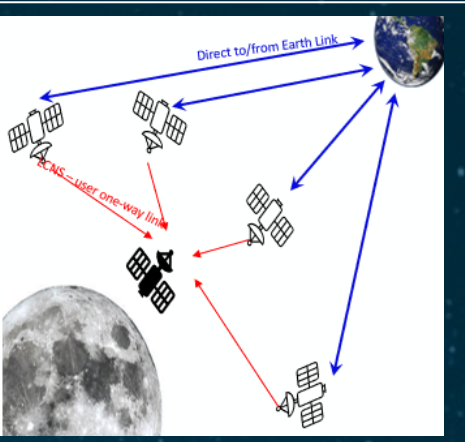
embarking a miniRAFS atomic clock, setting the lunar international standard time (at ns-level) and establishing the basis for the lunar reference time definition.

NOVAMOON performances: Sub-meter accuracies over the whole South pole (Artemis Lunar exploration area)

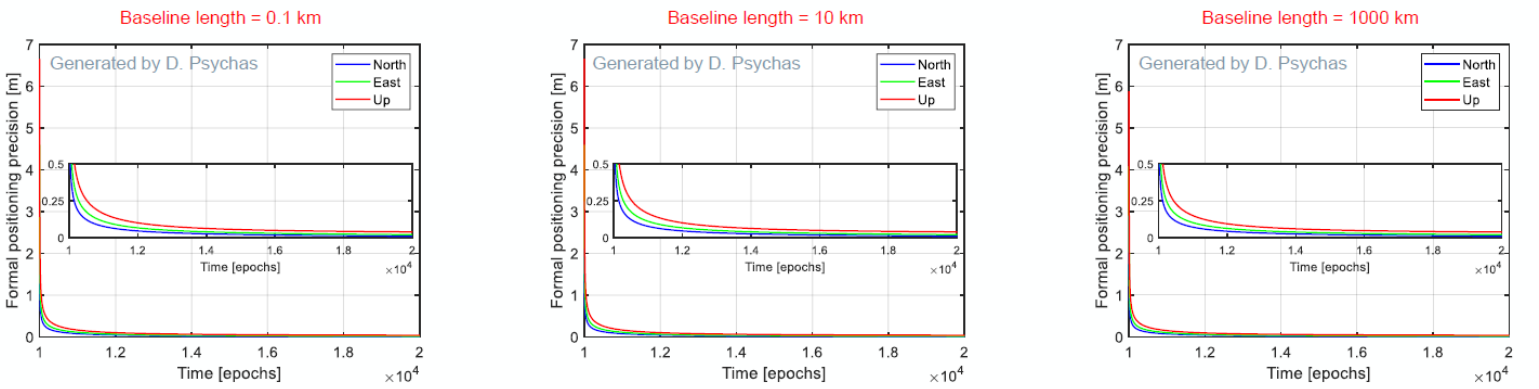
ARTEMIS SERVICE AREA







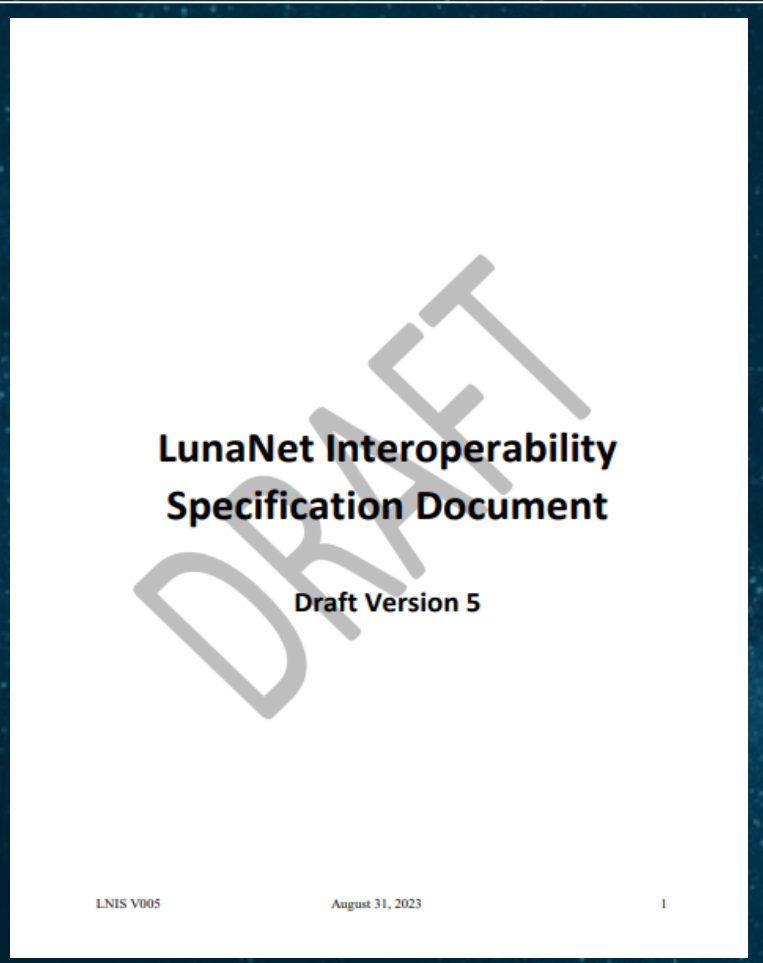
ODTS estimation



Our analysis demonstrate that a Single station will cover the whole South Pole

- NO ionosphere
- NO troposphere
- Minimum Orbital projection error
- Lunar South pole message reception

MOONLIGHT will comply with LunaNet Interoperability Specifications (last update LNIS v5, Sept 2023)



Joint NASA, ESA and JAXA cooperation: LunaNet dedicated WGs established and active

LNIS v5 is currently being updated, taking into account feedback received (incl. notably IOAG and CCSDS)

AD1: LunaNet Signal-In-Space Recommended Standard – AFS (could be the basis for a CCSDS lunar PNT Recommended standards)

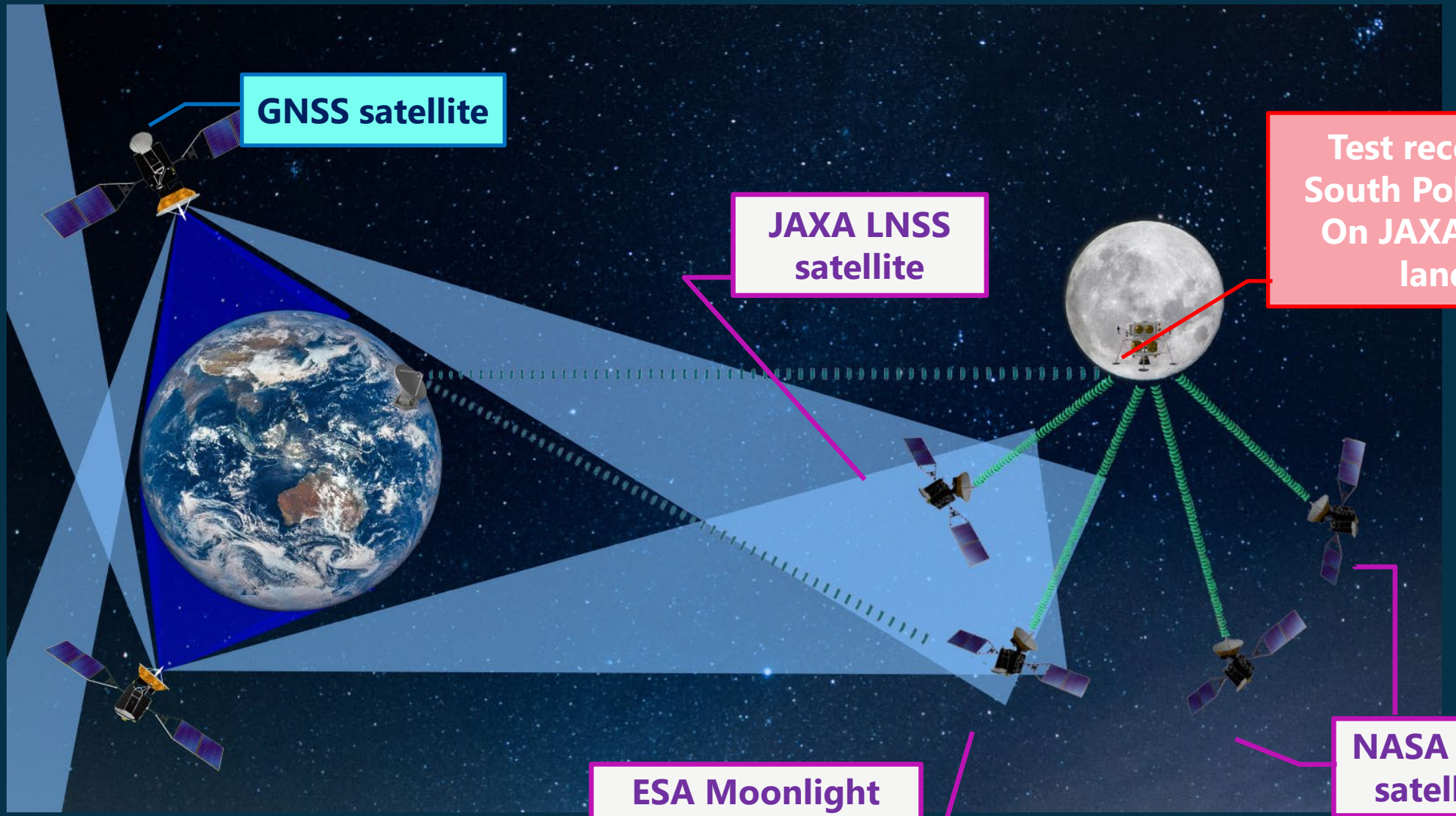
Work in progress to integrate feedback received on first Draft and preparing future updates

- RF signal specifications
- Navigation message format specifications
- Message and data content specifications

LNIS planned updates:

- Consolidation of TBC/TBD's (AD1)
- Spreading Codes definition (AD1)
- Detailed AFS Messages definition (AD1 & AD3)
- Lunar Reference Frame & Time standards (AD5)
- Consolidation of two-way ranging services

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



Moonlight Lift Off : industrial implementation started in Feb. 2024

2022 Ministerial Council Approved the Moonlight Programme

Feb 2024
Start of Implementation Phase

2025
Lunar Pathfinder

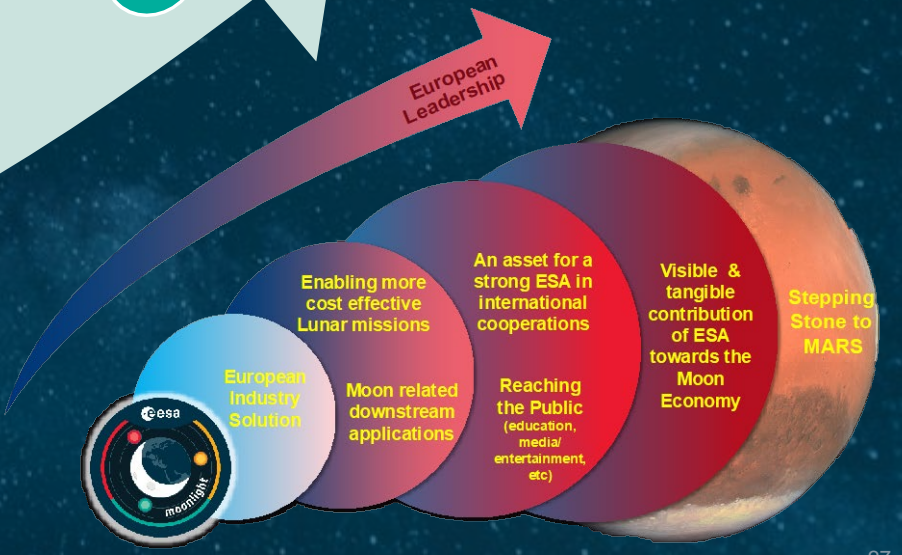
2028
Initial Services (IOC)

2028
LunaNet Interoperability Demonstration

2030
Full Services (FOC)

CM25

CM28



Thank you!

Moonlight ESA website esa.int/Moonlight

Email: moonlight@esa.int