The Future of Navigation: Towards Moon and Mars

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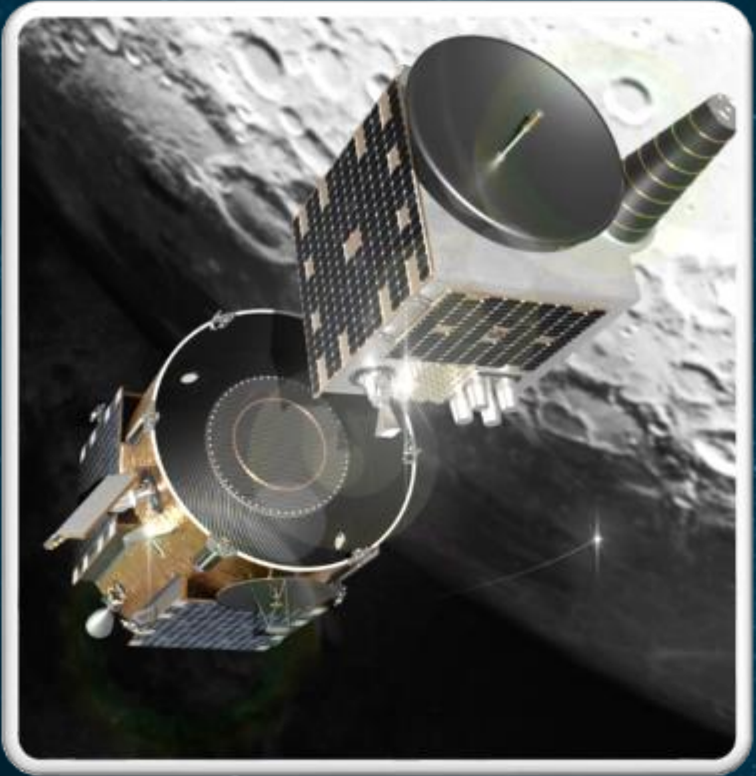
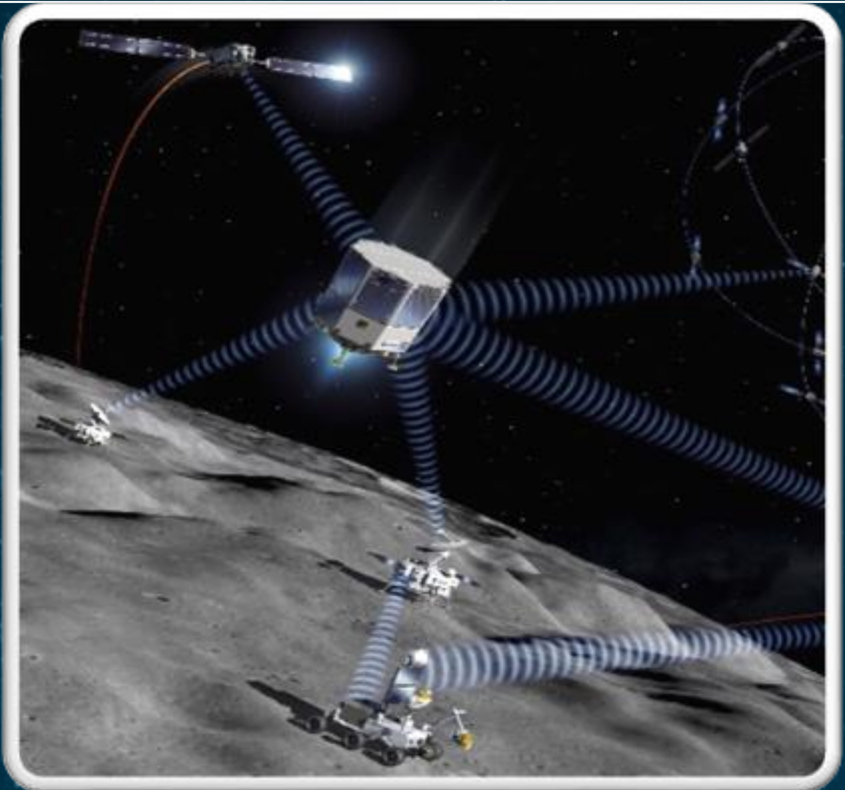
ESA Roadmap For Lunar COMM and PNT Services



STEP 1:
LUNAR PATHFINDER

(LAUNCH in 2026 !)



STEP 2:
MOONLIGHT System

(Initial: 2028; Final: 2030)

STEP 3:
NOVAMOON: Local PNT Differential Station
(Launch: 2031)

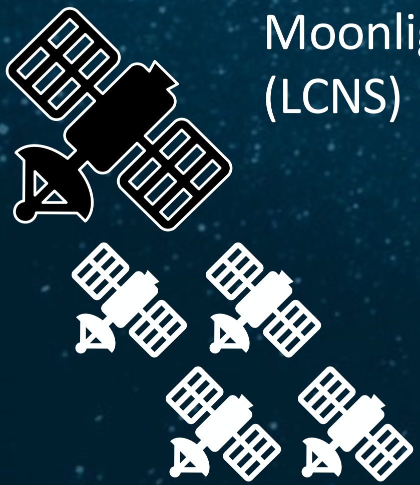
The road to Moonlight

Lunar Pathfinder

SSTL LUNAR

COM satellite (S-Band)
3 Hosted Payload Experiments

- GNSS Weak Signal Detection receiver
- Laser Retro-Reflector
- Radiation Monitor



Moonlight Lunar COM and NAV System (LCNS)

1x COM Satellite (Ka & S-Band)
4x NAV Satellites
High Data Rate

TELESPAZIO
a LEONARDO and THALES company

2026
CommSSTL Lunar Pathfinder Launch COM and NAV Demo, Commercial Service

2028
Moonlight LCNS IOC Launch (1x COM, 1x NAV)

2030
Moonlight LCNS FOC Launch (3x NAV)

Moonlight LCNS High-level PNT Performances

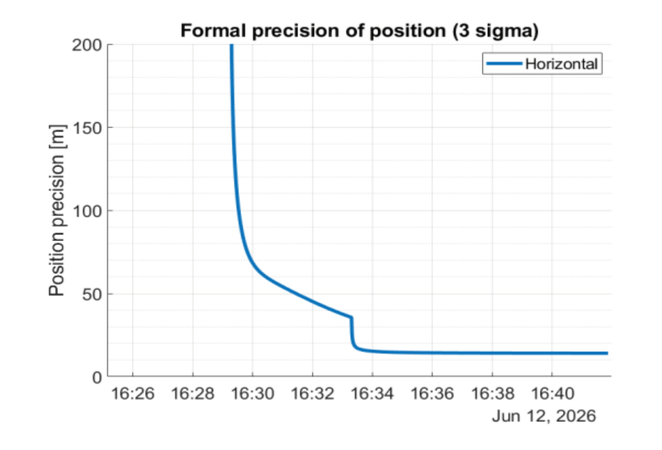
Real time < 10 m (95%)
Post-processing < 3 m (95%)
Estimated Real time: 3-5 meters

Surface Rover

Audet, Yoann, Floor Thomas Melman, Serena Molli, Andrea Sesta, Michael Plumaris, Dimitrios Psychas, Richard Swinden, Pietro Giordano, and Javier Ventura-Traveset. "Positioning of a lunar surface rover on the south pole using LCNS and DEMs." *Advances in Space Research* 74, no. 6 (2024): 2532-2550.

< 50 m (95%) Landing accuracy
Estimated: ~20 meters

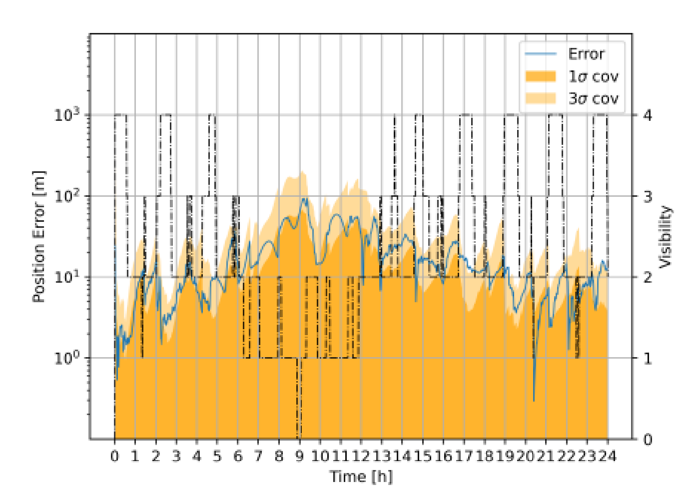
Lunar Lander



Grenier, Antoine, et al. "Positioning and velocity performance levels for a Lunar Lander using a dedicated Lunar Communication and Navigation System." *NAVIGATION: Journal of the Institute of Navigation* 69.2 (2022).

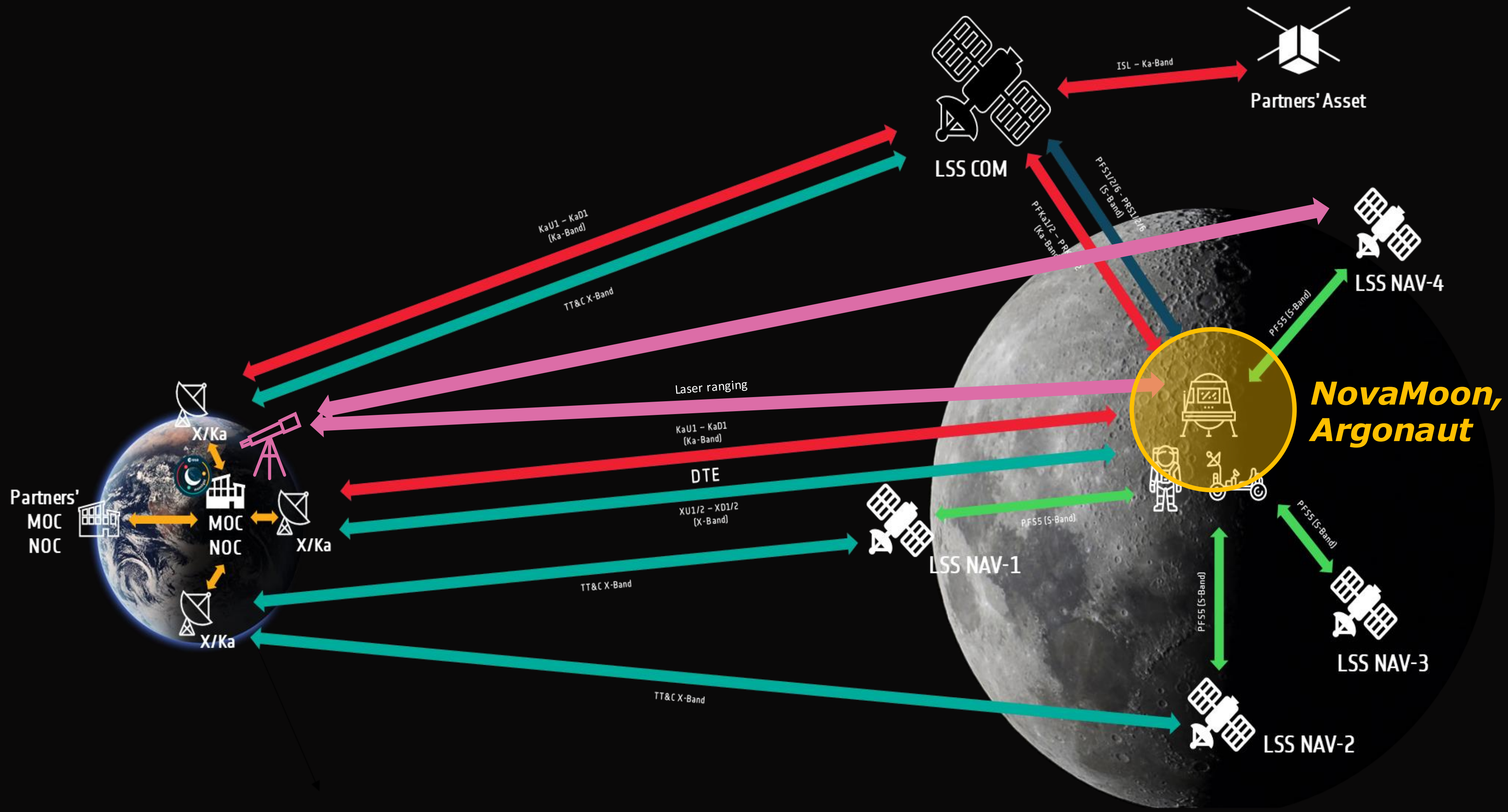
Lunar orbiter

Real time < 100 m (95%)
LLO accuracies
Estimated: 30-60 meters



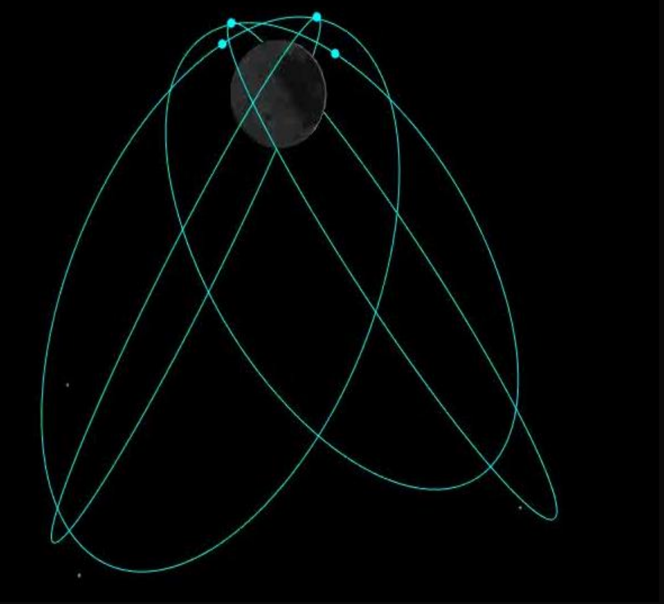
Molli, Serena, et al. "Navigation performance of low lunar orbit satellites using a lunar radio navigation satellite system." *Proceedings of the 36th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2023)*. 2023.

Moonlight LCNS Concept



Moonlight
Elliptical Lunar Frozen Orbits (ELFO)

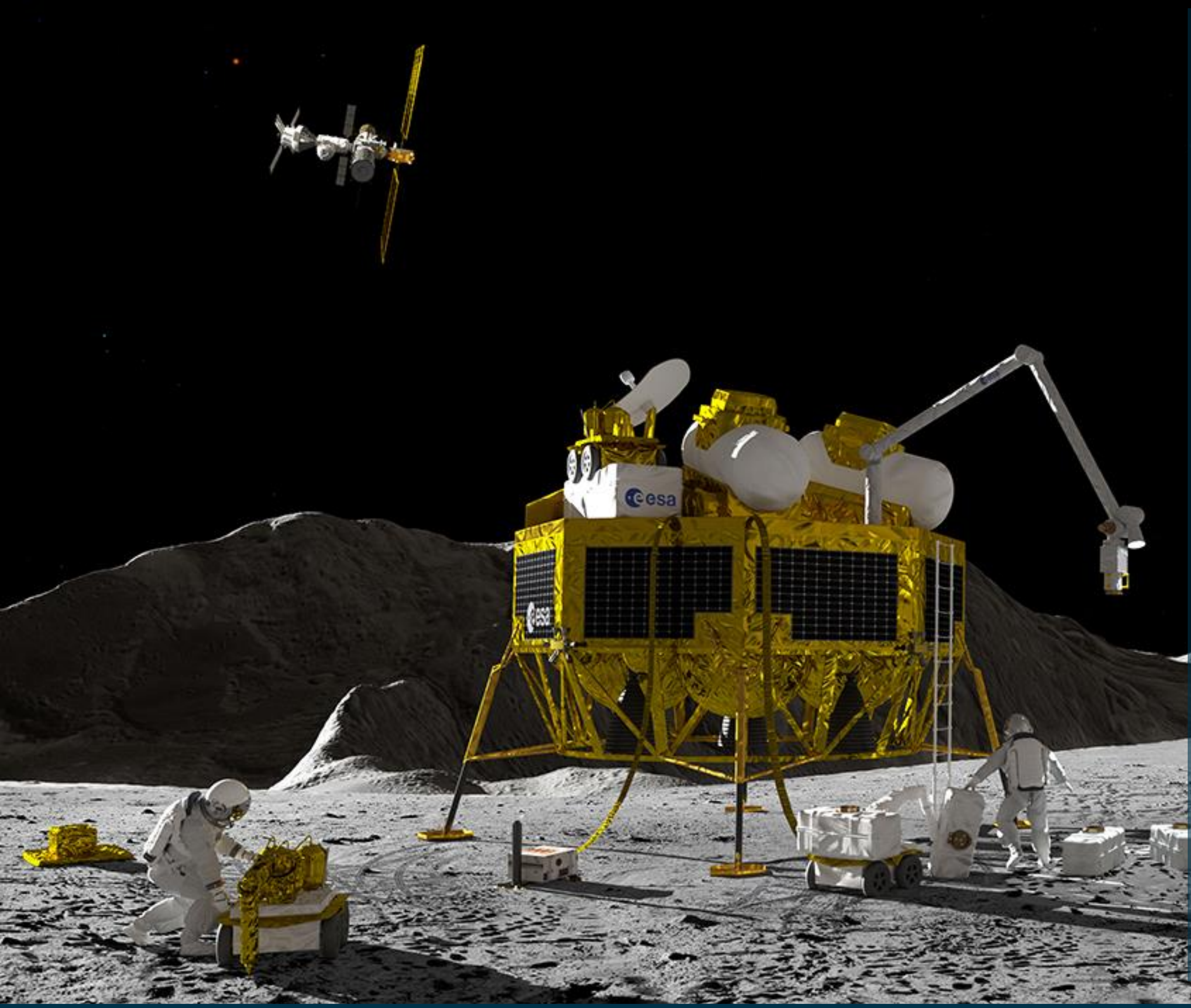
Apogee above South Pole



ESA ARGONAUT Programme is a family of planned lunar landers that will deliver infrastructures, scientific instruments, rovers, technology demonstrators and vital resources for astronauts on the lunar surface such as food, water and air.

ARGONAUT-1 lander will be launched in 2031 to land in the South pole region, providing **continuous operations during 5 years,** including periods of lunar night.

Recurrent Argonaut missions planned every 2-3 years



NovaMoon Payload: Further Enhancing Moonlight

NOVAMOON: Lunar differential and Selenodetic station

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

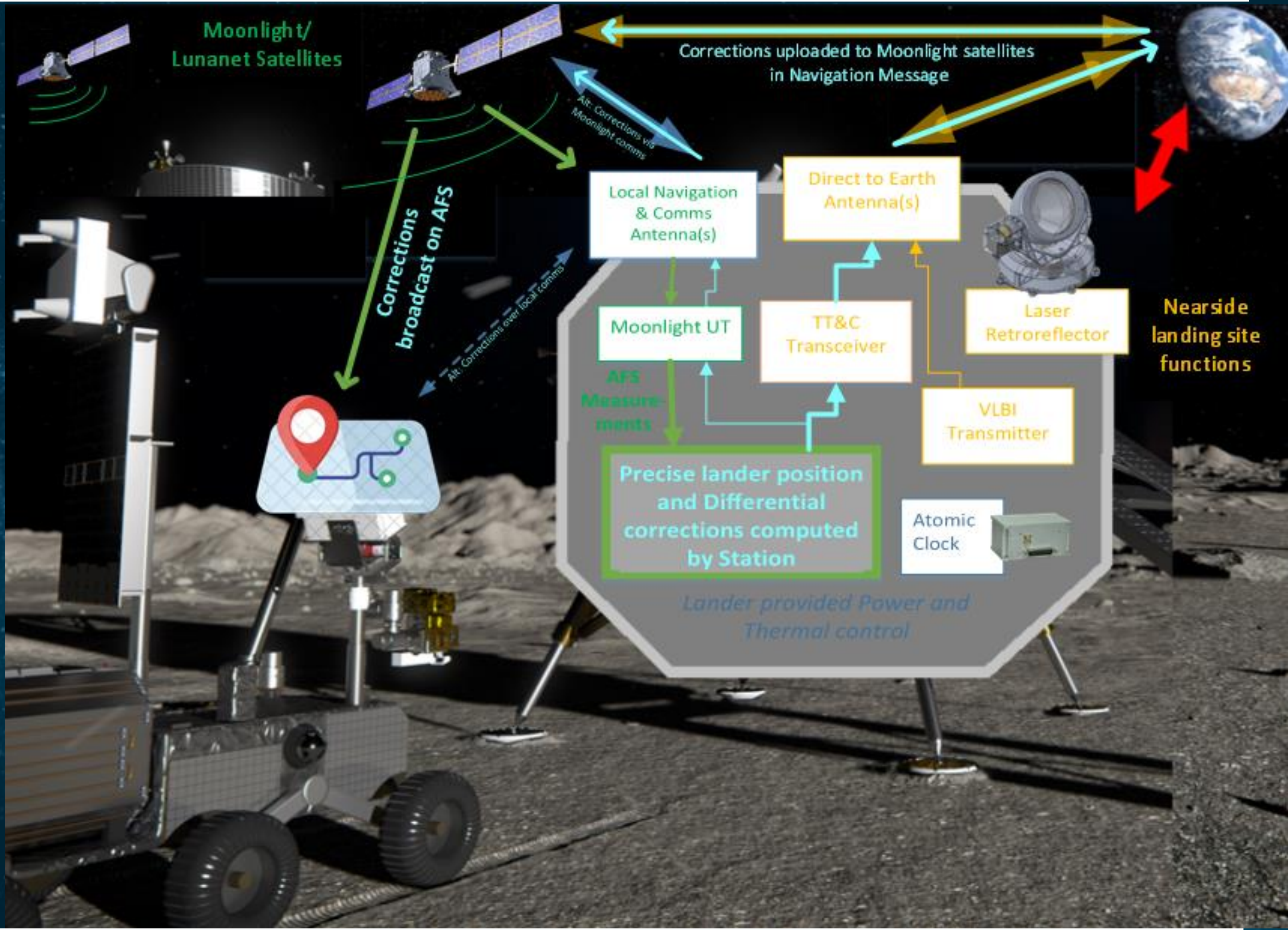
   Compute Moonlight NAV satellite **pseudo-range error corrections** and broadcast via Moonlight PNT Channel → **decimeter level** navigation accuracies over the Lunar South Pole to standard LunaNet users.

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

   Co-locating 4 geodetic techniques: **Moonlight, VLBI TX, LLR and Two-way DTE ranging** → locate the Argonaut lander station at **cm-level** accuracy → setting the international standard station for Lunar Reference Frame realisation

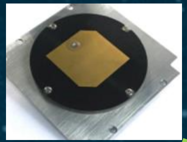
3. Install **the first-ever "Time-reference" station on the lunar surface**

   setting the lunar international standard time (at **ns-level**) and establishing the basis for the lunar reference time definition.



NOVAMOON: hardware architecture

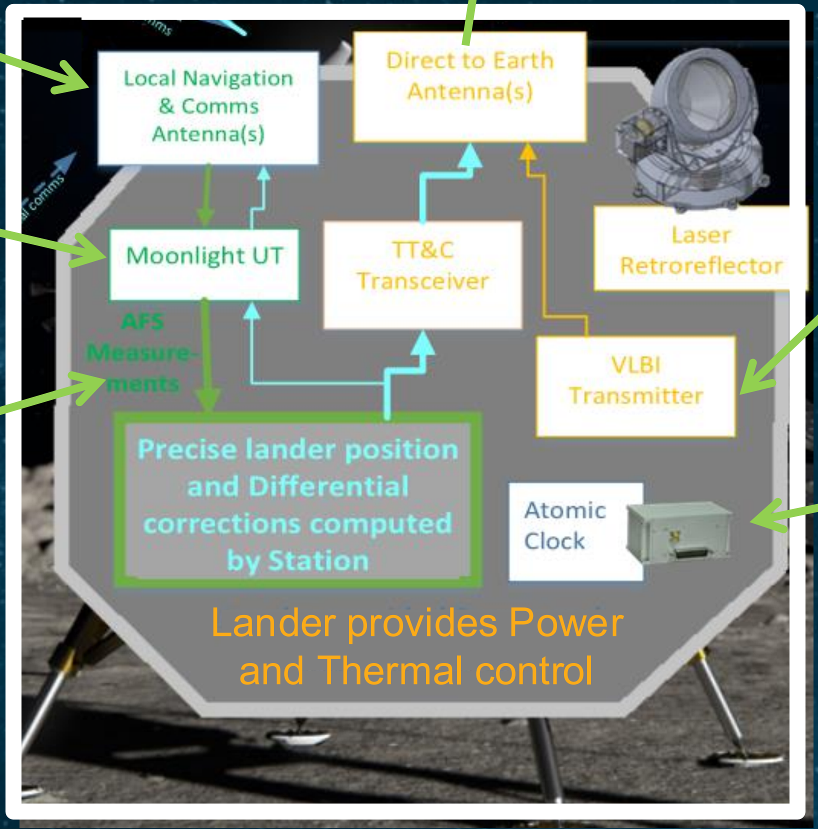
S-Band antenna => 0.5 Kg (EM launch in 2024 – TRL 6 in 2025)



Moonlight Comms Terminal => 2kg, 40W (EM launch in 2024– TRL 6 in 2025)

Moonlight Navigation receiver => 2kg, 10W (EM launch in 2024– TRL 6 in 2025)

DTE provided by Argonaut platform



Installed at Argonaut-1 Mission

Laser retroreflector => 5kg, 12W (with pointing mechanism). Based on ESA's MoonLIGHT MPAc, TRL 9 in 2024)

Lunar VLBI transmitter (TRL 4/5 today and TRL 9 with Genesis development in 2027) => 1.5kg, 17W

Atomic clock based on miniRAFS => 1kg, 10W. - TRL 6 today - TRL 9 in 2027 with Moonlight IOC

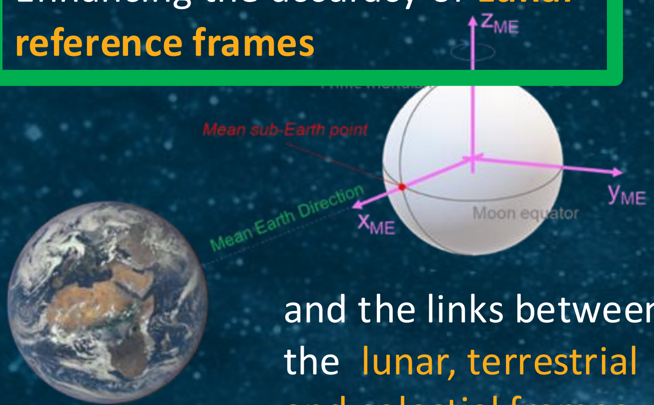
Optional

- Active Laser Retroreflector
- Laser Retroreflector INRRI
- GNSS RX
- SBI
- Camera
- L-band GNSS TX

Moonlight fully compatible

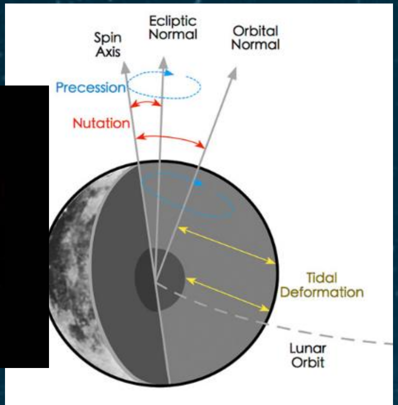
Science objectives overview

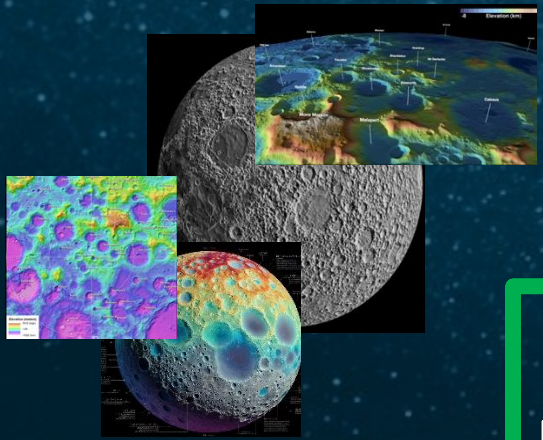
Enhancing the accuracy of **Lunar reference frames**



and the links between the lunar, terrestrial and celestial frames

Allowing precise measurements of the Moon tidal deformations and Moon librations





Improving the knowledge of the lunar gravity field, Moon rotation, **Moon interior**, etc

Enhancing the accuracy of Lunar DEM maps

Providing the first ever time laboratory on the Moon and supporting the realisation of lunar reference times

Unique Fundamental Physics tests may be conceived thanks to the exceptional Earth-Moon relativistic long-baseline testbed.

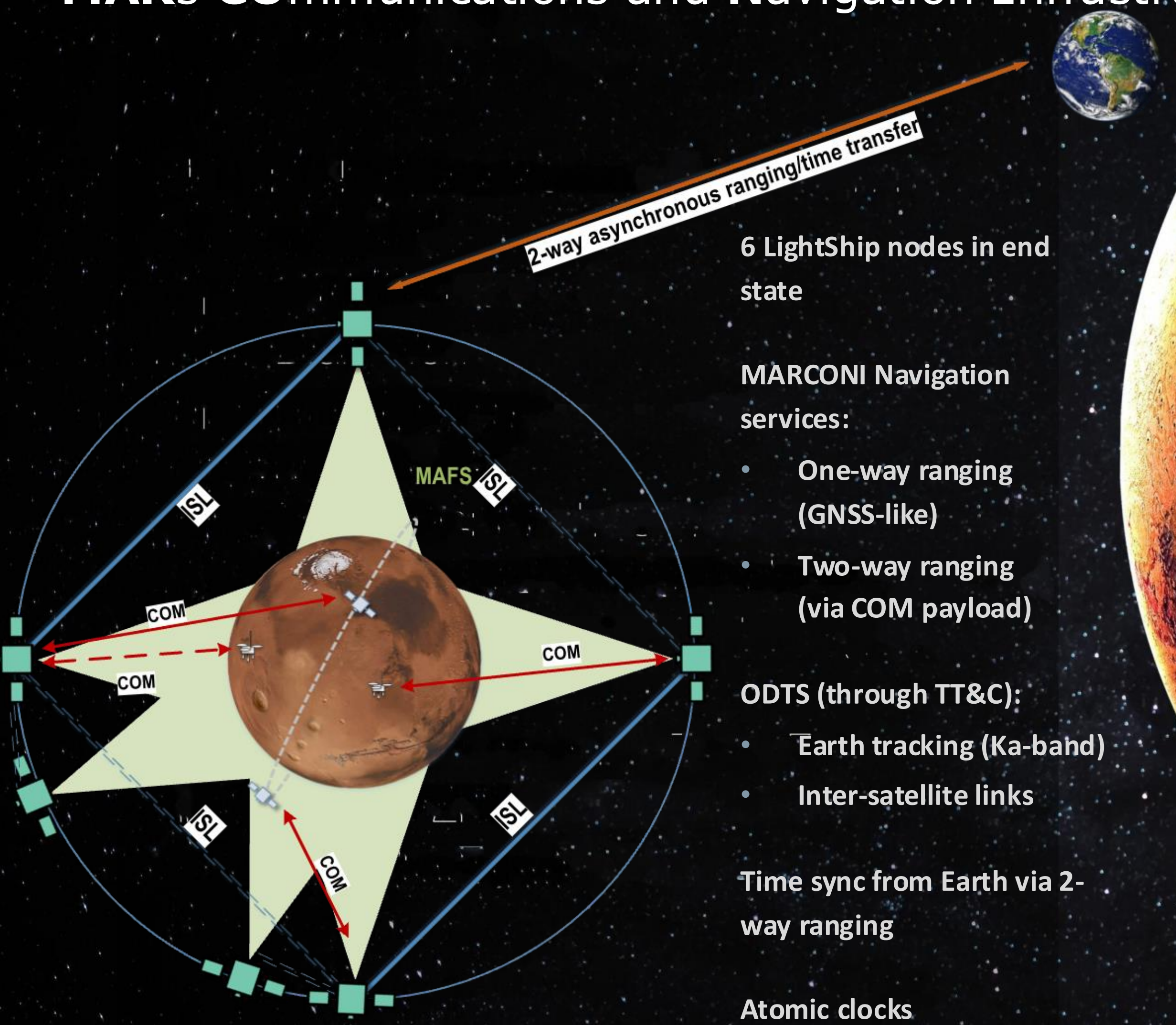
Detect **gravitational waves** at the microhertz frequency

Investigate massive black hole binaries and cosmic strings.

Allows testing the boundaries between **quantum mechanics** and **general relativity**.

MARCONI

MARs COmmunications and Navigation Infrastructure



6 LightShip nodes in end state

MARCONI Navigation services:

- One-way ranging (GNSS-like)
- Two-way ranging (via COM payload)

ODTS (through TT&C):

- Earth tracking (Ka-band)
- Inter-satellite links

Time sync from Earth via 2-way ranging

Atomic clocks

ODTS

- Different techniques: GNSS-like, DTE, ISL, time synchronization

Reference frame and time

- State of the art in Mars reference frames and systems
- Foster international collaboration at space agencies level
- Coordination with the scientific community

esa

The Future of Navigation: Towards Moon and Mars

Thanks for your attention.

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