NaviLEO: A GNSS Receiver for Alternate PNT Services from LEO to Cislunar Orbits

Dr Cyril BOTTERON, Director, SpacePNT, Switzerland

CGSIC 2021 - International Information Subcommittee

Image credit: ESA

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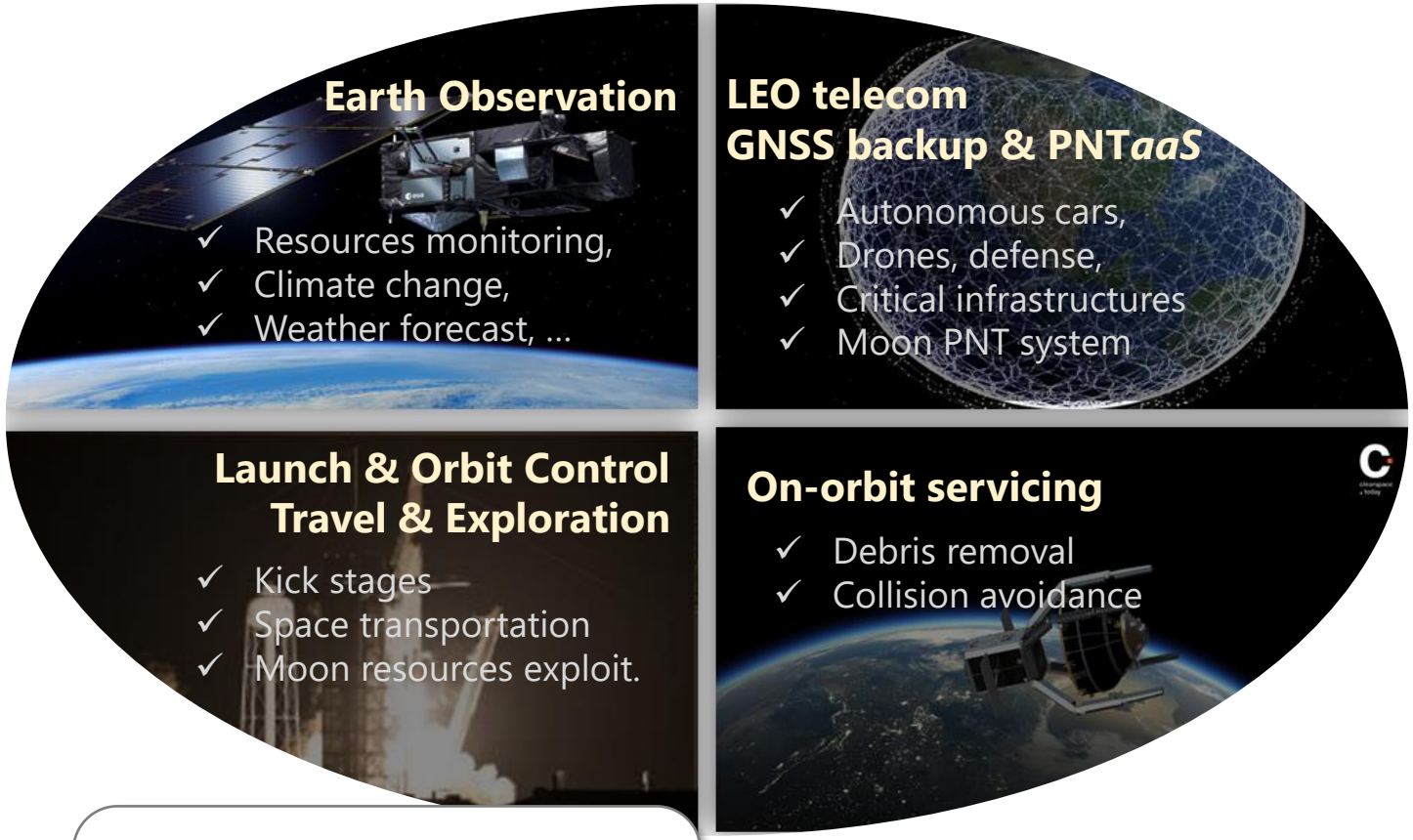
"New Space" Spaceborne GNSS Receiver Applications

Space 2.0 Paradigm Shift

- **Private** space industry
- LEO mega **constellations**
- Technological **innovations**
- **Low cost**, fast development
- **>1000 sat.** launched per year

Market Drivers

Earth observation
Satellite com. / Internet everywhere
Backup GNSS PNT services
Launch & orbit control
Travel, exploration,
On-orbit servicing



PNT Technology Reliance

P - Positioning
N - Navigation
T - Timing

NaviLEO™
Spaceborne Receiver (Rx)
Platform

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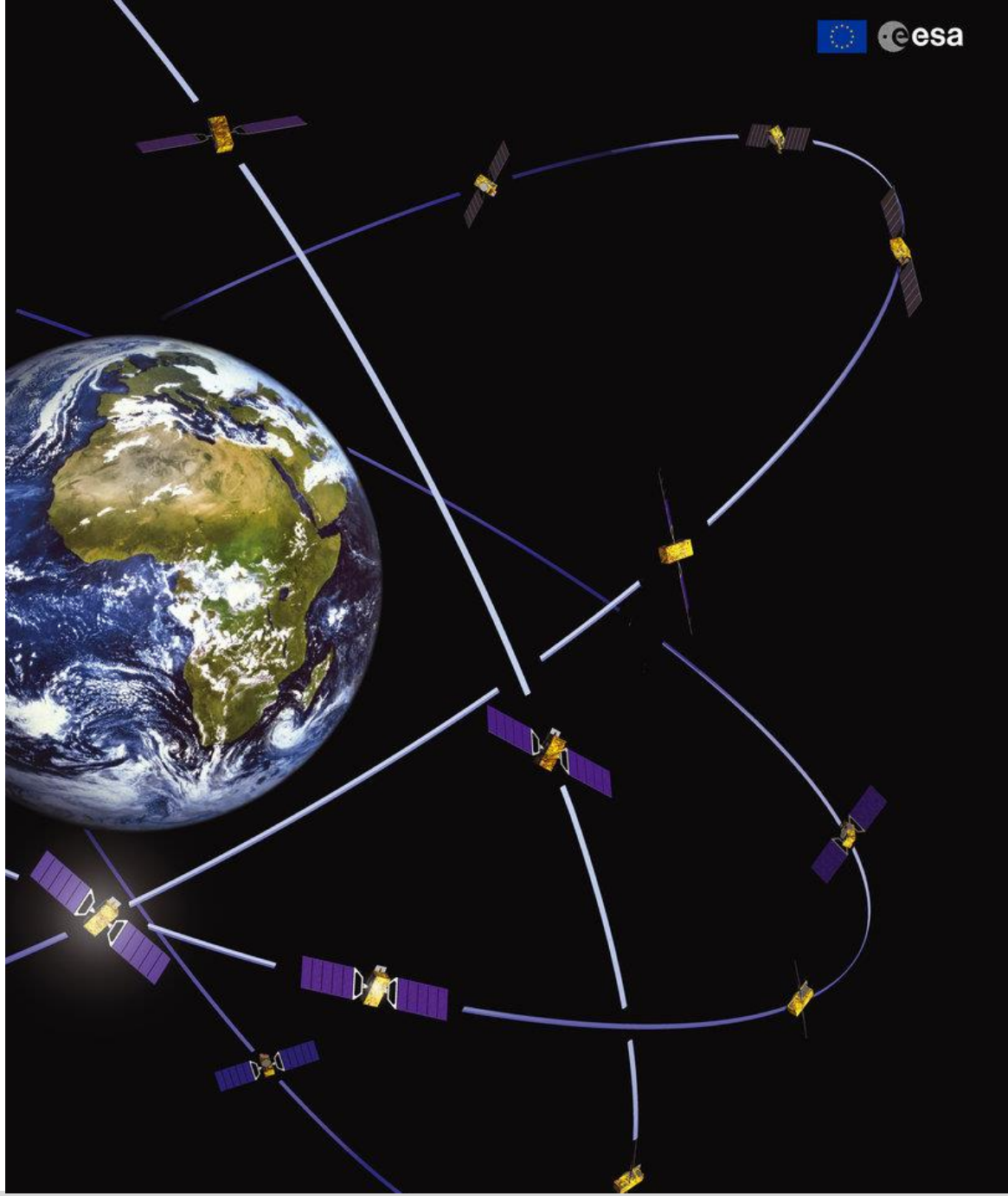
LEO GNSS Rx – Challenges

- **Very High dynamics**
  - ±60 kHz Doppler shifts in LEO versus ±5 kHz on Earth
- **Poor geometry, poor visibility**
  - Satellite spinning
  - Maneuvers
- **Shocks, vibrations & space radiation environment**
  - Use of space grade qualified parts
  - Space product assurance
  - ECSS standards
  - Expensive qualifications

As a result, a spaceborne GNSS receiver may cost **10 k-100 k times more** than a mass-market GNSS receiver module!



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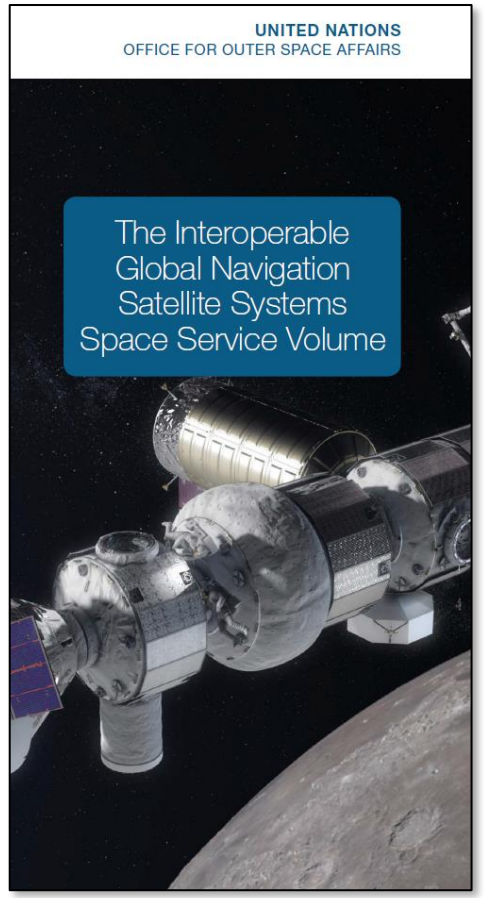
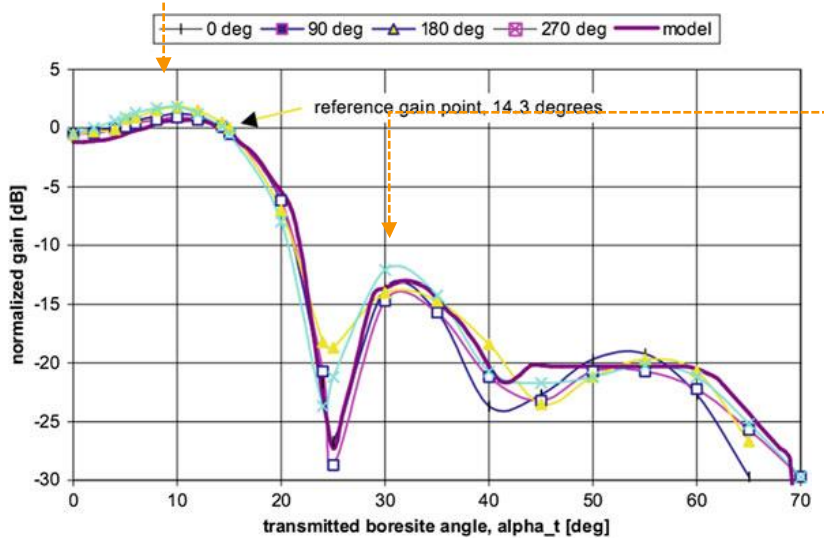
Above LEO GNSS Rx (HEO, Moon) – Additional Challenges

- **Earth shadowing** ➔ reception of spillover of GNSS signals around Earth
- **Side lobes reception & free space signal attenuation** ➔ high-sensitivity architectures
- **Poor system geometry / availability & reduced pseudorange accuracy** (low C/No)
  - ➔ Make use of Interoperable GNSSs SSV
  - ➔ Make use of "orbital filtering"



Typical GPS L1 legacy half beam antenna pattern



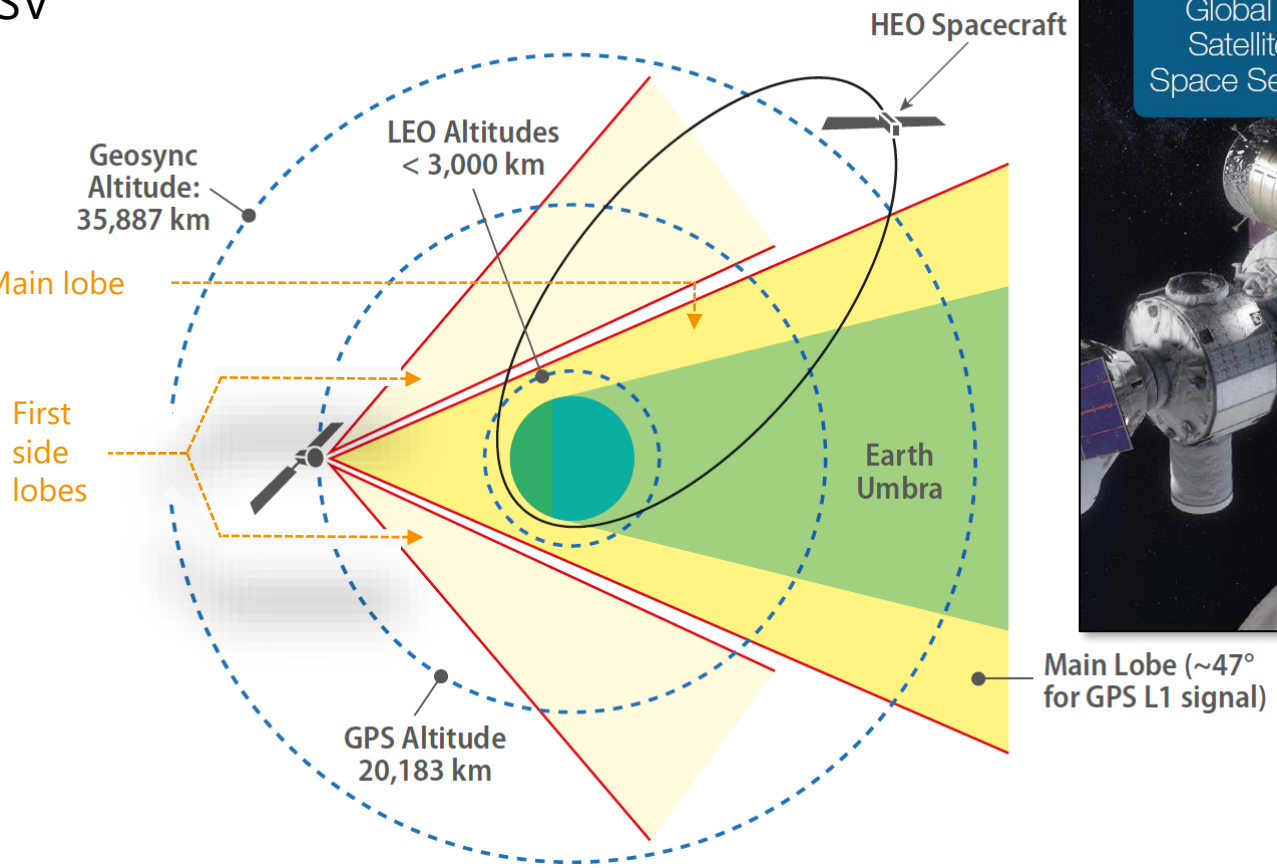


Image: GNSS User Technology Report, Issue 2, 2018

Earth GNSS Rx – Challenges & threats

- **Signal jamming**
  - Noise like signals
- **Signal spoofing**
  - GNSS like signals
- **Environmental conditions**
  - Solar weather
  - Multipath
- **GNSS signal malfunctions / attacks**

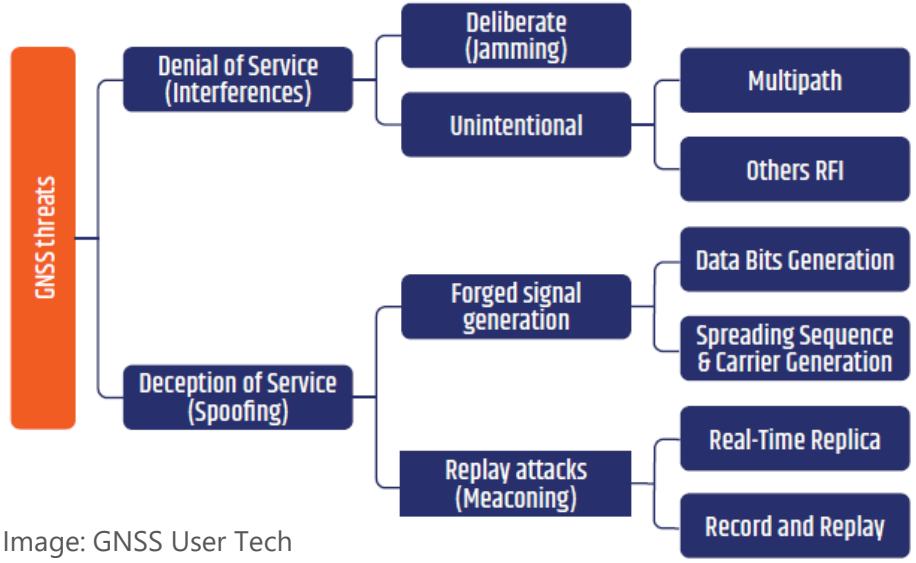


Image: GNSS User Tech Report | Issue 3, 2020

- **Some possible solutions**
  - **Hardened GNSS Rx**
    - Multi-constellation
    - Multi-frequency
    - Advanced antennas (beamforming)
    - Advanced (filtering) algorithms
    - Nav. Message Authentication
  - **Multiple GNSS Rx**
    - Spatial consistency
  - **System of systems**
    - Signals of opportunities
    - Sensors fusion (vision, IMU, clocks)
    - Multiple PNT systems (e.g., eLORAN, LEO PNT)

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Solution - NaviLEO™ Scalable Product Platform Solution

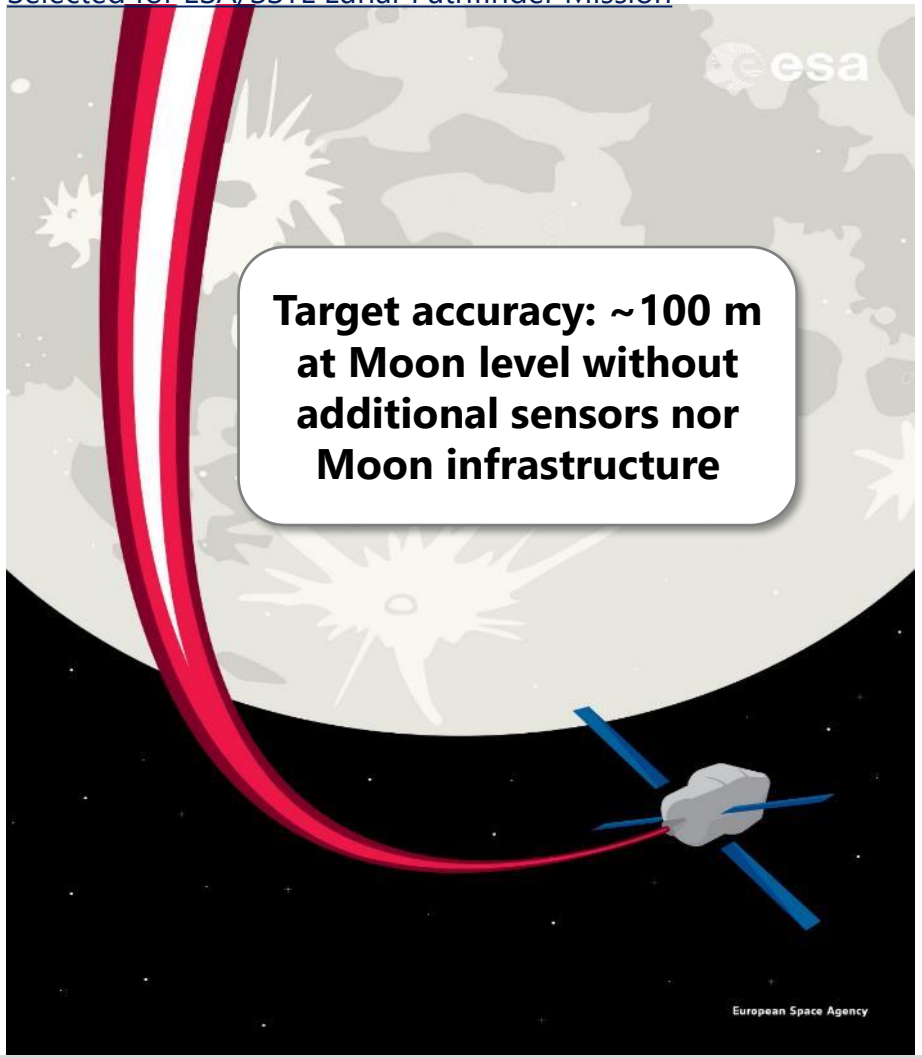
NaviLEO
NaviOrbit
NaviPNT

“New Space” solution
- Unmatched performances
- Low SWaP-C

- ✓ Use of rad-tolerant COTS EEE state-of-the-art components
- ✓ Rad-tolerant HW/SW/FW architecture
- ✓ High performance:
  - ➢ Multi-GNSS (L1/L5+E1/E5+E6+L-band Inmarsat)
  - ➢ Orbital propagator
  - ➢ In-flight upgradable
  - ➢ Many options (POD, dual ant., etc.)

NaviMoon

Selected for ESA/SSTL Lunar Pathfinder Mission



Target accuracy: ~100 m at Moon level without additional sensors nor Moon infrastructure

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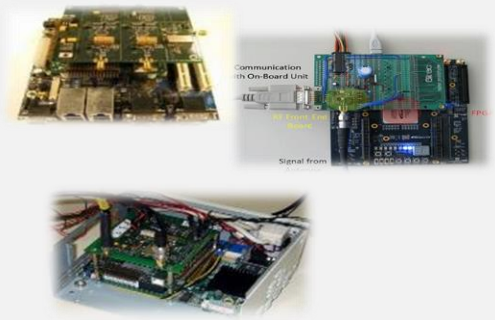
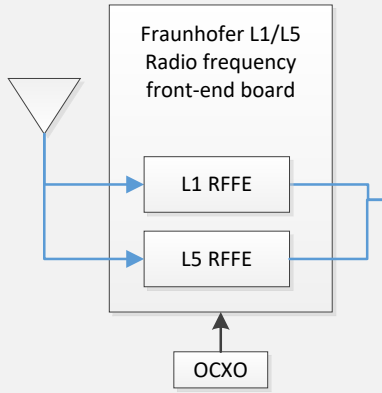
Timeline - Historical Technology & Product Development

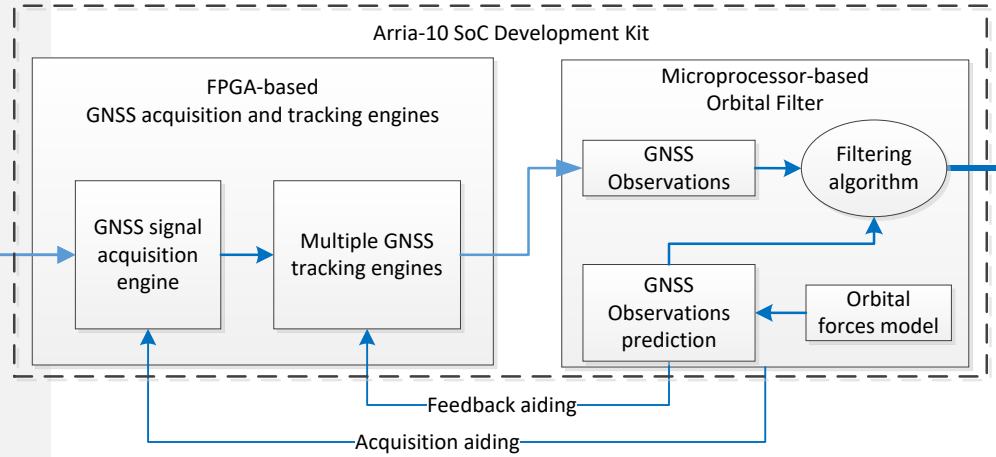
2004 — 2013 — 2016 — 2018

PNT & GNSS receiver R&D	Idea validation (TRL2/3)	Proof-of-concept (TRL3/4)
R&D	R&D	



WeakHEO PoC receiver





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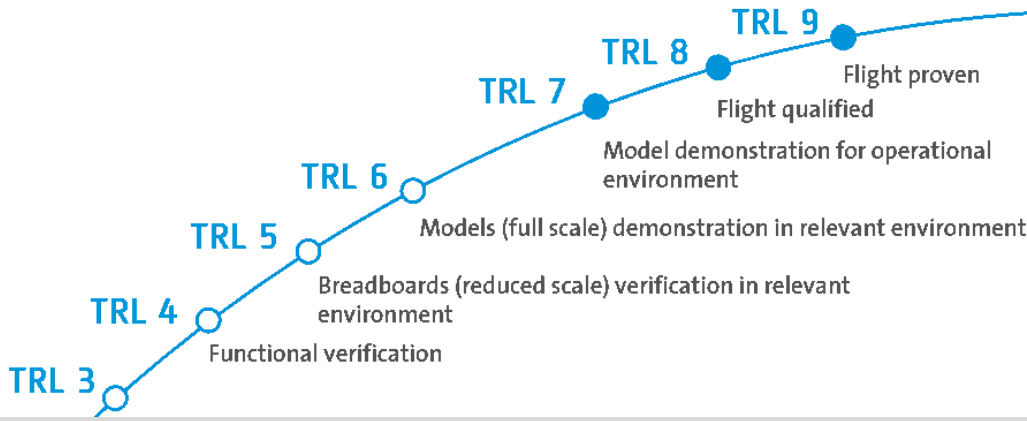
Milestones
- L1 C/A high sensitivity acquisition (15 dB-Hz)
- High sensitivity TOW decoding
- Orbital filtering

Citation from InsideGNSS Oct 2,2020 (Exploration with GNSS Technology): "The most significant amount of work in the field was performed by the ESPLAB of EPFL with the development of WeakHEO and SANAG proof-of-concept receivers....."



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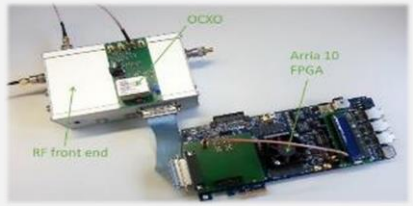
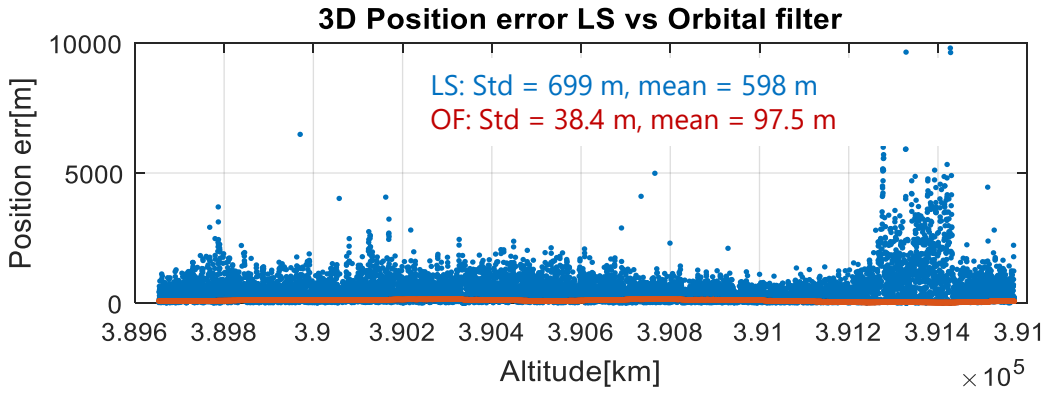
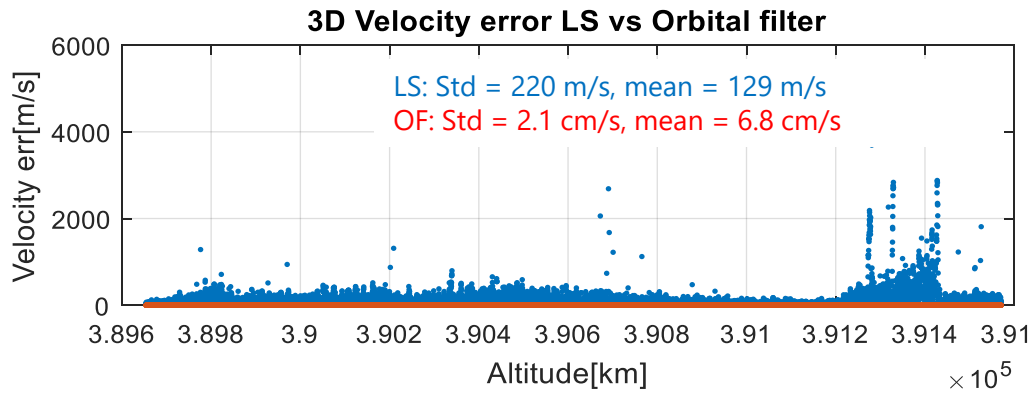


SANAG PoC receiver

Milestones
- Dual-frequency processing (L1+L5)
- Full hardware in the loop (HIL) validation on a direct Moon transfer orbit

HIL performance from 389'000 km to 392'000 km





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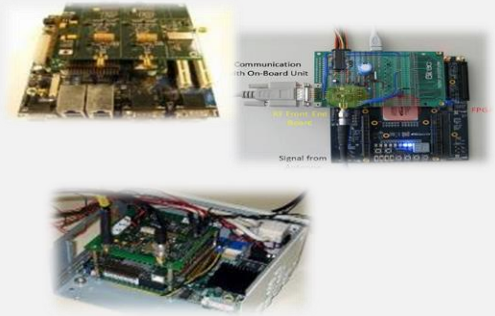
Timeline - Historical Technology & Product Development

2004 — 2013 — 2016 — 2018 — 2021 — 2022+

PNT & GNSS receiver R&D	Idea validation (TRL2/3)	Proof-of-concept (TRL3/4)	Proto (TRL5/6)	Flight ready (TRL7/8)
R&D	**R&D**	**Validation in HIL**	***EM Prototypes***	***EM/PFM TRL8***



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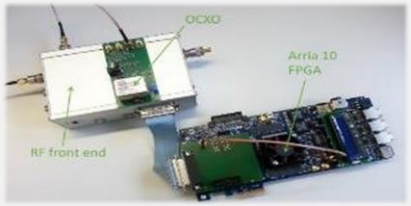

SANAG PoC receiver

esa

SYDERAL SWISS

MICROCITY NEUCHÂTEL INNOVATION

platinn

csem

Schweizerische Eidgenossenschaft
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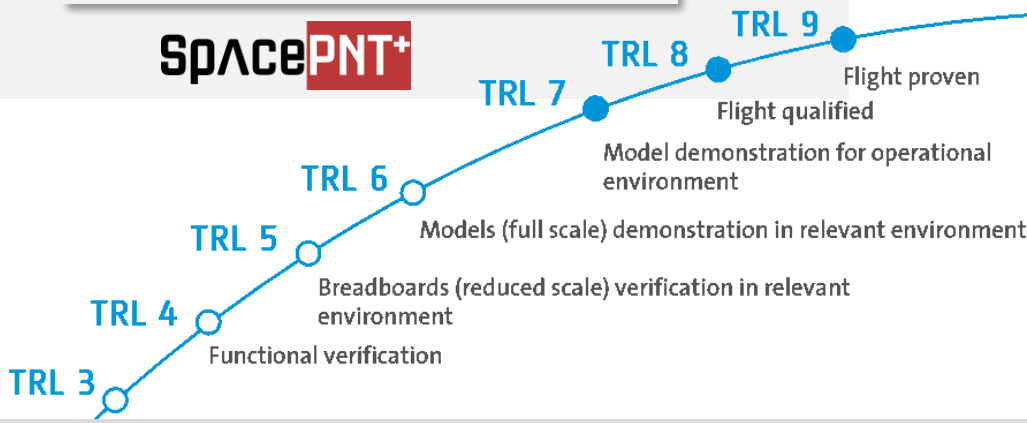
Milestones

- ESA selects NaviMoon for ESA/SSTL Lunar Pathfinder Mission



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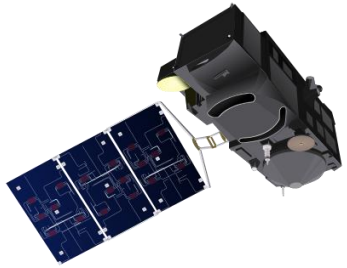
Key features of SpacePNT technology



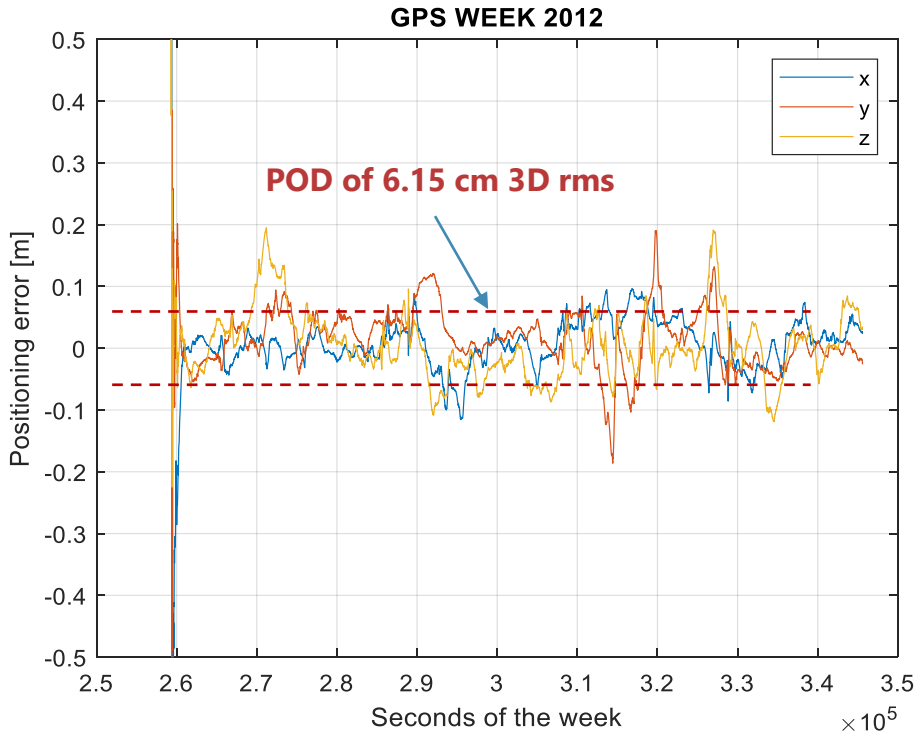
NaviLEO POD solution	3D rms accuracy (real-time)
RD POD (proprietary)	< 6 cm (LEO)

✓ **Reduced Dynamic Precise Orbit Determination (RD POD) algorithm**

A **Kalman Filter** that combines:
<**raw GNSS observables**>
+ <**complex obs. error. models**>
+ <**reduced dynamic models**>
+ <**self-determined accelerations**>
+ <real-time GNSS orbit & clock corrections(1)>

Also allows orbital propagation in the absence of GNSS signals

Verified POD performance using real Copernicus Sentinel 3a GPS L1/L2 observables and IGS real-time GNSS orbit & clock corrections



Key features of SpacePNT technology

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Also allows orbital propagation in the absence of GNSS signals

Several POD real-time correction channels possible with NaviLEO:

- **GEO satellite:** Through L-band geostationary satellites (e.g., Fugro SpaceStar)
- **Galileo E6 HAS:** High Accuracy Service from Galileo satellites
- **Inter-satellite links :** Ground-based real-time service corrections transmitted through inter-satellite links

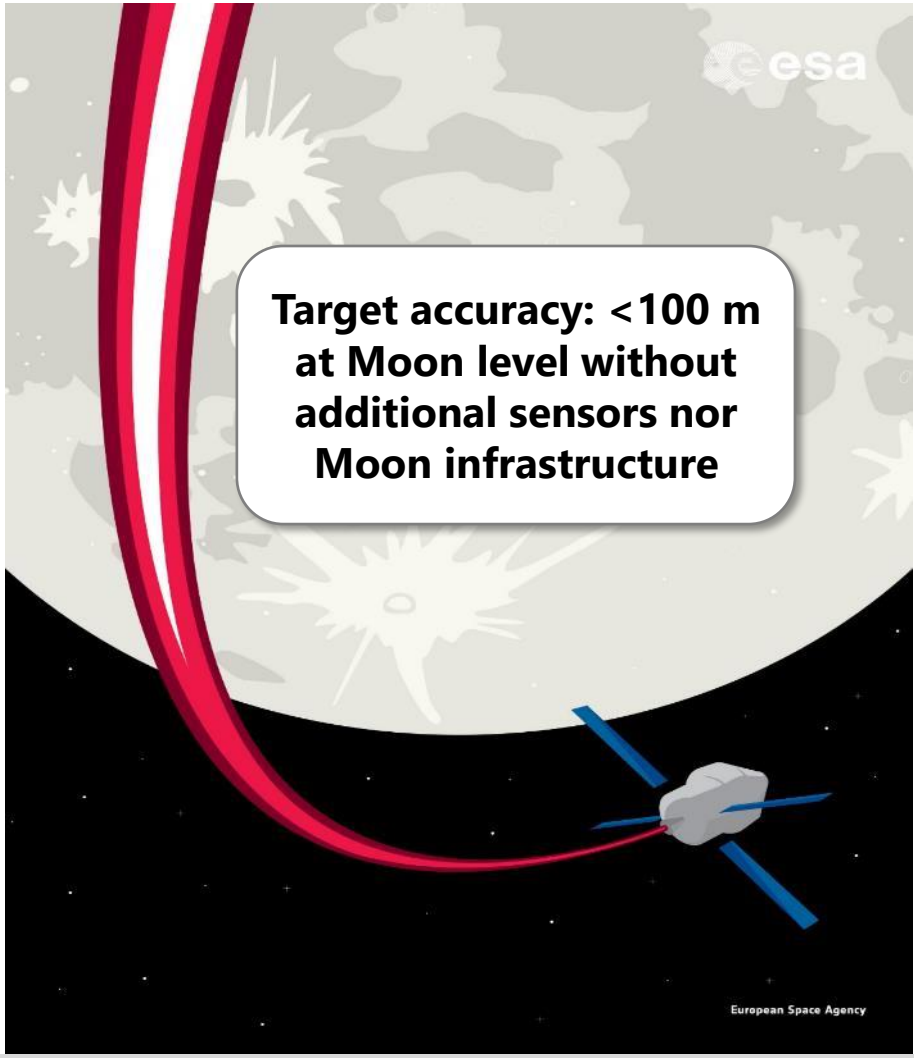
Image source: Fugro

Key features of SpacePNT technology

NaviMOON solution	3D rms accuracy (real-time)
Target accuracy	**< 100 m** (Moon altitude)

- ✓ Improved acquisition / tracking algorithms for high sensitivity
  - ➔ **Tracking of the GNSS spillover signals over the Earth**
- ✓ Tight integration of the GNSS solution with an orbital forces model
  - ➔ **Mitigates poor system geometry**
- ✓ Dual constellation and dual frequency
  - ➔ **Improves availability and precision**

Selected for ESA/SSTL Lunar Pathfinder Mission



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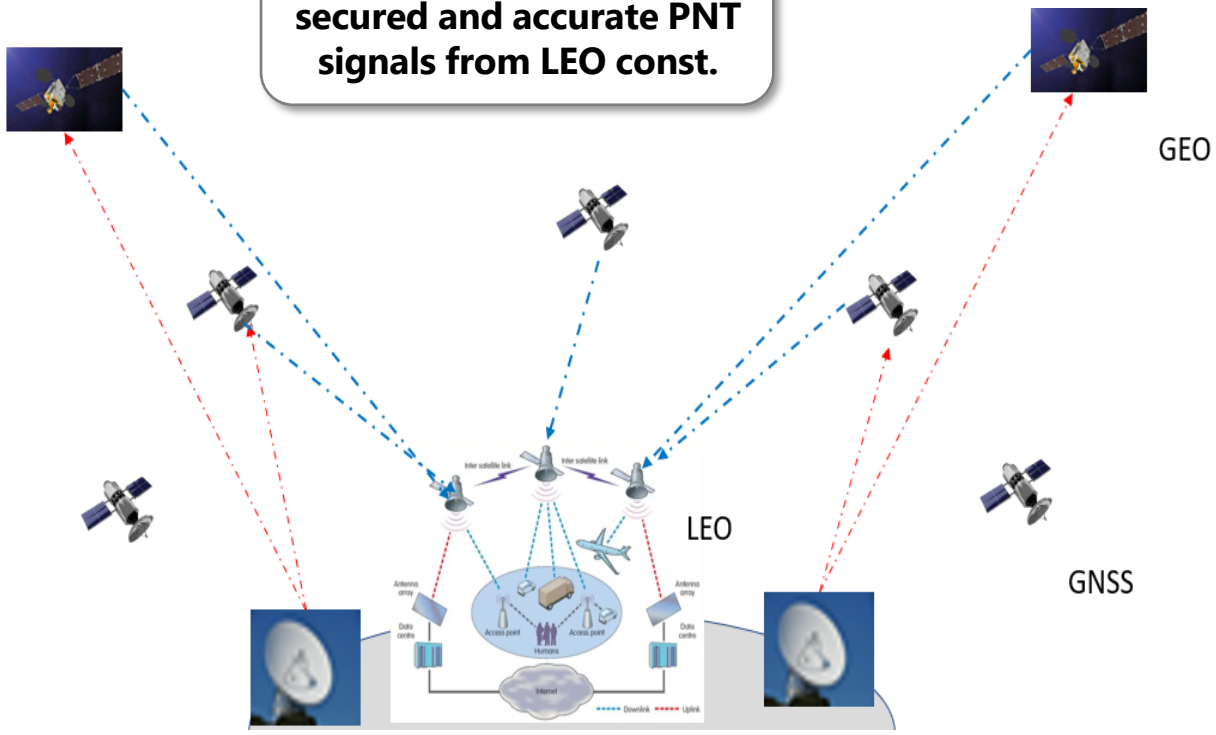
Key feature of SpacePNT technology

NaviLEO PNT solution (GNSS Backup & PNT aaS)

Generation of
secured and accurate PNT signals from LEO const.



Bloc diagram of LEO PNT operation

Requirements

- **Seamless integration** with MEO GNSS from user's perspective
- **Minimal ground support**
- Suitable for Low-cost LEO platforms as **LEO PNT payload**

Solution

- Reception of **GNSS signals** + **real-time orbit/clock corrections** (from GEO, MEO, or ground station)
- On-board **real-time POD** (generation of **LEO ephemeris** + GNSS **atomic time synch**)
- LEO transmitted signal **time-tagging & ephemeris message encapsulation** (encrypted, high power, …)

Also suitable for SIGINT

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Key feature of SpacePNT technology

NaviLEO PNT solution (GNSS Backup & PNT aaS)

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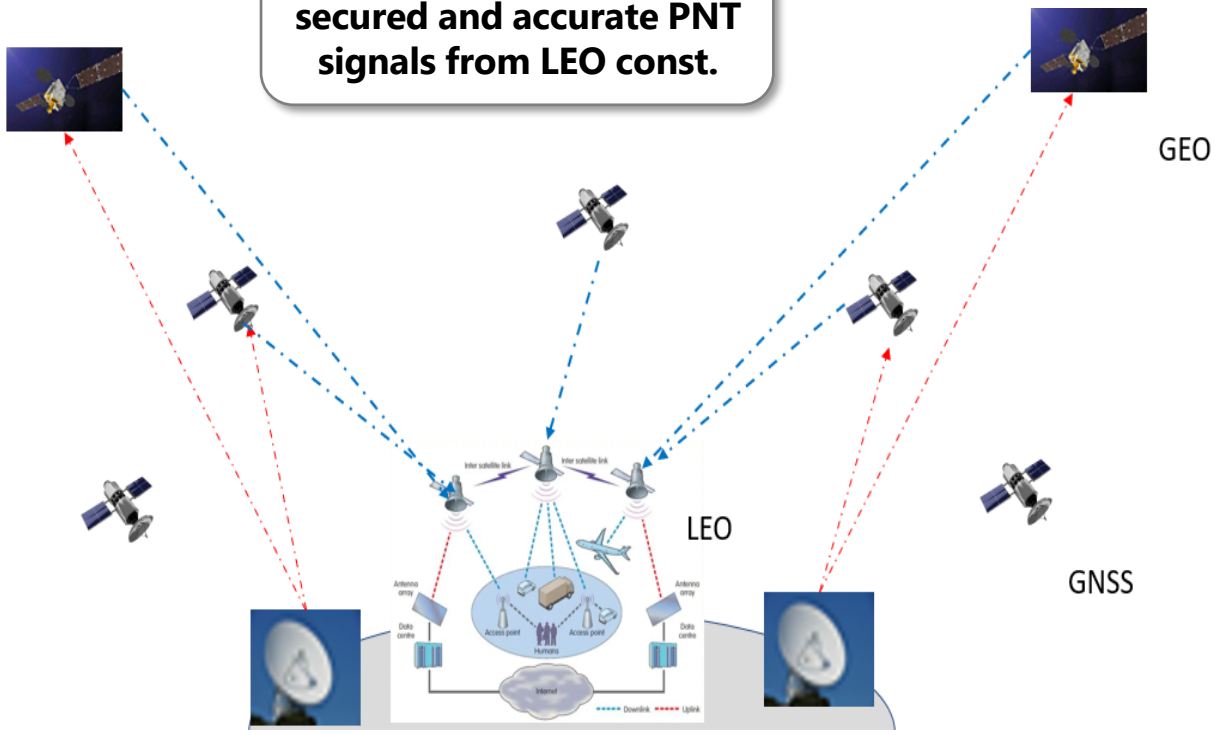

Bloc diagram of LEO PNT operation

Benefits

Lower propagation loss and more RX power
- ✓better indoor reception
- ✓low energy positioning (IoT)
- ✓more robustness (RFI & jammers)

Fast geom. changes even for a static receiver
- ✓Doppler positioning
- ✓faster PPP convergence
- ✓better precision (multipath averaging)

Low cost augmentation system
- ✓New Space approach
- ✓No dedicated ground control segment (relies on GNSSs)

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Conclusions

- **NaviLEO receiver platform in answer to "New Space" paradigm**
  - Single sat. and large/mega-constellations
  - Market driven
  - Short develop. time and faster replenishment rate
  - Lower SWaP-C

Fully compatible with LEO/Moon PNT concept

- to offer PNT aaS (more precision, more availability, more security, etc.)

NaviLEO scalable platform solution

- **NaviLEO** : 10 cm position, ns timing
- **NaviOrbit** : + dual-ant.
- **NaviMoon** : + highest sensitivity
- **NaviPNT** : PNT signal gen.

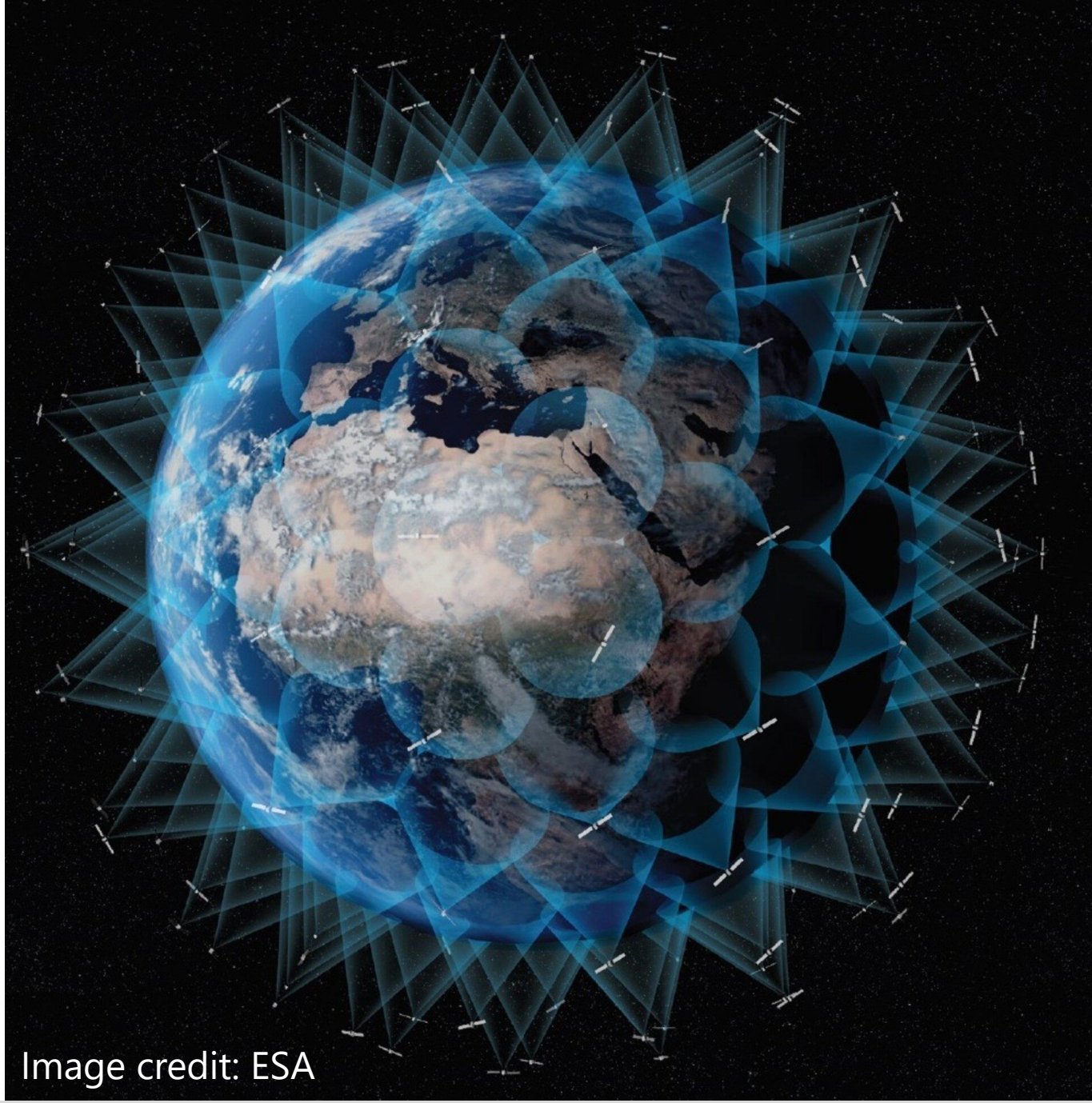

Image credit: ESA

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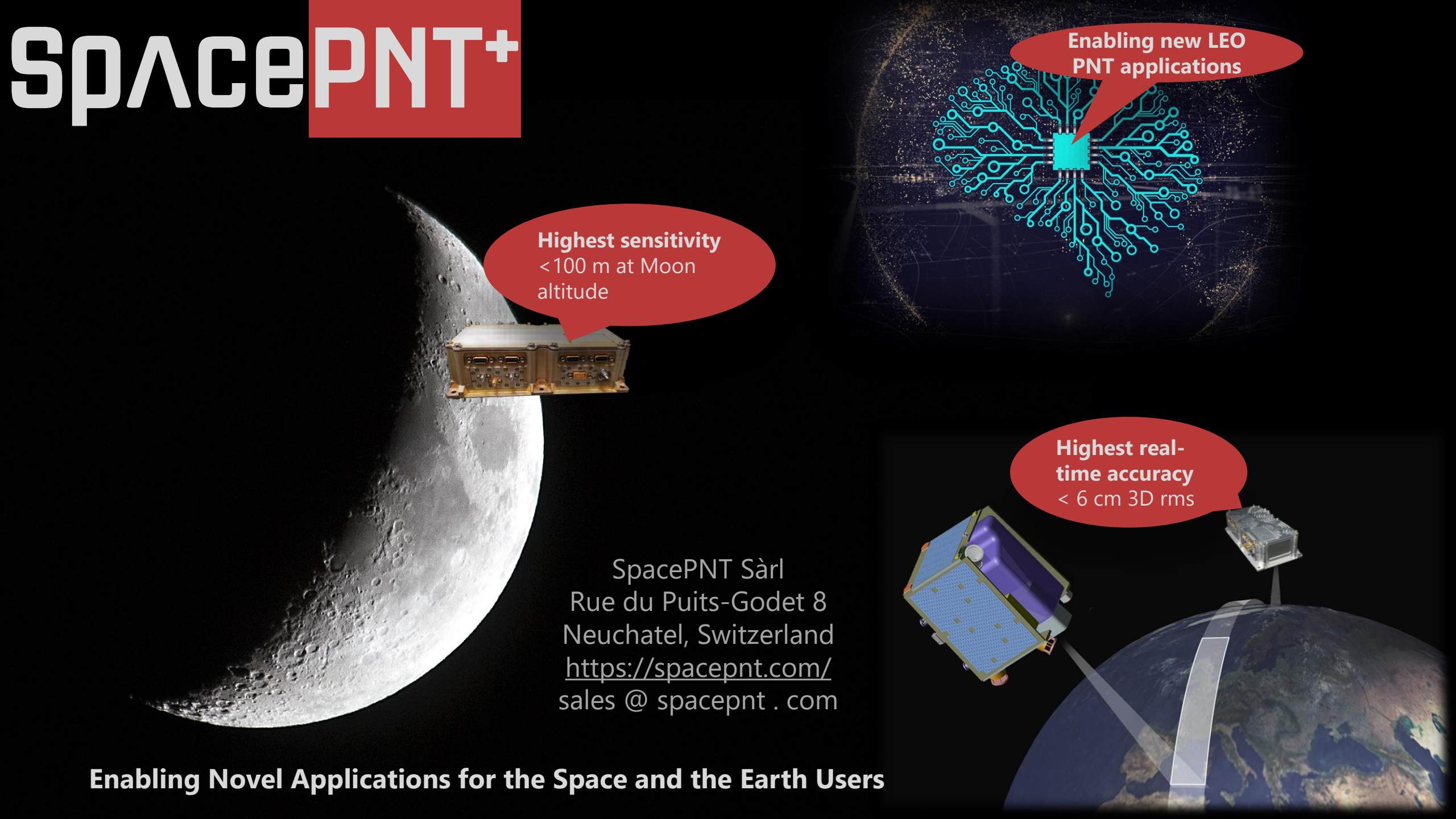

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Enabling Novel Applications for the Space and the Earth Users