Standardization for Lunar PNT Receivers

Samuele Fantinato, Qascom S.r.l.

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10^{th} February 2026

Qascom Lunar PNT receivers Development

- Qascom has defined a technology roadmap with the objective to support Navigation of Future Commercial and Governmental Moon Missions
- Qascom PNT Receiver Technology covers:
  - GNSS Moon Positioning
  - LCNS Moon Positioning
  - LCNS + Moon Beacon Positioning

PNT Receivers

Moon GNSS Products — 2023

Moon LCNS Products — 2026

Why Lunar PNT Receiver Standardization Matters?

- **Context: a New Lunar Economy**
  - >100 lunar missions by 2030
  - Lunar PNT receivers becoming strategic technology, not mission-specific payloads.

- **PNT is a Foundational Lunar Infrastructure**
  - Future lunar systems will broadcast standardized interoperable PNT services LCRNS (NASA) · Moonlight (ESA) · LNSS (Jaxa)
  - Standardized receivers are the key enabler of interoperability

- **Safety-Critical Operations → Integrity Is Mandatory**
  - 60% of mission are Safety Critical
  - Without standardization → no scalable safety

- **Industrial & Economic Impact**
  - Reduced Development & qualification cost
  - Standards transform a niche product into a scalable industry

- Lunar PNT receiver standardization is a strategic enabler of safe, interoperable, and sustainable lunar exploration

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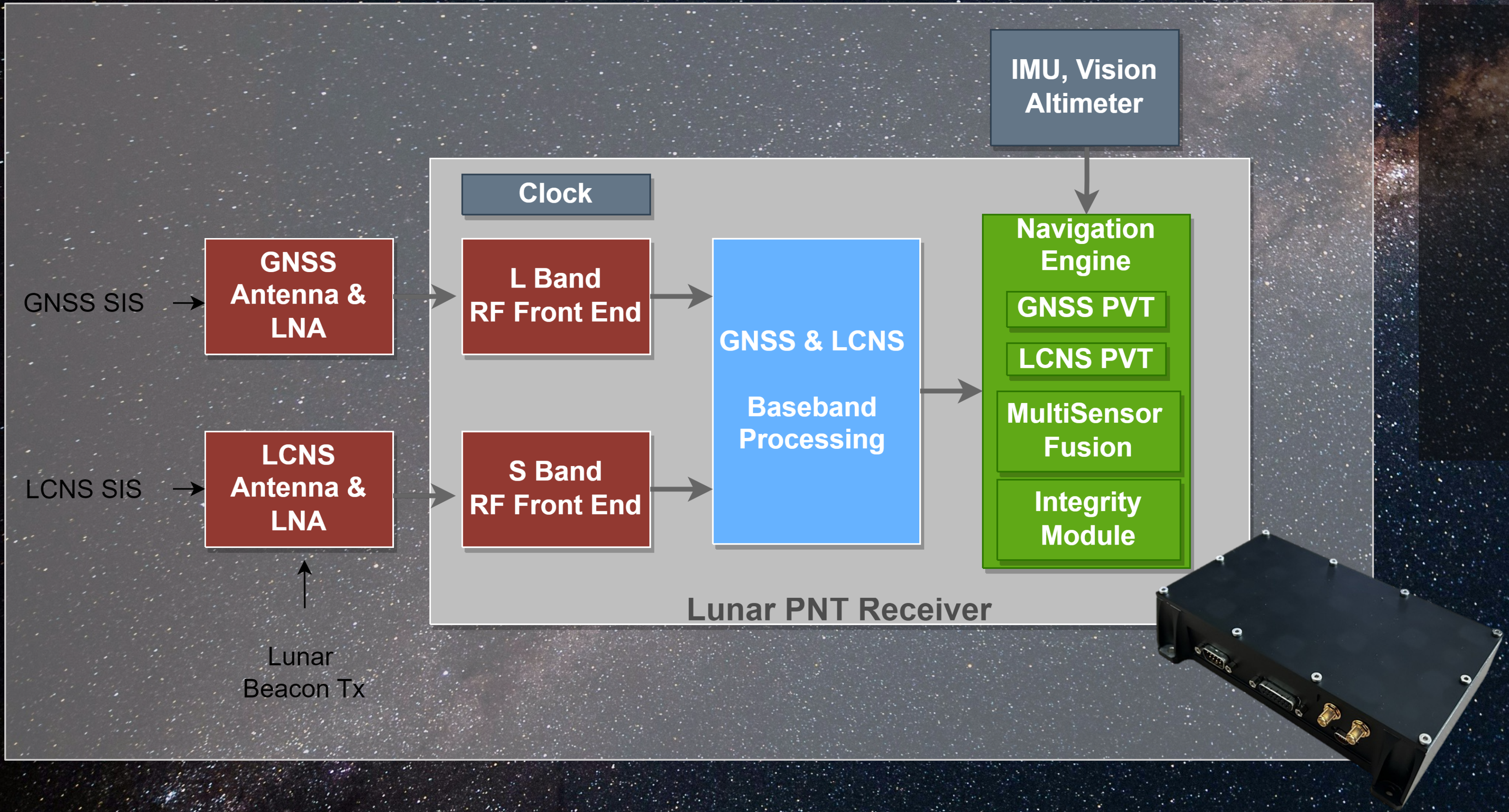
What Is a “Lunar PNT Receiver”?

- What Should Standardization Cover?



- Functional behavior
- Signal processing
- Nav Performance
- Interfaces
- Integrity
- Certification testing
- Environmental qualification (via Space Qual. Standards)

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Lunar PNT Receiver Standardization Layers

- Lunar PNT receiver standardization should combine the physical robustness of space GNSS receivers with the navigation performance and integrity definition of aviation GNSS standards.

Layer	GNSS Space Receiver Standards	GNSS Aviation Receiver Standards
1. RF and Antenna Layer	V	X
2. Signal Processing Layer	V	~
3. Navigation & PNT Algorithms	V	V
4. Data Interfaces & Protocols	~	V
5. Timing & Synchronization	~	V
6. Security & Authentication Layer	~	V
7. Environmental & Radiation Hardness Layer	V	X
8. System Performance Metrics	X	V

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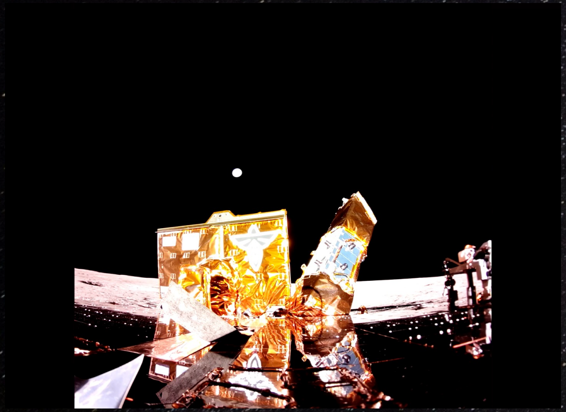
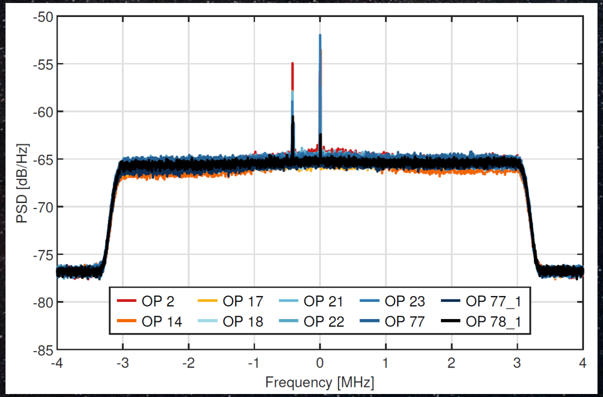
PNT Receiver Standardization Layers (1)

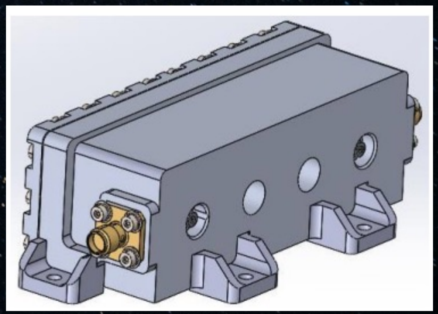
- **Layer 1: RF & Antenna Layer: main tradeoffs and key specifications**
  - Separate or unique L-Band / S-Band Antenna
  - Antenna Radiation patterns (RHCP, Gain, Axial Ratio).
  - RF Chain Filters frequency selectivity for interference immunity.
  - Phase Centre Stability: Phase Centre Offset (PCO) and Phase Centre Variation (PCV)

- **Lesson Learnt (LuGRE)**
  - Flat Panel Requires Earth pointing for GNSS reception.
  - 15 dBi peak gain, ~25° HPBW
  - EMI Compatibility Testing fundamental to assess impact on GNSS frequencies





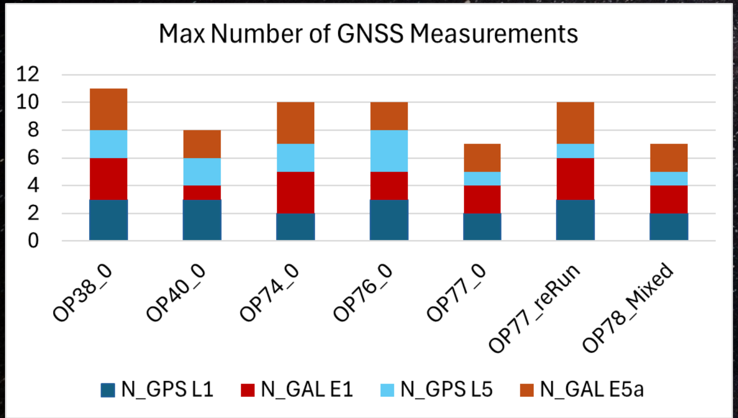
- **Lesson Learnt (Moonlight)**
  - Lunar Missions EMI environment shall be well defined.
  - LCNS Nav Frequency band is close to LCNS Com Frequency Band.
  - COTS products (S-Band TT&C) shall be optimized for NAV

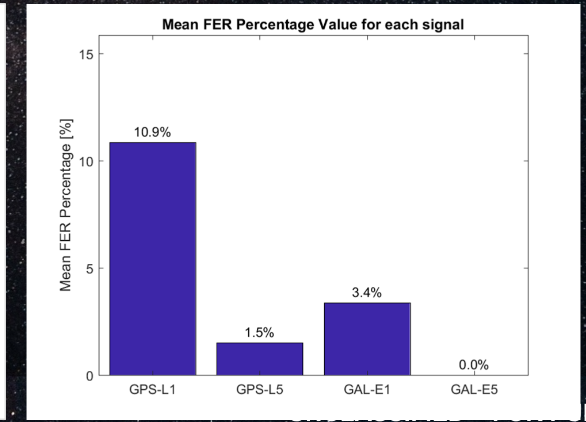


PNT Receiver Standardization Layers (2)

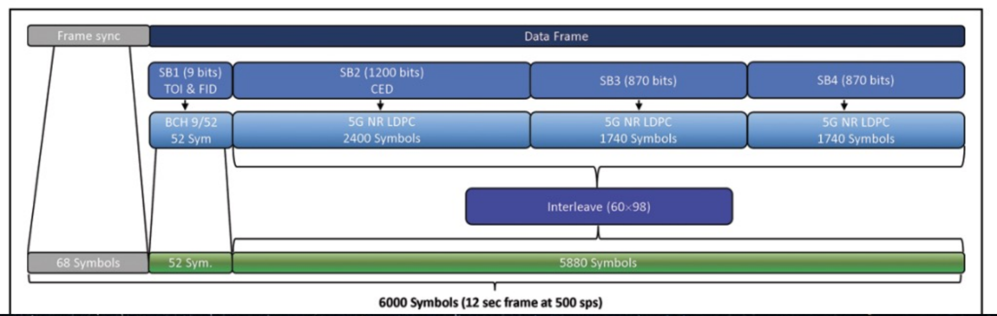
- **Layer 2: Signal Processing**
  - Signal Acquisition Sensitivity => Availability
  - Signal Tracking Sensitivity => Availability & Accuracy
  - Navigation Message Demodulation
  - Number of Channels

- **Lesson Learnt (LuGRE)**
  - In-flight C/N0 estimates are lower than predicted by LuGRE planning simulator
  - Reliable acquisition of GPS and Galileo Satellites
  - Up to 8 - 10 Dual Constellation/ Dual Frequency L1/L5 Measurements
  - IQS Postprocessing have demonstrated that Other Constellations can used (Beidou, SBAS, NAVIC, QZSS)
  - Navigation Message can be reliably decoded.
  - **=> Reserve at least 12 Tracking Channels to GNSS**





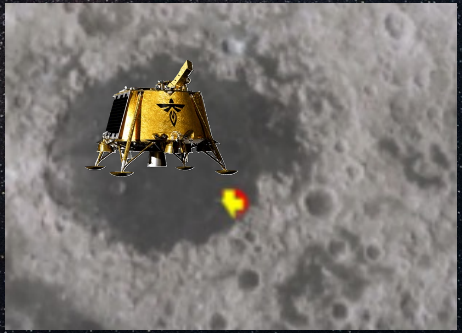
- **Consideration (Moonlight)**
  - Size the early design stage to size the receiver for several channels adequate for LCNS, LNSS, LCRNS (16 channels - 8 Channels x 2 Antennas)
  - The Block Interleaver on SB2, SB3, SB4 introduce Latency in the single Blocks decoding => increased time to first fix.
  - Achieve **full interoperability** between systems require **Almanacs** information from all the constellations to be shared between systems



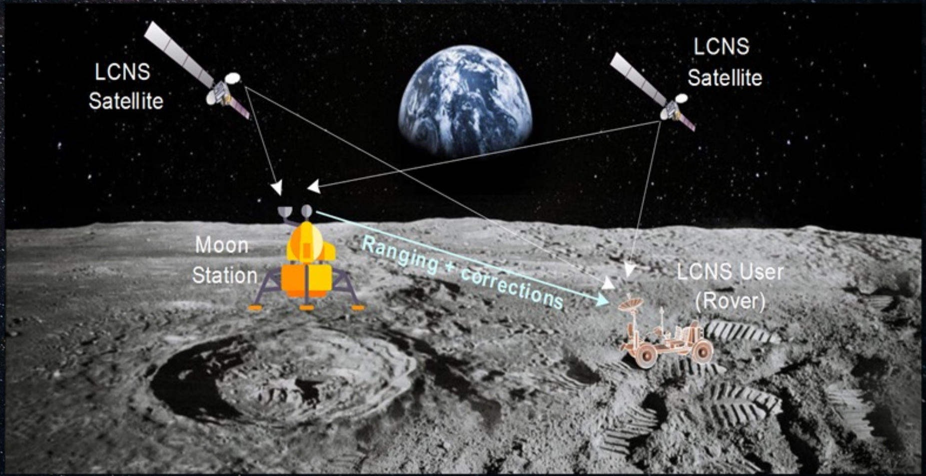
PNT Receiver Standardization Layers (3)

- **Layer 3: Navigation & PNT Algorithms**
  - Required position, velocity, and time outputs
  - Use of Differential Corrections, DEM & other Sensors
  - Integrity Monitoring & Fault Detection
  - Performance Budget Allocation (Orbit, Clock, Noise)
  - Validation Scenarios

- **Lesson Learnt (LuGRE)**
  - **Lunar Orbit**
    - 3D POD Position Accuracy < 200 m
    - POD Availability > 85%
  - **Lunar Surface**
    - 3D POD Position Error < 1 km
    - PVT Availability < 20%
    - POD Availability >95%



- **Lesson Learnt (Moonlight)**
  - **Lunar Surface**
    - 3D EKF Position Error < 20 m
    - With Differential Corr. – 60%
    - With DEM – 70%
    - With DEM + Differential Corr. – 73%

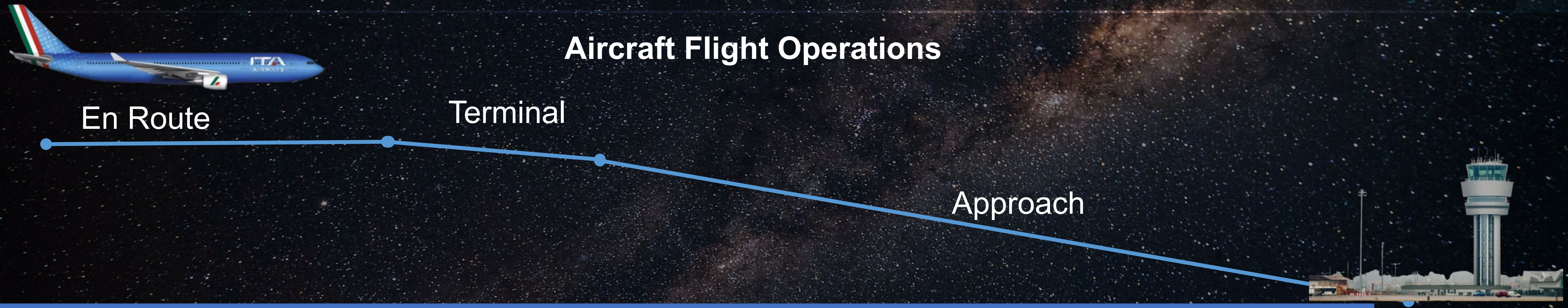


- **Download LuGRE Data!**

What can Be Reused from Aviation GNSS Standards?

- Aviation: Possible reuse of a Concept from Aviation (Equipment Classes (DO-229D/E/F and ED-259): **MOPS performance classes** refers to **operational equipment classes** that define *which phases of flight and approach types a GNSS receiver is certified to support*

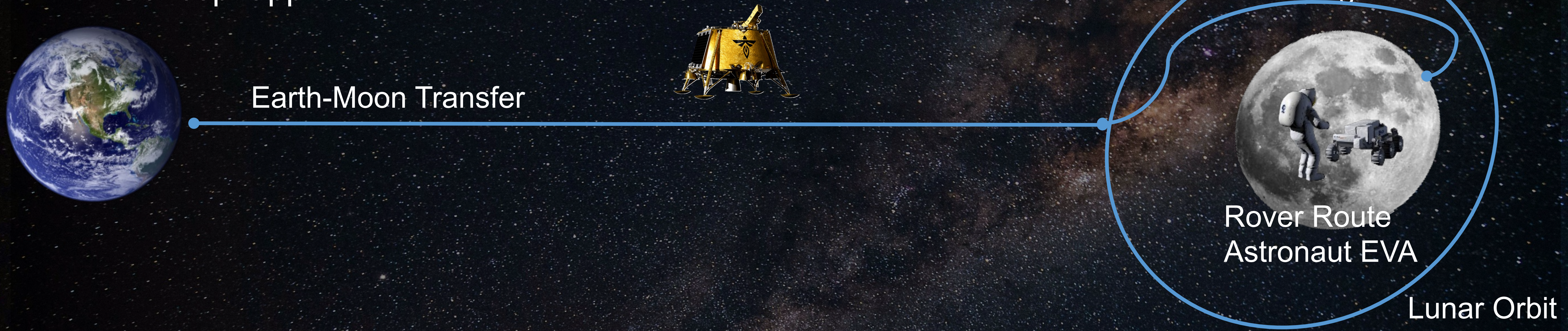
Aircraft Flight Operations



Aircraft Flight Operations	MOPS Operational / Functional Class	Positioning technology	Performance
En-route	Class 1 / Beta	GNSS	RNP 4 / RNP 2
Terminal	Class 1 / Beta	GNSS	RNP 2 / RNP 1
Approach LNAV (Lateral Nav)	Class 1 / Beta	GNSS + SBAS + Baro-altimeter	RNP 0.3
Approach LNAV/VNAV (Lateral Nav / Vertical Nav)	Class 2 / Gamma	GNSS + SBAS/GBAS + IRS + Baro-altimeter	RNP 0.3
Precision Approach LP/LPV (Localizer performance)	Class 4 / Delta	GNSS + SBAS/GBAS + ILS + VOR + DME	RNP 0.1-0.3

What can Be Reused from Aviation GNSS Standards?

- Concept applied to Lunar PNT Receiver



Lunar Nav Operations	Lunar Performance Class (Hypothesis)	Positioning Technology Required	Performance	Integrity Required
Earth – Moon Transfer	Lunar Class 1	GNSS		
Lurar Orbit	Lunar Class 1	GNSS + LCNS Receiver	3D Pos < 100 m	
Landing	Lunar Class 4	LCNS Receiver + Lunar Beacons + Sensors (IMU, Altimeter, Vision, DEM)	H. Pos < 50 m V. Pos < 100 m	Yes
Rover	Lunar Class 2	(GNSS) + LCNS Receiver + Lunar Beacons + Sensors (IMU, Altimeter, Vision, DEM)	H. Pos < 50 m	Yes
Astronaut Eva	Lunar Class 3	LCNS Receiver + Lunar Beacons + Sensors (IMU, Altimeter, DEM)	H. Pos < 50 m	Yes

Example of Standardization: LuGRE EWSS Experiment

- Galileo EWSS is a successful example of service–receiver interoperability and provides a powerful model for Lunar PNT receiver standardization
- During Operation #34 (13-14 March 2025), Dummy EWSS Message added by ESA on Galileo Satellites PRN 13, 15 and 34

Message Type 2 bits	Issuing entity 14 bits	Hazard type 7 bits	Hazard Characteristics 19 bits	Type of Instr. Library + version 4 bits	Instruction library 10 bits	Target area 49 bits	Specific settings 17 bits

Test

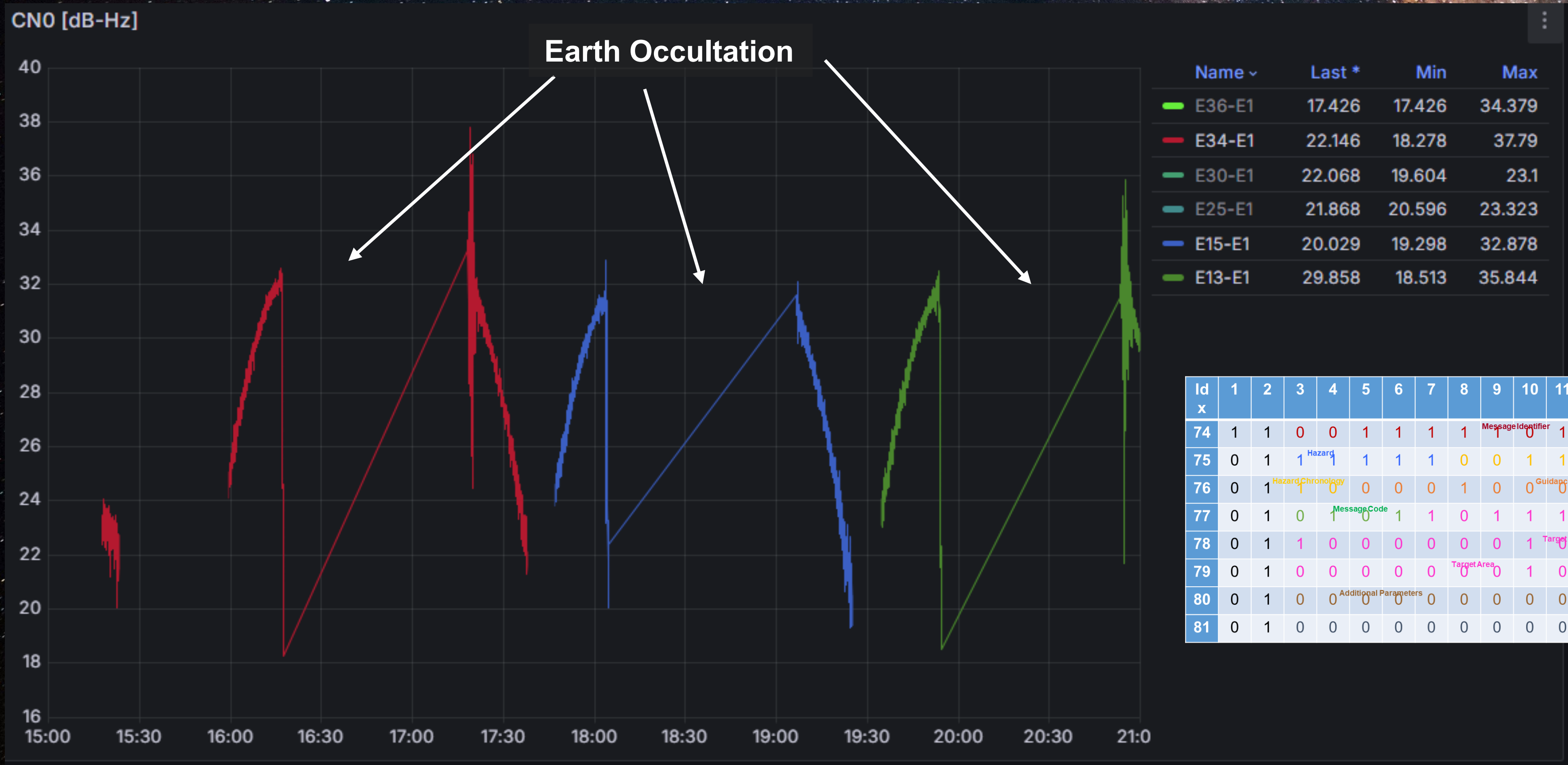
UN Nation (Lunar Safety Org)

UV Radiation (Extreme)

Highest (extreme 11/11) UV Index scale by United States Environmental Protection Agency

Example of Standardization: LuGRE EWSS Experiment

- **Galileo PRN 13, 15 and 34 were Acquired and Tracked at the Moon:**
  - Between 15:00 and 21:00 on March 14th 2025
  - Between 06:00 and 12:00 on March 15th 2025



Idx	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
74	1	1	0	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0
75	0	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1	1	1	1
76	0	1	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
77	0	1	0	1	0	1	1	0	1	1	1	1	0	1	1	1	1	1	0	0	1	1
78	0	1	1	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	0	0	0
79	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	1	0
80	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Field labels shown over the table: Message Identifier; Hazard; Hazard Chronology; Guidance to React; Message Code; Target Area; Additional Parameters; Spare

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Proposed Standardization Approach & Elements for Future Work

2026: Lunar PNT Standardization Status

Lunanet Architecture	well defined
Protocols and Signals	under definition
PNT Receivers	R&D phase, prototypes
Certification	not defined

Recommended Bodies

- **ICG** → International coordination
- **ESA / NASA / JAXA / ASI / CNES** → System alignment
- **CCSDS** → Technical standards & architecture
- **Industry consortium** → Implementation feedback

Lunar PNT Standardization: Proposed Phased Approach (Next 5 Years)

Foundations

1. Functional Architecture, Performance Classes
- Shared receiver model across agencies
- Lunar equivalent of GNSS MOPS classes

2. Time & Reference Frame Handling
- Prevent early fragmentation of time handling.
- Plug-and-play spacecraft integration.

Interoperability

3. Multi-service profiles, test scenarios
- Receiver forward compatibility
- Comparable performance validation

4. Integrity framework
- Support crewed missions

Certification

5. Compliance & certification framework
- Independent verification of compliance

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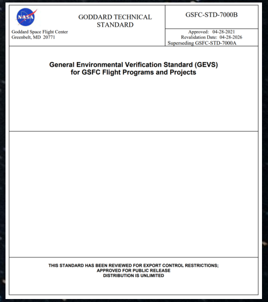
Thank you!

SAMUELE FANTINATO
Head of Navigation Technologies Division, Qascom

Mail: samuele.fantinato@qascom.it

What can Be Reused from Space GNSS Standards?

- From GNSS Space Receivers (e.g. for LEO Navigation) the following standards are relevant and well established:
  - **Space Qualification & Environmental Standards (Space Hardware).**
    - European Space Agency ECSS Standards
    - NASA GEV Standard and others
  - **Radiation & Reliability Standards (Critical for GNSS Space Receivers)**
    - ECSS and MIL
  - **Fundamental is also to look to "Technology trends" for Space Receivers**
    - New Space modular hardware design with hybrid commercial/rad tolerant electronics.
    - Software Defined Radio (SDR) concept for reconfiguration and adaptability to new mission requirements
    - Adoption of Multi constellation and Multifrequency.
    - Introduction of High Accuracy Positioning (e.g. with Galileo HAS) and Robustness against Jamming/Spoofing.


GODDARD TECHNICAL STANDARD

Goddard Space Flight Center
Greenbelt, MD 20771

GSFC-STD-7000B

Approved: 04-28-2021
Revalidation Date: 04-28-2026
Superseding GSFC-STD-7000A

General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects

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