24th PNT Advisory Board Meeting

Interoperable GNSS Space Service Volume – Update on ESA Activities

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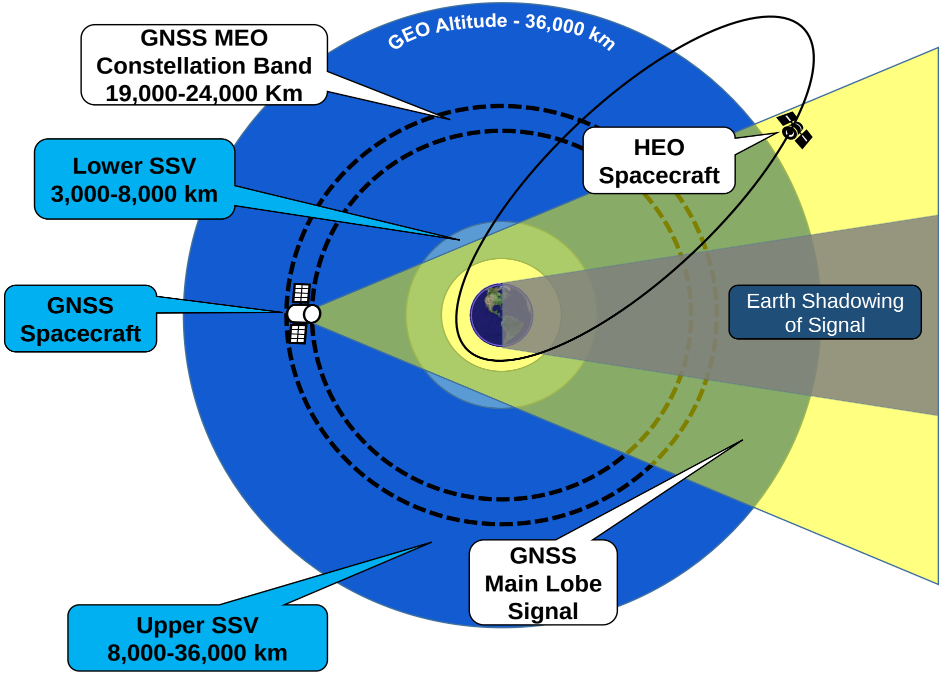
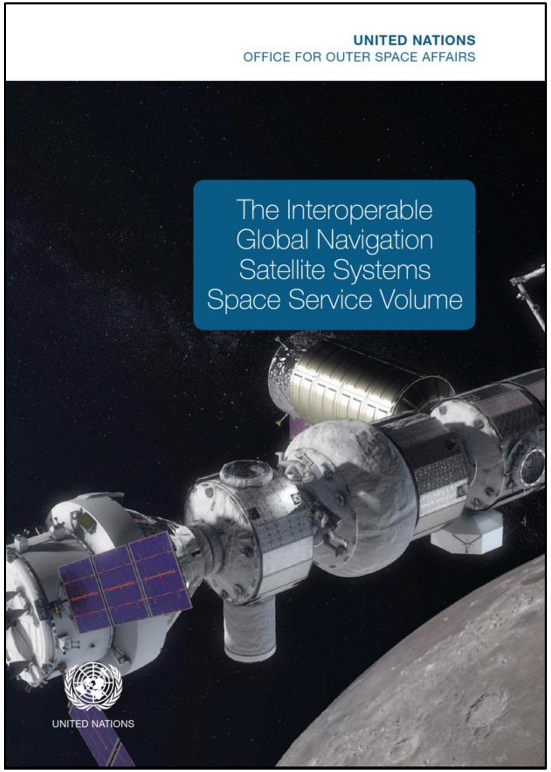
Overview

- Introduction
- Space Users Benefit and Applications
- Changing GNSS Environment
- ESA's Activities related to GNSS SSV
- Conclusions

Introduction – Definition of GNSS Space Service Volume





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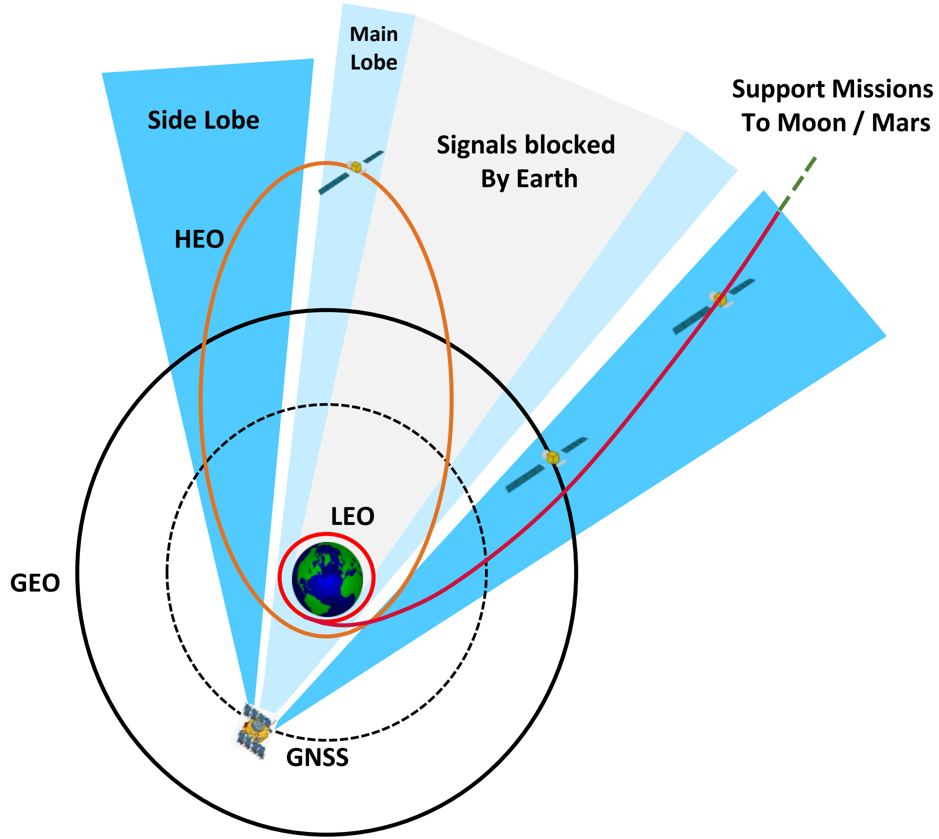
Introduction – Space Users Community



Space Users Community is DIVERSE

- Orbital Regime (LEO,…, Moon)
- Size of Spacecraft (CubSat, ISS)
- Applications (Earth Obs, Com, Sci)
- Single Sat, Formation Flying
- Level of Accuracy (100m, <5cm)
- Navigation Concept (on-board, Ground)

Introduction – Interoperable GNSS

Interoperability between GNSS can only be achieved in case

- Common Geodetic Reference Frame
  - All Service Providers have their respective geodetic reference frame aligned to the International Terrestrial Reference Frame (ITRF)
- Common Time Reference
  - All service providers steer their system time towards TAI (basis for UTC)
  - Currently no interoperable GNSS time exists in real time
- Common centre frequency and coordinated signal design
  - Only partially given, on bilateral basis (e.g. GPS and Galileo)

Space Users Benefits and Applications – Benefits

- Performance
  - On-board generation of Position, Velocity and Time (PVT) with high accuracy
  - Interoperable GNSS SSV allows development of new positioning concepts/algorithms tailored to specific mission needs
  - Precise Orbit Determination (POD) – highest possible accuracy
- Operational
  - New operations concepts with reduced Ground interaction
  - Increase of on-board autonomy
  - Increase of robustness of spacecraft navigation and operations resilience
- Technology
  - Enabler for new mission and service concepts
  - Development of GNSS Receiver core technology

Space Users Benefits and Applications - Applications

- Position, Velocity and Time (PVT) for on-board Navigation
- Precise Orbit Determination – Highest Level of Accuracy (on-ground or on-board)
- On-board Attitude Determination (3-Axis or spinning SV)
- Rendezvous and Docking
- Time synchronisation
- Launch Vehicle Range Operations
- Earth Science/Science
- Manoeuvre calibration
- Relative Navigation for Sat Formation Flying or Sat Constellations

Changing GNSS Environment - New Services

- Real-Time High Accuracy Services (HAS)
  - several Service Providers (Galileo, GLONASS, BeiDou, QZSS) confirmed at the ICG-13 in early November 2018 that they intend to provide such services
  - HAS will provide information for a PPP solution at end user level – processing of carrier phase
  - The Galileo High Accuracy Service shall be provided on a global scale for free
  - HAS is currently under definition/testing
- Galileo Commercial Authentication Services

Galileo E6-B/C Codes
Technical Note

Galileo E6-B/C Codes
Technical Note

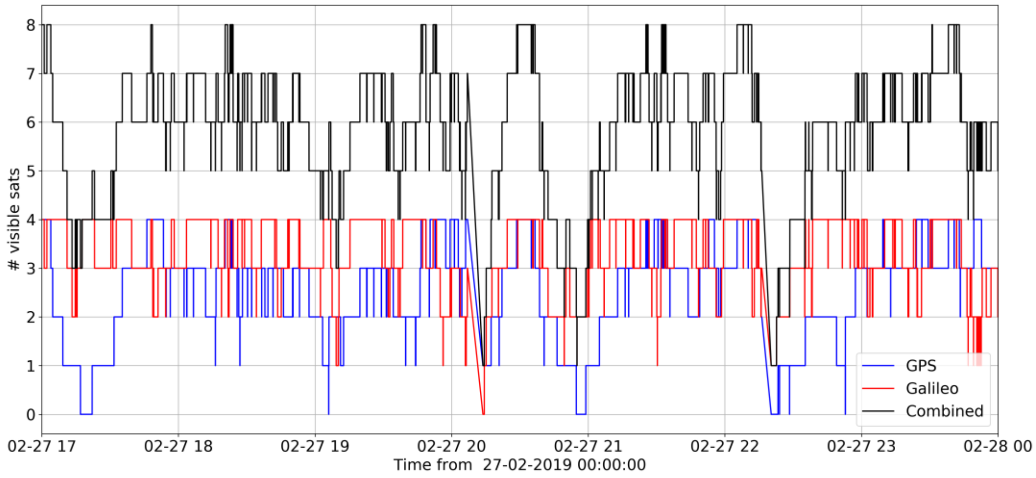
ESA's Activities related to GNSS SSV - Overview

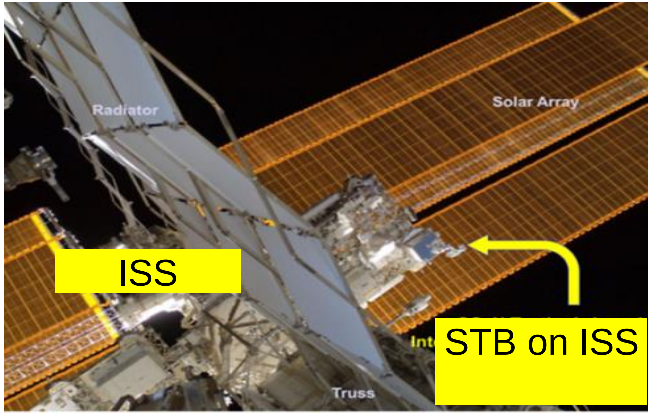
ID	Study Activities	Objectives
1	GNSS Space Service Volume Extension – Phase 1	Impact analysis and identification of technology and operational drivers
2	GNSS Space Service Volume Extension – New Precise Orbit Determination Concepts (Phase 2)	Detailed Req identification and development of new POD concepts for GNSS SSV and cis-Lunar missions
3	On-Board Precise Orbit Determination – New POD Concepts	Development of new on-board POD concepts for the GNSS SSV and cis-Lunar missions
4	Next Generation of Space Receiver – AGGA5	Identification of new Requirements for GNSS space receivers

ESA's Activities related to GNSS SSV - Overview

ID	Study Activities	Objectives
5	Space GNSS Receiver for In-Orbit Demonstration of Precise Point Positioning	Development of a low cost GNSS receiver and in-orbit demonstration of PPP concept on-board a cubsat
6	Kinematic Precise Orbit Determination for satellites based on the Galileo High Accuracy Service	To develop new Kinematic Precise Orbit Determination concepts for all space users, based on the usage of the Galileo High Accuracy Service
7	Use of GNSS for Moon Missions	Activity related to the use of GNSS Signals for Moon missions and identification of potential Augmentation of GNSS Infrastructure on the Moon
8	GNSS Interoperable Time activities – ESA works on two concepts (one for high accuracy users **MGET** and one for mass market **xGTO**)	Development of a concept for interoperable GNSS time

ESA's Activities related to GNSS SSV - GARISS

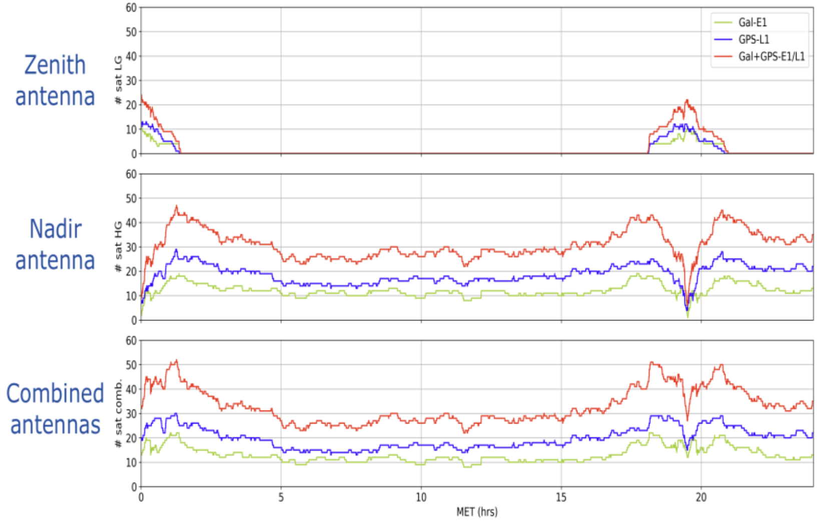




- Joint ESA/NASA Project -Demonstration of added value of GNSS SSV – Visibility of GAL/GPS SV
- First Position Fix in space from GAL/GPS E5a/L5

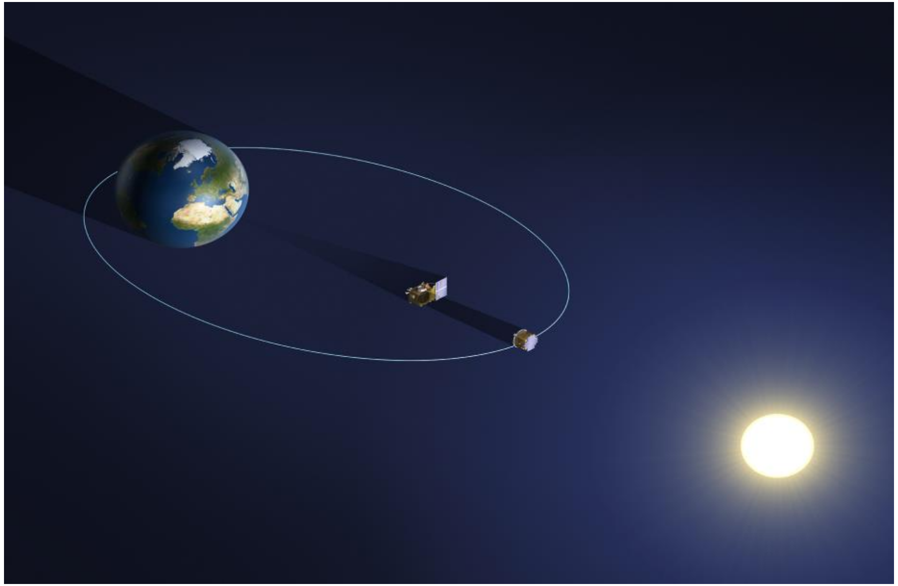
ESA's Activities related to GNSS SSV – PROBA-3

- ESA's PROBA-3 mission is a Technology Demonstration Mission for high-precision formation-flying of a pair of satellites in an HEO orbit
- **Important: More Observations -> Better Orbit Determination Accuracy**
- **Precise Orbit Determination Accuracy: absolute 15cm, relative 3mm**



$CN0_{min}$ = 20dB-Hz

>25 signals
~10 Galileo
~15 GPS

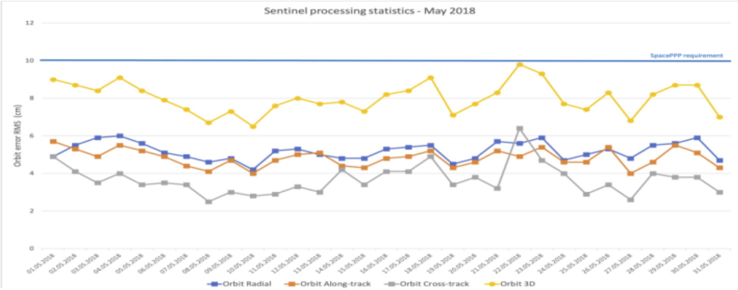


ESA’s Activities related to GNSS SSV – LEO PPP

- Development of a low cost Galileo/GPS receiver with dual frequency E1/L1, E5a/L5 for in-orbit demonstration in 2020-2021 on-board a cubesat
- Demonstration of real time on-board Precise Point Positioning (PPP) for LEO satellites
- GNSS orbit and clock dissemination via Inmarsat L-band link from GEO
- **PPP Orbit Accuracy (GPS only): with real Sentinel 3A data < 10 cm (3DRMS)**

(Source: J.M. Palomo et. al. *Space GNSS Receiver Performance Results With Precise Real-Time On-board Orbit Determination (P2OD) in LEO Missions*, ION GNSS 2019+, Sept. 2019, Miami, FL, USA)

	GNSS Receiver Characteristics
RF Signals	Dual frequency L1/E1 + L5/E5a Inmarsat L-Band
# GNSS Satellites	24 GNSS satellites in dual band configuration
# L –Band Inmarsat	≥ 2 parallel demodulators
Operation Modes	Standalone PVT and PPP in LEO
Acquisition Sensitivity	35 dBHz (cold start) in LEO orbit 30 dBHz (warm start) in LEO orbit
Tracking Sensitivity	30 dBHz in LEO orbit
PVT Accuracy (rms)	3D Position: 4 m 3D Velocity: 2 cm/s Time: 30 ns (TBC)
PPP Accuracy (rms)	3D Position: 10 cm 3D Velocity: 4 mm/s Time: 10 ns (TBC)
TTFF (90%)	< 600 s (cold start) < 90 s (warm start)
TTPF (90%)	< 15 m (since the PVT accuracy is within the standard positioning accuracy)
Others	Telemetry and Telecommand capability, patch and dump functions, upgradability from ground, etc.



ESA's Activities related to GNSS SSV - Moon

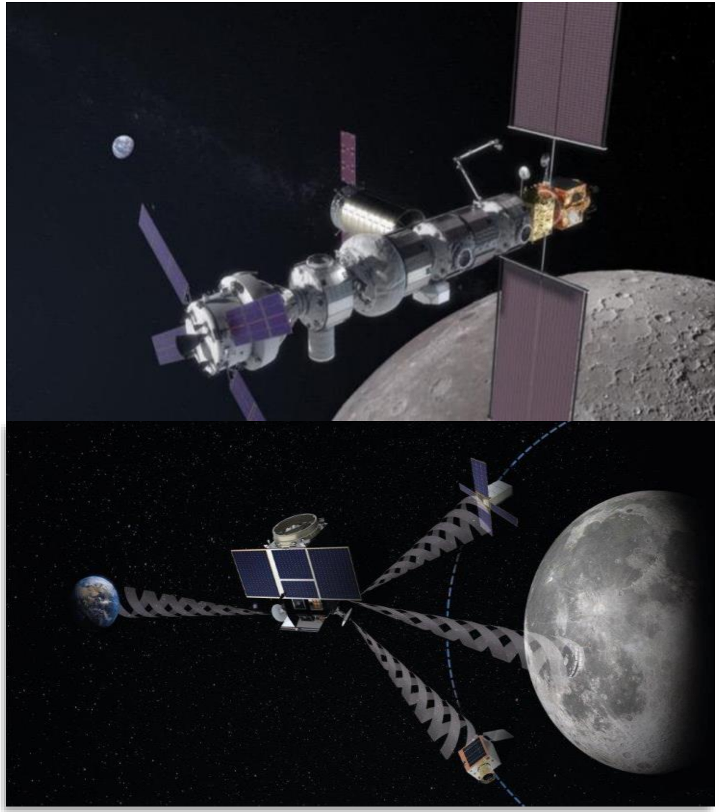
Earth-Moon GNSS based system study with two main elements

Architecture

- Consolidation of PNT User Requirements
- Identification of preliminary architecture with possible enhancements/augmentations

GNSS Receiver development

- Development and test of specific GNSS equipment (receiver and antenna) for weak signal processing



Conclusions

- The interoperable multi-GNSS Space Service Volume (GNSS SSV) offers enormous benefits for space users and is an enabler for future advanced missions (Improved signal availability, Improved navigation performance)
- The GNSS SSV activities at ESA are distributed and coordinated across several ESA directorates
- ESA has a clear roadmap for the exploitation of the GNSS SSV advantages and strategic developments are on-going (systems, equipment, concepts and algorithms)
- ESA has a strong interest to use GNSS also for Moon missions (e.g. Gateway) and is open for cooperation
- ESA supports international activities related to the GNSS SSV, like ICG, IGS, IOAG, ISECG, CCSDS,…