An Introduction to the Interoperable GNSS Space Service Volume (SSV) from an ESA Perspective

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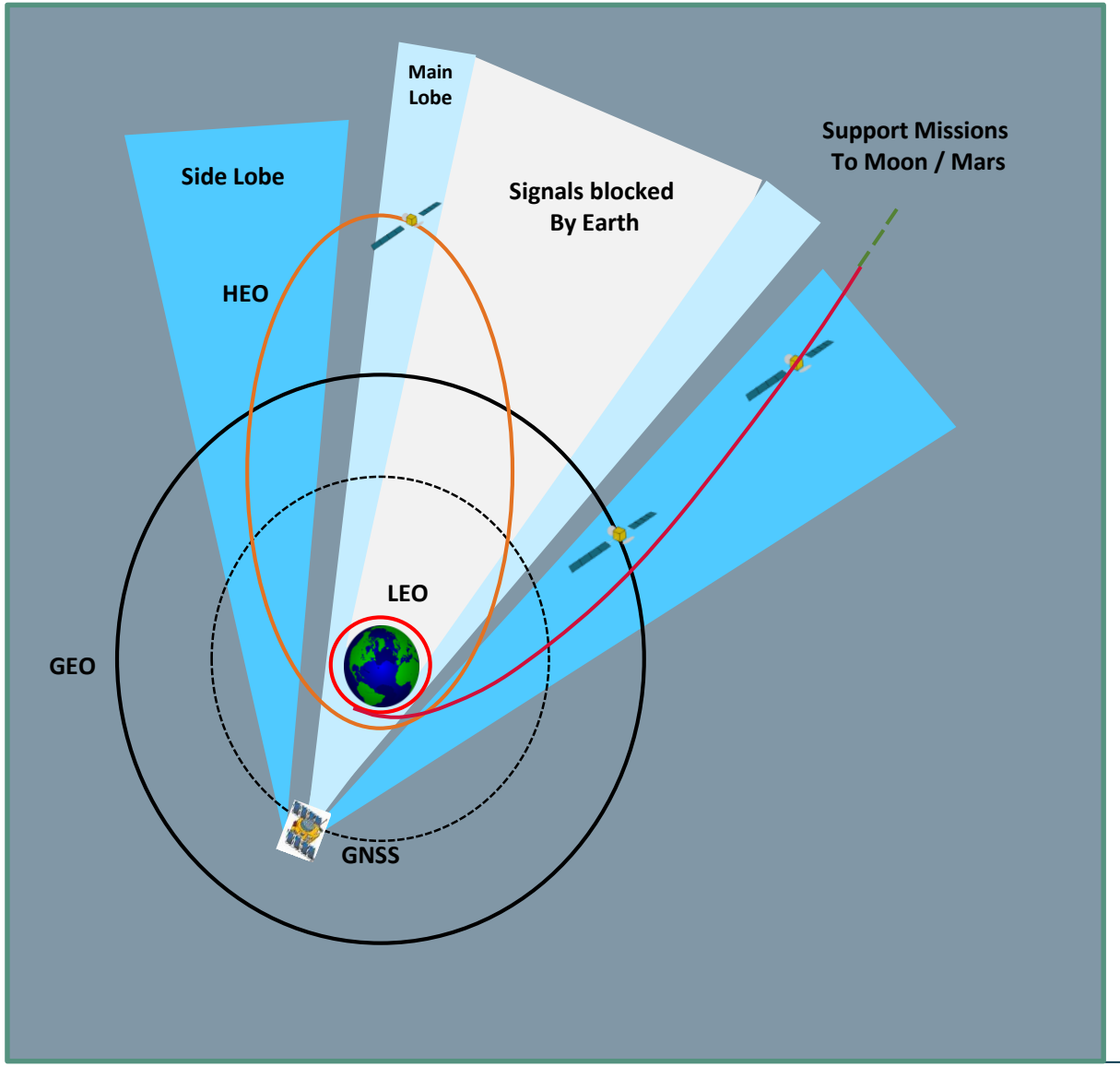
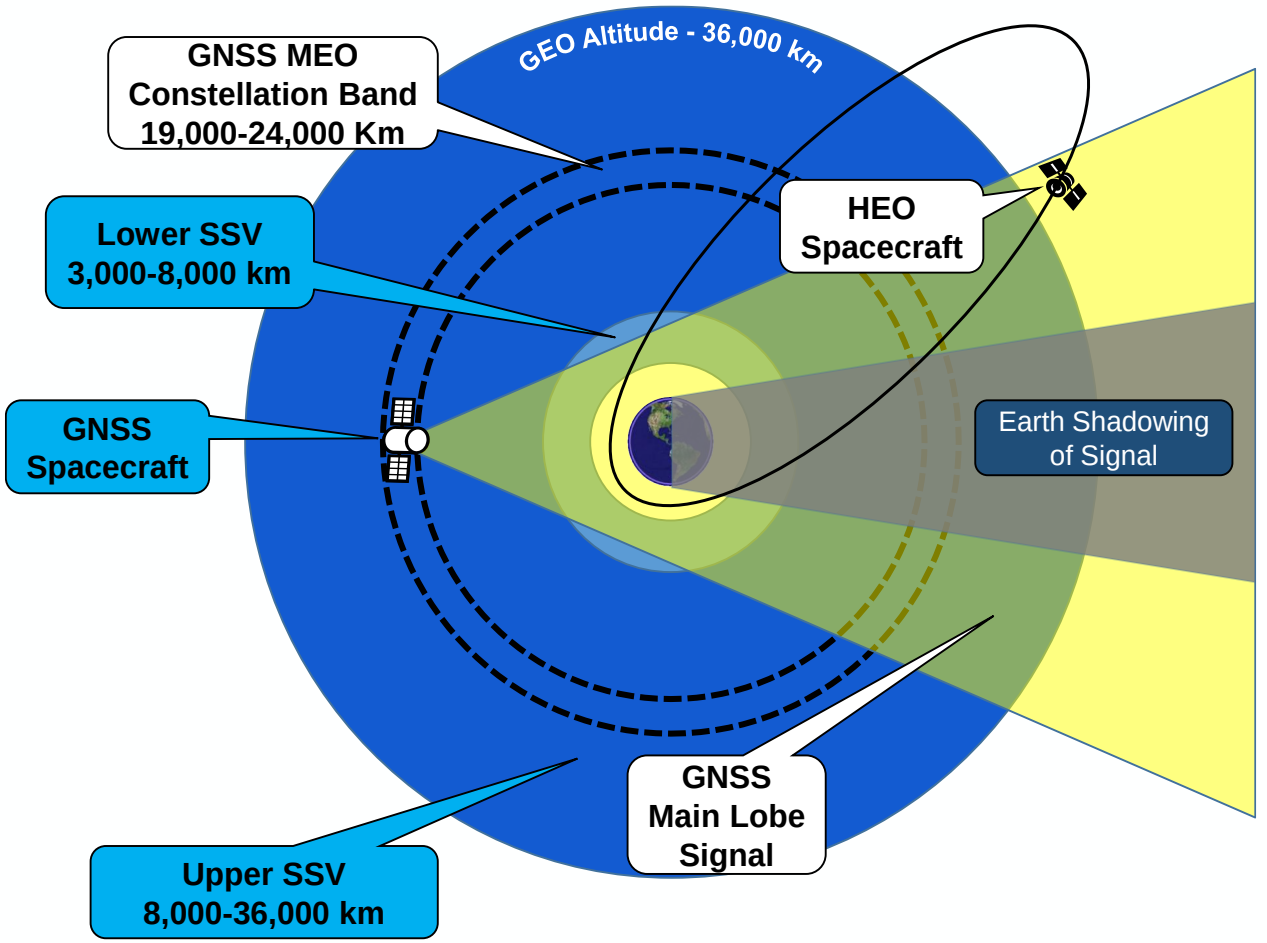
Space User Community



Space User Community is Very 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)

Definition of Interoperable GNSS Space Service Volume (SSV)



- Only GPS and Galileo (since 2020) have a definition for SSV
- Definition for GPS SSV is different to definition of Galileo SSV
- UN – International Committee on GNSS (ICG) Space Use Subgroup provided a definition of an interoperable GNSS SSV and associated reference scenarios, which is supported by all GNSS providers

International Committee on GNSS (ICG)

- The ICG emerged from 3rd UN Conference on the Exploration and Peaceful Uses of Outer Space in July 1999
- The ICG brings together all six GNSS providers (United States–GPS, European Union–Galileo, Russia–GLONASS, China–BeiDou, India–NavIC and Japan–QZSS), as well as other members and observers to:
  - *Promote the use of GNSS and its integration into infrastructures*
  - *Encourage compatibility and interoperability among global and regional systems*
- Observers: International organizations and associations (BIPM, **IOAG**, ITU, IGS, etc.,)

https://www.unoosa.org/oosa/en/ourwork/icg/icg.html

International Committee on GNSS (ICG)

The ICG consist of the GNSS Service Providers Forum and four Working Groups (WG-S, WG-B, WG-C and WG-D).

WG-S
Systems, Signals and Services

Major Topics
- Spectrum compatibility
- Interference detection & mitigation
- Service interoperability
- Performance standards & monitoring

WG-B
Enhancement of GNSS
Performance, New Services and Capabilities

Major Topics
- Development of interoperable, multi GNSS SSV
- GNSS hosted search and rescue payloads
- Space weather and atmosphere modelling

Applications Subgroup

Space Use Subgroup

The WG-B Space Use Subgroup is the body dedicated to representing needs of space users within ICG.

WG-D
Geodetic Reference, Time Reference and Applications

Major Topics
- ITRF, geodetic reference frame
- Time standards & multi constellation time offsets
- High Accuracy applications (PPP)

WG-C
Information Dissemination and Capacity Building

Major Topics
- Training and Seminars
- Information Material

International Committee on GNSS (ICG)

ICG WG-B Space Use Subgroup (SUSG)
Terms of Reference

As adopted 15 Apr 2021

- *Objectives of Space Use Subgroup:*
  - *Lead evolution of the Interoperable Multi-GNSS Space Service Volume including the use of GNSS for missions beyond the existing SSV (e.g. lunar).*
  - *Encourage developments of space-based user equipment and emerging user community.*
  - *Encourage coordination with Interagency Operations Advisory Group (IOAG) and International Space Exploration Coordination Group (ISECG).*
  - *Encourage development of new services and augmentations beneficial to space users.*
  - *Promote space user community needs within ICG.*

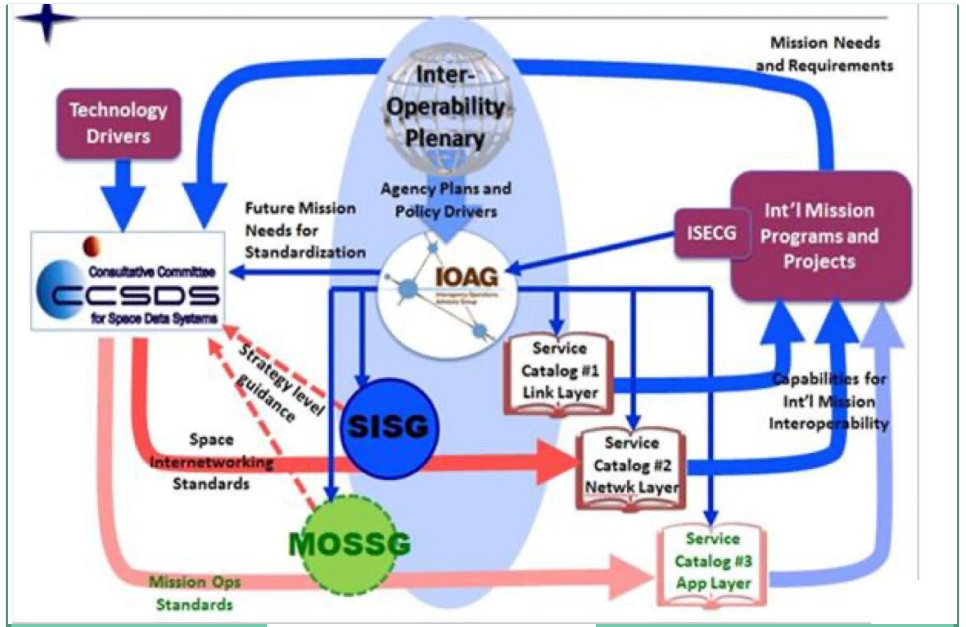
The Space Use Subgroup operates within the scope of the overall ICG Terms of Reference.

https://www.unoosa.org/documents/pdf/icg/2021/ICG15/ICG_ToR2021amended.pdf

Space Use Subgroup – Workplan 2021-2022 (Adopted, 24 Sept. 2021)

WP#	Activity	Lead	Participation
1	Public availability of provider antenna/signal technical data and requisite models	India	China Japan Europe USA
2	GNSS space user mission data and profile	China	USA Europe
3	GNSS space user timing requirement analysis and space user operations recommendations	Europe	USA China Japan India
4	Expansion of GNSS SSV to Support Lunar Operations	USA	Russia China Japan Europe
5	GNSS space user Standards	Europe	Russia USA China India

Coordination between IOAG and ICG-Space Use Subgroup



IOAG Organization : (15)

- 26 GHz Study Group
- Coding and Modulation Working Group
- Consultative Committee for Space Data Standards
- International Committee on Global Navigation Satellite Systems
- Lunar Communication Architecture Working Group
- Lunar-Mars Working Group
- Mars and Beyond Communications Architecture Working Group
- Mission Operations Systems Coordination Group
- Mission Operations Systems Strategy Group
- Optical Link Study Group
- Service Catalogs Working Group
- Space Frequency Coordination Group
- Space Internetworking Strategy Group
- Space Operations Sustainability Working Group
- Spacecraft Emergency Cross Support Working Group

Coordination to ensure

- Compatibility
- Interoperability
- Availability

GNSS Service Providers Forum

ICG Working Groups

WG-S Systems, Signals and Services	WG-B Enhancement of GNSS - Applications Subgroup - **Space Use Subgroup**	WG-D Geodetic Reference, Time Reference and Applications	WG-C Information Dissemination and Capacity Building

Members

Current and future core system providers, including China (Compass/BeiDou Navigation Satellite System (CNSS)), the European Union (European Satellite Navigation System (Galileo)), the Russian Federation (Global Navigation Satellite System (GLONASS)) and the United States of America (Global Positioning System (GPS)); States Members of the United Nations with an active programme in implementing or promoting a wide range of GNSS services and applications (Australia, Italy, Malaysia, New Zealand, United Arab Emirates);

Current and future space-based regional or augmentation system providers including, for example, the European Space Agency (European Geostationary Navigation Overlay Service (EGNOS)), India (Navigation with Indian Constellation (NavIC) or Indian Regional Navigation System (INRSS) and GPS Aided Geostationary (GEO) Augmented Navigation System (GAGAN)), Japan (Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) and Quasi-Zenith Satellite Space Based Augmentation System (QZSS)), Nigeria (Nigerian Communication Satellite Space Based Augmentation System(NigComsat-1 SBAS)), the Russian Federation (Wide-area System of Differential Corrections and Monitoring (SDCM) and the United States (Wide-area Augmentation System (WAAS));

Associate Members

International and regional organizations and associations dealing with GNSS services and applications, including the Office for Outer Space Affairs of the United Nations Secretariat, the Civil GPS Service Interface Committee (CGSIC), the European Position Determination System (EUPOS), the Fédération Aéronautique Internationale (FAI), the Fédération internationale des géomètres (FIG), the International Association of Institutes of Navigation (IAIN), the International Association of Geodesy (IAG), the International Association of Geodesy Reference Frame Sub-Commission for Europe (EUREF), the International Cartographic Association (ICA), the International GNSS Service (IGS, formerly International GPS Service), the International Earth Rotation and Reference Systems Service (IERS) and the International Society for Photogrammetry and Remote Sensing (ISPRS).

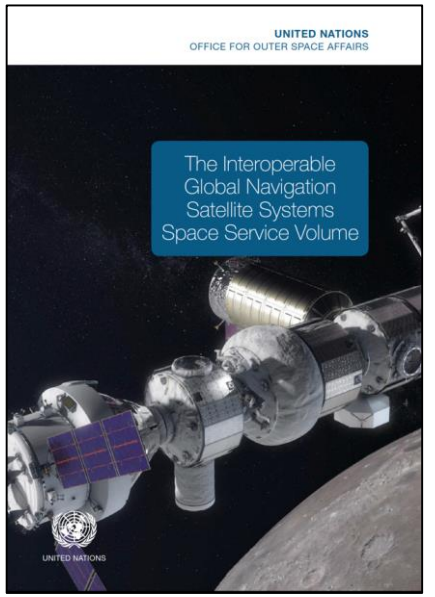
Observers

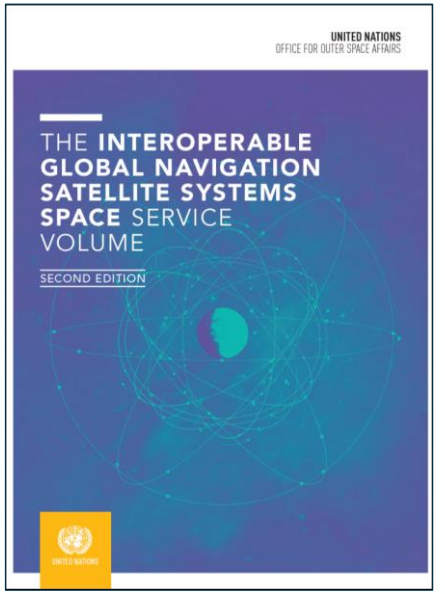
The Arab Institute of Navigation (AIN), the Asia-Pacific Space Cooperation Organization (APSCO), the Committee on Space Research (COSPAR), the Bureau international des poids et mesures (BIPM), the European Space Policy Institute (ESPI), the International Telecommunication Union (ITU), the Interagency Operations Advisory Group (IOAG) and the Union radio-scientifique internationale (URSI).

Interoperable GNSS Space Service Volume (SSV) – Booklets and Video

SSV Booklet, 1st and 2nd Editions

- -Full revision and update of all chapters
- -New content:
  - -GNSS constellation updates
  - -new Flight Experiences chapter featuring five real-world missions
  - -additional analysis of geometric aspects of SSV
- -Available at: https://undocs.org/ST/SPACE/75/REV.1





SSV Video

Four minute video, developed as an outreach tool to:

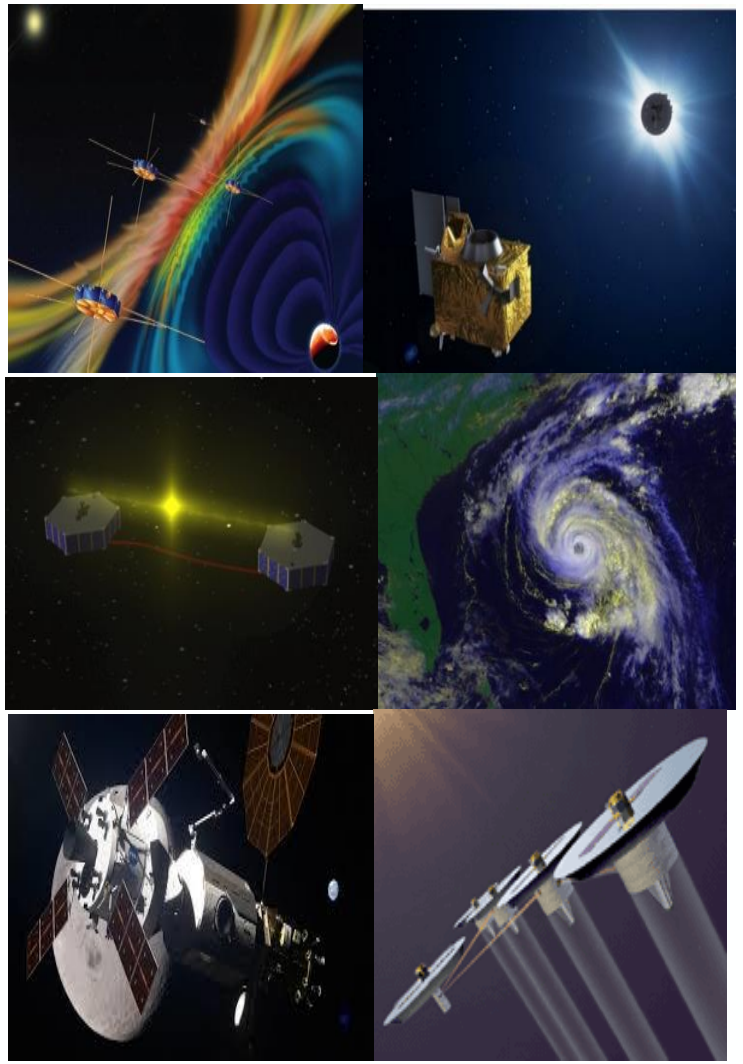
- Explain utility and benefits of a multi-GNSS SSV
- Show how it will transform navigation use in space, and
- Describe how it will impact humanity—in space and on Earth

Co-Sponsors: NASA and National Coordination Office for Space-based Positioning, Navigation and Timing

Available at: https://www.unoosa.org/oosa/en/ourwork/icg/documents/videos.html

Space User Applications

- Position, Velocity and Time (PVT) for real time on-board Navigation
- Precise Orbit Determination
- 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 Constellation

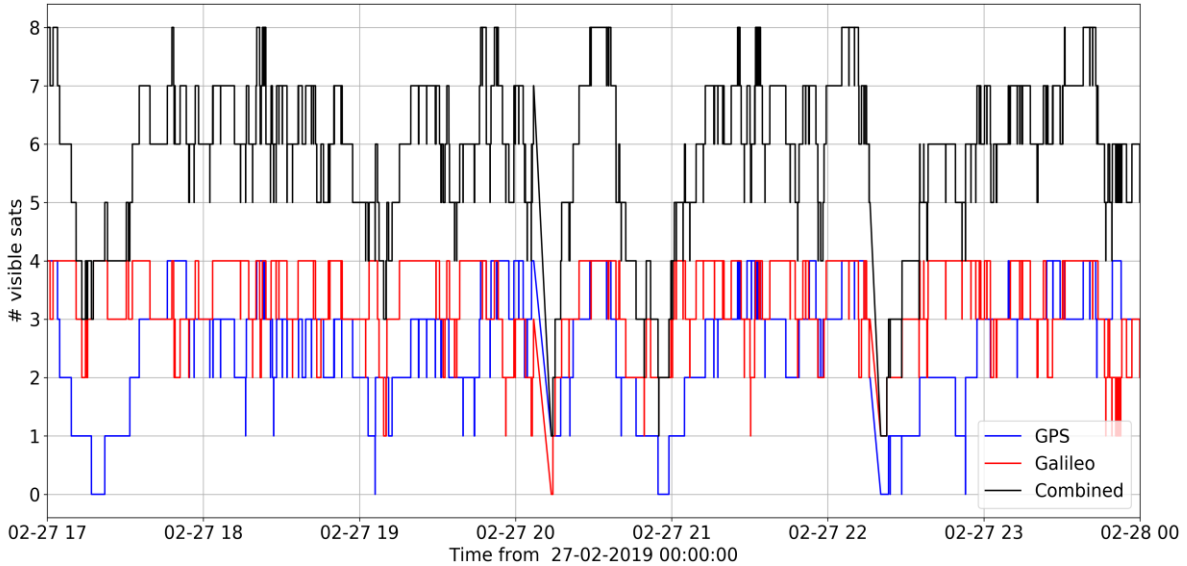


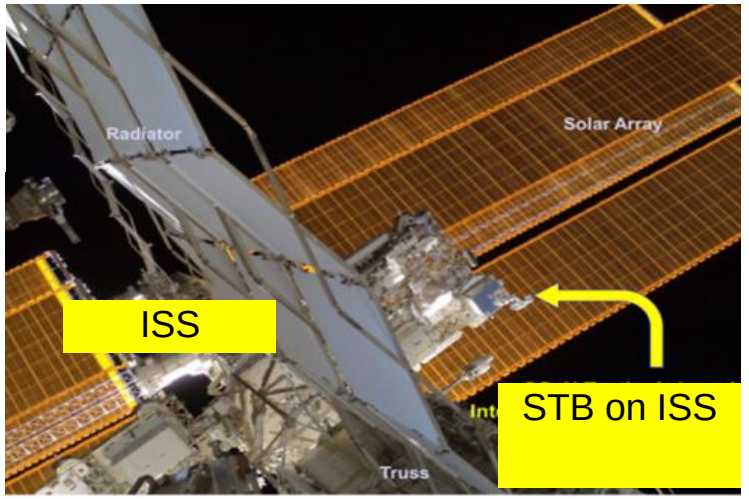
Space User Benefits

- Performance
  - On-board, real time generation of Position, Velocity and Time (PVT)
  - Precise Orbit Determination (POD) – highest possible accuracy based on post processing
  - Interoperable GNSS SSV allows development of new positioning concepts/algorithms tailored to specific mission needs
- 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 User Benefits and Applications – Example 1

Joint ESA-NASA Galileo/GPS Experiment On-board the ISS



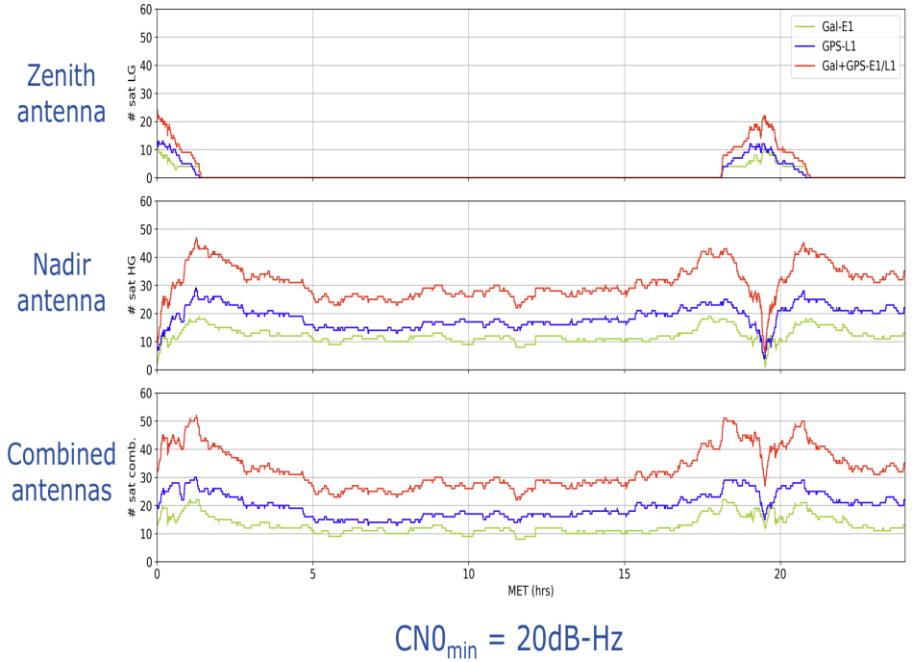


- Joint ESA/NASA Project -Demonstration of added value of GNSS SSV – Visibility of GAL/GPS SV
- First Position Fix in space from GAL/GPS E5a/L5 Receiver in space

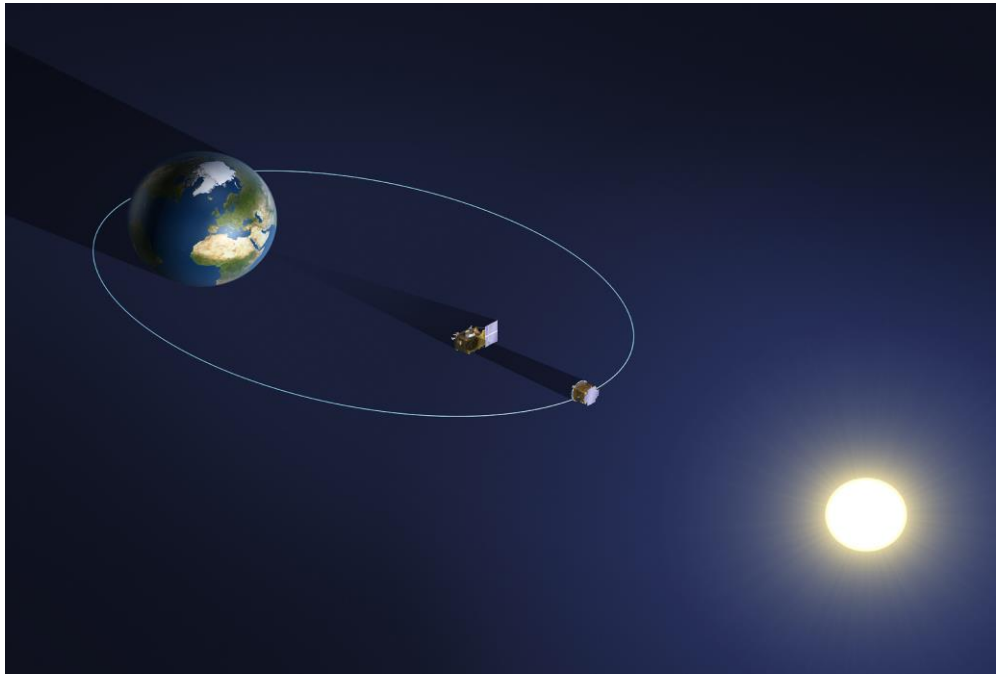
Space User Benefits and Applications – Example 2

GNSS based Precise Orbit Determination for ESA's PROBA-3 Mission

- 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**



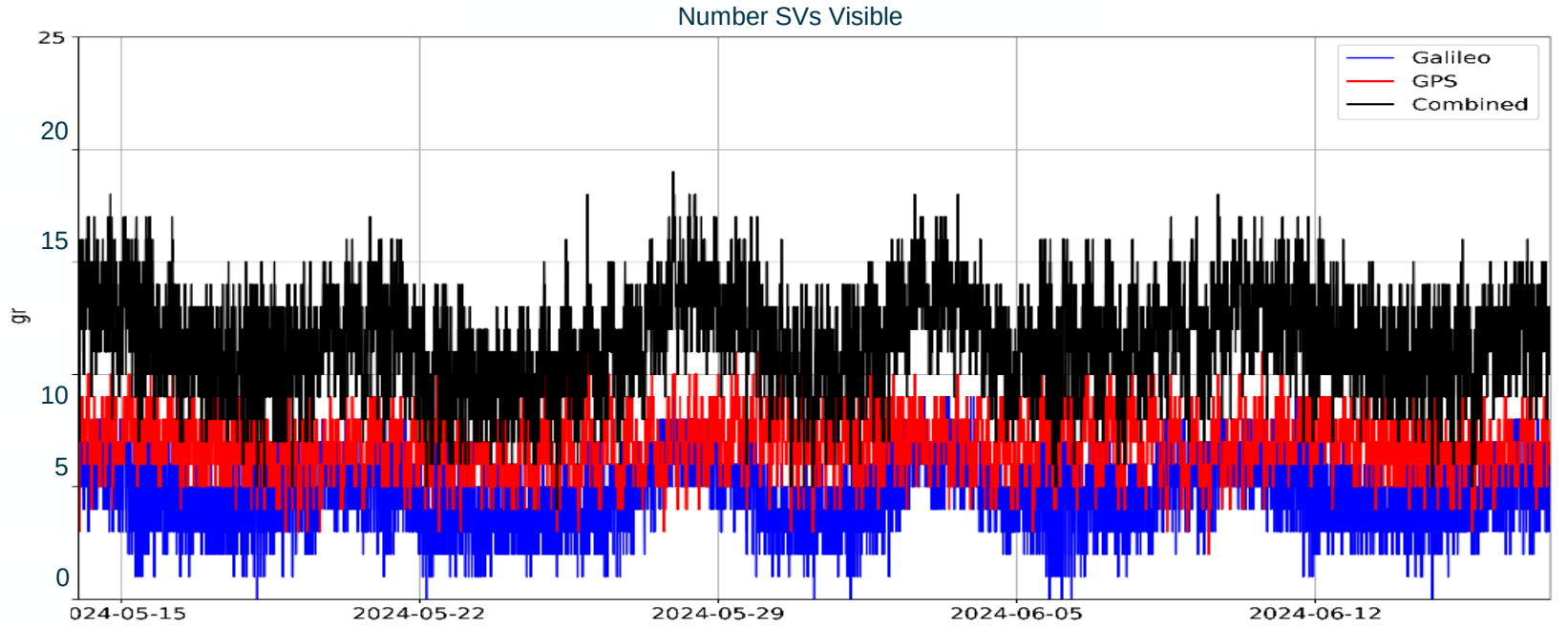
>25 signals
~10 Galileo
~15 GPS



Space User Benefits and Applications – Example 3

Impact of inclusion of GNSS Side Lobes Signals in Simulations for Gateway

(based on models, in orbit measurements and/or data released by the GNSS service providers)



Both

GPS

Galileo

Roadmap for Utilization of GNSS SSV in ESA Missions 1/2

ISS

GAL/GPS Receiver
on-board the ISS
First E5a/L5 only
position fix in space

2018 - 2019

Sentinel – 6 A

Precise Orbit Determination
based on dual freq.
GAL/GPS Receiver

2020

PROBA - 3

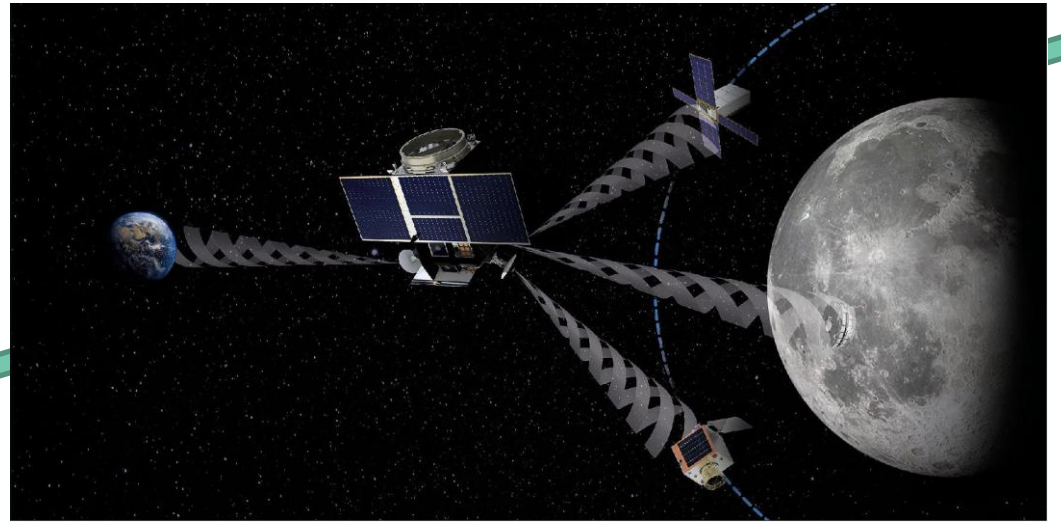
absolute and relative
Precise Orbit Determination
based on dual freq.
GAL/GPS Receiver

2023/2024

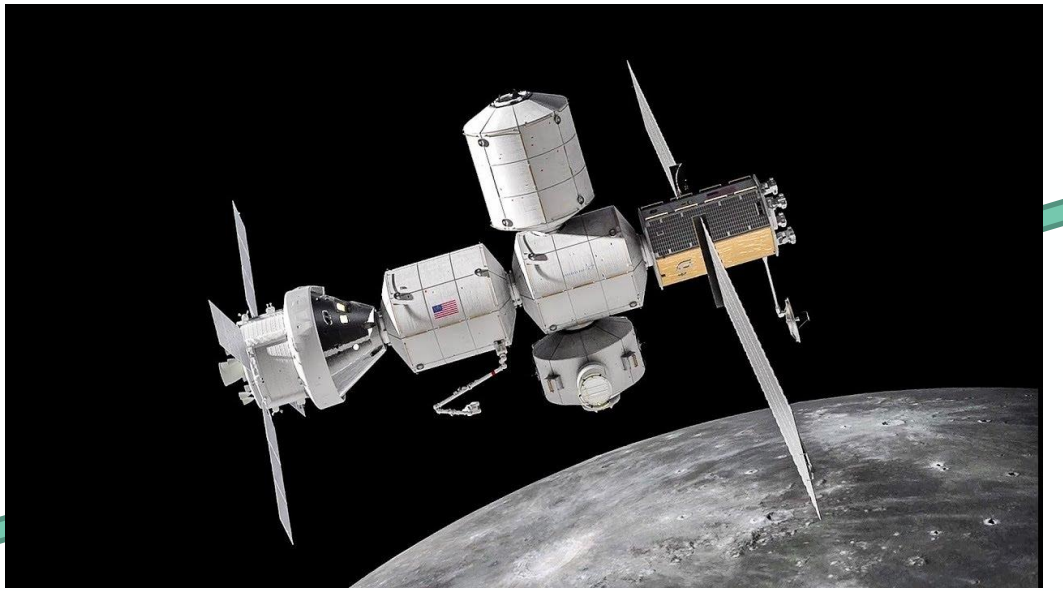
Roadmap for Utilization of GNSS SSV in ESA Missions 2/2

Lunar Pathfinder

- **Galileo/GPS receiver and also a Laser Reflector onboard**
- First time ever that such a combination is lying on a mission to the Moon
- Precise Orbit Determination Experiment based on GNSS and Laser Ranging



2024/2025



GATEWAY

Joint ESA/NASA proposal was made for on-board navigation and Precise Orbit Determination based on GAL/GPS Receiver

Future Vision

GNSS as an integral future infrastructure element for Spacecraft Navigation for missions to Moon and Mars

202x

Conclusion

- 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 number of Space Users in all orbital regimes, which are relaying on GNSS will grow significantly over the next 5 years -> from **several 100's** to **several 10000's**
- GNSS based navigation for space users is possible from Low Earth Orbit up to the Moon
- Coordination of international activities including standardization is considered as a key for the definition, generation and utilization of an interoperable Multi-GNSS Space Service Volume
- ESA supports a wide range of international activities related to the Interoperable GNSS SSV:
    - International Committee on GNSS (ICG), International GNSS Services (IGS), IOAG, ISECG, CCSDS,…