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GNSS Space Service Volume & Space User Data Update
Providers' Forum

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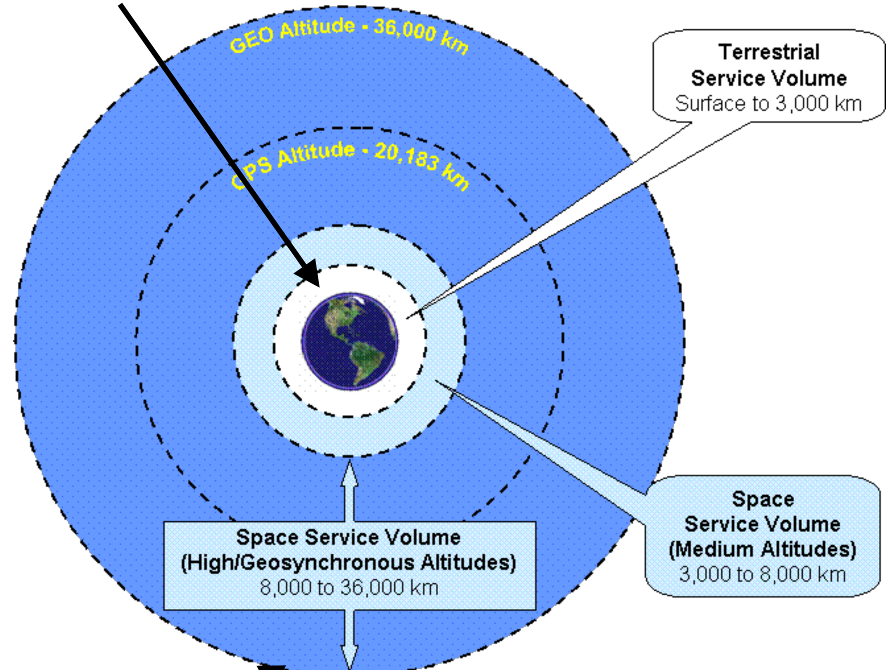
Expanding the GPS Space Service Volume (SSV) into a multi-GNSS SSV

- At least <u>four</u> GNSS satellites in line-of-sight are needed for on-board real-time position solutions
  - GPS currently provides this up to 3,000 km altitude
  - Enables better than 1-meter position accuracy in real-time
- At Geosynchronous altitude, 0-1 GPS satellites will be available using only GPS Main Antenna Lobe Signal.
  - GPS-only positioning still possible with on-board filtering, but only up to approx. 100-meter absolute position accuracy and long waits for navigation recovery from trajectory maneuvers.
  - GPS + Galileo combined would enable an average of approx 3 GNSS satellites in-view at all times, with infrequent 4 GNSS satellite availability (<30% of time).
  - GPS + Galileo + GLONASS would enable frequent 4 GNSS satellites in-view (68% of the time).
  - GPS + Galileo + GLONASS + Beidou would average 6 GNSS satellites in-view, with very frequent 4 GNSS satellite availability (91% of the time). This provides best accuracy and, also, on-board integrity.
- However, this requires:
  - Interoperability among these the GNSS constellations; <u>and</u>
  - Common definitions/specifications for use of GNSS signals within the Space Service Volume (3,000 km to Geosynchronous altitude)
- Further improvements can be realized by also specifying the Provider's side lobe signals

≥ 7 GPS satellites in line-of-sight here (surface to 3000 km)



Only average of 1.6 GPS satellites in line-of-sight at Geosynchronous orbit altitude

... but, <u>if</u> interoperable, then GPS + Galileo + GLONASS + Beidou provide > 4 GNSS sats in line-of-sight at Geosynchronous orbit altitude 91% of the time.

Space User/Space Service Volume Summary from ICG-8 (Dubai) Working Group-B

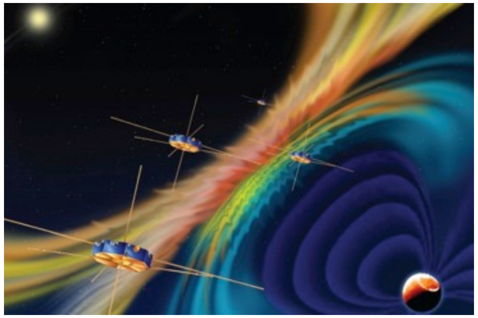
- **Discussions**
  - Significant progress has been made in establishing an interoperable Global Navigation Satellite System (GNSS) Space Service Volume (SSV) through pre-work, presentations, and additional robust contributions from the administrations of the Russian Federation and China.
  - Also recognize Europe, Japan and India for their long-term interest in a GNSS SSV and encourage SSV template completion and antenna characterization
  - The Working Group further discussed the benefits of an interoperable GNSS SSV
  - All WG-B participants believe that a fully interoperable GNSS SSV will result in significant benefits for future space users as it will allow for performance no single system can provide on its own
- **Recommendations from ICG-8**
  - **SSV Template Completion**: recommend all providers complete and formally submit SSV template. (Russia, China, Japan completed the templates, but not formally submitted)
  - **Definition Maturations**: Develop standard definitions of minimum number of satellites, constellation geometry, etc (this will help to perform unified GNSS SSV analysis)
  - **Spaceborne GNSS Receivers**: Build multi-frequency, and multi-constellation GNSS receivers to exploit the SSV
  - **Antenna / Electronics Characterization**: Measuring satellite transmit antenna patterns (pseudorange and phase vs. angle), and designing spacecraft electronics with strict requirements on phase and group delay coherence

The Promise of using GNSS to Navigate in Cis-Lunar Space

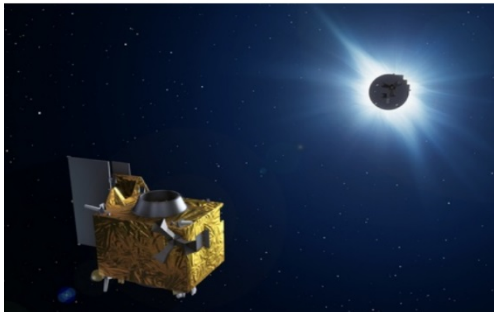
SSV specifications are crucial for all space users, providing real-time navigation solutions in Low, Medium & High Earth Orbit & Beyond!

- **Supports increased satellite autonomy for missions, lowering mission operations costs**
- **Significantly improves vehicle navigation performance in these orbits**
- **Supports quick mission recovery after spacecraft trajectory maneuvers**
- **Enables new/enhanced capabilities and better performance for HEO and GEO/GSO future missions, such as:**

Improved Weather Prediction using Advanced Weather Satellites

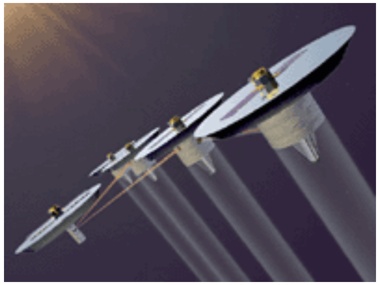


Space Weather Observations

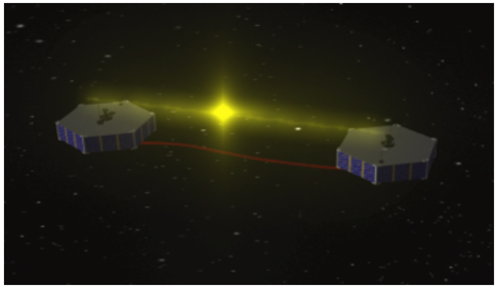


Solar Occultation Observations

En-route Lunar Navigation Support

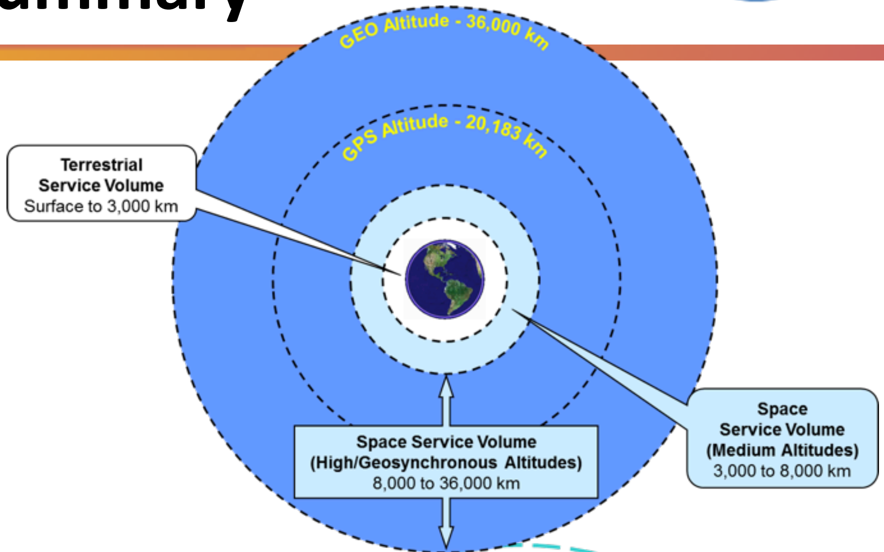


Formation Flying & Constellation Missions

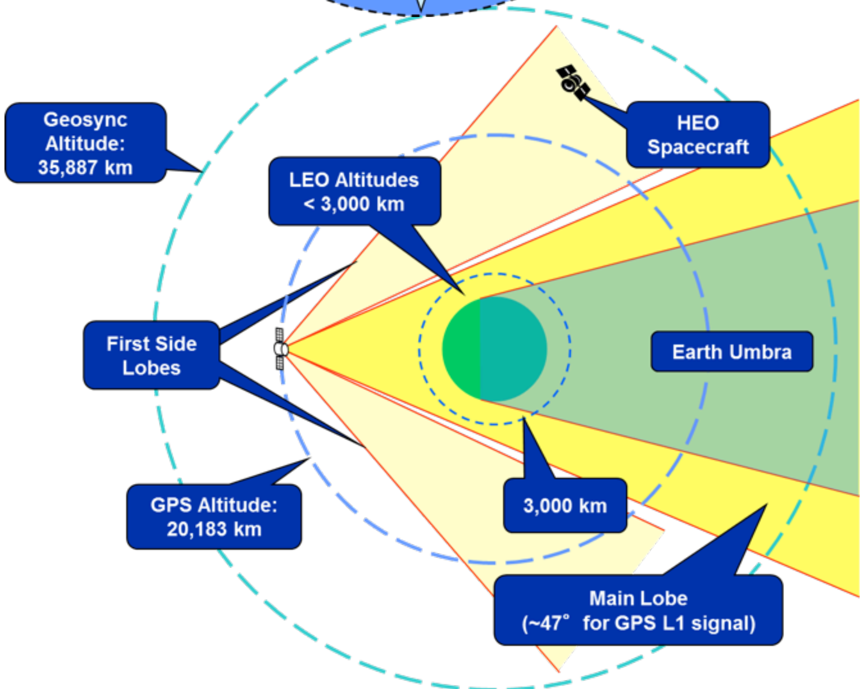


Closer Spacing of Satellites in Geostationary Arc

GPS SSV Status & Lessons Learned: Executive Summary



- Current SSV specifications, developed with limited on-orbit knowledge, employ only the GPS main lobe signal
- On-orbit data & lessons learned since spec development show significant PNT performance improvements when main lobe and side lobes are employed together
  - Side lobe signals make significant contributions to PNT performance, enabled by modern weak signal tracking GPS receivers
- Numerous operational missions in High & Geosynchronous Earth Orbit (HEO/GEO) employ GPS side lobes to enhance vehicle PNT performance; many other missions in development
- Space user community is vulnerable to GPS constellation design changes if side lobe signal performance parameters not formally recognized
- Failure to protect GPS side lobe signals can result in significant loss of capability for space users in HEO/GEO orbits and should be preserved for on-board PNT in the 2025-2040 timeframe



U.S. Initiatives and Contributions to the International Community to Ensure an Interoperable, Sustained, Quantified GNSS Capability for Space Users

- Performing additional flight experiments above the constellation (e.g. ACE)

- Developing new weak signal GPS/GNSS receivers for spacecraft in cis-Lunar space (e.g. NASA Goddard Navigator and its commercial variants)

- Working with the GPS Directorate and DoD community to formally document GPS requirements and antenna patterns for space users

- Encouraging international coordination with other GNSS constellations (e,g, Galileo, GLONASS, BeiDou) to specify interoperable SSV capabilities

- Developing missions and systems to utilize GNSS signals in the SSV (e.g. MMS, GOES)

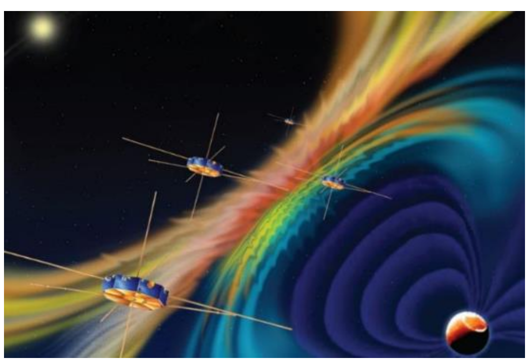
Using GPS above the GPS Constellation: NASA GSFC MMS Mission

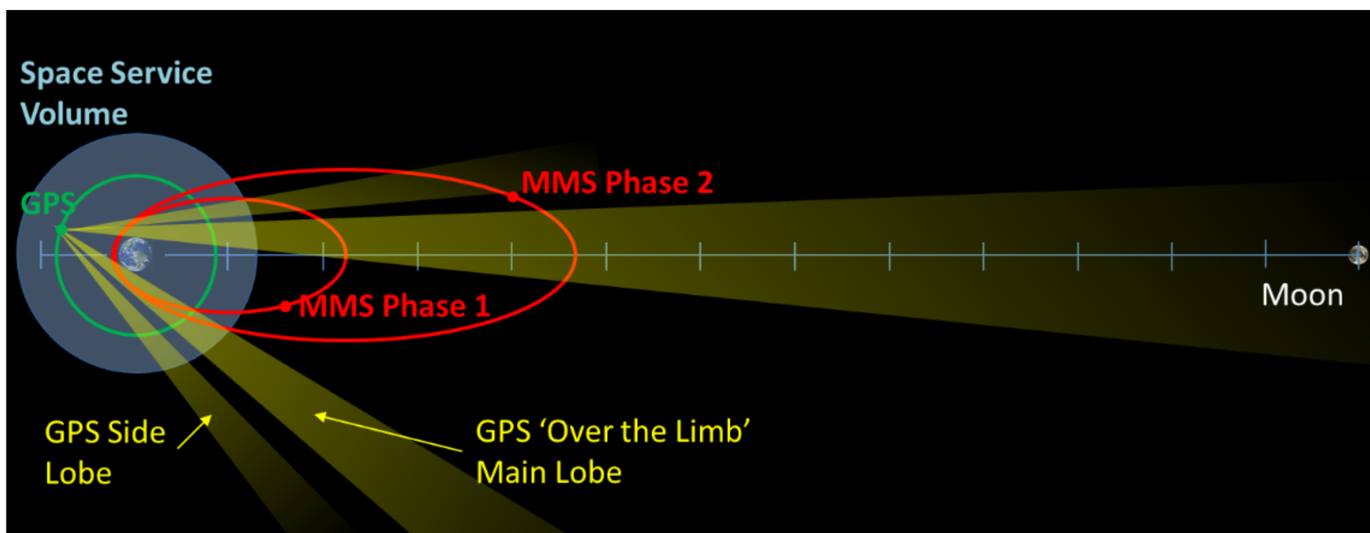
Magnetospheric Multi-Scale (MMS)

- Launched March 12, 2015
- Four spacecraft form a tetrahedron near apogee for performing magnetospheric science measurements (space weather)
- Four spacecraft in highly eccentric orbits
  - Phase 1: 1.2 x 12 Earth Radii (Re) Orbit (7,600 km x 76,000 km)
  - Phase 2: Extends apogee to 25 Re (~150,000 km)

MMS Navigator System

- GPS enables onboard (autonomous) navigation and near autonomous station-keeping
- MMS Navigator system exceeds all expectations
- At the highest point of the MMS orbit Navigator set a record for the highest-ever reception of signals and onboard navigation solutions by an operational GPS receiver in space
- At the lowest point of the MMS orbit Navigator set a record as the fastest operational GPS receiver in space, at velocities over 35,000 km/h



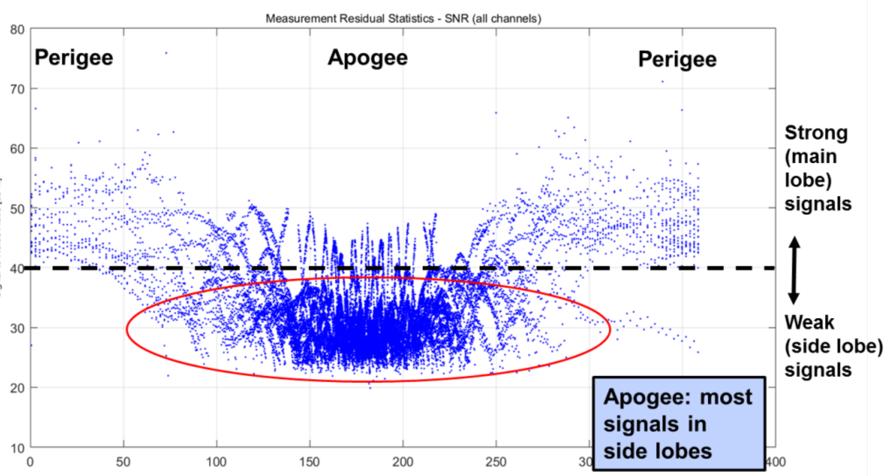


Measured Performance of MMS with Side Lobe Signal Availability

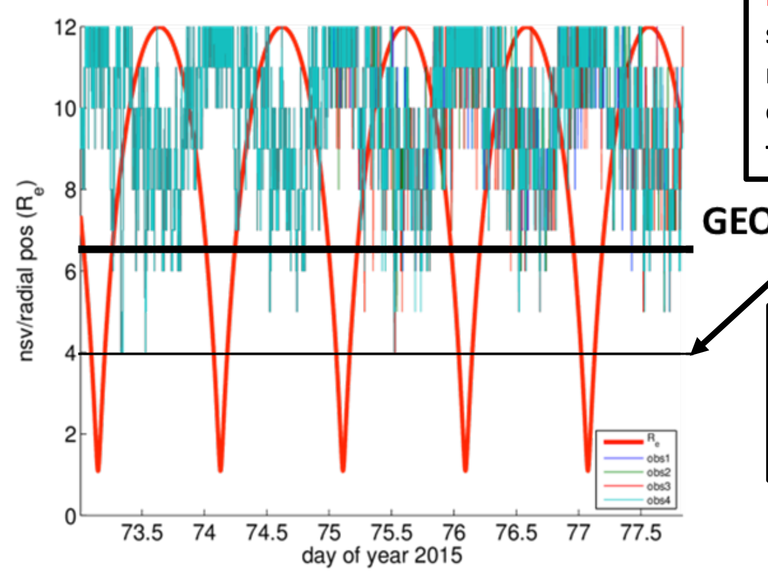
Signal Availability Contributed by Side Lobes (Assumes 24 Satellite Constellation)		
L1 Signal Availability	**Main Lobe Only**	**Main and Side Lobes**
4 or More SVs Visible	**Never**	**99%**
1 or More SVs Visible	59%	Always
No SVs Visible	41%	Never

Current Spec: L1 Signal Availability→4 or more SVs visible: >1%

Recent Flight Data From Magnetosphere Multi-Scale (MMS) Mission



Signal strength (C/N0) vs. position in orbit



Current spec: Four or more PRs shall be available more than or equal to 1% of the time

MMS is seeing **100%**

NASA GNSS Spaceborne Receiver Request for Information (RFI)

- Encompasses GNSS spaceborne receiver systems in industry, government, and academic institutions (US & international)
- Will help NASA understand receiver technology status currently available & will be available in 2-3 years
- Data specified as public is planned to be published in a public database
- Organizations with multiple receivers can provide multiple RFI inputs—1 per receiver
- To review the RFI & submit inputs
  - https://www.fbo.gov/spg/NASA/LaRC/OPDC20220/RFI-GNSS2015/listing.html
  - Easier Approach through Google Keyword Search: NASA RFI GNSS 2015
  - RFI planned to be open until December 11
- All are encouraged to submit; Please spread the word!