GPS Space Service Volume

Ensuring Consistent Utility Across GPS Design Builds for Space Users

NASA

May 27, 2015 Revision

Agenda

- Background
- SSV History
- SSV Revisit: Space Service Volume Knowledge Gained & Lessons Learned
- Proposed SSV Specification Updates to Ensure Minimal Degradation in signal strength/availability
- Summary and Closing Remarks

Background

Space Service Volume Observations

- **GPS availability and signal strength originally specified for users on or near surface of Earth with transmitted power levels specified at edge-of-Earth, 14.3 degrees**
- **Prior to the SSV specification, on-orbit performance of GPS varied from block build to block build (IIA, IIRM, IIF) due to antenna gain and beamwidth variances**
  - Unstable on-orbit performance results in significant risk to space users
- **Side-lobe signals, although not specified, were expected to significantly boost GPS signal availability for users above the constellation**
- **During GPS III Phase A, NASA noted significant discrepancies in power levels specified in GPS III specification documents, and measured on-orbit performance**
- **To stabilize the signal for high altitude space users, NASA/DoD team in 2003-2005 led the creation of new Space Service Volume (SSV) definition and specifications**
  - Guarantee backward compatibility
  - Identify areas for improved performance through objective requirements

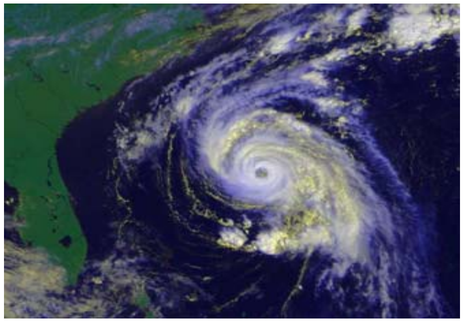
Use of GPS in the Space Service Volume (SSV)

- **GPS signals in High Earth Orbit and Geosynchronous Altitude utilized by multiple DOD, NASA & NOAA programs**
  - SBIRS, ANGELS, Classified Programs
  - GOES-R, MMS
- **Autonomous navigation enables new mission needs and significantly improves PNT performance over past methods**
  - GPS Ephemeris and timing data can be provided near real time with collected satellite products
  - Achievable accuracy is greatly improved over typical methods using ground based ephemeris processing via ranging and angle measurements
- **NASA activities have included:**
  - Conducting flight experiments to characterize GPS performance in SSV
  - Development of new weak signal GPS receivers for spacecraft in Geostationary or highly elliptical orbits
  - Working with the GPS Directorate and DoD community to formally document GPS requirements for space users
  - International coordination to encourage other GNSS constellations (e,g, Galileo, GLONASS, BeiDou) to specify interoperable SSV capabilities
  - Developing missions and systems to utilize GPS signals in the SSV

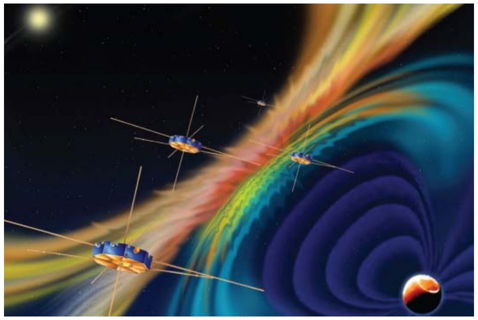
Why is an Interoperable Space Service Volume Important?

SSV specifications are crucial for DoD, NASA and Commercial users, providing real-time GNSS navigation solutions in High Earth Orbit

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



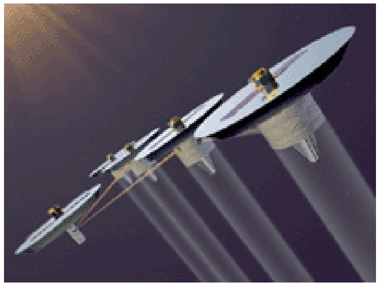
Improved Weather Prediction using Advanced Weather Satellites



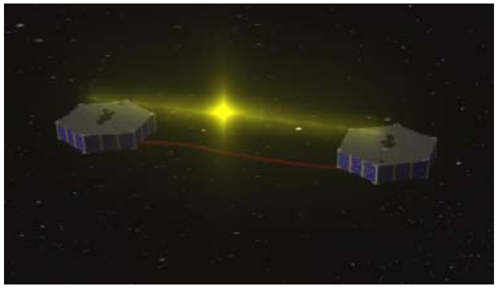
Space Weather Observations

Astrophysics Observations

En-route Lunar Navigation Support



Formation Flying & Constellation Missions



Closer Spacing of Satellites in Geostationary Arc

Current Civil Space Missions using GPS above the GPS Constellation

GOES-R Weather Satellite Series

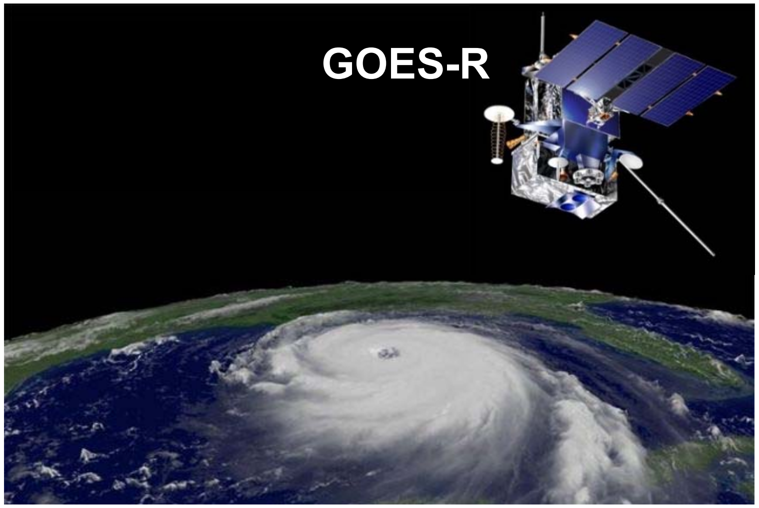
•First safety of life use of GPS above the constellation

•Improves navigation performance for GOES-R

•Station-keeping operations on current GOES-N-Q constellation require relaxation of Image Navigation Registration for several hours

•GPS supports GOES-R breaking large station-keeping maneuvers into smaller, more frequent ones

- Quicker Recovery
- Minimal impact on Earth weather science



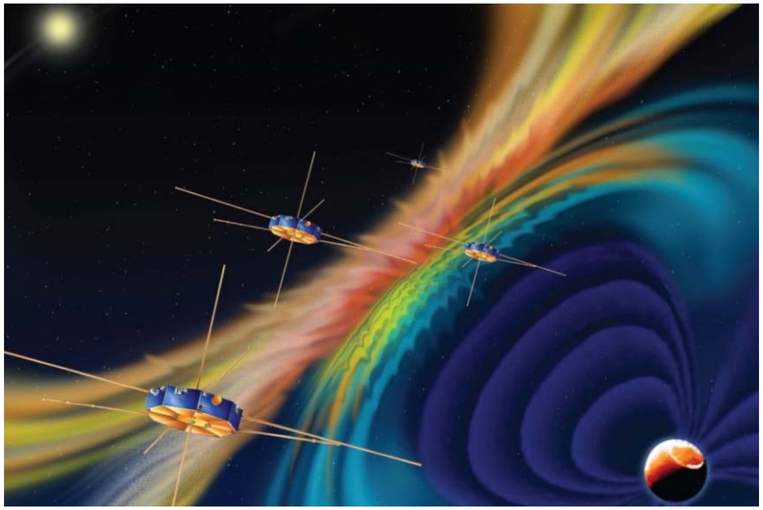
Magnetospheric Multi-Scale (MMS) Mission

•Launched March 12, 2015

•Four spacecraft form a tetrahedron near apogee for performing magnetospheric science measurements (space weather)

•Four spacecraft in highly eccentric orbits

- Starts in 1.2 x 12 Re-orbit (7,600 km x 76,000 km)
- Ultimately extends to 25 Re-orbit ~150,000 km)



SSV History

GPS Space Service Volume Specification History

- Mid-1990s—efforts started to develop a formal Space Service Volume
  - –Discussion/debate about requiring "backside" antennas for space users limited discussion
  - –Use of main lobe/side-lobe signals entertained as a no cost alternative
- 1997-Present—Several space flight experiments, particularly the AMSAT-OSCAR-40 experiment demonstrated critical need to enhance space user requirements and SSV
- February 2000—GPS Operational Requirements Document (ORD), released with first space user requirements and description of SSV
- 2000-2010—NASA/DoD team coordinated set of updated Space User requirements to meet existing and future PNT needs
  - –Team worked with SMC/GPE, Aerospace support staff and AFSPACE to assess impacts of proposed requirements to GPS-III and to incorporate appropriate language into GPS-III Capabilities Description Document (CDD)
  - – **Threshold requirements** correspond to performance from current constellation **(do no harm to space users)**
  - – Future space user needs included as Objective requirements
  - – Continual Joint Program Office "zero impact" push back on CDD levels to GPS-III baseline (Objective requirements)
  - – Government System Spec (SS-SYS-800) includes CDD threshold & objective performance

Evolving Space User Requirements

GPS IIF Operational Requirements Document (ORD) (ca. 2000)

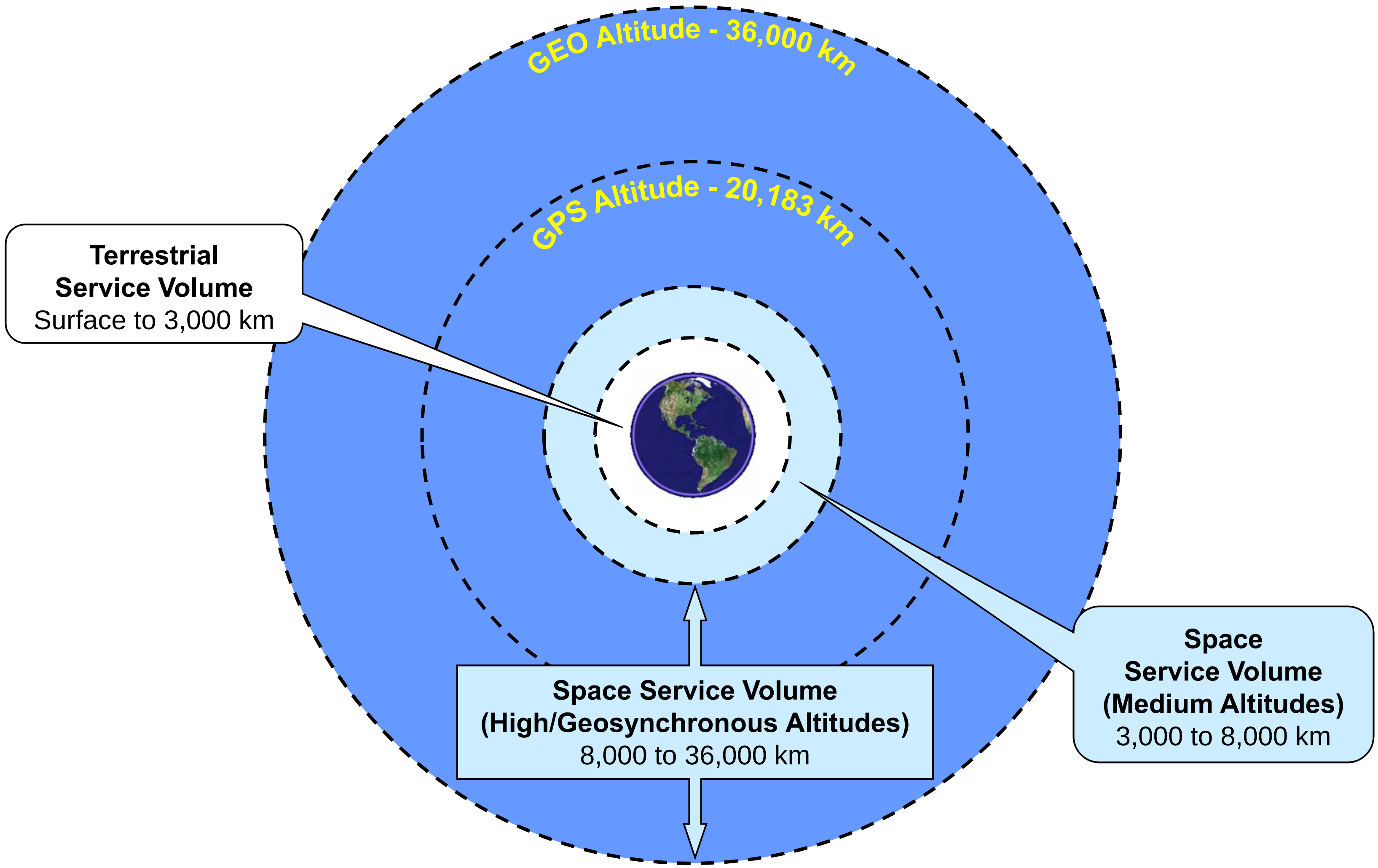
- **Established two operational volumes**
  - Terrestrial Service Volume (TSV)
    - Earth surface to 3,000 km altitude
  - Space Service Volume (SSV)
    - 3,000 km to 36,000 km (~GEO) altitude
    - Signal availability and power defined only for geostationary equatorial users
    - Minimum performance specified corresponding to a 23.5º GPS transmitter half angle
- **Shortcomings of ORD space user requirements:**
  - Did not cover mid-altitude users (above LEO but below GPS)
  - Did not cover users outside of the equatorial plane
  - Only specified reqts on L1 signals (L2 and L5 have wider beam-width and therefore, better coverage)

Evolving Space User Requirements continued

GPS III Capability Development Document (CDD)

- ***Threshold*** **requirements specifically document current system performance**
  - Divided Space Service Volume into two regions
    - Medium Earth Orbit (MEO) SSV
      - 3,000 km to 8,000 km altitude
    - High Earth Orbit / Geostationary Earth Orbit (HEO/GEO) SSV
      - 8,000 km to 36,000 km altitude
  - Minimum performance specified at 23.5° (L1) and 26° (L2/L5) GPS transmitter antenna half-angles
  - Specified signal strength (dBW) for each signal and expected signal availability
  - Based on on-orbit experiment data coupled with analysis statistics
- ***Objective*** **requirements also defined**
  - Objective signal availability consistent with current performance if side-lobe signals are considered.
- **Shortcomings of CDD SSV requirements**
  - Developed using very limited on-orbit experiment data and no understanding of GPS satellite antenna patterns

GPS III Terrestrial and Space Service Volumes



SSV Pseudorange Accuracy

- **Also known as User Range Error (URE)**
- **Error bound on GPS range measurement**
- **Function of**
  - Accuracy of GPS orbit and clock solutions from Control Segment
  - Age of Data
  - Uncertainty in GPS physical and modeling parameters
    - Antenna group delay and phase errors vary as a function of off-nadir angle
- **Current performance ≈ 1 meter**
- **GPS III requirement: ≤ 0.8 meter (rms)**
- **GPS III objective: ≤ 0.2 meter (rms)**

GPS III Minimum Received Signal Power (dBW) Requirement

Signal	Terrestrial Minimum Power (dBW)	SSV Minimum Power (dBW)	Reference Half-beamwidth
L1 P(Y)	-161.5	-187.0	23.5
L1 C/A	-158.5	-184.0	23.5
L1 M	-158.0	-183.5	23.5
L1C	-157.0	-182.5	23.5
L1 composite	-151.2		
L2 P(Y)	-161.5	-186.0	26
L2 C/A or L2C	-158.5	-183.0	26
L2 M	-158.0	-182.5	26
L2 composite	-151.5		
L5 I5	-157.0	-182.0	26
L5 Q5	-157.0	-182.0	26
L5 composite	-154.0		

- **SSV minimum power levels were specified based on the worst-case (minimum) gain across the Block IIA, IIR, IIR-M, and IIF satellites**
- **Some signals have several dB margin with respect to these requirements at reference half-beamwidth point**

GPS III Minimum Availability Requirement

- **Assuming a nominal, optimized GPS constellation and no GPS spacecraft failures, signal availability at 95% of the areas at a specific altitude within the specified SSV are planned as:**

	MEO SSV		HEO/GEO SSV	
	at least 1 signal	4 or more signals	at least 1 signal	4 or more signals
L1	100%	≥ 97%	≥ 80% 1	≥ 1%
L2, L5	100%	100%	≥ 92% 2	≥ 6.5%

1. With less than 108 minutes of continuous outage time.
2. With less than 84 minutes of continuous outage time.

- **Objective Requirements:**
  - MEO SSV: 4 GPS satellites always in view
  - HEO/GEO SSV: at least 1 GPS satellite always in view

SSV Revisit: Knowledge Gained & Lessons Learned

Knowledge Gained and Lessons Learned from GPS IIIA SSV Specification

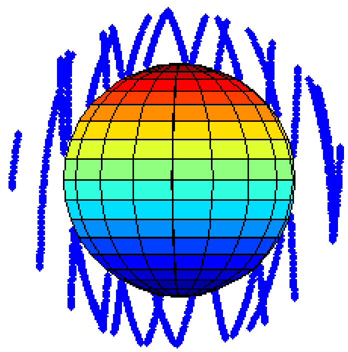
- **At last SSV specification update (2003-2005), GPS community had limited understanding of SSV signal strength/capabilities**
- **Data limited to brief flight experiments above the constellation**
  - Most comprehensive data from AMSAT-Oscar-40 flight experiment which spanned several weeks
- **Over the past decade, have gathered significant information from:**
  - Additional flight experiments (e.g. GIOVE)
  - On-orbit missions in HEO (e.g. MMS and ACE)
  - Newly developed weak signal spaceborne receivers (e.g. Navigator)
  - Released GPS Antenna Pattern measurement data

Knowledge Gleaned Over Past Decade Illustrates Criticality of Protecting Side Lobe Information for SSV Space Users to Ensure Robust Signals in the SSV and to "Do No Harm" to Current and Future Space Users

HEO & GEO Space Mission Navigation Significantly Enhanced when GPS Side Lobes Included

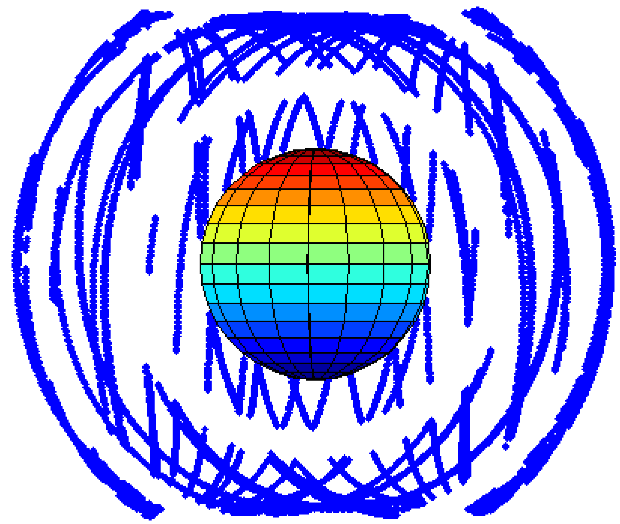
Signal Availability Results from AO-40 Flight Experiment

Main Lobe Only



4 or more SVs visible: never
1 or more SVs visible: 59%
no SVs visible: 41%

Main and Side Lobes



4 or more SVs visible: 99%
1 or more SVs visible: always
no SVs visible: : never

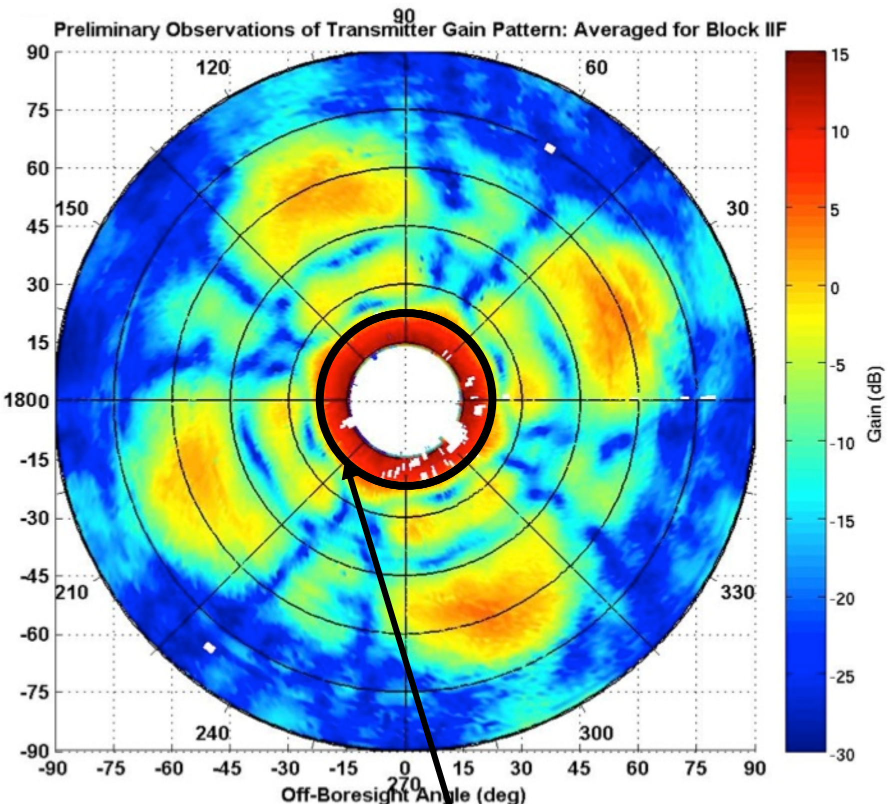
- Side lobe signals afford HEO/GEO missions:
  - Significantly improved signal availability
  - Improved Dilution of Precision (DOP)
- However, side lobe signals are not specified in the current SSV specifications

Current HEO/GEO mission success relying on unspecified GPS signals in the SSV

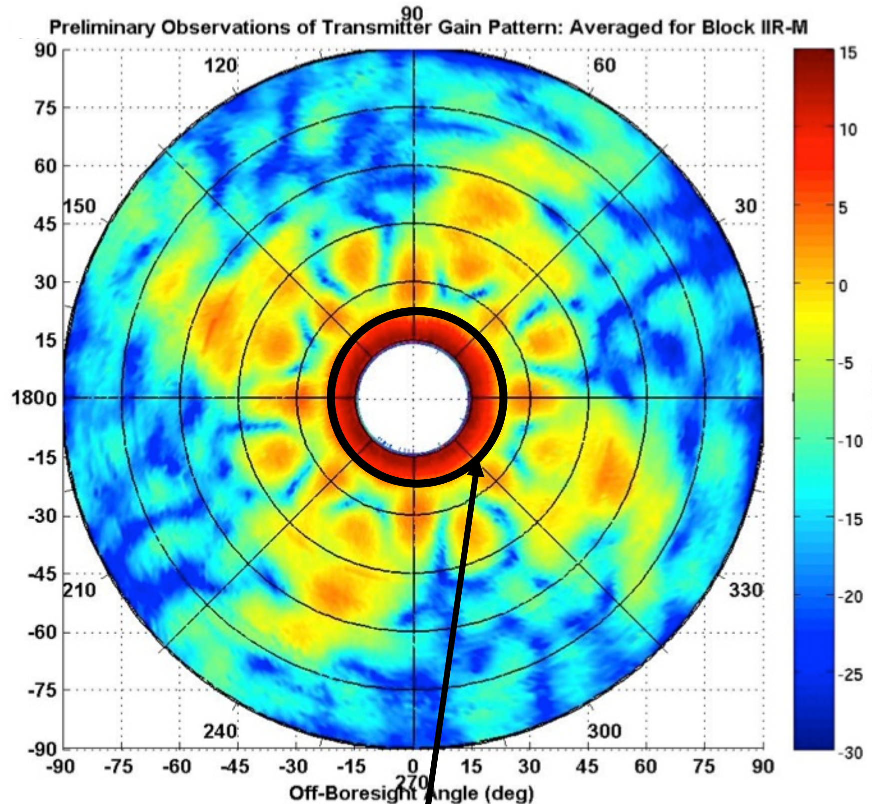
GPS ACE Flight Data for Block IIR-M and IIF

- GPS ACE project deployed advanced GPS receivers at the ground station of a GEO satellite
- Comprehensive collection of side lobe data as seen at GEO in order to characterize the transmit antenna patterns

In-Flight Measurement Average from **IIF** SVs



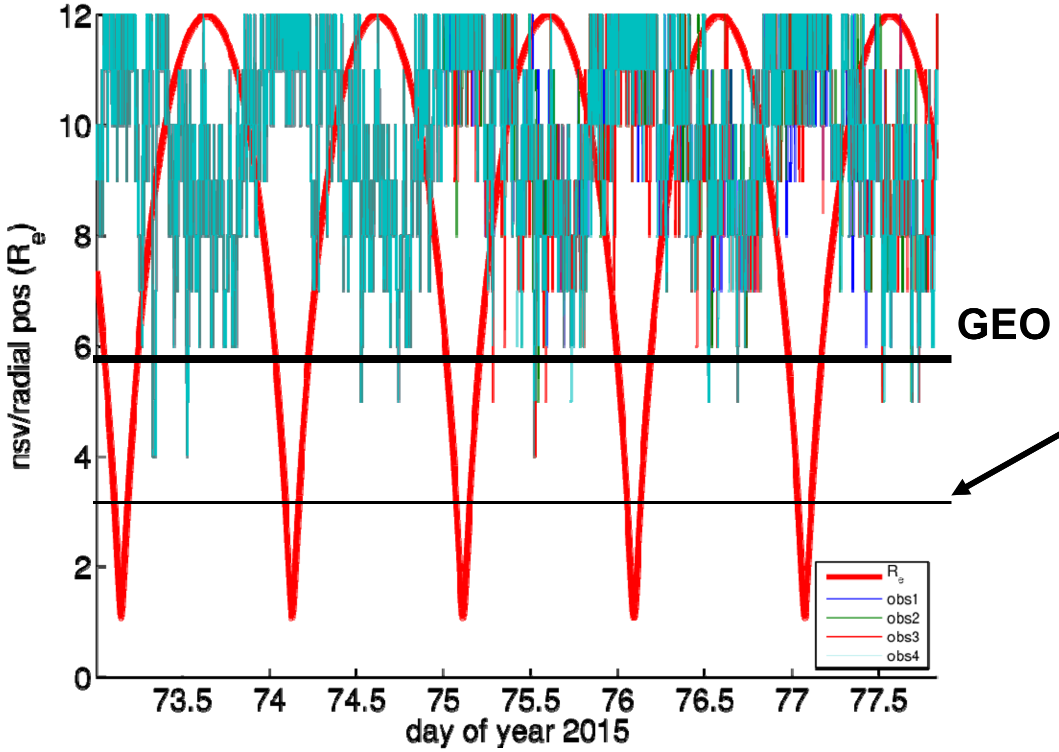
In-Flight Measurement Average from IIR-M* SVs



Current spec only covers out to 23.5°

MMS Data: Sneak Peak

- **Goal is to demonstrate newly available signals using MMS flight data, and show what benefits they have for spacecraft in the SSV.**
- **Leading to that, some “raw” data is helpful to understand what we can show.**
- **Below: on-orbit number of SVs tracked against orbit radius**



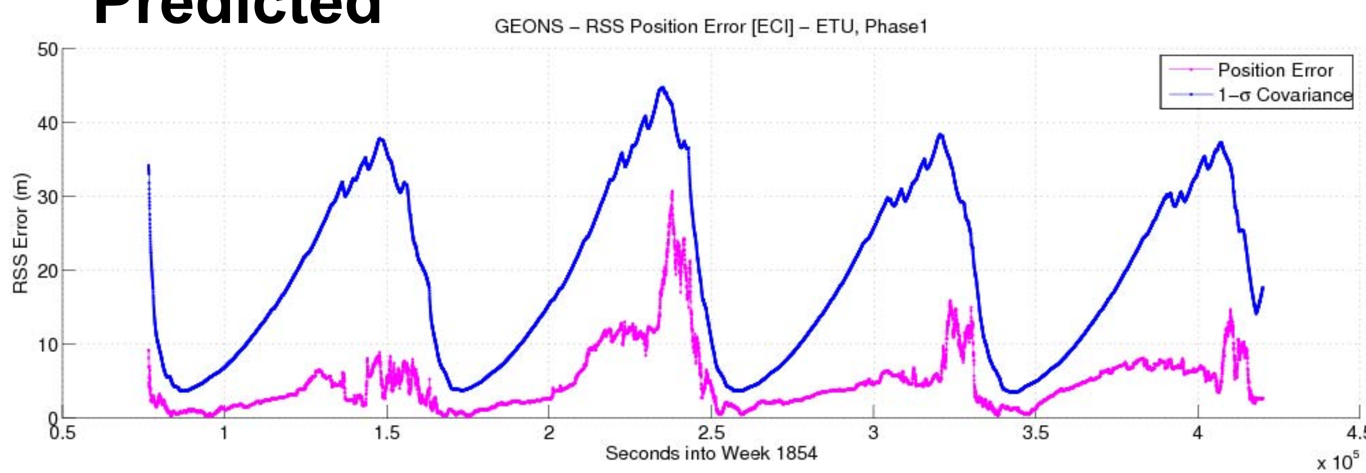
Current spec:
Four or more PRs shall be available more than or equal to 1% of the time.

MMS is seeing **100%.**

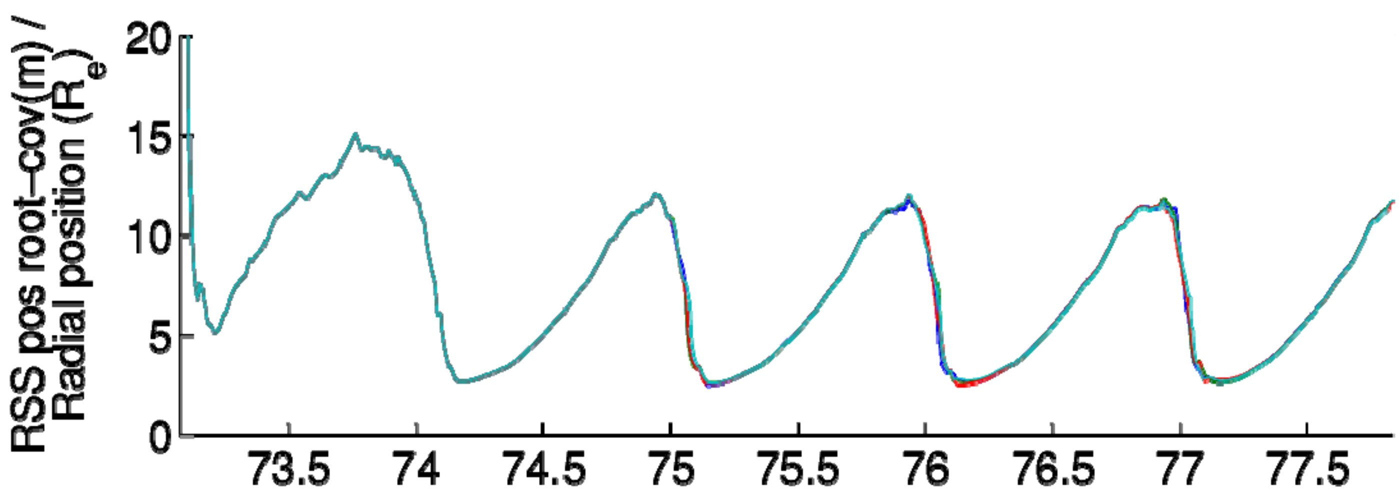
MMS Data: Sneak Peak

Position error:

Predicted



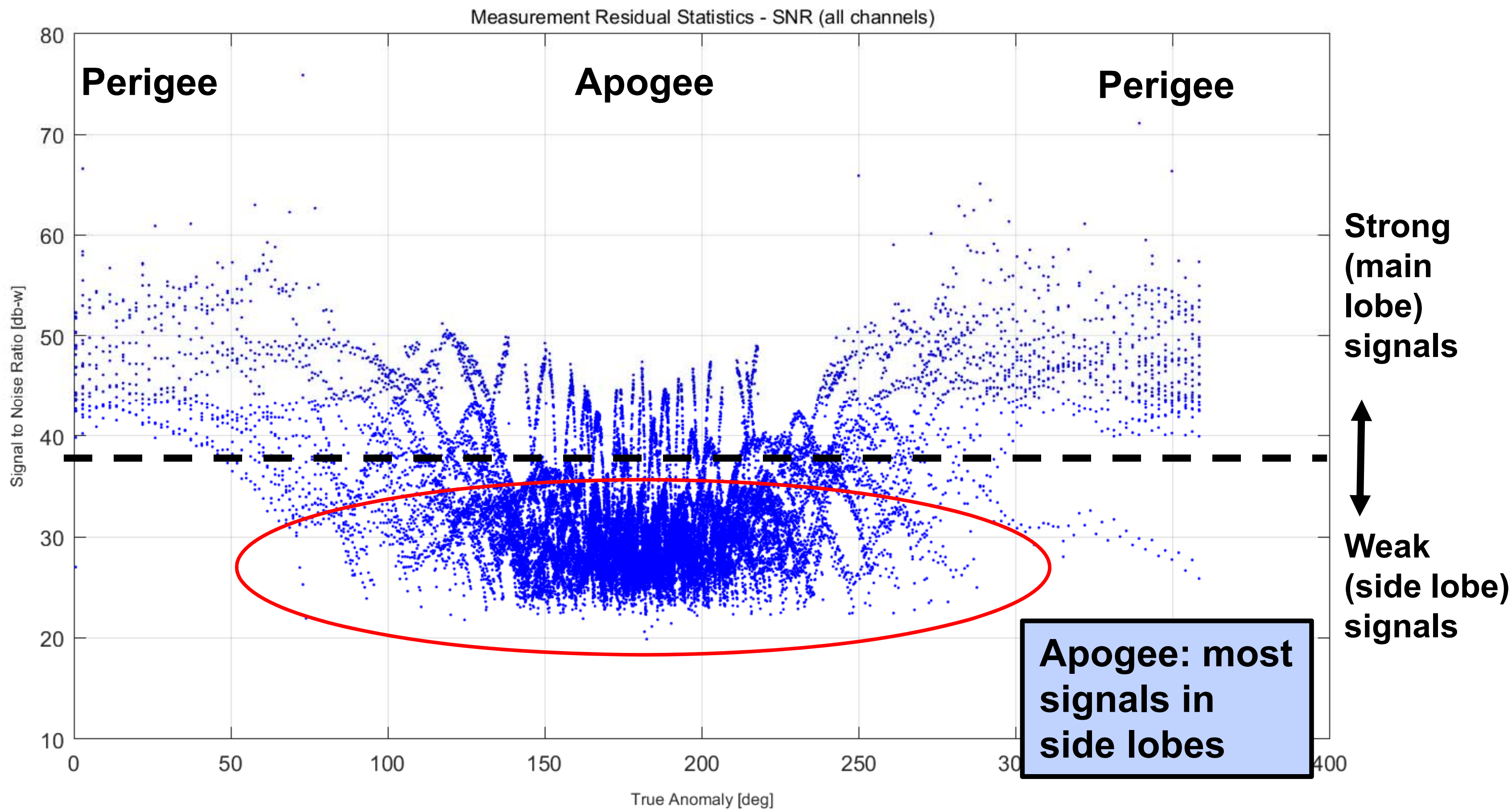
Achieved



Achieved covariance is >50% improved over prediction.

Primary differentiator: availability of extra side-lobe signals in the SSV.

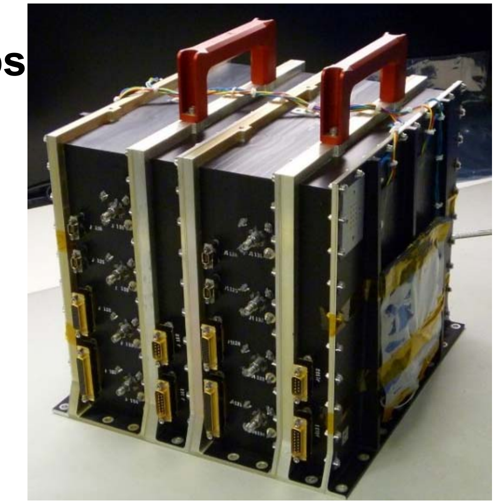
MMS Data: Sneak Peak



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

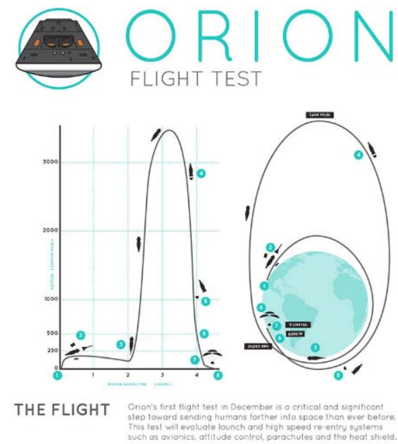
Navigator GPS Receiver for HEO/GEO Ops

- **Single frequency C/A code Rx ~10m level onboard accuracy for LEO/GEO/HEO**
- **Performance for high altitude applications enabled by**
  - Weak signal acquisition and tracking (25 dB-Hz)
  - Integrated on-board navigation filter (GEONS)
  - Radiation hardness
- **Navigator innovations incorporated in commercial HEO/GEO ops receivers developed by Moog Broad Reach, Honeywell and General Dynamics**



<u>Missions</u>

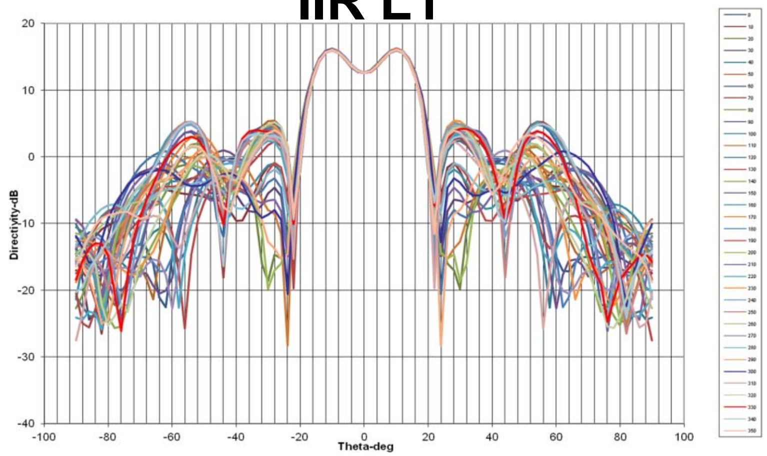
- **Early demonstration on Hubble Space Telescope Servicing Mission 4 STS-125 RNS (May 2009)**
  - Captured unique reflected GPS dataset
- **Global Precipitation Measurement (GPM) Mission (2014) Launch)→First operational use of Navigator**
- **Orion EFT-1 (2014)**
  - Navigator technology integrated into the Honeywell GPS receiver
  - ***Fast acquisition of GPS signals*** benefits navigation recovery after re-entry radio blackout without relying on IMU, stored states.
- **Magnetospheric Multi-Scale (MMS) Mission (2015)**
  - Four spacecraft form a tetrahedron near apogee for performing magnetospheric science measurements (space weather)
  - Four spacecraft in highly eccentric orbits
    - Starts in 1.2 x 12 Re-orbit (7,600 km x 76,000 km)
    - Ultimately extends to 25 Re-orbit ~150,000 km)



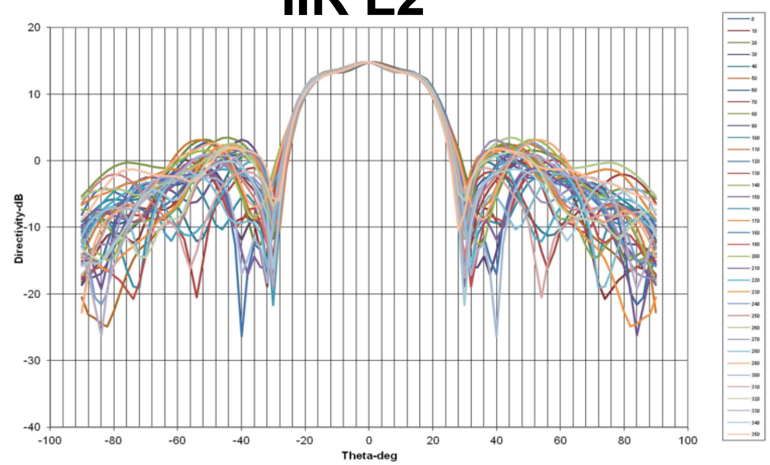
U.S. Publication of GPS Block IIR & IIR(M) Antenna Patterns

- Substantial pre-flight ground measurement of IIR & IIR(M) antenna patterns performed by Lockheed Martin for each GPS spacecraft
- Data now publically released. To access: www.gps.gov & click on support, technical documentation, GPS antenna patterns
- Hemispherical gain patterns for each GPS satellite can be developed by combining data along (+/- 90 degrees) and around (0-360 degrees) antenna boresight
- Enables high fidelity analyses and simulations for HEO/GEO missions
- Information bolsters confidence in developing new mission types, enhances navigation performance predictions and **enables development of enhanced GPS SSV specification, including sidelobe information**

IIR L1



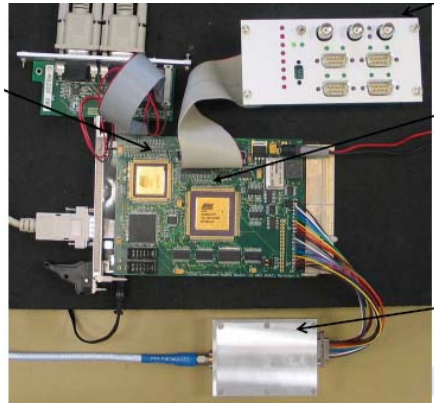
IIR L2



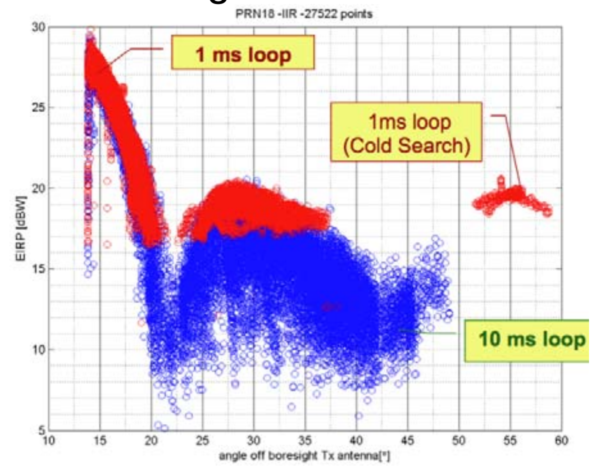
Special thanks to Willard Marquis/Lockheed Martin & Air Force GPS Program for publicly releasing this information!!

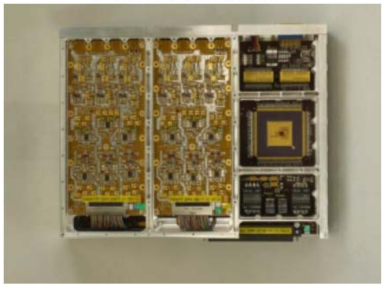
International Engagement in HEO/GEO GNSS Operations

- **Airbus/Astrium**
  - Development of LION Navigator GNSS receiver for operations in HEO/GEO
  - Performed 2011 study on Galileo SSV
  - Paper presented at AAS GN&C conference on Lion Navigator receiver and interest in SSV specification for Galileo
- **SSTL**
  - GIOVE-A SGR-GEO experiment (2013) which carried 12 channel L1 C/A code GPS Receiver and operated in circular orbit at 23,200 km (3,200 km above GPS)
  - Successfully tracked some 2nd side lobe signals & characterized antenna patterns for GPS IIA, IIR, IIR(M) and IIF satellites
  - New GNSS receiver for HEO/GEO: SGR-Axio
  - Future pattern characterization of Galileo, Glonass & Beidou
- **RUAG PODRIX HEO GPS/Galileo Receiver**
  - Planned operational use on ESA Proba-3 HEO (600 km x 60,000 km)



Lion Navigator Breadboard





Lessons Learned Summary

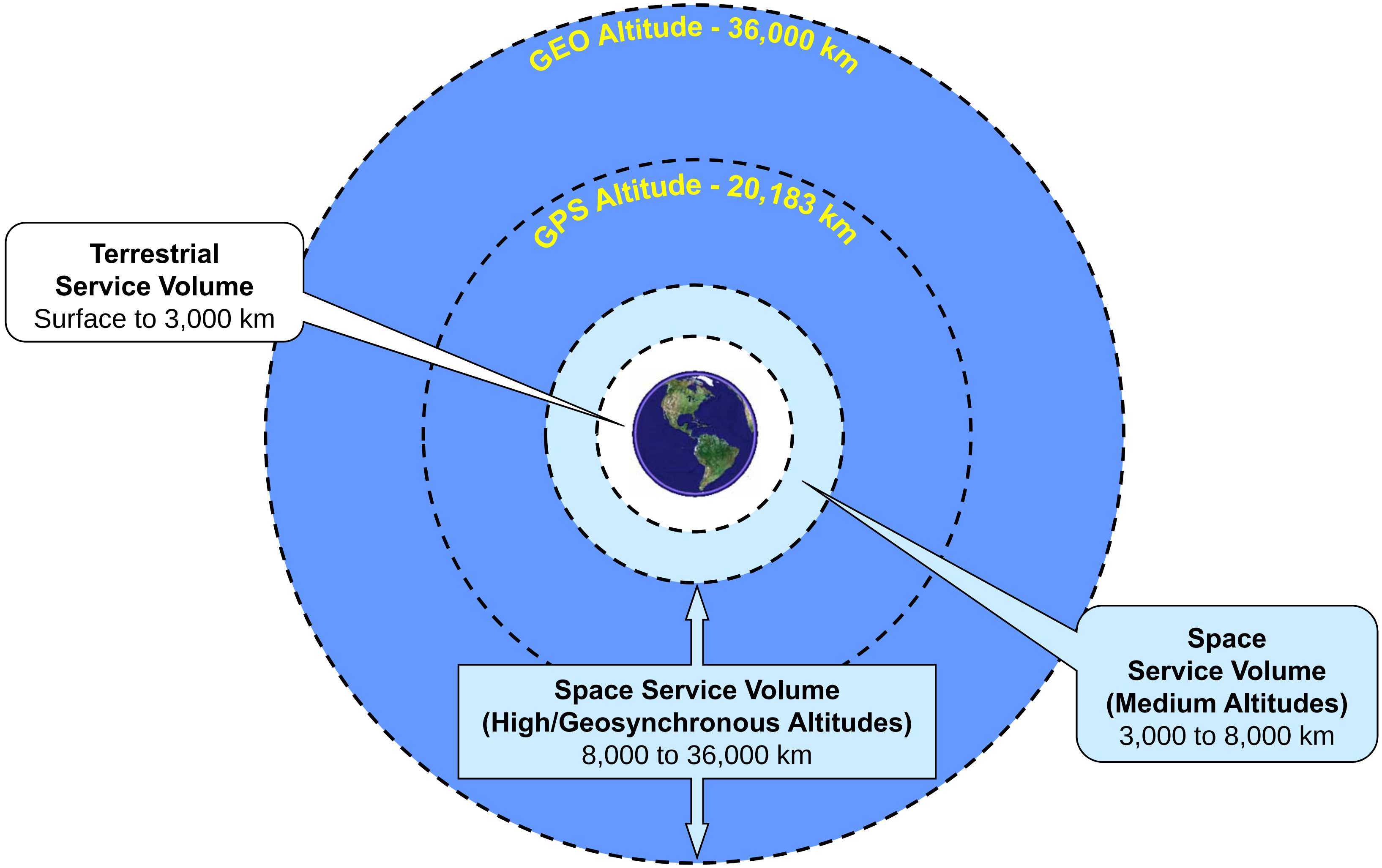
SSV Lessons Learned Over Past Decade:

- **GPS side lobe signals critically important for civil and military space users in HEO/GEO orbits**
  - Current and future civil and military space missions rely on side lobe signals to augment and enhance on-board PNT performance, improving vehicle resiliency
  - Side Lobe signals enhance Space and Earth weather prediction through improved navigation performance; strategically important for civil and military operations
- **Protection of side lobe signals ensures consistent GPS signal availability to U.S. civil & military missions at HEO/GEO**
  - No other GNSS constellation specifies SSV and side lobe signals

Protection of GPS Side Lobe Signals through Specification is Critically Important to "Do No Harm" to Current and Future Users of the SSV

Proposed SSV Specification Updates to Ensure Minimal Degradation in Signal Strength/Availability

GPS III Terrestrial and Space Service Volumes



No Change from Current Specification

SSV Pseudorange Accuracy

- **Also known as User Range Error (URE)**
- **Error bound on GPS range measurement**
- **Function of**
  - Accuracy of GPS orbit and clock solutions from Control Segment
  - Age of Data
  - Uncertainty in GPS physical and modeling parameters
    - Antenna group delay and phase errors vary as a function of off-nadir angle
- **Current performance ≈ 1 meter**
- **GPS III requirement: ≤ 0.8 meter (rms)**

No Change from Current Specification

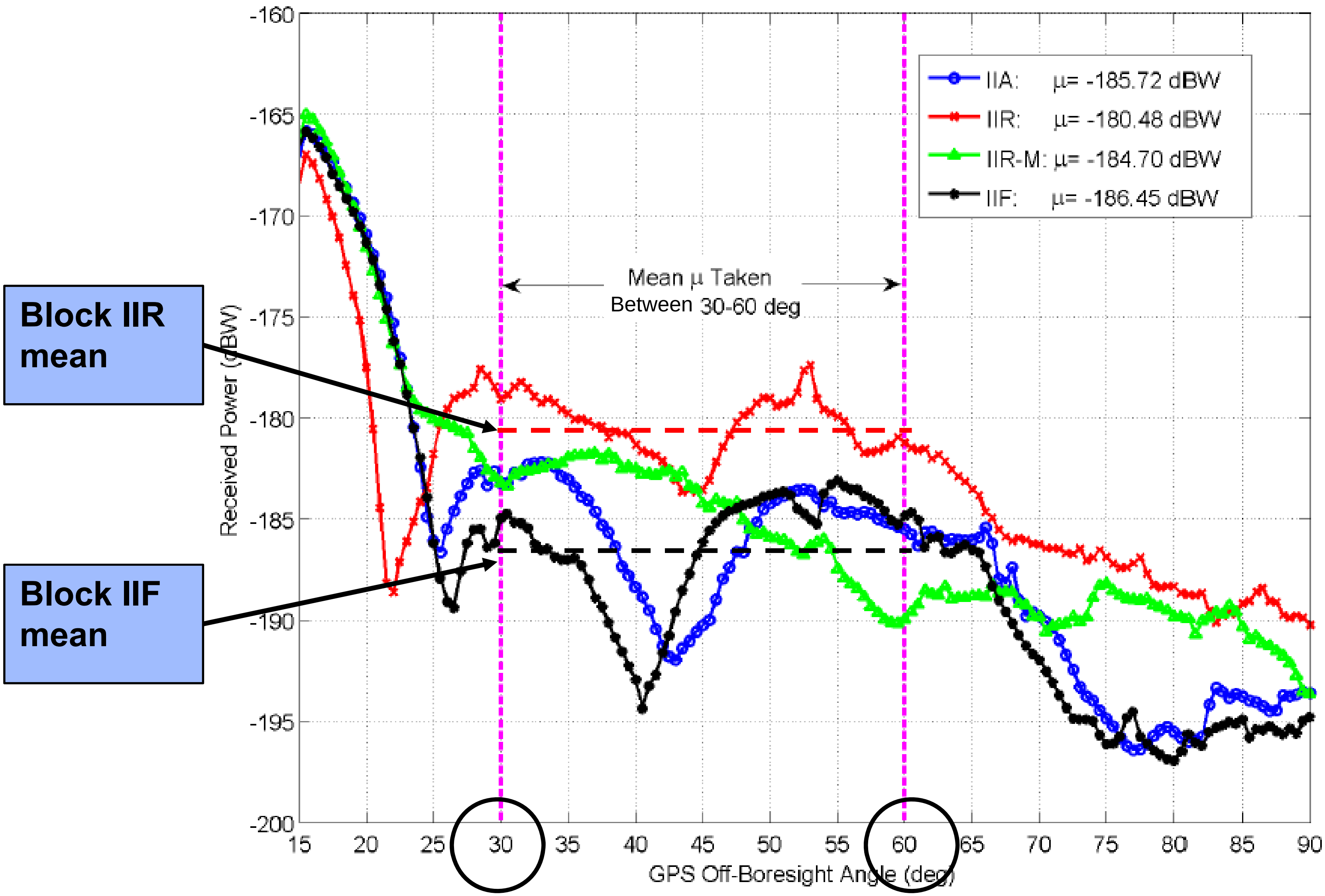
GPS III Minimum Main Lobe Received Signal Power (dBW) Requirement

Signal	Terrestrial Minimum Power (dBW)	SSV Minimum Power (dBW)	Reference Half-beamwidth
L1 P(Y)	-161.5	-187.0	23.5
L1 C/A	-158.5	-184.0	23.5
L1 M	-158.0	-183.5	23.5
L1C	-157.0	-182.5	23.5
L1 composite	-151.2		
L2 P(Y)	-161.5	-186.0	26
L2 C/A or L2C	-158.5	-183.0	26
L2 M	-158.0	-182.5	26
L2 composite	-151.5		
L5 I5	-157.0	-182.0	26
L5 Q5	-157.0	-182.0	26
L5 composite	-154.0		

- **SSV minimum power levels were specified based on the worst-case (minimum) gain across the Block IIA, IIR, IIR-M, and IIF satellites**
- **Some signals have several dB margin with respect to these requirements at reference half-beamwidth point**

No Change from Current Specification

Side Lobe Received Signal Power Requirement Derivation



GPS III Minimum Side Lobe Received Signal Power (dBW) Requirement

- **50% of SSV signals within the off-Nadir angle beamwidth shall be above the mean power**
- **84% of SSV signals within the off-Nadir angle beamwidth shall be above the mean power minus standard deviation power**

Signal	Mean Power (dBW)	Mean Power Minus Standard Deviation Power (dBW)	Off-Nadir Angle (degrees)
L1 P(Y)	TBD	TBD	30 to 60 (TBR)
L1 C/A (TBR)	-184.0	-190.0	30 to 60 (TBR)
L1 M	TBD	TBD	30 to 60 (TBR)
L1C	TBD	TBD	30 to 60 (TBR)
L1 composite			
L2 P(Y)	TBD	TBD	30 to 60 (TBR)
L2 C/A or L2C	TBD	TBD	30 to 60 (TBR)
L2 M	TBD	TBD	30 to 60 (TBR)
L2 composite			
L5 I5	TBD	TBD	30 to 60 (TBR)
L5 Q5	TBD	TBD	30 to 60 (TBR)
L5 composite			

GPS III Minimum Availability Requirement

- **Assuming a nominal, optimized GPS constellation (24 satellites) and no GPS spacecraft failures, signal availability at 95% of the areas at a specific altitude within the specified SSV are planned as:**

	MEO SSV		HEO/GEO SSV	
	at least 1 signal	4 or more signals	at least 1 signal	4 or more signals
L1	100%	≥ 97%	100% [1]	≥ 97% (TBR)
L2, L5	100%	100%	100% [2]	≥ 97% (TBR)

1. With less than 108 minutes of continuous outage time.
2. With less than 84 minutes of continuous outage time.

- **Objective Requirements:**
  - MEO SSV: 4 GPS satellites always in view
  - HEO/GEO SSV: at least 4 GPS satellite always in view

Red: Specification Changes

DRAFT

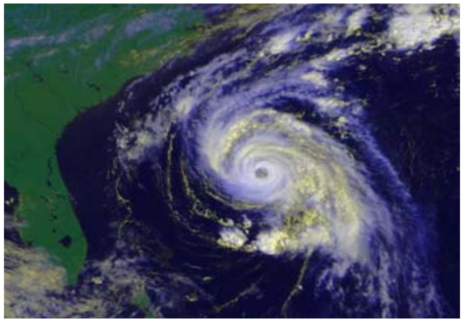
Requirements Verification

- **Requirements verified through combination of test and analysis**
- **Each new GPS satellite antenna gain pattern is tested from boresight to +/- 90 degrees**
  - Similar to GPS IIR and IIRM antenna pattern tests
- **Test data is combined analytically with data from existing constellation to gather statistics for:**
  - SSV signal availability
  - Side lobe signal power
    - Mean power
    - Mean minus standard deviation power
- **Statistics compared to requirements “shall” statements**
- **White paper (TBS) will define one method to verify proposed requirements**

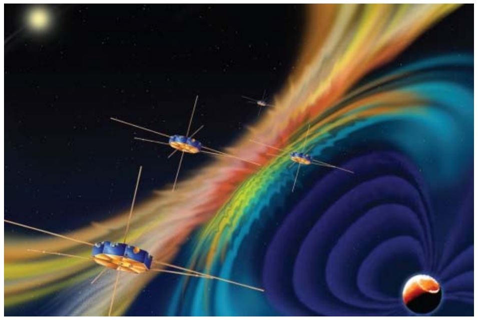
Summary and Closing Remarks

GPS Side Lobe Specification Strategically Important for Current & Future Civil & Military Space Missions

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



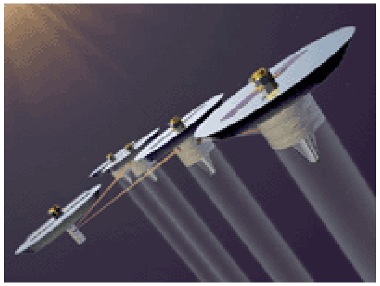
Improved Weather Prediction using Advanced Weather Satellites



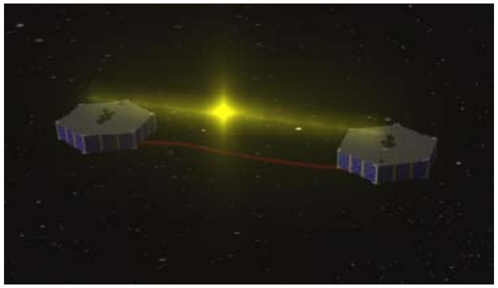
Space Weather Observations

Astrophysics Observations

En-route Lunar Navigation Support



Formation Flying & Constellation Missions



Closer Spacing of Satellites in Geostationary Arc

HEO/GEO Missions Operational and on the Horizon

SATELLITE	LAUNCH DATE OR OPERATIONAL PERIOD	ORBIT	RECEIVER/VENDOR	GPS APPLICATION	RECEIVER
Restricted	2014**	GEO	General Dynamics Viceroy	OPERATIONAL	HEO Receiver
Restricted	2014**	GEO	General Dynamics Viceroy	OPERATIONAL	HEO Receiver
Restricted	2014**	GEO	General Dynamics Viceroy	OPERATIONAL	HEO Receiver
Small GEO	2015	GEO	Astrium Mosiac GNSS	EXPERIMENT	HEO Receiver
SBIRS GEO 3	2015	GEO	General Dynamics Monarch	OPERATIONAL	Modified Legacy Receiver
GOES-R	2016	GEO	General Dynamics Viceroy	OPERATIONAL	HEO Receiver
SBIRS GEO 4	2016	GEO	General Dynamics Monarch	OPERATIONAL	Modified Legacy Receiver
EAGLE	2017	GEO	Moog NavSBR	OPERATIONAL	HEO Receiver
GOES-S	2017	GEO	General Dynamics Viceroy	OPERATIONAL	HEO Receiver
Restricted	2017**	GEO	General Dynamics Viceroy	OPERATIONAL	Modified Legacy Receiver
Orion Exploration Mission 1	2018	Trans-lunar	Honeywell	EXPERIMENT	Modified Legacy Receiver
Proba-3	2018	HEO	Ruag PODRIX	OPERATIONAL	HEO Receiver

- ** Date of delivery of receiver to customer

And many more coming…

Closing Remarks

- **NASA, NOAA, DoD and other space GPS users rely on GPS as critical component of space navigation infrastructure over an expanding range of orbital applications**
- **Space user community is still vulnerable to GPS constellation design changes because requirements not explicitly stated; specifically the side lobe signals**
- **Proposed SSV requirements update:**
  - Maintains backward compatibility with current constellation
  - Identifies potential areas for improved performance through objective requirements
  - Provides a green-light for civil and military space missions considering future operational use of GPS beyond LEO
- **Interoperability for all space users will be enhanced if other PNT service providers such as Galileo also implement similar requirements/operational capabilities.**
  - This issue has been actively worked as part of ICG meetings since 2011

Protection of GPS Side Lobe Signals through Specification is Critically Important to "Do No Harm" to Current and Future Users of the SSV

References

F.H. Bauer, M.C. Moreau, M.E. Dahle-Melsaether, W.P. Petrofski, B.J. Stanton, S. Thomason, G.A Harris, R.P. Sena, L. Parker Temple III, The GPS Space Service Volume, ION GNSS, September 2006.

M.Moreau, E.Davis, J.R.Carpenter, G.Davis, L.Jackson, P.Axelrad "Results from the GPS Flight Experiment on the High Earth Orbit AMSAT AO-40 Spacecraft," Proceedings of the ION GPS 2002 Conference, Portland, OR, 2002.

Kronman, J.D., "Experience Using GPS For Orbit Determination of a Geosynchronous Satellite," Proceedings of the Institute of Navigation GPS 2000 Conference, Salt Lake City, UT, September 2000.

Chuck H. Frey, et al., "GPS III Space Service Volume Improvements," Joint Navigation Conference, June 19, 2014.

These and other NASA References:

http://www.emergentspace.com/related_works.html

Backup Charts

U.S. Contributions to Ensure an Interoperable, Sustained, Quantified GNSS Capability for Space Users

Space Service Volume (SSV)

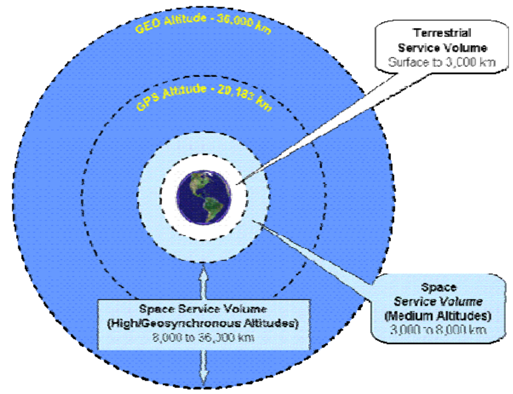
- Development and specification of a SSV and solidification of specifications that define signal strength and availability of GPS signals in space for all locations and all users within the SSV

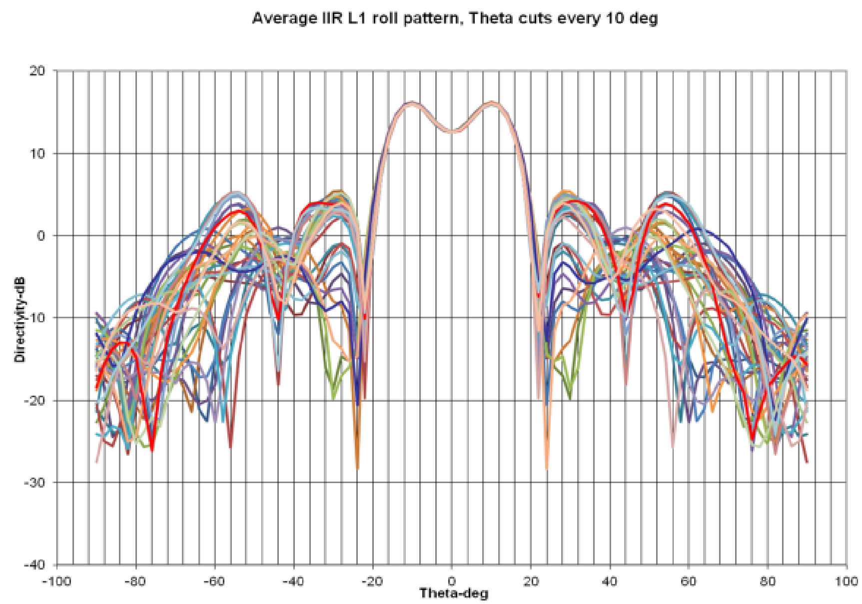
GPS Antenna Pattern Publication

- GPS Block II-R and II-R(M) antenna pattern pre-flight testing & post-flight publication
  - Quantifies antenna characteristics, including main & side lobe gain
  - Enables space users to perform pre-flight analyses to determine end-to-end navigation performance and signal availability
  - Enables space users to leverage side lobe information (per SV) to enhance GPS availability, particularly for space missions above the GPS constellation, including missions in High Earth Orbit (HEO) & Geostationary/Geosynchronous Orbit (GEO/GSO)

International GNSS Interoperability

- Highly encouraging other GNSS, and regional navigation systems, partners to participate
  - Complete SSV templates
  - Develop GNSS constellation SSV specification
  - Publish constellation antenna data





SSV Spec vs IIR-M Performance

	New SYS-SS-800 (SSV)		
	SSV Power (dBW)	Ref To (deg)	Total Margin vs min IIRM
L1 P(Y)	-187.0	23.5	-1.3
L1 C/A	-184.0	23.5	-1.3
L1 M	-183.5	23.5	-1.3
L1C	-182.5	23.5	-1.3
L2 P(Y)	-186.0	26.0	1.4
L2 C/A or L2C	-183.0	26.0	1.4
L2 M	-182.5	26.0	1.4
L5 I5***	-182.0	26.0	5.8
L5 Q5***	-182.0	26.0	5.8

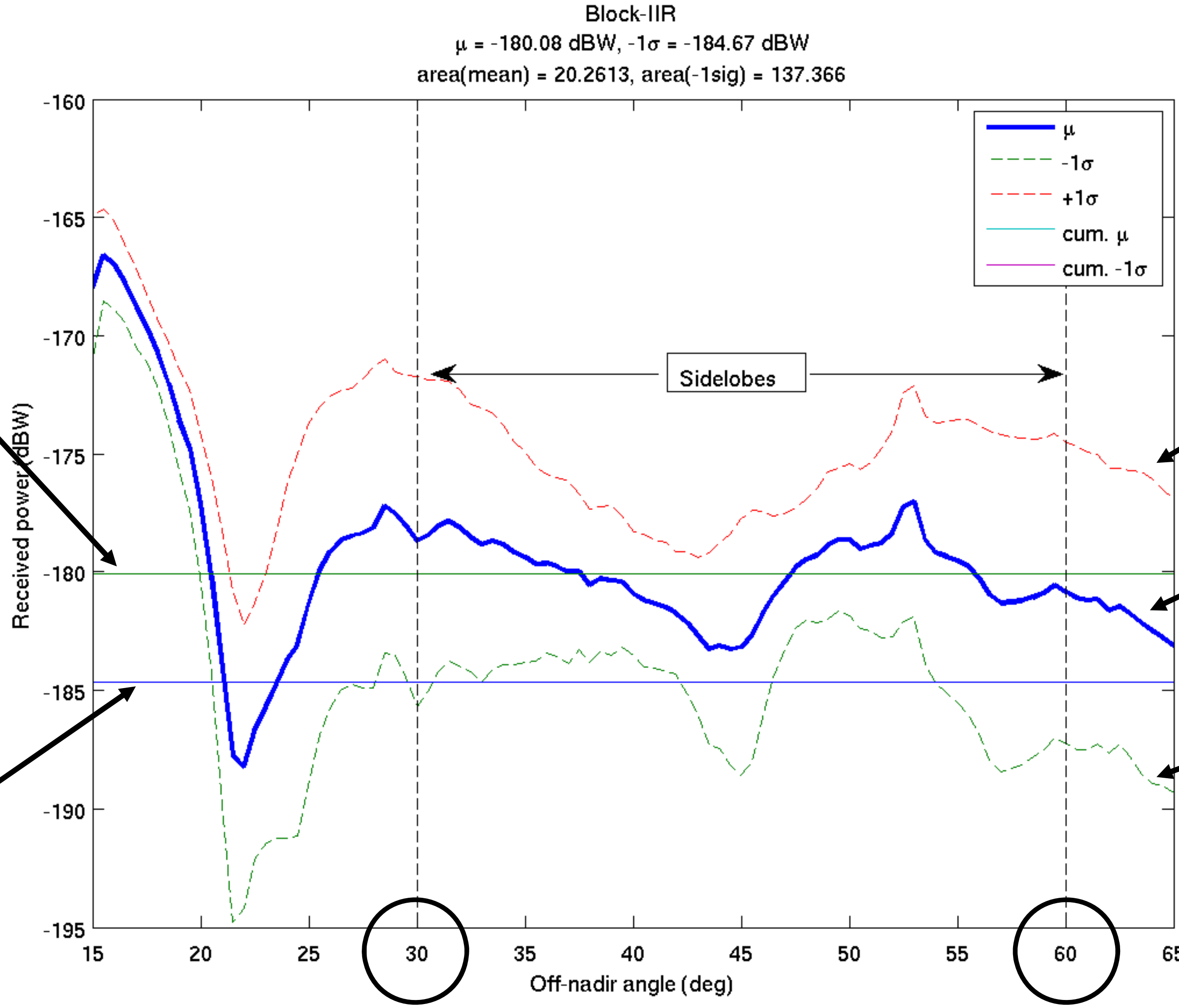
- **These are the updated power numbers that the JPO agreed to. Note that the amount of margin on each signal is very different.**
- **Note that this does NOT address the Lockheed request to relax L1 power by 1 dB. L1 power stays the same.**
- **Note that the L2 power is 1.4 dB LOWER than the worst case IIR-M power we estimated.**
- **Note that the L5 power is actually 5.8 dB lower than the minimum L5 power we estimated. NASA felt the margin on L5 was too large in light of the recent analysis. JPO did not want to give up any margin since L5 data was based on only a single antenna.**

Side Lobe Received Signal Power Requirement Derivation

Block IIR

Side Lobe Mean Power

Sidelobe -1σ Power



+1σ

Mean

-1σ

Side Lobe Received Signal Power Requirement Derivation

Block IIR-M