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GNSS Space Service Volume & Space User Data Update
ICG WG-B

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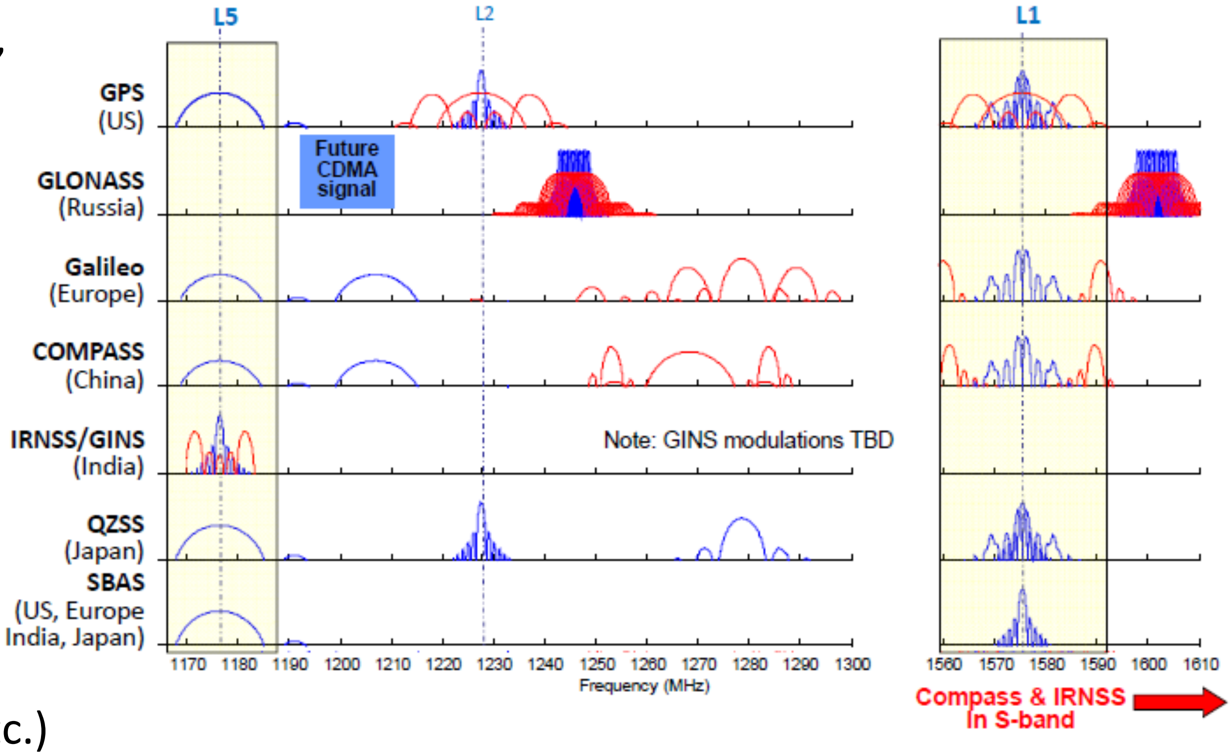
Human Exploration and Operations Mission Directorate (HEOMD), NASA

ICG-9, Prague, Czech Republic, November 12, 2014

Current Global and Regional International Navigation Signal Plans

- There is an ongoing expansion of global (GPS, GLONASS, Galileo, Beidou) and regional (IRNSS, QZSS, SBAS) space systems to support PNT
- More than 100 GNSS satellites could be available in the near future
- The Radio Navigation Satellite Service (RNSS) spectrum is increasingly being populated with new signals to support various user communities (navigation, science, timing, etc.)



- Interoperability is the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system

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
  - 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

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

Space Service Volume (SSV)

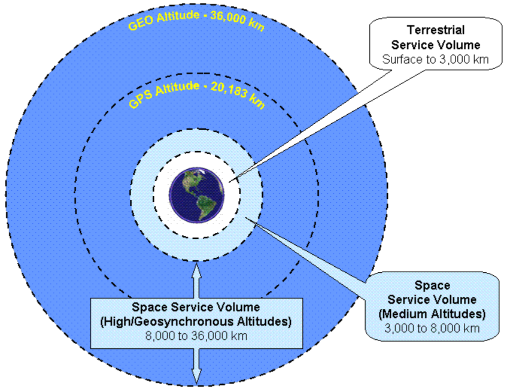
- Development and specification of a SSV and solidification of specifications that define signal strength and availability of GPS signals in space for all locations and all users within the SSV

GPS Antenna Pattern Publication

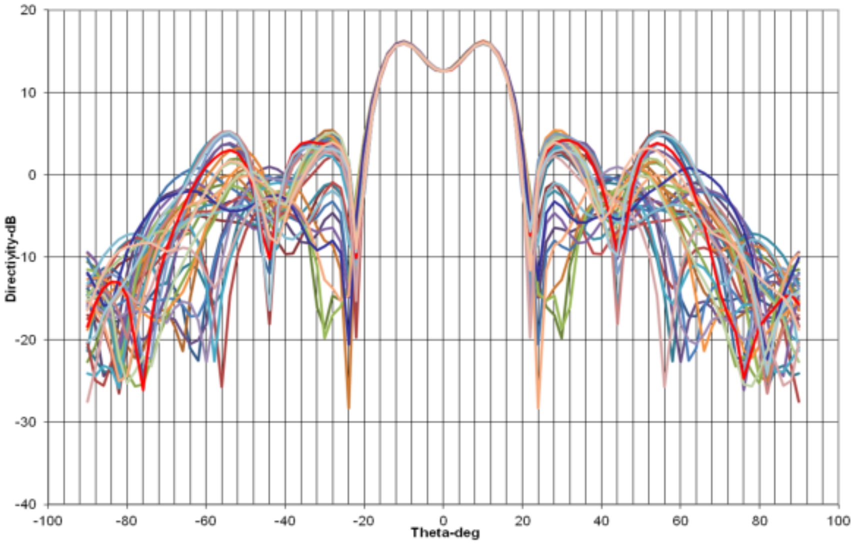
- GPS Block II-R and II-R(M) antenna pattern pre-flight testing & post-flight publication
  - Quantifies antenna characteristics, including main & side lobe gain
  - Enables space users to perform pre-flight analyses to determine end-to-end navigation performance and signal availability
  - Enables space 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 Forward Work

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



Average IIR L1 roll pattern, Theta cuts every 10 deg

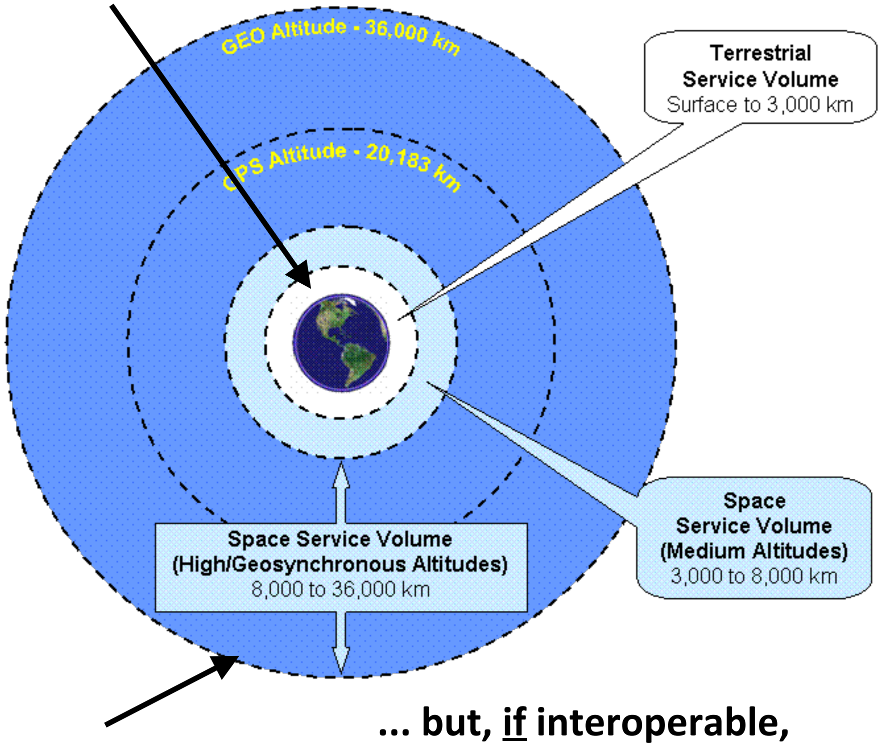


Partners: Galileo, GLONASS, Beidou, & IRNSS

Expanding the GPS SSV into a multi-GNSS SSV

- At least four GNSS satellites in line-of-sight are needed for on-board real-time autonomous navigation
  - GPS currently provides this up to 3,000 km altitude
  - Enables better than 1-meter position accuracy in real-time
- At GEO/GSO only one GPS satellite will be available at any given time.
  - **GPS-only** positioning still possible with on-board filtering, but only up to approx. 100-meter absolute position accuracy.
  - **GPS** + **Galileo** combined would enable 2-3 GNSS sats in-view at all times.
  - **GPS** + **Galileo** + **GLONASS** would enable at least 4 GNSS sats in-view at all times.
  - **GPS** + **Galileo** + **GLONASS** + **Beidou** would enable > 4 GNSS sats in view at all times. This provides best accuracy and, also, on-board integrity.
- However, this requires:
  - Interoperability among these the GNSS constellations; and
  - Common definitions/specifications for use of GNSS signals within the Space Service Volume (3,000 km to GEO/GSO altitudes)

≥ 4 GPS satellites in line-of-sight here (surface to 3000 km)

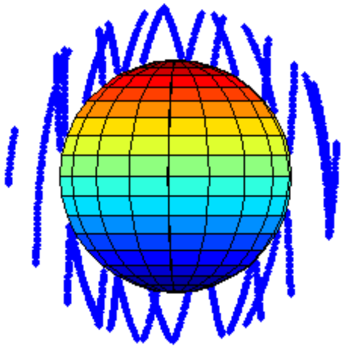


Only 1-2 GPS satellites in line-of-sight at GEO/ GSO altitudes

... but, if interoperable, then GPS + Galileo + GLONASS + Beidou provide > 4 GNSS sats in line-of-sight at GEO/GSO altitudes

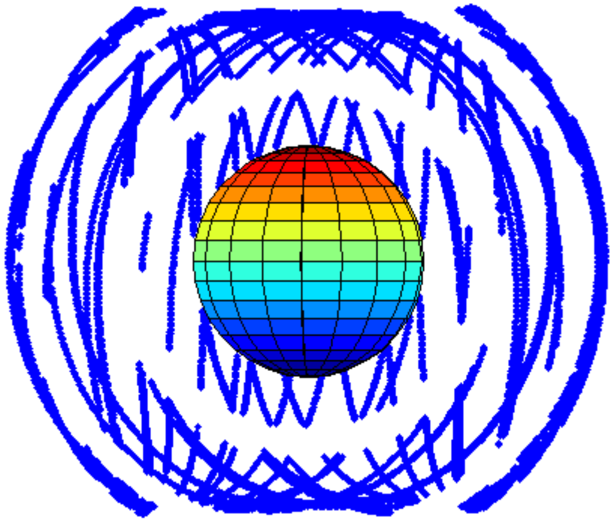
HEO & GEO Space Mission Navigation Significantly Enhanced when GPS Side Lobes Included

Main Lobe Only



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

Main and Side Lobes



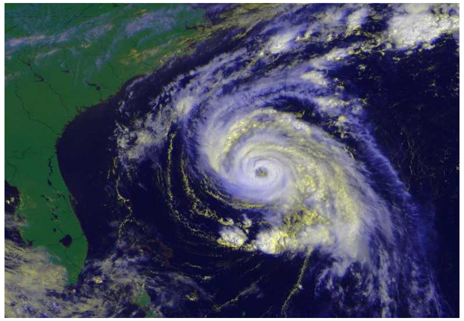
4 or more SVs visible: 99%
1 or more SVs visible: always
no SVs visible: : never

- 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
- HEO/GEO missions relying on unspecified GPS signals in the SSV for success
- Future specification of SSV side lobe signals?

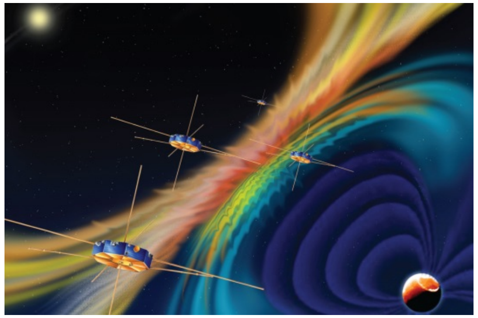
Why is an Interoperable Space Service Volume Important?

Global, interoperable SSV specifications are crucial for real-time GNSS navigation solutions in High Earth Orbit

- **Supports increased satellite autonomy for missions, lowering mission operations costs**
- **Enables new/enhanced capabilities for HEO and GEO/GSO future missions, such as:**



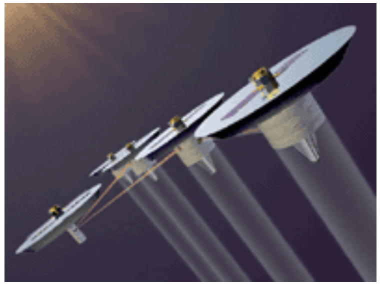
Improved Weather Prediction using Advanced Weather Satellites



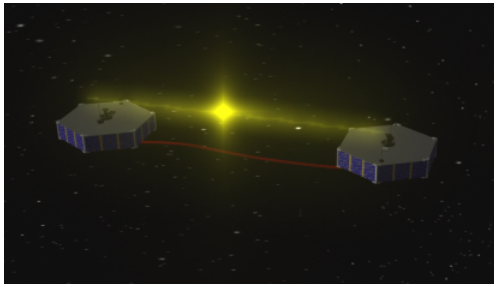
Space Weather Observations

Astrophysics Observations

En-route Lunar Navigation Support

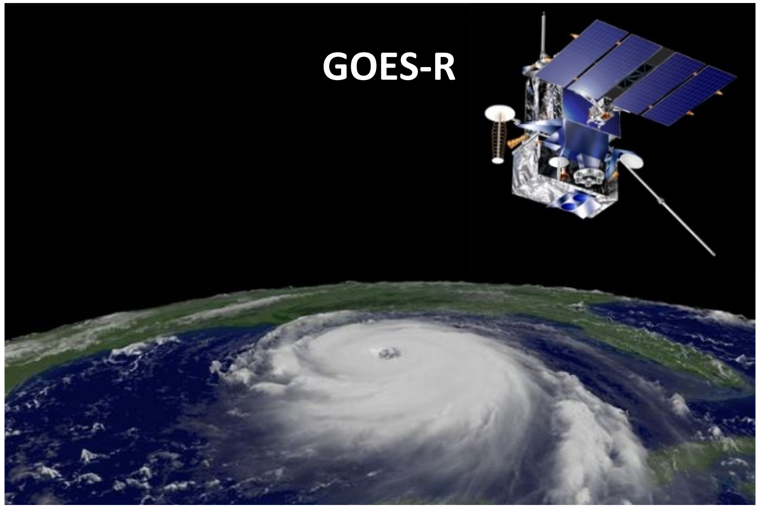


Formation Flying & Constellation Missions



Closer Spacing of Satellites in Geostationary Arc

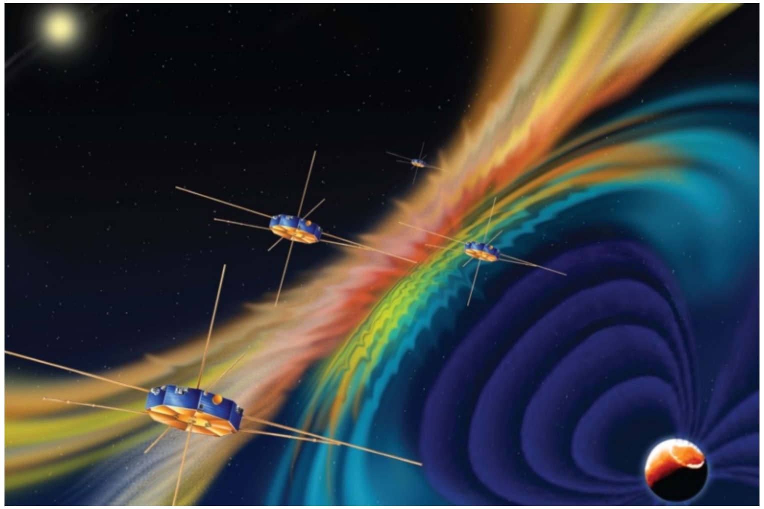
Current U.S. Missions using GPS above the GPS Constellation



GOES-R Weather Satellite Series

- First operational use of GPS above the constellation
- Improves navigation performance for GOES-R
- Station-keeping operations on current GOES-N through -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 weather science

Magnetospheric Multi-Scale (MMS) Mission



- 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)
- GPS enables onboard (autonomous) navigation and potentially autonomous station-keeping

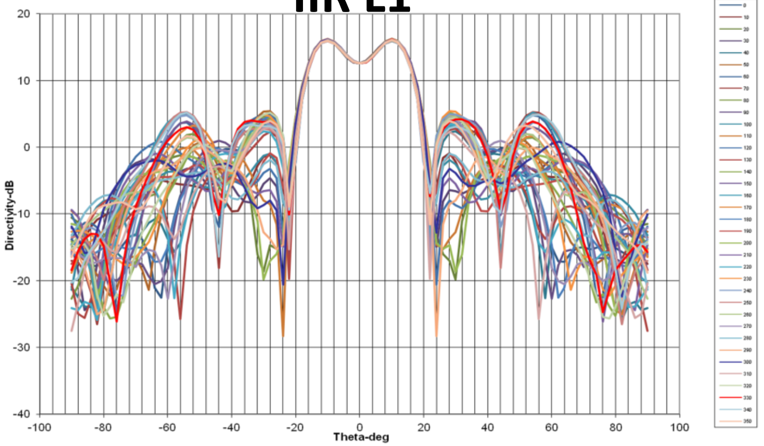
U.S. Delegation Experience attaining a GPS Space Service Volume Specification

- Mid-1990s—efforts started to develop a formal Space Service Volume
- February 2000—GPS Operational Requirements Document (ORD), released with first space user requirements and description of SSV
- 1997-Present—Several space flight experiments, particularly the AMSAT-OSCAR-40 experiment demonstrated critical need to enhance space user requirements and 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
- 2014 and beyond—Specification of side lobes to further enhance HEO/GEO space users?

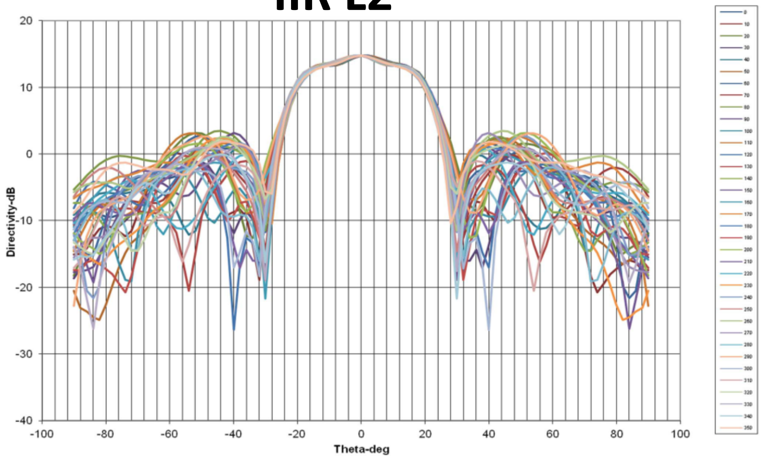
U.S. Publication of GPS Block IIR & IIR(M) Antenna Patterns

- 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 capabilities of current missions

IIR L1



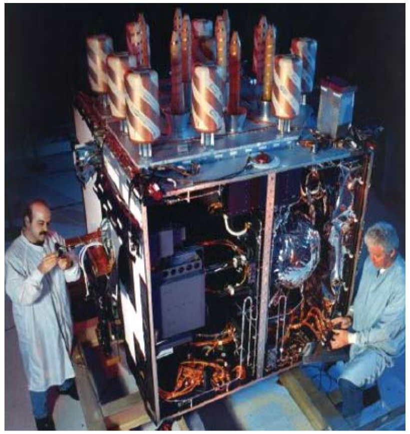
IIR L2



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

GPS Block IIR Antenna Panel Types

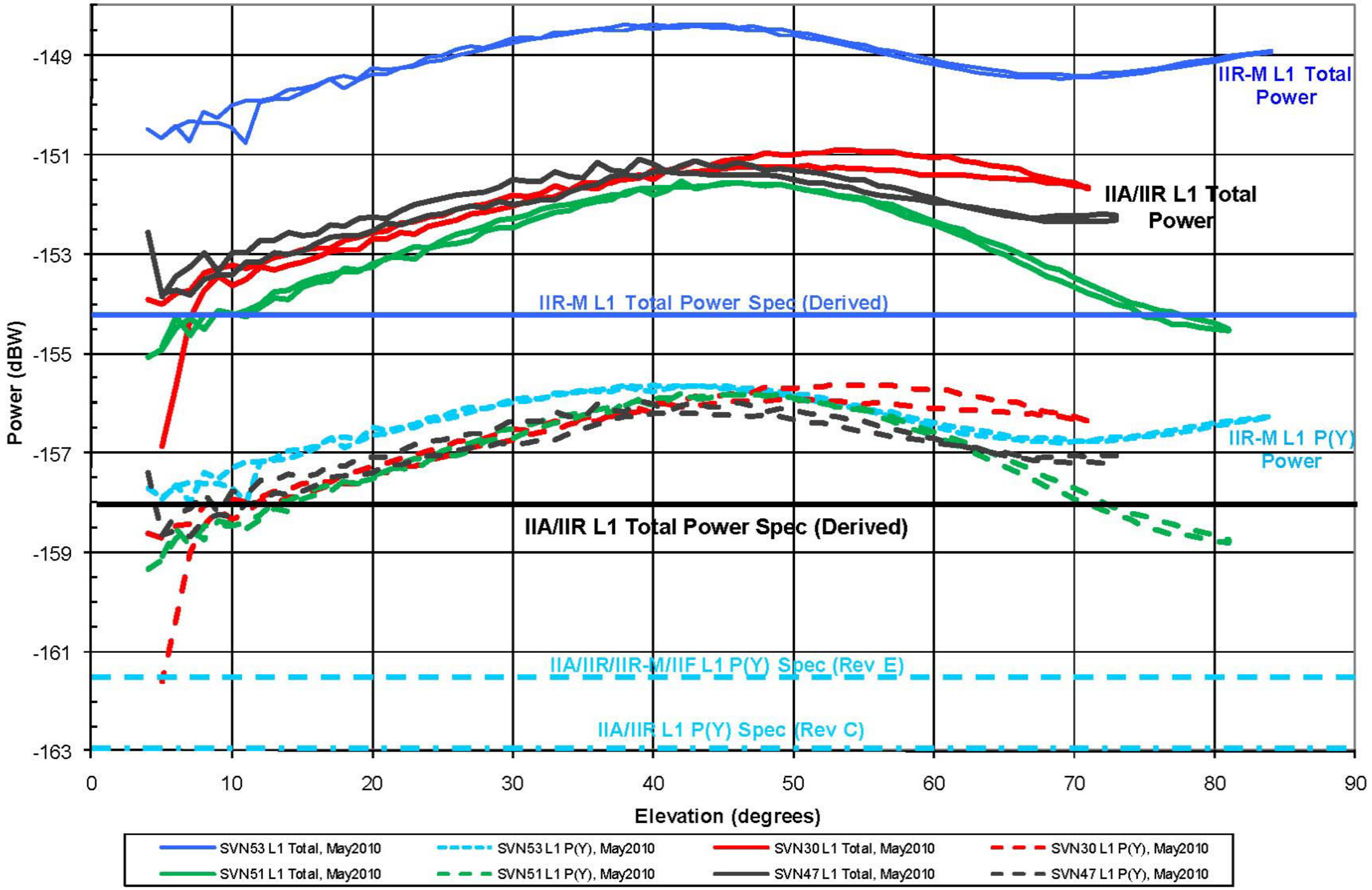
- **Two antenna panel types used on GPS Block IIR / IIR(M) spacecraft**
  - ‘Legacy’ (original) antenna panel used on first 8 of 12 IIR SVs
  - GPS IIR ‘Improved’ antenna panel used on final 4 of 12 IIR SVs, and all 8 IIR(M) SVs
- **Legacy Antenna Design**:
  - 8 helix elements in circle w/ 4 center elements
  - 12-way power divider & beam forming network distributes signal power with phase offset between the rings to provide balanced power over the horizon-to-nadir earth coverage range (13.8 deg)
- **Improved Antenna Design**:
  - New element designs & configurations on the panel
  - At edge of Earth,1-2 dBW added to L1 & L2 for IIR
  - IIR(M) SVs provide additional power due to higher power transmitters; power envelope further increased with new *modernized signals: L2C, L1M, L2M*



Legacy Antenna Panel

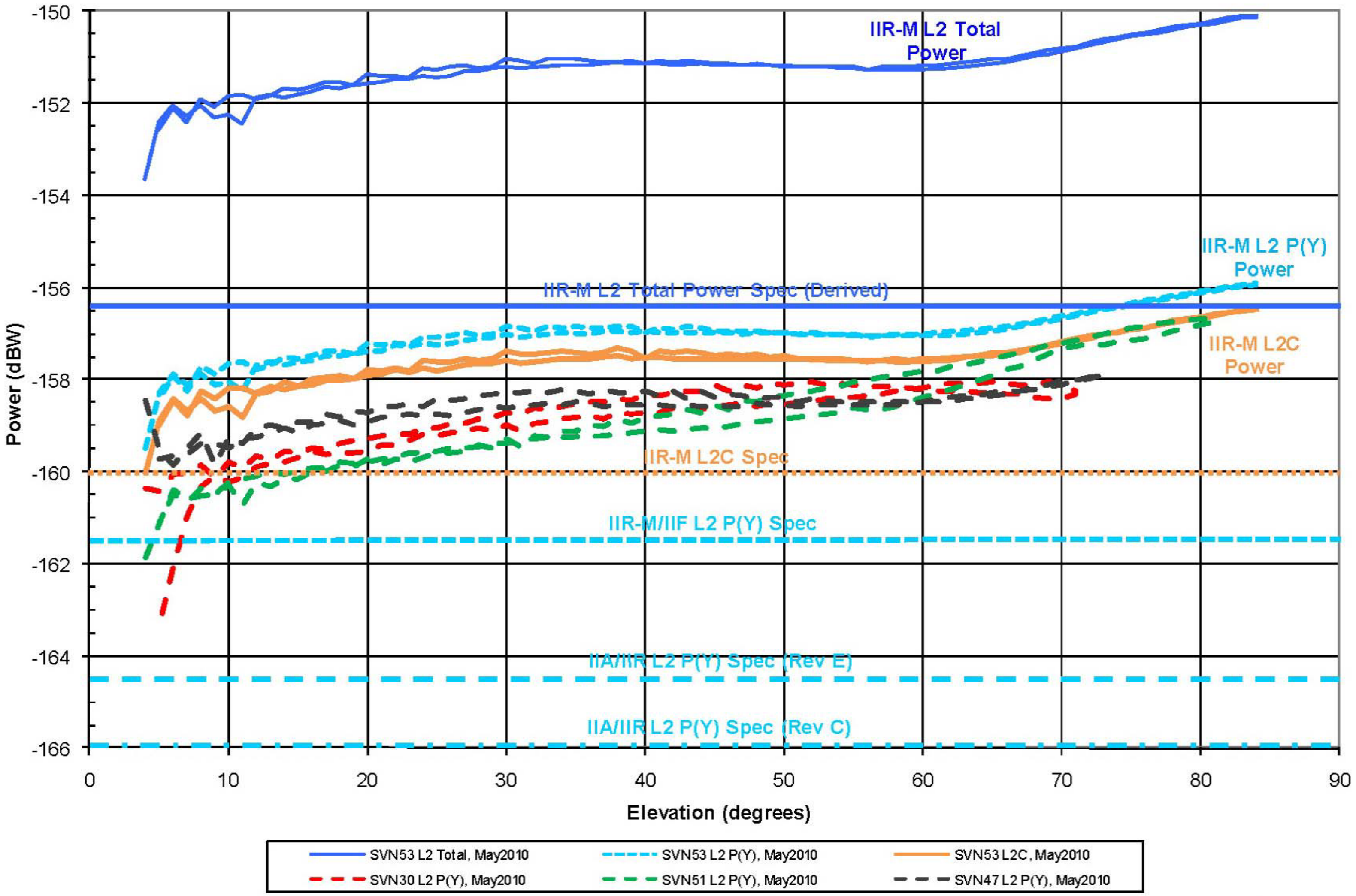
Improved Antenna Panel

GPS L1 Antenna Power Measurements



Courtesy of GPS Program, Lockheed Martin & SRI, Inc.

GPS L2 Antenna Power Measurements



Courtesy of GPS Program, Lockheed Martin & SRI, Inc.

IIR/IIR(M) Comparison to SSV Specification

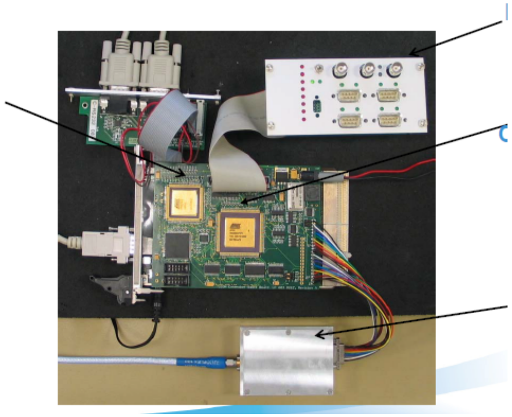
	Though not a IIR requirement, the following service is provided at the levels presented in IS-GPS-200:			
	L1, at 20 deg	L1, at 23 deg	L2, at 23 deg	L2, at 26 deg
IIR Legacy Panel	At some yaw angles	At some yaw angles	Yes	At some yaw angles
IIR Improved Panel	At some yaw angles	Yes	Yes	Yes

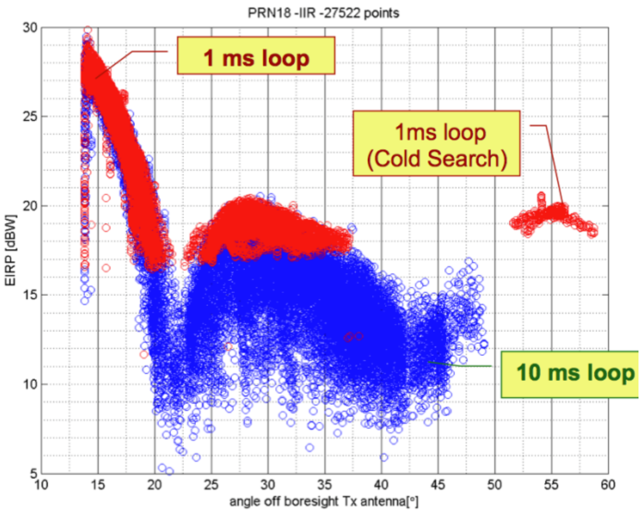
The IIR improved panel provides stronger Space Service, though SSV not a requirement for IIR/IIR(M) (SSV Requirements baselined on GPS III)

Recent HEO/GEO Space User Initiatives Observed and Discussions Held

- Airbus/Astrium (Eveline Gottzein, Peter Krauss)
  - 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 (Martin Unwin)
  - 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

First Breadboard of LION Navigator





GNSS Mission Areas (1): Precise Orbit Determination, Time, Relative Nav. for Rendezvous, Formation Flight, Radio Occultation, Oceanography

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
1	ASI	CSK	GPS			Es	2007	4 satellites
2	ASI	CSG	GPS, Galileo Ready			Es	2016	2 satellites
3	ASI	AGILE	GPS			Ee	2007	
4	ASI	PRISMA	GPS			Es	2015	
5	ASI	OPSIS	GPS			Es	2017	
6	CNES	CALIPSO	GPS	L1 C/A	Orbit, Time	Es	2006	CNES controls the in flight satellite .
7	CNES	COROT	GPS	L1 C/A	Orbit, Time	Ep (90°)	2006	CNES controls the in flight satellite .
8	CNES	JASON-2	GPS*	L1 C/A	Orbit, Time	Ei (66°)	2008	CNES controls the in flight satellite in case of emergencey on behalf of NASA/NOAA or EUMETSAT.* GPS on Bus + GPSP on Payload (NASA)
9	CNES	SMOS	GPS	L1 C/A	Orbit, Time	Es	2009	Launch was Nov 02, 2009. CNES controls the satellite in routine operations ; ESA operates the mission.
10	CNES	ELISA	GPS	L1 C/A	Orbit, Time	Es	2011	The system is with four satellites launched in Dec 2011. Receiver: MOSAIC
11	CNES	JASON-3	GPS*	L1 C/A	Orbit, Time	Ei (66°)	2015	CNES controls the in flight satellites in case of emergencey on behalf of NASA/NOAA or EUMETSAT.* GPS on Bus + GPSP on Payload (NASA)
12	CNES	MICROSCOPE	GPS, Galileo	L1 C/A, E1	Precise Orbit Determinatin (POD), Time	Es	2016	One satellite to be launched in 2016 Receiver: SKYLOC
13	CNES	CSO-MUSIS	GPS, Galileo	L1 C/A, L2C, L5 E1, E5a	Orbit, Time	Es	2017	The system is with three satellites to be launched from 2017. Receiver : LION
14	CNES	MERLIN	GPS, Galileo	L1 C/A, E1	Orbit, Time	Es (TBC)	2018	Receiver : not yet decided
15	CNES	SWOT	GPS, Galileo (to be decided)	GPS L1 C/A, other (to be decided)	Orbit, Time	Ep (77,6°)	2020	Receiver : not yet decided
16	DLR/NASA	GR1 / GR2 (GRACE)	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO	Ep	17-Mar-2002	Joint mission with NASA.
17	DLR	TSX-1	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO, precsie relative determination	Es	15-Jun-2007	
18	DLR	TDX-1	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO, precsie relative determination	Es	21-Jun-2010	
19	DLR	TET	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support)	Ep	22-July-2012	
20	DLR	TET NOX experiment	GPS	GPS L1 C/A, L1/L2 P(Y)	Experiment (POD, RO)	Ep	22-July-2012	
21	DLR	BIROS	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support)	Ep	2015	
22	DLR	HAG-1	GPS	GPS L1 C/A	Experiment (navigation)	G	2014	GPS used for on-board experiment
23	DLR	Eu:CROPIS	GPS	GPS L1 C/A	navigation, flight dynamics	Ep	2016	
24	DLR	ENMAP	GPS			Ep	2017	
25	DLR/NASA	GRACE_FO	GPS GLO/GAL?)	GPS L1 C/A, L1/L2 P(Y), (others?)	Navigation, POD	Ep	2018	Joint mission with NASA.

GNSS Mission Areas (2): Precise Orbit Determination, Time, Relative Nav. for Rendezvous, Formation Flight, Radio Occultation, Oceanography

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
26	DLR	DEOS	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support), relative navigation (formation flight/ rendezvous)	Ep	2017	
27	DLR	Electra	GPS		orbit determination	G	2018	
28	DLR	PAZ	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD	Ep	2014	Same as TSX
29	ESA	GOCE			POD	LEO	2009	
30	ESA	Swarm			POD	LEO	2013	
31	ESA	MetOp			Radio Occultaiton	LEO	2006	
32	ESA	EarthCare			Orbital GPB	LEO	2016	
33	ESA	BIOMASS				LEO	2018	
34	ESA	GMES S1			Orbit, POD	LEO	2013	
35	ESA	GMES S2			Orbit	LEO	2015	
36	ESA	GMES S3			Orbit, POD	LEO	2015	
37	ESA	MTG			Orbit, Time	GEO	2018	
38	ESA	NGGM			FF with MetOp	LEO		
39	ESA	STE-QUEST			Orbit, Time	LEO		
40	ESA	Proba 2			Orbit	LEO	2009	
41	ESA	Proba 3			FF with MetOp	HEO	2017	
42	ESA	ATV			Rendezvous	LEO	Began in 2009	
43	ESA	Small GEO			Orbit, Time	GEO	2014	
44	JAXA	GOSAT	GPS	L1	Orbit, time	LEO	2009-present	Remote Sensing
45	JAXA	GCOM-W1	GPS	L1	Orbit, time	LEO	2012-present	Remote Sensing
46	JAXA	GCOM-C1	GPS	L1	Orbit, time	LEO	2016	Remote Sensing
47	JAXA	ALOS-2	GPS	L1, L2	Precise orbit ($3\sigma<1m$), Orbit, time,	LEO	2013	Remote Sensing
48	JAXA	HTV-series	GPS	L1	Orbit(relative)	LEO	2009-present	Unmanned ISS transportation
49	JAXA	GOSAT-2	GPS	L1, L2 (TBD)	Orbit, time	LEO	2017	Remote Sensing
50	JAXA	ASTRO-H	GPS	L1, L2	Orbit, time	LEO	2015	Remote Sensing

GNSS Mission Areas (3): Precise Orbit Determination, Time, Relative Nav. for Rendezvous, Formation Flight, Radio Occultation, Oceanography

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
51	NASA	ISS	GPS	L1 C/A	Attitude Dynamics	LEO	Since 1998	Honeywell SIGI receiver
52	NASA	COSMIC (6 satellites)	GPS	L1 C/A, L1/L2 semicodeless, L2C	Radio Occultation	LEO	2006	IGOR (BlackJack) receiver; spacecraft nearing end of life
53	NASA	SAC-C	GPS	L1 C/A, L1/L2 semicodeless, L2C	Precise Orbit Determination, Occultation, surface reflections	LEO	2000	BlackJack receiver; mission retired 15 August 2013
54	NASA	IceSat	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination	LEO	2003	BlackJack receiver; mission retired 14 August 2010
55	NASA	GRACE (2 satellites)	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination, Occultation	LEO	2002	BlackJack receiver, joint mission with DLR
56	CNES/NASA	OSTM/Jason 2	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination	LEO	2008	BlackJack receiver
57	NASA	Landsat-8	GPS	L1 C/A	Orbit	LEO	2013	GD Viceroy receiver
58	NASA	ISS Commercial Crew and Cargo Program - Dragon	GPS	L1 C/A	Orbit / ISS rendezvous	LEO	2013+	
59	NASA	ISS Commercial Crew and Cargo Program: Cygnus	GPS	L1 C/A	Orbit / ISS rendezvous	LEO	2013+	
60	NASA	CONNECT / SCaN Test-Bed (ISS)	GPS	L1 C/A, L1/L2 semicodeless, L2C, L5, + option for Galileo & GLONASS	Radio occultation, precision orbit, time	LEO	2013	Blackjack-based SDR. Monitoring of GPS CNAV testing began in June 2013.
61	NASA	GPM	GPS	L1 C/A	Orbit, time	LEO	2014	Navigator receiver
62	NASA	Orion/MPCV	GPS	L1 C/A	Orbit / navigation	LEO	2014 - Earth Orbit, 2017 Cislunar	Honeywell Aerospace Electronic Systems 'GPSR' receiver
63	NSPO/USAF/NASA	COSMIC IIA (6 satellites)	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Occultation	LEO	2015	TriG receiver
64	NASA	DSAC	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Time transfer	LEO	2015	TriG receiver
65	CNES/NASA	Jason-3	GPS, GLONASS, Galileo	L1 C/A, L1/L2 semicodeless, L2C	Precise Orbit Determination, Oceanography	LEO	2015	IGOR+ (BlackJack) receiver
66	NASA	MMS	GPS	L1 C/A	Rel. range, orbit, time	up to 30 Earth radii	2015	Navigator receiver (8 receivers)
67	NASA	GOES-R	GPS	L1 C/A	Orbit	GEO	2016	General Dynamics Viceroy-4
68	NASA	ICESat-2	GPS	-	-	LEO	2016	RUAG Space receiver
69	NASA	CYGNSS (8 sats)	GPS	-	GPS bi-scatterometry	LEO	2016	Delay Mapping Receiver (DMR)
70	NSPO/USAF/NASA	COSMIC IIB (6 satellites)	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS, BeiDou	Occultation	LEO	2017	TriG receiver
71	NASA/DLR	GRACE FO	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Occultation, precision orbit, time	LEO	2018	TriG receiver, joint mission with DLR
72	NASA	Jason-4	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Precise Orbit Determination	LEO	2018	Trig receiver (proposed)
73	NASA	GRASP	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Precise Orbit Determination	LEO	2017	Trig receiver (proposed)
74	NASA	GRACE II	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Science	LEO	2020	Trig receiver (proposed)
75	NASA	NICER (ISS)	GPS	L1 C/A	Orbit	LEO	2016	Moog/Navigator receiver

GNSS Mission Areas (4): Precise Orbit Determination, Time, Relative Nav. for Rendezvous, Formation Flight, Radio Occultation, Oceanography

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
76	NASA	Pegasus Launcher	GPS	L1 C/A	Navigation	Surface to LEO	Since 1990	Trimble receiver
77	NASA	Antares (formerly Taurus II) Launcher	GPS	L1 C/A	Integrated Inertial Navigation System (INS) & GPS	Surface to LEO	Since 2010	Orbital GPB receiver
78	NASA	Falcon-9 Launcher	GPS	L1 C/A	Overlay to INS for additional orbit insertion accuracy	Surface to LEO	Since 2013	
79	NASA	Launchers* at the Eastern and Western Ranges	GPS	L1 C/A	Autonomous Flight Safety System	Range Safety	2016*	(*) Including ULA Atlas V and Delta IV (GPS system: Space Vector SIL, uses a Javad receiver). (**) Estimated initional operational test.
80	NASA	NI-SAR (was Desdyni)	GPS, GLONASS, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS	Precise Orbit Determination, timing	LEO	2020	TriG receiver

Notes: (1) Orbit Type: Ee = Equatorial Earth Orbiter; Ei = Inclined Earth Orbiter; Ep = Polar Earth Orbiter; Es = Sun Synchronous Earth Orbiter; G = Geostationary; H = High Elliptical Earth Orbit; R = Earth orbiter Relay; O = Other orbit type (specify in remarks)

- These tables were initially prepared for the Interagency Operations Advisory Group (IOAG), and then updated for the International Committee on GNSS (IGS)
- The objective for these reference tables is to ensure the space user community does not remain vulnerable when using other GNSS constellations for space applications
- Space agency stakeholders need to provide user requirements to GNSS/PNT service providers now -- before Performance Standards and Interface Specifications are finalized. Space agencies are positioned to help GNSS service providers plan for provision of PNT signals to support space users out to GEO/GSO altitudes
- NASA has been recommending that space agencies define their space user performance needs for their respective GNSS constellations, and strengthen collaboration with other international bodies such as ICG to ensure implementation of such capabilities
- As a result of these efforts, the *Joint Statement* issued at the 8th meeting of the ICG included language on the GNSS SSV: (http://www.unoosa.org/pdf/icg/2013/icg-8/ICG-8_JointStatement.pdf)

UNOOSA United Nations Office for Outer Space Affairs

ICG International Committee on Global Navigation Satellite Systems

Conclusions
(Chart 1 of 2)

- For the commercial and space science community to exploit the full potential of GNSS in space, it is crucial for the international GNSS to develop an interoperable, sustained, and quantified GNSS Capability that provides robust PNT support to users throughout the SSV
- The U.S. GPS partners have made significant steps in accomplishing this through the specification of the SSV, publication of GPS antenna patterns and open discussions on on-orbit experiment results
- Others are starting to follow the U.S. lead, but formal documentation and GNSS specifications are still forthcoming

Conclusions
(Chart 2 of 2)

- Partners should work aggressively to complete the ICG-8 WG-B recommendations:
  - **SSV Template Completion**: recommend all providers complete and formally submit SSV template (Russia, China, Japan completed, but not formally submitted, the templates)
  - **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

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Backups

Specifications (1): Received Signal Power

Signal	Terrestrial Minimum Power (dBW)	SSV Minimum Power (dBW)*	Reference Half-beamwidth
L1 C/A	-158.5	-184.0	23.5
L1C	-157.0	-182.5	23.5
L2C	-158.5	-183.0	26
L5	-157.0	-182.0	26

(*) SSV Minimum power from a 0 dBiC antenna at GEO

- 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 specifications at reference off-nadir point

Specifications (2): Pseudorange Accuracy

- In the Terrestrial Service Volume, a position accuracy is specified. In the Space Service Volume, pseudorange accuracy is specified.
- Position accuracy within the space service volume is dependent on many mission specific factors, which are unique to this class of user, such as user spacecraft orbit, CONOPS, navigation algorithm, and User Equipment
- Specification: The space service volume pseudorange accuracy shall be ≤ 0.8 m (rms) (**Threshold**); and ≤ 0.2 m (rms) (**Objective**)
- In order for GPS to meet the SSV accuracy requirement, additional data must be provided to users:
  - The group delay differential parameters for the radiated signal with respect to the Earth Coverage
- To better clarify the pseudorange accuracy specification, it is suggested that partners consider the following in lieu of the above pseudorange accuracy specification:
  - Pseudorange specification: The space service volume maximum systematic error in pseudorange shall be ≤ 0.8 m (rms) (**Threshold**); and ≤ 0.2 m (rms) (**Objective**)
- Also, the following Carrier Phase specification is suggested:
  - Carrier Phase specification: The space service volume maximum systematic error in carrier phase shall be ≤ 8 mm (rms) (**Threshold**); and ≤ 2 mm (rms) (**Objective**)

Specifications (3): Signal Availability

- 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 should be as follows:

	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:
  - MEO SSV: 4 GPS satellites always in view
  - HEO and GEO SSV: at least 1 GPS satellite always in view