NASA's Role in Protecting National GPS Investments

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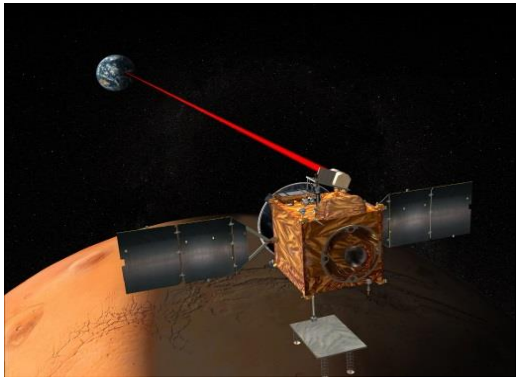
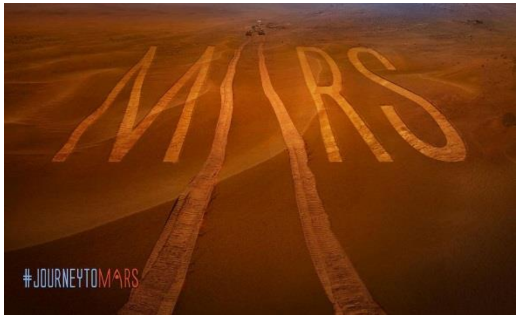
Secure World Foundation – 8 April 2016

Spectrum Protection: An Examination of the Policy and Practical Implications

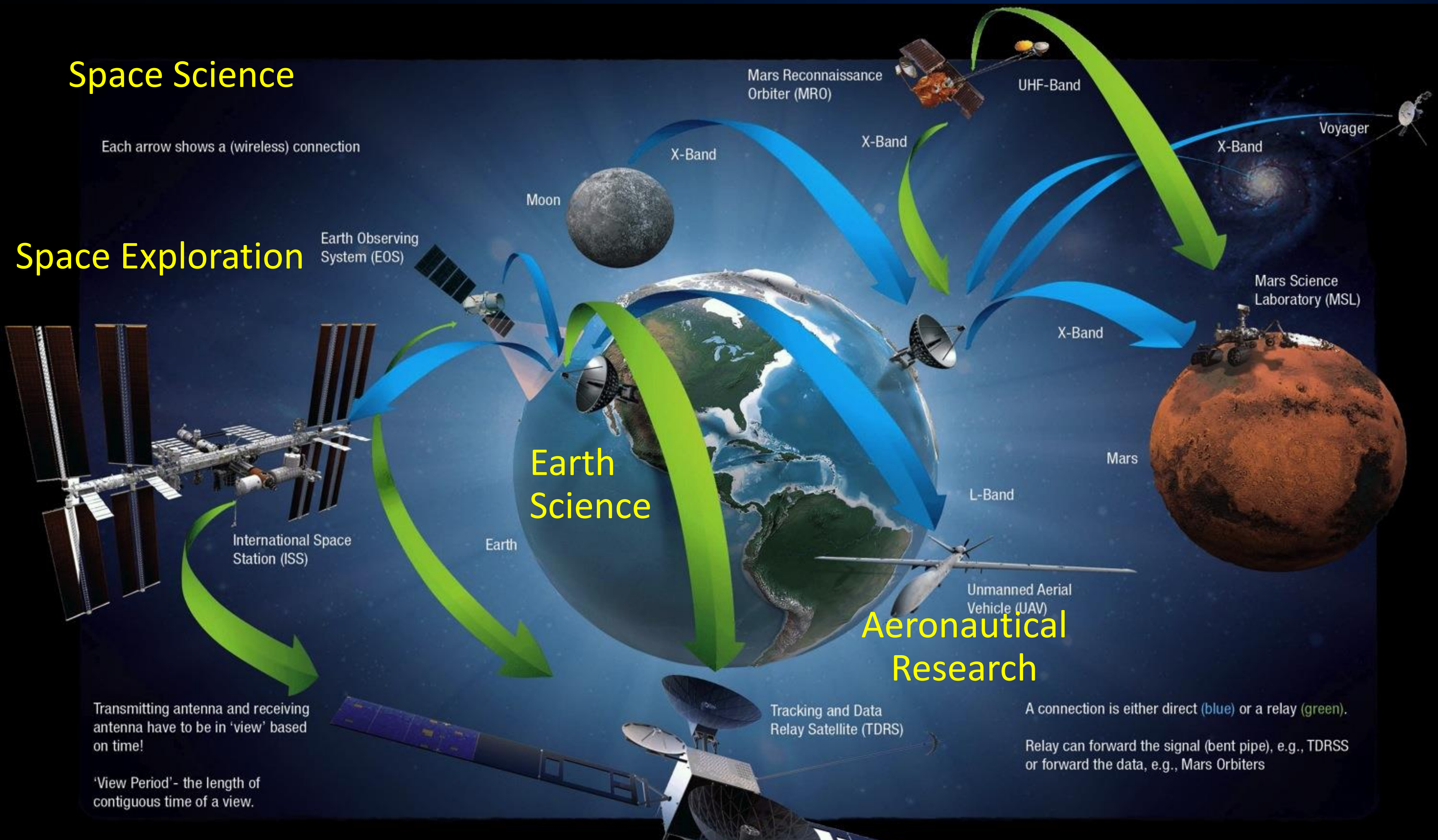
SCaN Oversees NASA Infrastructure for Space Communications and Navigation





- The Space Communications and Navigation (SCaN) program is responsible for providing worldwide communications & navigation services to enable and enhance robotic and human exploration and science missions
- SCaN leads in enabling NASA's overall navigation capabilities through:
  - standards development
  - systems engineering
  - architecture integration
  - technology R&D
  - national policy advocacy
  - international interoperability
  - spectrum coordination
- Use of GPS/GNSS as another position and time source allows NASA to maximize the "autonomy" of spacecraft while reducing the burden on network operations and enabling countless science applications

Why Is Spectrum Important to NASA?



Virtually every NASA mission requires radio spectrum

NASA Spectrum Management
Policy and Program Functions

- **NASA Spectrum Division** led by Vic Sparrow in SCaN/HEO
- **NASA Spectrum Management Program** provides overall planning, policy coordination and implementation necessary to ensure adequate ***access to*** and ***protection of*** spectrum in support of NASA programs
- Ensure NASA system operations and spectrum usage are **in compliance** with Federal regulatory policies
  - Coordinates with and informs NASA stakeholder community, including international partners
  - Advances NASA's strategic spectrum requirements and policies in national & international technical and regulatory forums
  - Promotes technology development that ensures efficient & effective use of spectrum
- **Spectrum** & **Policy & Strategic Communications (PSC) Divisions** are partners in preserving GPS spectrum to meet Agency-level needs

Why does NASA care so much about GPS/GNSS?

- **PNT stands for the Positioning, Navigation, and Timing (PNT) services** enabled by the U.S. Global Positioning System (GPS) and it's international constellation counterparts such as GLONASS, Galileo, and BeiDou, collectively known as Global Navigation Satellite Systems (GNSS)

- **GPS is a "Dual-Use" USG system managed by the PNT Executive Committee (EXCOM)** created via Presidential Policy. NASA has a voice in how GPS is governed through its role on the PNT EXCOM at the Deputy Administrator level. SCaN provides technical expertise to NASA leadership on PNT policy issues that affect the Agency.

- **SCaN is responsible for NASA infrastructure required for communications & navigation services**: In addition, SCaN leads in enabling NASA's overall navigation capabilities through standards development, systems engineering, architecture integration, technology R&D, spectrum coordination, international interoperability and national policy advocacy

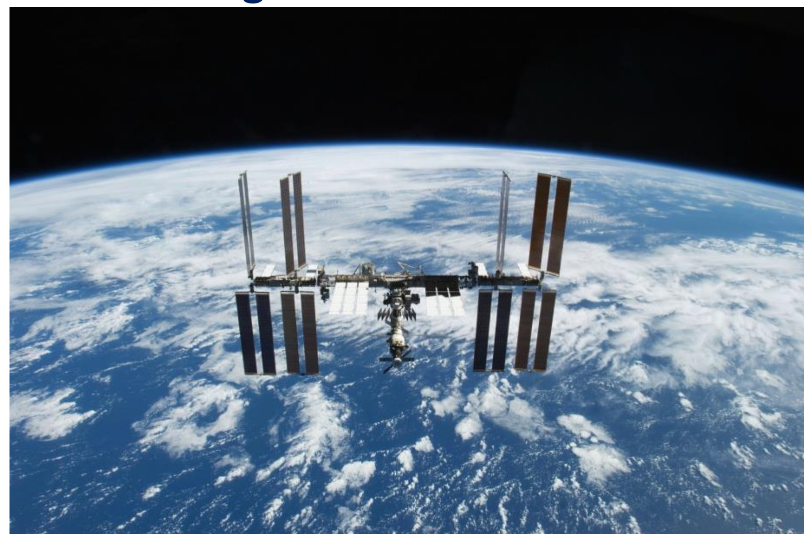
- **Use of GPS/GNSS as another position and time source allows NASA to maximize the "autonomy" of spacecraft and reduces the burden and costs of network operations** that otherwise would be required to maintain two-way communications and tracking. It also enables a myriad of science missions that benefit the nation and the world.

GPS Extends the Reach of NASA Networks to Enable New Space Ops, Science, and Exploration Apps

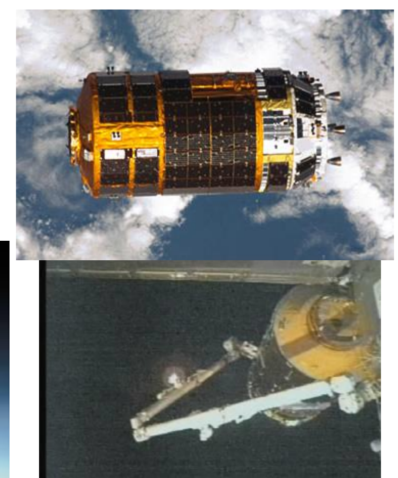
GPS PNT Services Enable:

- **Attitude Determination:** Use of GPS enables some missions to meet their attitude determination requirements, such as ISS
- **Real-time On-Board Navigation:** Enables new methods of spaceflight ops such as precision formation flying, rendezvous & docking, station-keeping, GEO satellite servicing
- **Earth Sciences:** GPS used as a remote sensing tool supports atmospheric and ionospheric sciences, geodesy, and geodynamics -- from monitoring sea levels & ice melt to measuring the gravity field

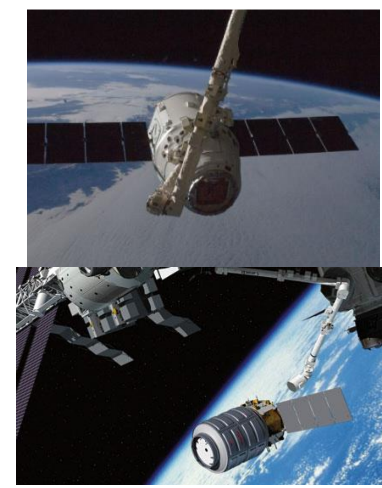
GPS Relative Navigation is used for Rendezvous to ISS



ESA ATV 1st mission to ISS in 2008



JAXA's HTV 1st mission to ISS in 2009



Commercial Cargo Resupply (Space-X & Cygnus), 2012+

GPS and Human Space Flight

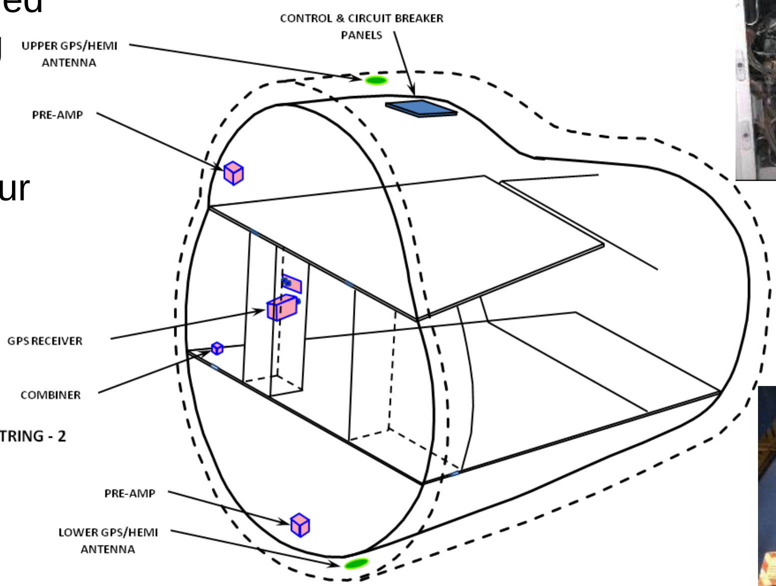
Past, Present, and Future

Space Shuttle Program

- Specialized GPS receivers (MAGR) were designed to accept Inertial Navigation System (INS) aiding
- One GPS receiver (retaining TACAN as backup) was installed on Discovery and Atlantis
- Three GPS receivers were installed on Endeavour (TACAN was removed)

International Space Station (ISS)

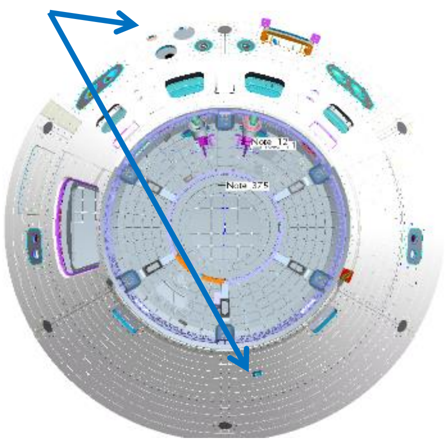
- Combined GPS + INS receiver tested on shuttle flights in April 2002 (STS-110 / Atlantis)
- Four GPS antennas on the ISS truss assembly
- Used for attitude determination
- Relative GPS navigation used for rendezvous of ISS unmanned resupply



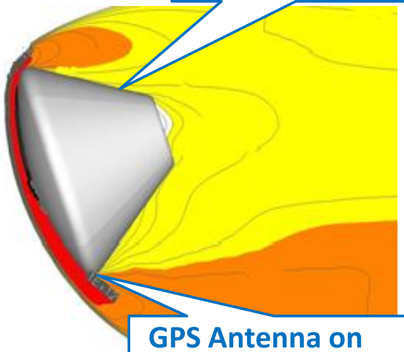
A MAGR installed in Av Bay 3B

The DFT Collins 3M Receiver today

GPS Antennas (2)



GPS Antenna on Windward Side



GPS Antenna on Leeward Side

Honeywell GPS Receiver

Orion

- Two Honeywell GPS receivers integrated with INS
- Highly sensitive RF radio can track weak signals from the GPS constellation half way to the moon
- Orion Exploration Flight Test-1 (1st unmanned flight) launched on Delta-IV in Dec. 2014

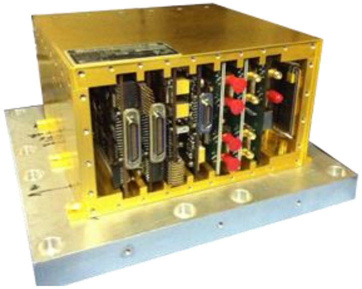
NASA GPS/GNSS Receiver Developments: Navigator & BlackJack "Family"

Goddard Space Flight Center

- Navigator GPS Flight Receiver: GPS L1 C/A
  - 1st flew on Hubble Space Telescope SM4 (May 2009), currently flying on MMS, GOES, GPM, and Orion (commercial version developed by Honeywell)
  - Onboard Kalman filter for orbit/trajectory estimation, fast acquisition, RAD hard, unaided acquisition at 25 dB-Hz
- Possible Future Capabilities
  - High-sensitivity Signal Acquisition and Tracking:
    - Acquisition thresholds down to 10-12 dB-Hz
    - Applicable to HEO, lunar, and cislunar orbits
  - Reception of modernized GPS Signals: L2C and L5
  - GPS-derived Ranging Crosslink Communications
    - Developed for MMS Interspacecraft Ranging and Alarm System (IRAS) to support formation flying
    - Features S-band communications link with code phase ranging, used in formation flying

Jet Propulsion Laboratory

- BlackJack Flight GPS Receiver: GPS L1 C/A, P(Y) and L2 P(Y)
  - Supports: precise orbit determination (JASON, ICESat, SRTM missions), radio occultation science (CHAMP, SAC-C, FedSat, 2 GRACE , 6 COSMIC); gravity field (CHAMP, GRACE); and surface reflections (SAC-C, CHAMP)
  - Over 18 BlackJack receivers launched to-date
- IGOR GPS receiver (commercial version from Broad Reach Engineering)
- CoNNeCT Software Defined Radio: GPS L1 C/A, L2C, L5
- Multi-GNSS Receiver (TriG): GPS L1, L2C, L5, GLONASS, and Galileo
  - Supports: precision orbit determination (cm level positioning, mm/sec level velocity); radio occultation science for weather and climatology; and reflections science applications (in development)
  - In development: Capability to track BeiDou
  - In production since 2013

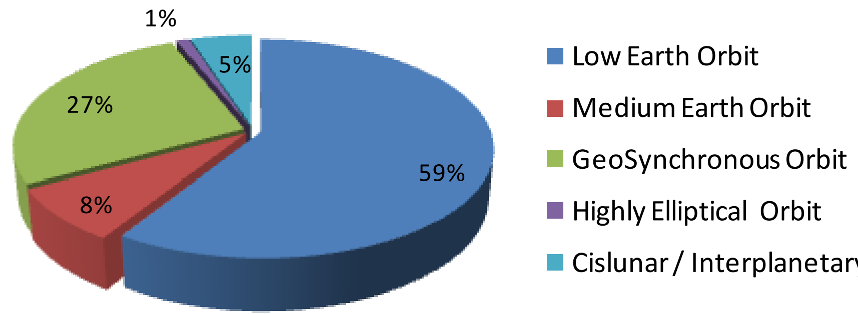


Growing GPS Uses in Space: Space Operations & Science

- NASA strategic navigation requirements for science and space ops continue to grow, especially as higher precisions are needed for more complex operations in all space domains
- **Nearly 60%*** of projected worldwide space missions over the next 20 years will operate in LEO
  - That is, inside the Terrestrial Service Volume (TSV)
- **An additional 35%*** of these space missions that will operate at higher altitudes will remain at or below GEO
  - That is, inside the GPS/GNSS Space Service Volume (SSV)
- In summary, approximately **95% of projected worldwide space missions over the next 20 years** will operate within the *GPS service envelope*

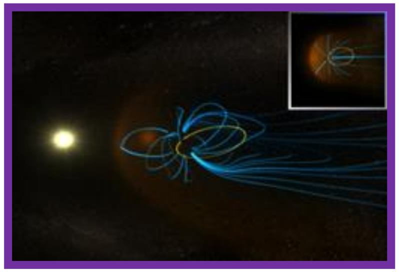
(*) Source: Aerospace America, American Institute of Aeronautics and Astronautics (AIAA), Dec. 2007

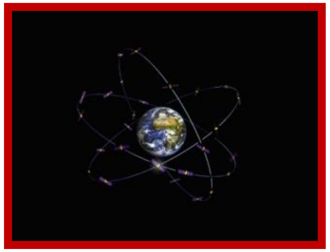
20-Year Worldwide Space Mission Projections by Orbit Type *



Highly Elliptical Orbits*: Example: NASA MMS 4-satellite constellation.

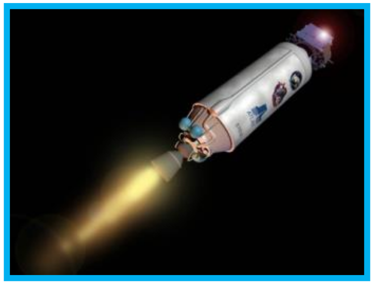
(*) Apogee above GEO/GSO





Medium Earth Orbit: GNSS Constellations, etc.,

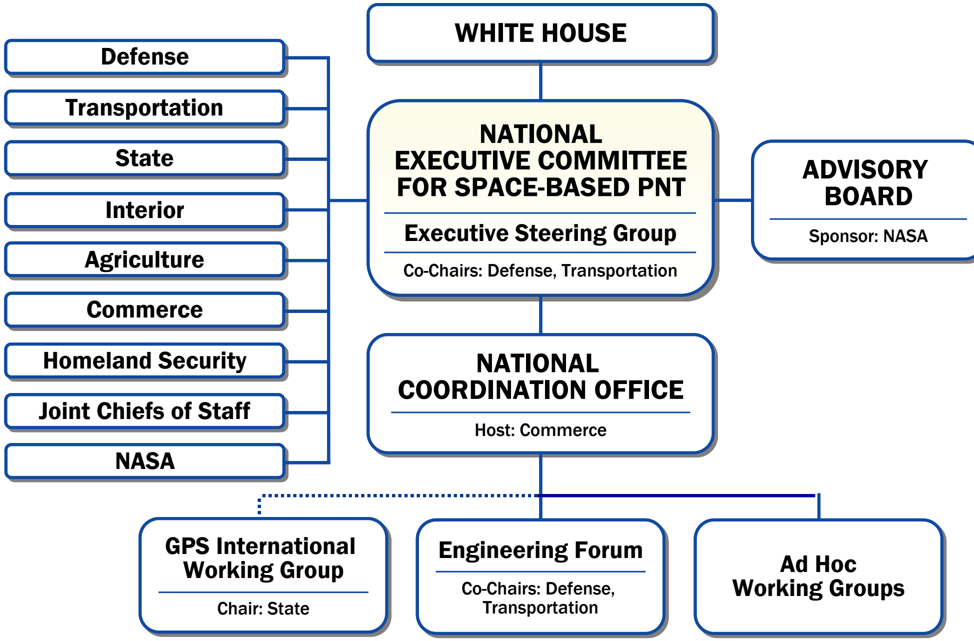
GeoSynchronous: Communication Satellites, etc.,



Orbital Transfers: LEO-to-GSO, cislunar transfer orbit, transplanetary injection, etc.

NASA's Role: U.S. PNT & Space Policy

- The 2004 U.S. Space-Based Positioning, Navigation, and Timing (PNT) Policy tasks the NASA Administrator, in coordination with the Secretary of Commerce, to develop and provide requirements for the use of the Global Positioning System (GPS) and its augmentations to support civil space systems
- The 2010 National Space Policy reaffirms PNT Policy commitments to GPS service provisions, international cooperation, and interference mitigation
  - Foreign PNT services may be used to augment and strengthen the resiliency of GPS
- Besides direct collaboration with interagency partners & foreign space agencies, NASA international engagement is conducted at:
  - Interoperability Plenary (IOP)
  - Interagency Operations Advisory Group (IOAG)
  - Space Frequency Coordination Group (SFCG)
  - Consultative Committee for Space Data Systems (CCSDS)
  - International Telecommunications Union (ITU)
  - International Committee on Global Navigation Satellite Systems (ICG)



U.S. Space-Based PNT Policy Goal & Objectives

GOAL: Ensure the U.S. maintains space-based PNT services, augmentation, back-up, and service denial capabilities that…

- Provide *uninterrupted availability* of PNT services
- Meet growing national, homeland, economic security, and civil requirements, and *scientific* and commercial *demands*
- Remain the *pre-eminent military* space-based PNT service
- Continue to provide *civil services that exceed or are competitive* with foreign civil space-based PNT services and augmentation systems
- Remain essential components of *internationally accepted* PNT services
- Promote U.S. *technological leadership* in applications involving space-based PNT services

2010 U.S. National Space Policy

Space-Based PNT Guideline: Maintain leadership in the service, provision, and use of GNSS

- Provide civil GPS services, free of direct user charges
  - Available on a continuous, worldwide basis
  - Maintain constellation consistent with published performance standards and interface specifications
  - **Foreign PNT services may be used to complement services from GPS**
- Encourage global ***compatibility*** and ***interoperability*** with GPS
- Promote transparency in civil service provisions (*public ICDs, etc.,*)
- Enable market access to industry (*i.e., fight patent claims on L1C*)
- Support international activities to detect and mitigate harmful interference (*coordinate spectrum protection across boundaries*)

2015-2017 PNT Advisory Board Membership

- **John Stenbit (Chair)**, former DoD Chief Information Officer
- **Bradford Parkinson (Vice Chair)**, Stanford University original GPS Program Director
- **James E. Geringer (2nd Vice Chair)**, ESRI Former Governor of Wyoming
- **Thad Allen**, Booz Allen Hamilton retired Commandant of the Coast Guard
- **Penina Axelrad**, University of Colorado, Chair of Department of Aerospace Engineering
- **John Betz**, MITRE, Former Chair Air Force Scientific Advisory Board
- **Dean Brenner**, Vice President, Government Affairs Qualcomm
- **Scott Burgett**, Garmin International
- **Joseph D. Burns**, United Airlines, Former Chief Technical Pilot, United Airlines
- **Per K. Enge**, Stanford University, Head of Stanford Center for PNT
- **Martin C. Faga**, MITRE Retired CEO of Mitre
- **Dana A. Goward**, Resilient Navigation & Timing Foundation, Founde,
- **Ronald R. Hatch**, consultant to John Deere, inventor of the GPS “Hatch” filter
- **Larry James**, Deputy Director, Jet Propulsion Laboratory
- **Peter Marquez**, Planetary Resources, Former White House National Security Space Policy
- **Terence J. McGurn**, private consultant, retired CIA analyst of Position, Navigation and Control
- **Timothy A. Murphy**, The Boeing Company, Technical Fellow with Boeing Commercial Airplane
- **Ruth Neilan**, Jet Propulsion Laboratory, vice chair, Global Geodetic Observing System
- **T. Russell Shields**, Ygomi, a founder of NavTeq
- **Ann Ciganer**, VP Trimble Navigation, Director of GPS Innovation Alliance

International Members:

- **Gerhard Beutler**, Professor of Astronomy and Director of the Astronomical Institute, U. of Bern.
- **Sergio Camacho-Lara**, Regional Centre for Space Science and Technology Education for Latin America and the Caribbean, Mexico
- **Arve Dimmen**, Division Director Maritime Safety Norwegian Coastal Administration (Norway)
- **Matt Higgins**, President International GNSS Society (Australia)
- **Rafaat M. Rashad**, Chairman Arab Institute of Navigation (Egypt)

PNT Advisory Board Focus Areas

- Primary PNTAB Objective:
  - Assured *PNT* for all users
- Current Assessment
  - No current or foreseeable alternative to GNSS (primarily GPS) can deliver equivalent accuracy (to millimeters, 3D) and world wide 24/7 availability
  - But the L-Band signals are very weak
- Therefore our Focus is ***PTA Program***
  - ***P***rotect the radio spectrum + identify + prosecute interferers
  - ***T***oughen GPS receivers against natural and human interference
  - ***A***ugment with additional PNT sources and techniques

PNT Advisory Board
GPS Economic Benefits Assessment

PNTAB GPS Economic Benefits Study

- Requested by the PNT EXCOM after the relative benefits of GPS were questioned by advocates for a new mobile broadband service
  - » In 2010 a certain company sought to "rezone" frequencies near those used by GPS for a terrestrial wireless broadband network
  - » A 2011 Brattle Group study sponsored by a certain company claimed its plan for broadband would "create approximately $12 billion in value to the economy and potentially 10 times that amount in benefits to consumers"
- However, preliminary results of a GPS Economic Benefits Assessment with input from PNT Board sector experts demonstrates that:
  - » Conservative estimates show GPS contributed more than **$68 billion** to the U.S. economy in 2013
  - » GPS boosted the American economy by $37.1 to $74.5 billion dollars in 2013, the most recent year for which data was available, with a mid-range estimate of $68.7 billion
- Future research will work to quantify the international economic benefits of GPS services and the broader economic implications of GPS in the U.S., such as the system's effect on jobs and market prospects going forward

InsideGNSS

Engineering Solutions from the Global Navigation Satellite System Community

Study: GPS Contributed More Than $68 Billion to the U.S. Economy

Latest News

Dee Ann Divis

June 16, 2015

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GPS contributed more than $68 billion to the U.S. economy in 2013, according to the preliminary results of a new study presented to the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board.

And the study's author, Irv Leveson, a consultant to ASCR Federal Research and Technology Solutions, LLC, described that figure as conservative because it did not fully incorporate a host of GPS applications including those depending on GPS timing information.

The study found that GPS boosted the American economy by $37.1 to $74.5 billion dollars in 2013, the most recent year for which data was available, with a mid-range estimate of $68.7 billion. Of that more than $26 billion was from vehicle location services, $13.7 billion was from grain-related precision farming, $11.9 billion was from fleet vehicle connected telematics, $11.6 billion was from surveying, and $5 billion was from GPS-based guidance of earth-moving equipment.

The results were presented to the advisory board, which helped guide the work, at its June 11 meeting.

"This is not just an academic exercise," said Leveson. The research was undertaken, he said, "to have a basis for policy analysis which can be used for looking at the implications of actions such as allowing interference, spectrum sharing [or] reallocation, developing supplementary backup systems and toughening [receivers]."

Closing Remarks

- NASA and other space users increasingly rely on GPS/GNSS over an expanding range of orbital applications to serve Earth populations in countless ways
- GPS services reflect a spectrally efficient way to provide benefits to billions of users
- Since GPS spectrum is considered “beachfront property”, it will always be under threat from the next “cool new app”
- Simply making GPS a victim service by shifting the burden to receivers will not solve the problem – one company’s business plans should not pollute the spectrum allocations we all rely on
- Policy makers and regulators must remain vigilant to continue shaping the operating environment in which GPS operates

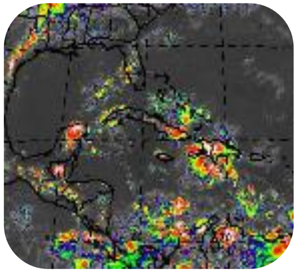
http://www.gps.gov/

Back-Up

NASA Spectrum Management

AGENCY SPECTRUM MANAGEMENT

- **Spectrum access/use is absolutely vital to scientific/aeronautics communities**
- **Spectrum is a highly valued regulated resource**
- **Spectrum is limited – subject to continuous scrutiny and competition for its use**
- **Requirement for NASA Spectrum Management codified in Federal law**
  - Communications Act of 1934
  - Communications Satellite Act of 1962
  - Commercialization of Space Act of 1983
  - National Space Policy (classified/non-classified)
- **Responsibility for Agency Spectrum Management vested in SCaN**
  - Agency Spectrum Manager is AA/HEOMD
  - NASA Policy Directive 2570.5E
  - Director Spectrum Policy responsible for program execution
  - Ensure spectrum is available for current and planned missions
- **Domestic Spectrum Management a bifurcated mandated process**
  - Federal Communications Commission (FCC)
  - National Telecommunications and Information Administration (NTIA)
- **International Spectrum Management**
  - International Telecommunications Union (ITU) - treaty based
    - World Radiocommunication Conference (WRC)
  - Space Frequency Coordination Group (SFCG)
  - Regional coordination with CITEL



The National Players

COMMUNICATIONS ACT OF 1934
Telecom Authorization Act of 1992

The PRESIDENT

National Telecommunications and Information Administration (NTIA)

The JUDICIARY

COORDINATION

The CONGRESS

Federal Communications Commission (FCC)

(ADVISORY)

(LIAISON)

NTIA Chairs IRAC and The Subcommittees

INTERDEPARTMENT RADIO ADVISORY COMMITTEE (IRAC)

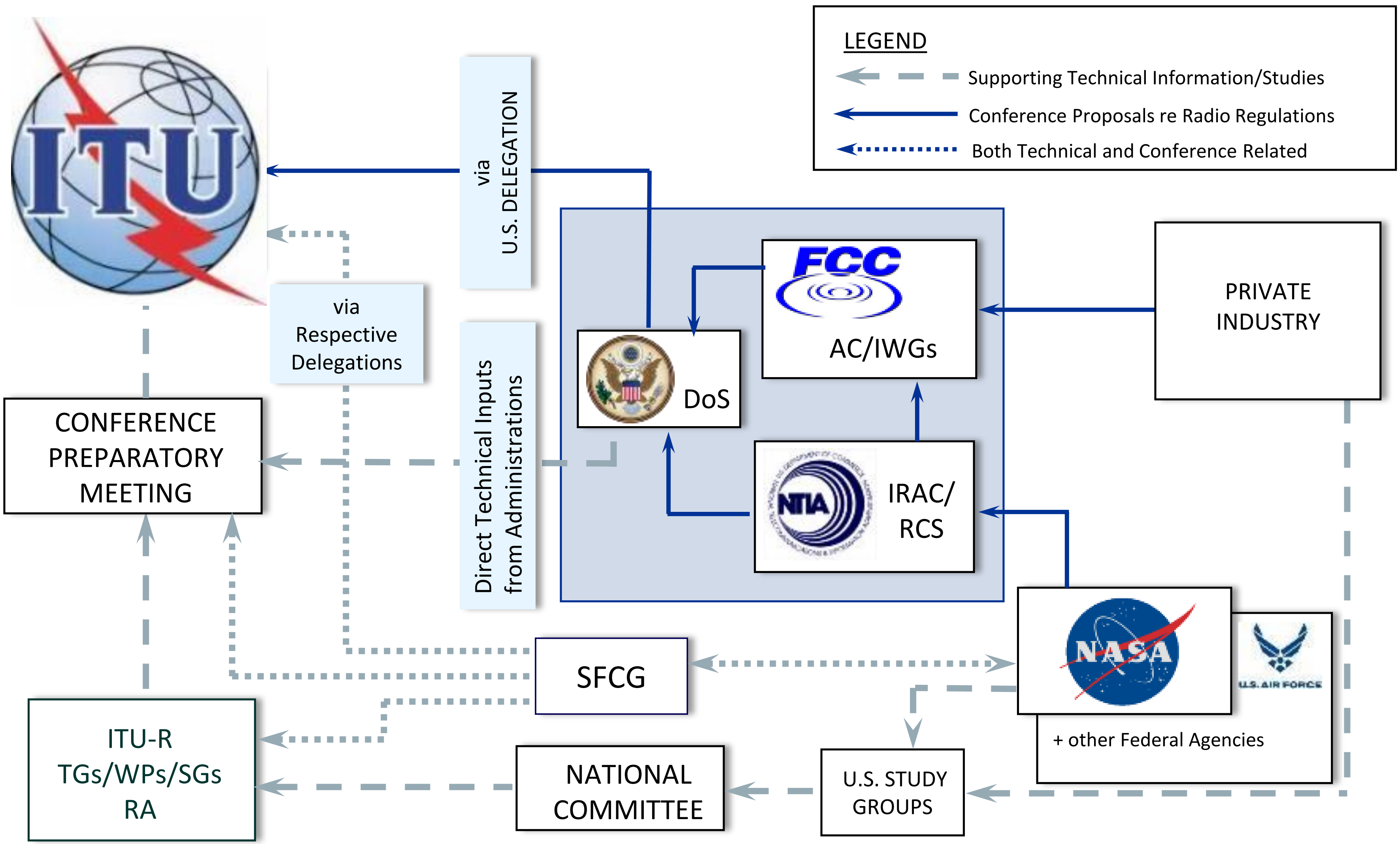
20 Government Departments/ Agencies are Members, including

Private Industry

State and Local Governments

- **Frequency Assignment Subcommittee**
- **Spectrum Planning Subcommittee**
- **Technical Subcommittee**
- **Radio Conference Subcommittee**
- **Space Systems Subcommittee**

International Spectrum Management Process



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

Updated Oct. 2015

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
1	ASI	COSMO SKYMED (CSK)	GPS	L1/L2 C/A, P(Y)	Precise Orbit Determinatin (POD), Time	Es	2007, 2008, 2010	4 satellites
2	ASI	COSMO SKYMED SECOND GENERATION (CSG)	GPS, Galileo Ready	L1/L2/L2C (GPS) ready for E1 (Galileo)	Precise Orbit Determinatin (POD), Time	Es	2018 1st SAT, 2019 2nd SAT	2 satellites
3	ASI	AGILE	GPS	L1 C/A	Orbit, Time	Ee	2007	
4	ASI	PRISMA	GPS		Orbit, Time	Es	2018	
5	CNES	CALIPSO	GPS	L1 C/A	Orbit, Time	Es	2006	CNES controls the in flight satellite .
6	CNES	COROT	GPS	L1 C/A	Orbit, Time	Ep (90°)	2006	CNES controls the in flight satellite .
7	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)
8	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.
9	CNES	ELISA	GPS	L1 C/A	Orbit, Time	Es	2011	The system is with four satellites launched in Dec 2011. Receiver: MOSAIC
10	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)
11	CNES	MICROSCOPE	GPS, Galileo	L1 C/A, E1	Precise Orbit Determinatin (POD), Time	Es	2016	One satellite to be launched in 2016 Receiver: SKYLOC
12	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
13	CNES	MERLIN	GPS, Galileo	L1 C/A, E1	Orbit, Time	Es (TBC)	2018	Receiver : not yet decided
14	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
15	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.
16	DLR	TSX-1	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO, precsie relative determination	Es	15-Jun-2007	
17	DLR	TDX-1	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO, precsie relative determination	Es	21-Jun-2010	
18	DLR	TET	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support)	Ep	22-July-2012	
19	DLR	TET NOX experiment	GPS	GPS L1 C/A, L1/L2 P(Y)	Experiment (POD, RO)	Ep	22-July-2012	
20	DLR	BIROS	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support)	Ep	2015	

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

Updated Oct. 2015

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
21	DLR	HAG-1	GPS	GPS L1 C/A	Experiment (navigation)	G	2014	GPS used for on-board experiment
22	DLR	Eu:CROPIS	GPS	GPS L1 C/A	navigation, flight dynamics	Ep	2016	
23	DLR	ENMAP	GPS			Ep	2017	
24	DLR/NASA	GRACE_FO	GPS GLO/GAL?)	GPS L1 C/A, L1/L2 P(Y), (others?)	Navigation, POD	Ep	2018	Joint mission with NASA.
25	DLR	DEOS	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support), relative navigation (formation flight/ rendezvous)	Ep	2017	
26	DLR	Electra	GPS		orbit determination	G	2018	
27	DLR	PAZ	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD	Ep	2014	Same as TSX
28	ESA	SWARM			POD	LEO	2013	Magnetosphere, 3 spacecraft
29	ESA	Earth Care			Orbit	LEO	2018	
30	ESA	BIOMASS					2020	SAR
31	ESA	Sentinel S1			Orbit, POD	LEO	2014 / 16	SAR, 2 spacecraft
32	ESA	Sentinel S2			Orbit	LEO	2015	Imager, 2 spacecraft
33	ESA	Sentinel S3			Orbit, POD	LEO	2015	Altimetry & Imager, 2 spacecraft
34	ESA	Sentinel S4				LEO		UV Spectrometry
35	ESA	Proba 2			Orbit	LEO	2009	Tech Demo
36	ESA	Proba 3			FF	HEO	2019	FF Demo, 2 spacecraft
37	ESA	Small GEO			Orbit, Time	GEO	2015	Telecom
38	ESA	FLEX				LEO	2022	Florescence Explorer
39	ESA	JASON-CS				LEO	2017	Altimetry
40	ESA	METOP			Radio Occultation	LEO	2012 / 18	Atmospheric Sounder, 2 spacecraft

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

Updated Oct. 2015

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
41	ESA	MTG			Orbit, Time	GEO	2018 / 19	IR Sounder & Imager, 2 spacecraft
42	ESA	Post EPS					2021/27/33	3 spacecraft
43	JAXA	GOSAT	GPS	L1	Orbit, time	LEO	2009-present	Remote Sensing
44	JAXA	GCOM-W1	GPS	L1	Orbit, time	LEO	2012-present	Remote Sensing
45	JAXA	GCOM-C1	GPS	L1	Orbit, time	LEO	2016	Remote Sensing
46	JAXA	ALOS-2	GPS	L1, L2	Precise orbit （3σ<1m), Orbit, time,	LEO	2013	Remote Sensing
47	JAXA	HTV-series	GPS	L1	Orbit(relative)	LEO	2009-present	Unmanned ISS transportation
48	JAXA	GOSAT-2	GPS	L1, L2 (TBD)	Orbit, time	LEO	2017	Remote Sensing
49	JAXA	ASTRO-H	GPS	L1, L2	Orbit, time	LEO	2015	Remote Sensing
50	NASA	ISS	GPS	L1 C/A	Attitude Dynamics	LEO	Since 1998	Honeywell SIGI receiver
51	NASA	COSMIC (6 satellites)	GPS	L1 C/A, L1/L2 semicodeless, L2C	Radio Occultation	LEO	2006	IGOR (BlackJack) receiver; spacecraft nearing end of life
52	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
53	NASA	IceSat	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination	LEO	2003	BlackJack receiver; mission retired 14 August 2010
54	NASA	GRACE (2 satellites)	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination, Occultation	LEO	2002	BlackJack receiver, joint mission with DLR
55	CNES/NASA	OSTM/Jason 2	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination	LEO	2008	BlackJack receiver
56	NASA	Landsat-8	GPS	L1 C/A	Orbit	LEO	2013	GD Viceroy receiver
57	NASA	ISS Commercial Crew and Cargo Program - Dragon	GPS	L1 C/A	Orbit / ISS rendezvous	LEO	2013+	
58	NASA	ISS Commercial Crew and Cargo Program: Cygnus	GPS	L1 C/A	Orbit / ISS rendezvous	LEO	2013+	
59	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.
60	NASA	GPM	GPS	L1 C/A	Orbit, time	LEO	2014	Navigator receiver

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

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N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes
61	NASA	Orion/MPCV	GPS	L1 C/A	Orbit / navigation	LEO	2014 - Earth Orbit, 2017 Cislunar	Honeywell Aerospace Electronic Systems 'GPSR' receiver
62	NSPO/USAF/NASA	COSMIC IIA (6 satellites)	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Occultation	LEO	2015	TriG receiver, 8 RF inputs, hardware all-GNSS capable, will track GPS + GLONASS at launch
63	NASA	DSAC	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Time transfer	LEO	2015	TriG lite receiver
64	CNES/NASA	Jason-3	GPS, GLONASS FDMA	L1 C/A, L1/L2 semicodeless, L2C	Precise Orbit Determination, Oceanography	LEO	2015	IGOR+ (BlackJack) receiver
65	NASA	MMS	GPS	L1 C/A	Rel. range, orbit, time	up to 30 Earth radii	2015	Navigator receiver (8 receivers)
66	NASA	GOES-R	GPS	L1 C/A	Orbit	GEO	2016	General Dynamics Viceroy-4
67	NASA	ICESat-2	GPS	-	-	LEO	2016	RUAG Space receiver
68	NASA	CYGNSS (8 sats)	GPS	-	GPS bi-scatterometry	LEO	2016	Delay Mapping Receiver (DMR), SSTL UK
69	NSPO/USAF/NASA	COSMIC IIB (6 satellites)	GPS, GLONASS FDMA, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Occultation	LEO	2017	TriG receiver
70	NASA/DLR	GRACE FO	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Occultation, precision orbit, time	LEO	2018	TriG receiver with microwave ranging, joint mission with DLR
71	NASA	Jason-CS	GPS, GLONASS FDMA, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Precise Orbit Determination	LEO	2020	TriG receiver with 1553
72	NASA	GRASP	GPS, GLONASS FDMA, Beudou, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Precise Orbit Determination	LEO	2017	Trig receiver (proposed)
73	NASA	GRACE II	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Science	LEO	2020	Trig receiver (proposed)
74	NASA	NICER (ISS)	GPS	L1 C/A	Orbit	LEO	2016	Moog/Navigator receiver
75	NASA	Pegasus Launcher	GPS	L1 C/A	Navigation	Surface to LEO	Since 1990	Trimble receiver
76	NASA	Antares (formerly Taurus II) Launcher	GPS	L1 C/A	Integrated Inertial Navigation System (INS) & GPS	Surface to LEO	Since 2010	Orbital GPB receiver
77	NASA	Falcon-9 Launcher	GPS	L1 C/A	Overlay to INS for additional orbit insertion accuracy	Surface to LEO	Since 2013	
78	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.
79	NASA	NISAR	GPS, GLONASS, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Precise Orbit Determination, timing	LEO	2020	TriG Lite receiver
80	NASA	SWOT	GPS, GLONASS FDMA	L1 C/A, L2C, L5, Galileo, GLONASS FDMA	Precise Orbit Determination - Real Time	LEO	2020	TriG Lite receiver with 1553