Report from Interagency Operations Advisory Group (IOAG) to ICG

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Co-Chairs of ICG WG-B Space Use Subgroup

Providers' Forum, 6 June 2022

International Committee on Global Navigation Satellite Systems

IOAG ROLE

The IOAG (Interagency Operations Advisory Group) provides a forum for **identifying common needs across multiple international agencies** for coordinating space communications policy, high-level procedures, technical interfaces, and other matters related to interoperability and space communications. Its goals are to:

- Enable safe, secure, and efficient interoperable mission operations;
- Enable higher rate throughput for space missions;
- Enable responsive networks around the Earth, Moon, and Mars to enable future exploration and science missions.

The IOAG was founded by the Interoperability Plenary (IOP) to:

- Understand issues related to interagency interoperability and other space communications matters;
- Identify common solutions complying with IOP guidance;
- Recommend resolutions to the IOP for specific actions created by the IOP and put to the IOAG.

IOAG
Interagency Operations Advisory Group

Members

Agenzia Spaziale Italiana
CENTRE NATIONAL D'ÉTUDES SPATIALES
CSA ASC
DLR
esa
JAXA
Explore to Realize
NASA
UK SPACE AGENCY

Observers

Australian Space Agency
CNSA
इसरो isro
KARI
ROSCOSMOS
United Arab Emirates

WORKING GROUPS

IOAG members are divided into working groups that meet independently and deliver reports and updates to all delegates at IOAG meetings.

- Coding and Modulation Working Group (C&MWG)
- Low Earth Orbit 26 GHz Group (LEO26WG)
- Lunar Communications Architecture Working Group (LCAWG)
- Lunar-Mars Working Group (LMWG)
- Mars and Beyond Communication Architecture Working Group (MBC-AWG)
- Mission Operations Systems Coordination Group (MOSCG)
- Mission Operations Systems Strategy Group (MOSSG)
- Optical Link Study Group (OLSG)
- Service Catalog Working Group (SCWG)
- Space Internetworking Strategy Group (SISG)
- Space Operations Sustainability Working Group (SOSWG)
- Spacecraft Emergency Cross Support Working Group (SECSWG)

Active
Dormant
Closed

IOAG
Interagency Operations Advisory Group

ACTIVITIES UPDATE

IOAG-25

- 25th IOAG annual meeting held 23-25 May 2022
  - European Space Operations Center (ESOC), Darmstadt, Germany
- Minutes of Meeting, actions, etc. under development

- IOAG-ICG liaison briefing provided by Joel Parker/NASA and Werner Enderle/ESA
  - Overview of ICG
  - Activities of ICG WG-B Space Use Subgroup
  - Potential areas of coordination between ICG and IOAG
- This presentation captures key content

International Committee on GNSS (ICG)

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

WG-S
Systems, Signals and Services

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

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

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

Applications Subgroup

Space Use Subgroup

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

WG-D
Geodetic Reference, Time Reference and Applications

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

WG-C
Information Dissemination and Capacity Building

Major Topics
- Training and Seminars
- Information Material

(Subgroups of WG-S, WG-D, WG-C not shown.)

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

- As adopted 15 Apr 2021

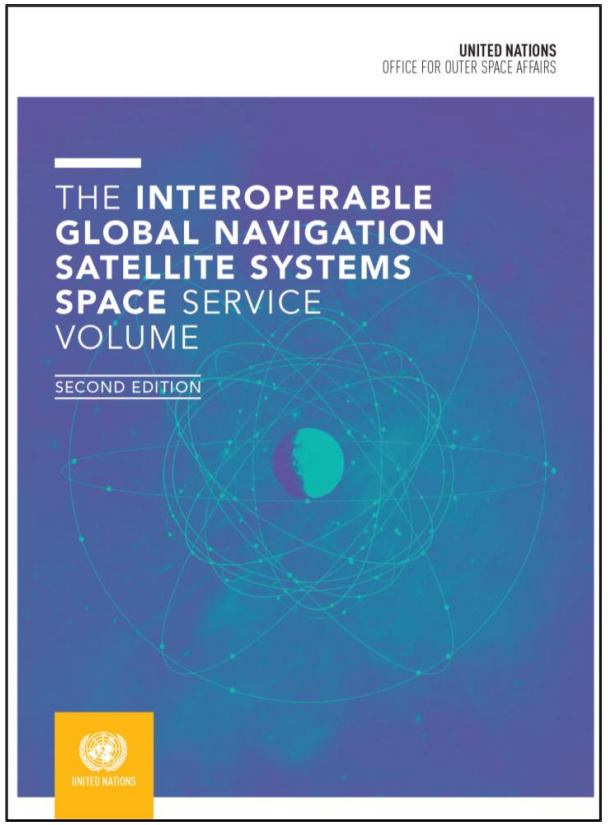
Objectives of Space Use Subgroup:

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

- The Space Use Subgroup operates within the scope of the overall ICG Terms of Reference.
  - https://www.unoosa.org/documents/pdf/icg/2021/ICG15/ICG_ToR2021amended.pdf

Space Users Subgroup (SUSG) – Accomplishments

- **SSV Booklet 2nd Edition**
  - Full revision and update of all chapters
  - New content:
    - GNSS constellation updates
    - new Flight Experiences chapter featuring five real-world missions
    - additional analysis of geometric aspects of SSV
  - **Published at ICG-15**
  - Available at: https://undocs.org/ST/SPACE/75/REV.1



- **SSV Video**
  - Four minute video, developed as an outreach tool to:
    - Explain utility and benefits of a multi-GNSS SSV
    - Show how it will transform navigation use in space, and
    - Describe how it will impact humanity—in space and on Earth
  - Co-Sponsors: NASA and National Coordination Office for Space-based Positioning, Navigation and Timing
  - **Published at ICG-15**
  - Available at: https://www.unoosa.org/oosa/en/ourwork/icg/documents/videos.html

Space Use Subgroup Work Plan 2021-2022

Adopted 24 Sep 2021 at ICG-15

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

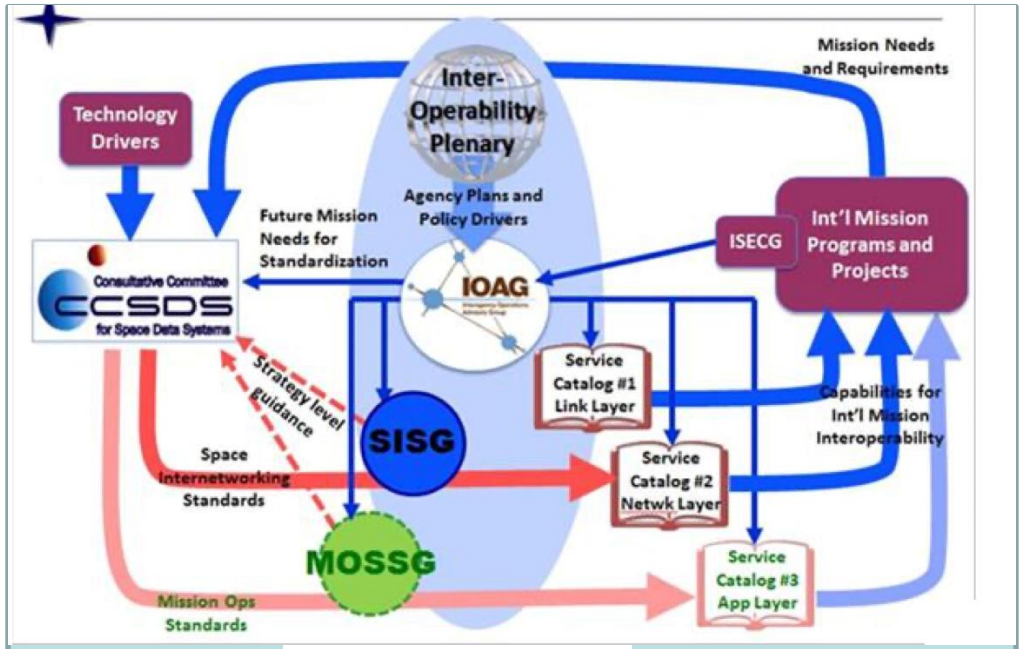
ICG WG-B SUSG
AREAS FOR COORDINATION

Background

- Different activities related to standards and definitions for GNSS usage for space applications are currently ongoing within various international groups which are partially overlapping
  - Within ICG WG-B Space Use Subgroup (SUSG):
    - WP3 – GNSS space user timing requirement analysis and space user operations recommendations
    - WP4 – Expansion of GNSS SSV to Support Lunar Operations
    - WP5 – GNSS Space User Standards
  - IOAG
  - Space Frequency Coordination Group
  - Lunar architecture definitions:
    - NASA LunaNet
    - ESA Moonlight
  - Others

- The objectives of this presentation are to:
  - To clarify the understanding of the roles of the ICG SUSG work packages and their contributions to international team coordination
  - To outline potential roles of ICG in coordination with other organizations (e.g. IOAG, SFCG)

Need for Coordination between IOAG and ICG-Space Use Subgroup



IOAG Organization : (15)

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

Coordination to ensure

- Compatibility
- Interoperability
- Availability

GNSS Service Providers Forum

ICG Working Groups

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

Members

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

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

Associate Members

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

Observers

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

WP 3 - GNSS Space User Timing Requirements

Activity objective:

- Perform analysis to develop a GNSS space user timing requirement analysis and develop GNSS space user timing operational recommendations

Approach:

a) Work to collect space user requirements for timing interoperability
b) Work with WG-D and develop proposed timing interoperability solutions
c) Present to SUSG for approval, rejection or modification
d) Socialize ideas with international providers
e) Action: Include/coordinate with other ICG time-related WGs

Activity outcome:

- Development of space user timing capabilities and requirements; space user operations recommendations

WP 5 - GNSS Space Use Standards

Activity objective:

- Work with other organizations (e.g, IOAG/CCSDS) on space user standards that will improve GNSS SSV interoperability and acceptance as an international standard

Approach:

- Collect requirements from different space users communities
  - Space agencies, Scientific, Commercial, Institutional/Governmental (none military), Mega Constellations, Universities, Regulations for Space Debris
- Review of existing standards in different domains related to GNSS space usage
  - CCSDS (space agencies)
  - NMEA – maritime applications
  - IGS (Scientific, Institutions/Organizations/Government, Industry)
    - RINEX for off-line processing
    - State Space Representation (SSR) – Real Time processing (used for RT high accuracy positioning)
- Develop proposals for GNSS Space User Standards
- Socialize ideas with international providers
- Work requisite standards organizations to determine their interest in in proposed standards;
- Identify joint projects/opportunities in order to conduct tests/demonstrations in space (e.g. usage of Cubsats)
- Present proposed standards to SUSG for approval, rejection or modification;
- Submit formal proposal for GNSS Space User Standard to selected standardization body and support implementation of standard

Activity outcome:

Proposal for GNSS space user Standards

WP 4 - Expansion of GNSS SSV to Support Lunar Operations

Primary goals:

- Maximize interoperability, compatibility and availability of **all** internationally developed Positioning, Navigation and Timing (PNT) resources on and in the vicinity of the moon
- Leverage expertise of GNSS SSV space use team to research, analyze and recommend definitions, user base, capabilities and architectures for lunar operations
  - System of systems approach needed to optimally employ Earth-centric GNSS capabilities with an expanding, evolving lunar-centric PNT capability
  - Operational use of GNSS and Lunar PNT systems during transit operations for robust PNT continuity will require special attention

ICG Terms of Reference:

- ICG provides recommendations; other organizations (e.g., IOAG, SFCG, space agencies) act on recommendations at their discretion.

Phased Expansion of Lunar PNT

GNSS-only Lunar demonstrations → GNSS Lunar Operations → GNSS + Lunar PNT Service Demos → Broad Infusion

Relative use of signal sources

Terrestrial GNSS

Lunar PNT Services (e.g. LunaNet)

Today

Time

Transit use of GNSS and Lunar PNT Services

GNSS Use

Lunar PNT Use

Lunar PNT Services (e.g. LunaNet)

Transit Distance

WP 4 - Expansion of GNSS SSV to Support Lunar Operations

- **WP4 Activities**
  - **Lunar PNT Frequency and Code Coordination**: Work with the Space Frequency Coordination Group (SFCG) to coordinate use of existing Earth-based GNSS L-band receive frequencies and transmit bands/frequencies and planned signal codes for proposed Lunar-based PNT systems, beacons and augmentations
  - **Lunar Use Cases**: Collect international lunar PNT use cases encompassing key present and expected future cis-lunar region missions and develop initial set of user performance needs for lunar PNT missions
  - **Lunar SSV Definition**: Develop a draft Lunar SSV definition and other relevant lunar PNT definitions; coordinate effort with international standards bodies (e.g. IOAG)
  - **Lunar PNT flight experiments**: Encourage lunar flight experiments employing Earth-based GNSS and/or Lunar PNT capabilities to gain an understanding of the performance and limitations of these systems; publish results and lessons learned
  - **Lunar PNT Architectures**: Research, analyze and recommend PNT system architectures, employing Earth-based GNSS and Lunar PNT capabilities, that are interoperable, compatible, available and support current and future user needs; highly leverage already performed work
  - **Lunar reference frame**: Work with international organizations to develop and coordinate Lunar reference frames

ICG WG-B SUSG Potential Areas of Coordination

- Continue current activities:
  - Liaison role with IOAG
  - Contribute to GNSS mission tables to support understanding of Earth-based GNSS use cases and mission applications
- Establish necessary liaison roles with SFCG, ISECG, etc.
- Collect and document lunar use cases
  - Contribute to expanded GNSS mission tables to included proposed missions that require lunar GNSS or PNT
- Encourage and consolidate results of lunar flight experiments using GNSS and lunar PNT systems
- Study and make recommendations to maximize compatibility, interoperability and availability of combined GNSS + lunar PNT “system of systems”, including:
  - Coordination of frequencies and codes
  - Service volume definitions
  - Combined lunar PNT architectures
  - Signal compatibility and interoperability
  - Reference frames and timing

Conclusions

- The ICG, via its WG-B Space Use Subgroup (SUSG), is working for greater representation of space user PNT needs.
  - Seeking to maximize compatibility, interoperability and availability of combined GNSS and lunar PNT services.

- SUSG has adopted a Work Plan for 2021 onwards that features significant efforts in areas that need coordination:
  - GNSS Space User Requirements for Timing
  - GNSS Space User Standards
  - Expansion of GNSS SSV to Support Lunar Operations

- ICG sees clear benefits to robust coordination with IOAG in addition to SFCG, ISECG, etc. in multiple areas to enhance the overall lunar PNT architecture.

BACKUP

IOAG GNSS Mission Table

Aggregate Table of IOAG Missions that Rely on GNSS signals

Last updated on 2022-May-20 (IOAG-25)

Active Missions:

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes	Last Updated	Updated By	Notes
1	ASI	COSMO SKYMED (CSK)	GPS	L1/L2 C/A, P(Y)	Precise Orbit Determinatin (POD), Time	Es	2007, 2008, 2010	4 satellites	2015-Oct-08	F.D'AMICO	Updated/Verified IOAG-24
2	ASI	COSMO SKYMED SECOND GENERATION (CSG)	GPS, Galileo Ready	L1/L2/L2C (GPS) ready for E1 (Galileo)	Precise Orbit Determinatin (POD), Time	Es	2019 1st SAT, 2021 2nd SAT	The first Flight Unit of CSG was launched on Dec 18, 2019. The satellite is in operations. It orbits in the same orbital plane of CSK satellites. The launch of the second Flight Unit of CSG is scheduled on 2021 with a VEGA-C rocket from ESA Kourou spaceport.	2020-09-04	F.D'AMICO	
3	ASI	AGILE	GPS	L1 C/A	Orbit, Time	Ee	2007		2015-Oct-08	F.D'AMICO	
4	ASI	PRISMA	GPS		Orbit, Time	Es	2019	The launch was Mar 22, 2019. The satellite is in operations.	2020-09-04	F.D'AMICO	
5	CNES	CALIPSO	GPS	L1 C/A	Orbit, Time	Es	2006	CNES controls the in flight satellite .	2014-Apr-23	JMS	Updated/Verified IOAG-24
6	CNES	COROT	GPS	L1 C/A	Orbit, Time	Ep (90°)	2006	CNES controls the in flight satellite .	2014-Apr-23	JMS	
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)	2014-Apr-23	JMS	
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.	2014-Apr-23	JMS	
9	CNES	ELISA	GPS	L1 C/A	Orbit, Time	Es	2011	The system is with four satellites launched in Dec 2011. Receiver: MOSAIC	2014-Mar-10	JMS	
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)	2014-Apr-23	JMS	
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	2014-Mar-10	JMS	
12	CNES	CSO-MUSIS	GPS, Galileo	L1 C/A, L2C, L5 E1, E5a	Orbit, Time	Es	2018	The system is with three satellites to be launched from 2017. Receiver : LION	2014-Mar-10	JMS	
13	CNES	SWOT	GPS, Galileo (to be decided)	GPS L1 C/A, other (to be decided)	Orbit, Time	Ep (77,6°)	2022	Receiver : not yet decided	2020-09-04	JMS	
14	CNES	MERLIN	GPS, Galileo	L1 C/A, E1	Orbit, Time	Es (TBC)	2025	Receiver : not yet decided	2020-09-04	JMS	

IOAG GNSS Mission Table

15	CSA	Scisat	GPS		Orbit, Time	LEO	2003		2016-Oct-21	JF Levesque	Updated/Verified IOAG-23
16	CSA	Radarsat-2	GPS		Orbit, Time	LEO	2007		2016-Oct-21	JF Levesque	
17	CSA	Neossat	GPS		Orbit, Time	LEO	2013		2016-Oct-21	JF Levesque	
18	CSA	M3MSat	GPS		Orbit, Time	LEO	2016		2016-Oct-21	JF Levesque	
19	CSA	RCM	GPS		Orbit, Time	LEO	2019	3 satellites	2019-Aug-8	Francois Alain	
20	CSA	QEYSSat	GPS		Orbit, Time	LEO	2022		2020-Sep-15	JF Levesque	
21	CSA	WildFireSat	GPS		Orbit, Time	LEO	2024		2020-Sep-15	JF Levesque	
22	DLR	TSX-1	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO, precsie relative determination	Es	2007-06-15		2019-Oct-01	Martin Pilgram, Rolf Kozlowski	Updated IOAG-23 (DLR inputs received 2019-10-07)
23	DLR	TDX-1	GPS	GPS L1 C/A, L1/L2 P(Y)	Navigation, POD, RO, precsie relative determination	Es	2010-06-21		2019-Oct-01	Martin Pilgram, Rolf Kozlowski	
24	DLR	BIROS	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support)	Ep	2016-05-26		2019-Oct-01	Martin Pilgram, Rolf Kozlowski	
25	Uni Stuttgart	FLP	GPS	GPS L1 C/A	onboard navigation, orbit determination (flight dynamics support)	Es	2017-07-14		2019-Oct-01	Martin Pilgram, Rolf Kozlowski	
26	DLR	Eu:CROPIS	GPS	GPS L1 C/A	navigation, flight dynamics	Ep	12/3/2018		2019-Oct-01	Martin Pilgram, Rolf Kozlowski	
27	DLR	ENMAP	GPS			Ep	2021		2019-Oct-01	Martin Pilgram, Rolf Kozlowski	
28	DLR/NASA	GRACE_FO	GPS GLO/GAL?)	GPS L1 C/A, L1/L2 P(Y), (others?)	Navigation, POD, (relnav?, RO?)	Ep	5/22/2018	Joint mission with NASA.	2019-Oct-01	Martin Pilgram, Rolf Kozlowski	

IOAG GNSS Mission Table

29	ESA	Sentinel 1 A	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2014	SAR	2020-Sep-09	WE	Updated/Verified IOAG-23
30	ESA	Sentinel 1 B	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2016	SAR	2020-Sep-09	WE	
31	ESA	Sentinel 1 C	GPS and Galileo	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2022	SAR	2020-Sep-09	ML	
32	ESA	Sentinel 1 D	GPS and Galileo	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2025-2027	SAR	2020-Sep-09	ML	
33	ESA	Sentinel 2 A	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2015	High-resolution, multispectral images	2020-Sep-09	WE	
34	ESA	Sentinel 2 B	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2017	High-resolution, multispectral images	2020-Sep-09	WE	
35	ESA	Sentinel 2 C	GPS and Galileo	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2022	High-resolution, multispectral images	2020-Sep-09	ML	
36	ESA	Sentinel 2 D	GPS and Galileo	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2026-2028	High-resolution, multispectral images	2020-Sep-09	ML	
37	ESA	Sentinel 3 A	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2016	Medium resolution optical and altimetry	2020-Sep-09	WE	
38	ESA	Sentinel 3 B	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2018	Medium resolution optical and altimetry	2020-Sep-09	WE	
39	ESA	Sentinel 3 C	GPS and Galileo	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2023	Medium resolution optical and altimetry	2020-Sep-09	ML	
40	ESA	Sentinel 3 D	GPS and Galileo	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2026-2028	Medium resolution optical and altimetry	2020-Sep-09	ML	
41	ESA	Sentinel 5 P	GPS	GPS dual frequency Codephase and carrierphase	Navigation (PVT)	LEO	2017	Atmospheric chemistry, Payload only	2020-Sep-09	WE	
42	ESA	CO2M	GPS and Galileo (TBC)	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD) - TBC	LEO	>2026	Imaging Spectrometer	2020-Sep-09	ML/WE	
43	ESA	CRISTAL	GPS and Galileo (TBC)	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD) - TBC	LEO	>2026	Polar Ice and Snow Topography	2020-Sep-09	ML/WE	
44	ESA	CIMR	GPS and Galileo (TBC)	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD) - TBC	LEO	>2026	Passive Microwave Imaging	2020-Sep-09	ML/WE	
45	ESA	LSTM	GPS and Galileo (TBC)	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD) - TBC	LEO	>2026	High Resolution Surface Temperature	2020-Sep-09	ML/WE	
46	ESA	CHIME	GPS and Galileo (TBC)	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD) - TBC	LEO	>2026	Hyperspectral Imaging	2020-Sep-09	ML/WE	
47	ESA	ROSE-L	GPS and Galileo (TBC)	GPS and GAL dual frequency Codephase and carrierphase	Navigation (PVT) and Precise Orbit Determination (POD) - TBC	LEO	>2026	L-Band SAR	2020-Sep-09	ML/WE	
48	ESA	Proba 2	GPS	GPS single Frequency, L1	Orbit Determination	LEO	2009	Tech Demo	2017-Nov-08	WE	
49	ESA/NASA	ISS	GPS and Galileo	Galileo: E1 and E5a, GPS: L1 and L5, Codephase and Carrierphase for GPS and Galileo	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2018	Joint demonstration mission with NASA, using NASA's SCAN Testbed on-board the ISS	2020-Sep-08	WE	
50	ESA	Proba 3	GPS and Galileo	Galileo: E1 and E5a, GPS: L1 and L5, Codephase and Carrierphase for GPS and Galileo	Navigation (PVT), Precise Orbit Determination (POD), Formation Flying relative POD Time	HEO	2022	Formation Flying Technology Demonstration Mission, 2 spacecraft	2020-Sep-08	WE	
51	ESA	Small GEO	GPS	single Frequency, L1	Navigation (PVT)	GEO	2017	Demonstrate in orbit the feasibility to use GPS signals in GEO orbit for satellite position determination. Telecom	2020-Sep-09	ML	
52	ESA	FLEX	GPS and Galileo	Galileo: E1 and E5a, GPS: L1 and L5, Codephase and Carrierphase for GPS and Galileo	Navigation (PVT) and Precise Orbit Determination (POD)	LEO	2022	Cloroflle Explorer (GPS similar to GPS & Galileo)	2017-Nov-08	WE	
53	ESA	METOP-A	GPS	L1	Radio Occultation	LEO	2006	Atmospheric Sounder	2017-Nov-08	WE	
54	ESA	METOP-B	GPS	L1	Radio Occultation	LEO	2012	Atmospheric Sounder	2017-Nov-08	WE	
55	ESA	METOP-C	GPS	L1	Radio Occultation	LEO	2018	Atmospheric Sounder	2017-Nov-08	WE	
56	ESA	OPS-SAT	GPS, GAL, GLO, BDS	Single Frequency, multi-constellation Receiver	Navigation (PVT) and delivery of Code and Carrier Phase measurements for Precise Orbit Determination	LEO	2019	As a flying laboratory, ESA's OPS-SAT will test and validate new techniques in mission control and on-board systems	2019-Aug-25	WE	
57	ESA	Lunar Pathfinder	GPS, GAL	Dual frequency, multi-constellation GPS and GAL	Navigation (PVT) and delivery of Code and Carrier Phase measurements for Precise Orbit Determination	Moon - Orbit	2023+	Precursor for Moon Communication Services and 1st in orbit demonstration of GNSS based navigation on Moon orbit	2020-Sept-08	WE	
58	ESA	EL3 - European Large Logistic Lander	GPS, GAL	Dual frequency, multi-constellation GPS and GAL	Navigation (PVT) and delivery of Code and Carrier Phase measurements for Precise Orbit Determination and Precise Landing Trajectory Determination	Moon - Landing	2027	Moon Landing supported by GNSS technology	2020-Sept-08	WE	

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59	JAXA	GOSAT	GPS	L1	Orbit, time	LEO	2009	Remote Sensing	2016-Nov-17	T.S	Updated/Verified IOAG-24
60	JAXA	GCOM-W1	GPS	L1	Orbit, time	LEO	2012	Remote Sensing	2016-Nov-17	T.S	
61	JAXA	GCOM-C1	GPS	L1	Orbit, time	LEO	2017	Remote Sensing	2016-Nov-17	T.S	
62	JAXA	ALOS-2	GPS	L1, L2	Precise orbit （3σ<1m), Orbit, time,	LEO	2014	Remote Sensing	2016-Nov-17	T.S	
63	JAXA	GOSAT-2	GPS	L1	Orbit, time	LEO	2018	Remote Sensing	2017-Oct-25	T.S	
64	JAXA	XRISM	GPS	L1, L2	Orbit, time	LEO	2022	Astronomical	2020-Sep-15	Hoshino	
65	JAXA	ALOS-3 (Advanced Optical Satellite)	GPS	L1, L2	Orbit, time	LEO	2021	Remote Sensing	2020-Sep-15	Hoshino	
66	JAXA	ALOS-4 (Advanced Radar Satellite)	GPS	L1, L2	Orbit, time	LEO	2022	Remote Sensing	2020-Sep-15	Hoshino	
67	JAXA	GOSAT-GW	GPS	L1, L2	Orbit, time	LEO	2023	Remote Sensing	2020-Sep-15	Hoshino	
68	JAXA	ETS-9(Engineering Test Satellite)	GPS	L1	Orbit, time	HEO + GEO	2022	Engineering testing	2020-Sep-15	Hoshino	
69	JAXA	JDRS	GPS	L1	Orbit	GEO	2020	Optical Data Relay	2020-Sep-15	Hoshino	
70	KARI	KOMPSAT-2	GPS	L1	Navigation, Time, POD	LEO	2006.07.28		2020-Nov-12	Sangil Ahn	Updated/Verified IOAG-24a
71	KARI	KOMPSAT-3	GPS	L1	Navigation, Time, POD	LEO	2012.05.18		2020-Nov-12	Sangil Ahn	
72	KARI	KOMPSAT-5	GPS	L1/L2	Navigation, Time, POD, Radio Occultation	LEO	2013.08.22		2020-Nov-12	Sangil Ahn	
73	KARI	KOMPSAT-3A	GPS	L1	Navigation, Time, POD	LEO	2015.03.26		2020-Nov-12	Sangil Ahn	
74	KARI	CAS-1	GPS	L1/L2	Navigation, Time, POD	LEO	2021		2020-Nov-12	Sangil Ahn	
75	KARI	KOMPSAT-6	GPS	L1/L2	Navigation, Time, POD	LEO	2021		2020-Nov-12	Sangil Ahn	
76	KARI	CAS-2	GPS	L1/L2	Navigation, Time, POD	LEO	2022		2020-Nov-12	Sangil Ahn	
77	KARI	KOMPSAT-7	GPS	L1/L2	Navigation, Time, POD	LEO	2021		2020-Nov-12	Sangil Ahn	

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78	NASA	ISS	GPS	L1 C/A	Attitude Dynamics	LEO	Since 1998	Honeywell SIGI receiver	2014-Feb-4	JJ Miller	Updated/Verified IOAG-24
79	NASA	Landsat-8	GPS	L1 C/A	Orbit	LEO	2013	GD Viceroy receiver	2014-Feb-4	JJ Miller	
80	NASA	ISS Commercial Crew and Cargo Program - Dragon	GPS	L1 C/A	Orbit / ISS rendezvous	LEO	2013+		2014-Feb-4	JJ Miller	
81	NASA	ISS Commercial Crew and Cargo Program: Cygnus	GPS	L1 C/A	Orbit / ISS rendezvous	LEO	2013+		2014-Feb-4	JJ Miller	
82	NASA	GPM	GPS	L1 C/A	Orbit, time	LEO	2014	Navigator receiver	2014-Feb-4	JJ Miller	
83	NASA	Orion	GPS	L1 C/A	Orbit / navigation	LEO	2014 - Earth Orbit, 2021 Cislunar	Honeywell Aerospace 'Mercury' SPS GPS receiver with GSFC 'Navigator" software.	2020-Sep-11	T. Freestone	
84	NASA	COSMIC IIA (6 satellites)	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Occultation	LEO	6/25/2019	TriG receiver, 8 RF inputs, hardware all-GNSS capable, will track GPS + GLONASS at launch. Mission is NASA collaboration with USAF and National Space Program (NSPO).	2019-Jul-30	G. Purcell	
85	NASA	DSAC	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Time transfer	LEO	6/25/2019	TriG lite receiver	2019-Jul-30	G. Purcell	
86	CNES/NASA	Jason-3	GPS, GLONASS FDMA	L1 C/A, L1/L2 semicodeless, L2C	Precise Orbit Determination, Oceanography	LEO	1/17/2016	IGOR+ (BlackJack) receiver	2020-Sep-14	G. Purcell	
87	NASA	MMS	GPS	L1 C/A	Rel. range, orbit, time	up to 30 Earth radii	3/13/2015	Navigator receiver (8 receivers)	2020-Sep-14	G. Purcell	
88	NASA	GOES-16	GPS	L1 C/A	Orbit	GEO	11/19/2016	General Dynamics Viceroy-4	2020-Sep-14	G. Purcell	
89	NASA	ICESat-2	GPS	-	Precise orbit determination for elevation measurements.	LEO	9/15/2018	RUAG Space receiver	2020-Sep-14	G. Purcell	
90	NASA	CYGNSS (8 sats)	GPS	-	GPS bi-scatterometry	LEO	12/15/2016	Delay Mapping Receiver (DMR), SSTL UK	2020-Sep-14	G. Purcell	
91	NASA/DLR	GRACE FO	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P2, L5	Occultation, precision orbit, time	LEO	5/22/2018	TriG receiver with microwave ranging, joint mission with DLR	2019-Jul-30	G. Purcell	
92	NASA/ESA	Sentinel-6, 2 SATELLITES	GPS, GLONASS FDMA, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Occultation, Precise Orbit Determination	LEO	2020 and 2025	TriG receiver with MIL-STD-1553 interface	2020-Sep-14	G. Purcell	
93	NASA	GRASP	GPS, GLONASS FDMA, BeiDou, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Precise Orbit Determination	LEO	2020	TriG receiver (proposed)	2019-Jul-30	G. Purcell	
94	NASA	NICER (ISS)	GPS	L1 C/A	Orbit, time	LEO	6/3/2017	Moog/Navigator receiver	2020-Sep-14	G. Purcell	
95	NASA	Pegasus Launcher	GPS	L1 C/A	Navigation	Surface to LEO	Since 1990	Trimble receiver	2014-Feb-4	JJ Miller	
96	NASA	Antares (formerly Taurus II) Launcher	GPS	L1 C/A	Integrated Inertial Navigation System (INS) & GPS	Surface to LEO	Since 2010	Orbital GPB receiver	2014-Feb-4	JJ Miller	
97	NASA	Falcon-9 Launcher	GPS	L1 C/A	Overlay to INS for additional orbit insertion accuracy	Surface to LEO	Since 2013		2014-Feb-4	JJ Miller	
98	NASA	Launchers* at the Eastern and Western Ranges	GPS	L1 C/A	Range Safety	Ascent	2016**	(*) Including ULA Atlas V and Delta IV (GPS system: Space Vector SIL, uses a Javad receiver). (**) Estimated initial operational test.	2022-May-20	J. Parker	

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99	NASA/ISRO	NISAR	GPS, GLONASS, Galileo	L1 C/A, L2C, semi-codeless P2, L5	Precise Orbit Determination, timing	LEO	Sep. 2020	TriG Lite receiver	2020-Sep-14	G. Purcell	
100	NASA/CNES	SWOT	GPS, GLONASS FDMA, Galileo	L1 C/A, L2C, L5, Galileo, GLONASS FDMA	Precise Orbit Determination - Real Time	LEO	Apr. 2022	TriG receiver with MIL-STD-1553 interface	2020-Sep-14	G. Purcell	
101	NASA	GEDI	GPS, GLONASS FDMA	L1 C/A, L2C, semi-codeless P1/P2, Glonass G1 & G2	Precise Orbit Determination	LEO/ISS	12/5/2018	Moog TriG-lite receiver	2020-Sep-14	G. Purcell	
102	NASA	SLS - ICPS (Artemis 1)	GPS	L1 C/A	Orbit Determination, TLI burn, End-of-Mission Disposal	Ascent, LEO, Cislunar, EoM Disposal	Nov. 2021	Orbit: Honeywell SIGI with SPS Trimble Force 524D	2020-Sep-11	T Freestone	
103	NASA	SLS - ICPS (Artemis 2)	GPS	L1 C/A Receiver + L1/L2 C/A & P(Y) Receiver	Orbit Determination, TLI burn, End-of-Mission Disposal + Shadow-Mode Range Certification for Auto-FTS	Ascent, LEO, Cislunar, EoM Disposal	Aug. 2023	Ascent: PPS Shadow Mode (Tentative: NovAtel OEM6255S (L-3 X-SAASM)) Orbit: Tentative: Honeywell SIGI with SPS Trimble Force 524D	2020-Sep-11	T Freestone	
104	NASA	SLS - ICPS (Artemis 3)	GPS	L1 C/A Receiver + L1/L2 C/A & P(Y) Receiver	Orbit Determination, TLI burn, End-of-Mission Disposal + Shadow-Mode Range Certification for Auto-FTS	Ascent, LEO, Cislunar, EoM Disposal	Q4 2024	Ascent: PPS Shadow Mode (Tentative: NovAtel OEM6255S (L-3 X-SAASM)) Orbit: Tentative: Honeywell SIGI with SPS Trimble Force 524D	2020-Sep-11	T Freestone	
105	NASA	SLS - EUS (Artemis 4)	GPS	L1/L2 C/A, P(Y), plans to transition to M-Code	Ascent Range Safety Tracking and Autonomous Flight Termination, Orbit Determination, TLI Burns, Disposal.	Ascent, LEO, Cislunar, EoM Disposal	2025 (notional)	Range Ascent: PPS. Tentative: NovAtel OEM6255S (L-3 X-FACTOR SAASM) Vehicle Ascent/Nav: Tentative: Honeywell Mercury SPS w/OSFC Navigator S/W	2020-Sep-11	T Freestone	
106	NASA	SLS - EUS (Artemis 5)	GPS	L1/L2 C/A, P(Y), plans to transition to M-Code	Ascent Range Safety Tracking and Autonomous Flight Termination, Orbit Determination, TLI Burns, Disposal.	Ascent, LEO, Cislunar, EoM Disposal	2027 (notional)	Range Ascent: PPS. Tentative: NovAtel OEM6255S (L-3 X-FACTOR SAASM) Vehicle Ascent/Nav: Tentative: Honeywell Mercury SPS w/OSFC Navigator S/W	2020-Sep-11	T Freestone	
107	NASA	GOES-17	GPS	L1 C/A	Orbit	GEO	3/1/2018	General Dynamics Viceroy-4	2020-Sep-14	G. Purcell	
108	NASA	GOES-T	GPS	L1 C/A	Orbit	GEO	Dec. 2021	General Dynamics Viceroy-4	2020-Sep-14	G. Purcell	
109	NASA	GOES-U	GPS	L1 C/A	Orbit	GEO	2024	General Dynamics Viceroy-4	2017-Nov-9	J. Parker	
110	NASA	Fermi Gamma-ray Space Telescope (GLAST)	GPS	L1 C/A	Orbit	LEO	6/11/2008	General Dynamics Viceroy	2017-Nov-9	J. Parker	
111	NASA	OSAM-1	GPS	L1 C/A	Orbit determination, spacecraft timing, GNSS measurements part of multi-sensor nav filter for AR&D with Landsat 7	Ep	2025	RUAG	2022-May-20	J. Parker	
112	NASA	PACE	GPS Galileo	GPS L1 C/A Galileo E1	Orbit Determination	LEO	2024	RUAG LEORIX	2022-May-20	J. Parker	
113	AFRL	NTS-3	GPS, Galileo	GPS L1 C/A, L2C, L5 Galileo E1, E5a	Autonomous navigation in GEO with sub-m URE. Onboard ensemble time and clock integrity monitoring. Characterization and exploitation of dual frequency GPS space service volume.	GEO	2022	JPL collaboration with Harris Corporation Space and Intelligence Systems. JPL's Cion GNSS receiver, JPL's RTOx orbit determination and prediction software, NRL's Ensemble Timescale Filter (ETF) software.	2019-Jul-17	George Purcell	
114	NASA	STP-H6 XCOM Demo	GPS	L1 C/A, L2C	Orbit, time	Ei (ISS)	2019	NASA NavCube receiver	2019-Oct-10	Munther Hassouneh	
115	NASA	Bobcat-1	GPS, GAL, GLO,BDS, QZSS, NavIC	GPSL1 C/A, L1C, L2C, L2P, L5 GLONASSL1, L2, L3, L5 BeiDou-B1I, B1C, B2a, B2I, B3I GalileoE1, E5 AltBOC, E5a, E5b, E6 SBAS L1, L5 QZSSL1 C/A, L1C, L2C, L5, LEX NavIC (IRNSS)L5	Orbit, time	Ei (ISS)	2020	NovAtel OEM719 GNSS receiver	26-Aug-20	Obed Sands	
116	NASA	SunRISE	GPS, possibly others	L5 or L2C	Absolute and relative positioning of 6 6U cubesats, precise time transfer	GEO graveyard	20247		2020-Sep-14	G. Purcell	
117	NASA/ASI	Lunar GNSS Receiver Experiment (LuGRE)	GPS, Galileo	GPS L1 C/A, L5 Galileo E1, E5a	Orbit, time	O	2023	NASA/ASI collaborative payload on Firefly Blue Ghost Mission 1 to demonstrate GNSS-based PNT during Earth-Moon transit, in lunar orbit, and on the lunar surface. Incorporates Qascom lunar receiver.	2022-May-20	J. Parker	
118	NASA	Geospace Dynamics Constellation (GDC) (6 satellites)	TBD	TBD	Orbit, time, radio occultation (dedicated instrument)	Ep	2027		2022-May-20	J. Parker	
119	NASA/ASI/ESA	UP Aerospace SL-15	GPS Galileo	GPS L1 C/A, L5 Galileo E1, E5a	Orbit, time	O	Nov. 2022	Suborbital flight test with two GNSS receivers provided by ASI and ESA. Each receiver will use the systems and signals indicated.	2022-May-20	J. Parker	
120	NASA	NOAA-20 (JPSS-1)	GPS	L1 C/A	Orbit, time	Es	18 Nov. 2017		2022-May-20	J. Parker	
121	NASA	TIMED	GPS	L1 C/A	Orbit, time	Ei	7 Dec. 2001		2022-May-20	J. Parker	
122	NASA	Ionospheric Connection Explorer (ICON)	GPS	L1 C/A	Orbit, time	Ei	11 Oct. 2019		2022-May-20	J. Parker	

IOAG GNSS Mission Table

Decommisioned or De-Scoped Missions:

N°	Agency	Mission	GNSS System/s Used	GNSS Signals Used	GNSS Application	Orbit	Launch (Actual or Target)	Notes	Last Updated	Updated By
1	NASA	iSat	GPS	L1 C/A	Orbit Determination	LEO	2018	Iodine Satellite CubeSat. 1 Year LEO Mission. GPS = SpaceQuest (NovAtel) SQ-GPS-12-V1. 2018 update: The iSat mission has been tabled until Iodine Thruster issues are resolved.	2018-Sep-17	T Freestone
2	NASA	MAPS	GPS	L1 C/A	Formation Flying pathfinder on ISS testbed	LEO	2018	2018 Update: De-scoped to no longer use GPS.	2018-Sep-17	T Freestone
3	NASA	GRACE (2 satellites)	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination, Occultation, precision time	LEO	2002	BlackJack receiver, joint mission with DLR. 2018 Update: Mission retired 13 October, 2017	2018-Sep-18	L. Young
4	NASA	SCAN Testbed on ISS	GPS, Galileo	L1 CA, L2C, L5, Galileo E1 and E5A	Demo of Software Defined Radio	LEO	2012	"Blackjack-based SDR. Monitoring of GPS CNAV testing began in June 2013. Development of Galileo E5a/GPS L5 waveform through agreement with ESA began in October 2016 2018 Update: Decommissioned with prejudice 6/3/19 (incinerated during SpaceX Dragon CRS-17 re-entry). See URL <https://www.nasa.gov/feature/communications-testbed-leaves-legacy-of-pioneering-technology>.	2019-Jul-30	G. Purcell
5	NASA	COSMIC (6 satellites)	GPS	L1 C/A, L1/L2 semicodeless, L2C	Radio Occultation	LEO	2006	IGOR (BlackJack) receiver; the last COSMIC-1 satellite was decommissioned April 30, 2020.	2020-Sep-14	G. Purcell
6	NASA	IceSat	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination	LEO	2003	BlackJack receiver; mission retired 14 August 2010	2020-Sep-14	G. Purcell
7	CNES/NASA	OSTM/Jason 2	GPS	L1 C/A, L1/L2 semicodeless	Precise Orbit Determination	LEO	2008	BlackJack receiver. Decommisioned October 9, 2019.	2020-Sep-14	G. Purcell
8	JAXA	HTV-series	GPS	L1	Orbit(relative)	LEO	2009+	Unmanned ISS transportation	2020-Sep-15	Hoshino
9	JAXA	SLATS	GPS	L1	Orbit, time	LEO	2017	Tech Demo	2020-Sep-15	Hoshino

IOAG GNSS Mission Table

Notes/Definitions:

Orbit Types: 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)

IOAG Members:

ASI	Agenzia Spaziale Italiana
CNES	Centre national d'études spatiales
CSA	Canadian Space Agency
DLR	German Aerospace Center
ESA	European Space Agency
ISRO	
JAXA	Japan Aerospace Exploration Agency
KARI	Korean Aerospace Research Institute
NASA	National Aeronautics and Space Administration

Other Organizations: (joint/collaboration mission with an IOAG agency)

AFRL	U.S. Air Force Research Laboratory
Uni Stuttgart	University of Stuttgart
USAF	U.S. Air Force