gAGE

gAGE/UPC research group of Astronomy and Geomatics
BarcelonaTECH, Spain

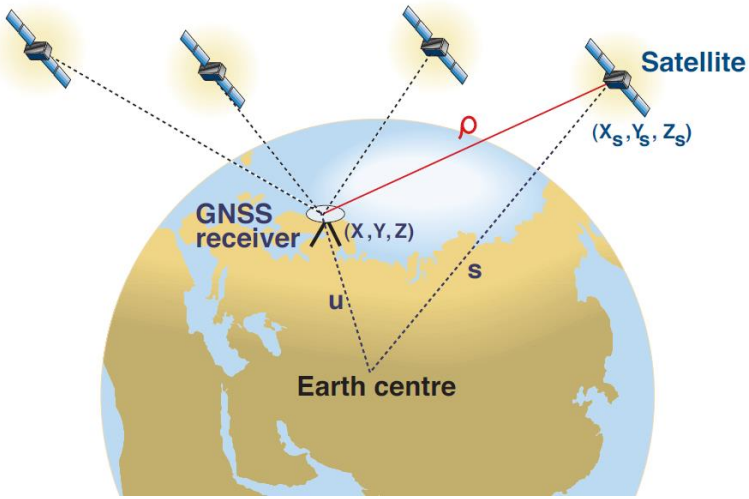
Lecture 2
GNSS Architecture

Professors: Dr. J. Sanz Subirana, Dr. J.M. Juan Zornoza
and Dr. A. Rovira-García

Contents

Introduction: GNSS Concept

Global Navigation Satellite System (GNSS) is a generic term denoting a satellite navigation system (e.g. GPS, GLONASS, Galileo and BeiDou) that provides continuous positioning and time over the globe.



Introduction: Historical Review

1957: Sputnik was launched on 4th of October

1973: Conceptual phase of Global Positioning System (GPS)

1984: Begin of civilian use of GPS

1995: Full operational capability of GPS

1996: Full operational capability of GLONASS

1999: First concept for Galileo

2000 May: Final deactivation of the selective availability

2000: BeiDou (COMPASS) is initiated

2002: Galileo programme was officially started.

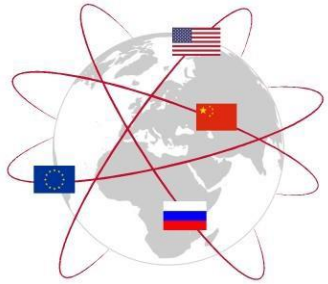
2004: Launching of the 50th GPS satellite

2005 December: Launch of 1st Galileo test satellite GIOVE-A

2008 April: Launch of 2nd Galileo test satellite GIOVE-B

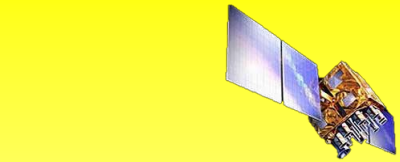
2011-2016: Launch of 14 Galileo satellites (troubles for two of them)

Up to 2024: 28 Galileo satellites (4 IOV + 24 FOC).



Main GNSS program countries

Current and Planned Global Navigation Satellite Systems

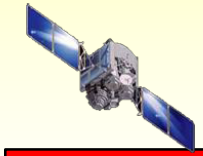


GPS

1995 FOC

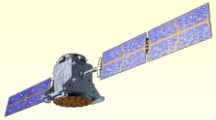
GLONASS

1996 FOC



BeiDou

2020 FOC

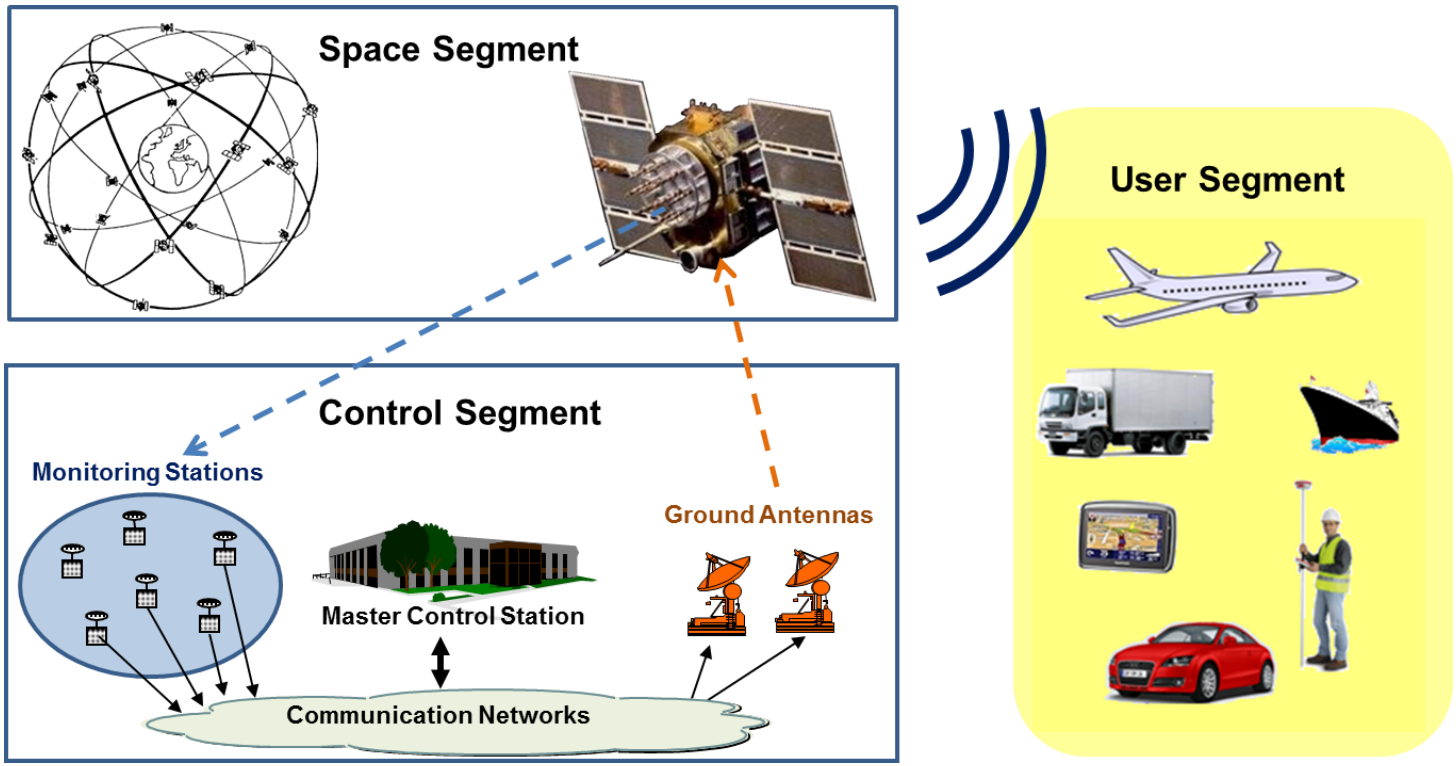


Galileo

2024 FOC?

Contents

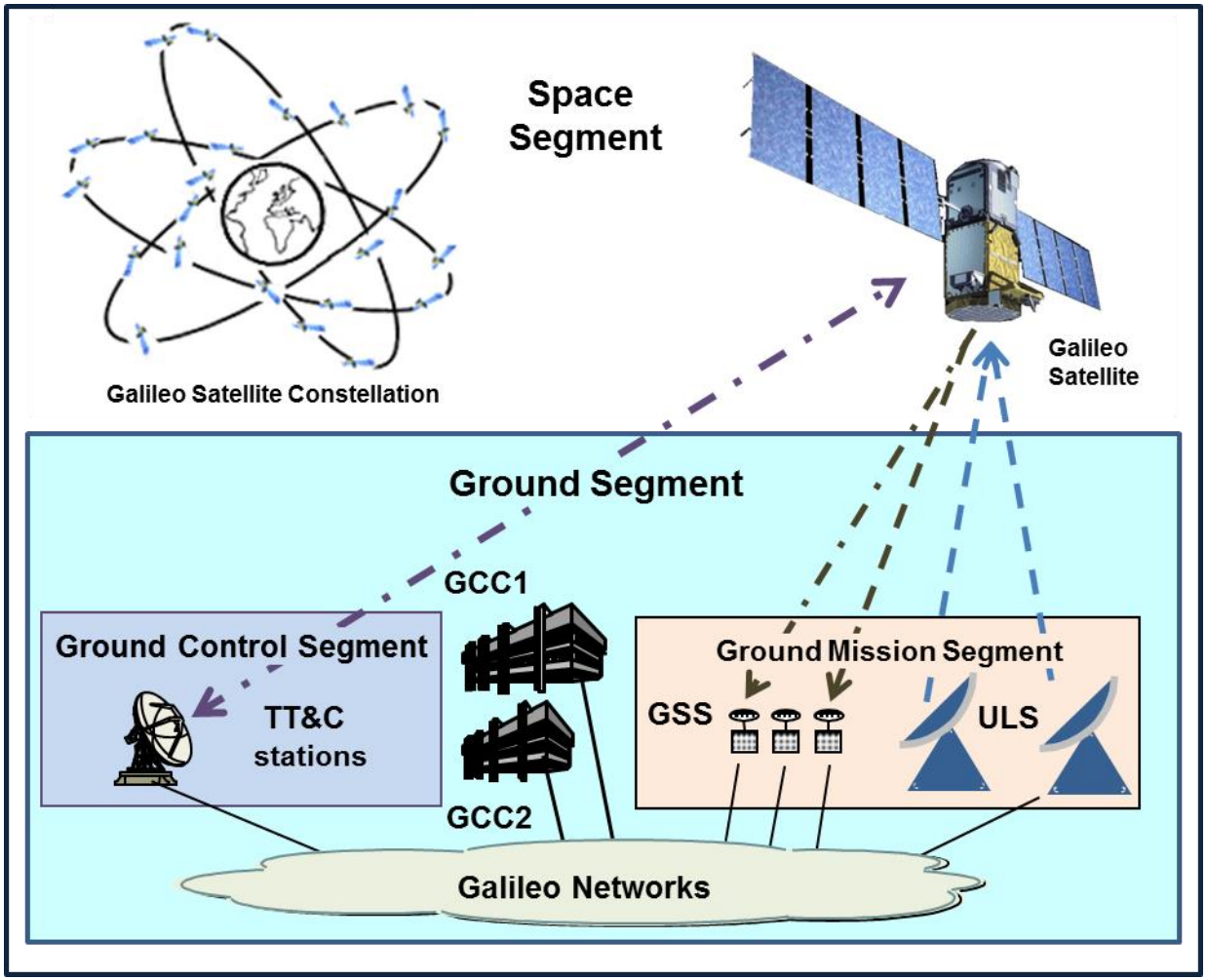
GNSS Segments

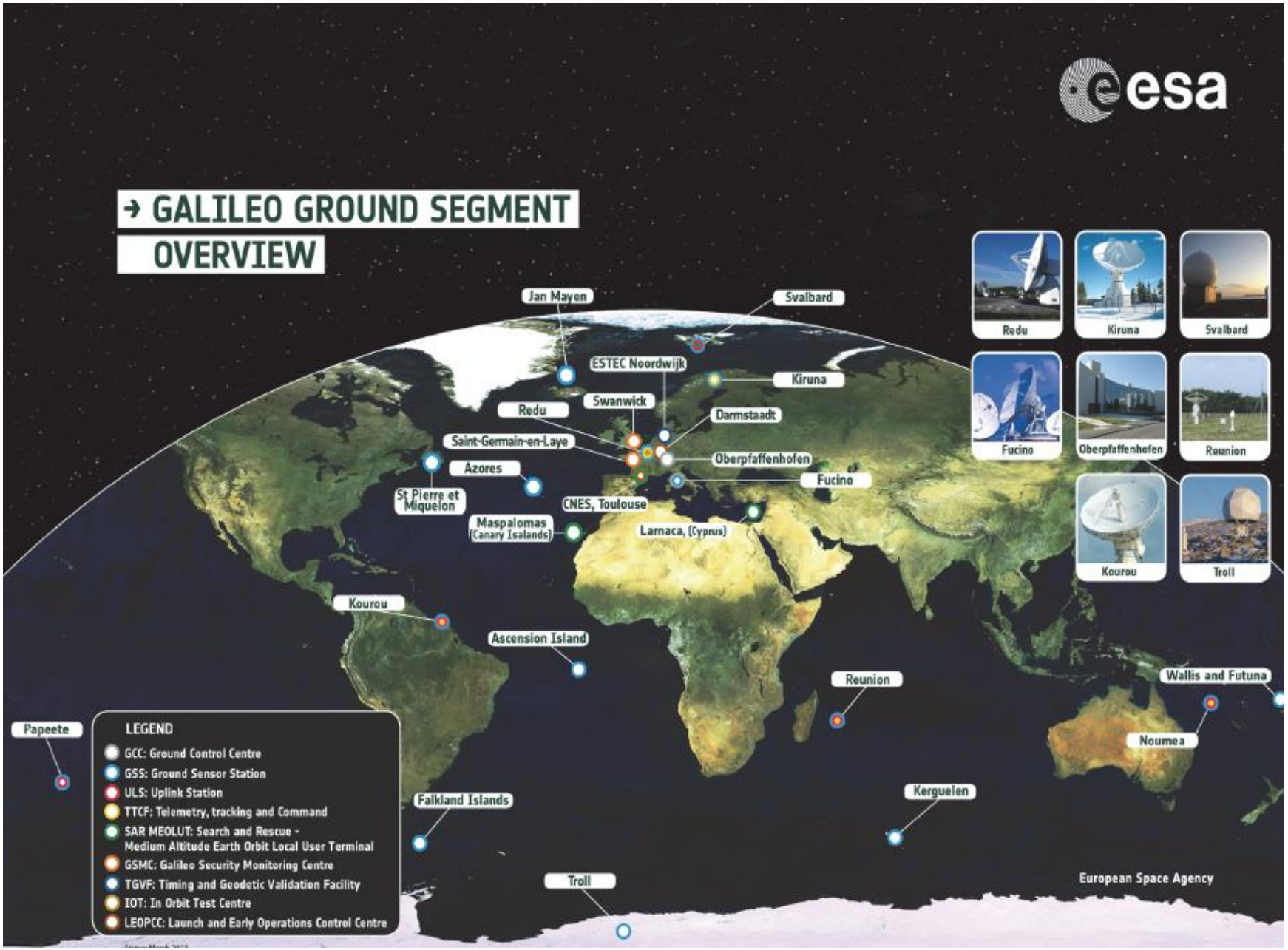


A GNSS basically consists of 3 main segments:

- Space segment: comprises the satellites
- Control (ground) segment: responsible of the proper operation of the system
- User segment: includes the GNSS receivers providing positioning, velocity and precise timing to users

Galileo Segments



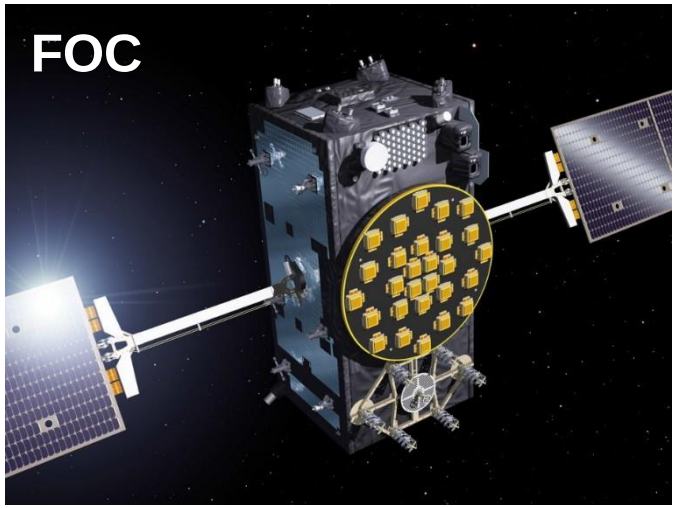


Galileo Space Segment

Spacecraft Prime Contractor Astrium GmbH
(now Airbus Defence & Space)

4 satellites – 4 In-Orbit (2011-2012)

Mass at Launch	700 kg
Power Consumption	1.420 W
Dimensions	2,7 x 1,6 x 14,5 m
Orbit Injection	Direct into MEO orbit
Attitude Profile	Yaw Steered

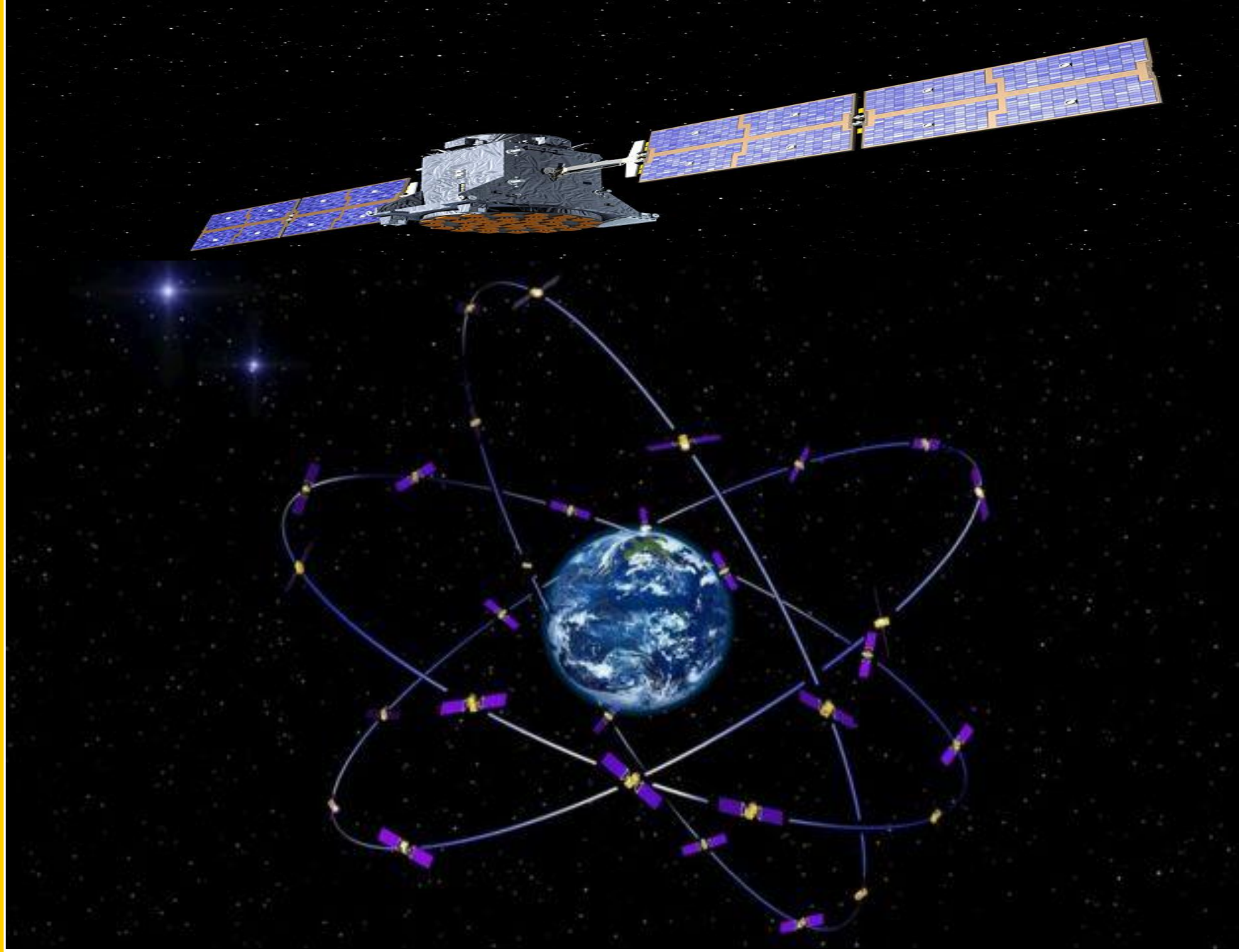


Spacecraft Prime Contractor OHB Systems GmbH
Payload Prime Contractor SSTL Ltd

26 satellites – 24 In-Orbit (2014-2021)

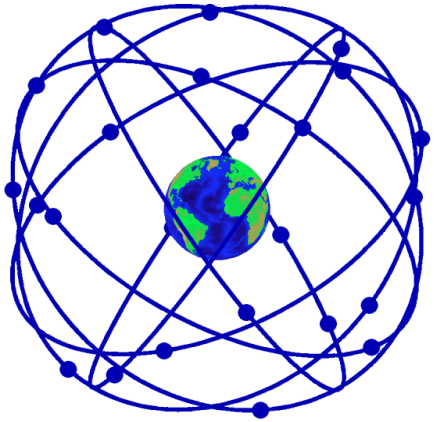
Mass at Launch	733 kg
Power Consumption	1.900 W
Dimensions	2,5 x 1,1 x 14,7 m
Orbit Injection	Direct into MEO orbit
Attitude Profile	Yaw Steered

Note: Medium Earth Orbiter (MEO) are at altitude of 23.222 km



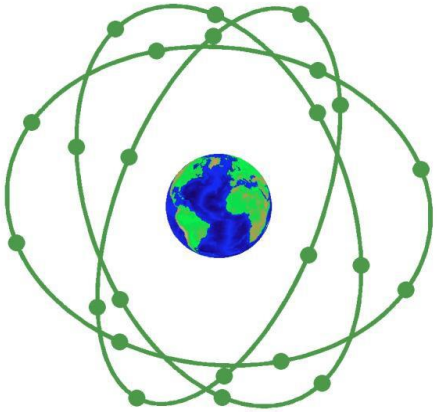
Nominal constellations

GPS



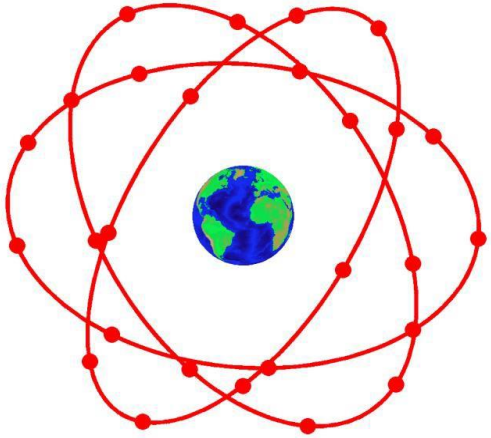
6 planes,
4 sats each

GLONASS

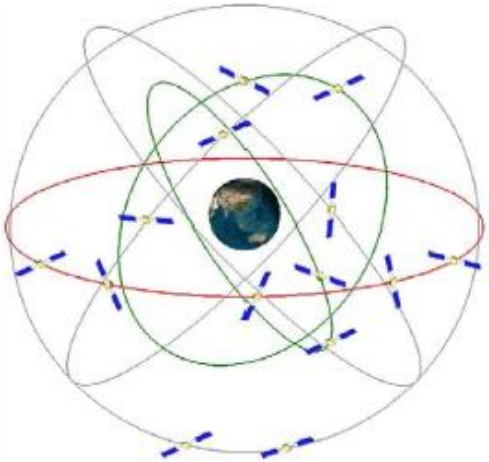


3 planes,
8 sats each

Galileo



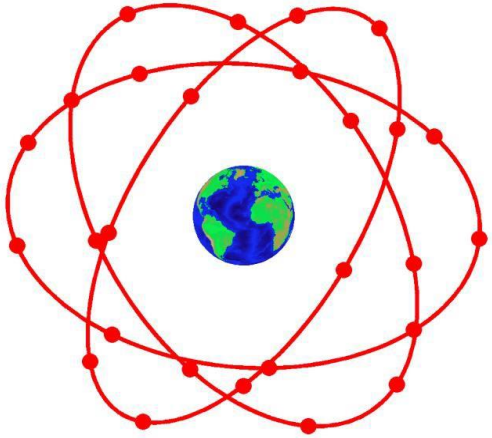
3 planes,
9 sats each



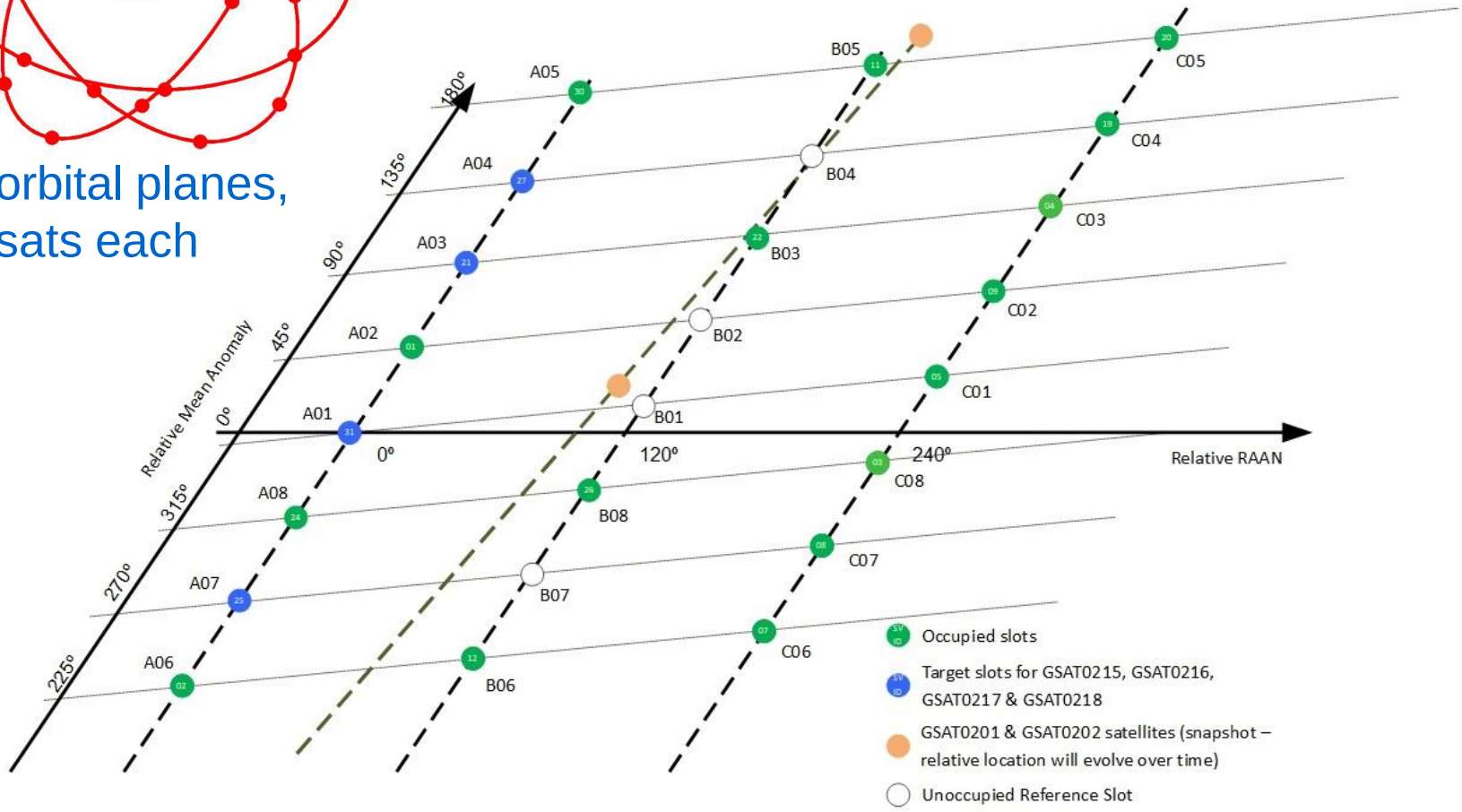
BeiDou (COMPASS)

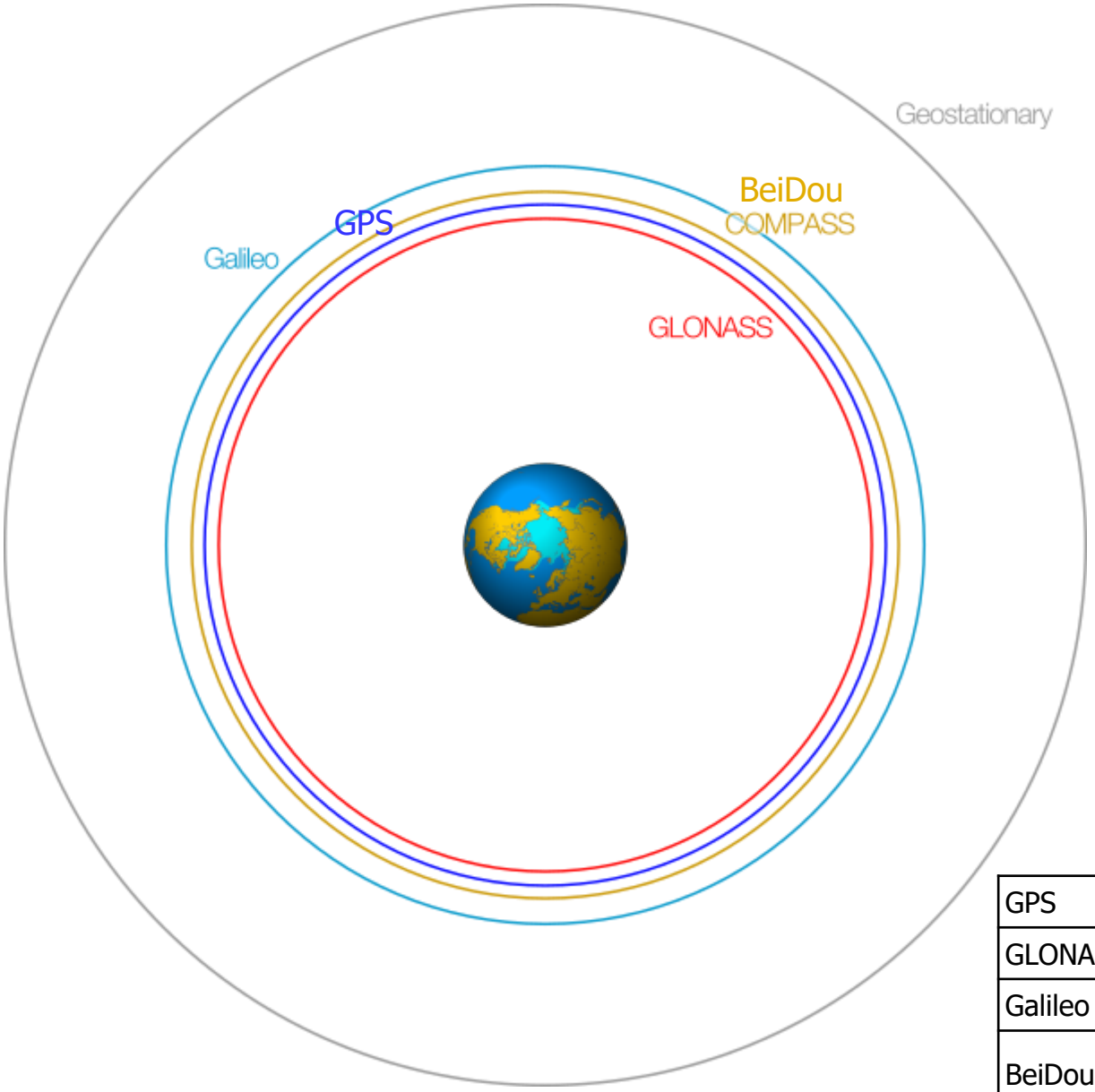
MEO: 3 planes,
9 sats each
IGSO: 3 planes
1 sat each
GEO: 5 GEO

Galileo constellation



3 orbital planes,
9 sats each



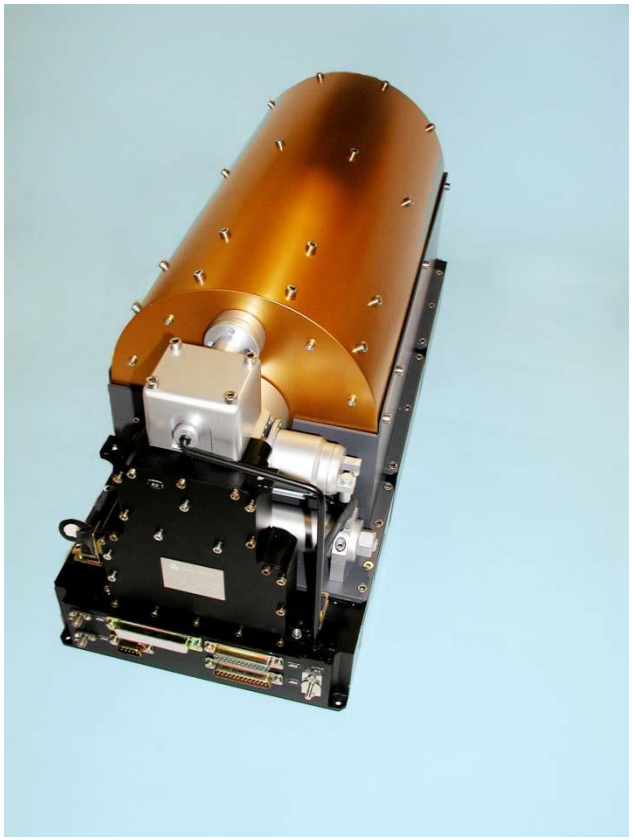


	Semi-Major Axis (km)	Orbit Period (h/m/s)
GPS	26 560	11h 58′ 02″
GLONASS	25 460	11h 15′ 44″
Galileo	29 582	14h 04′ 45″
BeiDou	27 888 42 164	12h 53′ 00″ 23h 56′

Contents

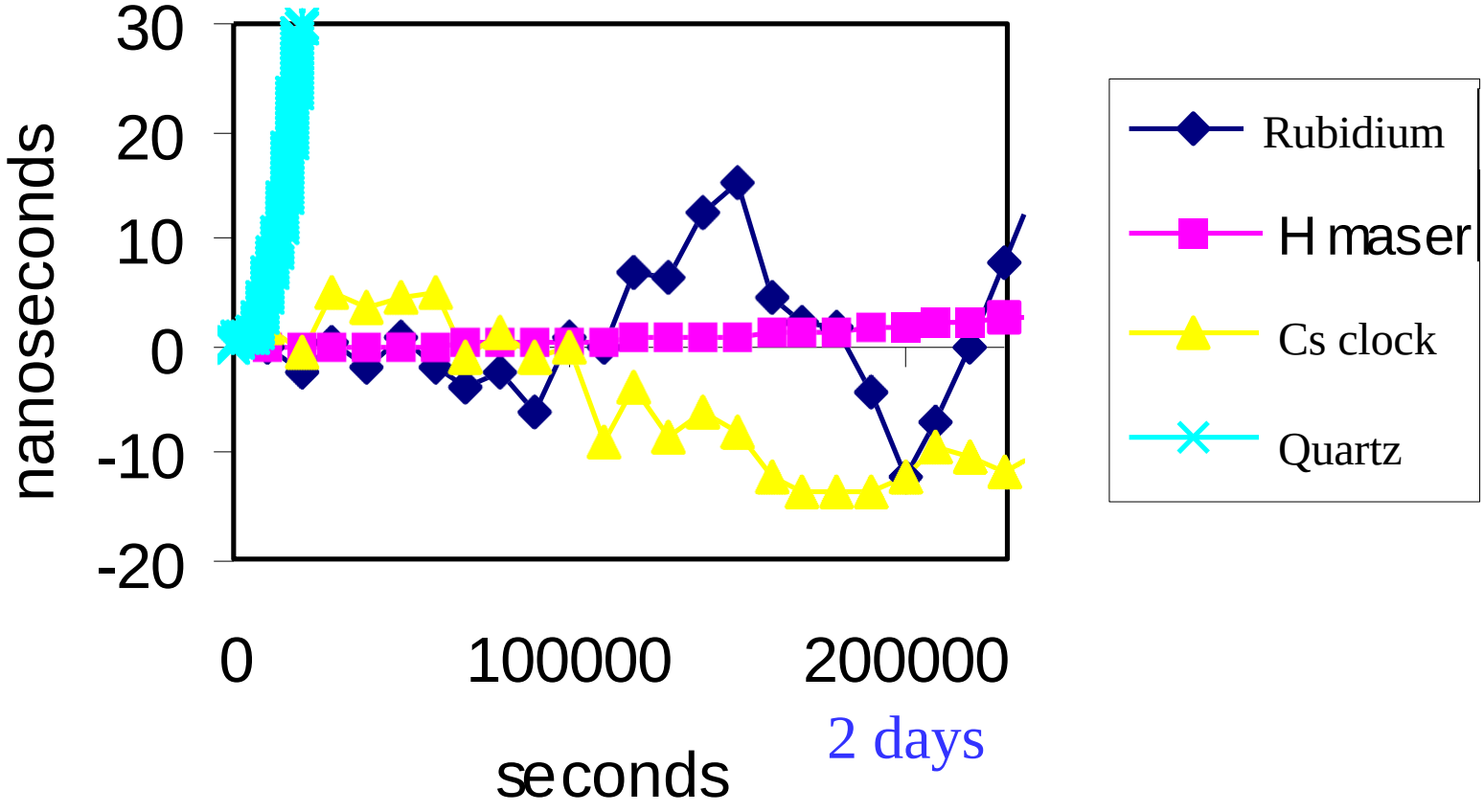
Galileo Clocks in Space

Rubidium Atomic
Frequency Standard



FIRST Space Passive
H-Maser

Clocks stability



Relativity effects can be measured with atomic clocks on board of satellites

- High velocity slows down clock
- Small gravitational potential (high altitude) accelerate clock

© Patrizia Tavella, INRIM, Torino

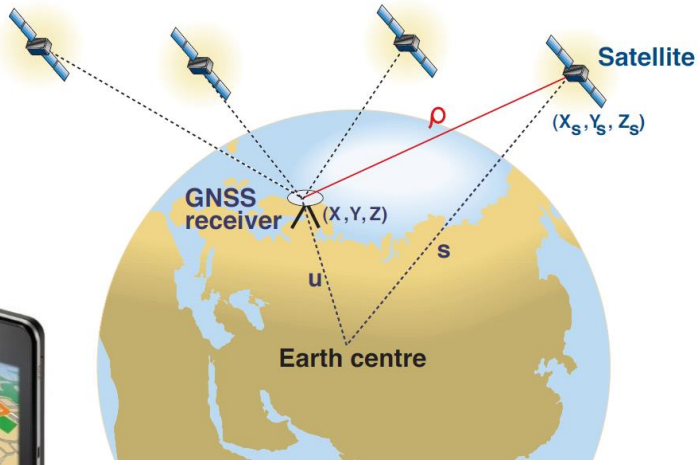
On board GPS/Galileo at 20.000 km

The effect is 10^{-10} which means 1 millisecond / year

$$\frac{f_0' - f_0}{f_0} = \frac{1}{2}\left(\frac{v}{c}\right)^2 + \frac{\Delta U}{c^2} = -4.464 \cdot 10^{-10}$$

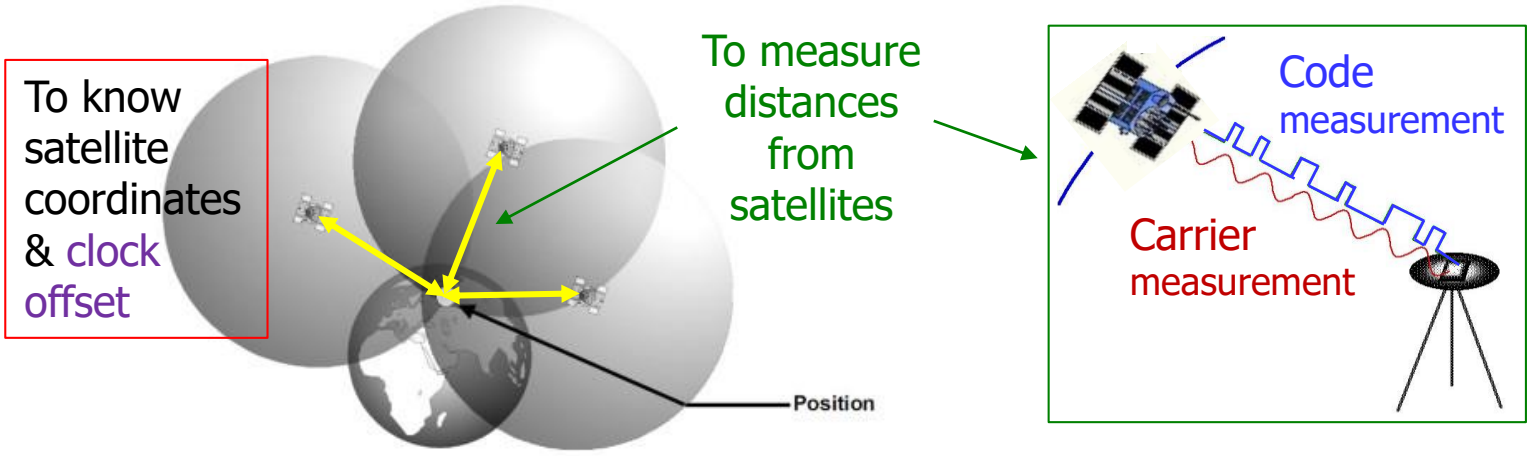
User Segment

The user segment is composed of GNSS receivers. Their main function is to receive GNSS signals, determine pseudoranges (and other observables) and solve the navigation equations in order to obtain the coordinates and provide a very accurate time.



Contents

GNSS positioning concept



This picture is from https://gpsfleettrackingexpert.wordpress.com

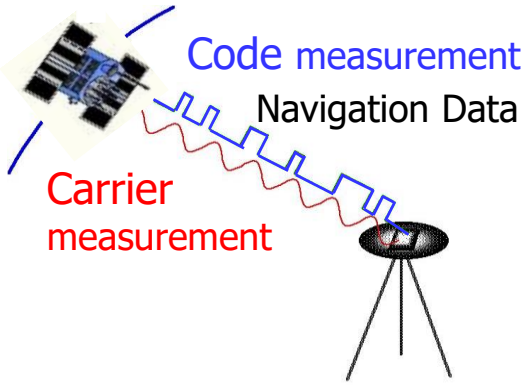
- GNSS uses technique of "triangulation" to find user location
- To "triangulate" a GNSS receiver needs:
  - To know the satellite coordinates and clock synchronism errors:
    - ➔ Satellites broadcast orbits parameters and clock offsets.
  - To measure distances from satellites:
    - ➔ This is done measuring the traveling time of radio signals: ("Pseudo-ranges": Code and Carrier measurements)
    - ➔ Measurements must be corrected by several error sources: Atmospheric propagation, relativity, clock offsets, instrumental delays…

Contents

GNSS Signals

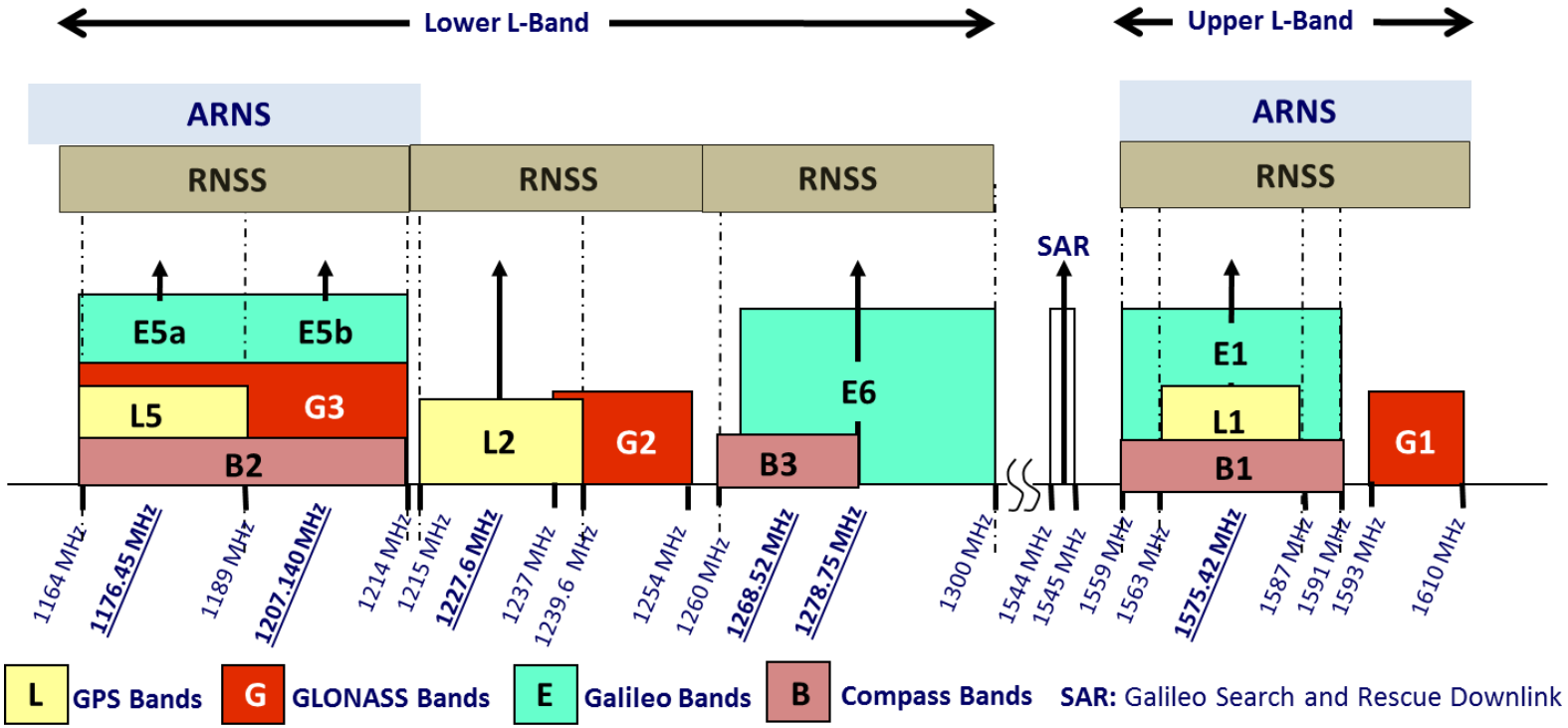
GNSS satellites continuously transmit navigation signals at two or more frequencies in L band.

These signals contain ranging codes and navigation data to allow users to compute both the travel time from the satellite to the receiver and the satellite coordinates at any epoch. The main signal components are described as follows:



- **Carrier:** Radio frequency sinusoidal signal at a given frequency.
- **Ranging code:** Sequences of zeros and ones which allow the receiver to determine the travel time of the radio signal from the satellite to the receiver. They are called Pseudo Random Number (PRN) sequences or PRN codes.
- **Navigation data:** A binary-coded message providing information on the satellite ephemeris (pseudo-Keplerian elements or satellite position and velocity), clock bias parameters, almanac, satellite health status and other complementary information.

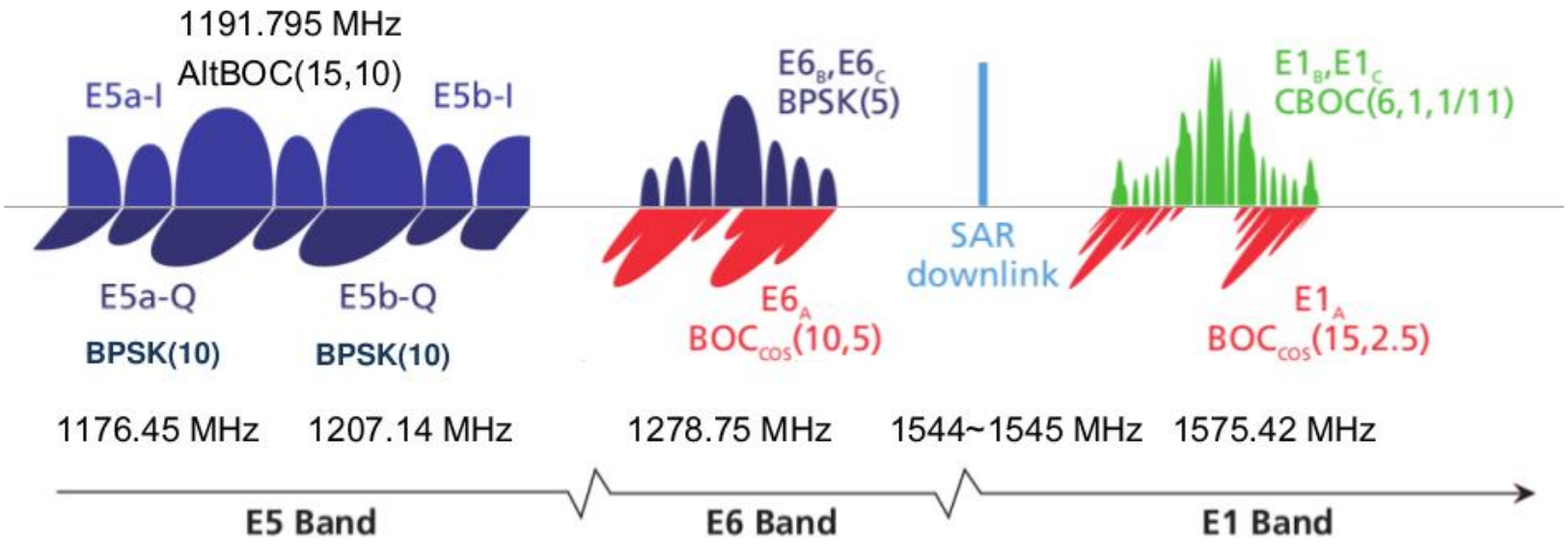
GNSS Signals



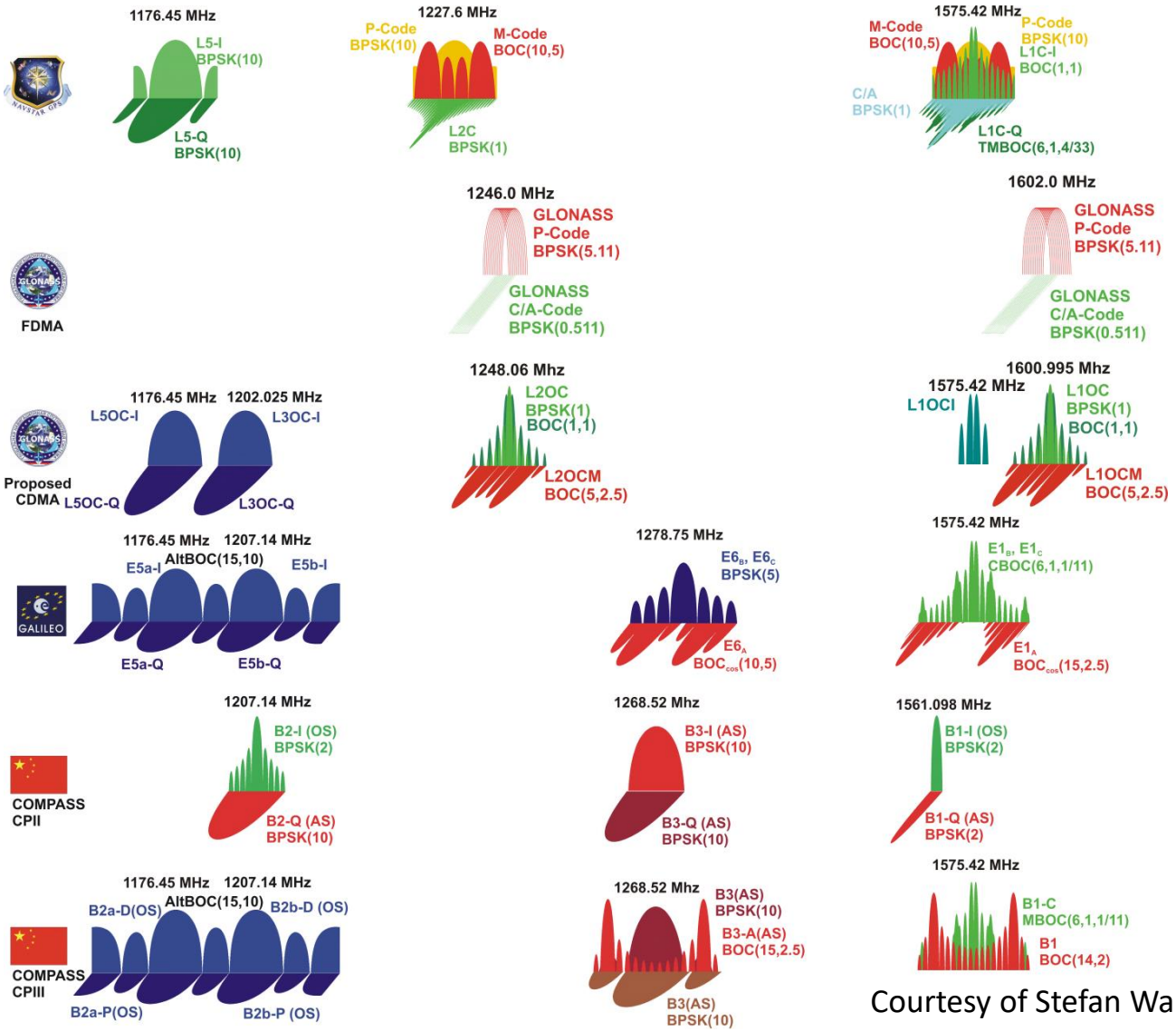
ARNS: Aeronautical Radio Navigation Service

RNSS: Radio Navigation Satellite Service

Galileo Signals



Signals and modulations implementations



Courtesy of Stefan Wallner

Galileo Services

Open Access	Free (as GPS) Mass market	
Public Regulated	Controlled access to government authorized-users only High Availability	
Commercial	Under development Access controlled by CS provider High Accuracy	
Search & Rescue	Near real-time relay of distress alarms to improve existing search & rescue serv. Return link feasible	

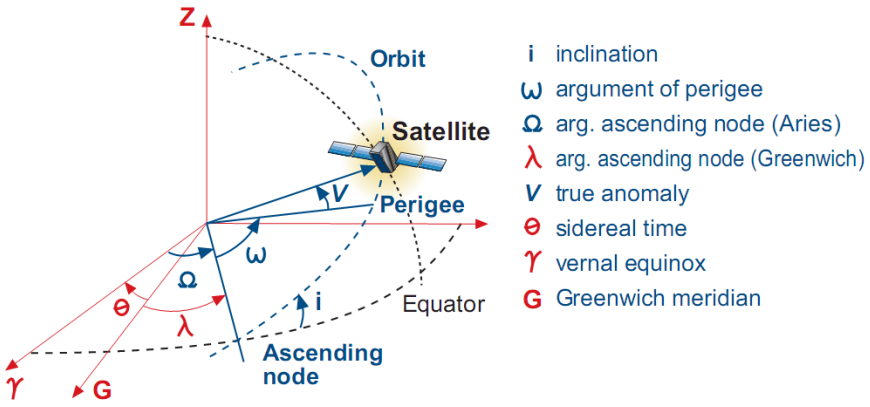
GNSS Navigation Data

GPS/Galileo/Beidou broadcast ephemeris and clock message parameters.

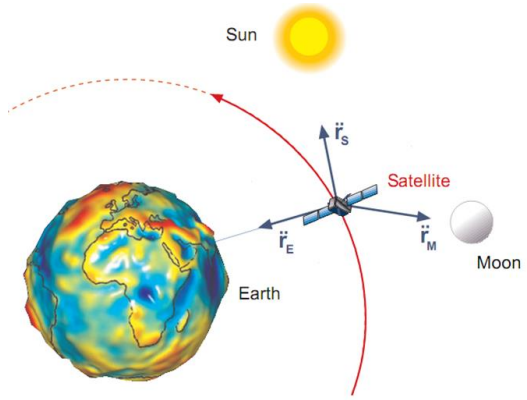
Parameter	Explanation
t_{oe}	Ephemerides reference epoch in seconds within the week
$\sqrt{a}$	Square root of semi-major axis
e	Eccentricity
M_o	Mean anomaly at reference epoch
ω	Argument of perigee
i_o	Inclination at reference epoch
Ω_0	Longitude of ascending node at the beginning of the week
Δn	Mean motion difference
$\dot{i}$	Rate of inclination angle
$\dot{\Omega}$	Rate of node's right ascension
c_{uc}, c_{us}	Latitude argument correction
c_{rc}, c_{rs}	Orbital radius correction
c_{ic}, c_{is}	Inclination correction
a_0	Satellite clock offset
a_1	Satellite clock drift
a_2	Satellite clock drift rate

Glonass broadcast ephemeris and clock message parameters.

Parameter	Explanation
t_e	Ephemerides reference epoch
$x(t_e)$	Coordinate at t_e in PZ-90
$y(t_e)$	Coordinate at t_e in PZ-90
$z(t_e)$	Coordinate at t_e in PZ-90
$v_x(t_e)$	Velocity component at t_e in PZ-90
$v_y(t_e)$	Velocity component at t_e in PZ-90
$v_z(t_e)$	Velocity component at t_e in PZ-90
$X''(t_e)$	Moon and Sun acceleration at t_e
$Y''(t_e)$	Moon and Sun acceleration at t_e
$Z''(t_e)$	Moon and Sun acceleration at t_e
$\tau_n(t_e)$	Satellite clock offset
$\gamma_n(t_e)$	Satellite relative frequency offset

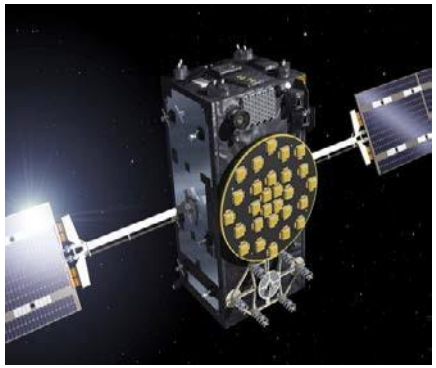


Fourth-order Ruge-Kutta orbit integration



Contents

Deployment and exploitation of Galileo



Development

GALILEO
GIOVE

2000-2008

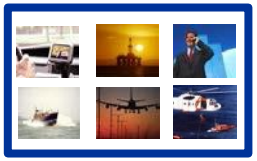
In-Orbit Validation

… 2013

FOC1
System deployment

2015-2016

Exploitation Phase

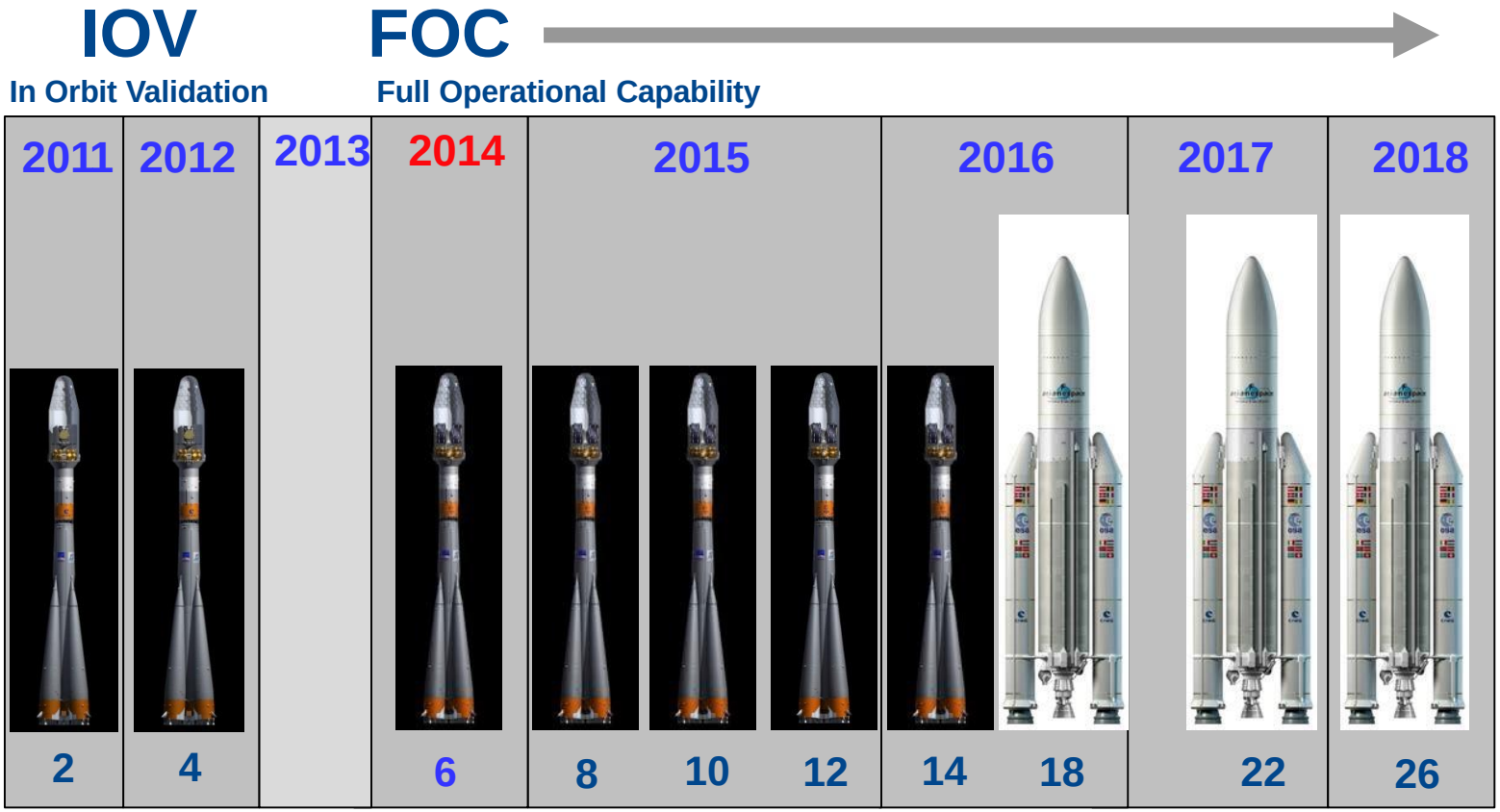


2017-2019

FOC2
Full Operational Capability

2024?

Galileo launch plan



27-28: December 2021 (Soyuz launcher)
29-30: April 28th 2024 (Falcon 9 of SpaceX)

Galileo Constellation Status

21.06.2024

Common Name	SVN	Int. Sat. ID	NORAD ID	NORAD Name	PRN	Notes
IOV-1, Galileo PFM	E101	2011-060A	37846	GALILEO-PFM	E11	Slot B05
IOV-2, Galileo FM2	E102	2011-060B	37847	GALILEO-FM2	E12	Slot B06
IOV-3, Galileo FM3	E103	2012-055A	38857	GALILEO-FM3	E19	Slot C04
IOV-4, Galileo FM4	E104	2012-055B	38858	GALILEO-FM4	E20	decommissioned 14-Mar-2024
FOC-1	E201	2014-050A	40128	GALILEO 5 (261)	E18	Orbit injection failure (i=49.7° e=0.23)
FOC-2	E202	2014-050B	40129	GALILEO 6 (262)	E14	Orbit injection failure (i=49.7° e=0.23)
FOC-3	E203	2015-017A	40544	GALILEO 7 (263)	E26	Slot B08
FOC-4	E204	2015-017B	40545	GALILEO 8 (264)	E22	Slot B14, not in service since 08-Dec-2017
FOC-5	E205	2015-045A	40889	GALILEO 9 (205)	E24	Slot A08
FOC-6	E206	2015-045B	40890	GALILEO 10 (206)	E30	Slot A05
FOC-8	E208	2015-079B	41174	GALILEO 12 (269)	E08	Slot C07
FOC-9	E209	2015-079A	41175	GALILEO 11 (268)	E09	Slot C02
FOC-10	E210	2016-030B	41550	GALILEO 13 (26A)	E01	Slot A02, not in service since 05-Sep-2023
FOC-11	E211	2016-030A	41549	GALILEO 14 (26B)	E02	Slot A06
FOC-7	E207	2016-069A	41859	GALILEO 15 (267)	E07	Slot C06
FOC-12	E212	2016-069B	41860	GALILEO 16 (26C)	E03	Slot C08
FOC-13	E213	2016-069C	41861	GALILEO 17 (26D)	E04	Slot C03
FOC-14	E214	2016-069D	41862	GALILEO 18 (26E)	E05	Slot C01
FOC-15	E215	2017-079A	43055	GALILEO 19 (2C5)	E21	Slot A03
FOC-16	E216	2017-079B	43056	GALILEO 20 (2C6)	E25	Slot A07
FOC-17	E217	2017-079C	43057	GALILEO 21 (2C7)	E27	Slot A04
FOC-18	E218	2017-079D	43058	GALILEO 22 (2C8)	E31	Slot A01
FOC-19	E219	2018-060C	43566	GALILEO 23 (2C9)	E36	Slot B04
FOC-20	E220	2018-060D	43567	GALILEO 24 (2C0)	E13	Slot B01
FOC-21	E221	2018-060A	43564	GALILEO 25 (2C1)	E15	Slot B02
FOC-22	E222	2018-060B	43565	GALILEO 26 (2C2)	E33	Slot B07
FOC-23	E223	2021-116A	49809	GALILEO 27 (223)	E34	Slot B03
FOC-24	E224	2021-116B	49810	GALILEO 28 (224)	E10	Slot B15
FOC-25	E225	2024-079A	59598	GALILEO 29 (10C)	E29	Slot C05
FOC-27	E227	2024-079C	59600	GALILEO 30 (10E)	E06	Slot C12

https://igs.org/mgex/constellations/#galileo

Galileo Constellation Status

21.06.2024

Constellation Status

Satellite Name[1]	SV ID[2]	Clock[3]	Status[4]	Active NAGU[5]	NAGU Type[6]	NAGU Subject[7]
GSAT0101	E11	RAFS	USABLE			
GSAT0102	E12	RAFS	USABLE			
GSAT0103	E19	RAFS	USABLE			
GSAT0104	E20	RAFS	NOT AVAILABLE	2024015	DECOMMSNG	SATELLITE DECOMMISSIONING
GSAT0201	E18	PHM	NOT USABLE	2021008	GENERAL	GSAT0201 AND GSAT0202 UNAVAILABLE
GSAT0202	E14	PHM	NOT USABLE	2021008	GENERAL	GSAT0201 AND GSAT0202 UNAVAILABLE
GSAT0203	E26	PHM	USABLE			
GSAT0204	E22	RAFS	NOT USABLE	2017045	GENERAL	GSAT0204 REMOVED FROM ACTIVE SERVICE ON 2017-12-08 UNTIL FURTHER NOTICE FOR CONSTELLATION MANAGEMENT PURPOSES
GSAT0205	E24	PHM	USABLE			
GSAT0206	E30	PHM	USABLE			
GSAT0207	E07	PHM	USABLE			
GSAT0208	E08	PHM	USABLE			
GSAT0209	E09	PHM	USABLE			
GSAT0210	E01	RAFS	NOT USABLE	2023048	GENERAL	GSAT0210 REMOVED FROM ACTIVE SERVICE
GSAT0211	E02	PHM	USABLE			
GSAT0212	E03	PHM	USABLE			
GSAT0213	E04	PHM	USABLE			
GSAT0214	E05	PHM	USABLE			
GSAT0215	E21	PHM	USABLE			
GSAT0216	E25	PHM	USABLE			
GSAT0217	E27	PHM	USABLE			
GSAT0218	E31	PHM	USABLE			
GSAT0219	E36	PHM	USABLE			
GSAT0220	E13	PHM	USABLE			
GSAT0221	E15	PHM	USABLE			
GSAT0222	E33	PHM	USABLE			
GSAT0223	E34	PHM	USABLE			
GSAT0224	E10	PHM	USABLE			
GSAT0225	E29		UNDER COMMISSIONING	2024020	GENERAL	LAUNCH OF GSAT0225 AND GSAT0227
GSAT0227	E06		UNDER COMMISSIONING	2024020	GENERAL	LAUNCH OF GSAT0225 AND GSAT0227

23 Usable

Number of USABLE satellites: 23.
Number of NOT USABLE/NOT AVAILABLE satellites: 7.
TOTAL number of satellites: 30.

1: Satellite Name: Galileo Satellite (GSAT) identifier of the satellites:
- GSAT01XX: IOV satellites
- GSAT02XX: FOC satellites

https://www.gsc-europa.eu/system-service-status/constellation-information

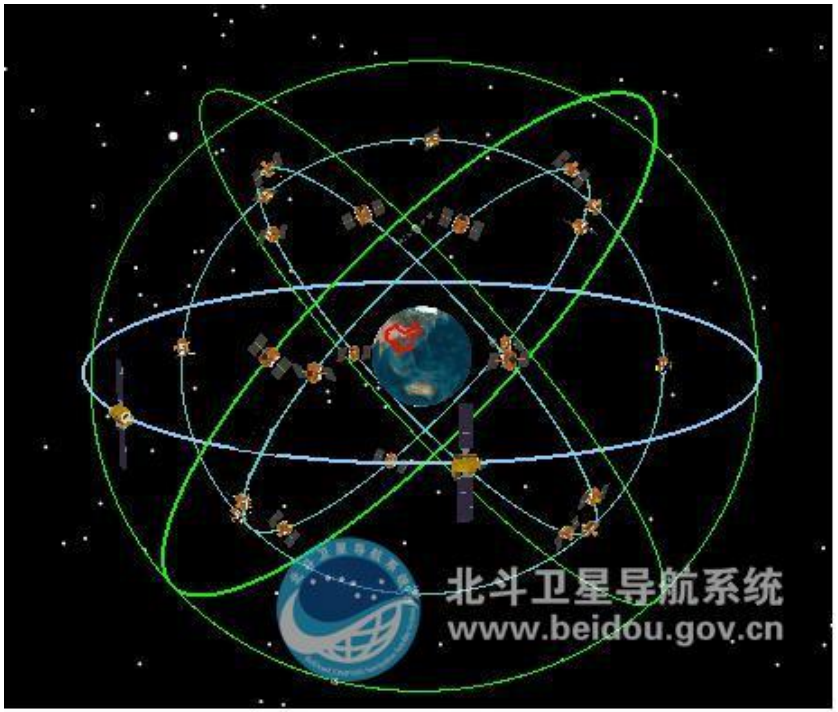
BeiDou Constellation Status

At May 2019, 34 satellites are operational:

- 6 in geostationary orbits,
- 7 in 55-degree inclined geosynchronous orbits
- 21 in medium Earth orbits.

The full constellation was scheduled to comprise 35 satellites.

2020 FOC



Tab.1 Fundamental PNT Service

59 Operational

PRN	SVN	SatelliteType	NORADID	ClockType	Manuf	LaunchDate	SatStatus	Healthy	Service Signal
01	GEO-8	BDS-2	44231	Rubidium	CASC	2019-05-17	Operational	Healthy	B1I/B2I/B3I
02	GEO-6	BDS-2	38953	Rubidium	CASC	2012-10-25	Operational	Healthy	B1I/B2I/B3I
03	GEO-7	BDS-2	41586	Rubidium	CASC	2016-06-12	Operational	Healthy	B1I/B2I/B3I
04	GEO-4	BDS-2	37210	Rubidium	CASC	2010-11-01	Operational	Healthy	B1I/B2I/B3I
05	GEO-5	BDS-2	38091	Rubidium	CASC	2012-02-25	Operational	Healthy	B1I/B2I/B3I
06	IGSO-1	BDS-2	36828	Rubidium	CASC	2010-08-01	Operational	Healthy	B1I/B2I/B3I
07	IGSO-2	BDS-2	37256	Rubidium	CASC	2010-12-18	Operational	Healthy	B1I/B2I/B3I
08	IGSO-3	BDS-2	37384	Rubidium	CASC	2011-04-10	Operational	Healthy	B1I/B2I/B3I
09	IGSO-4	BDS-2	37763	Rubidium	CASC	2011-07-27	Operational	Healthy	B1I/B2I/B3I
10	IGSO-5	BDS-2	37948	Rubidium	CASC	2011-12-02	Operational	Healthy	B1I/B2I/B3I
11	MEO-3	BDS-2	38250	Rubidium	CASC	2012-04-30	Operational	Healthy	B1I/B2I/B3I
12	MEO-4	BDS-2	38251	Rubidium	CASC	2012-04-30	Operational	Healthy	B1I/B2I/B3I
13	IGSO-6	BDS-2	41434	Rubidium	CASC	2016-03-30	Operational	Healthy	B1I/B2I/B3I
14	MEO-6	BDS-2	38775	Rubidium	CASC	2012-09-19	Operational	Healthy	B1I/B2I/B3I
16	IGSO-7	BDS-2	43539	Rubidium	CASC	2018-07-10	Operational	Healthy	B1I/B2I/B3I
19	MEO-1	BDS-3	43001	Rubidium	CASC	2017-11-05	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
20	MEO-2	BDS-3	43002	Rubidium	CASC	2017-11-05	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
21	MEO-3	BDS-3	43208	Rubidium	CASC	2018-02-12	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
22	MEO-4	BDS-3	43207	Rubidium	CASC	2018-02-12	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
23	MEO-5	BDS-3	43581	Rubidium	CASC	2018-07-29	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
24	MEO-6	BDS-3	43582	Rubidium	CASC	2018-07-29	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
25	MEO-11	BDS-3	43603	Hydrogen	SECM	2018-08-25	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
26	MEO-12	BDS-3	43602	Hydrogen	SECM	2018-08-25	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
27	MEO-7	BDS-3	43107	Hydrogen	SECM	2018-01-12	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
28	MEO-8	BDS-3	43108	Hydrogen	SECM	2018-01-12	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
29	MEO-9	BDS-3	43245	Hydrogen	SECM	2018-03-30	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
30	MEO-10	BDS-3	43246	Hydrogen	SECM	2018-03-30	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
31	IGSO-1S	BDS-3S	40549	Hydrogen	SECM	2015-03-30	Experiment	--	--
32	MEO-13	BDS-3	43622	Rubidium	CASC	2018-09-19	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
33	MEO-14	BDS-3	43623	Rubidium	CASC	2018-09-19	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
34	MEO-15	BDS-3	43648	Hydrogen	SECM	2018-10-15	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
35	MEO-16	BDS-3	43647	Hydrogen	SECM	2018-10-15	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
36	MEO-17	BDS-3	43706	Rubidium	CASC	2018-11-19	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
37	MEO-18	BDS-3	43707	Rubidium	CASC	2018-11-19	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
38	IGSO-1	BDS-3	44204	Hydrogen	CASC	2019-04-20	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
39	IGSO-2	BDS-3	44337	Hydrogen	CASC	2019-06-25	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
40	IGSO-3	BDS-3	44709	Hydrogen	CASC	2019-11-05	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
41	MEO-19	BDS-3	44864	Hydrogen	CASC	2019-12-16	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
42	MEO-20	BDS-3	44865	Hydrogen	CASC	2019-12-16	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
43	MEO-21	BDS-3	44794	Hydrogen	SECM	2019-11-23	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
44	MEO-22	BDS-3	44793	Hydrogen	SECM	2019-11-23	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
45	MEO-23	BDS-3	44543	Rubidium	CASC	2019-09-23	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
46	MEO-24	BDS-3	44542	Rubidium	CASC	2019-09-23	Operational	Healthy	B1I/B3I/B1C/B2a/B2b
56	IGSO-2S	BDS-3S	40938	Hydrogen	CASC	2015-09-30	Experiment	--	--
57	MEO-1S	BDS-3S	40749	Rubidium	CASC	2015-07-25	Experiment	--	--
58	MEO-2S	BDS-3S	40748	Rubidium	CASC	2015-07-25	Experiment	--	--
59	GEO-1	BDS-3	43683	Hydrogen	CASC	2018-11-01	Operational	Healthy	B1I/B3I
60	GEO-2	BDS-3	45344	Hydrogen	CASC	2020-03-09	Operational	Healthy	B1I/B3I
61	GEO-3	BDS-3	45807	Hydrogen	CASC	2020-06-23	Testing	--	B1I/B3I

Tab.2 Precise Point Positioning Service

PRN	SVN	SatelliteType	LaunchDate	SatStatus	Service Signal	Position
59	GEO-01	BDS-3	2018-11-01	Operational	B2b	140°E
60	GEO-02	BDS-3	2020-03-09	Operational	B2b	80°E
61	GEO-03	BDS-3	2020-06-23	Operational	B2b	110.5°E

Tab.3 SBAS Service

PRN	SVN	SatelliteType	LaunchDate	SatStatus	Service Signal	Position
130	GEO-01	BDS-3	2018-11-01	Testing	B1C/B2a	140°E
143	GEO-03	BDS-3	2020-06-23	Testing	B1C/B2a	110.5°E
144	GEO-02	BDS-3	2020-03-09	Testing	B1C/B2a	80°E

Note: MEO-1S, MEO-2S, MEO-3S, IGSO-1S, IGSO-2S are BDS-3 testing satellites, and their signal systems are not the same as BDS-3.

Release Time: 2024-06-21 00:00:00

https://www.csno-tarc.cn/en/system/constellation

GPS and GLONASS Constellation Status

GPS CONSTELLATION STATUS, 10.05.2019	
Total satellites in constellation	32
Operational	**31**
In commissioning phase	-
In maintenance	1
In decommissioning phase	-

1995 FOC

https://www.glonass-iac.ru/en/GPS/

GLONASS CONSTELLATION STATUS, 10.05.2019	
Total satellites in constellation	26
Operational	**24**
In commissioning phase	-
In maintenance	-
Under check by the Satellite Prime Contractor	-
Spares	1
In flight tests phase	1

1996 FOC

https://www.glonass-iac.ru/en/GLONASS/

GLONASS Constellation Status
(June 20, 2024)

GLONASS number	Cosmos number	Plane/ slot	Frequ. chann.	Launch date	Intro date	Status	Outage date
730	2456	1/01	1	14.12.2009	30.01.2010	operating	.....
747	2485	1/02	-4	26.04.2013	04.07.2013	operating	.....
744	2476	1/03	5	04.11.2011	08.12.2011	operating	.....
759	2544	1/04	6	11.12.2019	03.01.2020	operating	.....
756	2527	1/05	1	17.06.2018	29.08.2018	operating	.....
733	2457	1/06	-4	14.12.2009	24.01.2010	operating	.....
745	2477	1/07	5	04.11.2011	18.12.2011	operating	.....
743	2475	1/08	6	04.11.2011	20.09.2012	operating	.....
702	2501	2/09	-2	01.12.2014	15.02.2016	operating	.....
723	2436	2/10	-7	25.12.2007	22.01.2008	operating	.....
705	2547	2/11	0	25.10.2020	28.04.2022	operating	.....
758	2534	2/12	-1	27.05.2019	22.06.2019	operating	.....
721	2434	2/13	-2	25.12.2007	08.02.2008	operating	.....
752	2522	2/14	-7	22.09.2017	16.10.2017	operating	.....
757	2529	2/15	0	03.11.2018	27.11.2018	operating	.....
761	2564	2/16	-1	28.11.2022	22.12.2022	operating	.....
751	2514	3/17	4	07.02.2016	28.02.2016	operating	.....
754	2492	3/18	-3	24.03.2014	14.04.2014	operating	.....
720	2433	3/19	3	26.10.2007	25.11.2007	operating	.....
719	2432	3/20	2	26.10.2007	27.11.2007	operating	.....
755	2500	3/21	4	14.06.2014	03.08.2014	operating	.....
706	2557	3/22	-3	07.07.2022	30.12.2022	operating	.....
732	2460	3/23	3	02.03.2010	31.03.2010	operating	.....
760	2545	3/24	2	16.03.2020	14.04.2020	operating	.....

Note: All the dates (DD.MM.YY) are given at Moscow Time (UTC+0300)

24 Operational

https://glonass-iac.ru/en/cus/

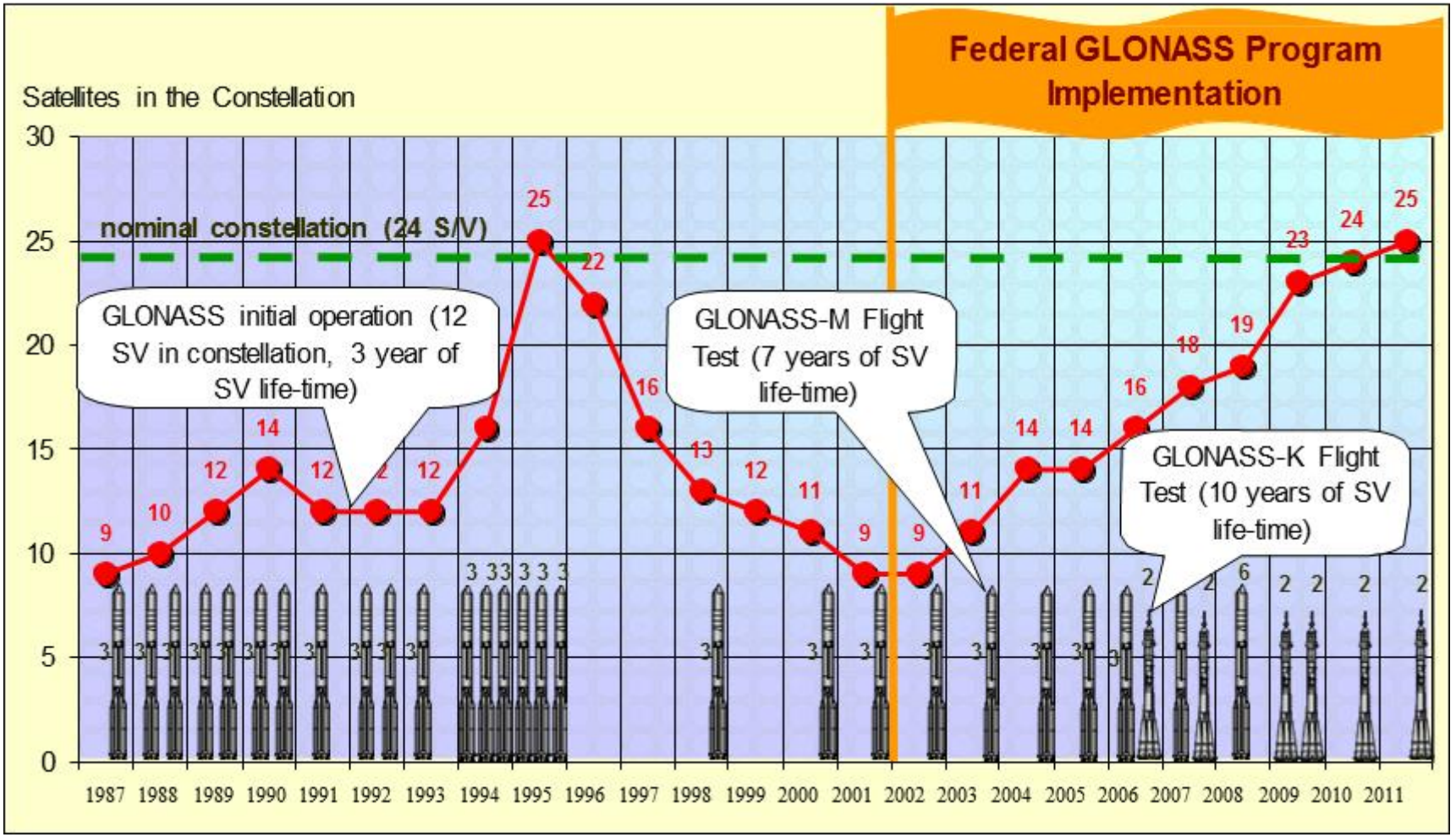
GPS CONSTELLATION STATUS FOR Fri Jun 21 2024

Plane	Slot	SVN	PRN	Block-Type	Clock	Outage Start	NANU Type	NANU Subject
B	1	56	16	IIR	RB			
C	1	57	29	IIR-M	RB			
D	1	61	2	IIR	RB			
A	1	65	24	IIF	RB			
E	1	69	3	IIF	RB			
F	1	70	32	IIF	RB			
A	2	52	31	IIR-M	RB			
F	2	55	15	IIR-M	RB			
B	2	62	25	IIF	RB			
C	2	66	27	IIF	RB			
E	2	73	10	IIF	CS			
B	3	44	22	IIR	RB			
D	3	45	21	IIR	RB			
E	3	50	5	IIR-M	RB			
A	3	64	30	IIF	RB			
F	3	68	9	IIF	RB			
C	3	72	8	IIF	CS			
A	4	48	7	IIR-M	RB			
A	4	48	7	IIR-M	RB			
E	4	51	20	IIR	RB	18 JUN 2024	FCSTSUMM	SVN51 (PRN20) FORECAST OUTAGE SUMMARY JDAY 170/1449 - JDAY 170/2015
C	4	53	17	IIR-M	RB			
B	4	58	12	IIR-M	RB			
D	4	67	6	IIF	RB			
F	4	74	4	III	RB			
C	5	59	19	IIR	RB			
B	5	71	26	IIF	RB			
E	5	76	23	III	RB			
D	5	78	11	III	RB			
F	6	43	13	IIR	RB			
D	6	75	18	III	RB			
B	6	77	14	III	RB			
A	6	79	28	III	RB			

30 Operational

https://www.navcen.uscg.gov/gps-constellation

GLONASS Constellation Evolution



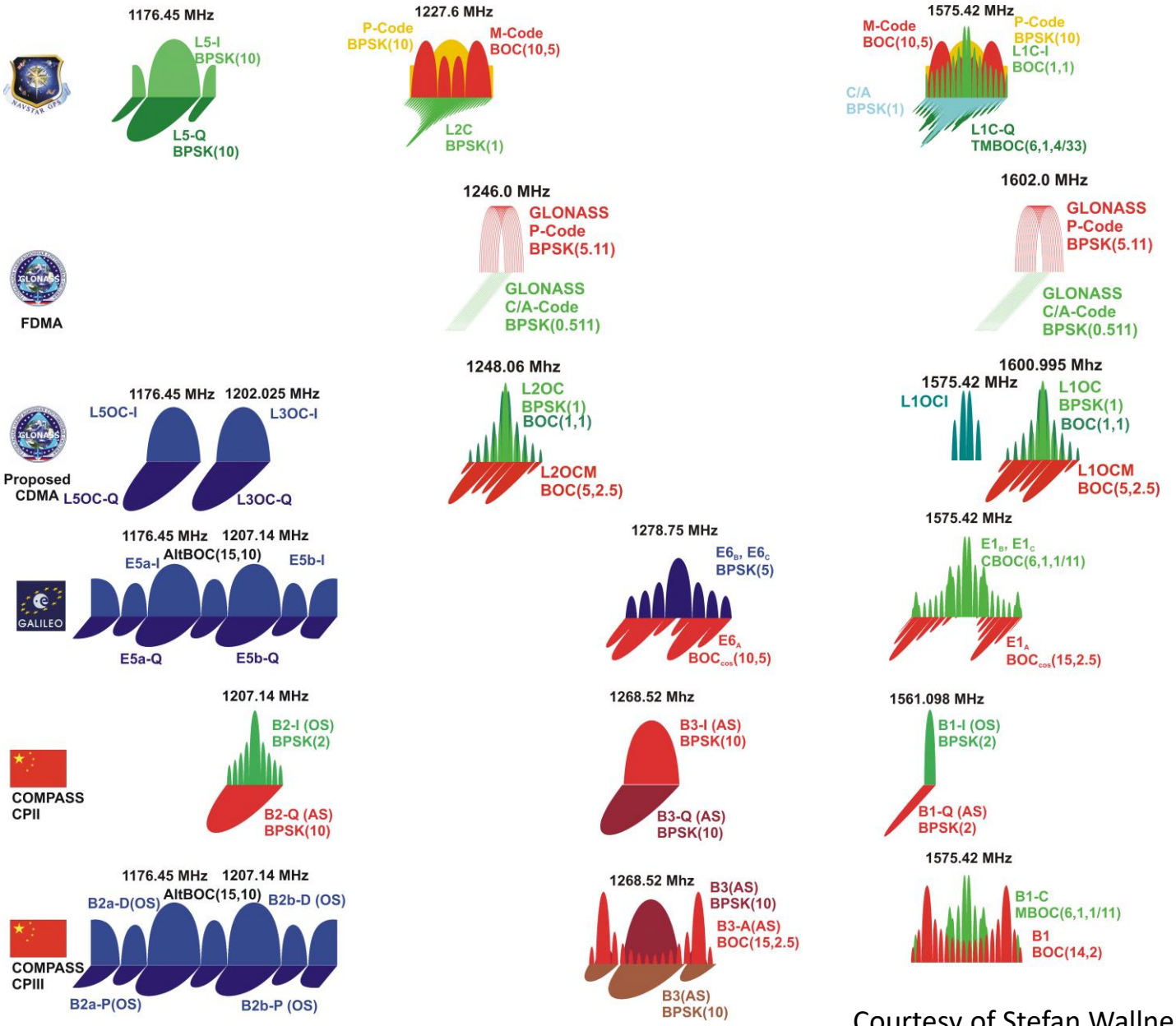
By 2010 has achieved again 100% coverage of Russia's territory and in October 2011 the full orbital constellation of 24 satellites was restored, enabling full global coverage

GLONASS Program is in progress and has been extended to 2020 by which time the system is scheduled to have all satellites transmitting both the new CDMA and legacy FDMA signals.

Contents

GNSS Systems Comparison

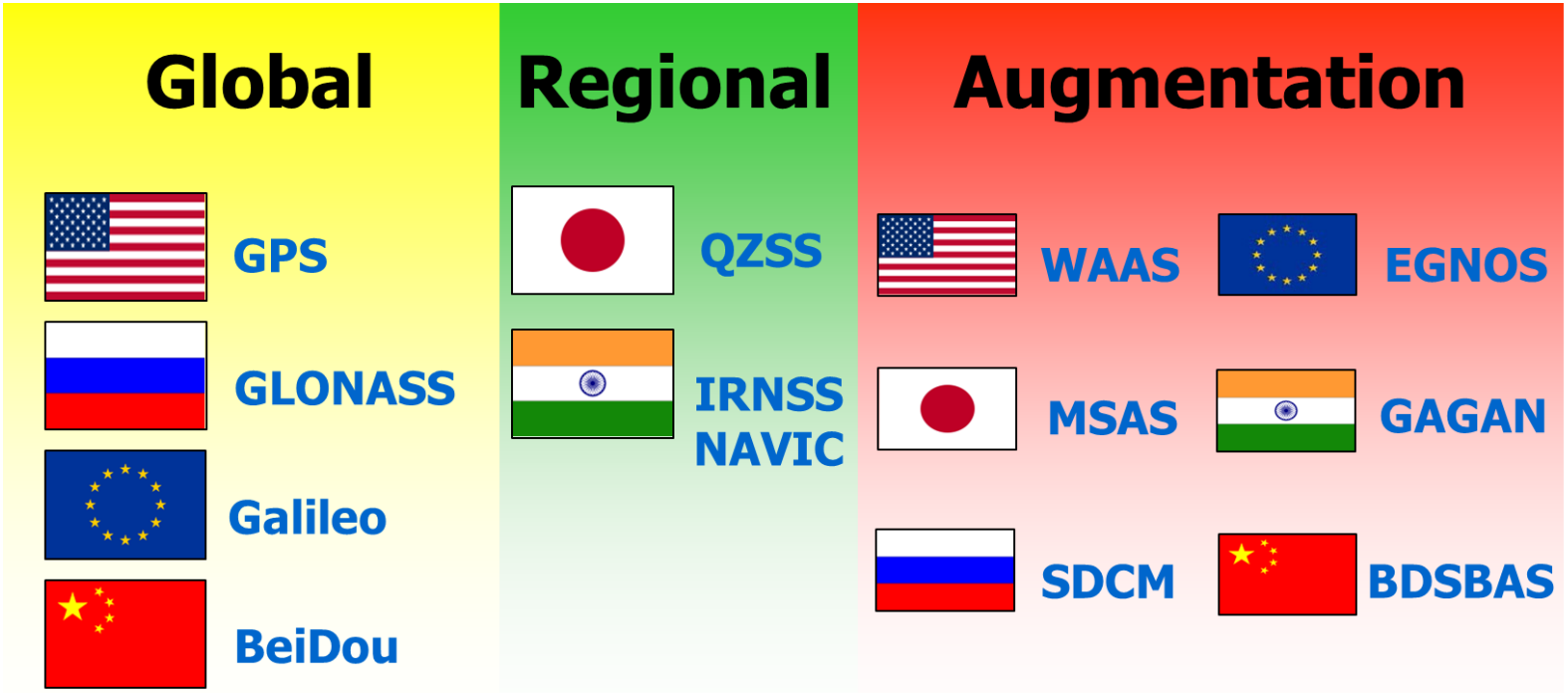
System	GPS	GLONASS	BeiDou	Galileo
Owner	United States	Russian Fed.	China	European Union
Coding	CDMA	FDMA (CDMA)	CDMA	CDMA
Orbit Height	20,180 km	19,130 km	21,150 km (MEO) 35,786 km	23,222 km
Period	11 h 58 m	11 h 16 m	12 h 38 m (MEO) 23h 56m	14 h 5 m
Revolutions / sidereal days	2/1	17/8	17/9 (MEO) 1/1	17/10
Number of Satellites	24	24	27(MEO) 3 (ISGO), 5 (GEO)	27
Accuracy (open service)	4-8 m	5-10 m	4-8 m	4-8 m
Frequency (RINEX Notation)	L1,L2,L5	L1, L2, (L5)	L1,L2,L6,L7	L1, L5, L6,L7,L8
Status	**Operational**	**Operational**	**Operational**	**Operational**



Courtesy of Stefan Wallner

Contents

Current and Planned Navigation Satellite Systems



Source: Guenter W. Hein
ESA/JRC International Summer School on GNSS 2016

Nominal Number of Satellites

Source: Guenter W. Hein
ESA/JRC International Summer School on GNSS 2016

GLOBAL CONSTELLATIONS

GPS	24+3
GLONASS	24+2
Galileo	27+3
BeiDou	

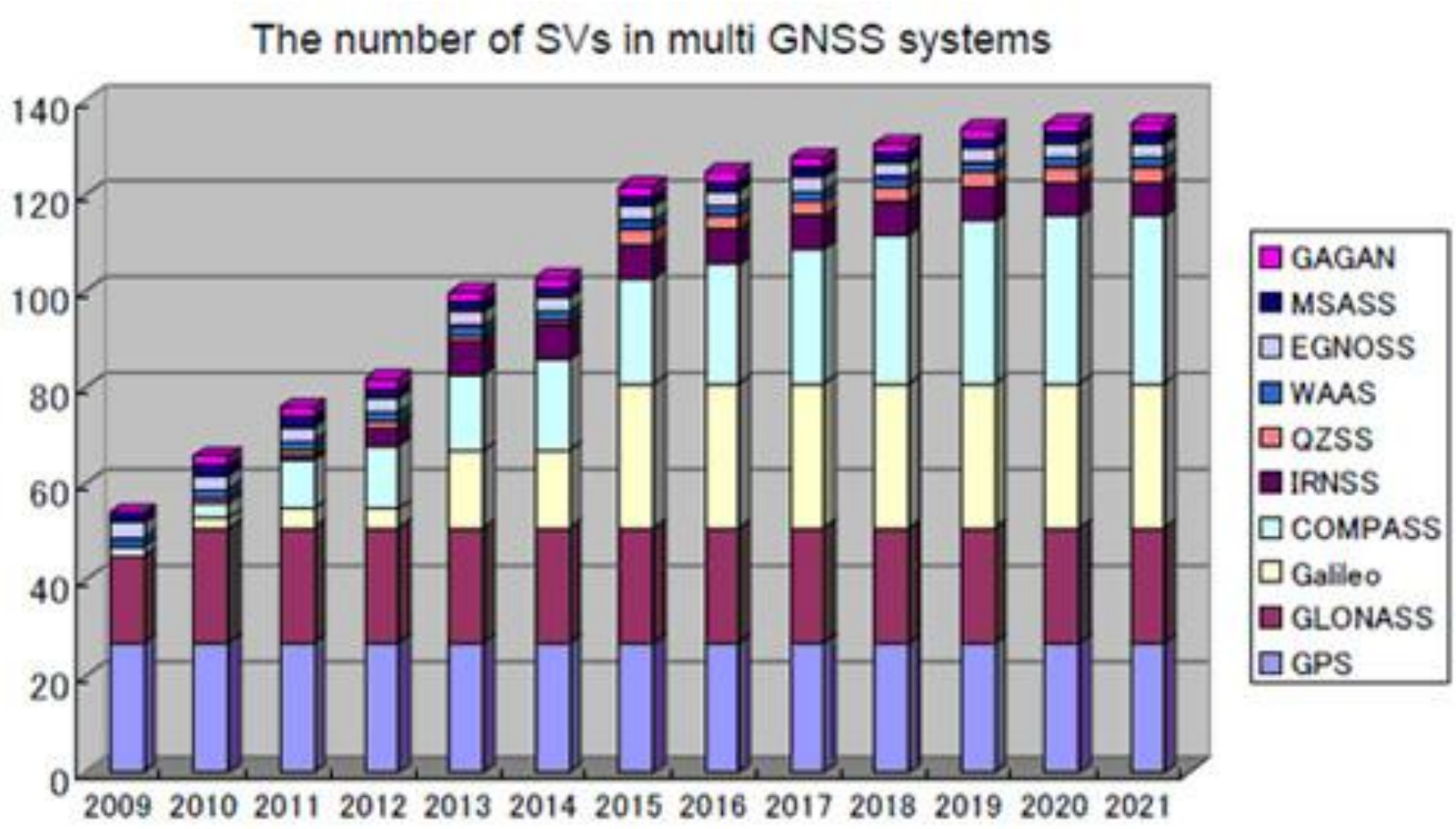
27MEO+3 IGSO+5 GEO

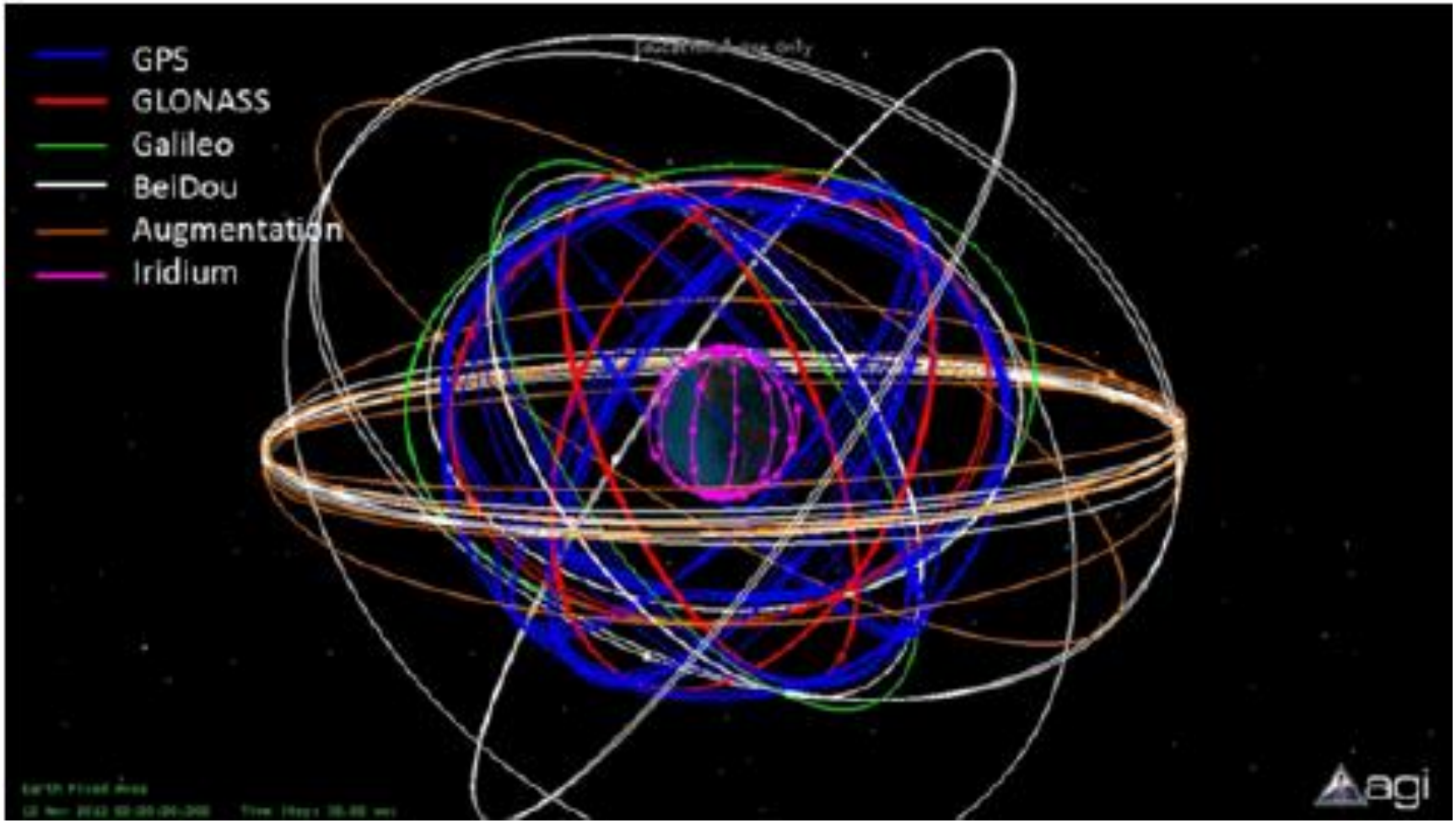
REGIONAL CONSTELLATIONS

QZSS	4+3
NAVIC (IRNSS)	7

SBAS (GEOs)

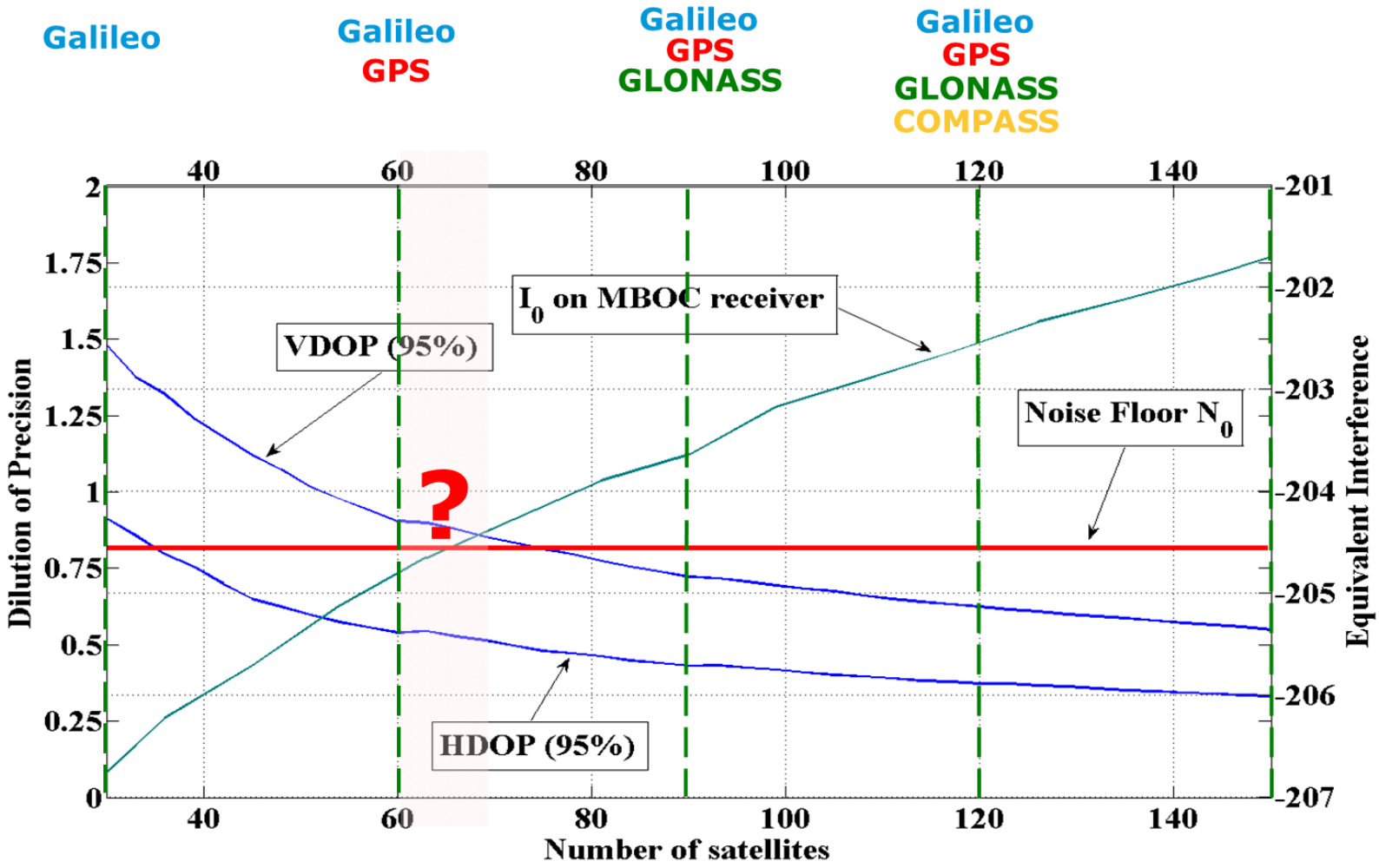
WAAS	3
MSAS	2
EGNOS	3
GAGAN	2
SDCM	3
BDSBAS	3





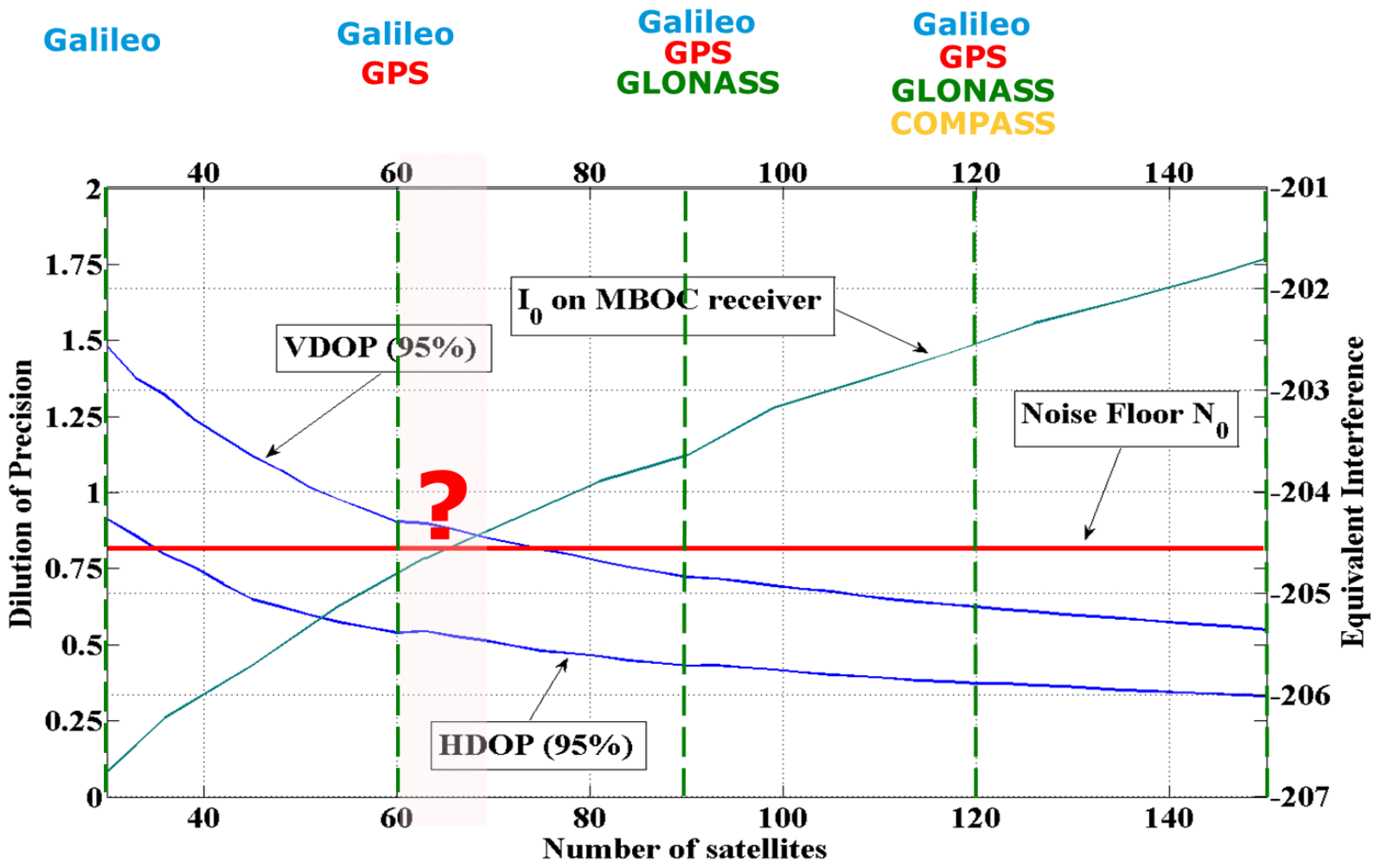
The More satellites the better?

Source: Guenter W. Hein
ESA/JRC International Summer School on GNSS 2016



GDOP decreases as the inverse square root of the number of satellites

$$GDOP \propto \frac{1}{\sqrt{N_{sat}}}$$



Once GNSS interference is dominant, noise floor increases linearly proportional to the number of satellites $I_{\text{intra}} \propto N_{sat}$

References

[RD-1] J. Sanz Subirana, J.M. Juan Zornoza, M. Hernández-Pajares, GNSS Data processing. Volume 1: Fundamentals and Algorithms. ESA TM-23/1. ESA Communications, 2013.

[RD-2] J. Sanz Subirana, J.M. Juan Zornoza, M. Hernández-Pajares, GNSS Data processing. Volume 2: Laboratory Exercises. ESA TM-23/2. ESA Communications, 2013.

[RD-3] Pratap Misra, Per Enge. Global Positioning System. Signals, Measurements, and Performance. Ganga-Jamuna Press, 2004.

[RD-4] B. Hofmann-Wellenhof et al. GPS, Theory and Practice. Springer-Verlag. Wien, New York, 1994.

[RD-5] ESA/JRC International Summer School on GNSS 2016. Presentation Booklet. Ispra (Italy), 18-29 July 2016.

Thank you

GNSS_Data_processing_course1.png | gAGE : Advanced GNSS Research and Innovative Applications - Mozilla Firefox

File Edit View History Bookmarks Tools Help

www.gage.es/drupal6/content/gnssdataprocessingcourse1png

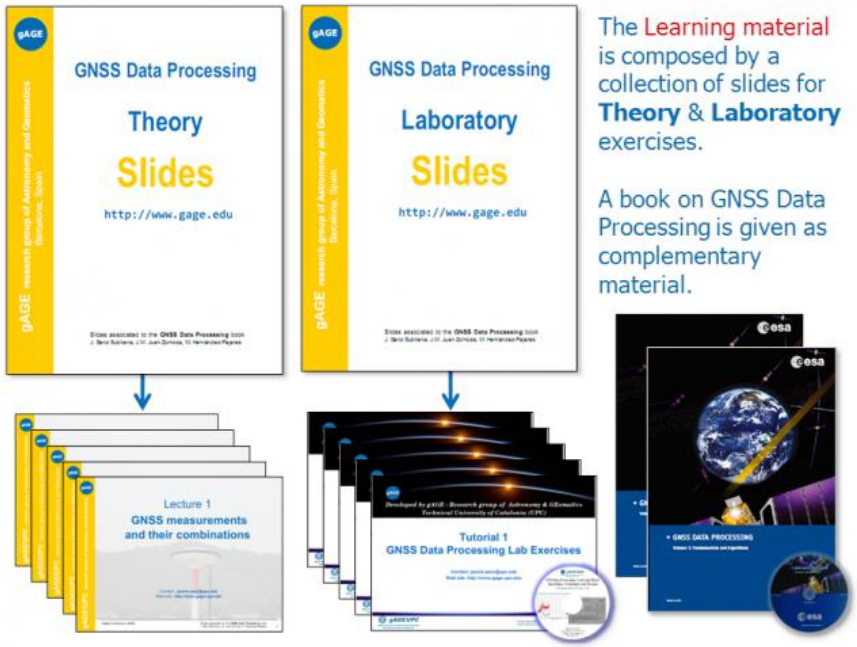
About gAGE/UPC | About gAGE-NAV, S.L. | Contact Us

gAGE : Advanced GNSS Research and Innovative Applications

Home

GNSS_Data_processing_course1.png

Tue, 09/03/2013 - 15:39 — jaume.sanz



The Learning material is composed by a collection of slides for **Theory** & **Laboratory** exercises.

A book on GNSS Data Processing is given as complementary material.

Login to post comments Original Thumbnail

Personnel
- Permanent Staff
- Researchers
- Former Researchers

Publications
- Peer Reviewed Papers
- Meeting proceedings
- Posters
- PhD Disertations

Learning Material
- Library
- Software Tools

Projects
- gAGE/UPC
- gAGE-NAV, S.L.

Patents
- Topics and description

About us

gAGE is a Consortium of the gAGE/UPC Research group of UPC and the Spin-off Company gAGE-NAV, S.L.

gAGE Brochure

Shortcuts
- gLAB Tool Suite
- gAGE Products
- Useful GNSS links
- GNSS Course and associated Tutorials
- MasterMast
- gAGE upload file facility

User login

Username: * jaume.sanz

Password: *

Log in

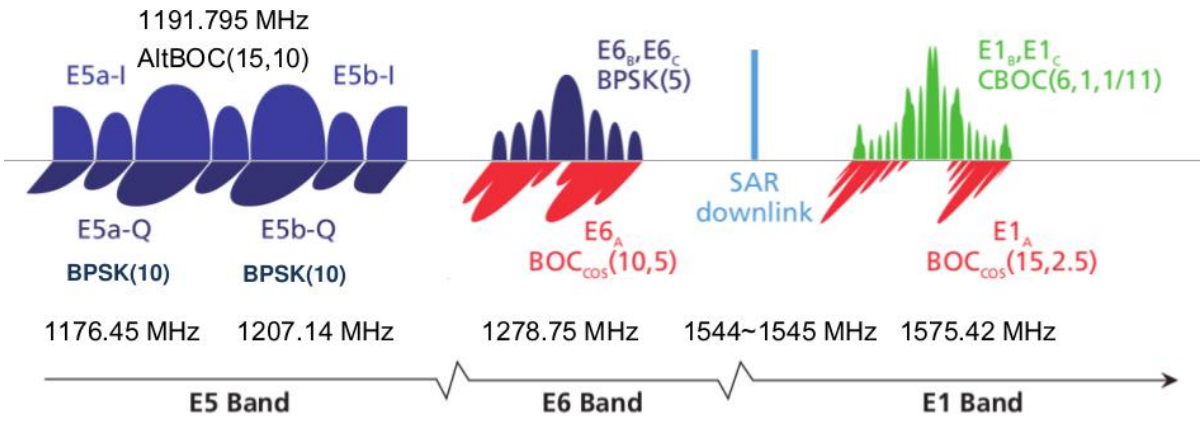
- Log in using OpenID
- Request new password

Who's online

GNSS Data Processing, Vol. 1: Fundamentals and Algorithms.
GNSS Data Processing, Vol. 2: Laboratory exercises.

Galileo navigation signals. The two signals located in the E5a and E5b bands respectively are modulated onto a single E5 carrier frequency of 1191.795 MHz using the AltBOC technique: AltBOC(15,10).

Band	Carrier freq. (MHz)	Channel or sig. comp.	Modulation type	Code rate (Mcps)	Data rate (bps)	Services
E1	1575.420	E1-A data	$BOC_{cos}(15,2.5)$	2.5575	N/A	PRS
		E1-B data	MBOC(6,1,1/11)	1.023	125	OS, CS
		E1-C pilot			–	
E6	1278.750	E6-A data	$BOC_{cos}(10,5)$	5.115	N/A	PRS
		E6-B data	BPSK(5)		500	CS
		E6-C pilot			–	
E5a	1176.450	E5a-I data	BPSK(10)	10.23	25	OS
		E5a-Q pilot			–	
E5b	1207.140	E5b-I data	BPSK(10)	10.23	125	OS, CS
		E5b-Q pilot			–	



Galileo Constellation Status

15.03.18

Common Name	SVN	Int. Sat. ID	NORAD ID	NORAD Name	PRN	Notes
IOV-1, Galileo PFM	E101	2011-060A	37846	GALILEO-PFM	E11	Slot B05
IOV-2, Galileo FM2	E102	2011-060B	37847	GALILEO-FM2	E12	Slot B06
IOV-3, Galileo FM3	E103	2012-055A	38857	GALILEO-FM3	E19	Slot C04
IOV-4, Galileo FM4	E104	2012-055B	38858	GALILEO-FM4	E20	Slot C05 Not available from 05/07/2014
FOC-1	E201	2014-050A	40128	GALILEO 5 (261)	E18	Orbit injection failure (i=49.7° e=0.23)
FOC-2	E202	2014-050B	40129	GALILEO 6 (262)	E14	Orbit injection failure (i=49.7° e=0.23)
FOC-3	E203	2015-017A	40544	GALILEO 7 (263)	E26	Slot B08
FOC-4	E204	2015-017B	40545	GALILEO 8 (264)	E22	Slot B03
FOC-5	E205	2015-045A	40889	GALILEO 9 (205)	E24	Slot A08 Not usable PLANNED OUTAGE
FOC-6	E206	2015-045B	40890	GALILEO 10 (206)	E30	Slot A05
FOC-8	E208	2015-079B	41174	GALILEO 12 (269)	E08	Slot C07
FOC-9	E209	2015-079A	41175	GALILEO 11 (268)	E09	Slot C02
FOC-10	E210	2016-030B	41550	GALILEO 13 (26A)	E01	Slot A02
FOC-11	E211	2016-030A	41549	GALILEO 14 (26B)	E02	Slot A06
FOC-7	E207	2016-069A	41859	GALILEO 15 (267)	E07	Slot C06
FOC-12	E212	2016-069B	41860	GALILEO 16 (26C)	E03	Slot C08
FOC-13	E213	2016-069C	41861	GALILEO 17 (26D)	E04	Slot C03
FOC-14	E214	2016-069D	41862	GALILEO 18 (26E)	E05	Slot C01
FOC-15	E215	2017-079A	43055	GALILEO 19 (2C5)	E21	Slot A03
FOC-16	E216	2017-079B	43056	GALILEO 20 (2C6)	E25	Slot A07
FOC-17	E217	2017-079C	43057	GALILEO 21 (2C7)	E27	Slot A04
FOC-18	E218	2017-079D	43058	GALILEO 22 (2C8)	E31	Slot A01
FOC-19	E219	2018-060C	43566	GALILEO 23 (2C9)	E36	Slot B04
FOC-20	E220	2018-060D	43567	GALILEO 24 (2C0)	E13	Slot B01
FOC-21	E221	2018-060A	43564	GALILEO 25 (2C1)	E15	Slot B02
FOC-22	E222	2018-060B	43565	GALILEO 26 (2C2)	E33	Slot B07 Not usable UNTIL FURTHER NOTICE

http://mgex.igs.org/IGS_MGEX_Status_GAL.php