GALILEO Introduction

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Training on GNSS T131 / T151

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Overview

- ➢ EGNOS
  - History
  - System Architecture
  - Constellation
  - Current status

- ➢ GALILEO
  - History
  - System Architecture
  - Constellation
  - Current status
  - Satellite and Launcher Specifications
  - Signals and Services
  - GALILEO Navigation Message Design
  - GALILEO Performance

GALILEO Introduction

Source: https://galileognss.eu

Source: https://de.wikipedia.org/wiki/European_Geostationary_Navigation_Overlay_Service#/media/File:EGNOS_logo.svg

Overview

GALILEO, alright, but what is EGNOS?

Source: https://de.wikipedia.org/wiki/European_Geostationary_Navigation_Overlay_Service#/media/File:EGNOS_logo.svg

European Geostationary Overlay System

EGNOS History

- 1996: Formal agreement on GNSS-1 (later on EGNOS)

- First satellite carrying EGNOS navigation payload launched in 1997

- Initial operations started in 2005 with an accuracy better than 2 meters

- Official service provided as of October 1st 2009

- 2010 certification for integrity applications

- 2011 official clearance from system provider for safety critical integrity applications

EGNOS System Architecture
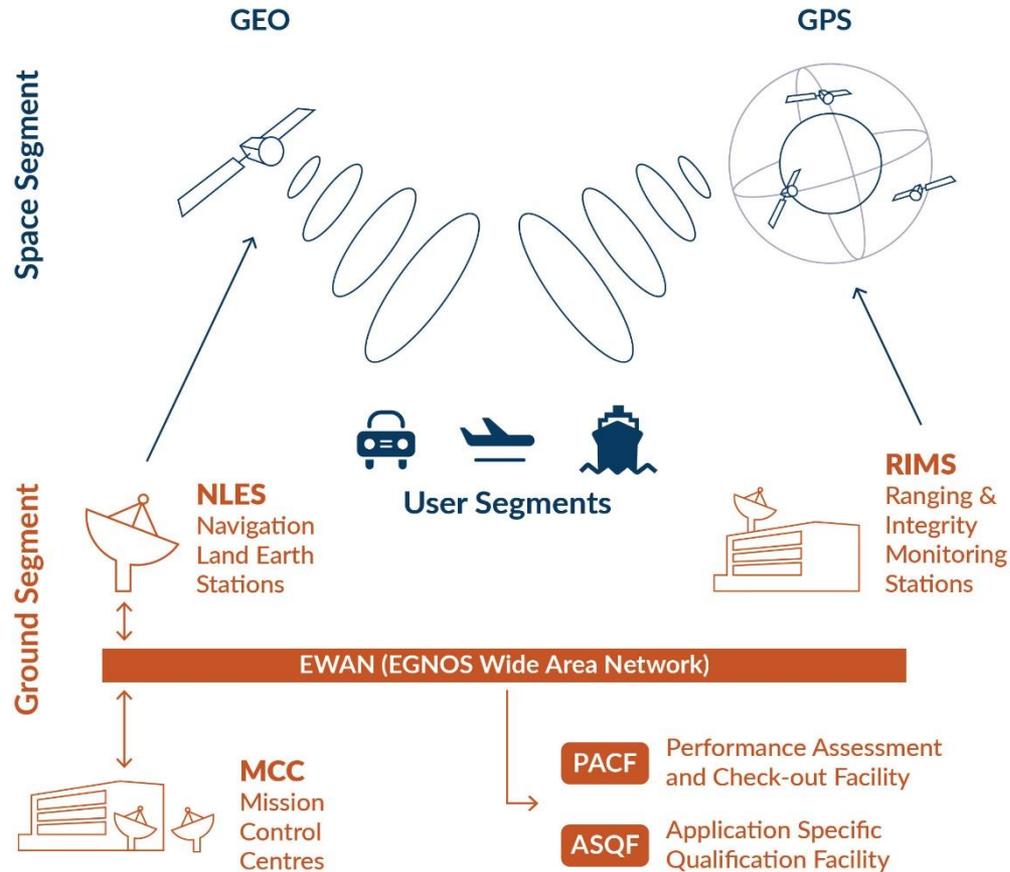
Source: https://egnos-user-support.essp-sas.eu/new_egnos_ops/egnos-system/about-egnos

EGNOS System Architecture

- Navigation Land Earth Stations (NLES)
- Ranging & Integrity Monitoring Stations (RIMS)
- Mission Control Stations (MCCs)
  - Central Processing Facility (CPF)
    - Receives data from RIMS
    - Produce elaborate clock and ephemeris corrections for each GPS satellite in view
    - Produce elaborate ionospheric corrections
  - Central Control Facility
    - Monitor and control all EGNOS ground subsystems
    - Monitor system mission, satellites and service performance
    - Archive all collected and produced data

EGNOS System Architecture
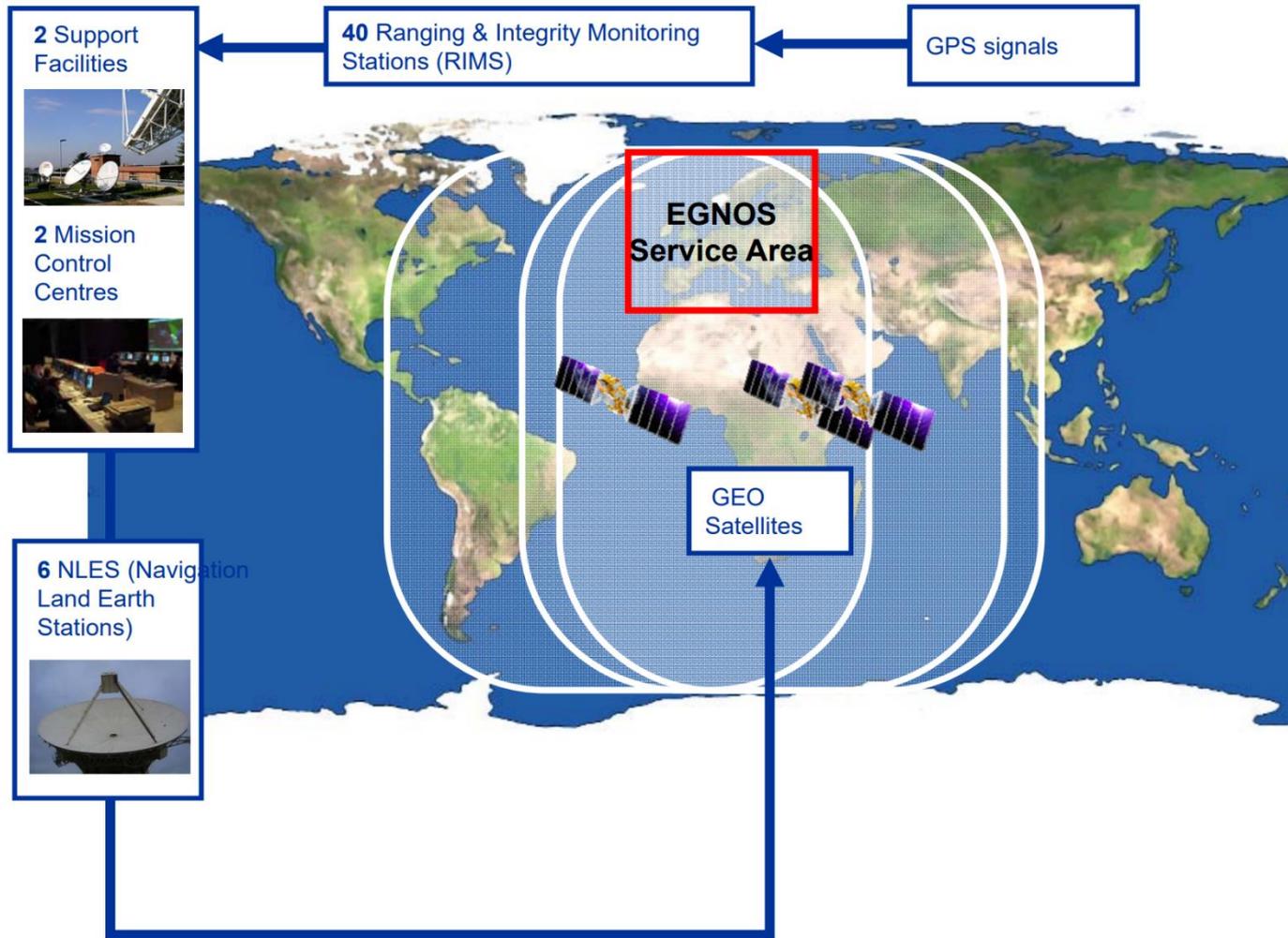
Source: https://www.icao.int/MID/Documents/2017/ACAC-ICAO%20GNSS%20Workshop/EC%20Rabat%20EGNOS%20status%20%20roadmap%20ext_final.pdf

EGNOS System – Ground Segment

Source: https://goo.gl/images/bJBTHw

EGNOS constellation

- Composed of 3 geostationary satellites broadcasting on L1

- ASTRA 5-B (PRN 123) in orbital slot 31.5 E

- ASTRA SES-5 (PRN 136) in orbital slot 5.0 E

- INMARSAT 4F2 EMEA (PRN 126) in orbital slot 64.0 E

- INMARSAT 3F2 (PRN 120) removed from service as of January 1st 2019
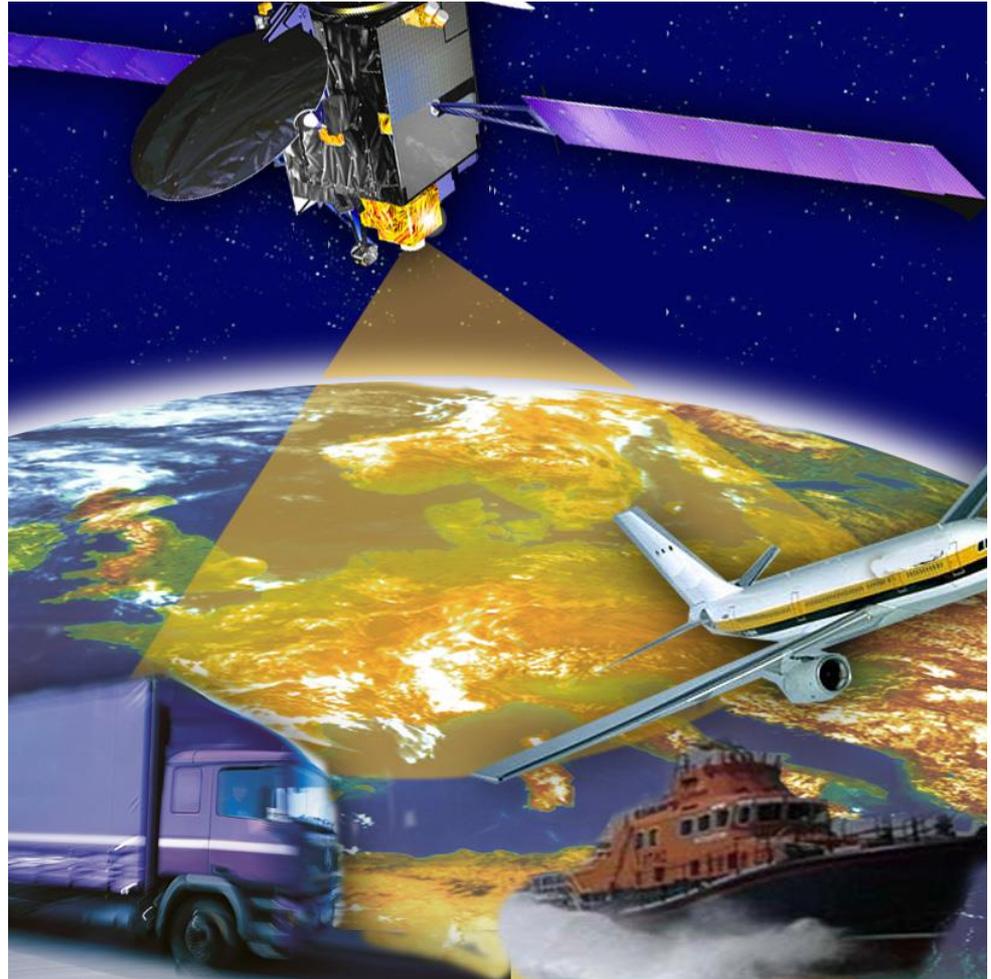
Source: https://gssc.esa.int/navipedia/index.php/File:EGNOS_vehicle_tracing.jpg

EGNOS current status

EGNOS GEO Name	PRN Number	Orbital Slot	Status BEFORE 23rd August 2018 (09:45h UTC)	Status ON 23rd August 2018 (09:45h UTC)	Status FROM 30th August 2018 (11:36h UTC)	Status FROM 1st January 2019
INMARSAT 3F2	PRN 120	15.5 W	Operational	Operational	Test	N / A
ASTRA-5B	PRN 123	31.5 E	Operational	Operational	Operational	Operational
SES-5	PRN 136	5 E	Test	Operational	Operational	Operational
INMARSAT 4F2	PRN 126	64 E	Test	Test	Test	Test

Source: https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/documents/service_notice_15.pdf

EGNOS current status
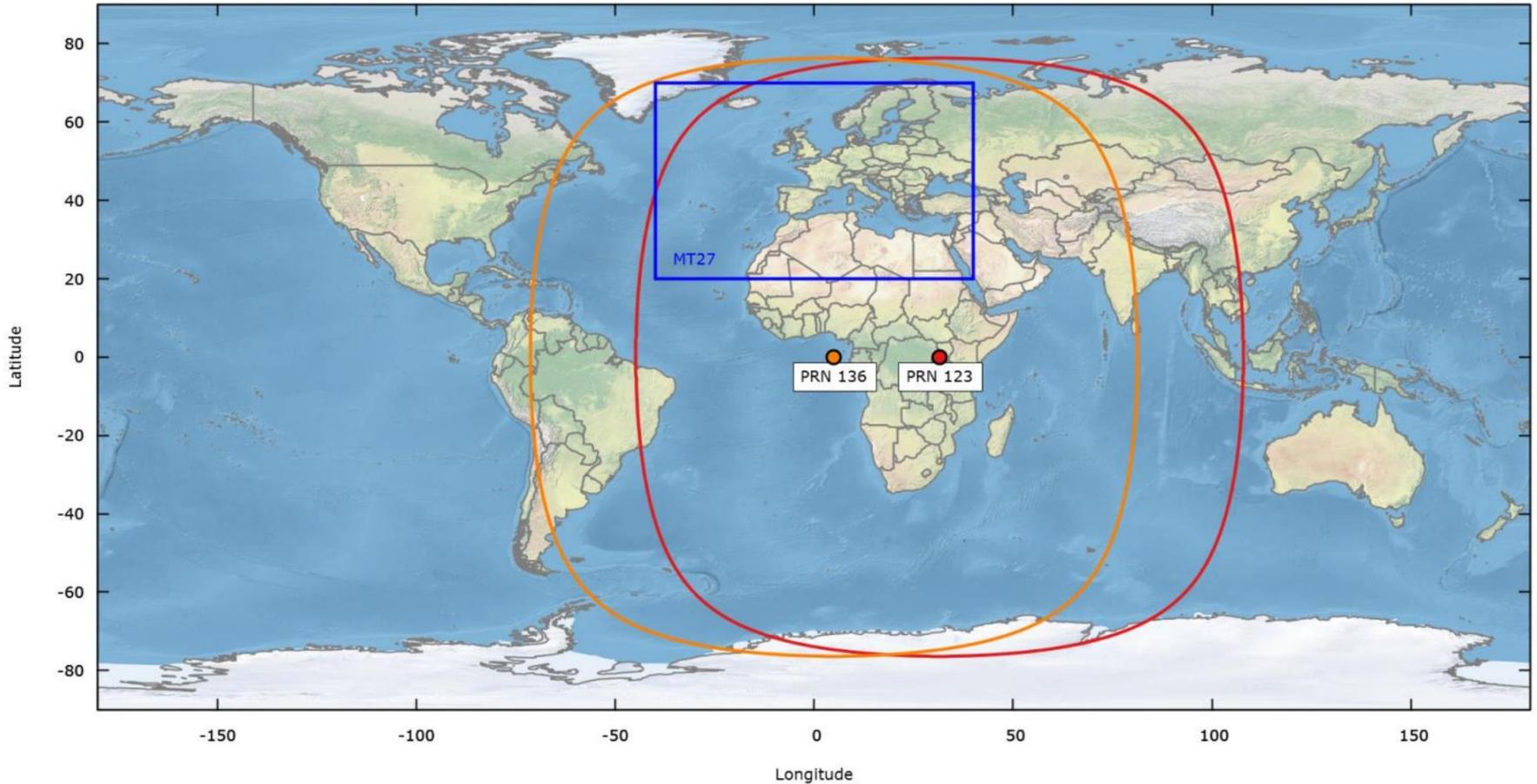
Source: https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/documents/service_notice_15.pdf

Overview

Source: https://galileognss.eu

Galileo History

- 1996: Formal agreement on GNSS-1 (later on EGNOS) and discussions about GNSS-2 (later on Galileo)

- 1999: decision to build Galileo:
  - Increase control over satellite-based safety-critical navigation systems
  - Ensure an independent positioning service for European users in the long term
  - Support EU industry competitiveness

- 2000: Allocation of the Galileo frequency plan at the World Radio Communications Conference

Galileo History

- 2005: Launch of GIOVE-A
- 2008: Launch of GIOVE-B (First to transmit characteristic MBOC signals)
- 2011: Beginning of IOV Phase
- 2014: Beginning of FOC Phase
- 2014: Soyuz Fregat upper stage malfunction, bringing SAT5 and SAT6 in very low, highly elliptical orbit
- 2018: US Federal Communications Commission grants usage of Galileo signals E1 and E5

Galileo System Architecture

- Funding and Operations:

- Funded and owned by the EU (EU citizens)
- Overall responsibility for the programme, management and implementation of all activities lies within the European Commission
- Deployment, design and development of new generations and technical infrastructure is carried out by ESA
- Operations and provision of services is entrusted to GSA

Galileo System Architecture
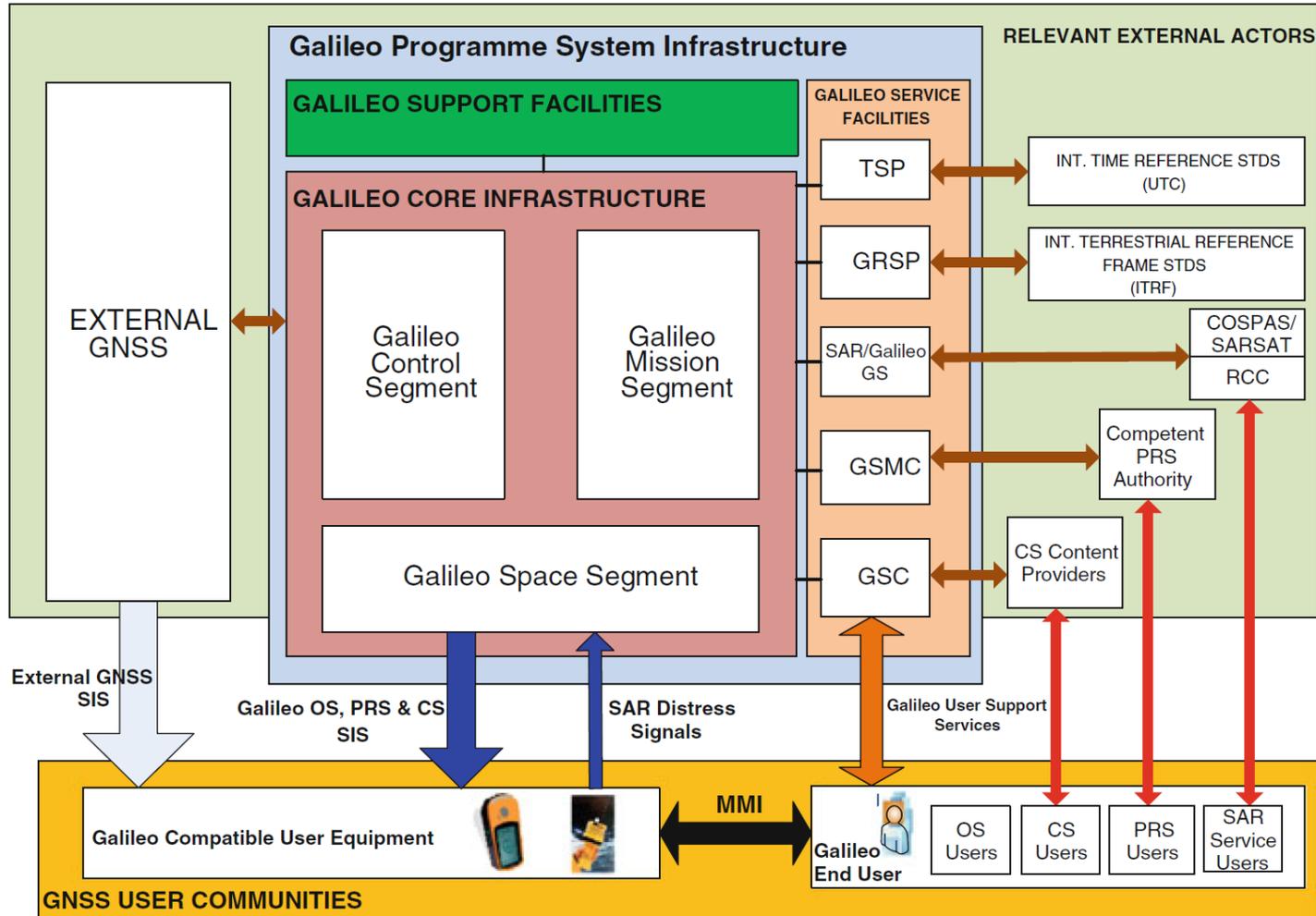
Source: 2014-springer-galsyst-9789400718296-c2

Galileo System Architecture - GCS

- Responsible for satellite constellation control and management of satellites

- Provision of telemetry, telecommand and control functions for the whole satellite const.

- Core facilities:
  - Galileo Control Centers (GCCs)
  - Telemetry, Tracking & Control (TT&C) stations

Source: 2014-springer-galsyst-9789400718296-c2

Galileo System Architecture - GMS

- Responsible for the determination and uplink of navigation data messages needed to provide navigation and UTC time transfer services

- Continuous, global monitoring of all Galileo navigation signals and upload of updated navigation messages

- Core facilities:
  - Galileo Control Centers (GCCs)
  - Galileo Up-Link Stations (ULS)
  - Galileo Sensor Stations (GSS)

Source: 2014-springer-galsyst-9789400718296-c2

Galileo System Architecture - GCC

- GCS facilities within GCC:
  - Spacecraft & Constellation Control Facility, SCCF
  - Spacecraft & Constellation Planning Facility, SCPF
  - Flight Dynamics Facility, FDS
  - Operations Preparation Facility, OPF
  - Central Monitoring & Control Facility, CMCF
  - GCS Key Management Facility, GCS KMF
  - Constellation Simulator, CSIM

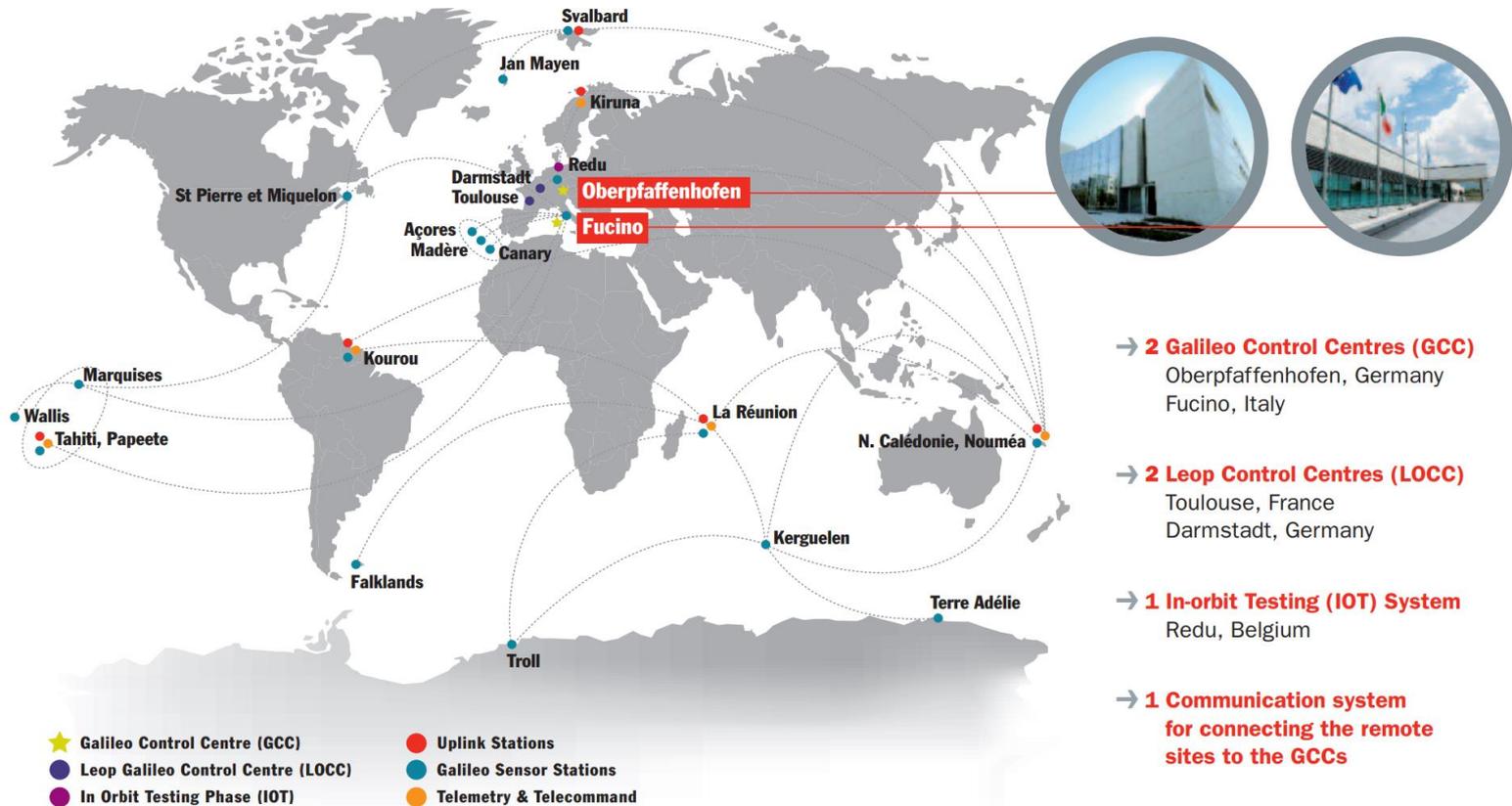Source: https://gssc.esa.int/navipedia/index.php/Galileo_Ground_Segment

Galileo System Architecture - GCC

- GMS facilities within GCC:
  - Orbit Determination and Synchronization Processing Facitility, OSPF
  - Message Generation Facility, MGF
  - Precision Timing Facility, PTF
  - Ground Assets Control Facility, GACF
  - Mission Uplink Control Facility, MUCF
  - Mission Support Facility, MSF
  - Maintenance and Training Platform, MTPF
  - GMS Key Management Facility, GMS KMF
  - Service Product Facility, SPF

Source: https://gssc.esa.int/navipedia/index.php/Galileo_Ground_Segment

Galileo System – Ground Segment

→ **2 Galileo Control Centres (GCC)**
Oberpfaffenhofen, Germany
Fucino, Italy

→ **2 Leop Control Centres (LOCC)**
Toulouse, France
Darmstadt, Germany

→ **1 In-orbit Testing (IOT) System**
Redu, Belgium

→ **1 Communication system
for connecting the remote
sites to the GCCs**

★ **Galileo Control Centre (GCC)**   ● **Uplink Stations**
● **Leop Galileo Control Centre (LOCC)**   ● **Galileo Sensor Stations**
● **In Orbit Testing Phase (IOT)**   ● **Telemetry & Telecommand**

Source: http://www.aiad.it/aiad_res/cms/documents/TELESPAZIOgalileocontrolcenter_eng.pdf

Galileo System Architecture – Add-on

Galileo Reference Center
Noordwijk (The Netherlands)

Galileo SAR Center
Toulouse (France)

Galileo Integrated Logistics Center
Transinnes (Belgium)

Galileo Service Center
Madrid (Spain)

Source: Galileo-At-the-Dawn-of-a-New-Age-of-GNSS-Services-12.19.16

Galileo System Architecture - GSA

- European GNSS Agency (formerly European GNSS Supervisory Authority) in Prague

- Responsible for operations and service provision

- Oversees key facilities:
  - Galileo Security Monitoring Center (GSMC)
  - European GNSS Service Center (GSC)
  - Galileo Reference Center (GRC)
  - Galileo Integrated Logistics Support Center (GILSC)
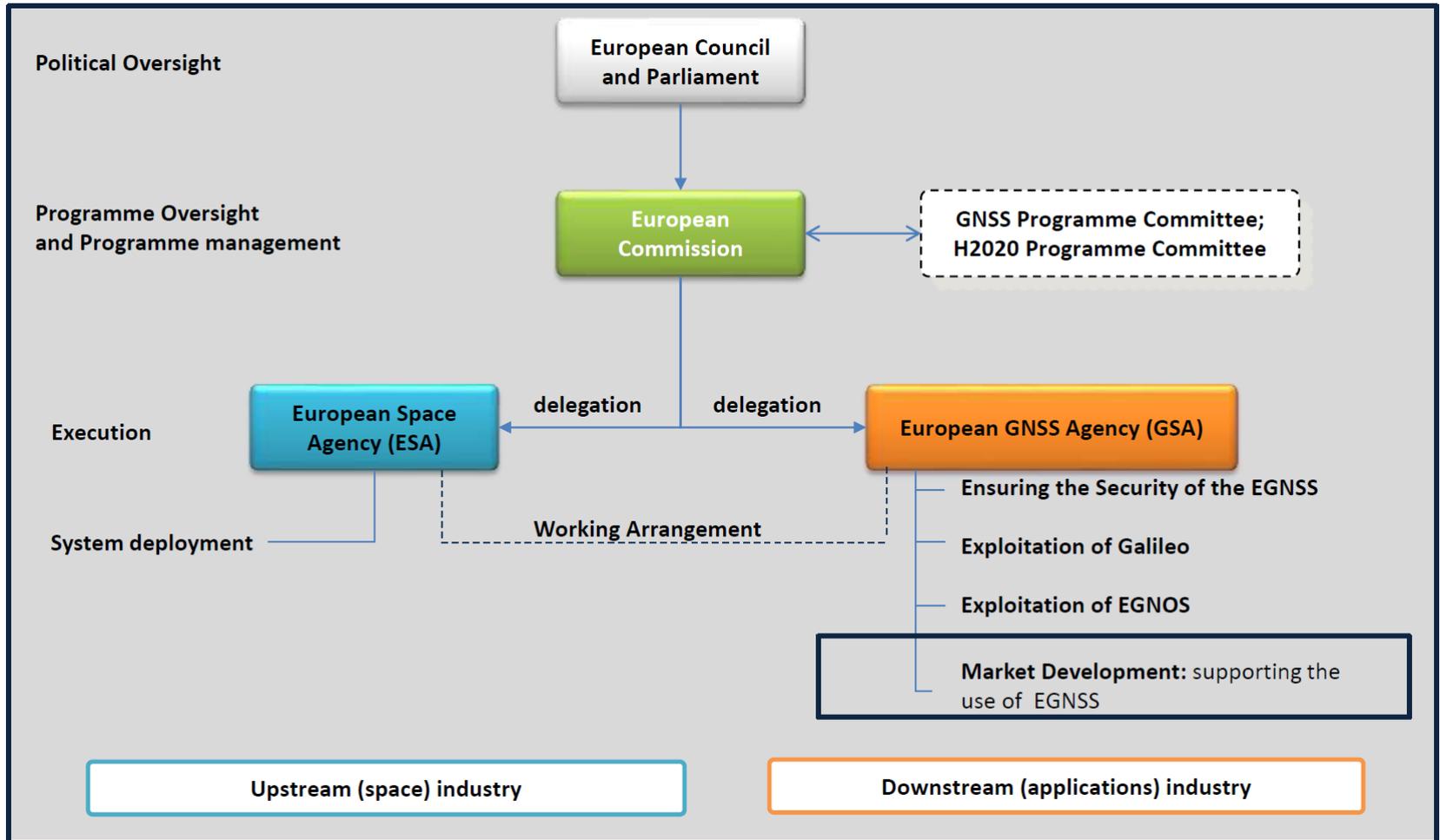 - Galileo Control Centers (GCCs)

- Market analysis
- GNSS/Galileo uptake

European **G**lobal Navigation **S**atellite Systems **A**gency

Source: https://www.gsa.europa.eu

Galileo System Architecture - GSA

Source: https://www.slideshare.net/EU_GNSS/gsa-egnos-and-galileo-for-aviation

Galileo Constellation

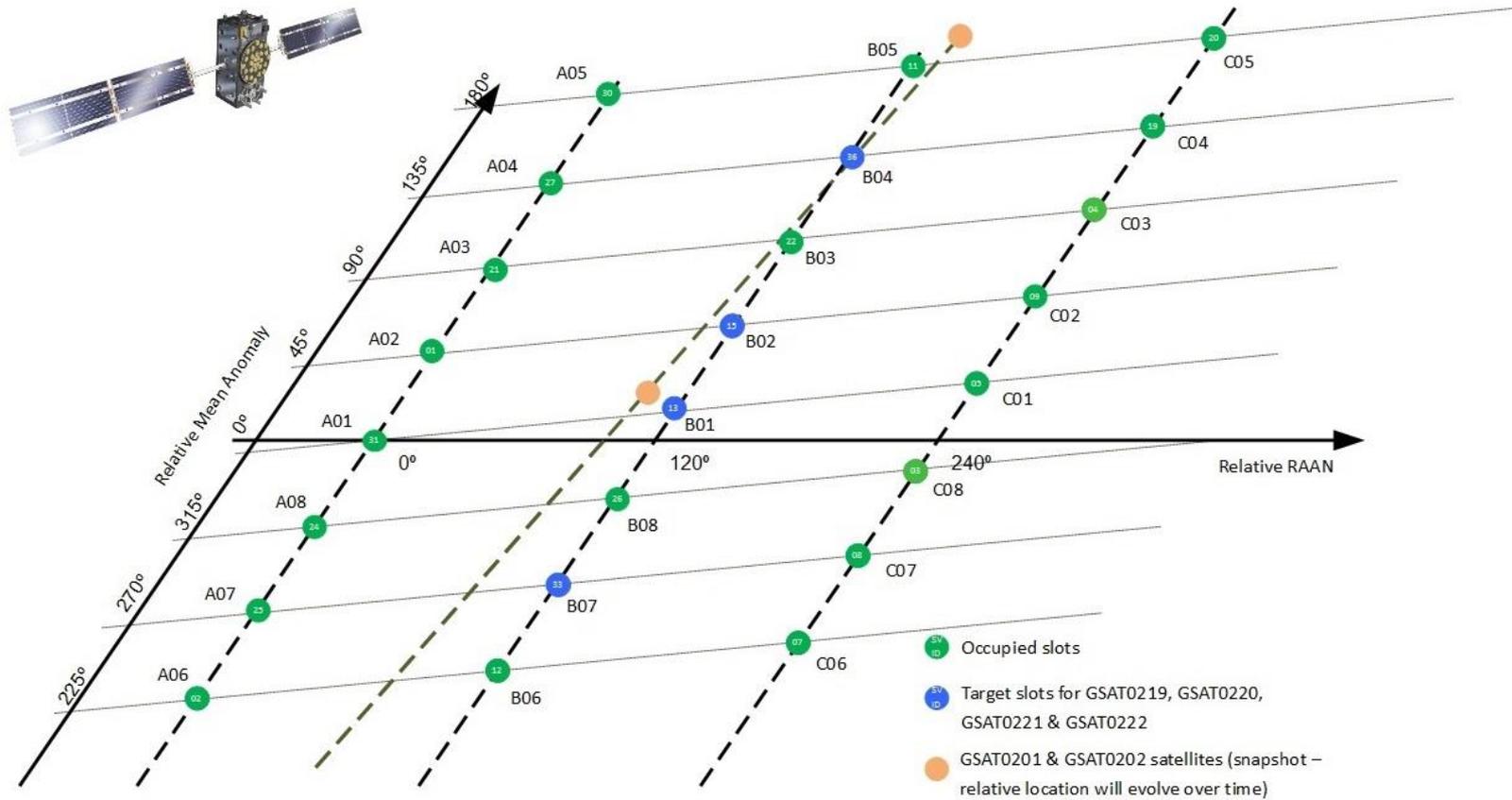- 30 Satellites, 24 operational 6 as spare

- 23.222 km altitude MEO

- 56° inclination

- 3 orbital planes, 120 ° spacing of ascending node

- 10 satellites per orbital plane

- Active SVs form Walker Delta Pattern Constellation (56°:24/3/1)

- 8 active SVs per orbital plane, 45° apart with a +/- 2° bound for nominal position
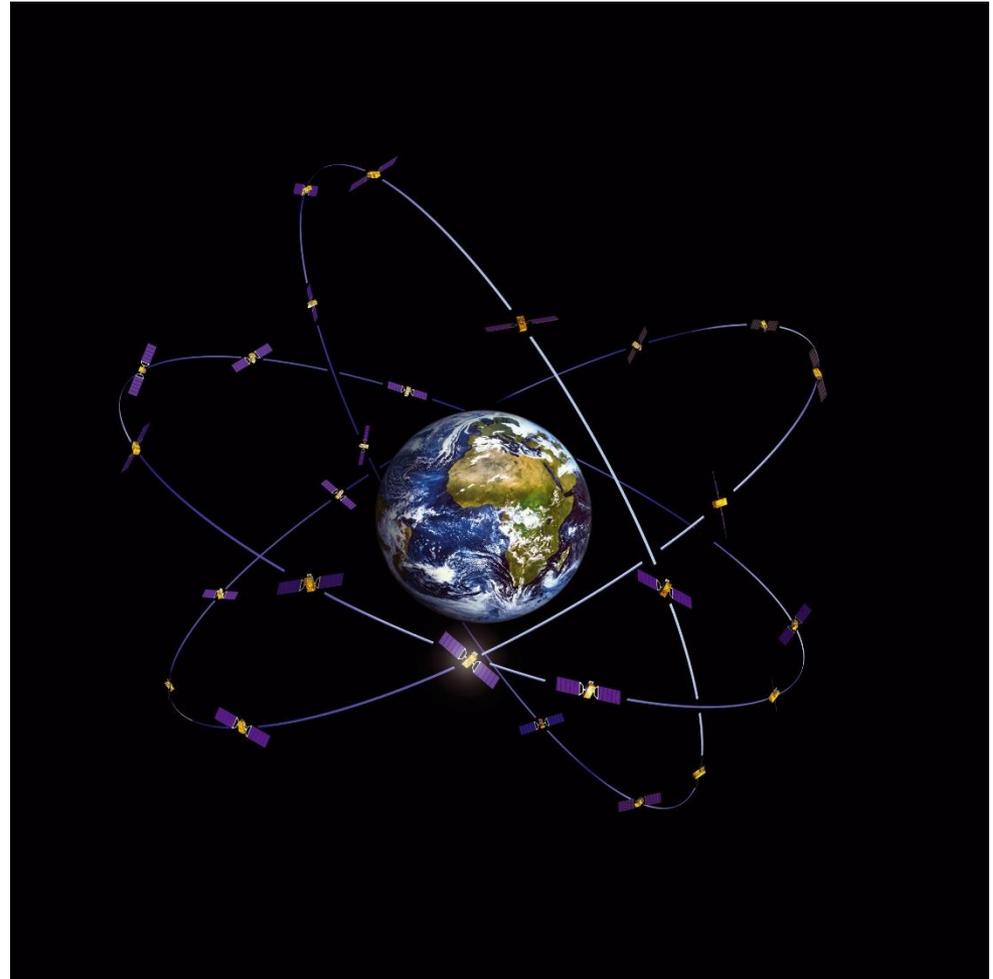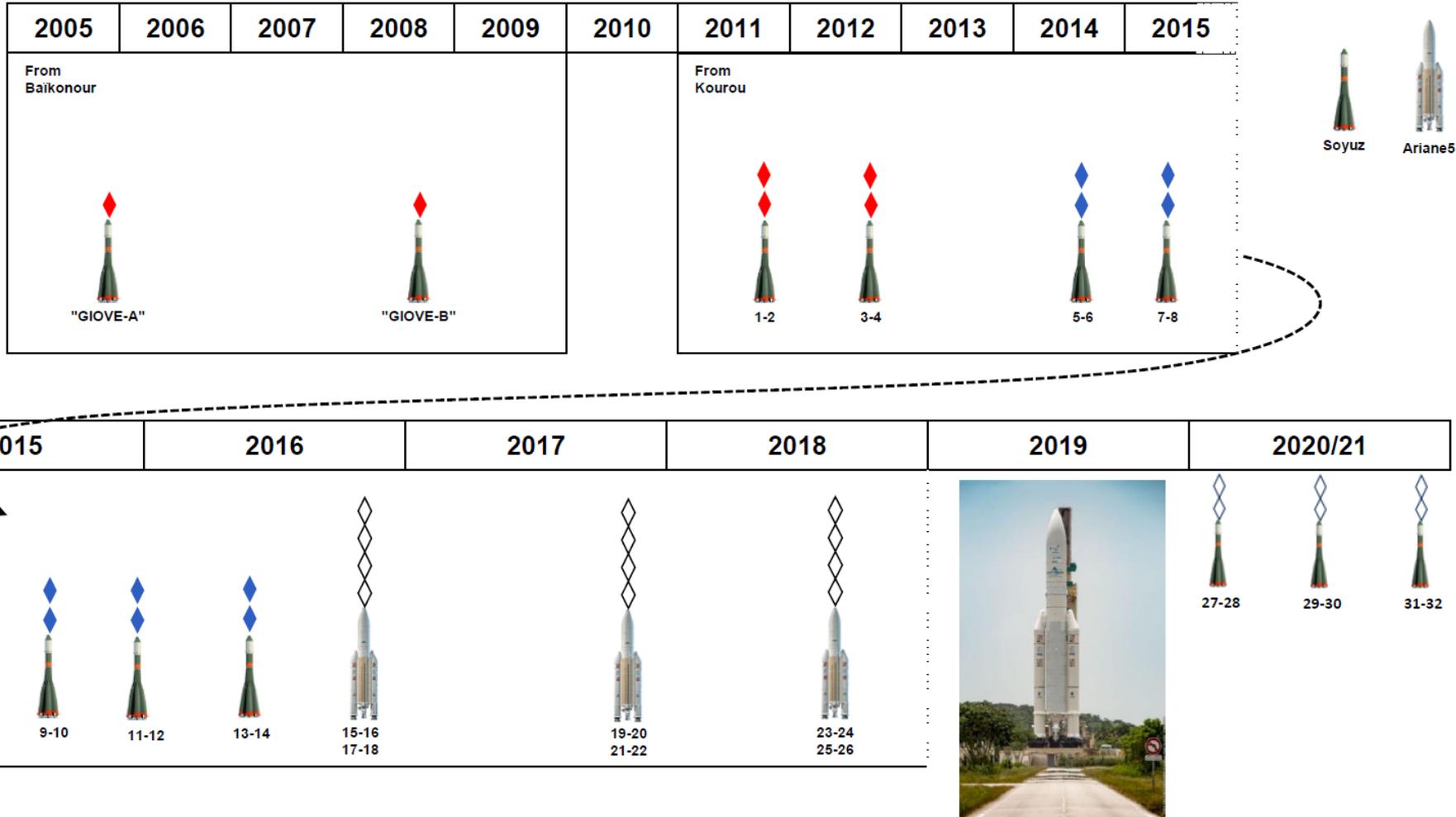

Source: https://gssc.esa.int/navipedia/images/5/56/Galileo_Space_Segment.jpg

Galileo current status

Source: https://www.gsc-europa.eu/system-status/orbital-and-technical-parameters/parameters-definition

Galileo Launch Plan

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015

From Baïkonour

"GIOVE-A"   "GIOVE-B"

From Kourou

1-2   3-4   5-6   7-8

Soyuz   Ariane5

2015	2016	2017	2018	2019	2020/21

9-10   11-12   13-14   15-16 17-18   19-20 21-22   23-24 25-26

27-28   29-30   31-32

Source: https://de.slideshare.net/EU_GNSS/status-of-galileo

Galileo Current 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	PHM	USABLE			
GSAT0103	E19	PHM	USABLE			
GSAT0104	E20	RAFS	NOT AVAILABLE	2014014	UNP_UNUFN	UNAVAILABLE FROM 2014-05-27 UNTIL FURTHER NOTICE
GSAT0201	E18	PHM	TESTING	2016029	GENERAL	TESTING OF GSAT0201
GSAT0202	E14	PHM	TESTING	2016030	GENERAL	TESTING OF GSAT0202
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	PHM	USABLE			

Satellite Name[1]	SV ID[2]	Clock[3]	Status[4]	Active NAGU[5]	NAGU Type[6]	NAGU Subject[7]
GSAT0210	E01	PHM	USABLE			
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		UNDER COMMISIONING	2018017	GENERAL	LAUNCH OF GSAT0219, GSAT0220, GSAT0221 AND GSAT0222
GSAT0220	E13		UNDER COMMISIONING	2018017	GENERAL	LAUNCH OF GSAT0219, GSAT0220, GSAT0221 AND GSAT0222
GSAT0221	E15		UNDER COMMISIONING	2018017	GENERAL	LAUNCH OF GSAT0219, GSAT0220, GSAT0221 AND GSAT0222
GSAT0222	E33		UNDER COMMISIONING	2018017	GENERAL	LAUNCH OF GSAT0219, GSAT0220, GSAT0221 AND GSAT0222

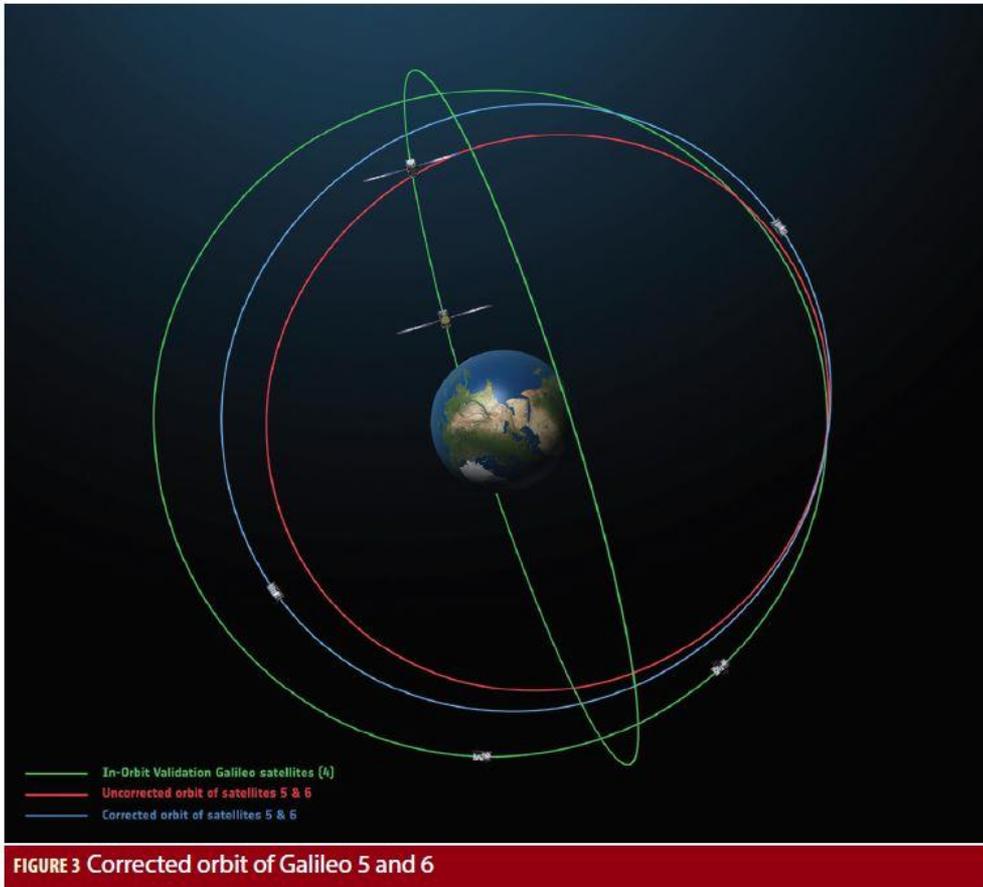Source: https://www.gsc-europa.eu/system-status/Constellation-Information, 10.01.2019, 15:01

Galileo – known issues

- Clock issues:
  - Overall 9 clock failures (6 PHM and 3 RAFS) until now (last one in 2017)
  - The 3 RAFS failures occured on FOC SVs
  - 1 PHM failure occured on an FOC SV
  - 5 PHM failures occured on IOV satellites
  - 3 of the 4 IOVs and 2 of the 26 FOCs are affected
  - Galileo fully functional due to redundancy

- Eccentrical orbits:
  - Galileo 5 and 6 deployed in too low, elliptical orbits
  - Correction maneuvers were carried out, satellites are now fully usable within Galileo

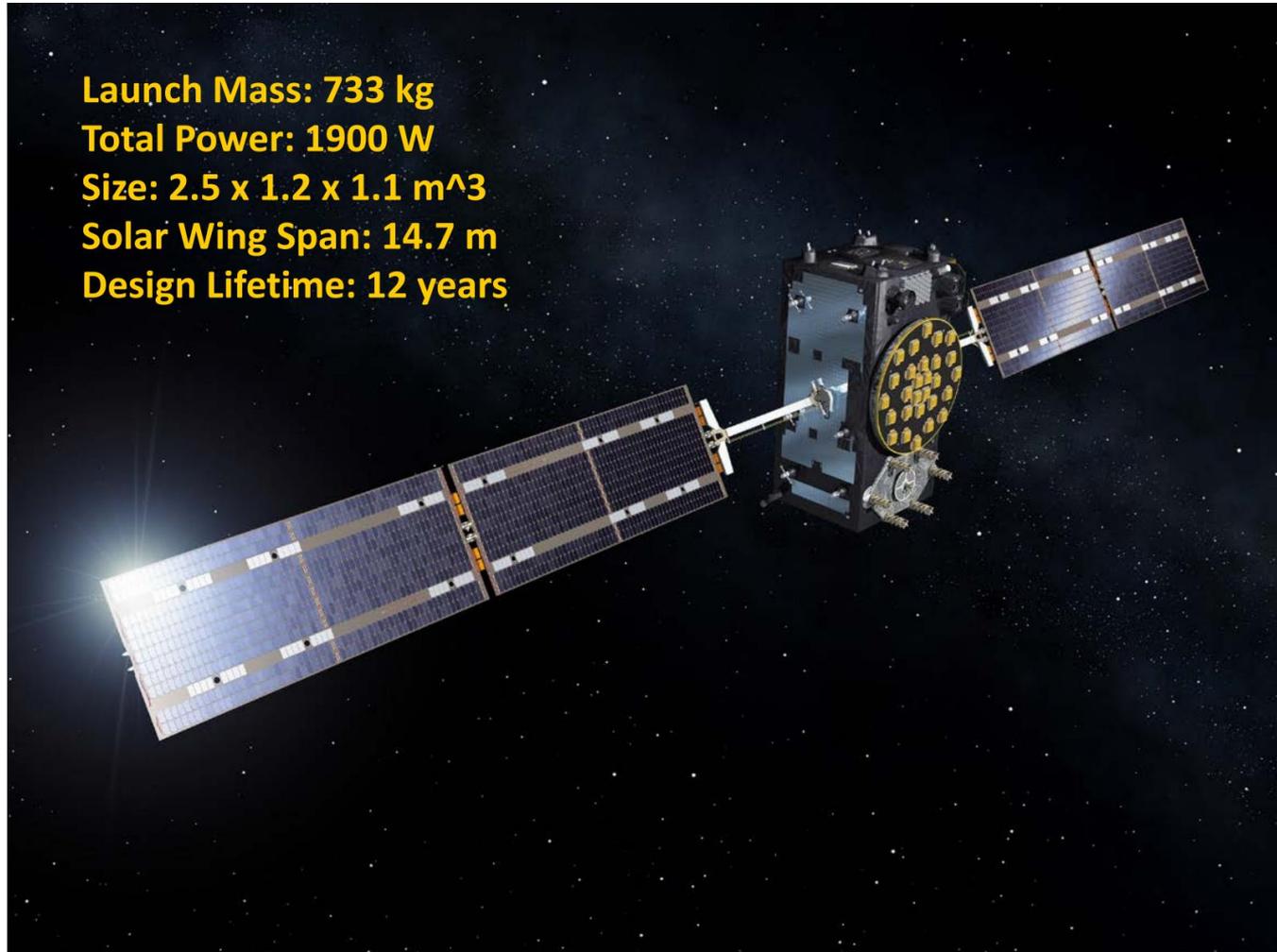# Galileo – known issues

- Eccentrical Orbits: Recovery Maneuvers

FIGURE 3 Corrected orbit of Galileo 5 and 6

Legend:
- In-Orbit Validation Galileo satellites (4)
- Uncorrected orbit of satellites 5 & 6
- Corrected orbit of satellites 5 & 6

Satellite	Semi-Major Axis (km)	Eccentricity	Inclination (deg)	RAAN (deg)	Argument of Perigee (deg)	Mean Anomaly (deg)
Galileo 5	27977.6	0.162	49.850	52.521	56.198	316.069
Galileo 6	27977.6	0.162	49.850	52.521	56.198	136.069
Nominal	29599.8	0.0	56.0	Sat. specific	0.0	Sat. Specific

Table 1 Galileo 5 & 6 reference orbital parameters following orbital corrections

Galileo Satellite Specs - FOC

Launch Mass: 733 kg
Total Power: 1900 W
Size: 2.5 x 1.2 x 1.1 m^3
Solar Wing Span: 14.7 m
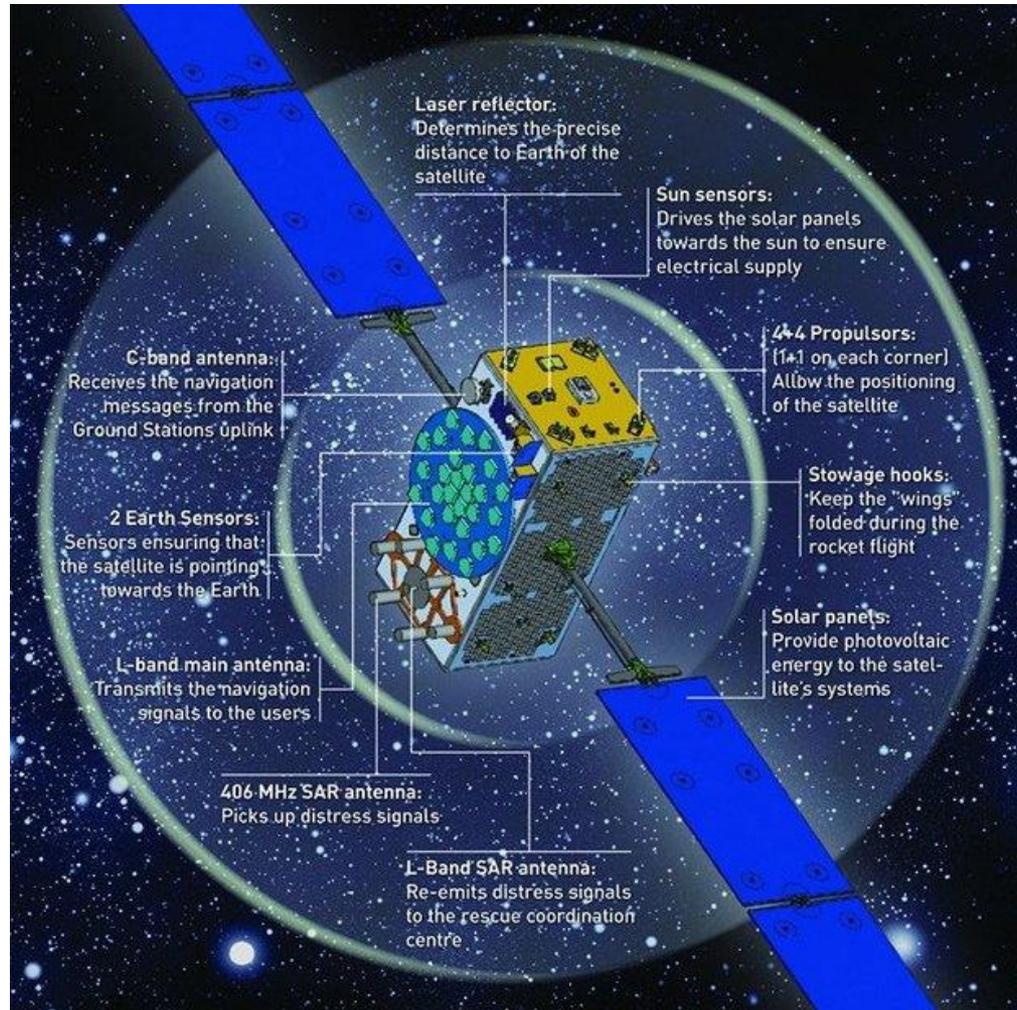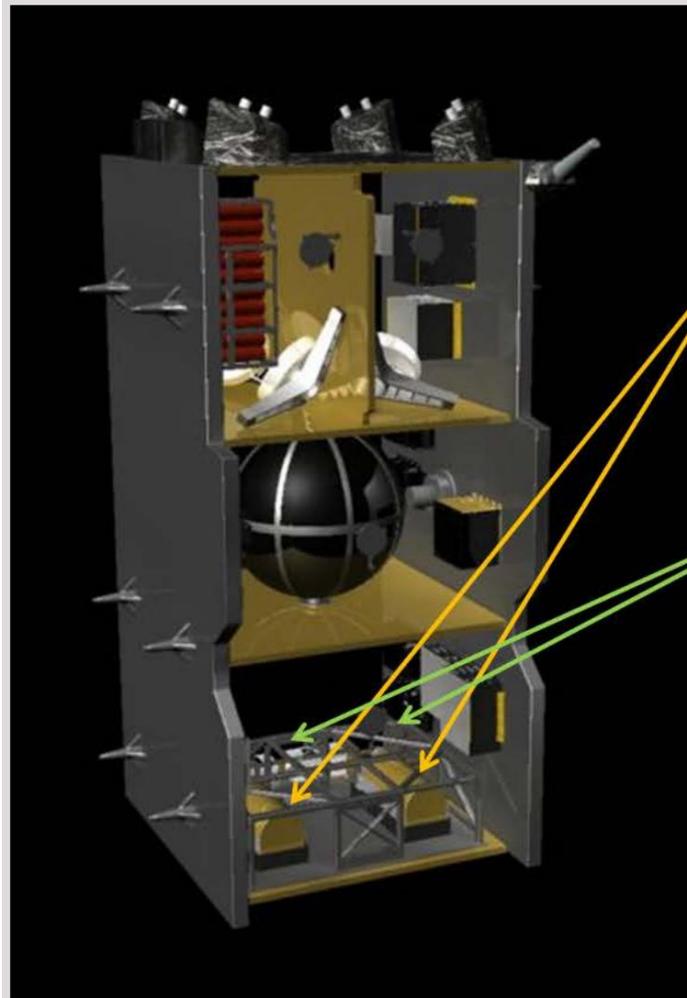Design Lifetime: 12 years

Source: http://insidegnss.com/wp-content/uploads/2018/04/Galileo-At-the-Dawn-of-a-New-Age-of-GNSS-Services-12.19.16.pdf

Galileo Satellite Specs

Source: http://www.esa.int/Our_Activities/Navigation/Galileo/Satellite_anatomy

Galileo Satellite Specs - FOC

Passive Hydrogen Maser
The most stable and accurate
→ Looses no more than 0.5 ns in 12h, i.e. 1s over 3 million years

Rubidium
→ Looses 3s over 1 million years

Error in time	Error in distance
1 s	300 000 000 m
1 ms (0.001 s)	300 m
1 ns (0.000000001 s)	0.3 m

Galileo Launcher Specs

OCTOBER 2011
FIRST FLIGHT

RUSSIAN FEDERAL SPACE AGENCY
PRIME SUPPLIER

3,250 kg.
PAYLOAD TO GTO

4,400 kg.
PAYLOAD TO SSO

SOYUZ TECHNICAL OVERVIEW

46.2 m HEIGHT	10.3 m DIAMETER	308 t MASS

Source: http://www.arianespace.com/vehicle/soyuz/

DUAL-PASSENGER CAPABILITY
AN ARIANE 5 TRADEMARK

AIRBUS SAFRAN LAUNCHERS
INDUSTRIAL PRIME CONTRACTOR
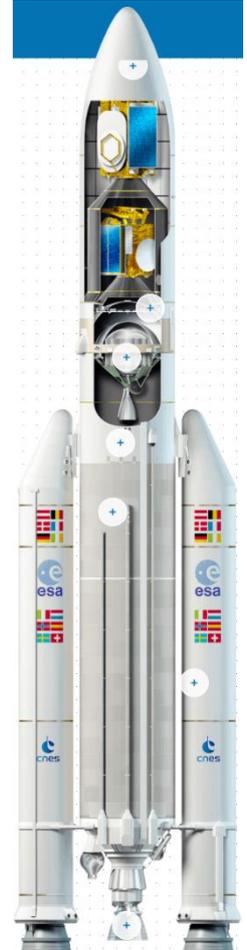
10 t
PAYLOAD TO GTO

20 t
PAYLOAD TO LEO

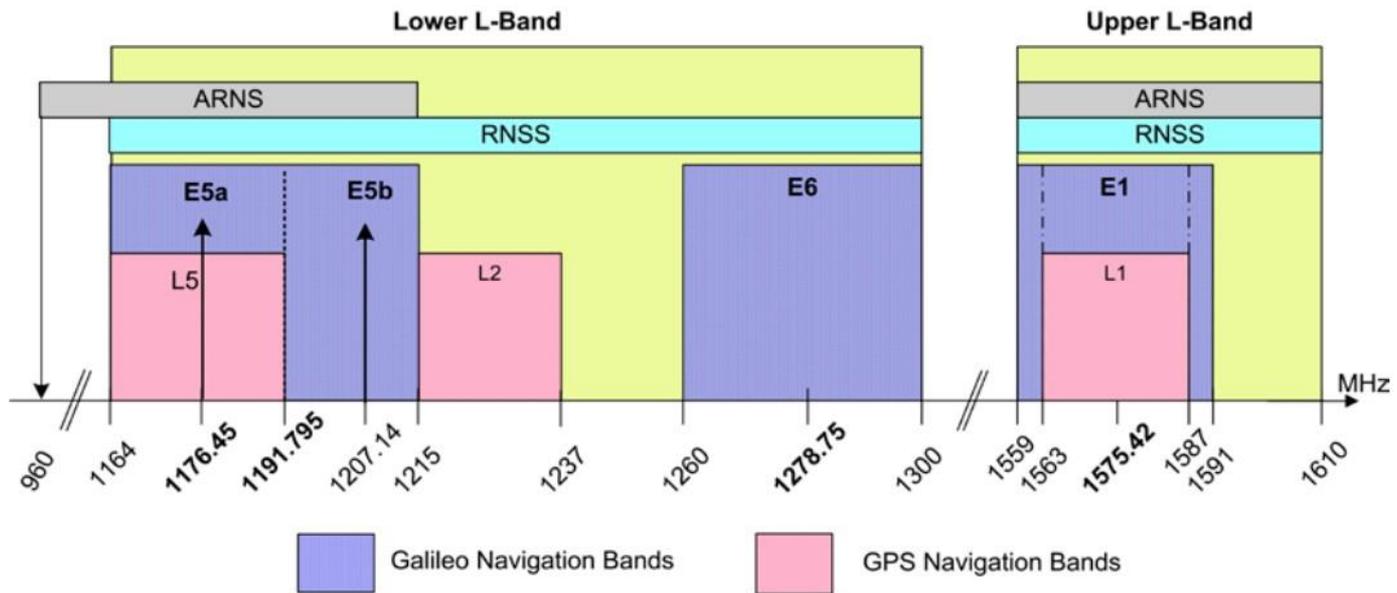**ARIANE 5 ECA TECHNICAL OVERVIEW**
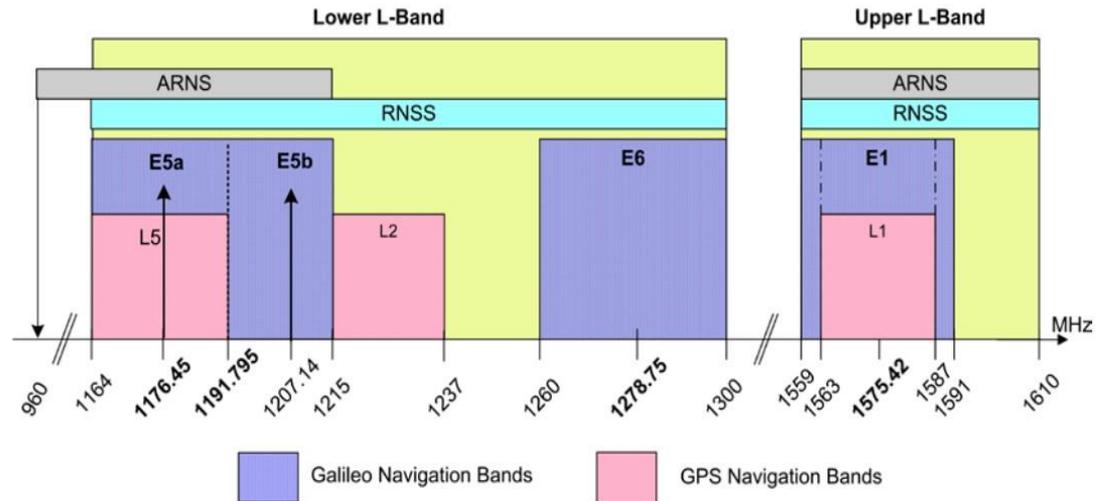
50.5 m HEIGHT	5.4 m DIAMETER	780 t MASS

Source: http://www.arianespace.com/vehicle/ariane-5/

Galileo Signals and Services

Source: Galileo OS SiS ICD

Galileo Signals and Services

Source: Galileo OS SiS ICD

| Service	Description	
Open Service (OS)	Freely accessible service for positioning and timing	
Public Regulated Service (PRS)	Encrypted service designed for greater robustness and higher availability	
Search and Rescue Service (SAR)	Assists locating people in distress and confirms that help is on the way	
High Accuracy Service (HAS)	Delivers high accuracy services, freely accessible	
Commercial Authentication Service (CS)	Delivers authentication services for commercial applications	

Source: The Galileo Reference Centre and Its Role in the Galileo Service Provision, 69th IAC, Bremen, 1-5 October 2018
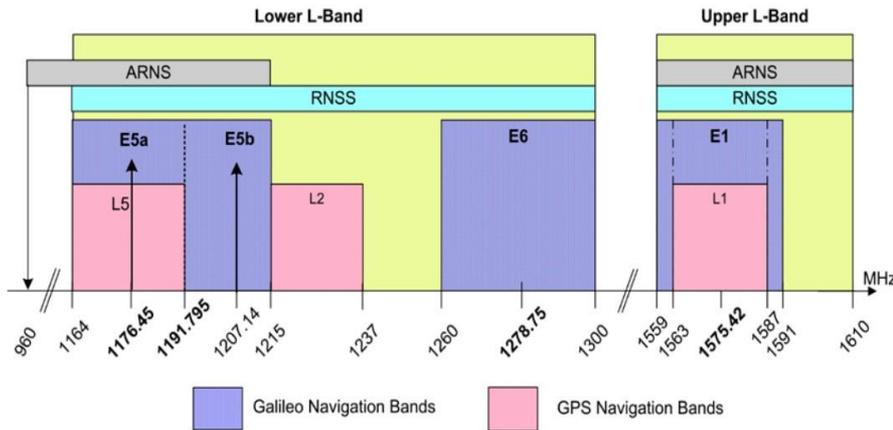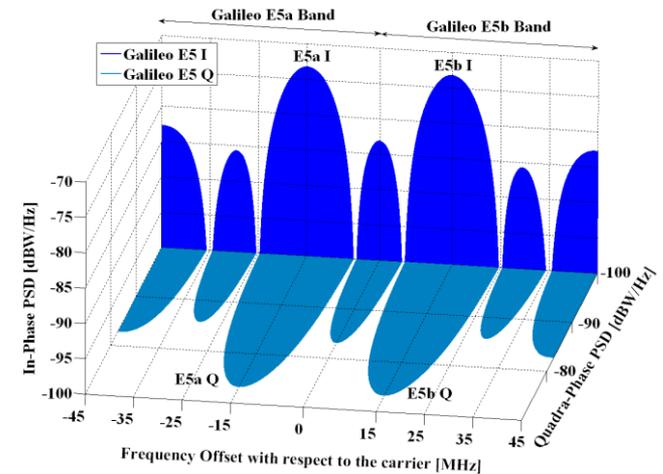
Galileo Signals and Services
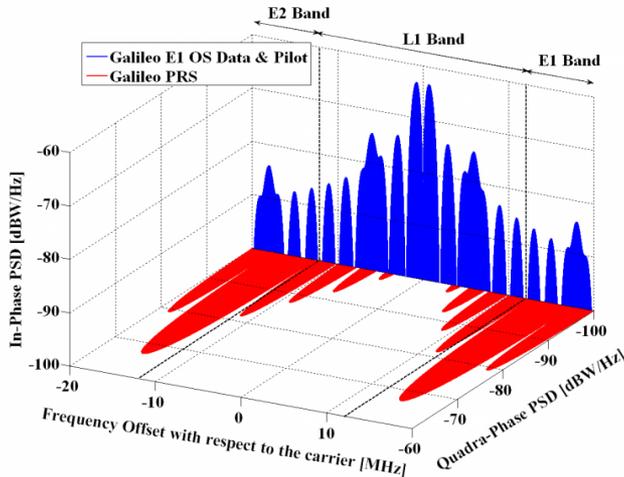
Source: https://gssc.esa.int/navipedia/index.php/File:Galileo_Signal_Plan_Fig_2.png
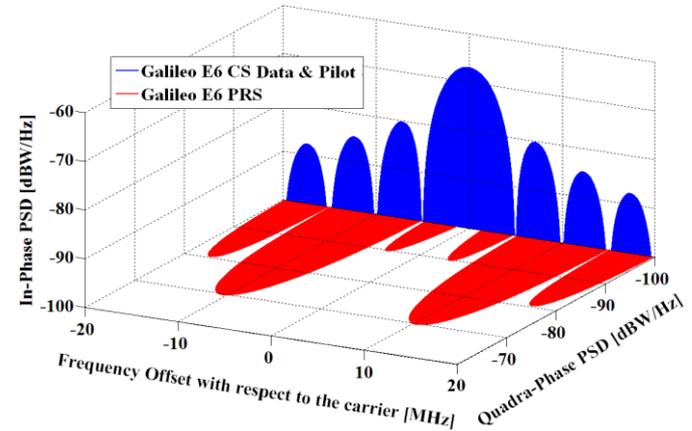
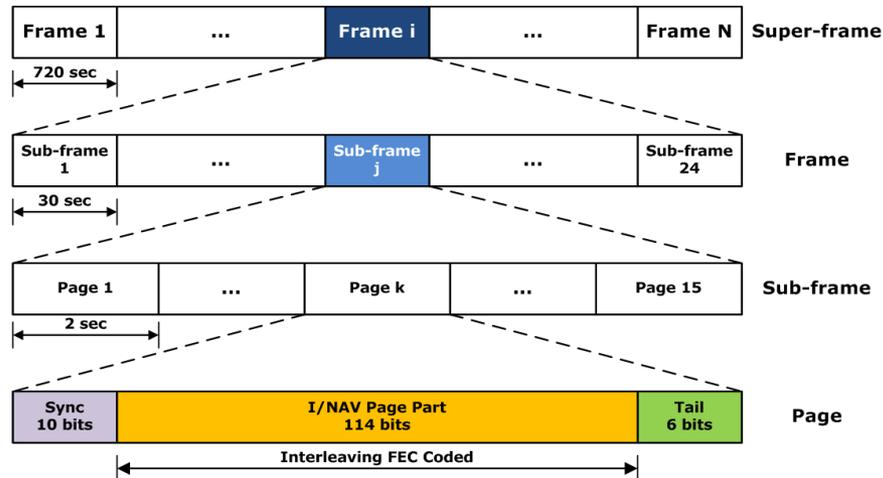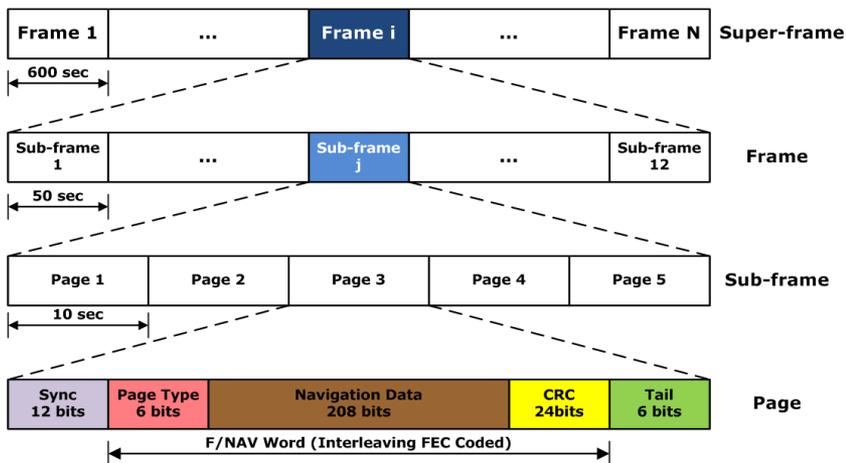Source: https://gssc.esa.int/navipedia/images/e/e7/Galileo_Signal_Plan_Fig_5.png

Source: Galileo OS SiS ICD

Source: https://gssc.esa.int/navipedia/images/e/e2/Galileo_Signal_Plan_Fig_7.png

Galileo Navigation Message

Source: https://gssc.esa.int/navipedia/index.php/Galileo_Navigation_Message

Left diagram (F/NAV):

| Super-frame | Frame 1 | ... | Frame i | ... | Frame N |
| 600 sec |

| Frame | Sub-frame 1 | ... | Sub-frame j | ... | Sub-frame 12 |
| 50 sec |

| Sub-frame | Page 1 | Page 2 | Page 3 | Page 4 | Page 5 |
| 10 sec |

| Page | Sync 12 bits | Page Type 6 bits | Navigation Data 208 bits | CRC 24bits | Tail 6 bits |

F/NAV Word (Interleaving FEC Coded)

Right diagram (I/NAV):

| Super-frame | Frame 1 | ... | Frame i | ... | Frame N |
| 720 sec |

| Frame | Sub-frame 1 | ... | Sub-frame j | ... | Sub-frame 24 |
| 30 sec |

| Sub-frame | Page 1 | ... | Page k | ... | Page 15 |
| 2 sec |

| Page | Sync 10 bits | I/NAV Page Part 114 bits | Tail 6 bits |

Interleaving FEC Coded

Message Type	Services	Component
F/NAV	OS	E5a-I
I/NAV	OS/CS	E5b-I and E1-B
C/NAV	CS	E6-B

Source: Galileo OS SiS ICD

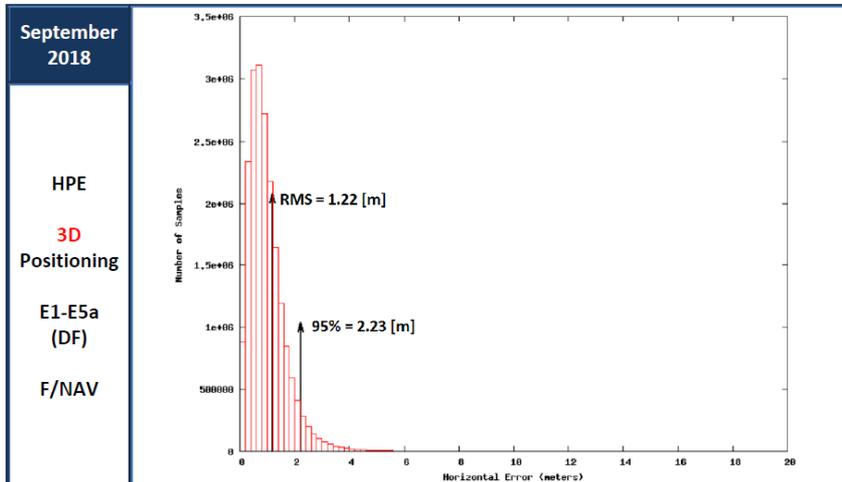| T_0 (GST$_0$ sync.) (s)	E5b Sub frame ID	E5b-I Page	E5b-I Content				E1-B Content						E1-B Page	E1B Sub frame ID
0	N	Even	Word 1 (1/2)				Spare Word (2/2)	Res	SAR	Spare	CRC	Res	Odd	N-1
1	N	Odd	Word 1 (2/2)	Res	CRC	Res	Word 2 (1/2)						Even	N
2	N	Even	Word 3 (1/2)				Word 2 (2/2)	Res	SAR	Spare	CRC	Res	Odd	N
3	N	Odd	Word 3 (2/2)	Res	CRC	Res	Word 4 (1/2)						Even	N
4	N	Even	Word 5 (1/2)				Word 4 (2/2)	Res	SAR	Spare	CRC	Res	Odd	N
5	N	Odd	Word 5 (2/2)	Res	CRC	Res	Word 6 (1/2)						Even	N
6	N	Even	Word 7 or 9 (1/2)*				Word 6 (2/2)	Res	SAR	Spare	CRC	Res	Odd	N

Galileo Performance

Galileo Signal in Space Ranging Accuracy - Constellation averages [m]
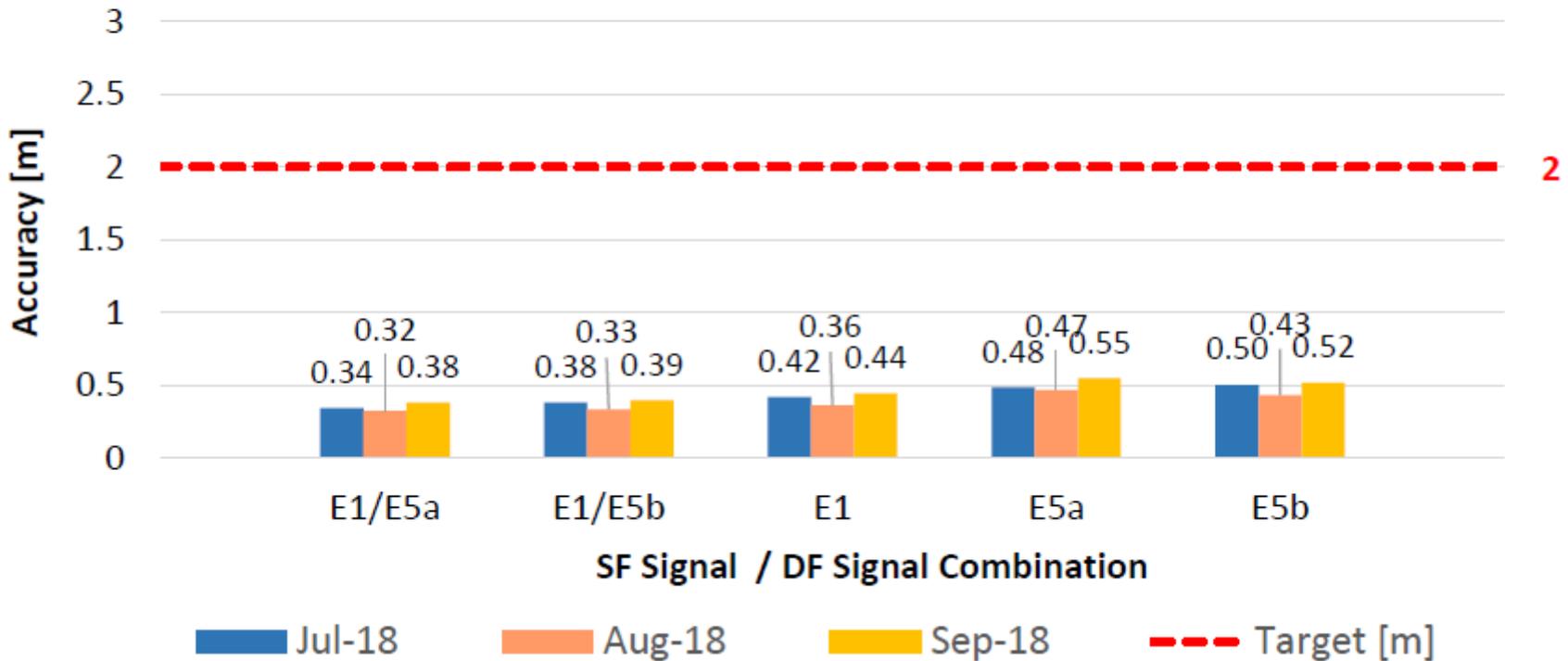
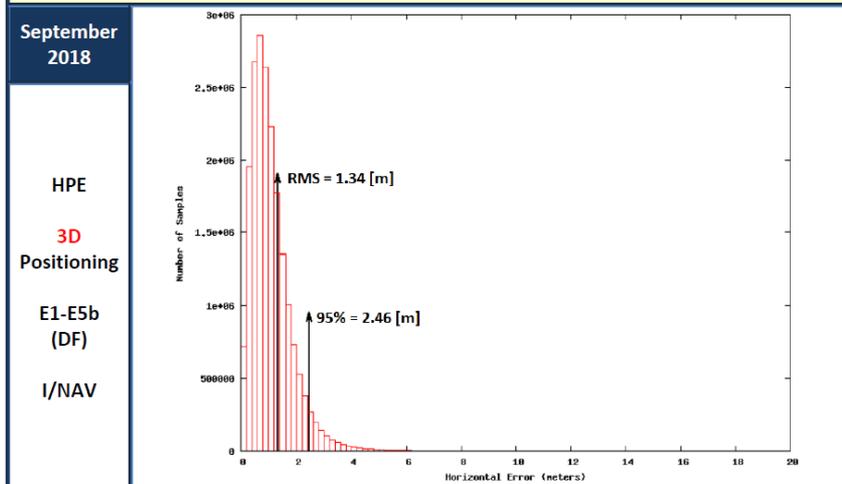Source: Galileo-IS-OS-Quarterly-Performance_Report-Q3-2018

Galileo Performance
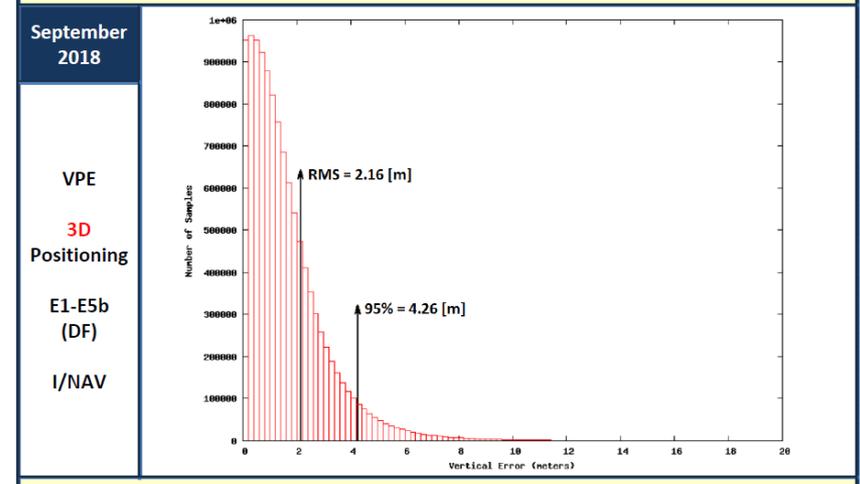

September 2018 · HPE · 3D Positioning · E1-E5a (DF) · F/NAV · RMS = 1.22 [m] · 95% = 2.23 [m] · Note: 54 samples > 20 [m], less than 0.01%
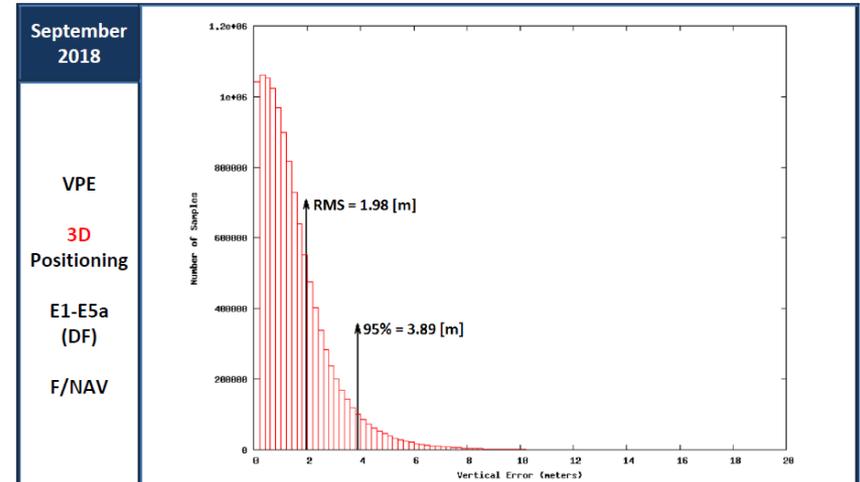
September 2018 · VPE · 3D Positioning · E1-E5a (DF) · F/NAV · RMS = 1.98 [m] · 95% = 3.89 [m] · Note: 681 samples > 20 [m], less than 0.01%

September 2018 · HPE · 3D Positioning · E1-E5b (DF) · I/NAV · RMS = 1.34 [m] · 95% = 2.46 [m] · Note: 43 samples > 20 [m], less than 0.01%

September 2018 · VPE · 3D Positioning · E1-E5b (DF) · I/NAV · RMS = 2.16 [m] · 95% = 4.26 [m] · Note: 538 samples > 20 [m], less than 0.01%

Source: Galileo-IS-OS-Quarterly-Performance_Report-Q3-2018

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