Galileo Outline

Compiled by International Engagement Subcommittee
for Redondo Beach Meeting - December 2024

Topics Requested from GNSS System Providers

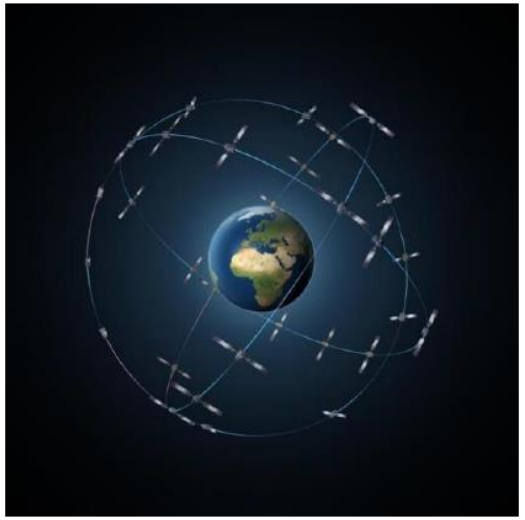
- Technical Characteristics
  - Description of current capabilities and services, open and restricted/authorized/military
  - Publicly available information on capabilities and services under development (planned/ to be initially operational by 2030 3035 2040
  - For both current and planned, which capabilities and services are seen as most critical?
- Program History
  - Public program schedule over past ten years or more showing development of current and imminent capabilities and services.
  - Publicly available costs for program contracts on satellites, upgraded ground segment, etc
- Program Organization
  - Organizational structure for planning, acquisition, operation
  - Contracting models
- Operating Models
  - Engagement with civil users, receiver manufacturers, and other nations
  - Legal requirements for adoption and use of the system, if any
  - Potential areas for synergy/cooperation with the US Global Positioning System

European Union's Galileo

Source: Boyero, EC, at ICG 17, Oct 2023

Galileo - Technical Characteristics

Galileo - Technical Characteristics



Space Segment: 28 Satellites in Orbit

- 23 in Service for Navigation
- 2 Auxiliary
- 24 in service for Search and Rescue

Programme Highlights

– Initial Services provision

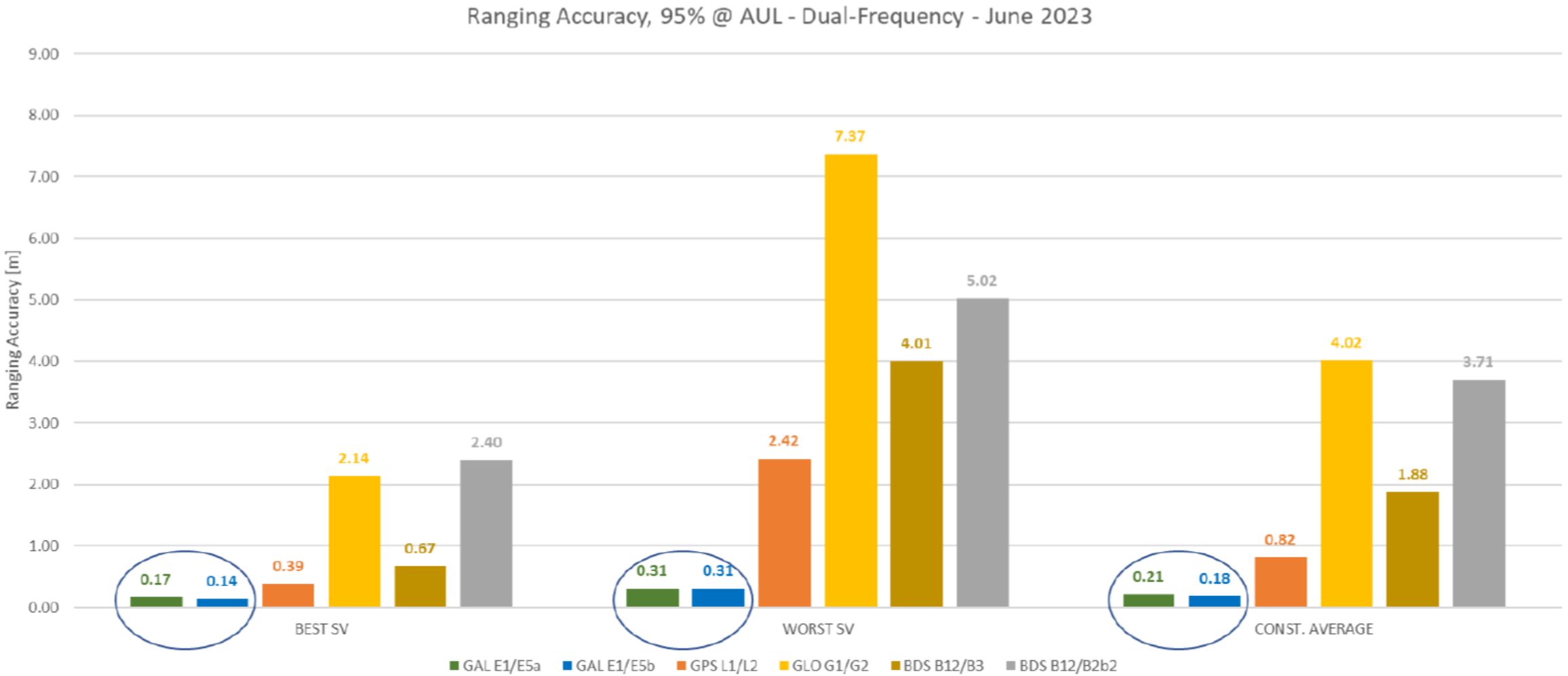
– Remarkable performance

– Strong link with users, market and industry

– G2G Development on-going

Source: Boyero, EC, at ICG 17, Oct 2023

GALILEO DELIVERS OUTSTANDING PERFORMANCE WORLDWIDE



Source: Boyero, EC, at ICG 17, Oct 2023

GALILEO SERVICES PORTFOLIO

Now, Then, & Next

Open Service (OS)

- Free and Open Positioning Navigation & Timing (3 frequencies)
- Emergency Warning Satellite Service + Timing Service + Space Service Volume

Public Regulated Service (PRS)

- Encrypted, more robust, unlimited & uninterrupted access
- PRS evolutions

Search and Rescue (SAR) - contribution

- Forward link + acknowledgement "return link"
- Remote Beacon Activation + Two Way Communication + Distress Position Sharing

High Accuracy and Authentication

- High Accuracy Service
- OSNMA + Advanced signal authentication services

Safety-of-Life (SoL) - contribution

- Advanced Receiver Autonomous Monitoring (ARAIM)
- SBAS Dual Frequency (EGNOS Version 3)

Then = To be implemented in current generation

Next = To be implemented in G2G

Source: Boyero, EC, at ICG 17, Oct 2023

Galileo Navigation Open Service Status

- Navigation Performance better than the Minimum Performance Levels defined in the Galileo OS Service Definition Document
- Enhanced Service Declaration end 2023/beg 2024
- Full Operational Capability (OS FOC) Declaration expected 2025

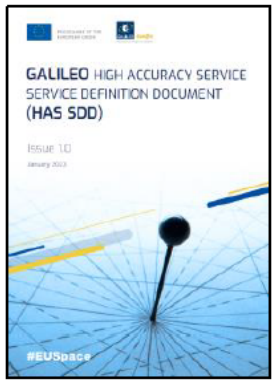
Search And Rescue Service Status

- Performance better than the levels defined in the Galileo SAR Service Definition Document
- Excellent Forward Link / Return Link Availability ≥ 99.9 % / 99.8%
- 4 Galileo MEOLUTs cover 20% world surface; further increase can be achieved through networking
- New Services under preparation
  - Remote Beacon Activation
  - Two-way communication (with predefined distress Q&A helping the rescue mission)
  - Distress Position Sharing: Emergency centers can contact Galileo to share the position of a beacon in distress with other nearby users. Enable quicker rescue.

Performance Reports available at the European GNSS Service Centre website
https://www.gsc-europa.eu/

Source: Boyero, EC, at ICG 17, Oct 2023

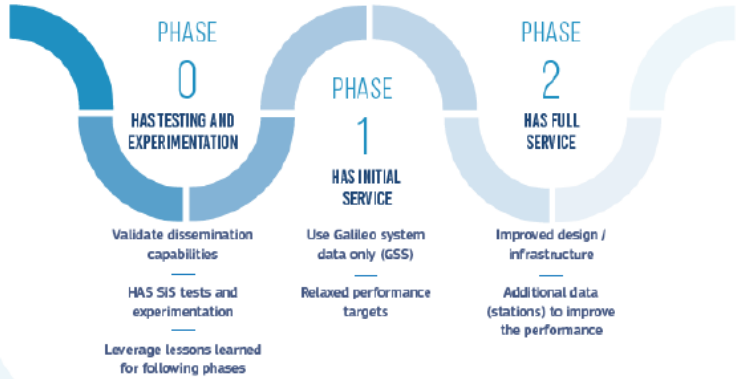
High Accuracy Service Status



- Initial Service Declared in January 2023 – Service **Operational**
- HAS Service Definition Document available

Galileo-HAS-SDD_v1.0.pdf (gsc-europa.eu)

- Full Service Declaration expected in 2025



Initial Service

- Targets 20/40cm horizontal/vertical accuracy (95%)
- Very good performance since start of Service

- Increasing demand after the HAS Declaration - current status: 225+ registered users including (Google Inc., Broadcom US, Furuno, Kongsberg, Fugro, Trimble, U-Blox, etc.)

Source: Boyero, EC, at ICG 17, Oct 2023

Open Service Navigation Message Authentication (NMA)

- OS NMA - Long awaited GNSS feature
- OSNMA SIS ICD and guidelines published in 2022
- Transition to final signal broadcast in July 2023
- Public Testing Phase ongoing
- Initial Service planned by beg 2024

Galileo Commercial Authentication Service (CAS)

- Allows derivation of user Position, Velocity and Timing solutions authenticated
- Initial Service: Assisted CAS (ACAS)
  - Testing in 2024
  - ACAS Initial Service in 2025

Source: Boyero, EC, at ICG 17, Oct 2023

Galileo Contribution to Safety of Life

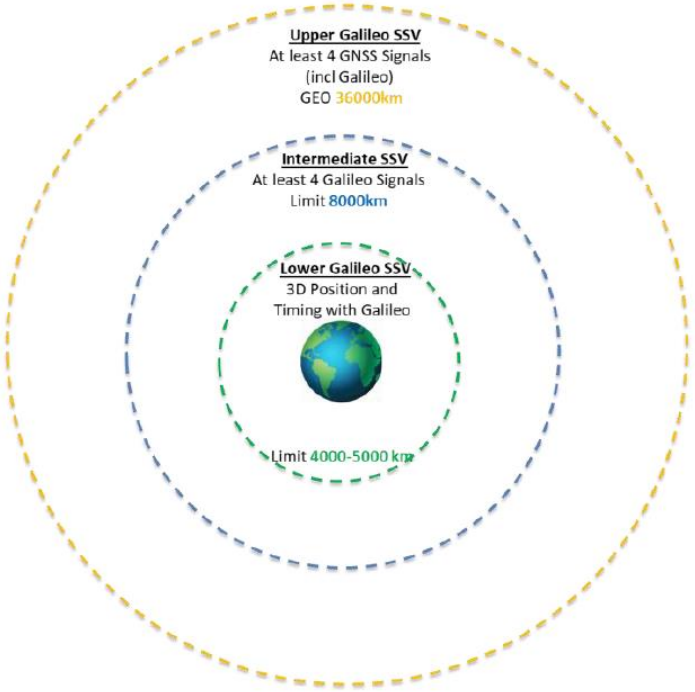
- Galileo already recognized for Civil Aviation
  - Formal adoption by ICAO of the Aviation Standards in March 2023
- Galileo will support Advanced Receiver Autonomous Monitoring
  - Initial Service, based on ARAIM parameters commitments, will follow OS FOC Declaration
- Galileo will support Dual Frequency Multiconstellation SBAS
  - Initial Service, based on Commitments needed for EGNOS v3, will follow OS FOC Declaration

Galileo Emergency Warning Satellite Service

- Service offered to National Civil Protection Authorities to broadcast alerts and associated guidance to targeted areas within minutes

- Demonstration phase on-going to showcase the end-to-end concept: confirm user interfaces, functionalities, performance
- Support the adoption by the civil protection authorities:
  collect feedback in support of Initial Service
- Initial Service: 2025

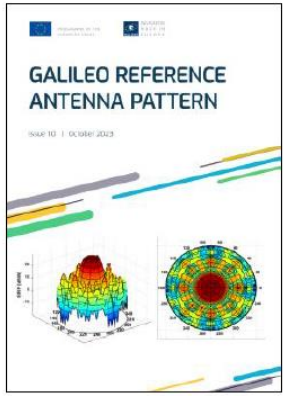
Source: Boyero, EC, at ICG 17, Oct 2023



Galileo Space Service Volume

- Galileo stand alone 3D Position and Timing up to around 4500 km
  - Higher than GPS thanks to higher MEO orbits
- Unique Galileo services fully available in LEO
- Multi-constellation for higher orbits

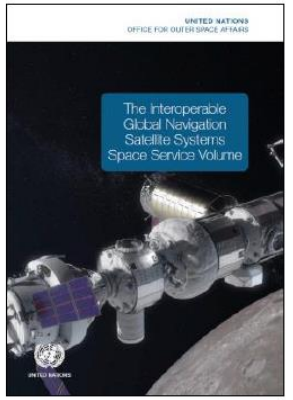
- Publication of the Galileo Reference Antenna Pattern



International Cooperation

- UN International Committee on GNSS defines, promotes an Interoperable GNSS SSV for the benefit of GNSS space users

- "SSV Booklet", 2nd Edition ICG-15, 2021. Executive Summary publication in multiple languages coming up



Source: Boyero, EC, at ICG 17, Oct 2023

G2G and Beyond

"The future starts today, not tomorrow" – Pope John Paul II

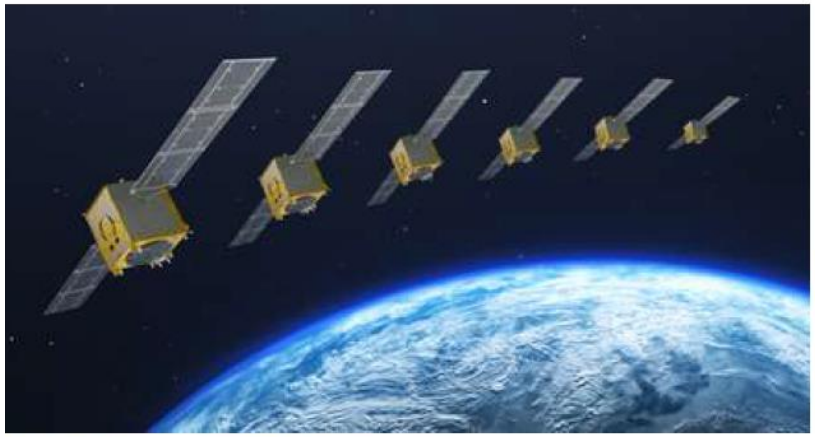
- Legal basis and requirements baseline in place
- Budget available
- Fast Track towards Galileo 2nd Generation
- R&D activity in parallel to maintain security of supply and study emerging concepts for GNSS (LEO-PNT)

From R&D….

…to launch and exploitation !

Source: Hahn, ESA, at ICG 16, Oct 2022

Galileo Second Generation Procurements



G2G B1 – ADS-DE Satellite
Preliminary Design Review passed
First HW available

G2G Satellite Clocks
2 Operational, 2 Evolutions & 5 Experimental clocks ongoing

G2G B1 – TAS-IT Satellite
Preliminary Design Review passed
First HW available

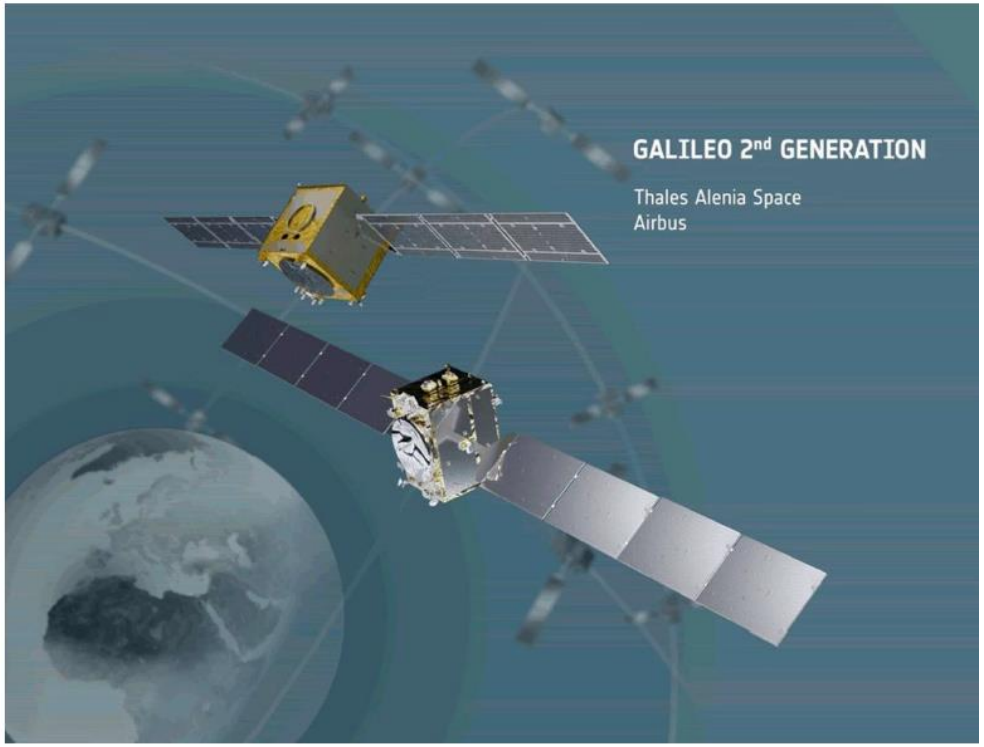
G2G Ground Segment & System Test Beds
7 G2G In Orbit Validation Ground Segment & System Test Beds procurements ongoing.
G2G IOC GSEG reaching PDR.

G2G System Support & Tools
System Support activities engaged.
Tools and R&D ongoing (Rx, Sims, etc…).

Source: Hahn, ESA, at ICG 16, Oct 2022

G2G Satellites: Designed for future generations

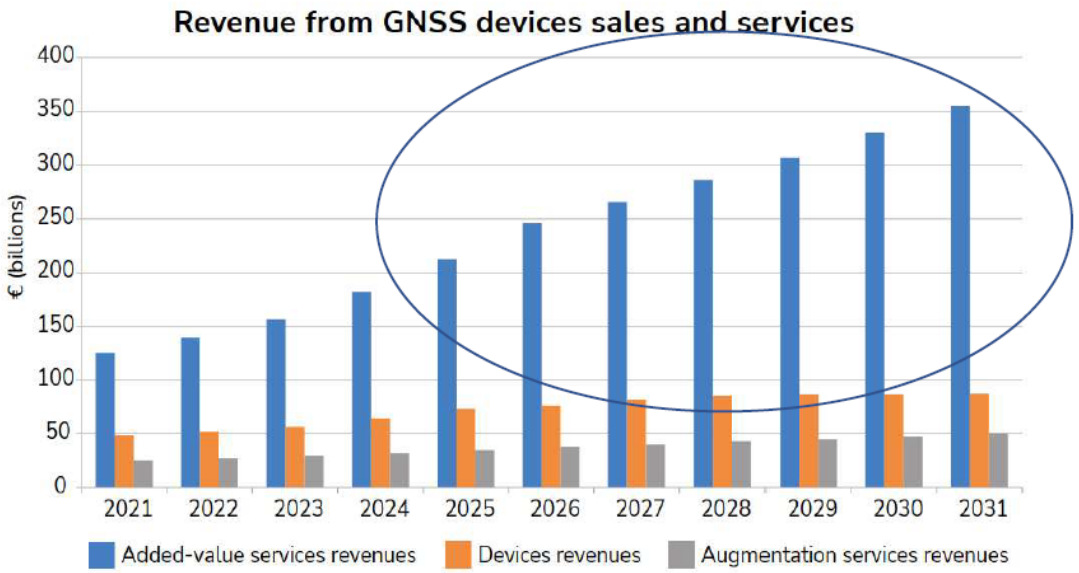
- New signal generation capabilities: increased number of signal components and configurability.
- Improved EIRP.
- Inter Satellite Links.
- On Board Authentication.
- Minimised in-orbit maintenance activities.
- Increased data rate in the Ground to Space communication.
- Improved Time Reference (number of atomic clocks and their relevant monitoring functions).
- Orbit Raising Capability – Dual Launch.
- 15 years lifetime.



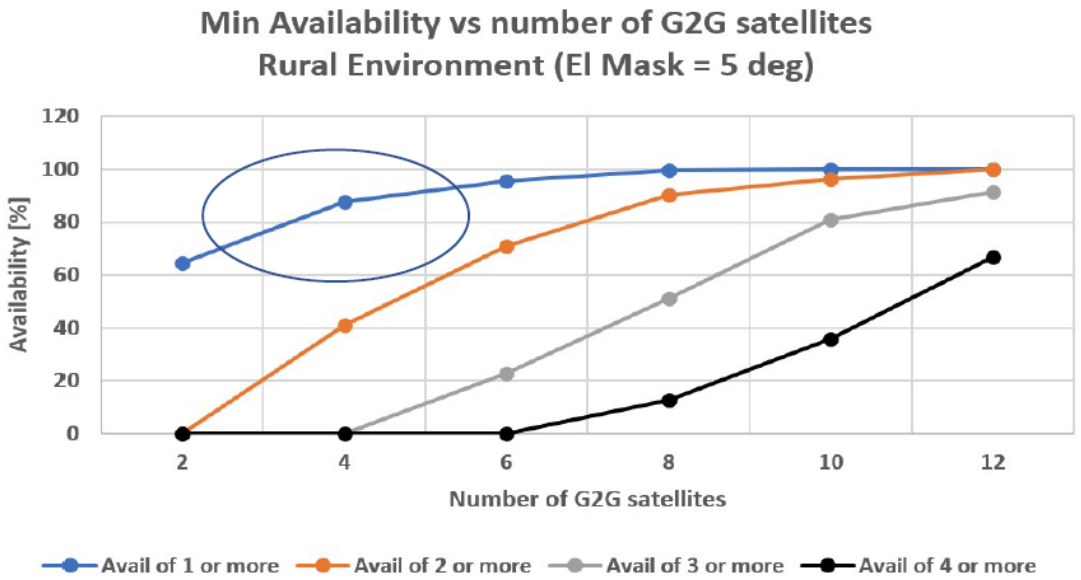
Source: Hahn, ESA, at ICG 16, Oct 2022

G2G System Flexibility and Added Value Services focused

- G2G design at all levels is embedded with internal flexibility to ensure new service implementation without constellation re-deployment (from 15 years to 1 year Time To Market).
- G2 development and satellite validation approach is compatible with progressive improvement and deployment of services already working with one line-of-sight:
  - E.g. Fast Acquisition, OS Signal Authentication, OS TTFF, HAS, EWS, ARAIM, etc…
  - This is the fastest growing market sector.



Courtesy EUSPA EO & GNSS Market Report:
https://www.euspa.europa.eu/sites/default/files/uploads/euspa_market_report_2022.pdf



Source: Hahn, ESA, at ICG 16, Oct 2022

LEO PNT

R&D Actions launched to study options for LEO PNT, covering

❑ Signals of Opportunity

- PNT measurements derived from 3rd party signals with Ad-hoc monitoring to support PNT service

❑ Fused PNT with Satcom

- PNT measurements derived from satcom signals, tailored for PNT

❑ Purpose-built LEO-PNT

- PNT measurements derived from PNT signals
  - Dedicated constellation
  - Hosted payload

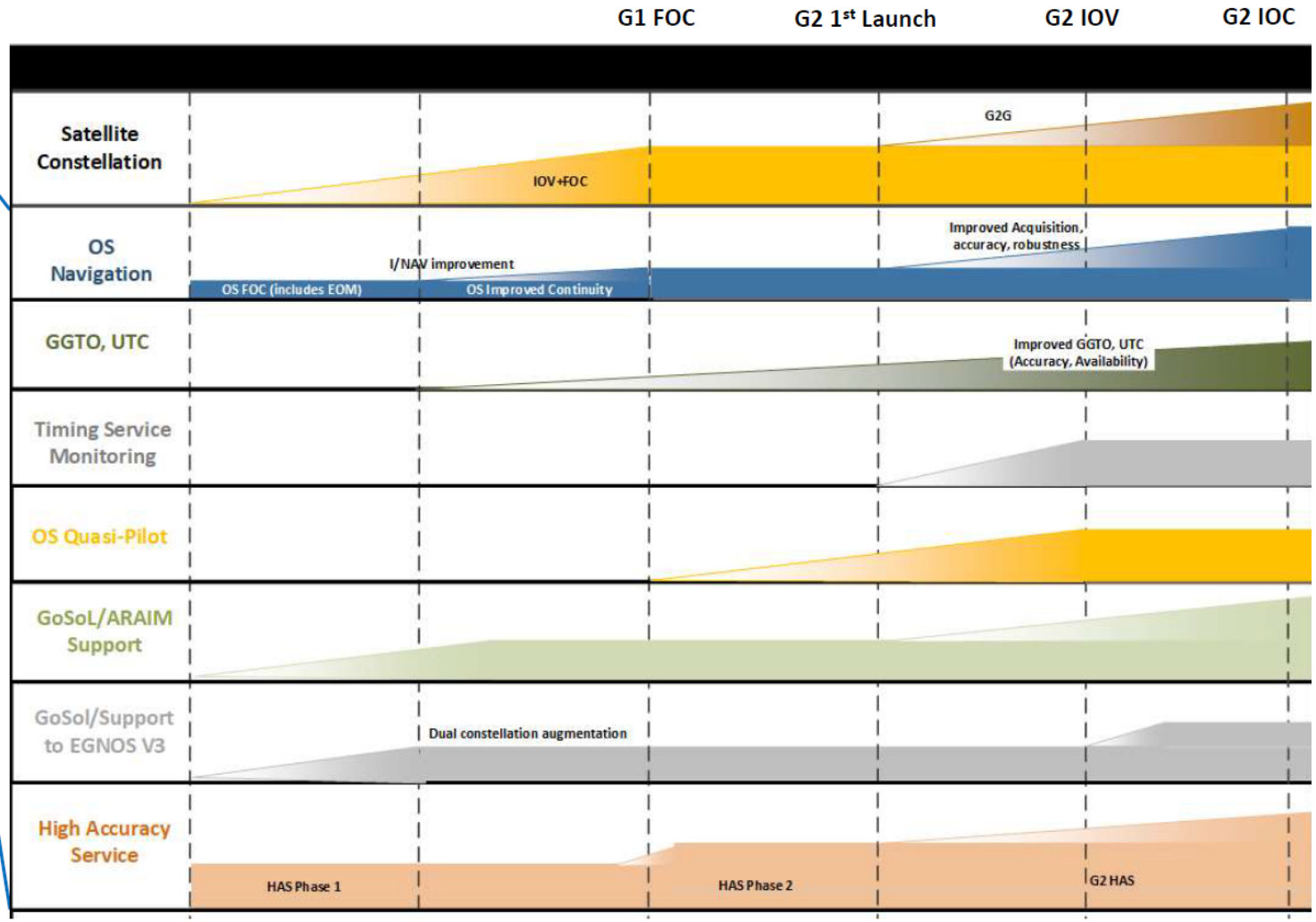
LEO-PNT fully complementary & boosting Galileo

Source: Boyero, EC, at ICG 17, Oct 2023

Galileo – Program History

Galileo Service Enhancements & New Services incremental build up (I)

Service	Service Component
Open Service (OS)	OS (Navigation Performance)
	Timing Service
	Quasi Pilot
	GOSOL (incl ARAIM)
High Accuracy Service (HAS)	Service Level 1 (global)
	Service Level 2 (regional)
OS Authentication (OS-A)	OS Nav Msg Authentication
	OS Ranging Authentication
Commercial/Signal Authentication (CAS/SAS)	Commercial/Signal Auth Service
Search & Rescue (SAR)	Forward Link
	Return link
	Remote Beacon Activation
	Two Way Communication
	Distress Position Sharing
Emergency Warning Service (EWS)	EWS-Return Link Message
	EWS-INAV
Public Regulated Service (PRS)	Public Regulated Service
	A-PRS
Ionospheric Prediction (CIP)	Ionosphere Prediction



Source: Hahn, ESA, at ICG 16, Oct 2022

Galileo Service Enhancements & New Services incremental build up (II)

Service	Service Component
Open Service (OS)	OS (Navigation Performance)
	Timing Service
	Quasi Pilot
	GOSOL (incl ARAIM)
High Accuracy Service (HAS)	Service Level 1 (global)
	Service Level 2 (regional)
OS Authentication (OS-A)	OS Nav Msg Authentication
	OS Ranging Authentication
Commercial/Signal Authentication (CAS/SAS)	Commercial/Signal Auth Service
Search & Rescue (SAR)	Forward Link
	Return link
	Remote Beacon Activation
	Two Way Communication
	Distress Position Sharing
Emergency Warning Service (EWS)	EWS-Return Link Message
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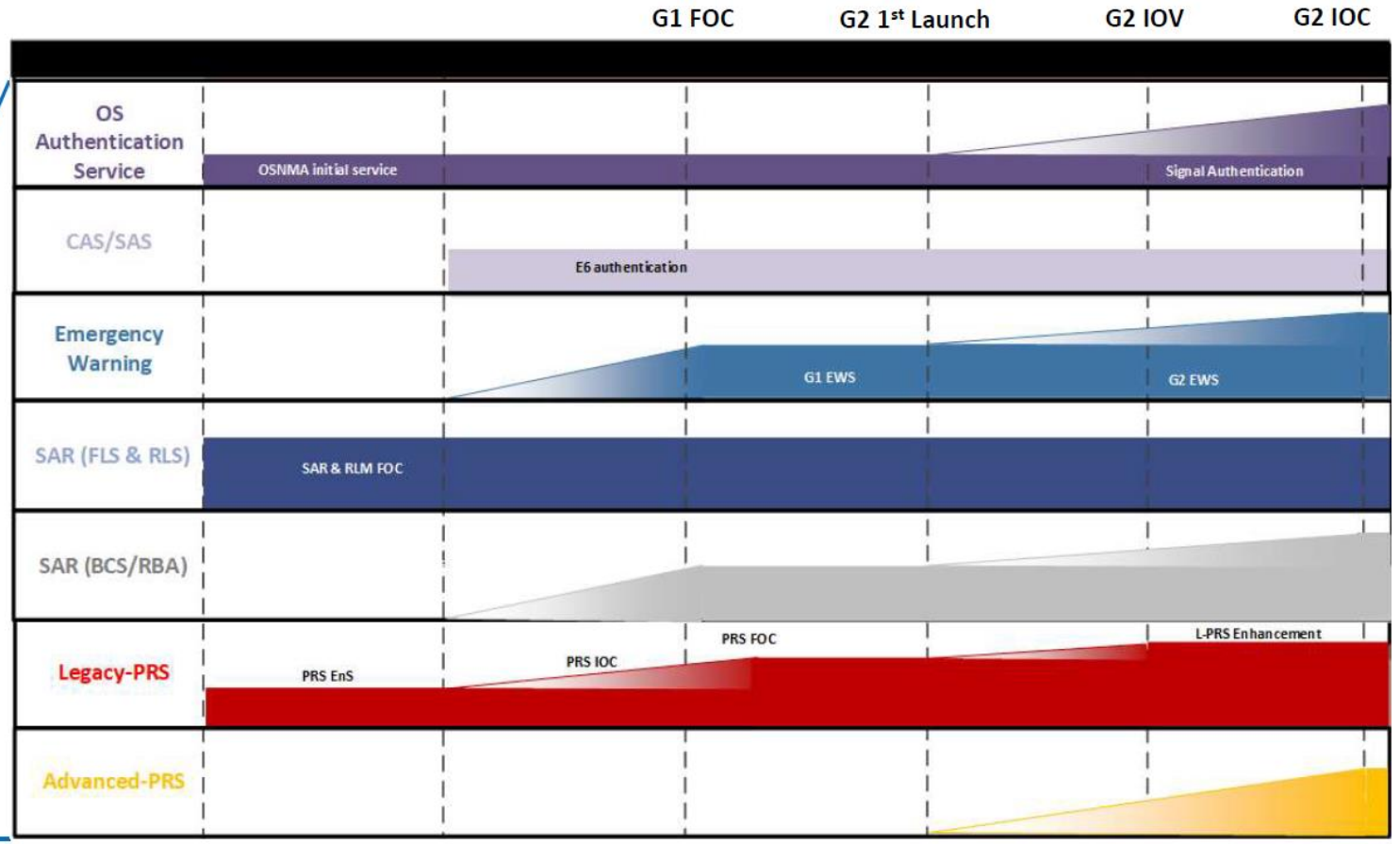

Source: Hahn, ESA, at ICG 16, Oct 2022

Galileo – Program History – Timeline - Galileo First Generation

- Galileo First Generation – 2003 – First stage of program officially agreed
- 2005 – First Test Satellite launched
- 2011 – Initial Orbit Validation Satellites Launched
- 2014 – 5th and 6th Satellites (anomalous orbits)
- 2015 – 7th and 8th Satellites
- 2015 – 9th and 10th Satellites
- 2016 – 11th and 12th Satellites
- 2016 – 13th to 16th Satellites (4 at once on Ariane 5)
- 2017 – 17th to 20th Satellites (4 at once on Ariane 5)
- 2016 – 21st to 24th Satellites (4 at once on Ariane 5)
- 2017 – Handover from ESA to GSA (<6 years after IOV Satellites and 11 Years after Draft ICD)
- Most recent launch September 2024 – 2 new satellites on SpaceX

- Note that E5a was included in original design so its implementation is in line with the timeline to the left.
- Draft ICD for the Open Service SIS was 2006
- OS SIS ICD Issue 1 was 2010
- Current ICD published November 2023

Galileo – Program History – Timeline - Galileo Second Generation

- 2020 – Procurement Started
- 2025 – First G2G Satellites
- 2028 – G2G IOC
- 2031 – G2G FOC

Source: Hahn, ESA, at ICG 16, Oct 2022

Galileo System Development Summary

- ✓ Galileo performances are outstanding.
- ✓ L11 successful (satellites in service).
- ✓ Galileo INAV qualification performed.
- ✓ High Accuracy Service capabilities under qualification.
- ✓ G2G In Orbit Validation activities ongoing (Satellite, GSEG, Test Beds, Tools):
  - ✓ They will ensure Galileo Legacy services enhancement and early G2 Capabilities and Services.
- ✓ G2G Initial and Final Operational Capability activities developing as planned, for the sake of final G2G Service Provision.

Source: Hahn, ESA, at ICG 16, Oct 2022

Galileo – Program History - Costs

Cost of initial Constellation (satellites and ground segment) stated as €10 billion ($10.6 billion USD)

The contract values for the Galileo Second Generation (G2G) satellites include:

- Thales Alenia Space and Airbus Defence and Space
  - The European Commission awarded these companies a €1.47 billion contract to design and build 12 G2G satellites in 2021. The contract was for six satellites each from the two companies.
  - ***This equates to a per satellite cost of $129M (USD), including two sets of nonrecurring costs for the two contractors.***
- GMV
  - The European Space Agency (ESA) awarded GMV a contract worth over €200 million to develop the ground segment for the G2G. The contract includes core G2G activities that will take place from mid-2023 to the end of 2026, with options to extend until 2028.
- Thales
  - Thales was awarded contracts worth over €60 million for the cybersecurity aspects of the G2G program. These contracts include the architecture, security equipment, and protection against cyberattacks.

Galileo – Program Organization

Galileo - Program Organization

- The Galileo Programme is owned by the European Union.
- A key difference from GPS (and the other global systems) is that Galileo is a Civil Program.
- The European Commission has overall responsibility for the programme, managing and overseeing the implementation of all activities on behalf of the EU.
- Galileo's design and system evolution, along with the technical development of its infrastructure, are entrusted to the European Space Agency (ESA).
- The European Commission has delegated the operational management of the programme to European Union Agency for the Space Programme (EUSPA), which is responsible for the deployment, maintenance and minor evolutions of the Galileo system, and that oversees how the Galileo infrastructure is used ensuring that Galileo services are delivered with the defined performance and without interruption.

Galileo – Operating Model

Galileo – Operating Model

These points were not found in published sources so following are opinion of the IE Subcommittee

- Engagement with civil users, receiver manufacturers, and other nations
  - Galileo has always been very strong in this regard. They knew from day one they needed to do the work to convince users and equipment suppliers of the advantages of a “Multi-GNSS” future
  - Galileo was a strong and active founding member of the UN ICG and has many active international outreach activities, including to developing countries etc.
- Legal requirements for adoption and use of the system, if any
  - Not a high level of legal enticements, e.g. less than Russia and China. Approach based on system earning its own merit.
- Potential areas for synergy/cooperation with the US Global Positioning System
  - Long history of strong and on-going cooperation with US. Current discussions for next level cooperation with US were cited for not yet presenting to this Board.