GALILEO Applications

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Training on GNSS T131 / T151

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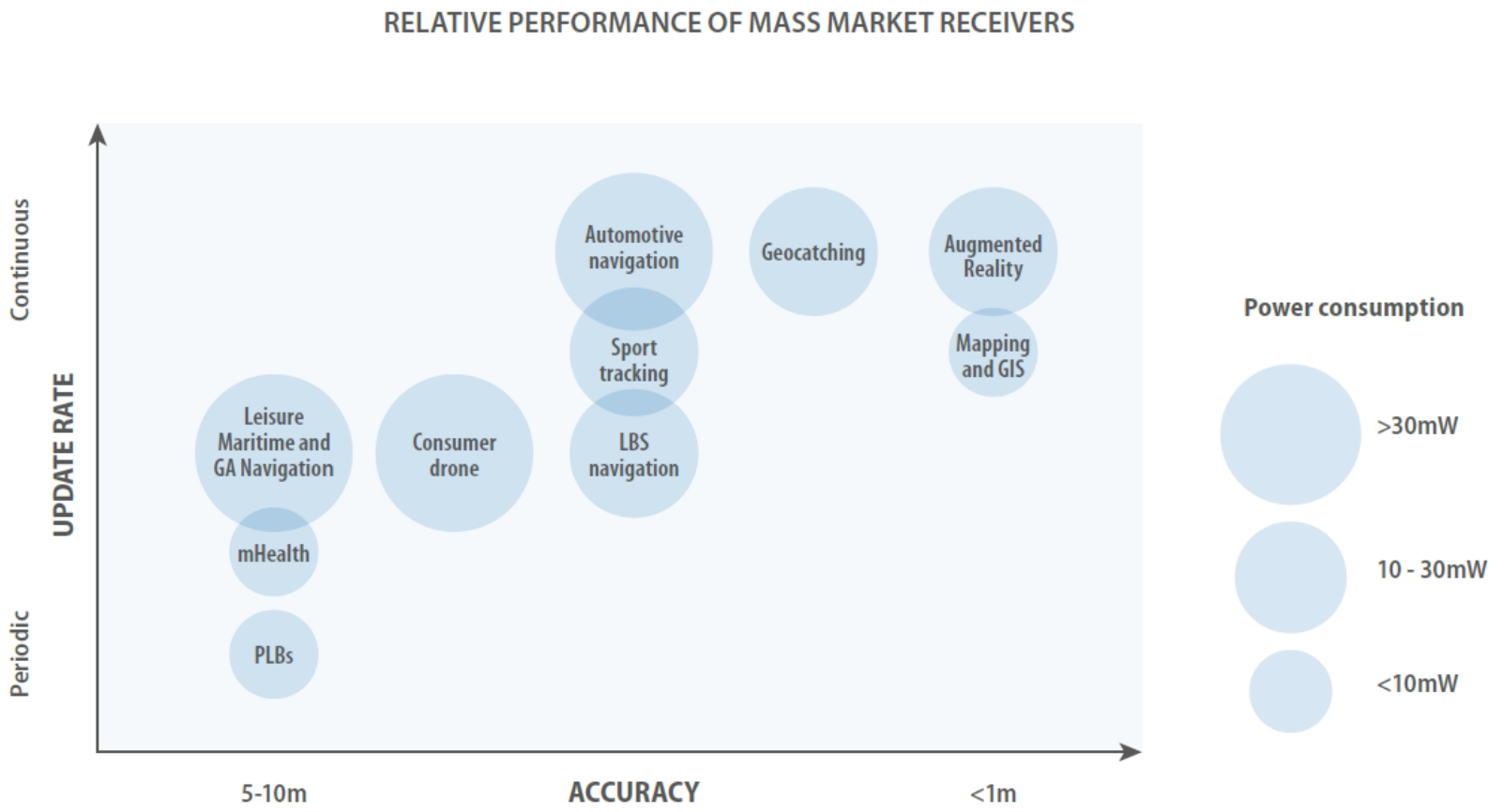
Overview

- GNSS Downstream Applications overview
- The GALILEO Open Service
- The GALILEO Public Regulated Service
- The GALILEO High Accuracy Service:
  - Service Definition
  - Motivation, History, Roadmap
  - Expected Performance
  - Application benefits
- GALILEO SAR
- GALILEO/GNSS Timing applications

GNSS Downstream Applications

Source: GNSS Market Report, Issue 5, 2017, GSA

GNSS User Requirements

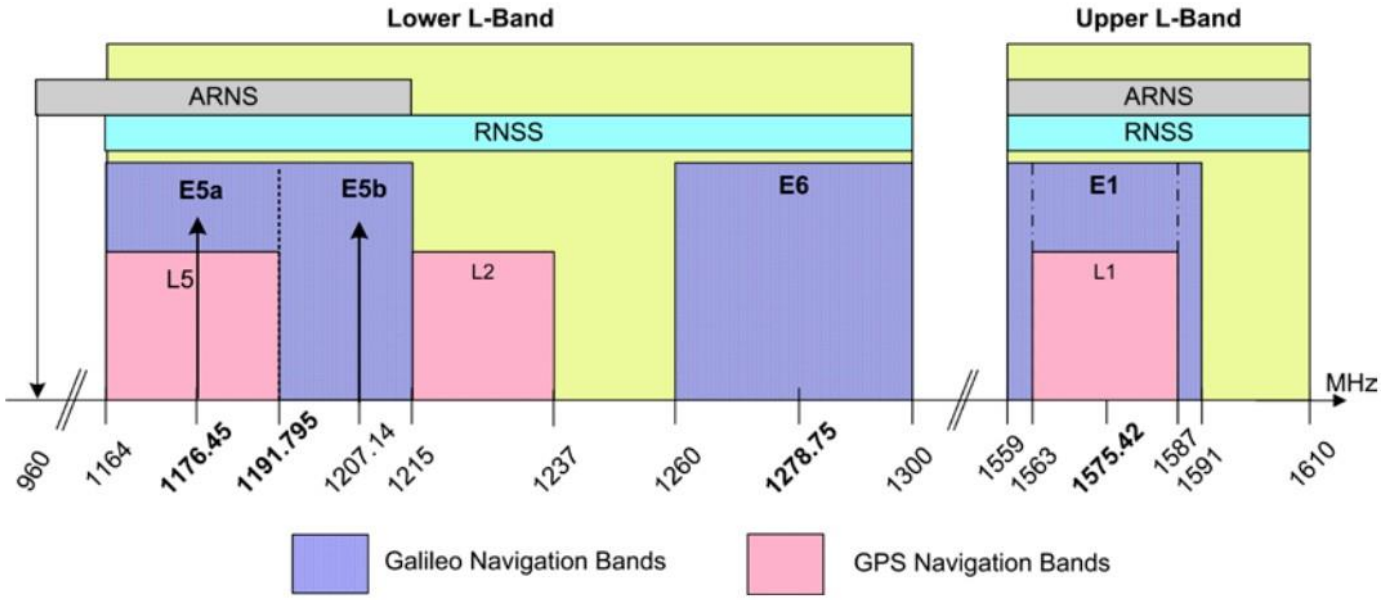


Source: GNSS User Technology Report, Issue 2, 2018, GSA

GALILEO Services

Source: GNSS User Technology Report, Issue 2, 2018, GSA

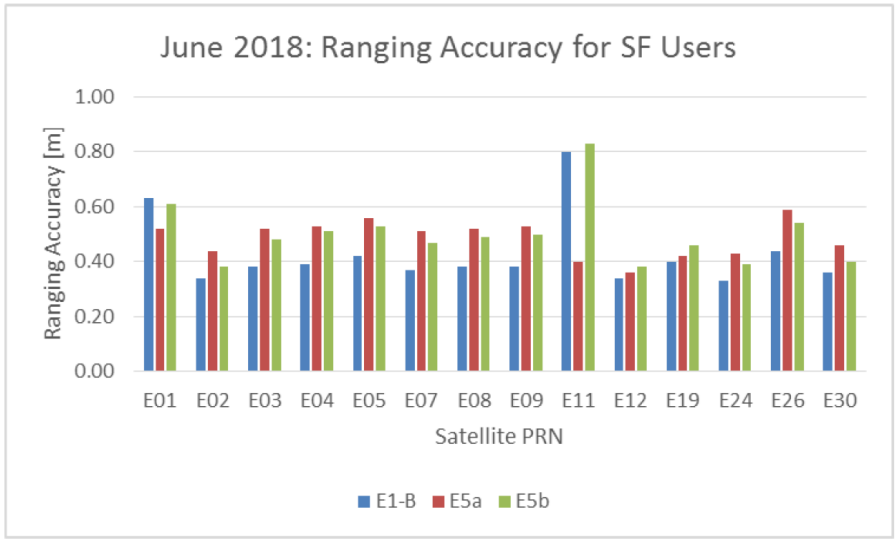
Signal Overview

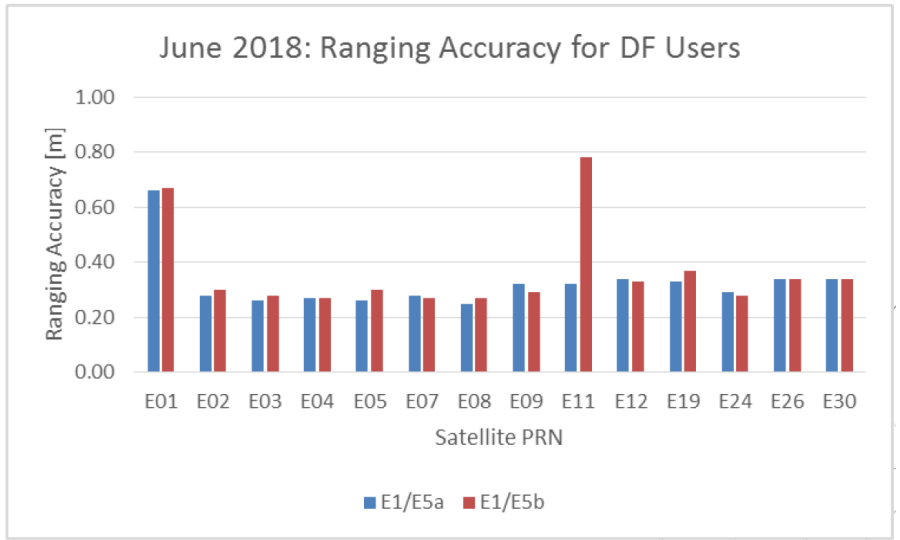


Source: Galileo OS SiS ICD

GALILEO Open Service

- Available via E1, E5a and E5b
- Offers classic PNT services without integrity information



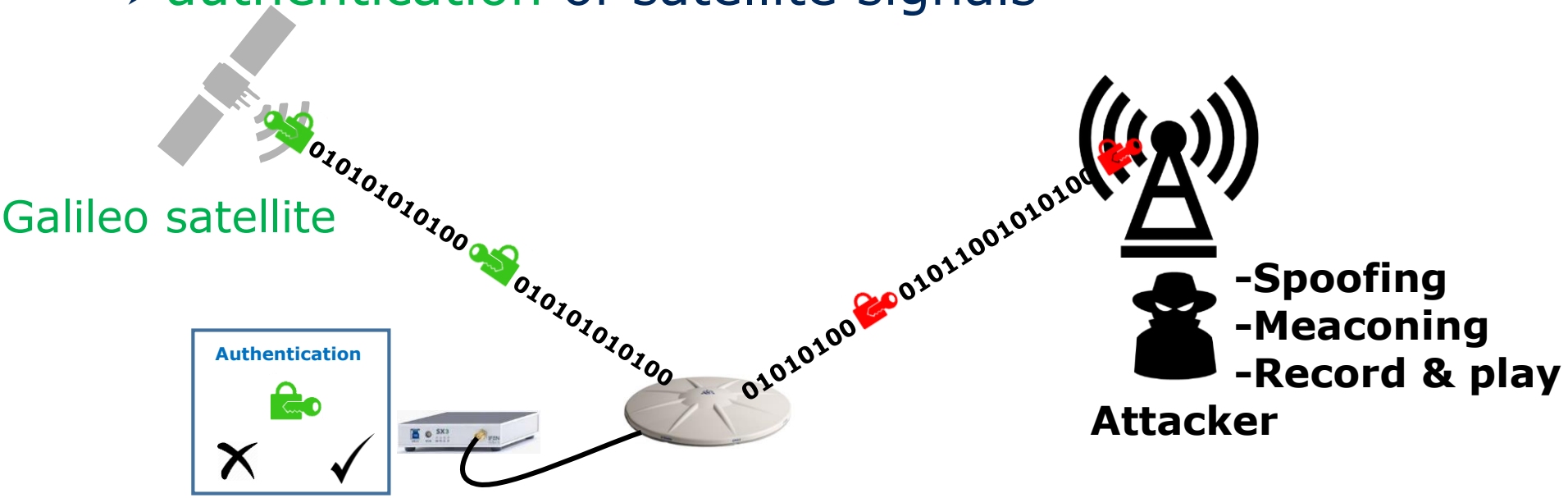


Source: The Galileo Reference Centre and Its Role in the Galileo Service Provision, 69th IAC, Bremen, 1-5 October 2018

OS Nav Message Authentication

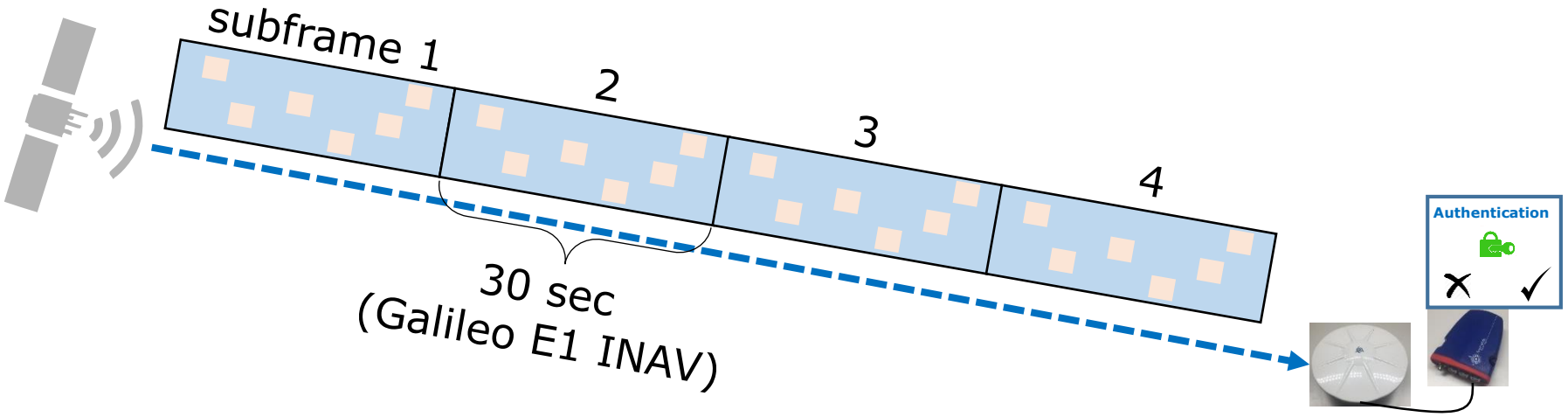
Needed for safety and critical applications:

- receiver position needs to be true/authentic
- ➢check if received signals comes from Galileo satellite or not
- ➢authentication of satellite signals



Software receiver with authentication module

OS Nav Message Authentication



Navigation Message Authentication (NMA):

- per subframe j: key K_j & MAC(K_j, m_j)
- key & MAC within navigation message m_j
- authentication by receiver per subframe:
  - comparison between computed and received MAC
  - verification of key $K_j \overset{\mathcal{F}}{\Rightarrow} \cdots \overset{\mathcal{F}}{\Rightarrow} K_0$ (K_0 signed)
- Based on the TESLA (Time Efficient Stream Loss-Tolerant Authentication) Protocol

GALILEO Public Regulated Service

- Available via E1 and E6
- Encrypted navigation service for governmental authorised users and sensitive applications with additional integrity information
- Grants higher continuity and robustness in case of arbitrary/malicious interference and if in time of crisis other navigation signals are unavailable
- Intended for fire brigades, ambulance, humanitarian aid, SAR, police, coastguards, border control, customs…

GALILEO HAS - Definition

- High accuracy (PPP) corrections provided in the Galileo E6-B signal component:
  - Satellite orbits
  - Satellite clock corrections
  - Code biases for multi-frequency
  - Signal/correction quality information
  - Phase biases (to be confirmed)
  - Ionosphere in EU (to be confirmed)
- Corrections will for Galileo (E1, E5a, E5b, E6, E5 TBC) and GPS (L1, L2, others TBC), and in the future potentially for other GNSS.
- Global coverage when fully operational. Partial coverage before. EU always included.
- "user error of less than two decimetres" This depends on user receiver, algorithm and environment.
- HAS data will be transmitted openly, for free, and through an open standard format. **RTCM CSSR used as starting point.** Format currently under definition
- Support HAS via terrestrial networks is under consideration.

Sub Type	Sub Type Name	No. of Bit
1	Compact SSR Mask	37 + 60 x Nsys
2	Compat SSR GNSS Orbit Correction	25 + (51 or 49) x Nsat
3	Compact SSR GNSS Clock Correction	25 + 15xNsat
4	Compact SSR GNSS Satellite Code Bias	25 + 11 x Ncode x Nsat
5	Compact SSR GNSS Satellite Phase Bias	25 + 17 x Nphase x Nsat
6	Compact SSR GNSS Satellite Code and Phase Bias	28 + 28 x Nsig x Nsat
7	Compact SSR GNSS URA	25 + 6 x Nsat
8	Compact SSR TEC Correction	25 + 34 x Ngrid

Source:https://www.kongress.intergeo.de/download/public/share/public/Intergeo/2018/Kongress/Geodaetische-Woche/Hernandez_Ignacio_Intergeo2018.pdf

GALILEO HAS - Definition

	Galileo	QZSS	SBAS	Commercial
Coverage	Global	Regional	Regional	Global (except high latitudes)
Satellites orbits	MEO	IGSO	GEO	GEO
Bandwidth per sat.	448 bps	2000 bps	250 bps	from ~2500 bps
Nb sat typically visible (open-sky)	4-6	1-3	1-2	1-2
Band/Frequency	E6, 1278.75 MHz	L6, 1278.75 MHz	E5b, 1207.14 MHz	L-band (~1-2 GHz)

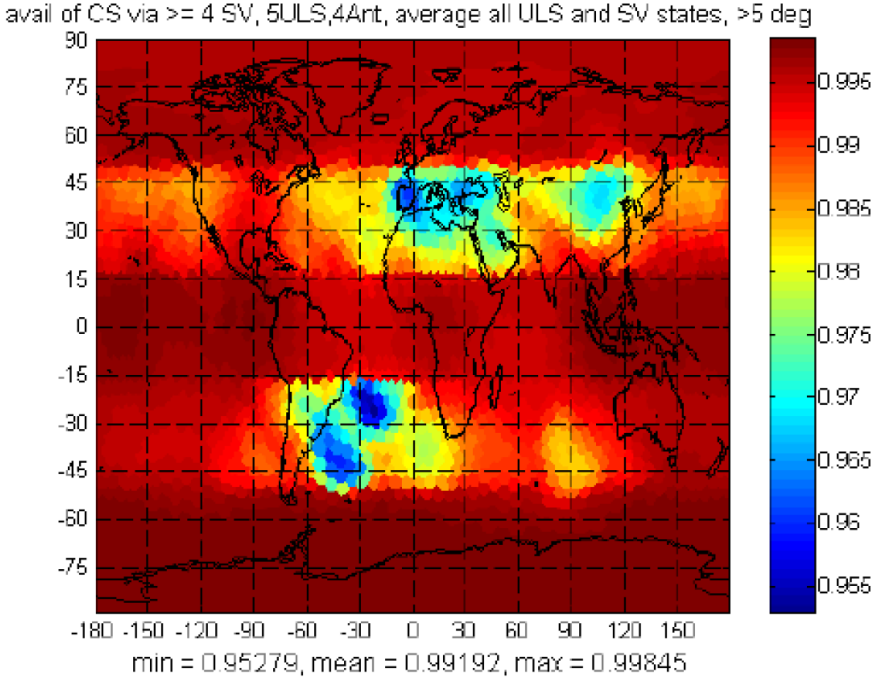
Signal and Data features	
Frequency	1278.75 MHz
Signal	E6B
Min. Power	-158 dBW
Modulation	BPSK(5)
Chip Rate	5.115 Mcps
Code Length	1 ms
Symbol Rate	1000 sps
Data Rate	492 bps
HA Data Rate	448 bps
Data Coding	FEC, as per Galileo OS SIS ICD and interleaving 123 x 8
Spreading Code Encryption	No
Data Format	TBD but based on open standard.
Data (TBC)	Orbit and clock corrections, code and phase biases, SQM, flags, ionospheric information.

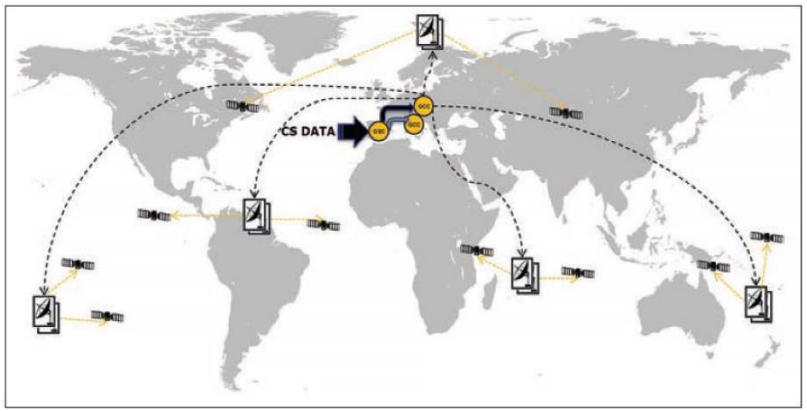
Source: Munich Satellite Navigation Summit 2018 Archive, Session 3, Galileo High Accuracy Service, Ignacio Fernandéz Hernández, European Commission

GALILEO HAS - Infrastructure

- 20 Downlinks (5x4) at a few-second latency at FOC
- Ground infrastructure allowing connection with external entity at GSC
- No extra investment in infrastructure foreseen

Nb Sats	Elevation	Availability
1	30º	98% WUL , +/- 60º Lat
1	20º	98% WUL
2	10º	98% WUL
4	5º	90% WUL
4	5º	98% Avg.





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GALILEO HAS – Motivation

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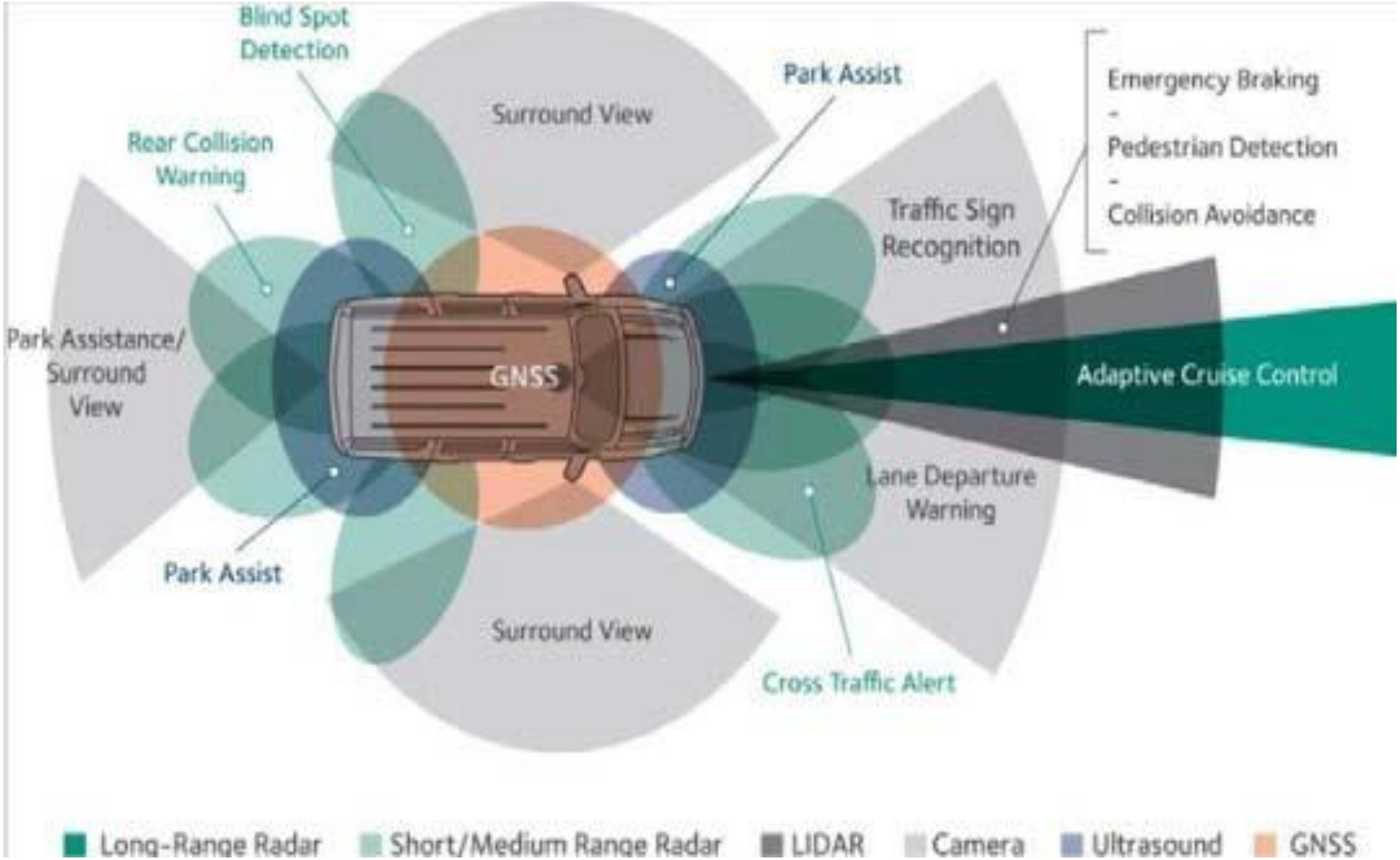
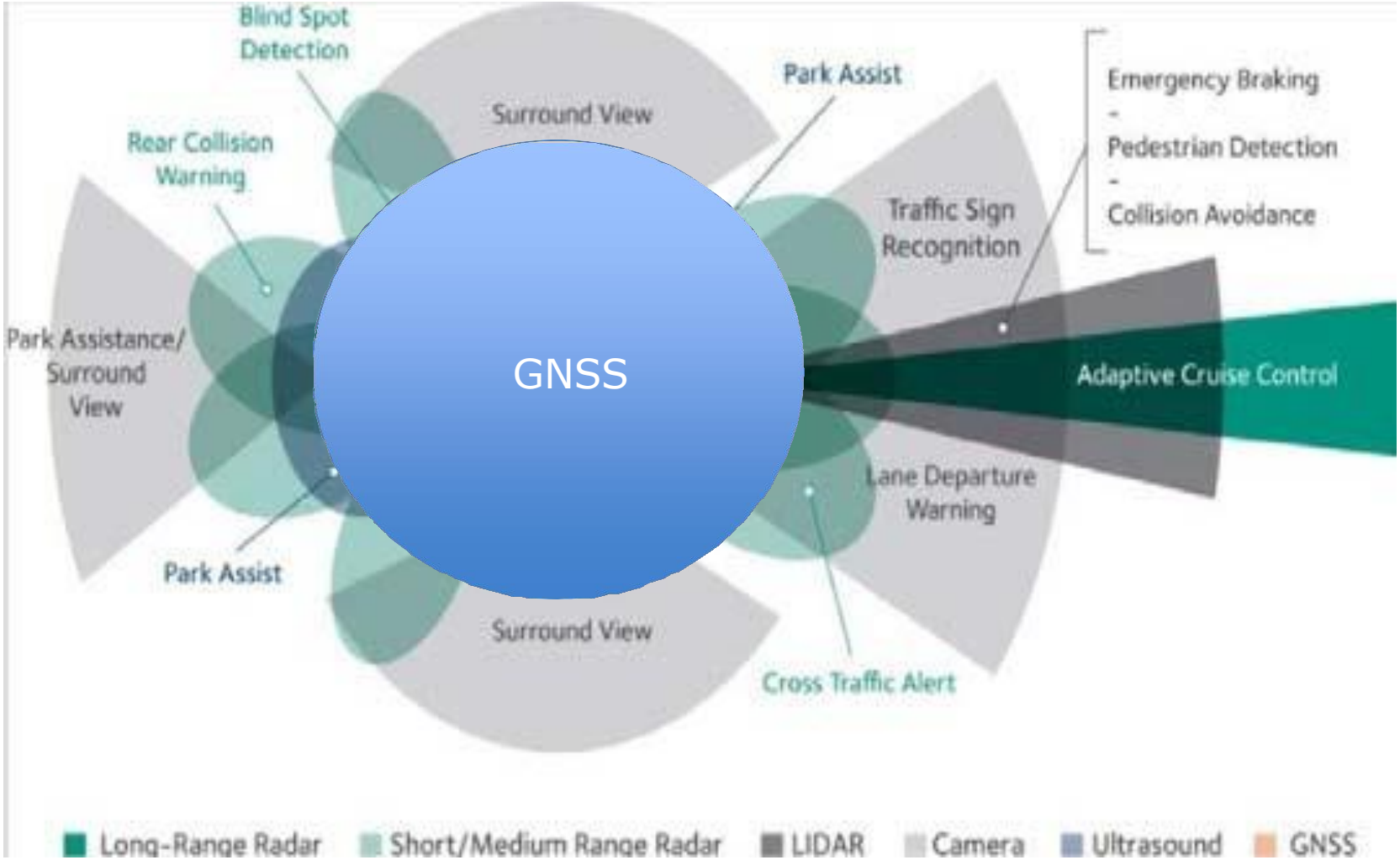


Source: http://insidegnss.com/assets/webinar/201611/Inside-GNSS-Webinar_Safety-Critical-Positioning-for-Automotive-20161103.pdf

GALILEO HAS – Motivation



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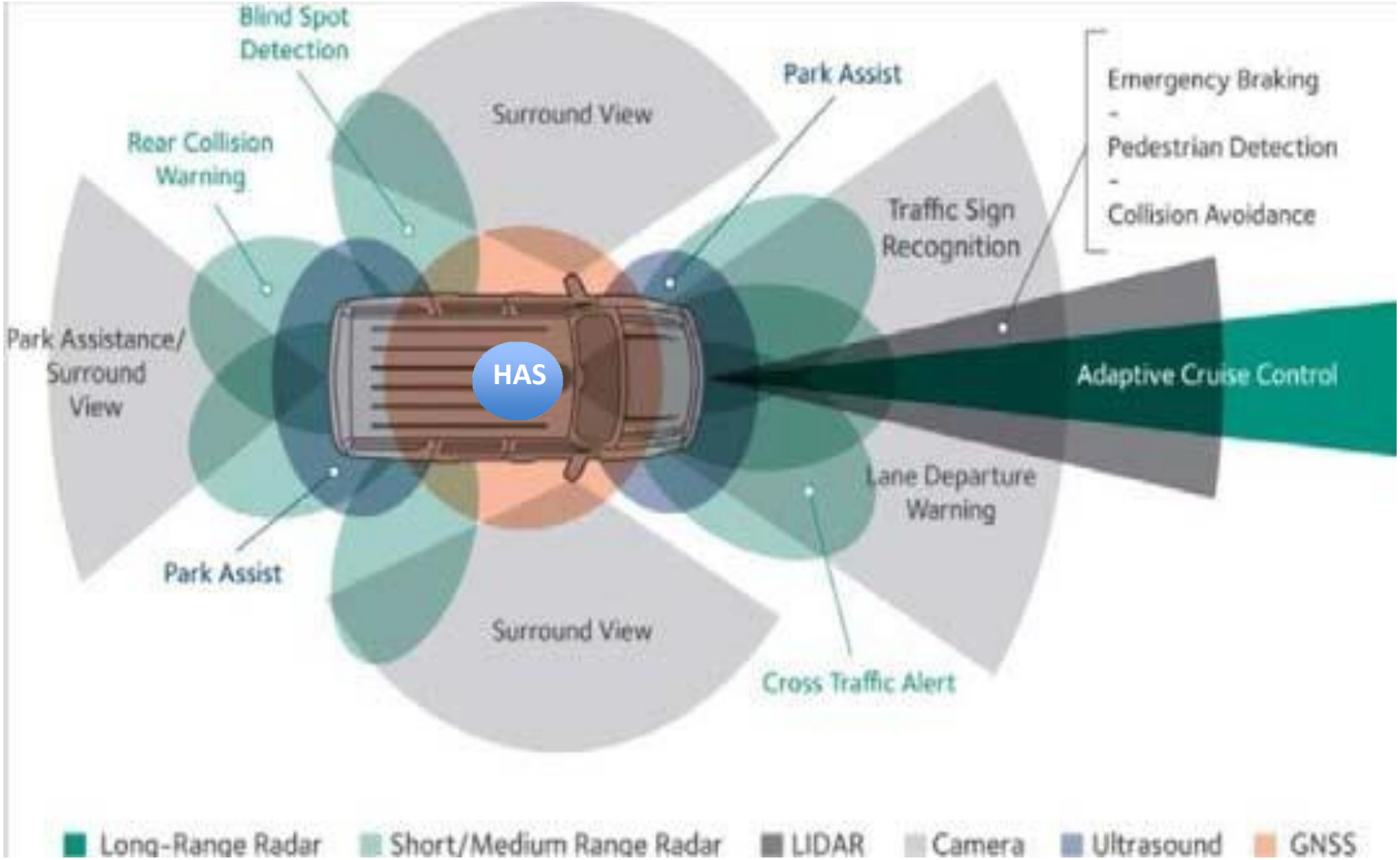
GALILEO HAS – Motivation



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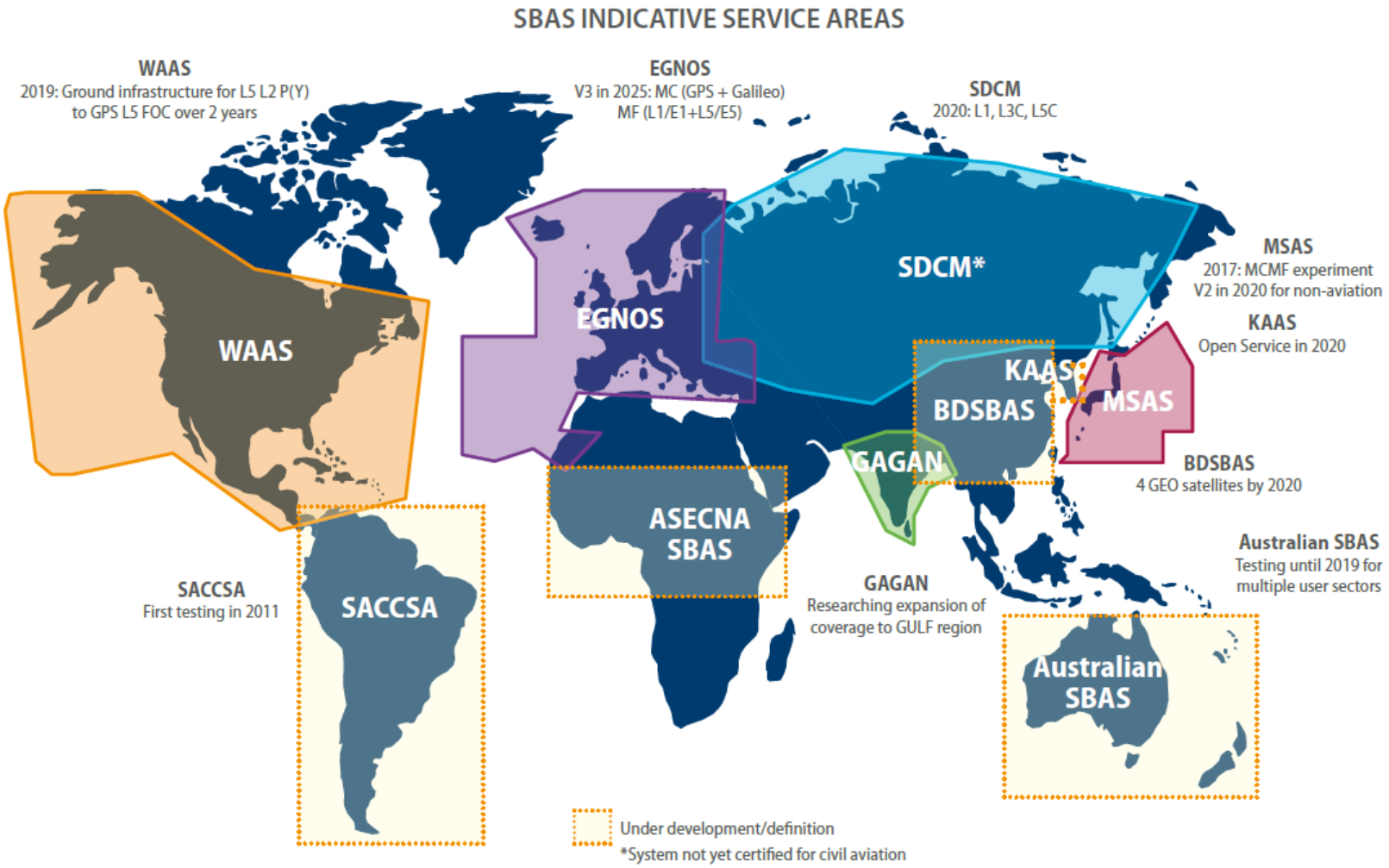
SBAS Coverage



Source: GNSS User Technology Report, Issue 2, 2018, GSA

GALILEO HAS - History

- As per EU GNSS Regulation, GALILEO foresees a Commercial Service offered for a fee for professional applications. Feature inherited from early GALILEO public/private funding initiative.

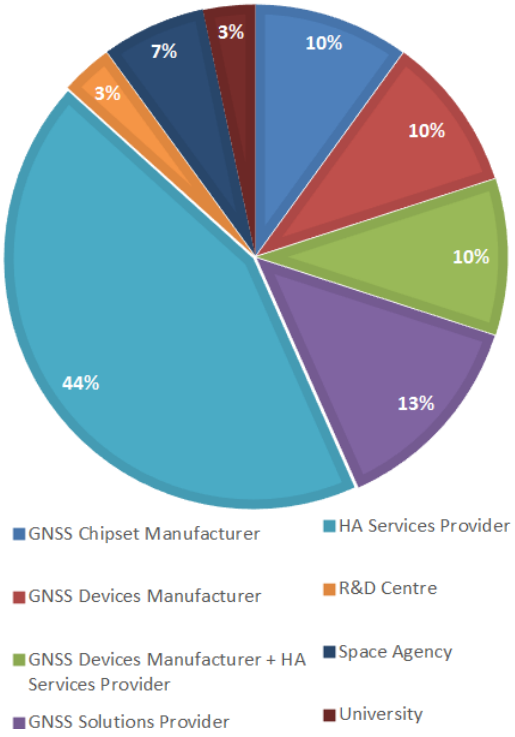
- In early 2017, the EU adopted a decision defining the fee-based Commercial Service as High Accuracy and Authentication. High Accuracy was foreseen to be based on a commercial, proprietary format, not under GALILEO‘s responsibility.

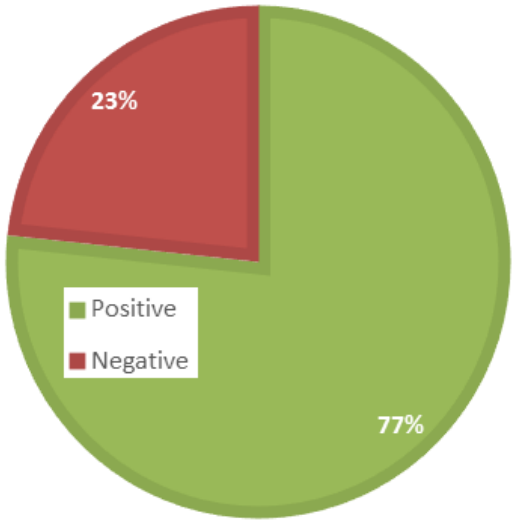
- New circumstances taken into account: High Accuracy broadening towards the mass market and being offered for free already by satnav providers and other public entities, therefore no agreement on fee-based model implementation

- Re-assessment process has culminated in an amendment to the decision, to redefine the High Accuracy Service and provide it for free. Commercial Service and Signal Authentication remains as a payable service.

GALILEO HAS - History

- GSA Stakeholder consultation on free HAS in December 2017
- 31 Participants including main HA commercial providers, research institutes and manufacturers

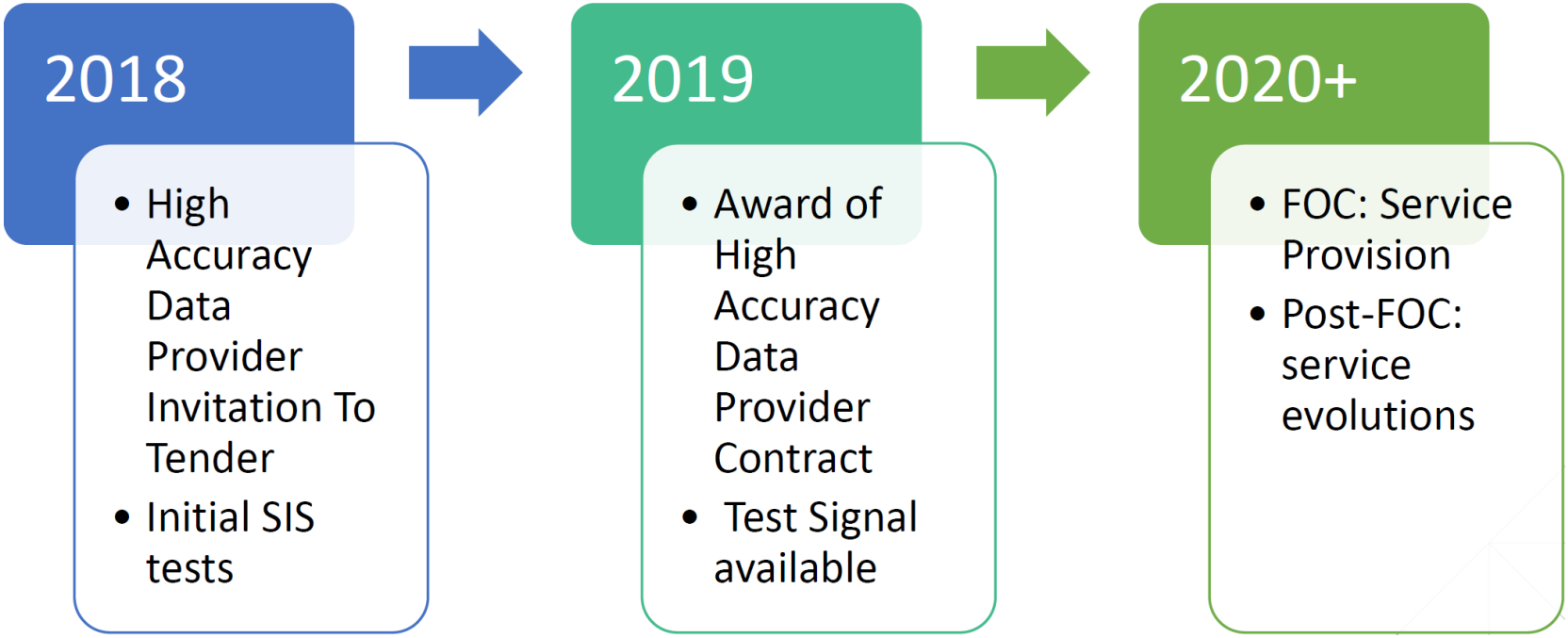




Source: Munich Satellite Navigation Summit 2018 Archive, Session 3, Galileo High Accuracy Service, Ignacio Fernandéz Hernández, European Commission

GALILEO HAS - Roadmap

- GALILEO High Accuracy Service Signal in Space Transmission is foreseen in 2019 while full service provision is planned in FOC 2020



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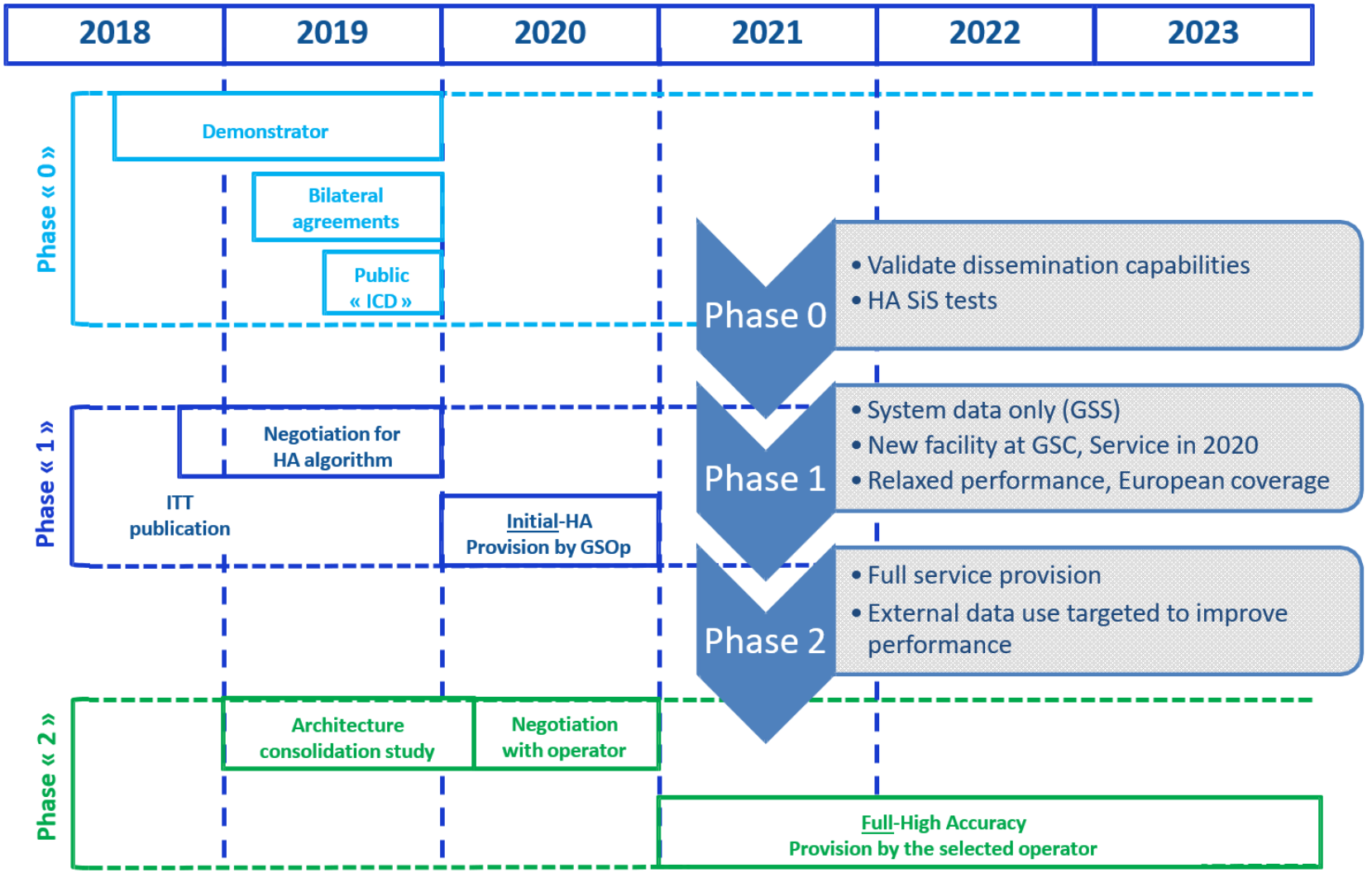
GALILEO HAS - Roadmap



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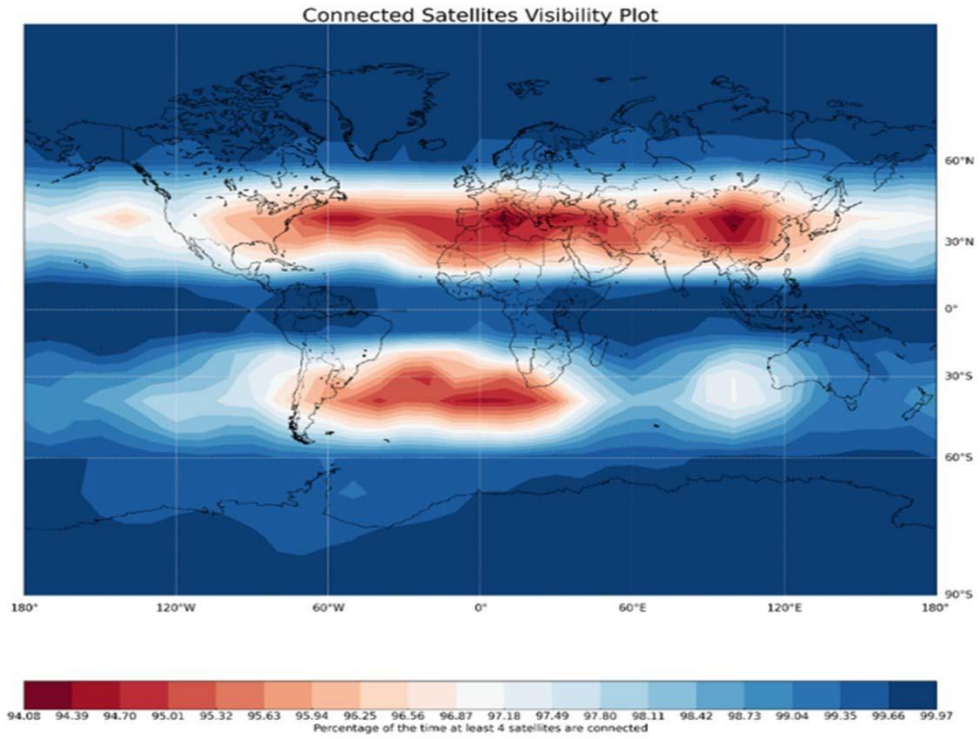
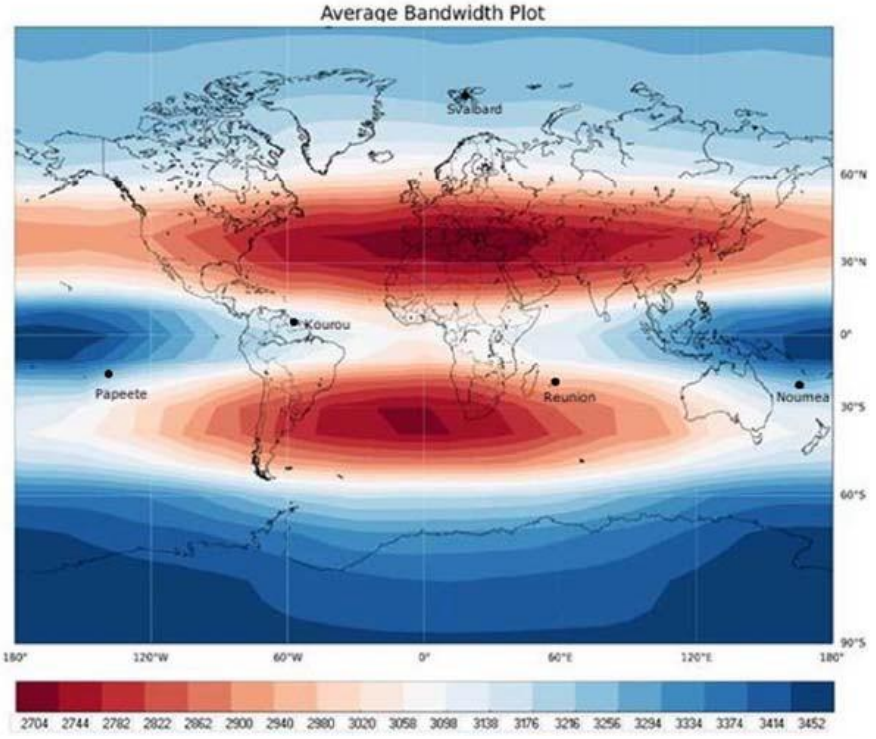
GALILEO HAS – Exp. Performance

- GALILEO Downlink capability estimation for FOC 2020





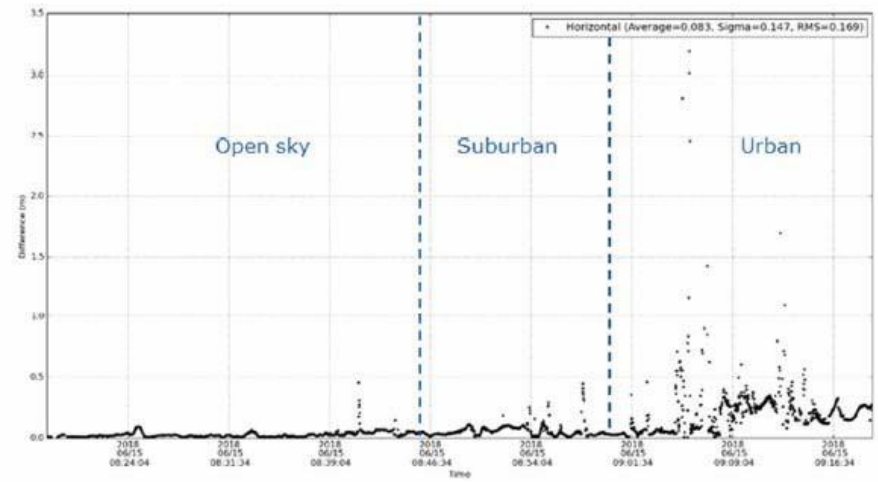
AVG. AVAILABILITY 4 SV [94-99.9%]

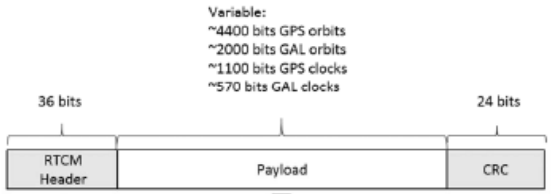
AVG. BW: [2704, 3472]

Source: https://www.kongress.intergeo.de/download/public/share/public/Intergeo/2018/Kongress/Geodaetische-Woche/Hernandez_Ignacio_Intergeo2018.pdf

GALILEO HAS – Exp. Performance

- Same message "transmitted" by all GALILEO satellites
- Possible improvements:
  - More satellites
  - More frequencies
  - SIS format & coding optimization
  - Better carrier tracking, less code/carrier noise, better multipath mitigation





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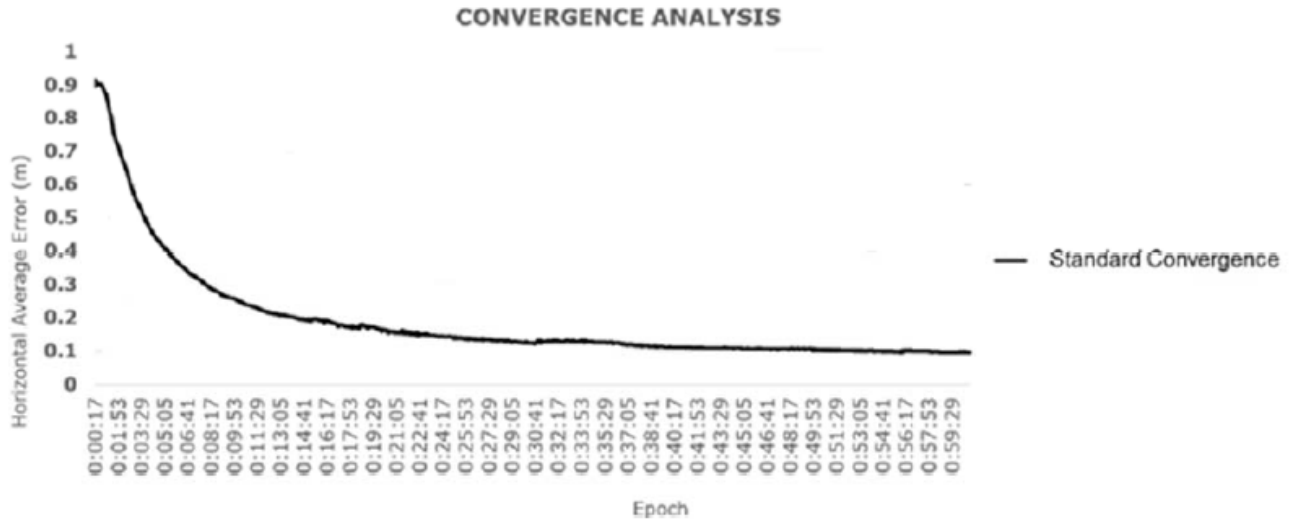
GALILEO HAS – Exp. Performance

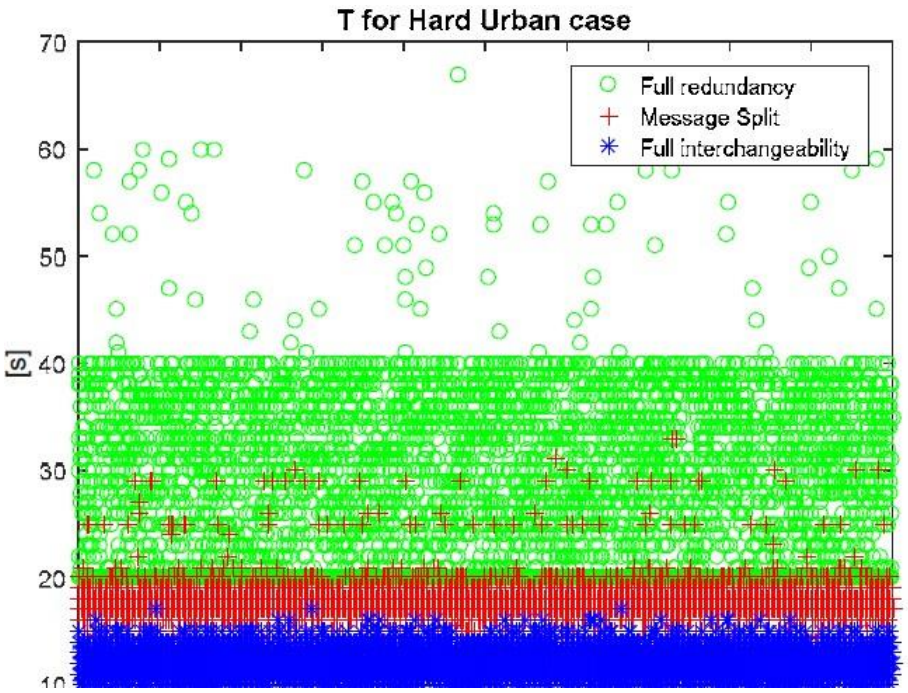
- PPP Convergence time is still the problem
- Assisted users can do RTK-PPP
- Standalone users can use 3-4 frequencies and/or ionosphere models for quasi instantaneous (few seconds) convergence

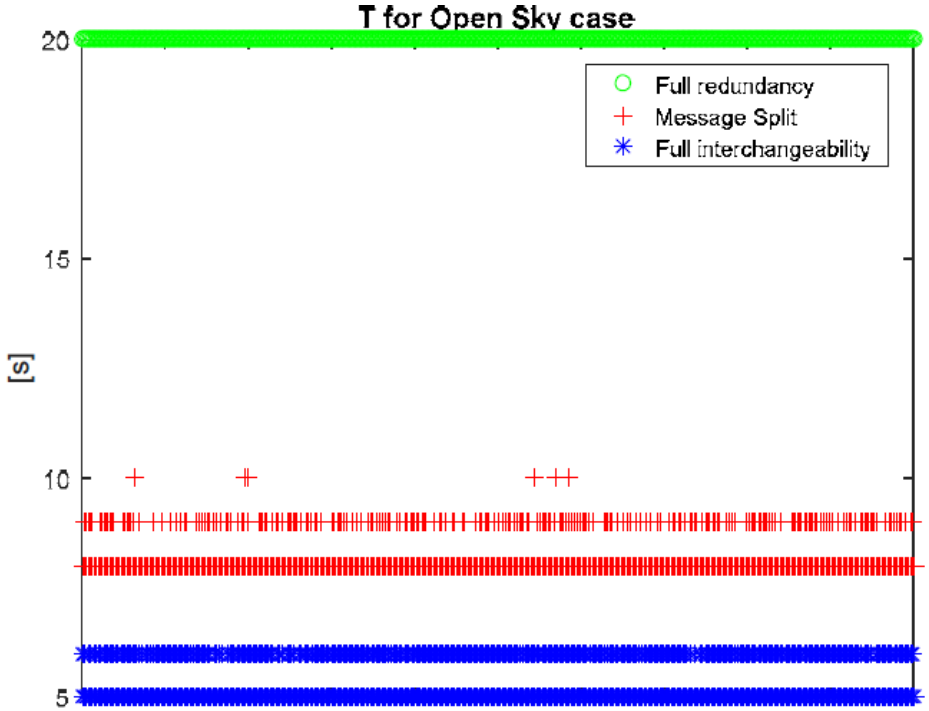


Source: https://www.kongress.intergeo.de/download/public/share/public/Intergeo/2018/Kongress/Geodaetische-Woche/Hernandez_Ignacio_Intergeo2018.pdf

GALILEO HAS – Exp. Performance

- GALILEO E6b SIS coding schemes can be key for time to first precise fix (several Kilobits to receive)
- Reception of a 20-page (8320-bit) message in E6b with different coding/packing schemes:





Source: https://www.kongress.intergeo.de/download/public/share/public/Intergeo/2018/Kongress/Geodaetische-Woche/Hernandez_Ignacio_Intergeo2018.pdf

GALILEO HAS – Status Overview

- The Galileo Programme will include a free and open HAS based on the transmission of PPP corrections globally through the E6b signal
- The HAS will coexist with commercial services and public and free HA initiatives. The EC expects it will accelerate ist adoption and lead to innovation in new applications such as autonomous driving and LBS for mobile devices: the first truly global, standalone HA service.
- It is based on open standards (RTCM CSSR as basis)
- Currently undergoing initial testing phase, during 2019 SIS initial services, 2020 operational phase with GALILEO FOC
- Global target accuracy < 20 centimeters

Benefits from GALILEO HAS

TYPICAL STATE-OF-THE-ART RECEIVER SPECIFICATIONS FOR THE TRANSPORT SAFETY- AND LIABILITY- CRITICAL SEGMENT

Features	Aviation	Maritime	Automotive
Number of channels	12-100+	12-100+	32-52
Code/ Phase processing	Code and carrier phase	Code and carrier phase	Code and carrier phase Doppler
Constellations/ Signals	GPS L1	GPS, GLONASS, BeiDou, Galileo, QZSS, NavIC	GPS, GLONASS, BeiDou, Galileo, QZSS, NavIC
Sensitivity (typical)	-135 dBm acquisition -140 dBm tracking	-130 dBm acquisition -135 dBm tracking	-147 dBm acquisition -162 dBm tracking
Multipath rejection techniques	Usually yes	Not documented	Usually yes
SBAS/ A-GNSS readiness	SBAS (E)TSO 145/146	SBAS supported (non-safety of life)	SBAS supported (non-safety of life)/A-GNSS supported
Receiver connectivity	Per ARINC 429	RS422/ NMEA 0183/ NMEA2000	
TTFF	Cold Start: <75s Warm Start: <30s Re-Acquisition: <3 to 10s	Cold Start: <60 to 120s Warm Start: <30s Re-Acquisition: <1 to 10s	Cold Start: <33s Warm Start: <30s Re-Acquisition: <1s
Horizontal accuracy (95%)	GNSS: 5 – 15m DGNSS: N/A SBAS: 3m	GNSS: 2.5 – 13m DGNSS: 0.3 – 5m SBAS: 2 – 8m	GNSS: 2.5 – 13m DGNSS: 0.3 – 0.5m SBAS: 2 – 8m
Vertical accuracy (95%)	GNSS: 10 – 20m DGNSS: N/A SBAS: 4m	Not documented	Not documented
Antenna	External	External	External

Source: GNSS User Technology Report, Issue 2, 2018, GSA

Benefits from GALILEO HAS

- IMO Maritime GNSS position accuracy requirements:
  - < 100 m on open water
  - < 10 m at harbour entrances, channels and coastal waters
- Navigation with < 10 m accuracy only possible with EGNOS/SBAS until now
- Inside harbours RTK systems are used

Benefits from GALILEO HAS

No	Application	Requirement				
		Accuracy	Integrity		Availability	
		Horizontal (m)	Alert limit (m)	Maximum time to alarm (s)	% of mission time	
Safety related applications						
I	ex: ATC on high density lines / Station / Parallel track	*(1)*	*2.5*	*<1.0*	*>99.98*	
II	ex: Train Control on medium density lines	*(10)*	*20*	*<1.0*	*>99.98*	
III	ex: Train Control on low density lines	*(25)*	*50*	*<1.0*	*>99.98*	
Mass commercial / information and management – operational applications						
IV	Tracing & Tracking of vehicles	50	125	<10	99,9	
V	Cargo monitoring	100	250	<30	99.5	
VI	Dispatching	50	125	<5	99,9	
VII	Passenger information	100	250	<30.0	99.5	
Infrastructure & civil engineering, professional applications						
VIII	Positioning of machines	1 cm	TBD	<5	99.5	
IX	Infrastructure survey	1 cm	0,1 cm	<10	99	
X	Fix point applications	5 mm	TBD	<30.0	99	

Source: GNSS Rail user forum, Requirements of rail applications, 2000

Benefits from GALILEO HAS

Source: https://www.zdnet.com/product/garmin-fenix-5-plus/

Source: https://connexies.nl/augmented-reality-en-uiteenlopende-toepassingen/

Benefits from GALILEO HAS

- No major benefits in surveying, since all applications require sub decimeter level accuracy, most even RTK level accuracy

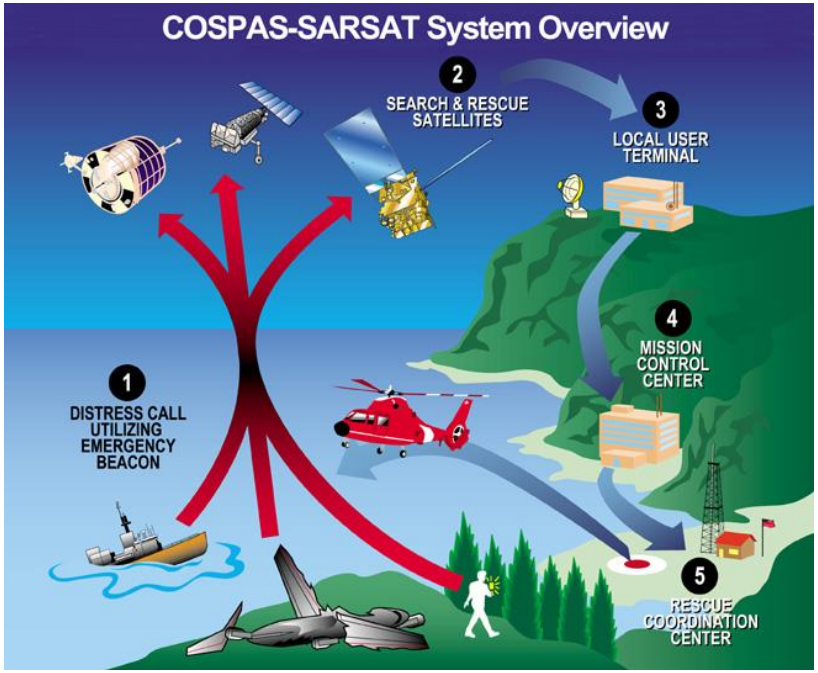
- Same goes for agricultural applications, only few use cases since also RTK level accuracy is needed for actual precision farming

Benefits from GALILEO HAS

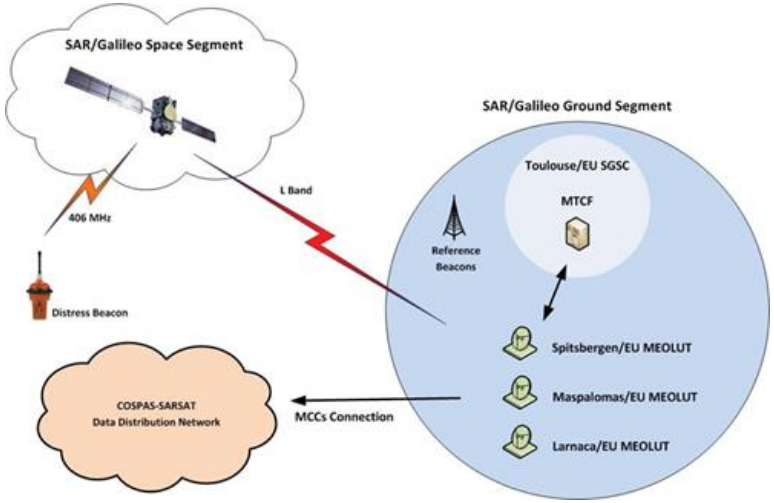
Source: GNSS Market Report, Issue 5, 2017, GSA

GALILEO SAR

- GALILEO Search and Rescue
- Part of COSPAS-SARSAT, implementing MEOSAR

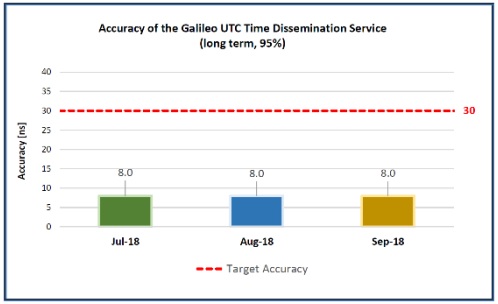


Source: https://de.wikipedia.org/wiki/COSPAS-SARSAT#/media/File:New_C-S_System_Overview.jpg



Source: https://gssc.esa.int/navipedia/index.php/File:SAR.png

GALILEO in Timing



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

	Galileo Open Service (positioning & timing)	
	Single Frequency (SF)	Dual Frequency (DF)
Coverage	Global	
Accuracy (95%)	Horizontal: 15 m	Horizontal: 4m
	Vertical: 35 m	Vertical: 8m
Availability	99.8 %	
Timing Accuracy wrt UTC/TAI	N/A	30 ns
Ionospheric Correction	Based on SF Model	Based on DF Measurements
Integrity	No	

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

- Frequency control
  - Precise control of transmitter frequency or reference frequencies
- Clock synchronization
  - Synchronized clocks across networks, organization or territory
- Data encryption and security
  - Accurate and secure encryption, signature and time-stamping for electronic documents and data
- Network synchronization and time distribution:
  - Increased security and performance in computer networks
  - Power grid synchronization (operation/troubleshooting)
  - Telecommunication cell synchronization
  - Financial and Market synchronization
- Test and Measurement:
  - Calibration and time-stamping for measurement campaigns

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