Galileo H-ARAIM: Update in Performance Characterization and Integrity Support Message

ESA/EC/EUSPA

UNOOSA ICG Annual Mtg, October 2022

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Outline

- **Introduction**

- Galileo Performance Characterization for H-ARAIM until May 2022
  - List of SISE events with high ranging errors
  - SISE Histograms and a-posteriori URA bounding
  - BGD Histograms and a-posteriori bounding

- Galileo Integrity Support Message (ISM)
  - I/NAV word type 22 for Galileo
  - Galileo ISM processing logic
  - Capability for cross-dissemination

- Summary

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- **Horizontal Advanced Receiver Autonomous Integrity Monitoring** (H-ARAIM) is emerging as a new Safety of Life application exploiting interoperability between GNSS

- Standardization work is now well advanced under ICAO and EUROCAE/RTCA, with the **inclusion of Galileo**

- In order to contribute to H-ARAIM a number of pre-requisites are needed

  - Evidence on **high quality ranging and low fault probabilities** for individual satellite faults **(Psat)** and faults at constellation level **(Pconst)**

  - **Input for the ARAIM user algorithm** including User Ranging Accuracy (URA), Nominal biases (Bnom), Fault probabilities (Psat, Pconst)

- Input parameters to ARAIM user algorithm can be disseminated through SiS ➔ **Integrity Support Message** (ISM)

- This briefing

  - provides latest results on the **Galileo performance characterization** for H-ARAIM

  - presents **Integrity Support Message** designed for dissemination in Galileo

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Complete List of SISE@WUL Events > 25m after Extrapolation to Galileo FOC (01/2017 – 05/2022)

| Date	Satellite-ID	PRN	Potential FEs derived from monitor's output		Extrapolated to FOC	
			Exposure time (*)	Max. error magnitude	Exposure time (*)	Max. error magnitude
06/06/2017	GSAT0203	E26	~25.5 h	> 40 m	30 min	> 40 m
29/10/2019	GSAT0101	E11	35 min	> 40 m	35 min	> 40 m
21/01/2021	GSAT0102	E12	25 min	30 m	25 min	30 m
05/09/2021	GSAT0210	E01	20 min	540 m	20 min	>40m
29/04/2022	GSAT0210	E01	35 min	51 m	35 min	>40m

(*) fault period is derived as the period in which the system experienced a |SISE| > 25m

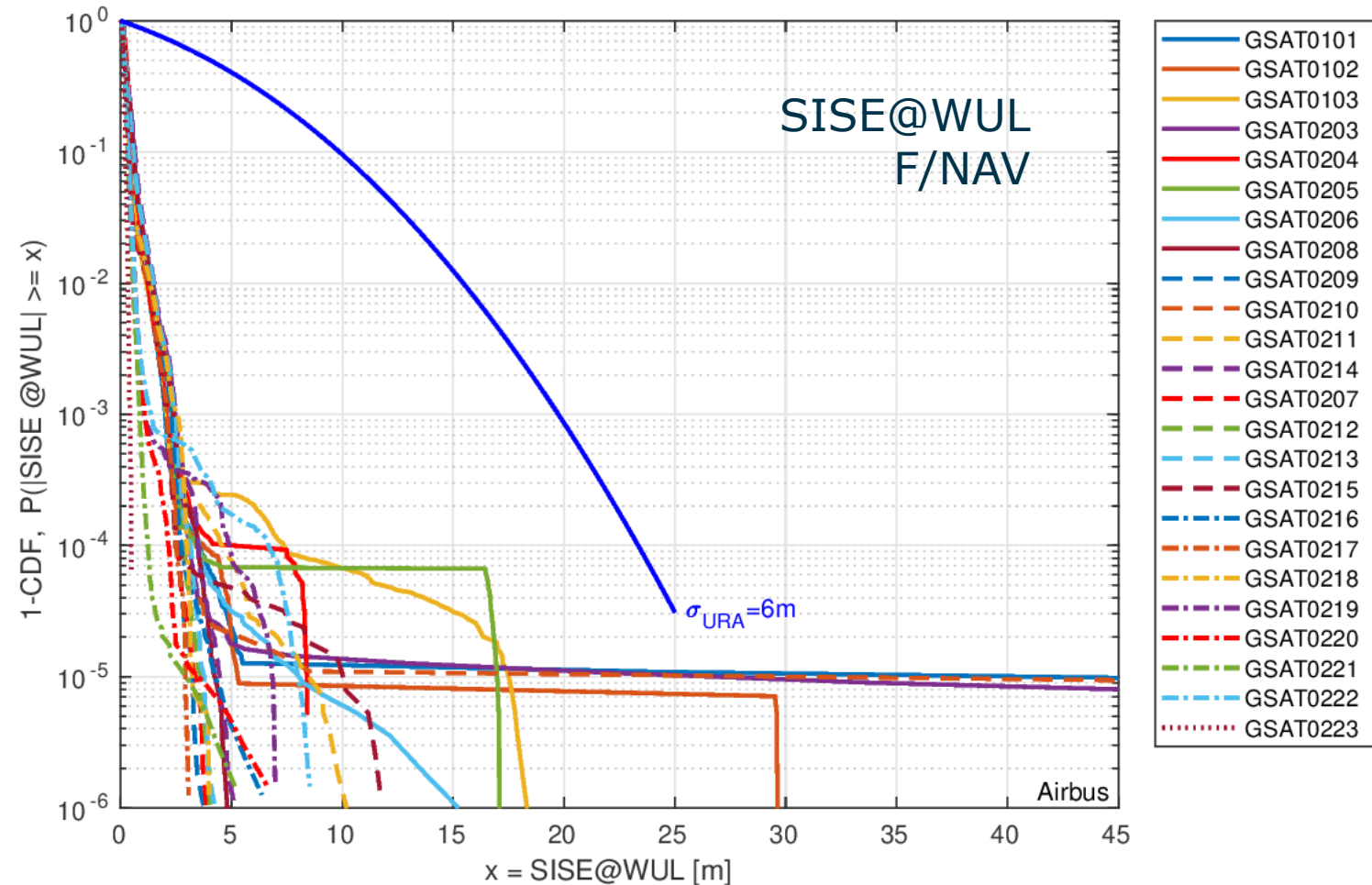→ Only <u>five events</u> with error magnitude > 25m remain after extrapolation to FOC

→ No wide constellation faults have been observed in the entire monitoring period

SIS Fault State and Availability Timeline (F/NAV)

- $SISE > k_f \cdot \sigma_{URA}$ with $\sigma_{URA,DF} = 6\text{m}$ and $k_f = 4.17$ (corresponding to $P_{sat} = 3 \times 10^{-5}$)
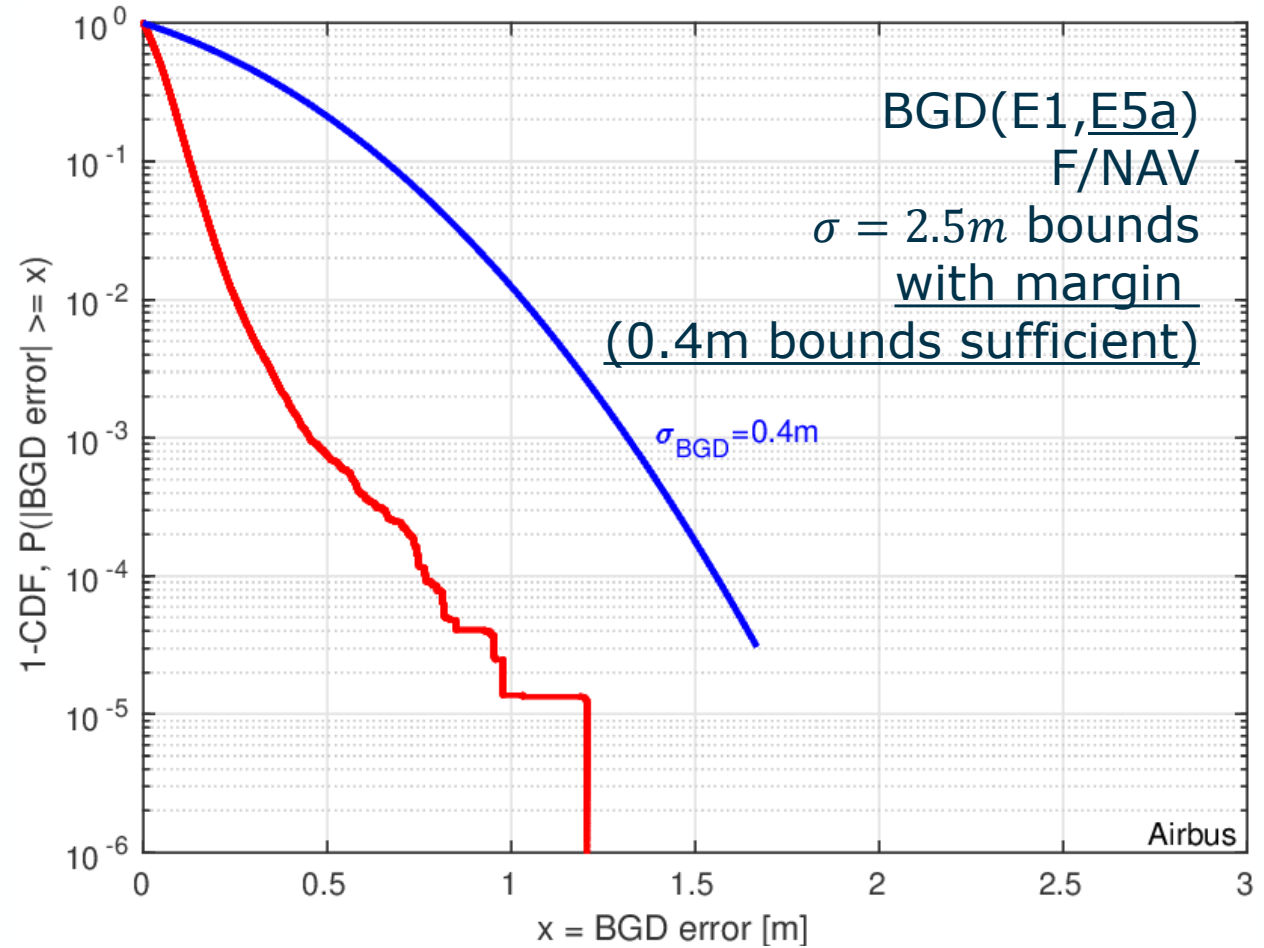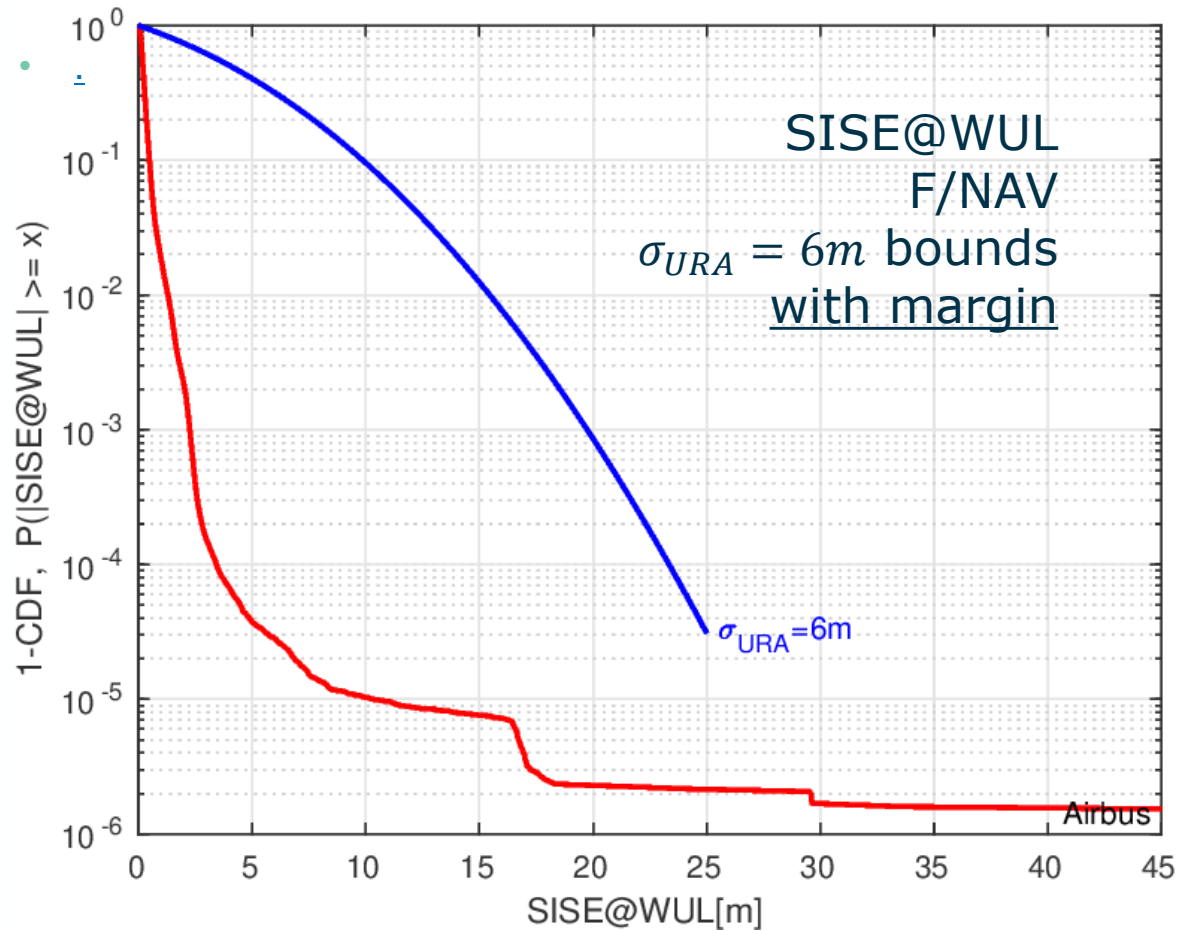
- After extrapolation to Galileo FOC
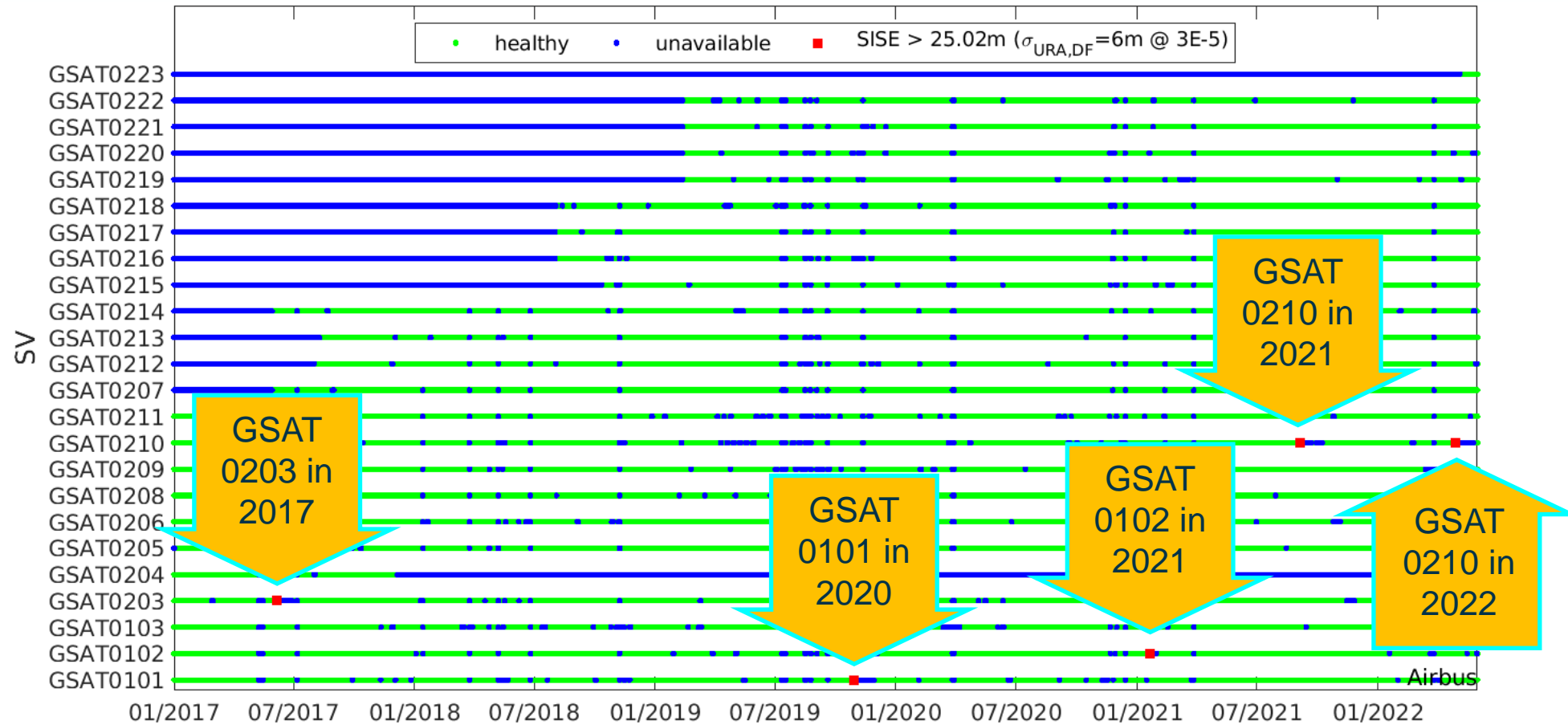
- SISE @ WUL is determined based on actual Galileo SIS

- Extrapolation to FOC is applied

- Bounding of the absolute SISE is applied **_a-posteriori_**

- As-observed performance confirms **_SARPS values_**

  ($\sigma_{URA,DF} = 6$m at $P_{sat} = 3 \times 10^{-5}$)

SISE@WUL
F/NAV

$\sigma_{URA} = 6$m

Airbus

Legend: GSAT0101, GSAT0102, GSAT0103, GSAT0203, GSAT0204, GSAT0205, GSAT0206, GSAT0208, GSAT0209, GSAT0210, GSAT0211, GSAT0214, GSAT0207, GSAT0212, GSAT0213, GSAT0215, GSAT0216, GSAT0217, GSAT0218, GSAT0219, GSAT0220, GSAT0221, GSAT0222, GSAT0223

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SISE@WUL
F/NAV
$\sigma_{URA} = 6m$ bounds
with margin

$\sigma_{URA} = 6m$

BGD(E1,E5a)
F/NAV
$\sigma = 2.5m$ bounds
with margin
(0.4m bounds sufficient)

$\sigma_{BGD} = 0.4m$

As per empirical distribution, the observed probability for SISE larger than 25m (URA =6 m) is 2e-6

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- **Galileo Integrity Support Message (ISM)**
  - I/NAV word type 22 for Galileo
  - Galileo ISM processing logic
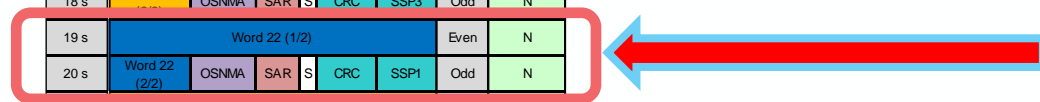 - Capability for cross-dissemination

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- Galileo to disseminate Integrity Support Message in the SiS

- Initial ISM content defined by WG-C ARAIM Milestone Report III

  - Several iterations within standardization bodies

- Final I/NAV word type 22 tailored to accomodate the ISM in E1-B

  - Almanac style: all Galileo satellites broadcast ISM for full constellation

  - Satellites can be assigned to groups to which identical ISM values apply

Galileo ISM Background

- I/NAV subframe structure

- One ISM word every 30 seconds

- Full ISD set may be included in several consecutive ISM words

- Capacity up to 24 different ISM Words (spanned in a full I/NAV frame)
  - Full 24 words to be broadcast in 12 mins
  - Almanac style (only one satellite is needed to retrieve full ISM)

- Capability to combine Galileo ISM and other GNSS in Galileo SIS

- Willingness to broadcast Galileo ISM via other GNSS SIS (cross-disseminaton with GPS)

One page per sub-frame in I/NAV E1B has been reserved to ISM MT

T_0 (GST$_0$ sync.)	E1-B content						E1-B page	E1-B sub frame ID
0 s	Word 16 (2/2)	OSNMA	SAR	S	CRC	SSP3	Odd	N-1
1 s	Word 2 (1/2)						Even	N
2 s	Word 2 (2/2)	OSNMA	SAR	S	CRC	SSP1	Odd	N
3 s	Word 4 (1/2)						Even	N
4 s	Word 4 (2/2)	OSNMA	SAR	S	CRC	SSP2	Odd	N
5 s	Word 6 (1/2)						Even	N
6 s	Word 6 (2/2)	OSNMA	SAR	S	CRC	SSP3	Odd	N
7 s	Word 7 or 9 or 21 (1/2)						Even	N
8 s	Word 7 or 9 or 21 (2/2)	OSNMA	SAR	S	CRC	SSP1	Odd	N
9 s	Word 8 or 10 or 21 (1/2)						Even	N
10 s	Word 8 or 10 or 21 (2/2)	OSNMA	SAR	S	CRC	SSP2	Odd	N
11 s	Word 17 or 18 (1/2)						Even	N
12 s	Word 17 or 18 (2/2)	OSNMA	SAR	S	CRC	SSP3	Odd	N
13 s	Word 19 or 20 (1/2)						Even	N
14 s	Word 19 or 20 (2/2)	OSNMA	SAR	S	CRC	SSP1	Odd	N
15 s	Word 16 (1/2)						Even	N
16 s	Word 16 (2/2)	OSNMA	SAR	S	CRC	SSP2	Odd	N
17 s	Word 43 IAR and CEFC data (1/2)						Even	N
18 s	Word 43 (2/2)	OSNMA	SAR	S	CRC	SSP3	Odd	N
19 s	Word 22 (1/2)						Even	N
20 s	Word 22 (2/2)	OSNMA	SAR	S	CRC	SSP1	Odd	N
21 s	Word 1 (1/2)						Even	N
22 s	Word 1 (2/2)	OSNMA	SAR	S	CRC	SSP2	Odd	N
23 s	Word 3 (1/2)						Even	N
24 s	Word 3 (2/2)	OSNMA	SAR	S	CRC	SSP3	Odd	N
25 s	Word 5 (1/2)						Even	N
26 s	Word 5 (2/2)	OSNMA	SAR	S	CRC	SSP1	Odd	N
27 s	Word 32 E1-B NMA data (1/2)						Even	N
28 s	Word 32 (2/2)	OSNMA	SAR	S	CRC	SSP2	Odd	N
29 s	Word 16 (1/2)						Even	N
30 s	Word 16 (2/2)	OSNMA	SAR	S	CRC	SSP3	Odd	N

I/NAV word type 22 for Galileo

- <u>Galileo</u> ISM word

The Galileo ISM content is tailored to the specific Service Level

Type=22	GNSS Constellation ID =001 (Galileo)	Service level	Galileo SL-specific ISM data	CRC	Total [bits]
6	3	3	84	32	128

	Galileo ISM Header				Galileo ISM SL3 Data Block										
Type=22	GNSS Constellation ID = 001 (Galileo)	Service level = 010 (Level 3)	ISM Week Number	ISM Time of Week	Mask – MSB	Mask	P_{const}	P_{sat}	URA	URE	b_{nom}	Validity period	Spare	CRC	Total [bits]
6	3	3	12	9	1	32	4	4	4	4	4	4	6	32	128

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I/NAV word type 22 for Galileo

Parameter	Definition	Bits	Scale Factor	Range/Index	Unit
GNSS Constellation ID	Identifier of the constellation the ISM message is applicable to	3	N/A	[000: ISM in Test 001: Galileo 010: Reserved 011: BeiDou 100: GPS 101: spare 110: spare 111: spare]	N/A
CRC	CRC	32	N/A	Refer to RTCA DO-246E-Change 1 document for more details on the ISM CRC	N/A
Service level	Identifier for the service level for the ARAIM Operation	3	N/A	[000=Level 1: No data available 001=Level 2: Non-safety of life use 010=Level 3: Safety of life use (horizontal) 011=Level 4: Safety of life use (Vertical) Level 5-8: Reserved]	N/A
ISM Week Number	Week number the ISM data is issued	12	1	Range: [0, 4095], Galileo WN	week
ISM Time of Week	Time of week the ISM data is issued	9	1800	Range: [0, 604799]	seconds
Mask-MSB	Satellite Mask Most Significant Bit	1	N/A	[0: Mask applies to SV ID 1 to 32 1: Mask applies to SV ID 33 to 64]	N/A
Mask	Satellite Mask	32	N/A	One bit per satellite in the SV ID range. Bit values mean: 0: ISM parameters do NOT apply to satellite 1: ISM parameters apply to satellite	N/A

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I/NAV word type 22 for Galileo

Parameter	Definition	Bits	Scale Factor	Range/Index	Unit
Pconst	Probability of constellation fault for ARAIM user	4	N/A	Values 0000 to 1111: [1e-8, 1e-7, 1e-6, 3e-6, 6e-6, 8e-6, 1e-5, 2e-5, 4e-5, 6e-5, 8e-5,1e-4, 1.25e-4, 1.5e-4, 1.75e-4, 2e-4]	N/A
Psat	Probability of satellite fault for ARAIM user	4	N/A	Values 0000 to 1111: [1e-7, 3e-7, 6e-7, 1e-6, 2e-6, 3e-6, 5e-6, 7e-6, 1.0e-5, 1.2e-5, 1.4e-5, 1.7e-5, 2.0e-5, 2.4e-5, 2.8e-5, 3e-5]	N/A
URA	User Ranging Accuracy	4	N/A	Values 0000 to 1111: [0.75, 1, 1.5, 2, 2.25, 2.5, 2.75, 3, 3.25, 3.5, 3.75, 4, 4.5, 5, 5.5, 6]	m
URE	User Ranging Error	4	N/A	Values 0000 to 1111: [0.25, 0.50, 0.75, 1,1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.25, 3.5, 3.75, 4]	m
bnom	Nominal Bias	4	N/A	Values 0000 to 1111: [0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.75, 0.85, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.4]	m
Validity Time	Validity Time of the ISM	4	N/A	Values 0000 to 1111: [1h, 2h, 3h, 4h, 6h, 8h, 10h, 12h, 18h, 24h, 2days, 3 days, 5 days, 7 days, 30 days, 60 days]	N/A

Capability for ISM Cross-Dissemination

- Galileo SIS to broadcast ISM for other constellations
  - e.g. GPS

- Galileo only responsible for dissemination, not for the generation of the ISM for external constellations
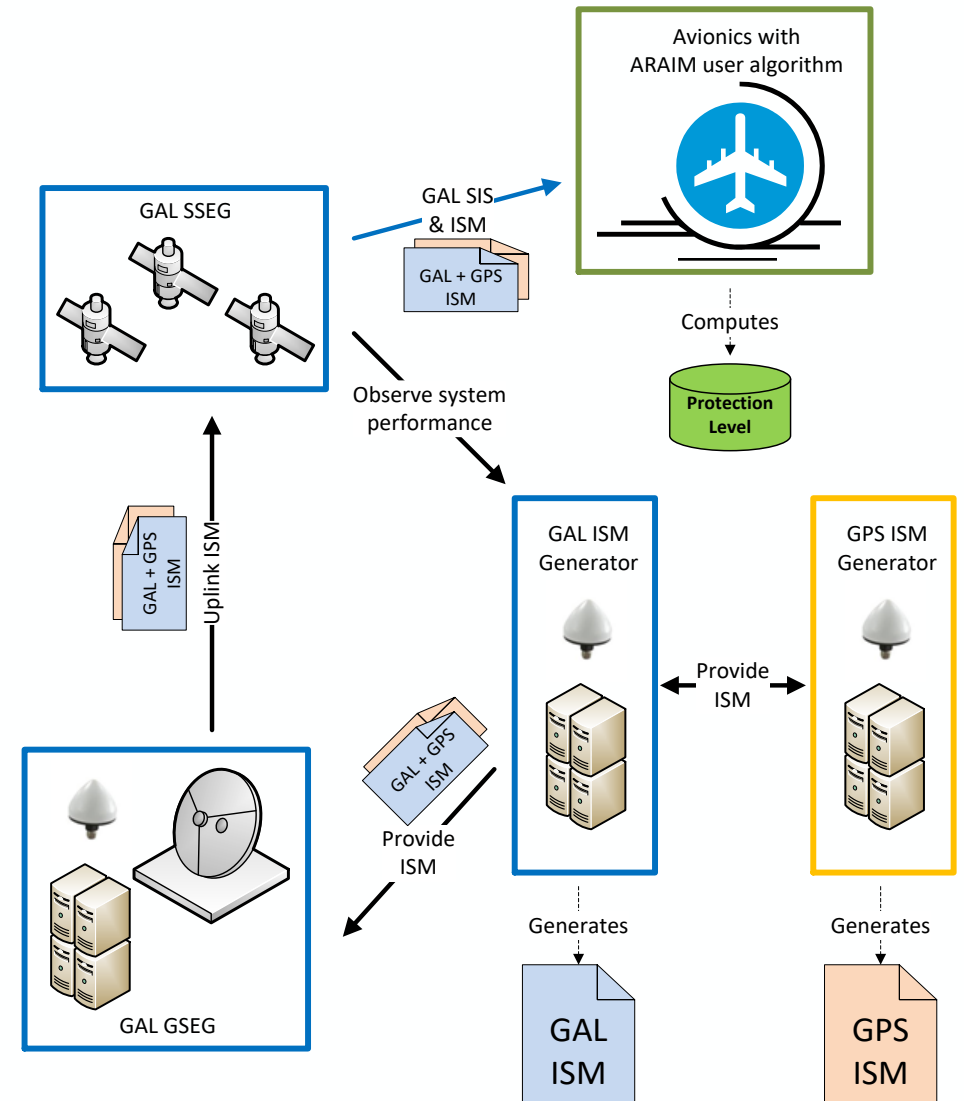
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Characterization for H-ARAIM

- Characterization conducted based on ~850.000 in-service hours over all SV's from **01/2017 to 05/2022**

- After extrapolation to FOC only five events exceeding an error threshold of $k_f \cdot \sigma_{URA}$ with $\sigma_{URA} = 6$m and $k_f = 4.17$ (corresponding to $P_{sat} = 3 \times 10^{-5}$)

- As per empirical distribution, the observed probability for SISE larger than 25m (URA=6m) is 2×10^{-6}

- No wide constellation faults have been observed in Galileo's service history

- Resulting a-posteriori bounds

  - $\sigma_{URA} = 6m$ is bounding the SISE distribution with margin

  - $\sigma_{BGD} = 2.5m$ is bounding the BGD error distribution with margin (largest BDG Error observed below 1.5m)

- <u>Characterization results confirm the ICAO SARPS values for Galileo are achieved with margin</u>

Galileo Integrity Support Message

- Galileo ISM structure and ISM parameters are established

- Galileo ISM insertion in the existing Galileo E1-B I/NAV message format is defined

- ISM cross-dissemination with GPS feasible with no impact on Galileo design

THANK YOU FOR YOUR ATTENTION

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