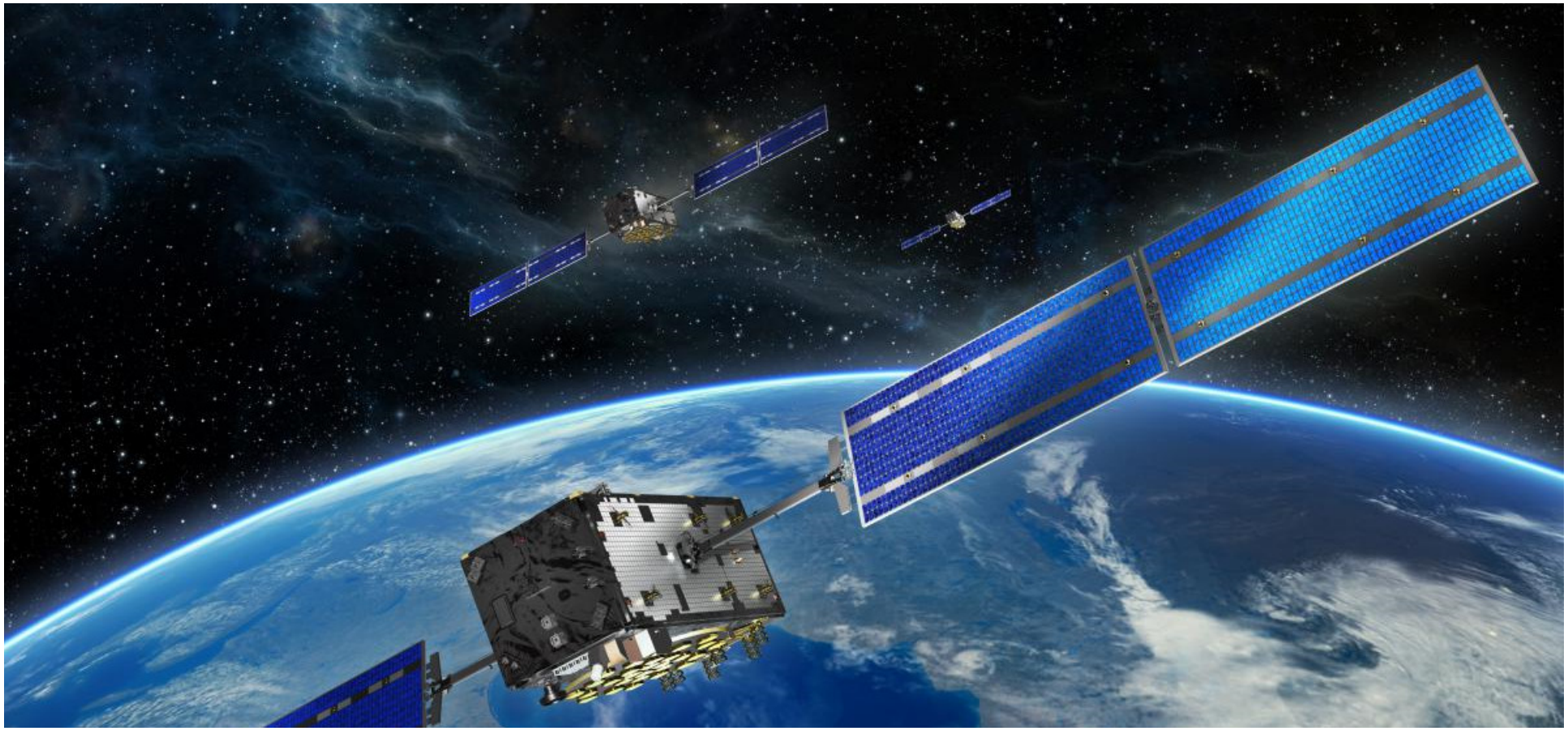

Galileo's Contribution to Interoperable GNSS SSV

UNOOSA ICG 10 – Working Group B

Boulder, CO, U.S., 04 November 2015

esa

European Space Agency

GALILEO

EGNOS

Navigation solutions powered by Europe

Outline

- ★ Relevance of GNSS SSV
- ★ Galileo SSV Characteristics
- ★ GSAT0201/0202 Orbit Anomaly – Unique Opportunity for SSV Characterization
- ★ Conclusions

GNSS Space Applications

- Main applications of GNSS in space:
  - Orbit determination
  - AOCS & Timing
  - Formation Flying & Rendezvous
  - Scientific instruments (RO, Reflectometry)

- GNSS is used at LEO, MEO and GEO altitudes
- Several studies done at ESA-level identifying the benefits of adding the new GNSS systems
- Several GNSS technologies under development, new ASICs and receivers

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Relevance of Space Service Volume

- Relevance and added value of an interoperable GNSS Space Service Volume (SSV) is well noted
- Already today a large number of ESA and EU Member State space missions have GNSS space receivers embarked

Application		Mission Examples	Orbit
Absolute Navigation (Platform Rx)	LEO Orbit	PLEIADES, UK-DMC, all ESA Earth Obs. (Explorers, Copernicus, MetOp), GlobalStar, Proba-2, Demeter, TDS-1	LEO
	GEO/GTO/HEO Orbit	STENTOR, SkyLAN, IntelSat, GMP, SmallGEO, MTG, STE-QUEST, Proba-3	GEO/HEO
	Re-entry	ARD, Pre-X	LEO to ground
	Launcher	Ariane V, VEGA	Ground to GTO
Relative Navigation (Platform Rx)	Rendevous	ATV	LEO
	Formation Flying	GRACE, PRISMA, Proba-2, MMS, TerraSAR-x, FF Xeus, NGGM	LEO/HEO GEO
EO/Scientific Instruments	Support to POD	ESA Explorers (GOCE, SWARM, ...), Copernicus Sentinels, MetOp-SG, MetOp, CHAMP, GRACE	LEO
	Atm. Sounding	MetOp, CHAMP, Jason-CS, MetOp-SG	LEO HEO
	Reflectometry	UK-DMC, TDS-1, GEROS-ISS	LEO HEO
Support to Other Systems	Attitude	PLEIADES, ROCSAT, ALPHABUS	LEO GEO
	Timing	GEO telecom, GlobalStar, Iridum, MTG	LEO GEO

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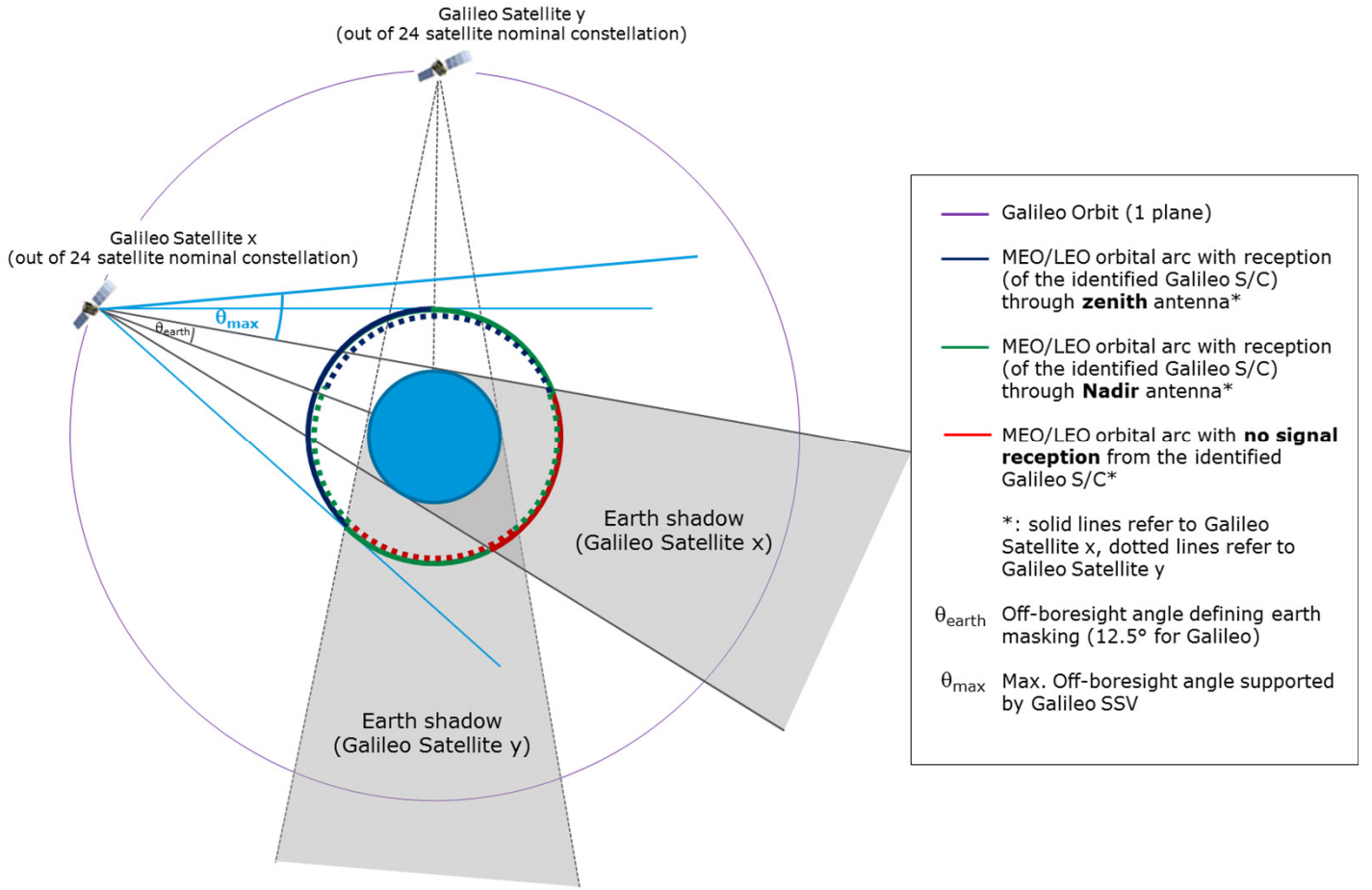
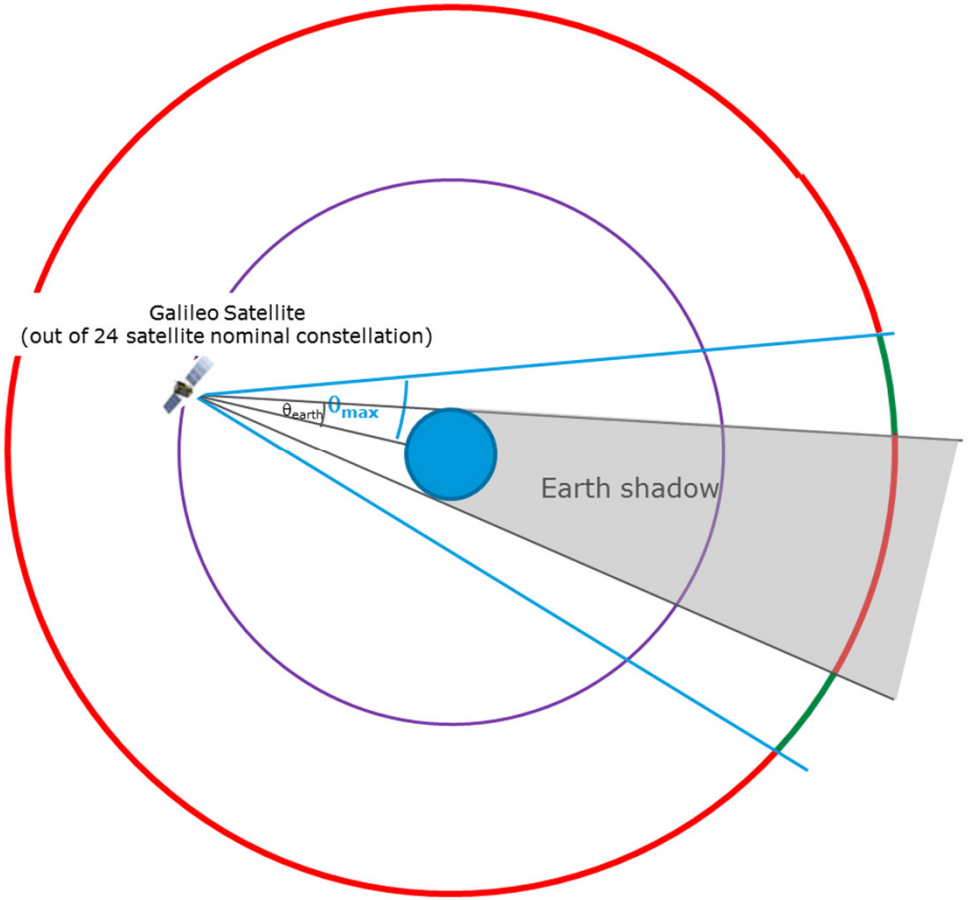
SSV Geometry for LEO/MEO



- Important note: It is assumed that the user has capability to receive signals from
  - NADIR direction and
  - Zenith direction

SSV Geometry for GEO/HEO



Galileo Orbit

HEO/GEO orbital arc with reception (of the identified Galileo S/C)

HEO/GEO orbital arc with **no signal reception** from the identified Galileo S/C

θ_{earth} Off-boresight angle defining earth masking (12.5° for Galileo)

θ_{max} Max. Off-boresight angle supported by Galileo SSV

★ Important note: It is assumed that the user has capability to receive signals from NADIR

Galileo SSV Characteristics (1/3)

- Galileo SSV characterization was conducted following the conventions identified by ICG WG-B regarding
  - Relevant User Orbits
    - LEO (represented by sphere at 3000 km altitude above earth)
    - MEO (represented by sphere at 8000 km altitude above earth)
    - GEO/HEO (represented by sphere at 36000 km altitude above earth)
  - Availability Evaluation
    - Availability of 1 satellite and availability of 4 satellites
    - Availability evaluation done per user on a sphere at relevant radius over time
    - Availability to report is the minimum out of the best 95% of all user locations
  - SSV Characteristics Reporting
    - User received power (not necessarily constrained by data demodulation threshold) at GEO altitude and corresponding off-boresight angle
    - Availability evaluation at GEO altitude
    - Availability evaluation at MEO altitude (based on off-boresight angle specification for GEO altitude)

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Galileo SSV Characteristics (2/3)

Definitions

Definition	Notes
Lower Space Service Volume (also known as 'MEO altitudes'): 3000 to 8000 km altitude	Four Galileo signals available simultaneously a majority of the time but Galileo signals over the limb of the Earth become increasingly important. Capability of the user to receive both from Nadir and from Zenith is considered.
Upper Space Service Volume (also known as 'HEO/GEO altitudes'): 8000 to 36000 km altitude	Nearly all Galileo signals received over the limb of the Earth. Users will experience periods when no Galileo satellites are available.

Power

Parameters	Typical Characteristics of Nominal GSAT02xx Satellites	
User Range Error	1.1 meters	
Minimum Received Civilian Signal Power	0 dBi RCP antenna at GEO	Reference Off-Boresight Angle
E1B/C	-182.5 dBW	20.5 deg
E6B/C	-182.5 dBW	21.5 deg
E5b	-182.5 dBW	22.5 deg
E5ABOC	-182.5 dBW	23.5 deg
E5a	-182.5 dBW	23.5 deg

- ★ Galileo SSV Characteristics are provided for Galileo FOC (GSAT02xx) satellites!
- ★ At this stage, the results presented above are not yet validated at programme level. They can under no circumstance be interpreted as commitment from the European Commission to comply with such characteristics for the already launched or future satellites. Official information related to SSV characteristics of Galileo will be published through the Galileo OS Service Definition Document

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Galileo SSV Characteristics (3/3)

Availability

Parameters	Typical Characteristics of Nominal GSAT02xx Satellites	
Signal Availability		
Lower Space Service Volume (MEO)	**At least 1 signal**	**4 or more signals**
E1B/C	100%	> 99% [6]
E6B/C	100%	100%
E5ABOC	100%	100%
E5a or E5b	100%	100%
Upper Space Service Volume (GEO/HEO)	**At least 1 signal**	**4 or more signals**
E1B/C	≥ 64% [2]	0%
E6B/C	≥ 72% [3]	0%
E5b	≥ 80% [4]	0%
E5ABOC	≥ 86% [5]	0%
E5a	≥ 86% [5]	0%

Note 1: Assumes a nominal, Galileo Walker 24/3/1 constellation, full navigation message availability and no Galileo spacecraft failures. Signal availability at 95% of the areas within the specific altitude.
Note 2: Assumes less than 93 minutes of continuous outage time
Note 3: Assumes less than 75 minutes of continuous outage time
Note 4: Assumes less than 64 minutes of continuous outage time
Note 5: Assumes less than 54 minutes of continuous outage time
Note 6: >99% at 21.5 deg (-182.5 dBW)

- Galileo SSV Characteristics are provided for Galileo FOC (GSAT02xx) satellites!
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GSAT0201/0202 Orbital Anomaly (1/2)

- Two Galileo FOC satellites (GSAT0201/0202) launched in August 2014 face orbital anomaly

	Nominal Galileo Orbit	GSAT0201/0202 Injection Orbit	GSAT0201/0202 Orbit after Correction Manoeuvres
Semi Major Axis (SMA) [km]	29600	26180	27980
Eccentricity	0	0.23	0.15

- Eccentricity and lower SMA provide unique opportunity
  - Characterization of SSV-relevant antenna off-boresight range from ground!

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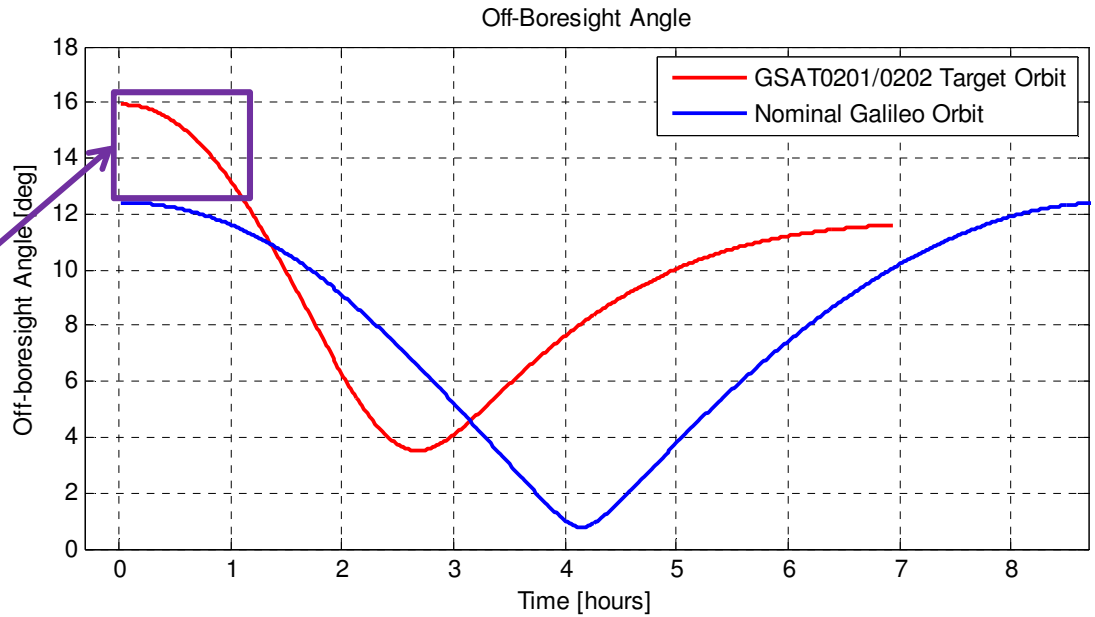
GSAT0201/0202 Orbital Anomaly (2/2)

- Off-boresight angles expected during In-Orbit Testing (IOT) of GSAT0202/0202

SSV-relevant off-boresight angle range that can be characterized on ground for GSAT0201/0202

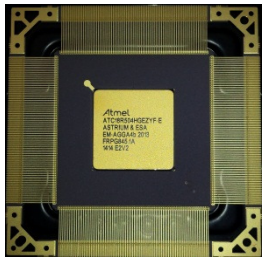


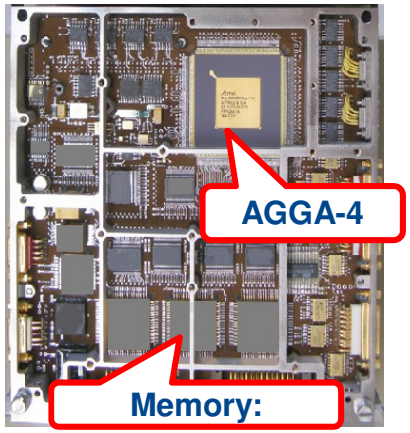
- Galileo SSV Characterisation up to off-boresight angle of 16° is supported by on-ground measurements!

ESA technology for Space Applications: AGGA-4 Multi-Constellation GNSS chip

- AGGA-4 (Adv. Galileo/GPS ASIC) available since 2014.
  - Compatible with L1/L5/L2C, E1bc, E5a, E5b, Beidou, Glonass too.

- Applications
  - Navigation solution, and Precise Orbit Determination (2 cm in GOCE mission)
  - Scientific Radio Occultation (RO) for atmospheric sounding. With MetOp &Cosmic, it is ranked among top 5 sources for Numerical Weather Prediction
  - Rapidly growing interest in GEO / GTO mission: **multi-constellation is key to overcome low SNR**





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Conclusions

- ★ Importance of an interoperable GNSS SSV is fully recognized
- ★ Characterisation of Galileo SSV conducted following the Figures of Merit established by ICG WG-B
- ★ Characterisation also backed up by on-ground measurements over wide-offboresight angles benefit from GSAT0201/0202 orbit anomaly

Galileo SSV Characteristics are available and will be formally published through the Galileo OS Service Definition Document

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