FOSTERING GNSS SCIENCE WITH GALILEO AND GALILEO SATELLITE METADATA

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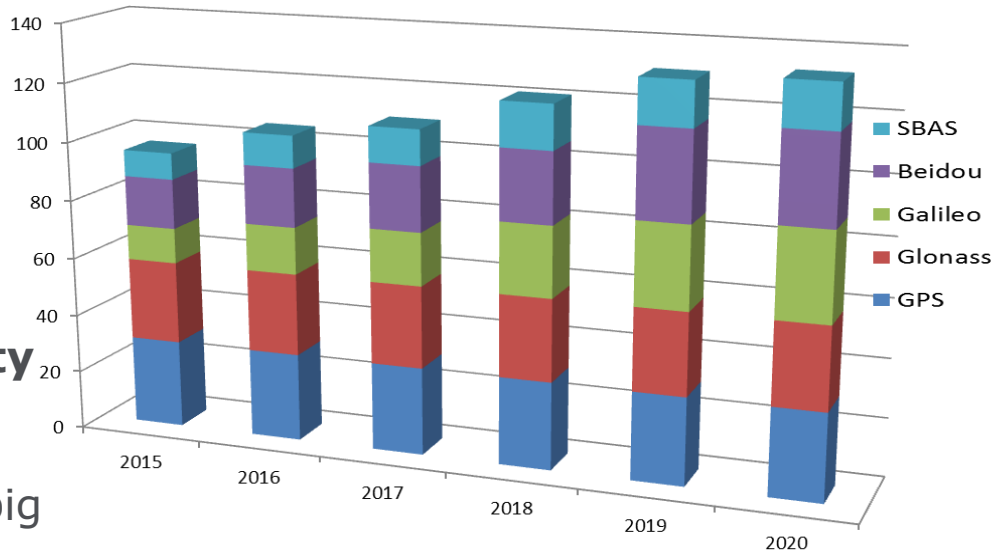
TALK OBJECTIVES

- **RECALL THE OPPORTUNITIES OF GNSS FOR SCIENCE**
- **RECALL SOME OF THE GALILEO FEATURES THAT ENABLE SCIENTIFIC APPLICATIONS**
- **EXPLAIN SOME OF THE ON-GOING ESA INITIATIVES TO FOSTER GNSS SCIENTIFIC RESEARCH**

GNSS: A MAJOR OPPORTUNITY for SCIENCE

- Within this Decade **around 130 GNSS satellites** will become available
- Providing **global coverage**, **multisystem** with **multi-frequency high quality Signals** in Space
- **Ensuring Long-term data availability**
- **Enhanced by major Technology improvements** (quality of receivers, big data processing, sensors quality, modernisation of GNSS, density/quality of stations, etc)



GNSS Scientific Fields

Earth Science:

E01 Geodesy / Precise positioning
E02 Geodynamics, geophysics and oceanography
E03 Global tectonics
E04 Reference frames
E05 Ionosphere / space weather
E06 Troposphere / climatology
E07 Disaster monitoring
E08 Gravity field
E09 GNSS remote sensing, GNSS reflectometry

Fundamental Physics:

P01 Test of General Relativity and alternative theories
P02 Fundamental constants
P03 Relativistic reference frames
P04 Relativistic positioning
P05 Astrometry, VLBI, pulsar timing
P06 Quantum technologies for positioning, navigation and timing

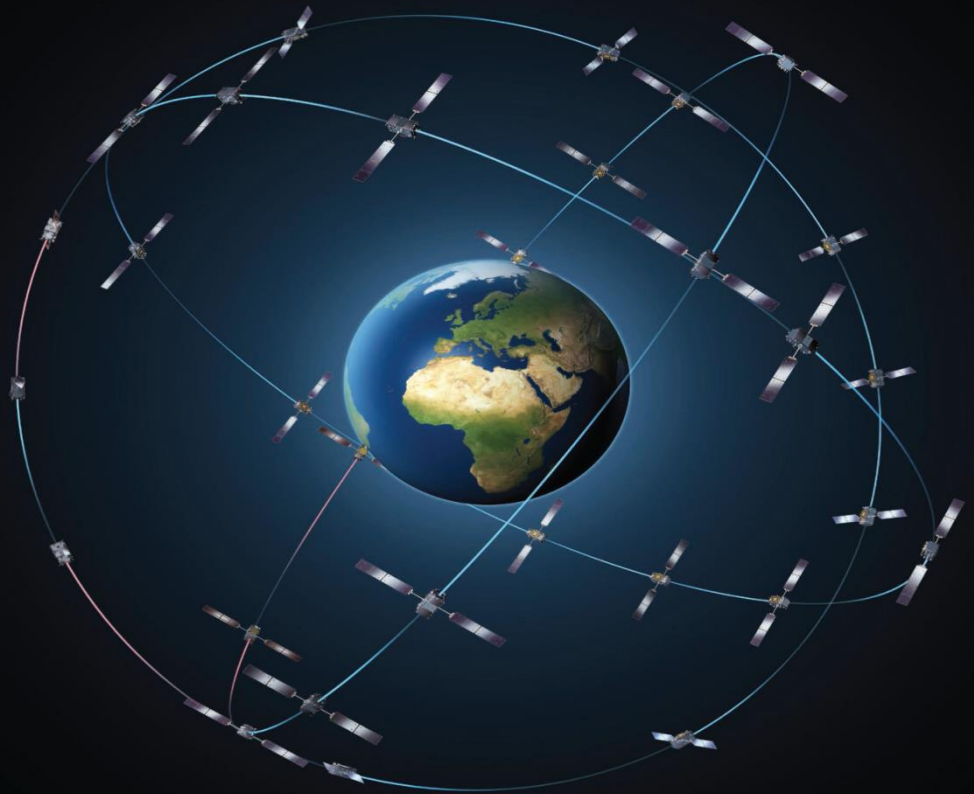
Space-Time Metrology:

M01 Atomic clocks for space and ground-segment
M02 Galileo timing system
M03 Time scales and time transfer
M04 Inter-satellite links
M05 Precise orbit determination
M06 High-precision clocks in receivers

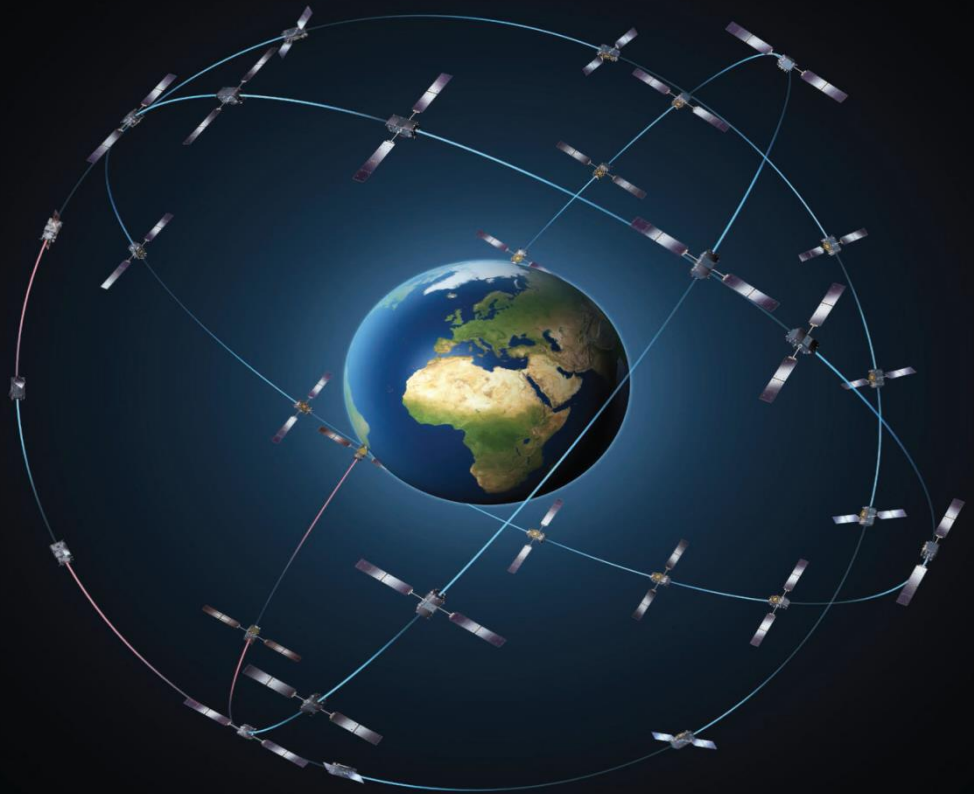
Other GNSS Scientific fields

T07 Space service Volume navigation
N01 Signal processing
N04 Sensors, hybridization for science
N06 Animal tracking / Migrations
T01 GNSS Big Data for science / scientific data archives
T04 Cubesats and UAVs for GNSS science
T05 Software receivers / low-cost SDR platforms
T06 GNSS science and education

GALILEO SPECIALLY SUITED FOR SCIENCE

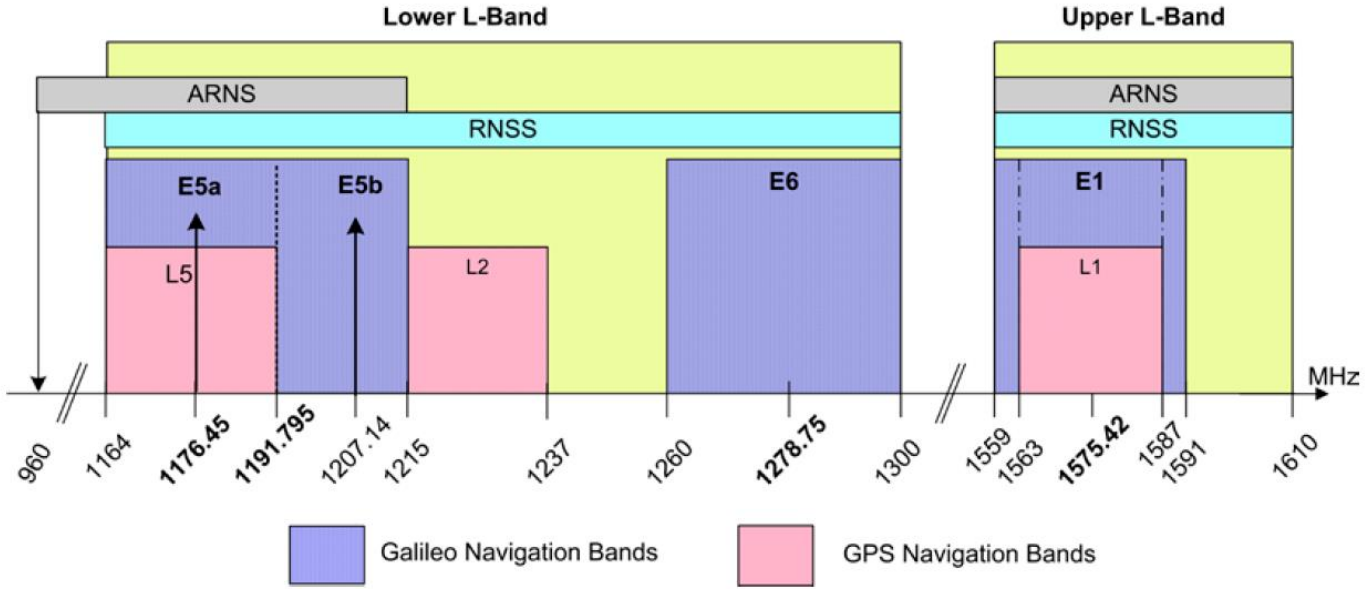


Stable Galileo orbits, avoiding Earth rotation resonances and minimum manoeuvres

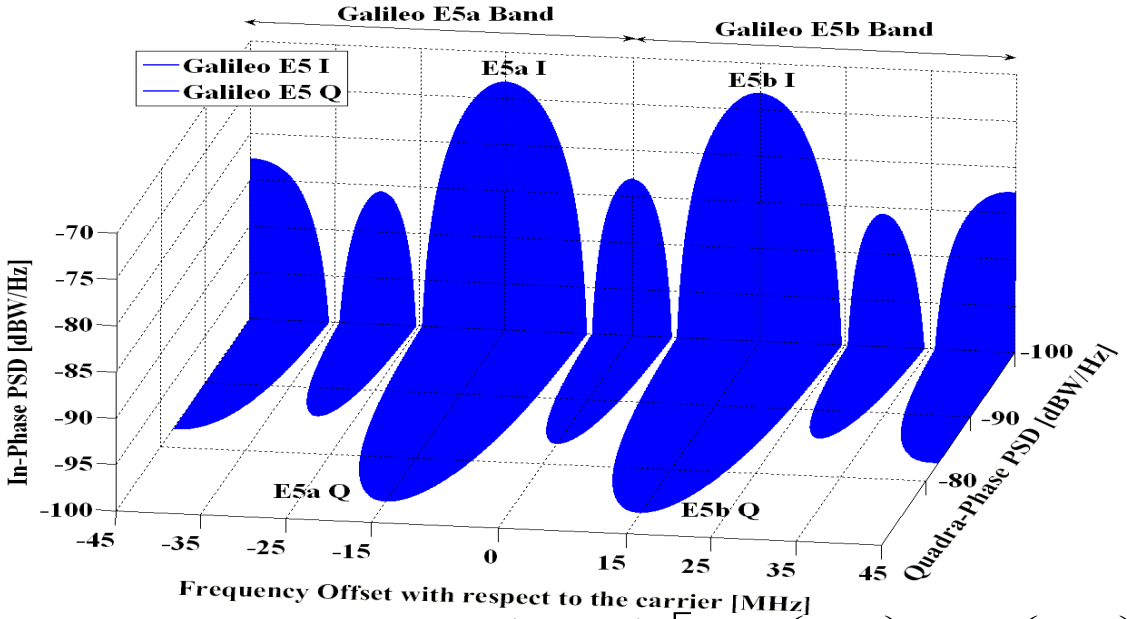


Robustness of Galileo signals

Galileo provides new signals, robust modulation schemes with lower noise in four frequency bands (E5a, E5b, E6 and E1 bands). They provide a wide bandwidth for the transmission of the Galileo Signals.



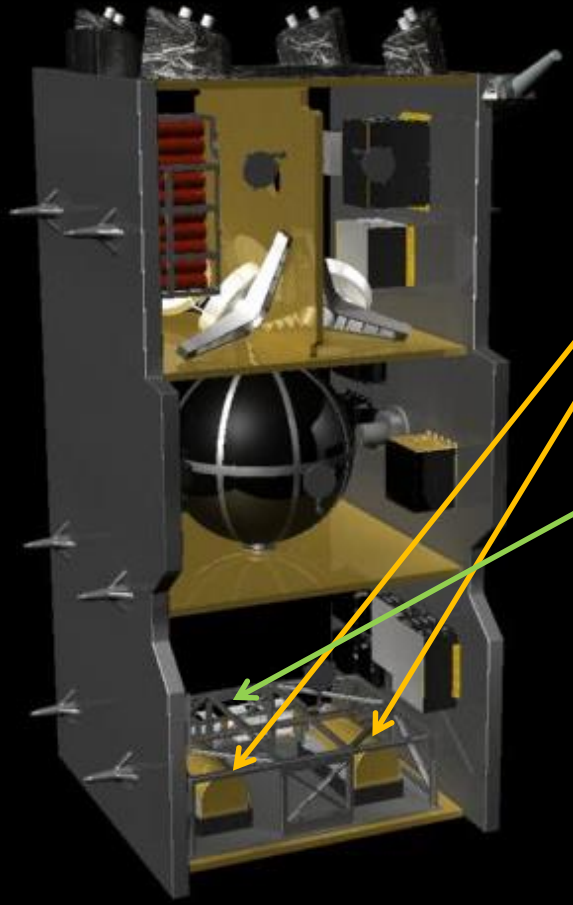
Major opportunities for science of Galileo Altboc E5 signal

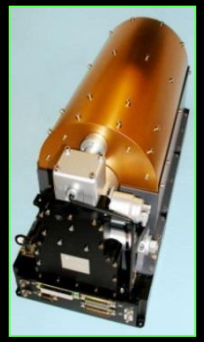


The most accurate signal among all existing GNSS signals

www.useGalileo.eu

$$G_{AltBOC}^{\Phi_{odd,c}}(f) = \frac{4 f_c}{\pi^2 f^2} \frac{\cos^2(\pi f T_c)}{\cos^2\left(\pi f \frac{T_c}{n}\right)} \left[\cos^2\left(\frac{\pi f}{2 f_s}\right) - \cos\left(\frac{\pi f}{2 f_s}\right) - 2\cos\left(\frac{\pi f}{2 f_s}\right)\cos\left(\frac{\pi f}{4 f_s}\right) + 2 \right]$$





Passive Hydrogen Maser

The most stable and accurate

→ Looses no more than 0.5 ns in 12h,

→ Frequency Stability ~ 10^{-14} / day

Rubidium

→ Looses 3s in 1 million of years

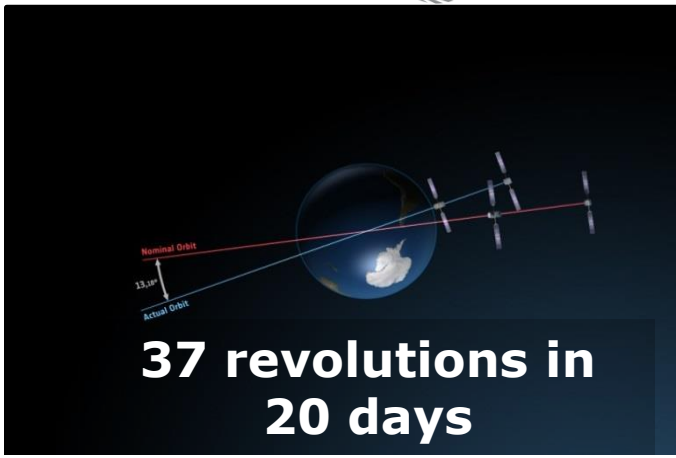
All Galileo satellites include

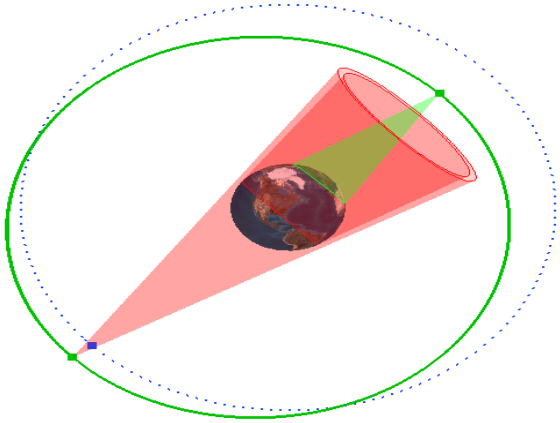
Highly stable PHM clocks

(with 2 placed in eccentric orbit)

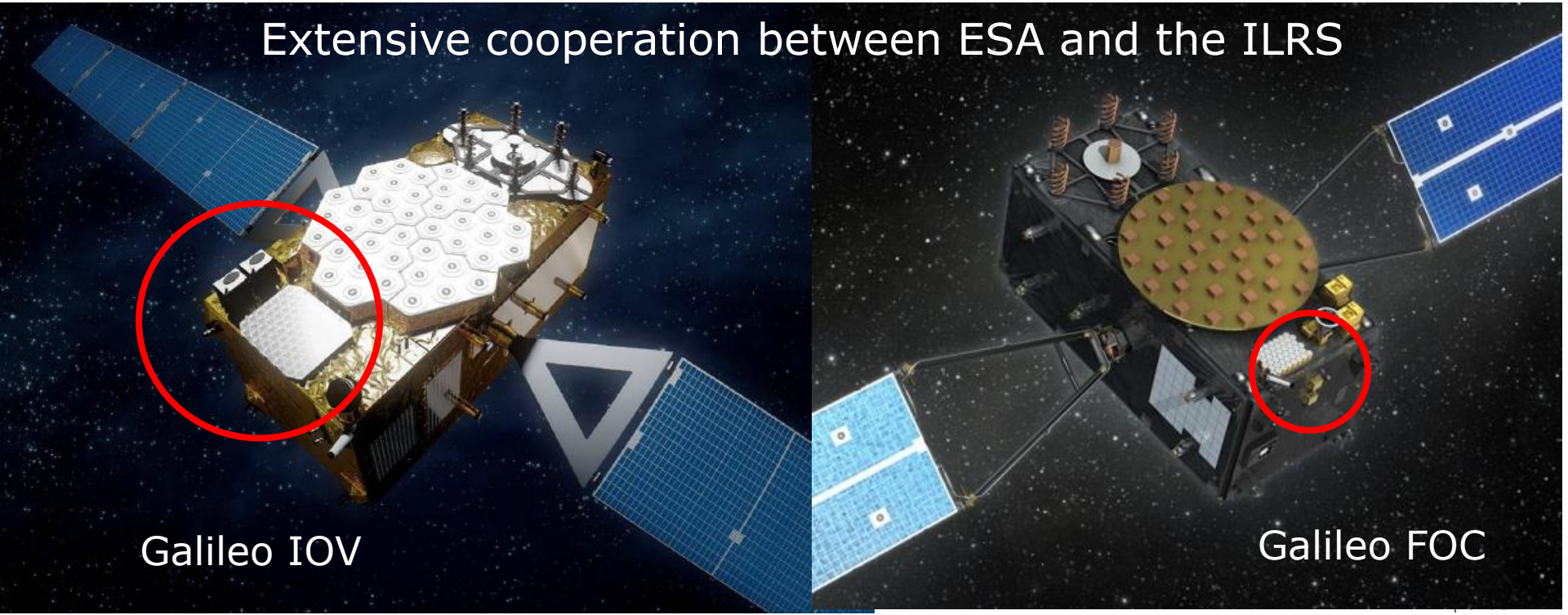
Two highly eccentric Galileo satellites in orbit

- Galileo L3 launch (VS09) had an Orbit injection anomaly which left Galileo Sat 5 /Sat 6 (GSAT0201/GSAT0202) satellites in a highly eccentric orbit.
- After an outstanding recovery operation, ESA/EC managed to save these 2 satellites and duly test and control then.
- The 2 Satellites are working nominally. Satellites, are currently used for SAR and its potential inclusion as part of the nominal operations of Galileo is under assessment.
- Both satellites have a high eccentricity (e=0.15), which combined with their high-stable PHM clocks, provide an unique test opportunity in the field of General Relativity and Fundamental Physics.





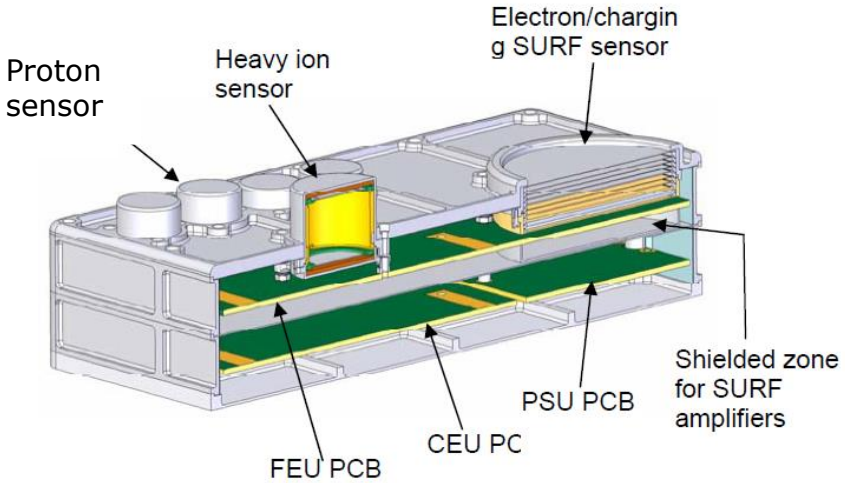
Galileo satellites equipped with Laser Reflector Arrays (LRAs)

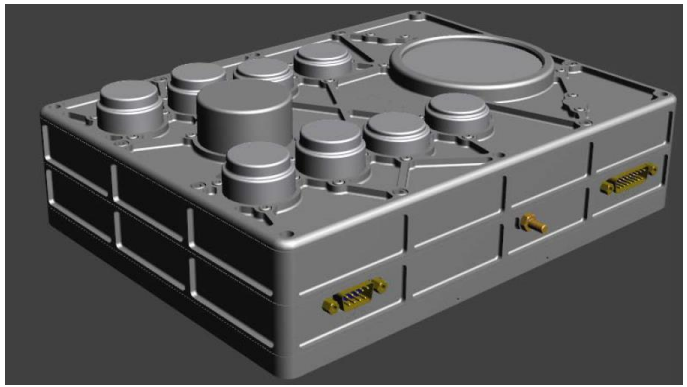


Environmental Monitoring Units on 2 Galileo FOC

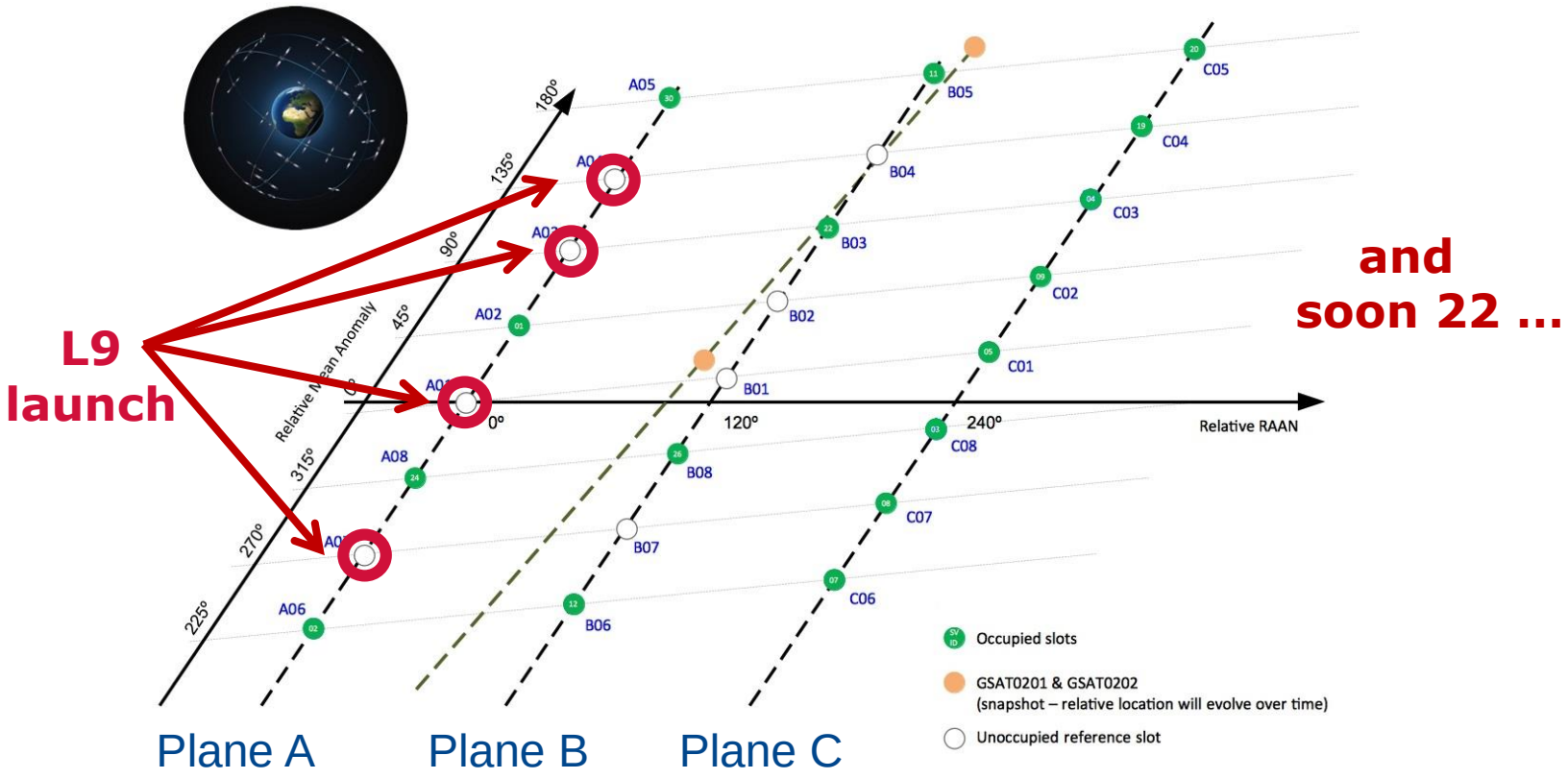
2 FOC s/c equipped with the Environmental Monitoring Unit (EMU)

- Heritage from Merlin (used in GIOVE-A), 3kg
- 8 SURF plates for electron current measurement
- 8 separate proton sensors, Flying as SEDA on two Himawari satellites in GEO





Current FOC1 constellation: 18 spacecraft



OBJECTIVES

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ESA Activities to foster GNSS Science

- **Setting-up a dedicated ESA Galileo/GNSS Navigation Science Office**
- **Setting-up a dedicated GNSS Science Advisory Committee (GSAC) of Support**
- **Supporting Research & Development Activities on GNSS Science**
- **Supporting GNSS infrastructure developments in support to Science**
- **Supporting the International GNSS Service (IGS)**
- **Setting-up a complete GNSS Science Service Center and archive**
- **Supporting the development of GNSS Scientific Cubesats with Universities**
- **Supporting high-level GNSS Education**
- **Organising a Bi-annual Colloquium on GNSS Scientific Aspects**

ESA GNSS Science Advisory Committee (GSAC)

Current Members

- Prof. Gunnar Elgered (CHAIRMAN)– Chalmers University of Technology, Sweden
- Prof. Bernd Dachwald - FH Aachen, Germany
- Dr Andreas Bauch – PTB, Germany
- Dr. Pascale Defraigne - Royal Observatory of Belgium, Belgium
- Dr Pacôme Delva - SYRTE, Observatoire de Paris, France
- Prof. Manuel Hernandez-Pajares – UPC, Spain
- Prof. Heidi Kuusniemi - The Finnish Geospatial Research Institute (FGI), Finland
- Prof. Gérard Lachapelle - University of Calgary, Canada
- Prof. Terry Moore - University of Nottingham, United Kingdom
- Prof. Stanislaw Oszczak - University of Warmia and Mazury, Poland
- Prof. Markus Rothacher - ETH Zurich, Switzerland
- Prof. Frantisek Vejrazka - Czech Technical University, Czech Republic
- Dr. Francesco Vespe - Space Geodetic Centre, Matera, Italy

GSAC ESA Executive Secretary: Dr Javier Ventura-Traveset (ESA)

Dedicated R&D Calls for GNSS Science activities

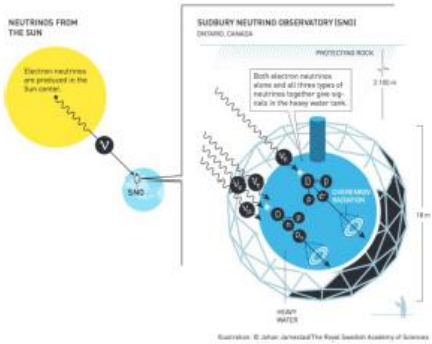
A new Call for Ideas is planned (**1st half 2018**) for H2020 HSNAV Program, addressing **scientific aspects relevant to Galileo/GNSS system**.

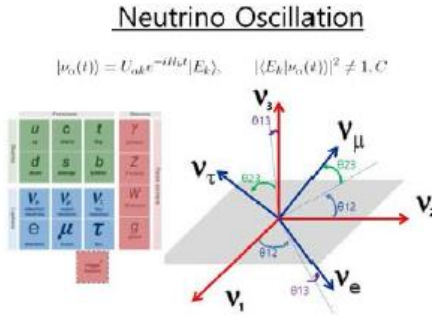
This call targets several activities **from 250 to 400 k€** each, **open to any GNSS scientific proposal** but with special interest on the following aspects:

- Fundamental Physics with Galileo (including FOC Satellites 5 and 6)
- Space Weather monitoring with Galileo
- Scientific Exploitation of Galileo E5 AltBOC

STUDIES LAUNCHED BY ESA IN SUPPORT TO PNT SCIENCE
ESA NAVISP PROGRAM (2017-2018)

1. Weather Monitoring based on GNSS and Crowdsourcing
2. Pulsar time-scale demonstration
3. Quantum-based sensing for PNT
4. PNT using Neutrino Particles
5. Resilient, Trustworthy, Ubiquitous Time Transfer
6. Design and practical aspects of a space-based relativistic PNT system
7. Low cost multi-frequency multi-constellation GNSS antenna for CubeSats





Support from ESA to IGS Community

ESOC Navigation Support Office is (and was since 1992) a **IGS Analysis Centers** . This center is regularly submitting products for all IGS product lines: Orbits and Clocks in Final, Rapid and Ultra-rapid modes, station positions, Ionosphere. In addition ESOC also provides the IGS Real-Time Service. Three Navigation Support Office staff are members of the IGS governing .

ESA has agreed to further contribute to the IGS with the set-up (Oct 2017) at **ESAC Galileo Navigation Science Office** a worldwide **IGS Global Data Centre reference**, so to preserve GNSS data for scientific purposes and ensure the incorporation of Galileo data.

www.igs.org/about/data-center

Supporting GNSS Scientific Cubesats with Universities

Scientific and Fundamental Aspects of GNSS / Galileo

6th International Colloquium

25-27 October 2017– Valencia, Spain

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25 - 27 October 2017, Valencia

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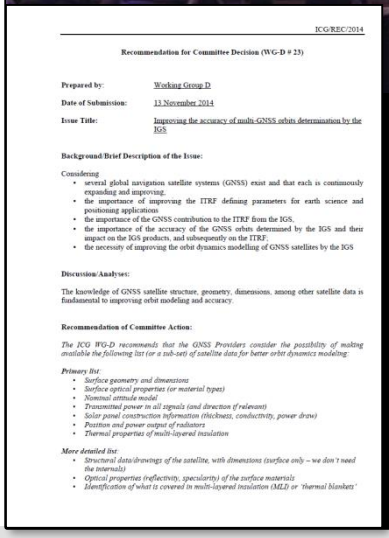
GALILEO Satellite Metadata

Strong interest of scientific community of access to GNSS satellite metada:

- ESA's Galileo scientific advisory committee (GSAC) on 2011
- International GNSS Service (IGS) on 2012
- **WG-D Rec#23 at ICG-9, Prague on 2014.**



ICG/REC/2014

Recommendation for Committee Decision (WG-D # 23)

Prepared by: Working Group D

Date of Submission: 13 November 2014

Issue Title: Improving the accuracy of multi-GNSS orbits determination by the IGS

Background/Brief Description of the Issue:

Considering

- several global navigation satellite systems (GNSS) exist and that each is continuously expanding and improving;
- the importance of improving the ITRF defining parameters for earth science and positioning applications
- the importance of the GNSS contribution to the ITRF from the IGS,
- the importance of the accuracy of the GNSS orbits determined by the IGS and their impact on the IGS products, and subsequently on the ITRF
- the necessity of improving the orbit dynamics modelling of GNSS satellites by the IGS

Discussion/Analyses:

The knowledge of GNSS satellite structure, geometry, dimensions, among other satellite data is fundamental to improving orbit modeling and accuracy.

Recommendation of Committee Action:

The ICG WG-D recommends that the GNSS Providers consider the possibility of making available the following list (or a sub-set) of satellite data for better orbit dynamics modeling:

Primary list:

- *Surface geometry and dimensions*
- *Surface optical properties (or material types)*
- *Nominal attitude model*
- *Transmitted power in all signals (and direction if relevant)*
- *Solar panel construction information (thickness, conductivity, power draw)*
- *Position and power output of radiators*
- *Thermal properties of multi-layered insulation*

More detailed list:

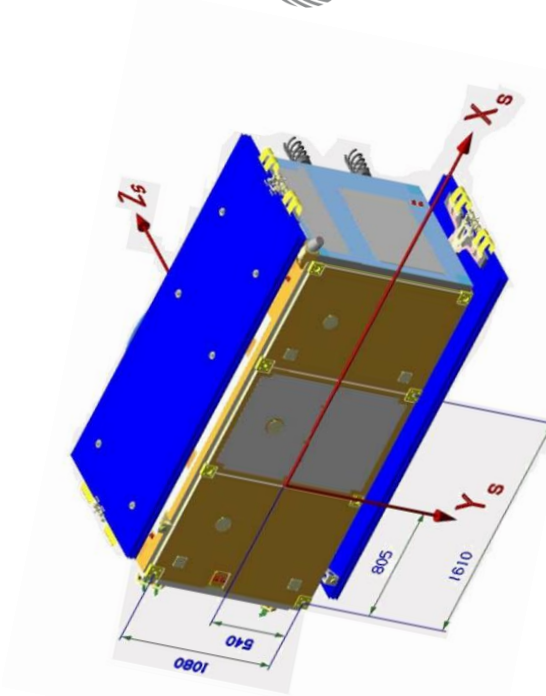
- *Structural data/drawings of the satellite, with dimensions (surface only – we don't need the internals)*
- *Optical properties (reflectivity, specularity) of the surface materials*
- *Identification of what is covered in multi-layered insulation (MLI) or 'thermal blankets'*

Galileo IOV and FOC: satellites Metadata Information is now available !

Galileo IOV Metadata released on **16th Dec 2016**

Galileo FOC metadata released on **5th October 2017**

- **Attitude Law**
- **Mass and Centre Of Mass evolution**
- **Geometry and material/optical properties**
- **Navigation Antenna Phase Centre Corrections**
- **Laser Retro Reflector Location**
- **Satellite Group Delay**

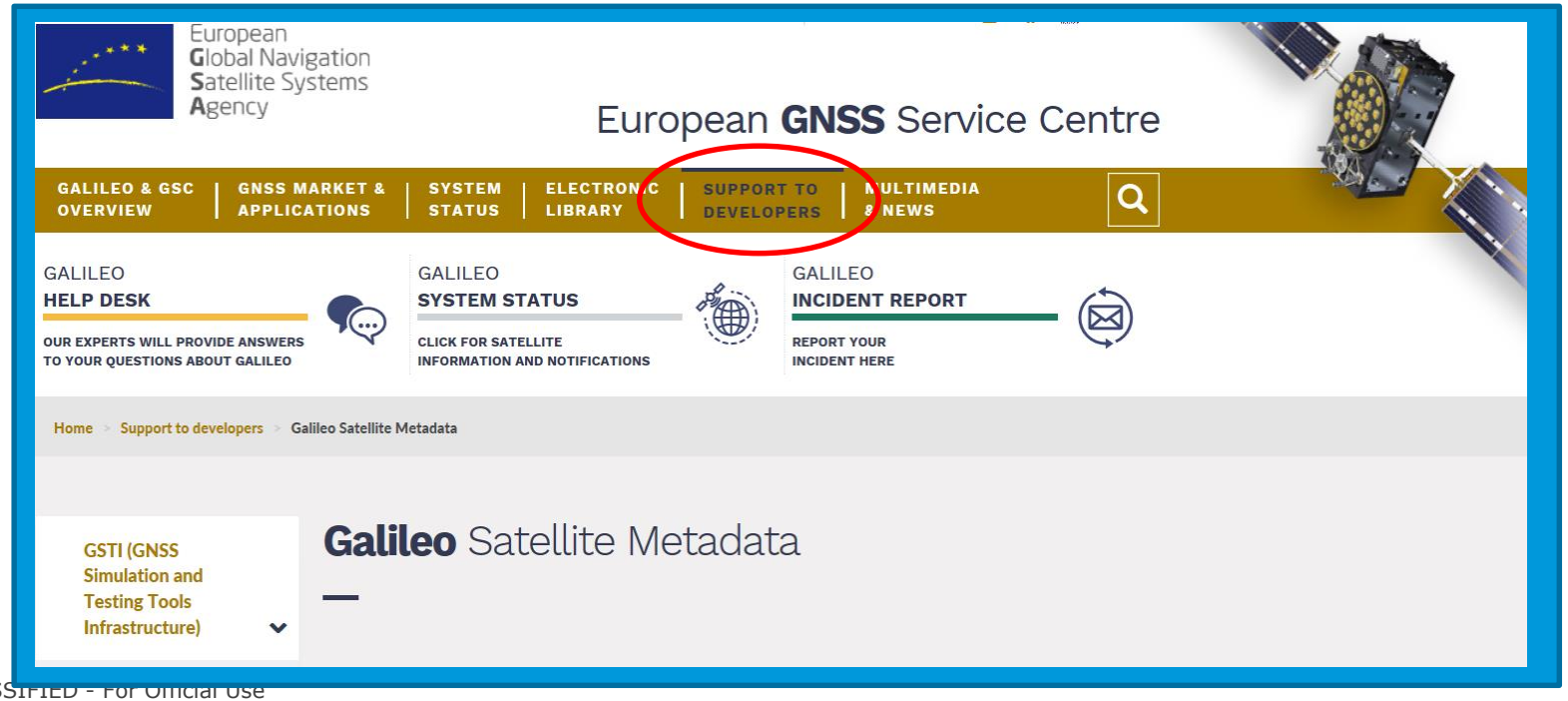


The processing of this data allows improvements of the Galileo satellites SRP modelling, to perform precise orbit determination and better Precise Point Positioning (PPP) solutions.

GALILEO IOV/FOC Metadata URL location

https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata

https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_missions/current_missions/ga01_com.html



Thank you for your attention !