“GNSS Scientific Activities at ESA"

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European Space Agency
GNSS: A great Opportunity for Science

1. Over 130 GNSS satellites available with unique features for scientific exploitation

2. Providing Global coverage, multi-constellation, multi-frequency and long-term data availability (decades !) which correlates with many scientific applications.

3. A dense network of precious GNSS data available worldwide including several hundreds of professional receivers and billions of smartphones anf IoT sensors.

4. Systems under continuous technological improvements (more stable clocks, new on-board sensors, more signals and of better quality) enhancing scientific possibilities

A fantastic opportunity for international Cooperation
GALILEO SPECIALLY SUITED FOR SCIENCE
GALILEO SPECIALLY SUITED FOR SCIENCE

1. Two on-board clock technologies, including Highly stable PHM atomic clocks
2. Robust modulation schemes, large BW and low noise (e.g. E5-AltBOC);
3. Laser Retro Reflectors present on all Galileo satellites;
4. Galileo satellites’ revolution period avoids Earth rotation resonances: Stable Galileo orbits without manoeuvres;
5. Radiation monitors in a number of satellites;
6. Two Galileo satellites placed in an eccentric orbit (e.g. excellent source for Fundamental Physics tests).
7. High Accuracy Services available soon
8. Metada information publicly available for Galileo IOC and FOC satellites
Galileo Satellite Metadata and recent Updates

The European GNSS Service Centre (GSC) has provided updated Galileo Satellite Metadata (April 2019):

- Metadata for Galileo satellites 18 to 26 (L9 and L10) now included
- Update of the Mass, Centre of Mass and ANTEX Reference Frame coordinates for all the others

The following Metadata information is now available for all Galileo in-orbit satellites:

- Geometry, dimensions, materials and reflectivity;
- Mass and Centre of Mass (COM);
- Antenna Reference Point (ARP);
- Phase Centre Offsets (PCO) for E1, E5a, E6 and E5b signals;
- Laser Retro Reflector Location; and
- Attitude laws.
This bi-annual colloquium brings together members of the International scientific involved in the use of Galileo and other GNSS in their research. The various possibilities to use GNSS satellites for scientific purposes are reviewed in detail during 3 days.
1. About **200 participants** from **25 countries**;
2. A total of **134 technical presentations**;
3. Full coverage of **all identified GNSS scientific fields** with a great scientific return;
4. A selected number of papers will appear on the **Journal of Applied Science** for a dedicated issue on GNSS Science.
Fostering Research Across Scientific Communities

Earth Science & Space Weather

Space Science

Metrology

Fundamental Physics
Most accurate measurement ever of the General Relativity Gravitational Red-shift (Best measurement in over 40 years)
Einstein's General Theory of Relativity
Measurements of Galileo orbit geometry deformations caused by general relativity

Satellite orbit in a curved spacetime

Satellite orbit in a flat spacetime

Spacesetime curved by the Earth mass

Source: Wroclaw University (Poland) of Environmental and Life Science
Search for dark matter with atomic clocks on board Galileo

- Some of the theories about Dark Matter suggest this could consists of ultra-light scalar fields, forming topological defects and producing space-time variation of fundamental constants.

- The large network of atomic clocks and electromagnetic links from the Galileo constellation could act as a gigantic detector of 60000 km of aperture to search for DM.

Source: SYRTE,CNRS, Royal Belgium Observatory
PulChron aims to demonstrate the effectiveness of a pulsar-based timescale for the generation and monitoring of satellite navigation timing in general, and Galileo System Time in particular.
By equipping a number of Galileo satellites with light Gamma Ray Burst (GRBs) detectors we could identify the location on neutron merging stars event with 100-1000 more precision (sub-degree level) that with current existing technologies.

Source: Max Planck Institute of Extraterrestrial Physics & University of Munich (Germany)
Use of GNSS in support to Climate Change Monitoring and earth science

- Enhancements on GNSS Radio-occultation & GNSS-R
- Weather Monitoring & Collaborative GNSS Crowdsourcing
- Exploiting GNSS sensor in trains for weather estimation
- IoT, climate monitoring and GNSS
- Possibilities of Artificial Intelligence technologies
- GNSS big-data and earth monitoring
- Animal tracking and climate change information

A dedicated panel of GNSS and Climate change was held during the ESA GNSS Scientific Colloquium
Tracking birds provides, in addition to ethological scientific information on animals (e.g. migration patterns), correlated information with wind profile variations, see level information, see waves data, etc.

Long-term availability of all this data may contribute to climate change monitoring.
1. Development of multi-constellation Space Receivers
2. Detailed Analysis on GNSS moon achievable performances
3. System studies for possible GNSS enhancements / augmentations
4. International cooperation

GNSS & Space Exploration
Join ESA / China SMILE mission
Our Mission: to provide a world-wide reference Science Exploitation and Preservation Platform that fosters international collaboration across Science Domains, through the provision of information and processing services based on GNSS assets.
Establishing a close cooperation with Universities

To our knowledge first ever space mission exploiting GALILEO, GPS, GLONASS, BEIDOU and the QZSS
Thank you!
**GNSS Scientific Fields at this ESA Colloquium**

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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)
GALILEO will soon provide High Accuracy Services (decimetre)