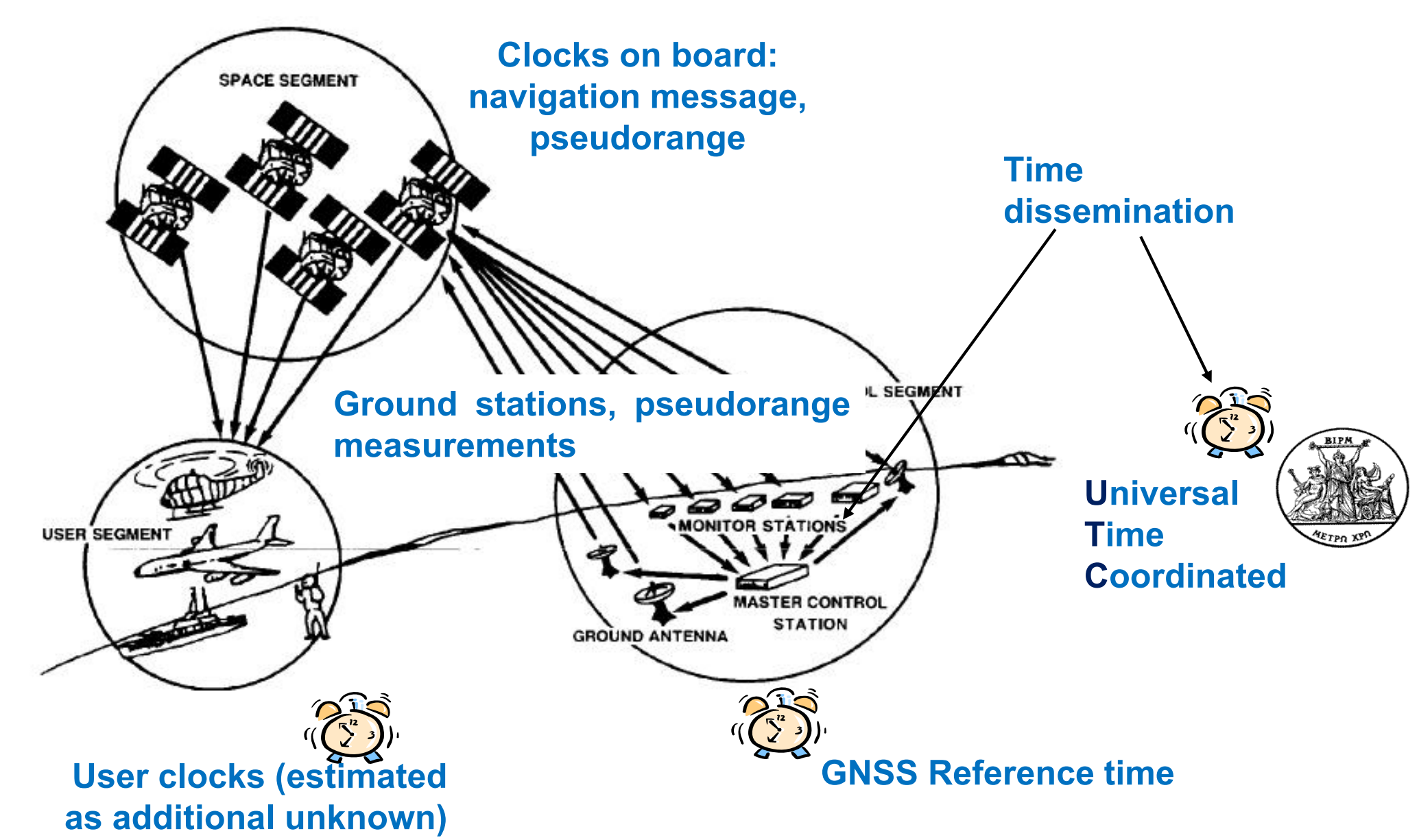


[Ilaria Sesia](#), Giovanna Signorile, Franco Fiasca, Andrea Perucca, Tung Thanh Thai, Salvatore Micalizio, Michele Gozzelino, Claudio E. Calosso, Cecilia Clivati, Albero Mura, Filippo Levi, Davide Calonico

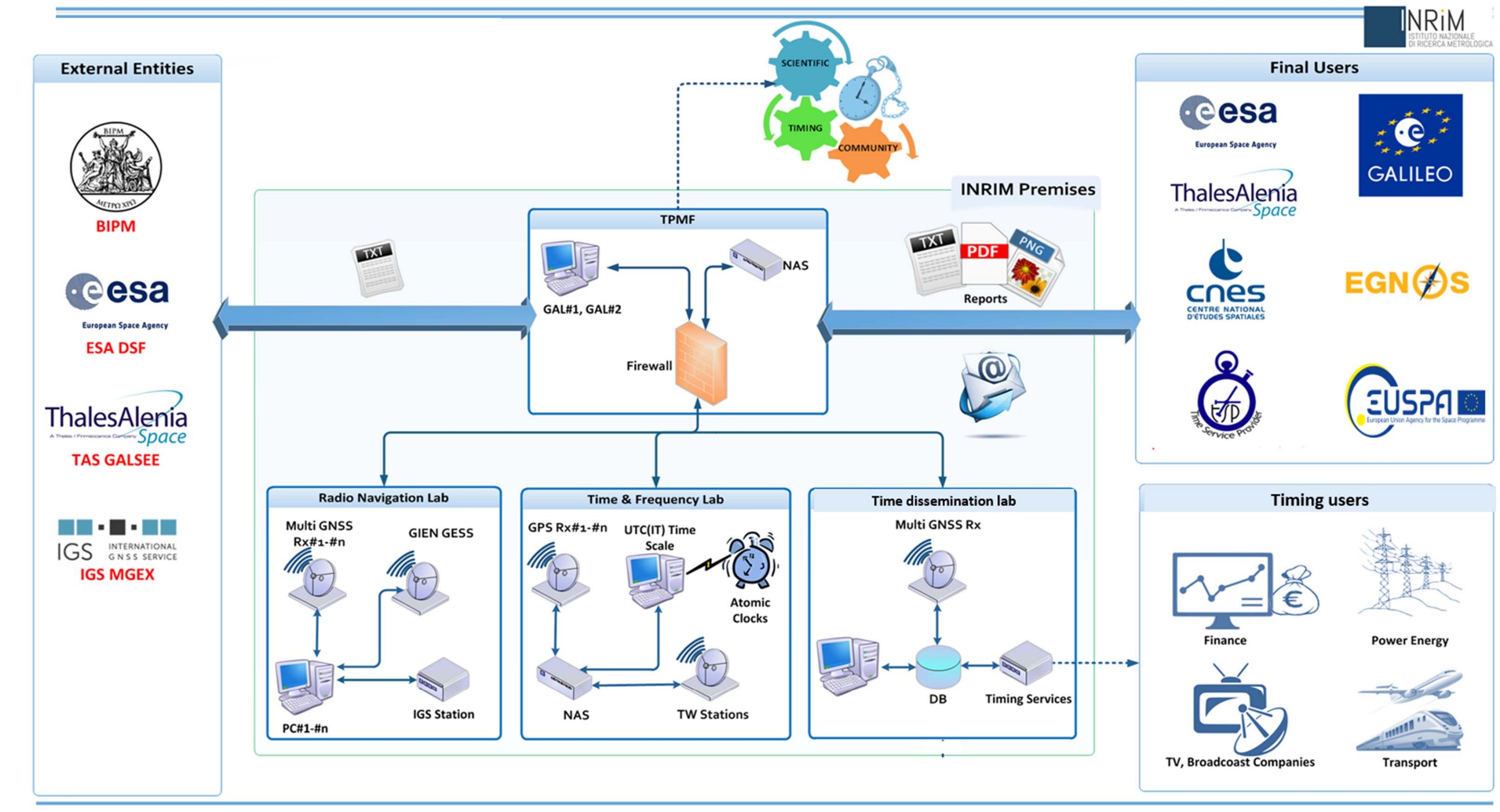
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Time Metrology and GNSS



Why time matters in GNSS positioning
The user position relies on the flight time of signals transmitted by the satellites
→ *Any error in time results in an error in position!*
That's why highly precise and stable clocks are essential in GNSS – both in space and ground segments.
All these clocks must be synchronized to a common reference system time
→ *Time metrology expertise is crucial to make it possible!*

INRiM Galileo Timing Research Infrastructure



At INRiM, the Galileo infrastructure promotes advanced research and in the field of satellite navigation, supporting both the evolution of European GNSS and the development of innovative applications and technologies. In particular, it supports the development, validation and monitoring of the Galileo system by

- *Providing the high-level competence required for system timing validation*
- *Supporting the design and testing of new timing services that can enhance the robustness, reliability, and market adoption of Galileo services*

Thanks to the Galileo infrastructure and INRiM's expertise in time metrology for space applications, the institute plays a key role in enabling Galileo's core timing functions, promoting industrial innovation and technological advancements.

INRiM main contributions to Galileo



INRiM has been collaborating for 25 years with major European space agencies and industries on the design and development of Galileo timing aspects, specifically on:

- ✓ Algorithms for Galileo's reference time, currently in use at the Galileo Control Centers
- ✓ On-board clock monitoring and anomalies detection
- ✓ Support to Galileo System Engineering Technical Assistance team for Galileo System timing aspect validation
- ✓ Member state Service Performance Monitor Support for the monitoring of EGNOS and Galileo timing aspects
- ✓ Hosting, Operation and upgrade of a Timing Galileo Experimental Sensor Station, connected to the Italian time scale
- ✓ Galileo final timing facility: the Time Service Provider

The Galileo Time Service Provider

Since 2017 INRiM coordinates the scientific aspect of the main Galileo Timing facility, the [Galileo Time Service Provider \(TSP\)](#). TSP represents the interface between the Galileo System and the time metrology community, allowing:

- ✓ the *steering of the Galileo System Time versus UTC*
- ✓ the *prediction of the time offset of Galileo System Time versus UTC*, directly broadcast to the users in the Navigation Message

Galileo starts to tell UTC, the world's time

25/04/2013 17:02 news 38 LUGA

ESA / Applications / Satellite navigation

Europe's four Galileo satellites are now working as clocks accurate to a few billionths of a second, disseminating the exact time through their signals expressed as the UTC Universal Coordinated Time global standard.

"A billionth of a second equals a nanosecond, a time interval far beyond our own human capacity of appreciation," explains Marco Falzone, ESA's Galileo System Manager.

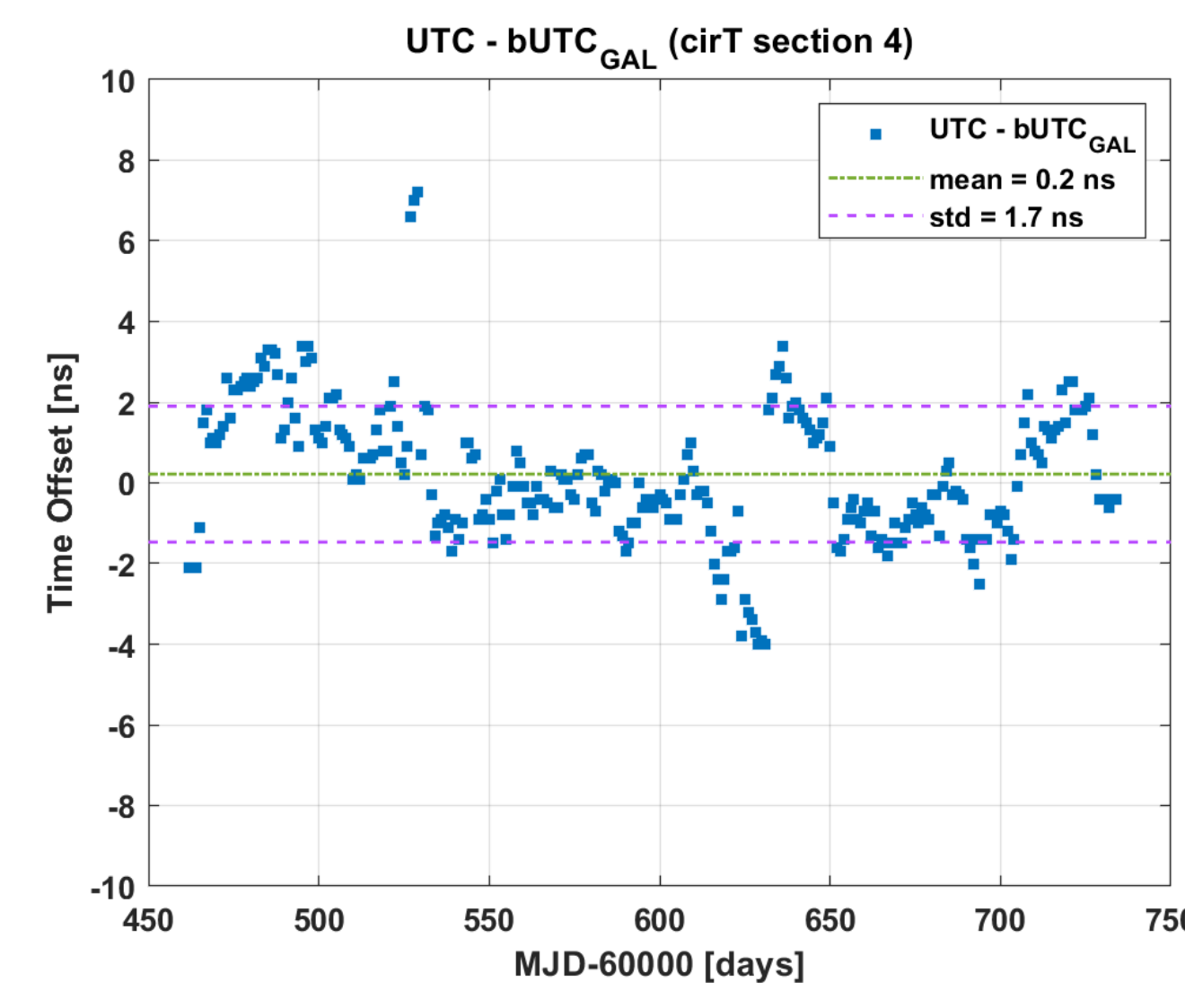
"A single lightning flash across the sky during a thunderstorm lasts about ten milliseconds, which is already 10 000 000 nanoseconds. But for high-tech applications, as well as navigation services, nanosecond accuracy is essential".

INRiM has been supporting ESA's Galileo development since the early phases of the project. More recently INRiM has overseen the creation of a "Time Validation Facility" for Galileo in collaboration with five other European time-measurement institutions: the Physikalisch Technische Bundesanstalt in Germany, the National Physical Laboratory in the UK, the Systeme de References Temps Espace/Observatoire de Paris in France, the Real Instituto y Observatorio de la Armada in Spain and Observatoire Royal de Belgique.

Each day, the most precise European clocks and national time scales are compared to GST and the offset compared to UTC is estimated and provided to the Galileo Control Centre. This offset is then updated to the Galileo satellites for transmission in the navigation message available to users.

As explained by Patricia Taveira from INRiM, "The UTC value available to the user via Galileo is expected to be accurate within 26 nanoseconds, but in the last two months it was even better, with a prediction error in the last two months of less than five nanoseconds".

2011-2013 INRiM designed, developed and operated at INRiM the *Time Validation Facility*, the first prototype of the TSP, enabling Galileo UTC dissemination



The difference between the true international UTC and the prediction of UTC computed by TSP and broadcast by Galileo, is published by BIPM in Section 4 of the Circular-T, since June 2024. The plot reports the data of December 2024 and January 2025, showing excellent performances.

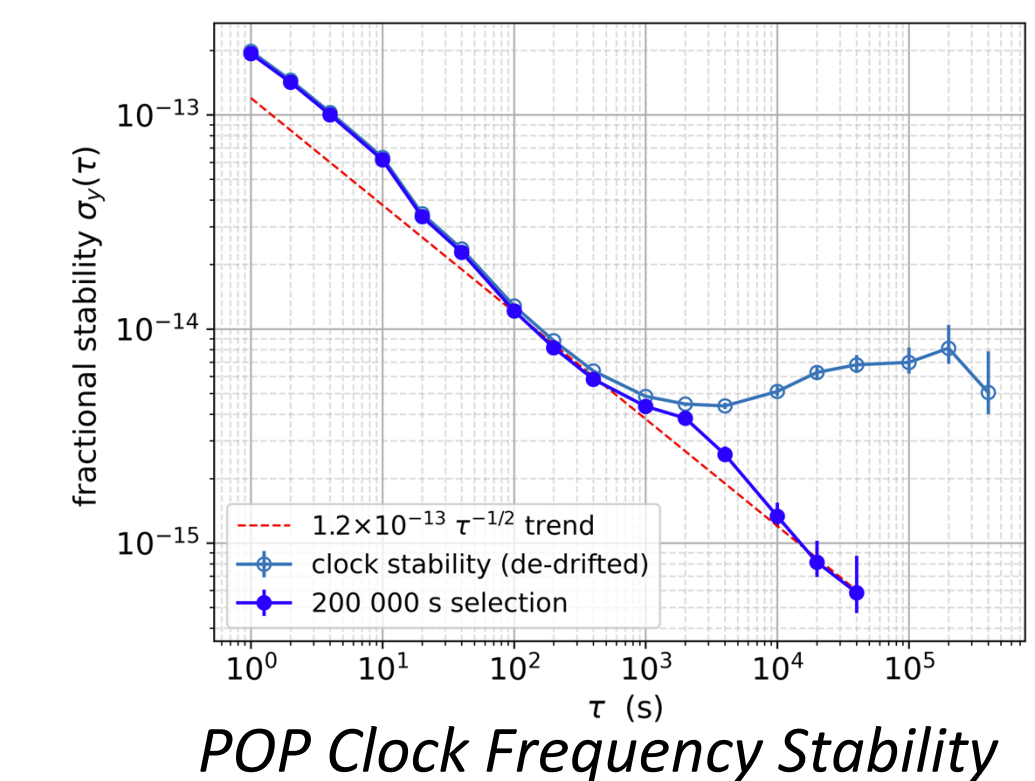
Supporting Future Galileo Generation

Innovative clocks

The [POP clock](#), with laser pumping and pulsed operation, offers exceptional stability. In collaboration with Leonardo S.p.A., INRiM is realizing the first space-qualified POP clock, suitable for PNT applications like the next-generation Galileo satellites



POP Clock Physics Package



Robust Time dissemination via optical fiber

Fucino Space Center connected to INRiM thanks to the Italian Quantum Backbone, such infrastructure allows time and frequency transfer via optical fiber for: fundamental metrology, clock comparison, quantum communication, radio-astronomy and Galileo timing activities.

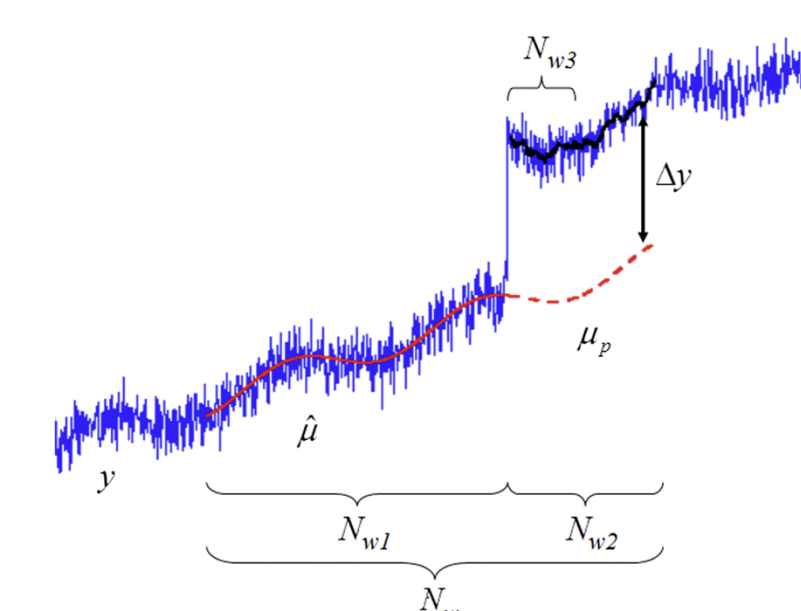
- Quantum skills
- ✓ Quantum Communication
 - ✓ Quantum Key Distribution



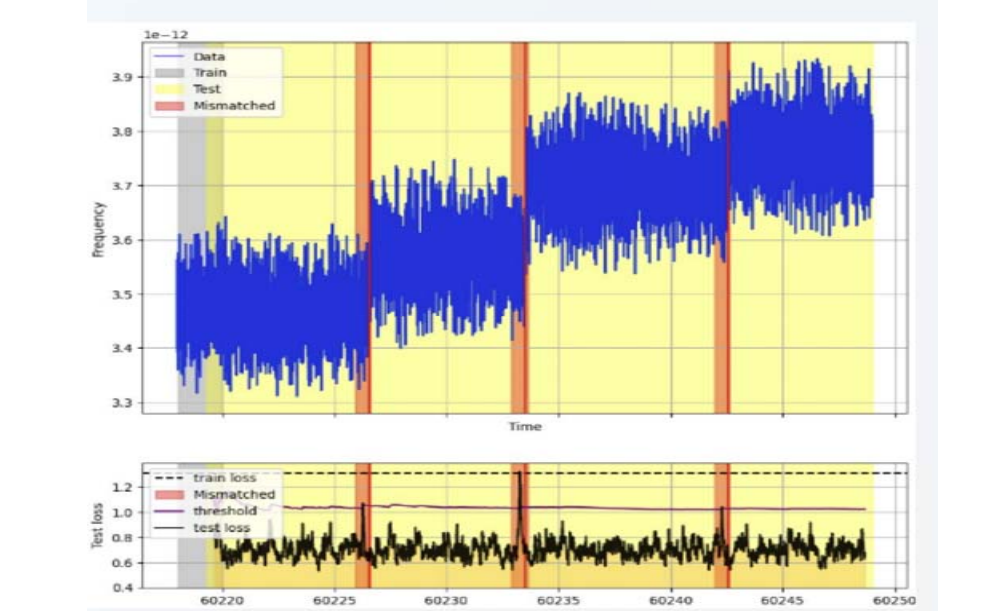
Next-generation timing algorithms

- ✓ On-board clock monitoring and anomalies detection based on [Machine Learning](#) techniques

Classical methods



Machine Learning Techniques



- ✓ Development of algorithms for time scale generation based on [Composite Clocks](#) approach, suitable for next Galileo generations