FIFTH MEETING OF THE INTERNATIONAL COMMITTEE
ON GLOBAL NAVIGATION SATELLITE SYSTEMS (ICG)

Time metrology in navigation systems:

the experience of INRIM in the Galileo project

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Metrologica

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with viewgraph courtesly by ESA

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

On 1st January 2006, the Istituto Elettrotecnico Nazionale "Galileo Ferraris" (IEN) and the Istituto di Metrologia "Gustavo Colonnetti" (IMGC) merged to establish the Istituto Nazionale di Ricerca Metrologica (I.N.RI.M).
INRIM is the national public body with the task of carrying out and promoting scientific research in metrology.

Time metrology research activities includes:

- atomic clocks
- clock comparison and synchronisation techniques
- mathematical modelling and algorithms
  - » to realise and disseminate the Italian Standard Time UTC(IT)
  - » to contribute to the Universal Time Coodinated UTC

and navigation systems

We therefore need:

good clocks (on Ground and in Space)

good clock synchronisation system

good reference time scale

good algorithms for clock evaluation

in timekeeping and navigation

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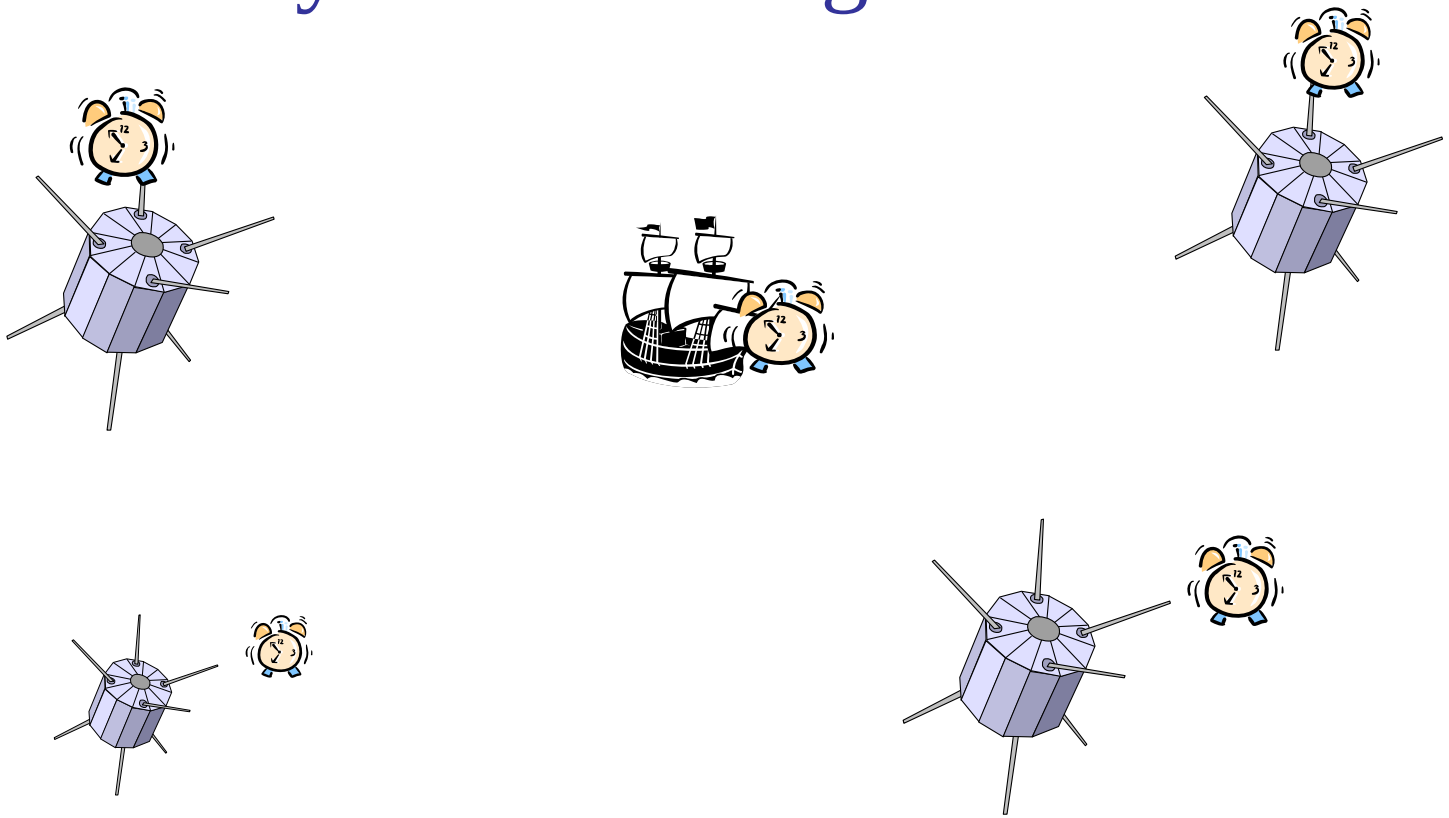
To have the system working



All the clocks must be synchronised to the highest level of accuracy

Shall they be synchronised to the international reference time? UTC?

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A navigation system is also a mean for

Time dissemination

Who needs time information?

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Topic	Title
Network synch	Network synchronization for telecomm (wireless /-line)
Network synch	Network synchronization for power generation / distribution
Network synch	Network synchronization for digital broad-casting
Network synch	Satellite monitoring / navigation (ground based)
Time tagging	Maintenance of international time standards
Time tagging	Frequency / time calibration services
Time tagging	Time tagging “general users”

A study from the European Commission in the year 2000

estimated thousands, even million users in Europe

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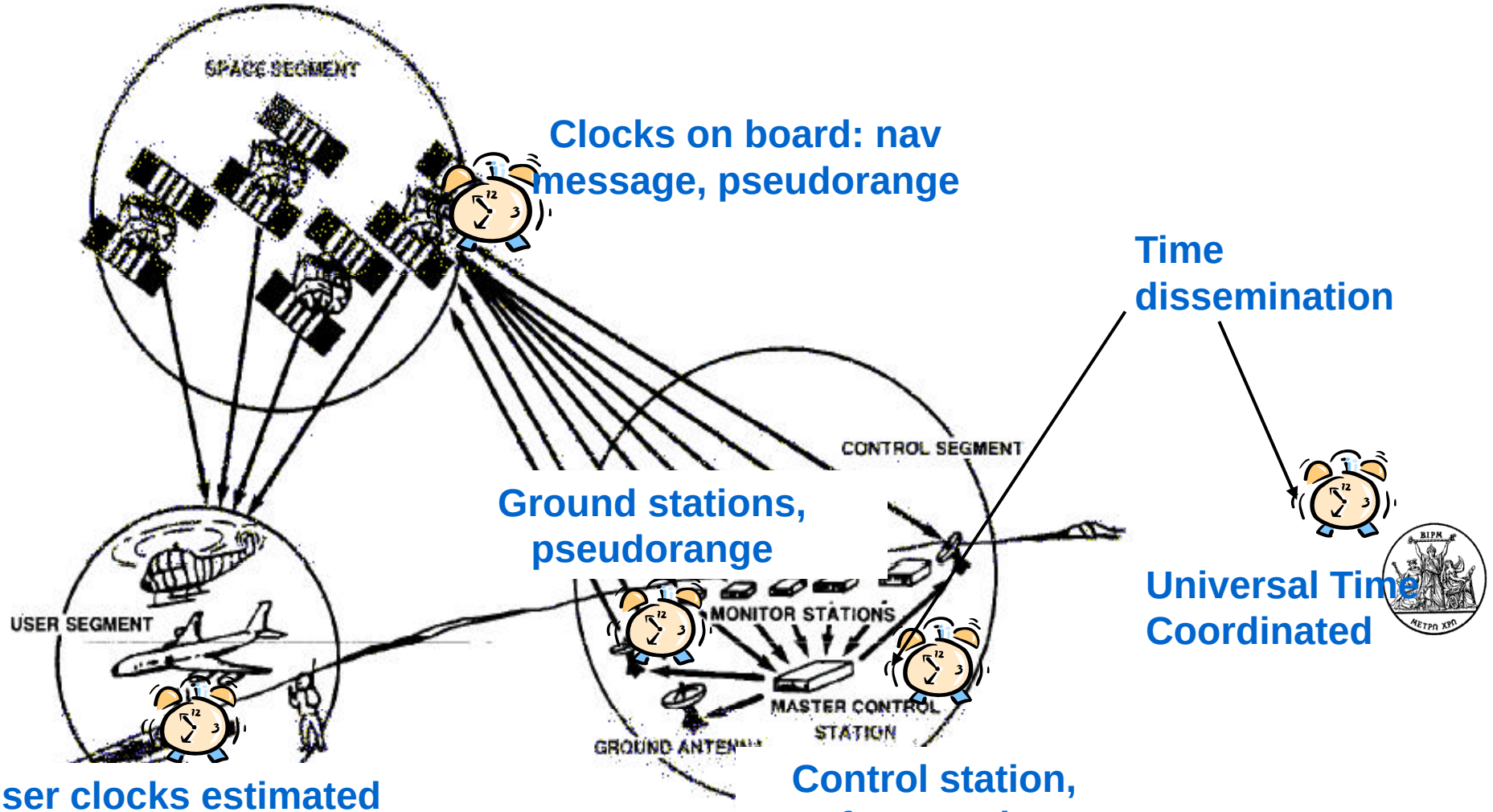
GNSS: where are the clocks and why



Typical question for a time metrologist

All the clock have to be synchronised, Synchonised to what? How to deal with leap second issue?

Is the clock stable enough?

How do we measure the degree of synchronization of the on board clock?

How do we predict the clock error after synchronisation?

How do we ensure time interoperability?

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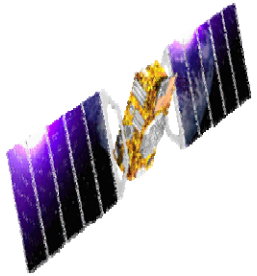
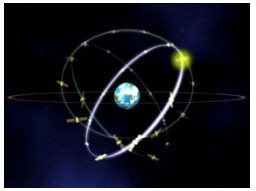
Galileo Programme Phasing



Full Operational Capability

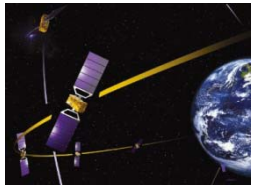
+26 operational satellites

complete ground infrastructure



In-Orbit Validation

4 operational satellites and ground infrastructure



Galileo System Testbed v2

GIOVE-A and -B Satellites

ground operations

GALILEO

GIOVE

Galileo System Testbed v1

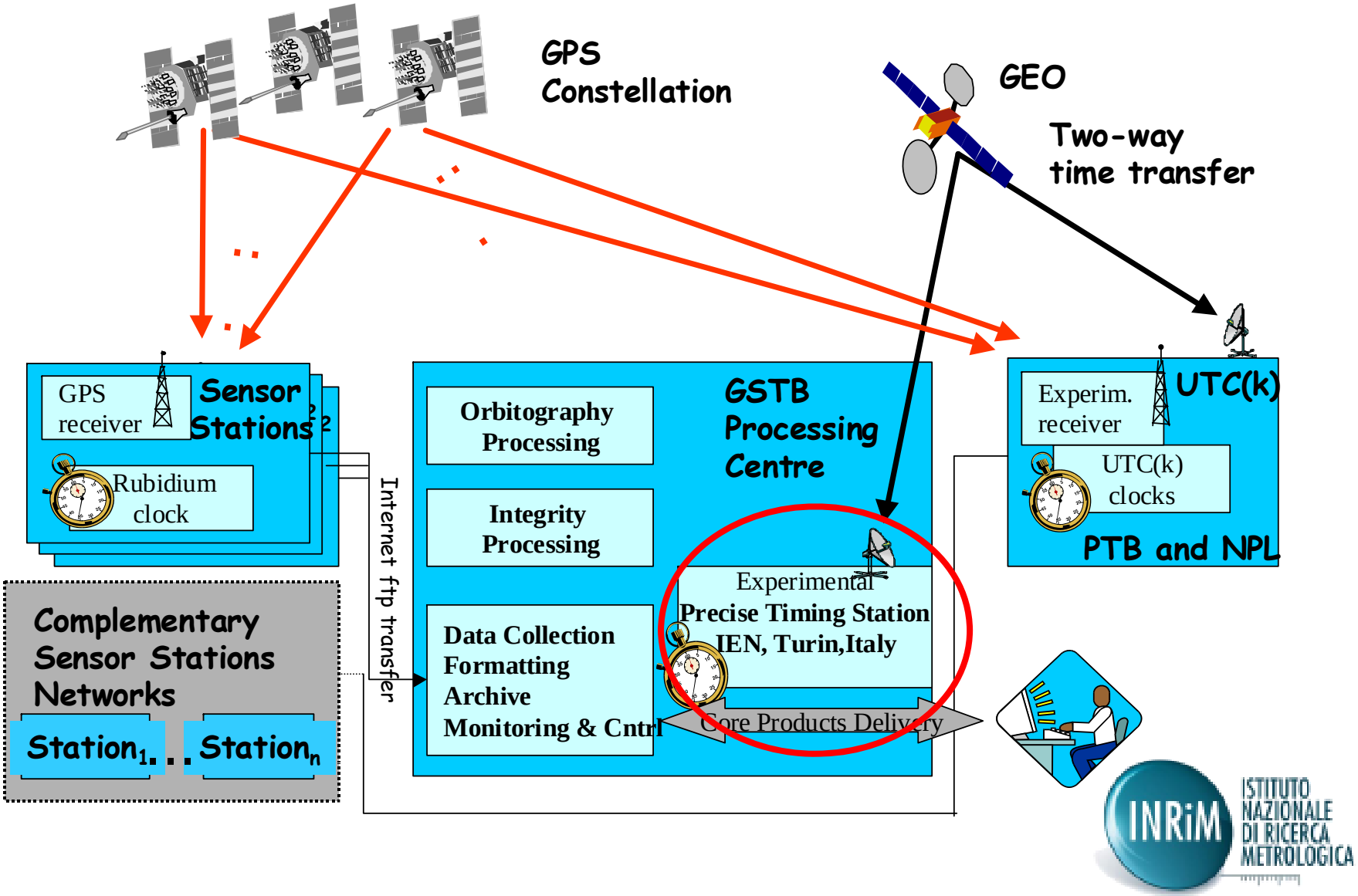
Critical algorithms validation

GALILEO

GSTB-V1

Experimental Precise Timing Station

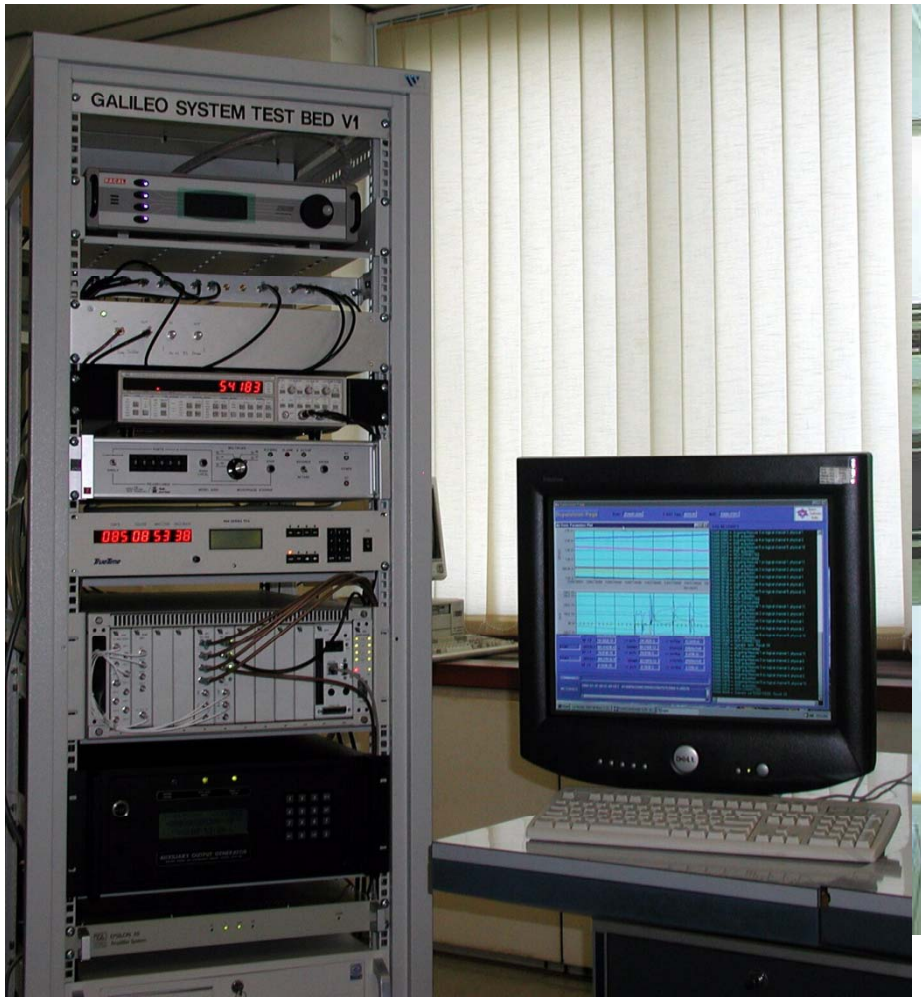
Galileo System Test Bed V1: 2002-2004



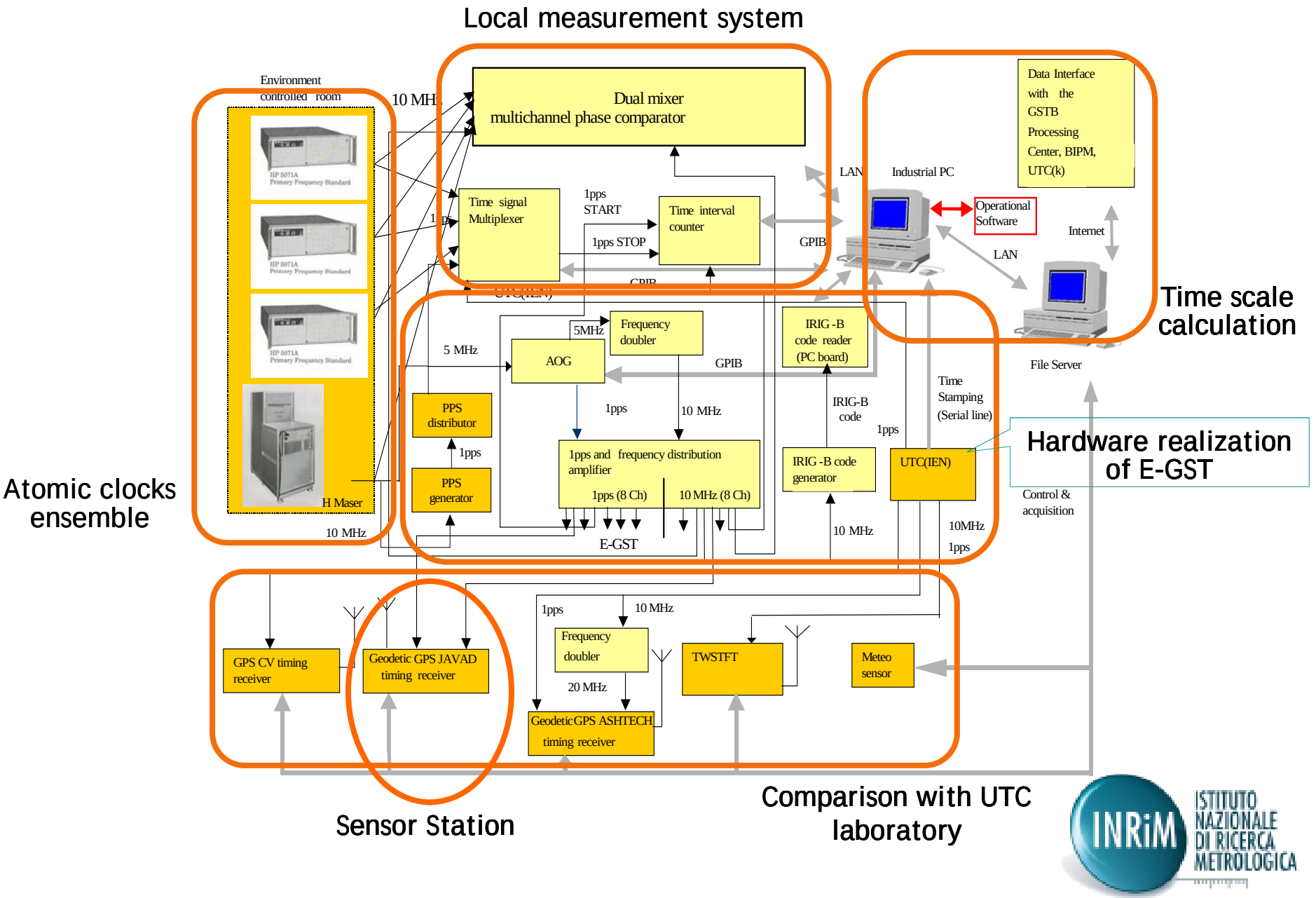
Experimental Precise Timing Station

During 2004-2005, the IEN Time and Frequency laboratory was the Experimental Galileo Time Station generating the Galileo System Time in agreement with UTC and compared with the German and English UTC(k) and the GPS time.

In collaboration with Agenzia Spaziale Europea, Alenia Spazio, Alcatel, …



Experimental PTS Architecture



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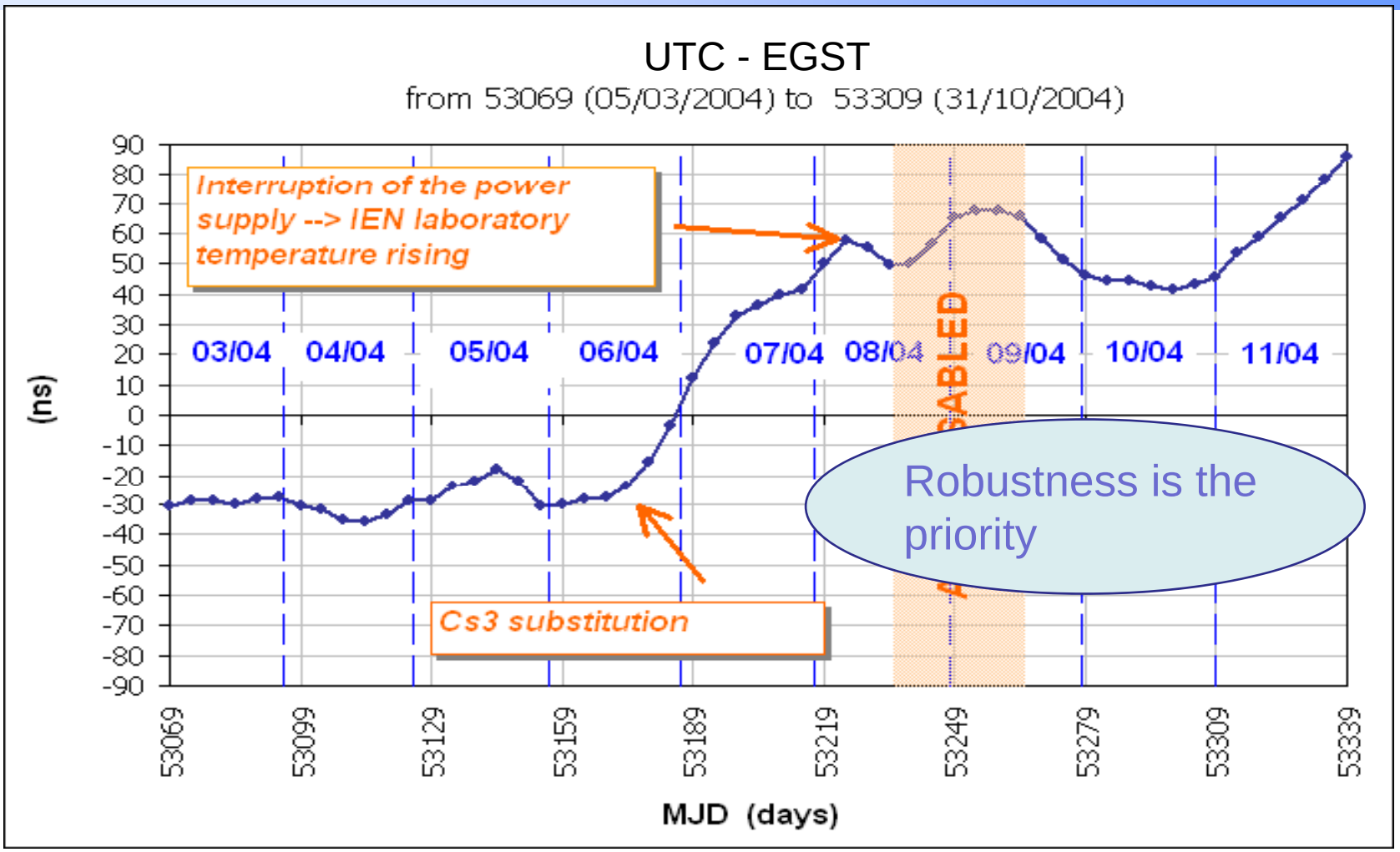
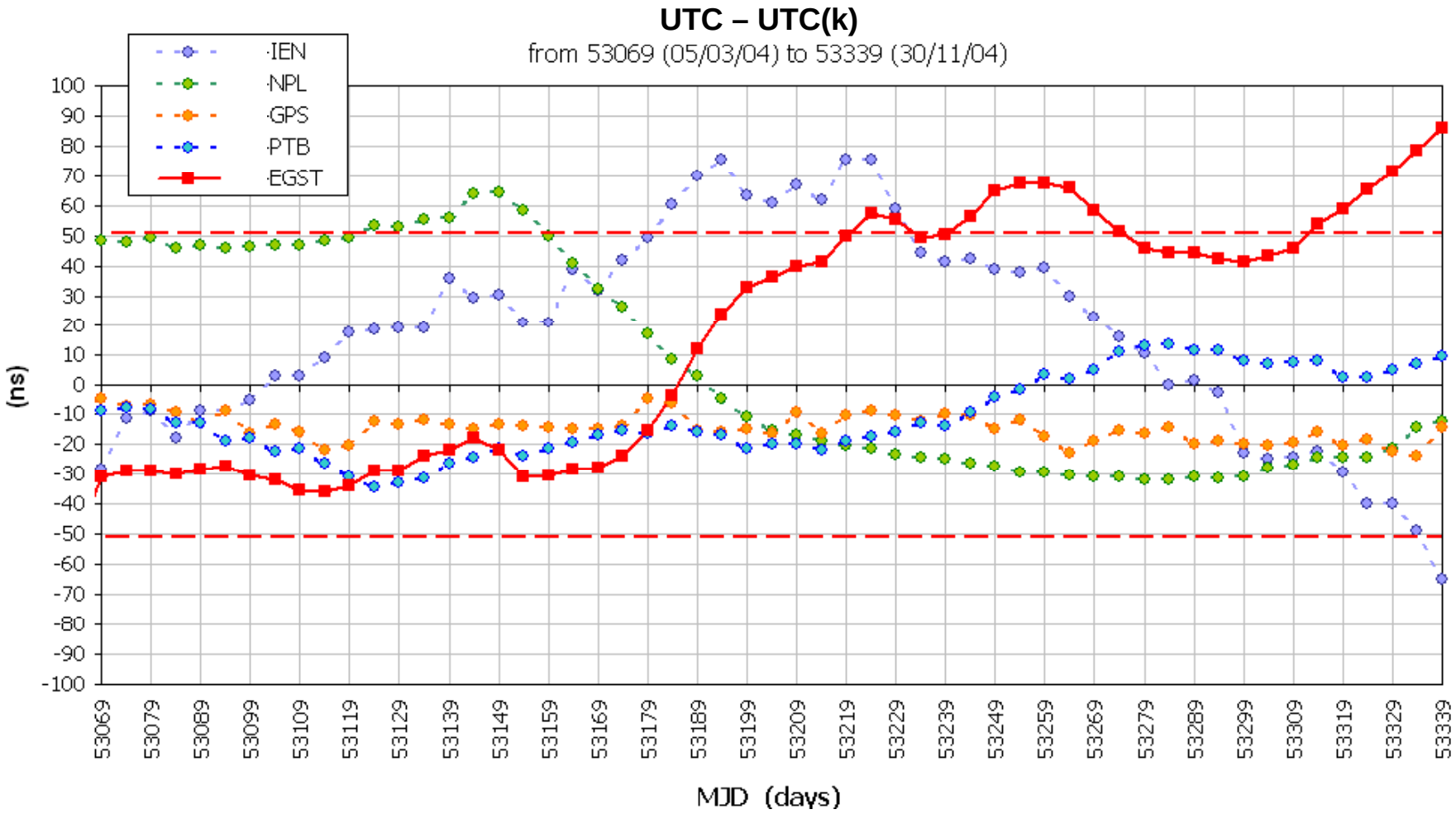
GSTB-V1 Performances



Some problems occurred during on-line experimentation related to HW/SW

GSTB-V1 Performances: Comparison respect to UTC



For comparison the behavior of some time scales UTC(k) versus UTC is also reported together with EGST

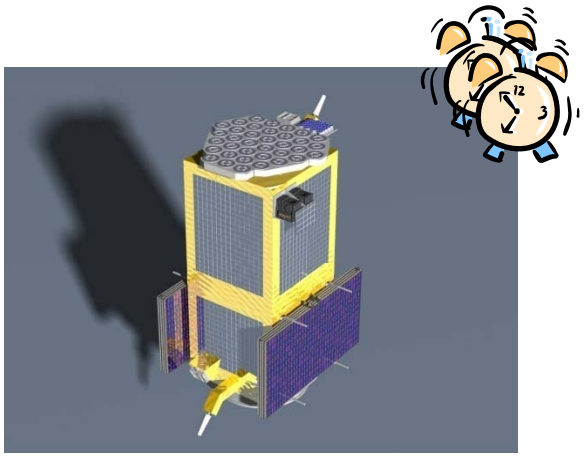
it can be seen that remaining within +-50 ns is a demanding goal, especially considering that the UTC(k) timescales are generated in scientific, manned, laboratories

GIOVE *First two Galileo satellites in space*

Galileo In Orbit Validation Experiment

GSTB V2
2005-2010

GIOVE A launched on Dec 28, 2005



GIOVE B
launched April
27, 2008

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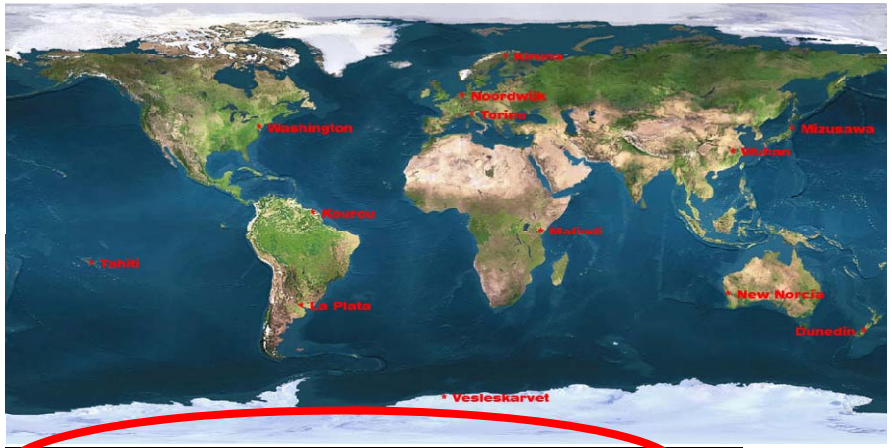
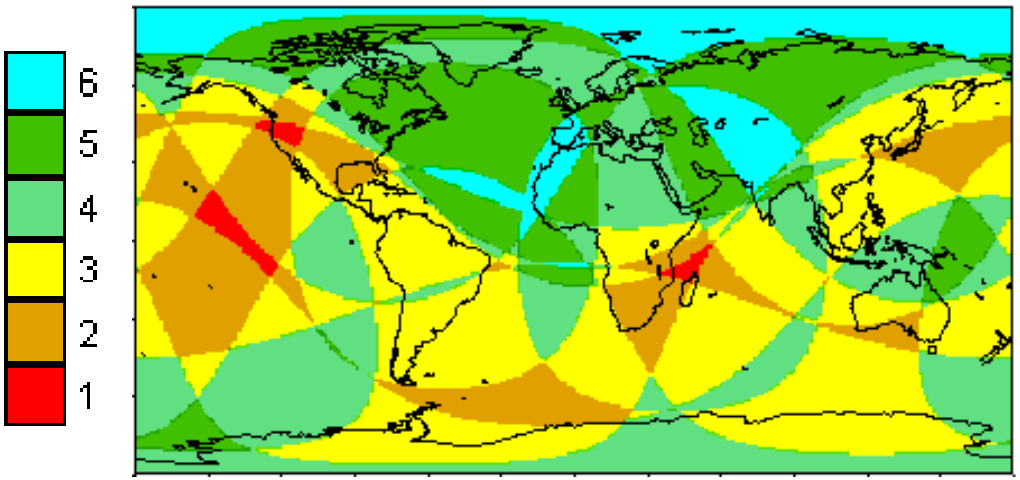
THE GESS NETWORK



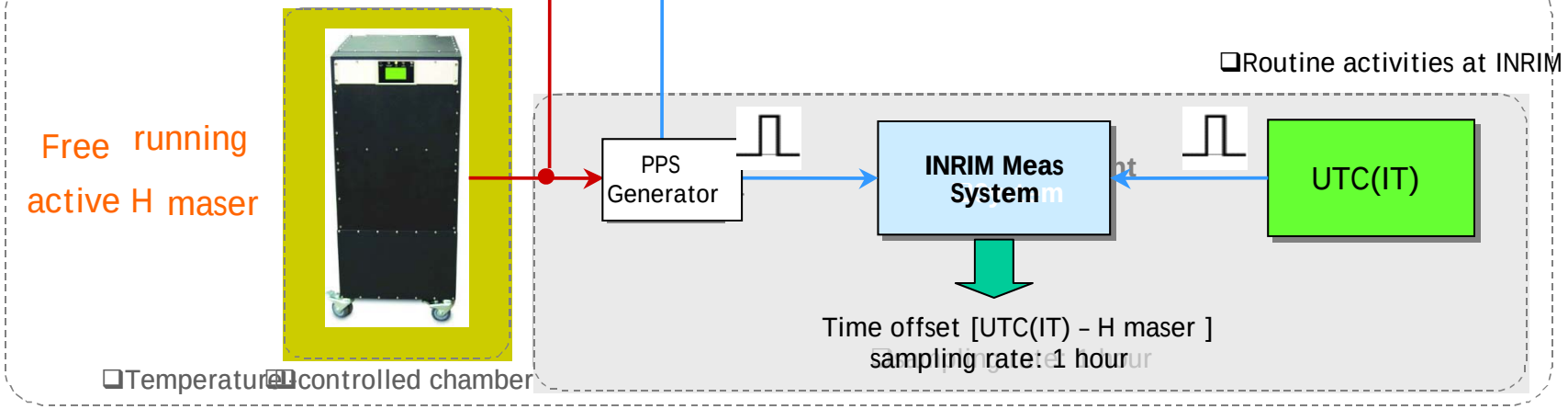
GIEN	INRiM, Turin	Italy
GKIR	Kiruna	Sweden
GKOU	Kourou	French Guyana
GLPG	La Plata	Argentina
GMAL	Malindi	Kenya
GMIZ	Mizusawa	Japan
GNNO	New Norcia	Australia
GNOR	ESA, Noordwijk	The Netherlands
GOUS	Dunedin	New Zealand
GTHT	Tahiti	French Polynesia
GUSN	USNO, Washington	USA
GVES	Vesleskarvet	Antarctica
GWUH	Wuhan	China

- 13 stations
- World-wide distribution
- Dual GPS+Galileo receivers
- GPS needed to synchronize all clocks with the master clock at any time (“common view”)
- Two master clocks:
  - GIEN (prime)
  - GUSN (backup)
- GIOVE (and GPS) always in view of at least 2 stations (DOC-2)



THE SENSOR STATION (GESS)

- **GESS** main elements:
  - Wide-band antenna
  - GPS+Galileo receiver (GETR)
  - UPS + computer
  - Rubidium clock or connectivity to an external clock

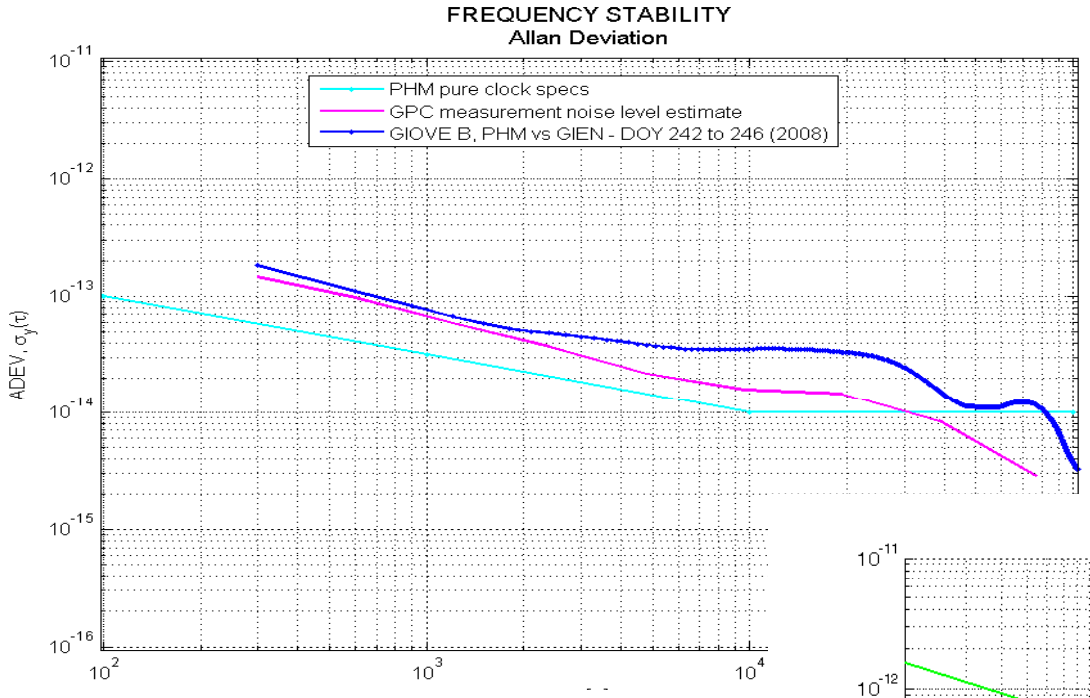


Galileo GSTB V2 Experimental Satellites

- First European navigation satellites in MEO orbit.
- Europe meets requirements for Galileo frequency filings.
- The H-maser clock is the most stable clock ever flown in space.
- On Board Clock and Sensor Station fully characterised

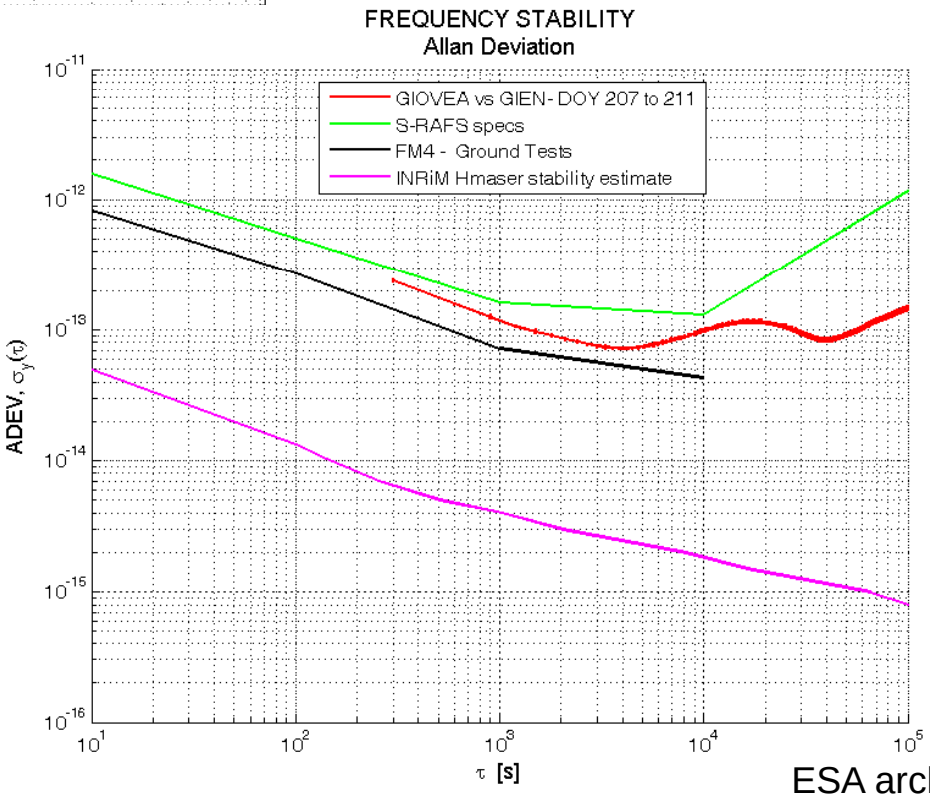
On ground a network of Sensor Station and an Orbit Determination & Time Synchronization processing similar to GSTB V1 with the addition of GIOVE tracking capabilities and Satellite Control Centers

Passive H Maser (GIOVE-B)

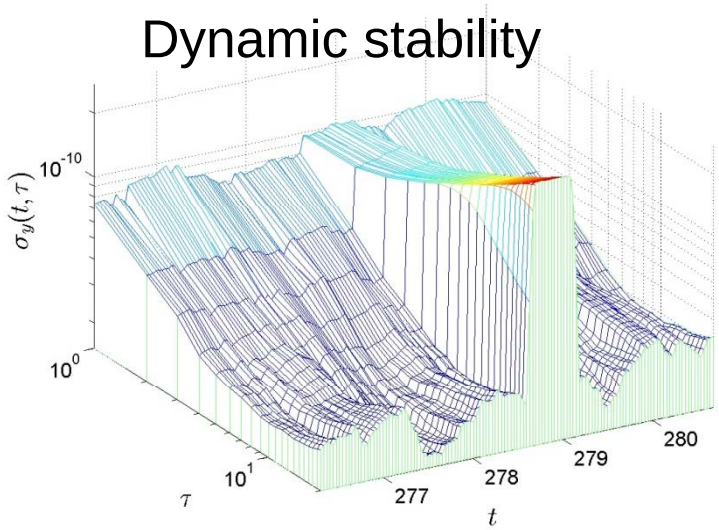


GIOVE clocks

Rubidium (GIOVE A)



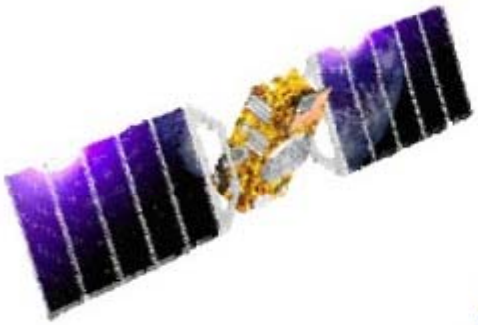
Dynamic stability



ESA archive

http://www.giove.esa.int

Galileo Implementation Plan



All services
30 satellites

2016

Open Service, Search & Rescue
Public Regulated Service
18 satellites

2014

In-Orbit Validation
4 IOV satellites plus
ground segment

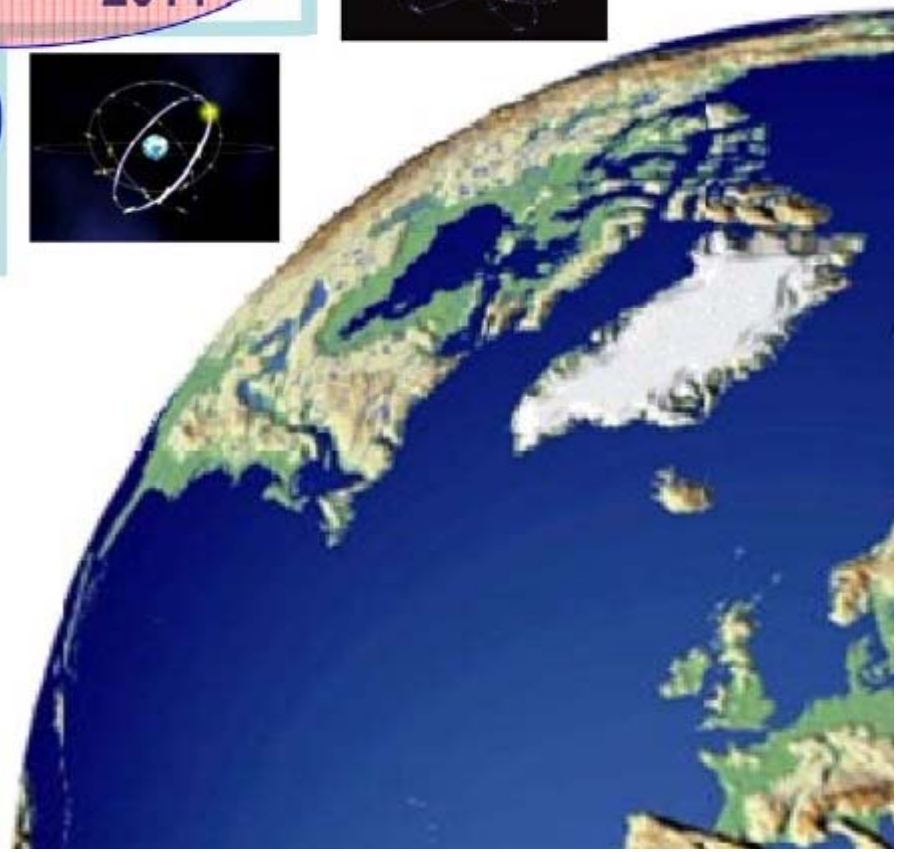
2011

GIOVE Testbed
2 initial test satellites

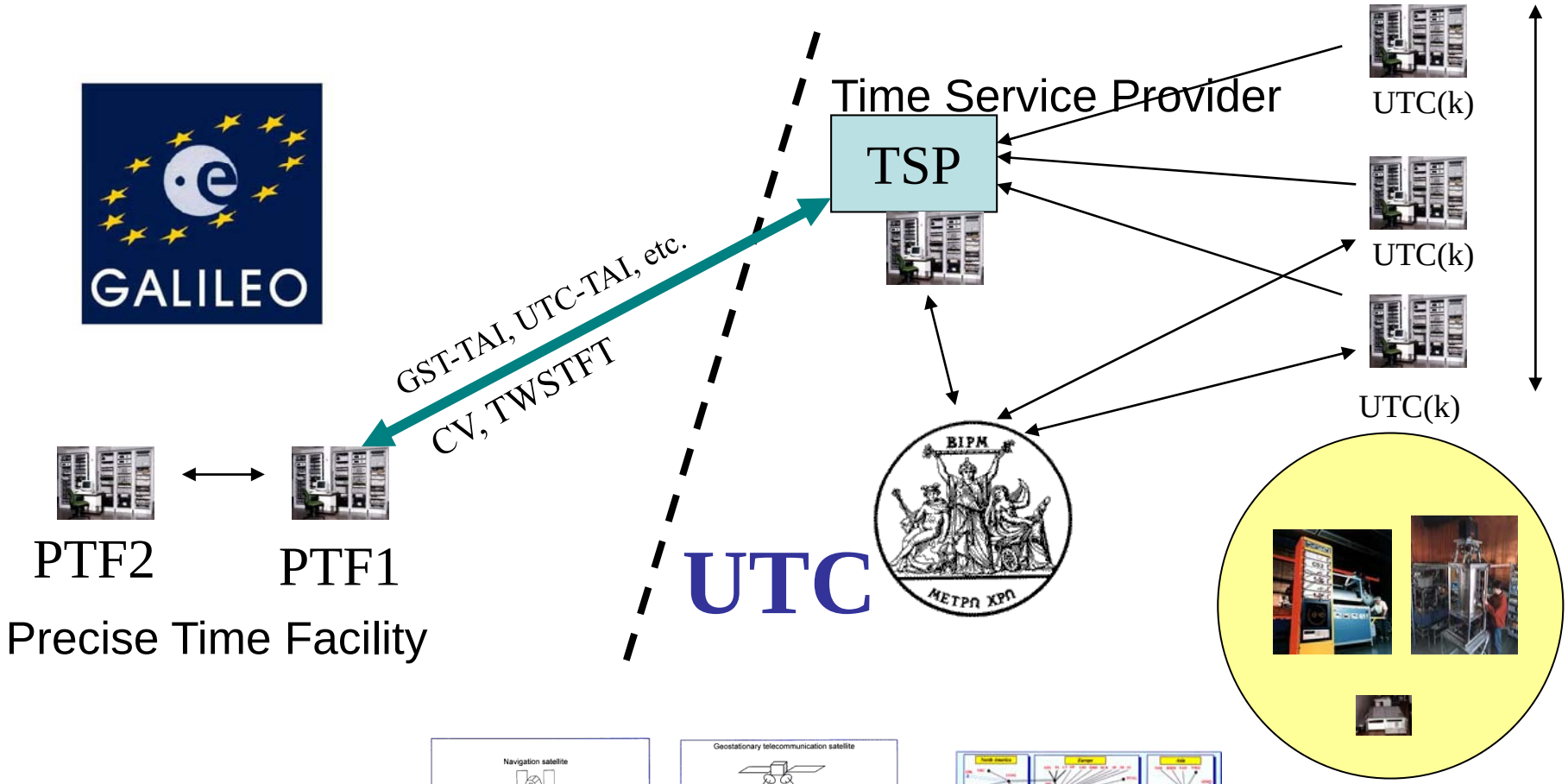
2005 - 2008

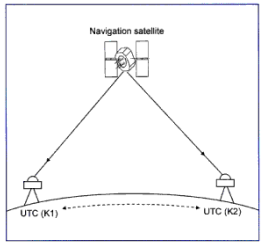
GALILEO

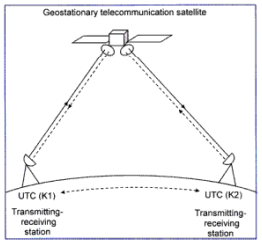
GIOVE

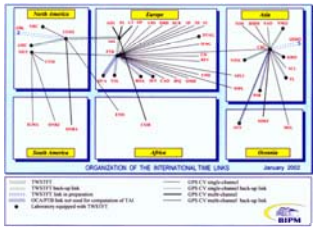


Galileo Time Keeping System Setup









ESA archive

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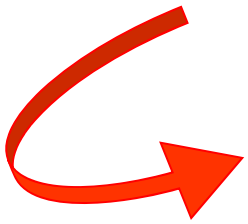
Currently in the

Development of the Ground Segment:

2 Galileo Control Centers

2 Precise Time Facilities

1. **Kayser Threde consortium**
2. **Consorzio Torino Time**



Time scale algorithms

- **INRIM**
- **Torino Wireless**
- **Finpiemonte**
- **Politecnico di Torino**
- **SEPA**
- **SIA**
- **Thales Alenia Space**
- **ISMB**

CONSORZIO TORINO TIME

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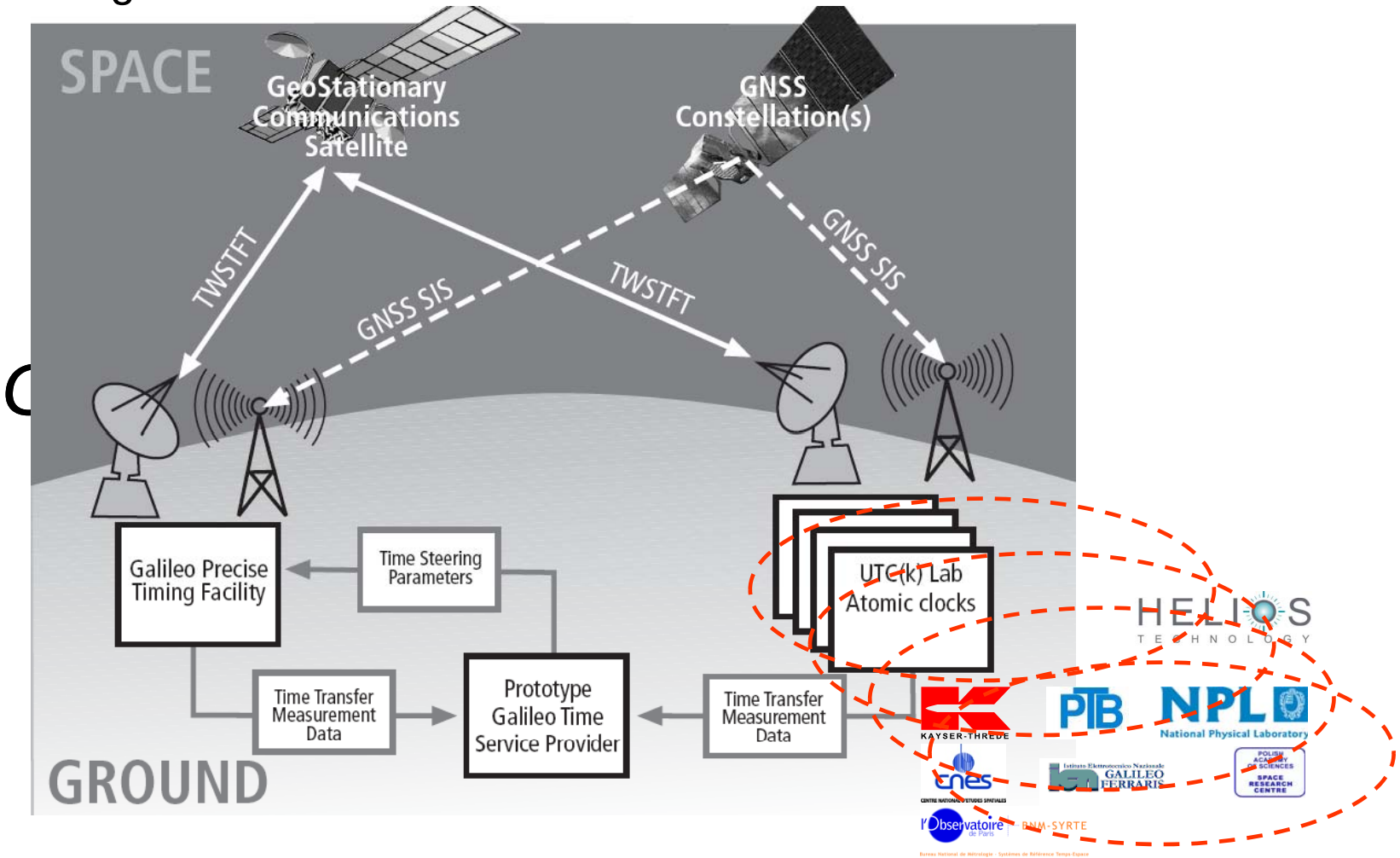
FIDELITY (2005-2009)

Delivering the Prototype of the Galileo Time Service Provider (GTSP)

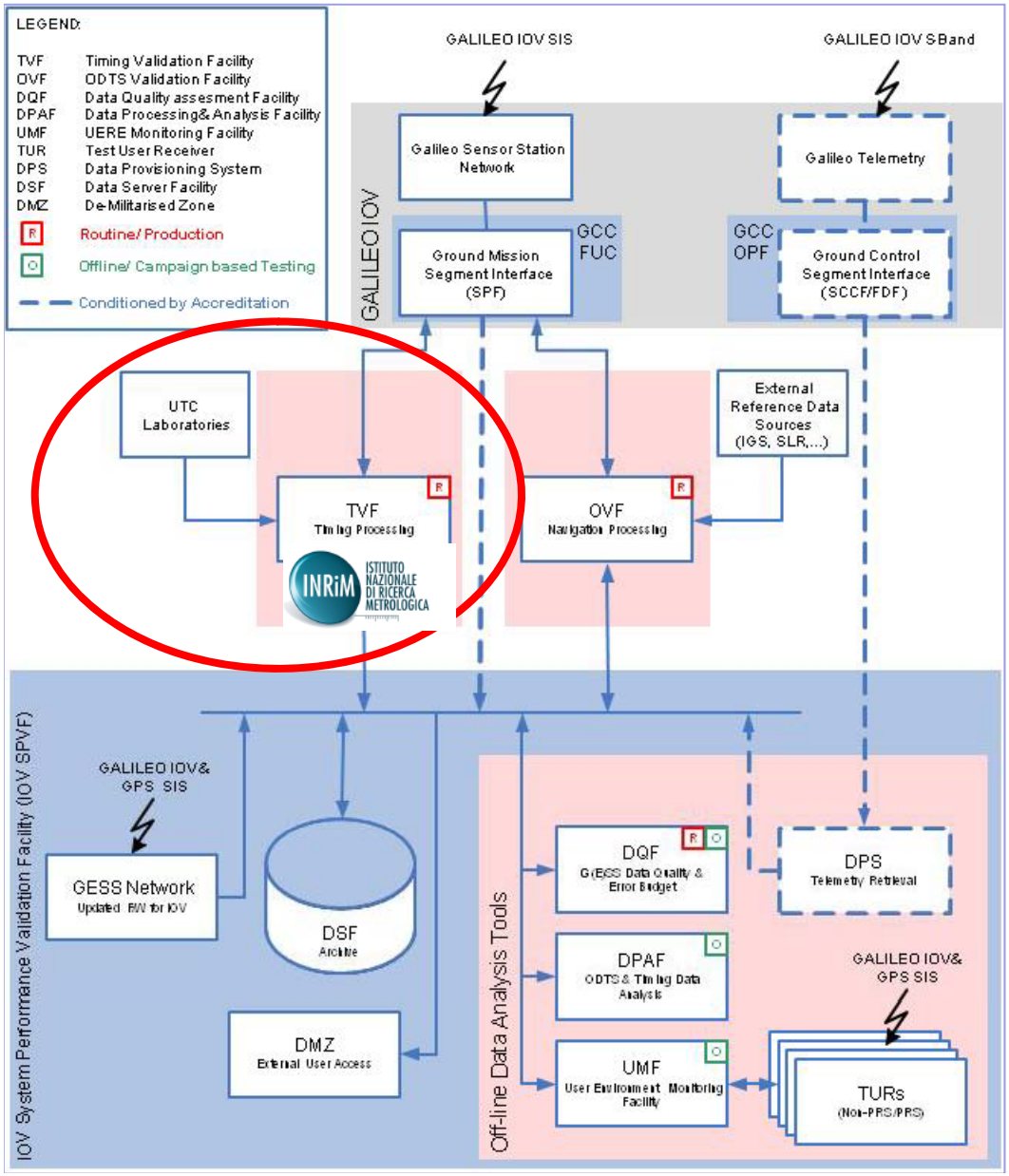
To maintain the Galileo System Time

in close agreement with the International UTC



Now preparing for the In Orbit Validation:

the Time and Geodetic Validation Facility TGVF 2010-2012



TGVF will :

Support of IOV satellites In-Orbit Test activities

Generate the necessary core products allowing validation of

- *Galileo System Time*
- *GSS and Onboard Clocks*
- *Geodetic Reference Service provision (Orbits, ERP, IONO, BGD, Tropo,...)*

Support the GMS-GTSP and GMS-GGSP External Interfaces

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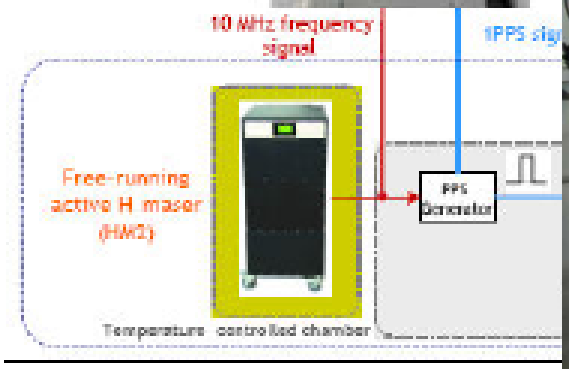
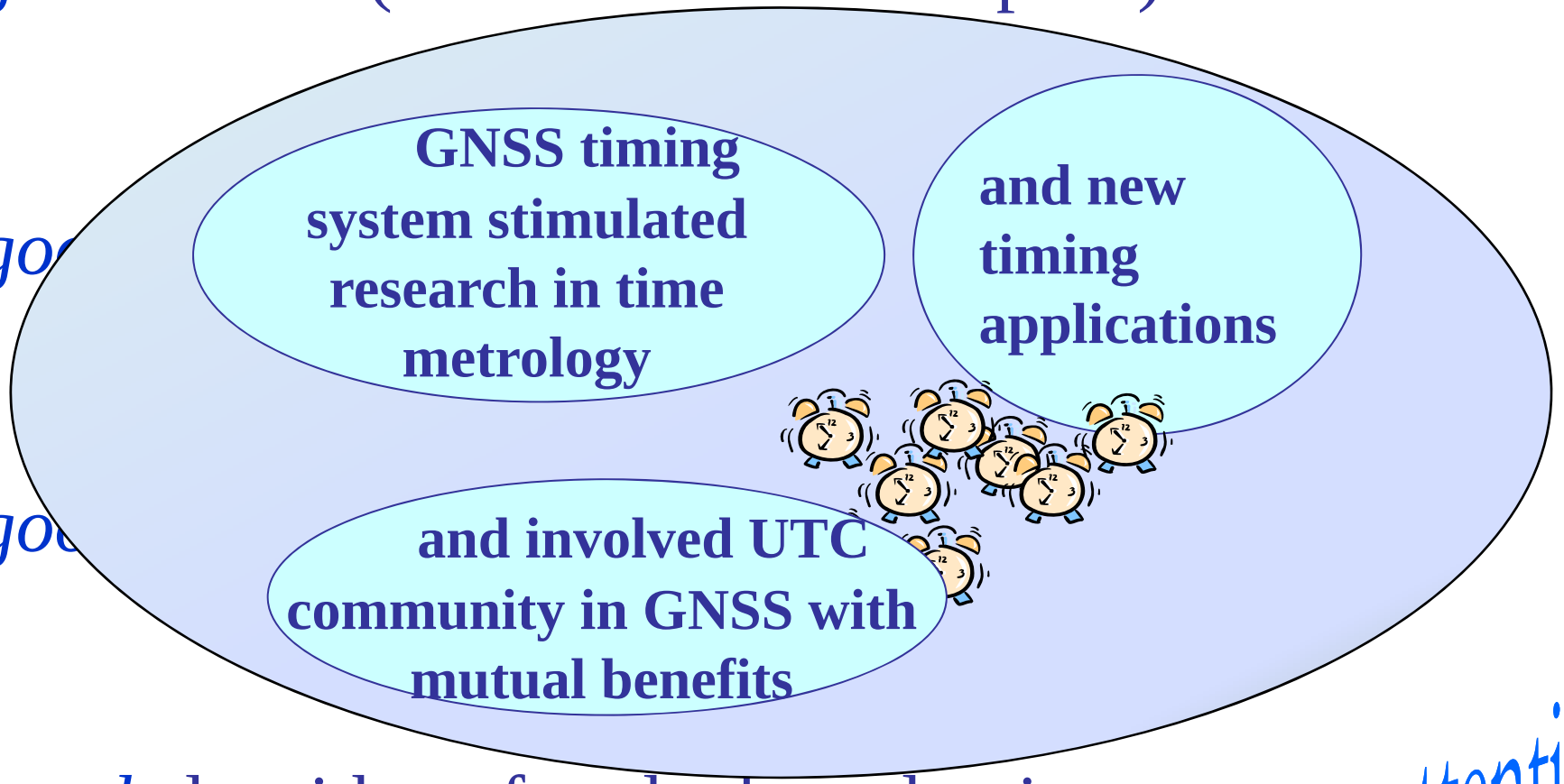
A visit to INRIM tonight



Timekeeping and Navigation

good clocks (on Ground and in Space)



good algorithms for clock evaluation

Thank you for your attention!

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