



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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Istituto Nazionale Ricerca

Metrologica

Torino, Italia

with viewgraph courtesy by ESA



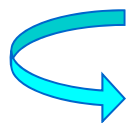


On 1<sup>st</sup> January 2006, the [Istituto Elettrotecnico Nazionale "Galileo Ferraris" \(IEN\)](#) and the [Istituto di Metrologia "Gustavo Colonnetti" \(IMGC\)](#) merged to establish the Istituto Nazionale di Ricerca Metrologica (I.N.RI.M).

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)



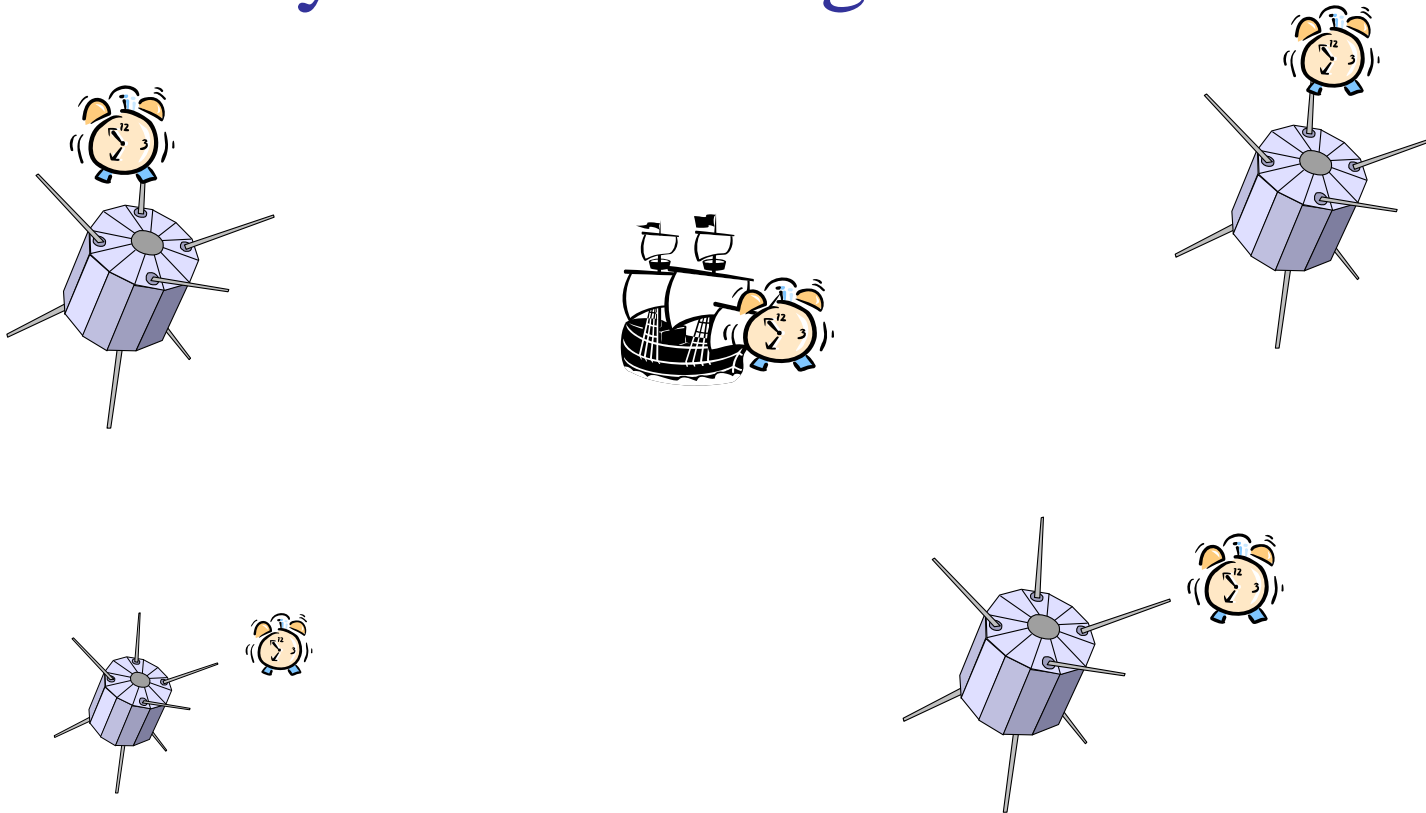
*good* clock synchronisation system

*good* reference time scale

*good* algorithms for clock evaluation

in timekeeping and navigation

# 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?

*A navigation system is also a mean for*

Time dissemination

Who needs time information?

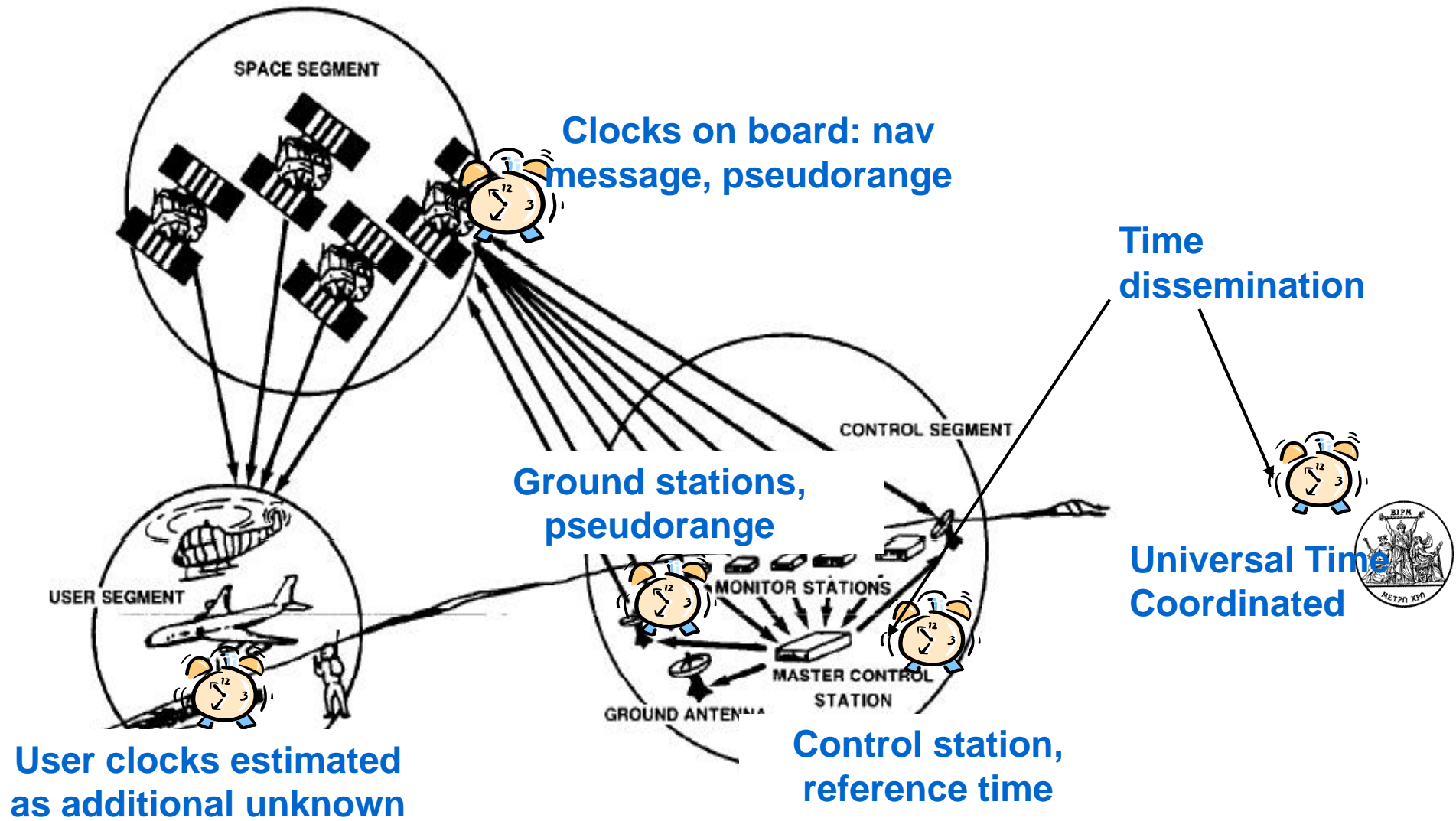
<u>Topic</u>	<u>Title</u>
Network synch	Network synchronization for telecomm (wireless /-line)
Network synch	Network synchronization for power generation / distribution
Network synch	Network synchronization for digital broad-casting
Network synch	Satellite monitoring / navigation (ground based)
Time 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**



# GNSS: where are the clocks and why



# Typical question for a time metrologist

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

*Is the clock stable enough?*

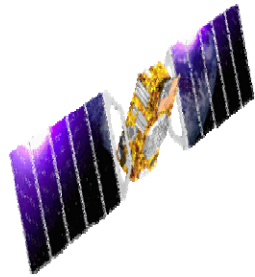
*How do we measure the degree of  
synchronization of the on board clock?*

*How do we predict the clock error after  
synchronisation?*

*How do we ensure time interoperability?*

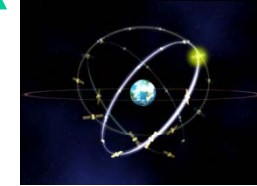


# Galileo Programme Phasing



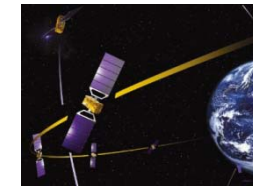
## Full Operational Capability

+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



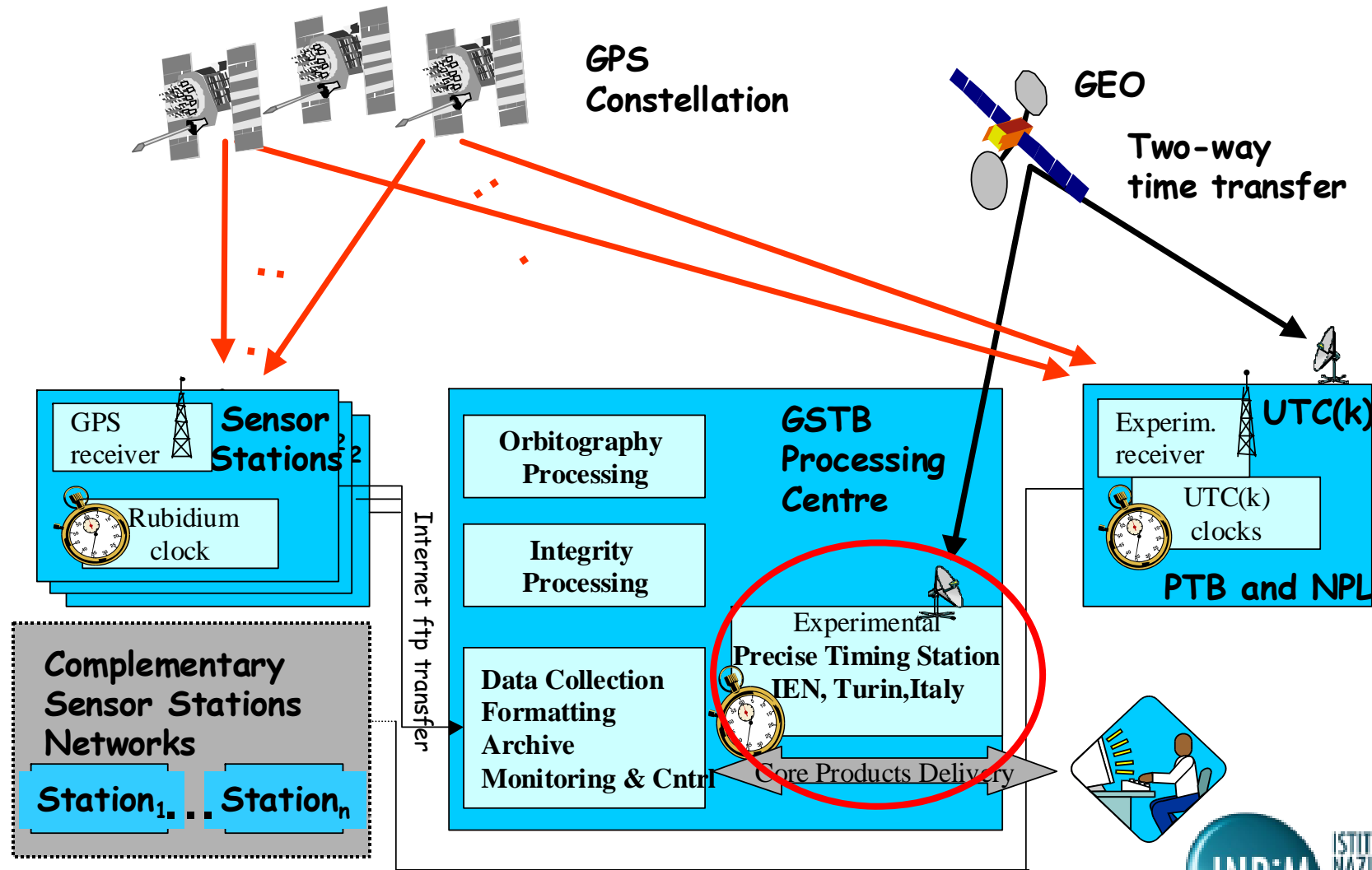
## Galileo System Testbed v1

Critical algorithms validation



# 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.

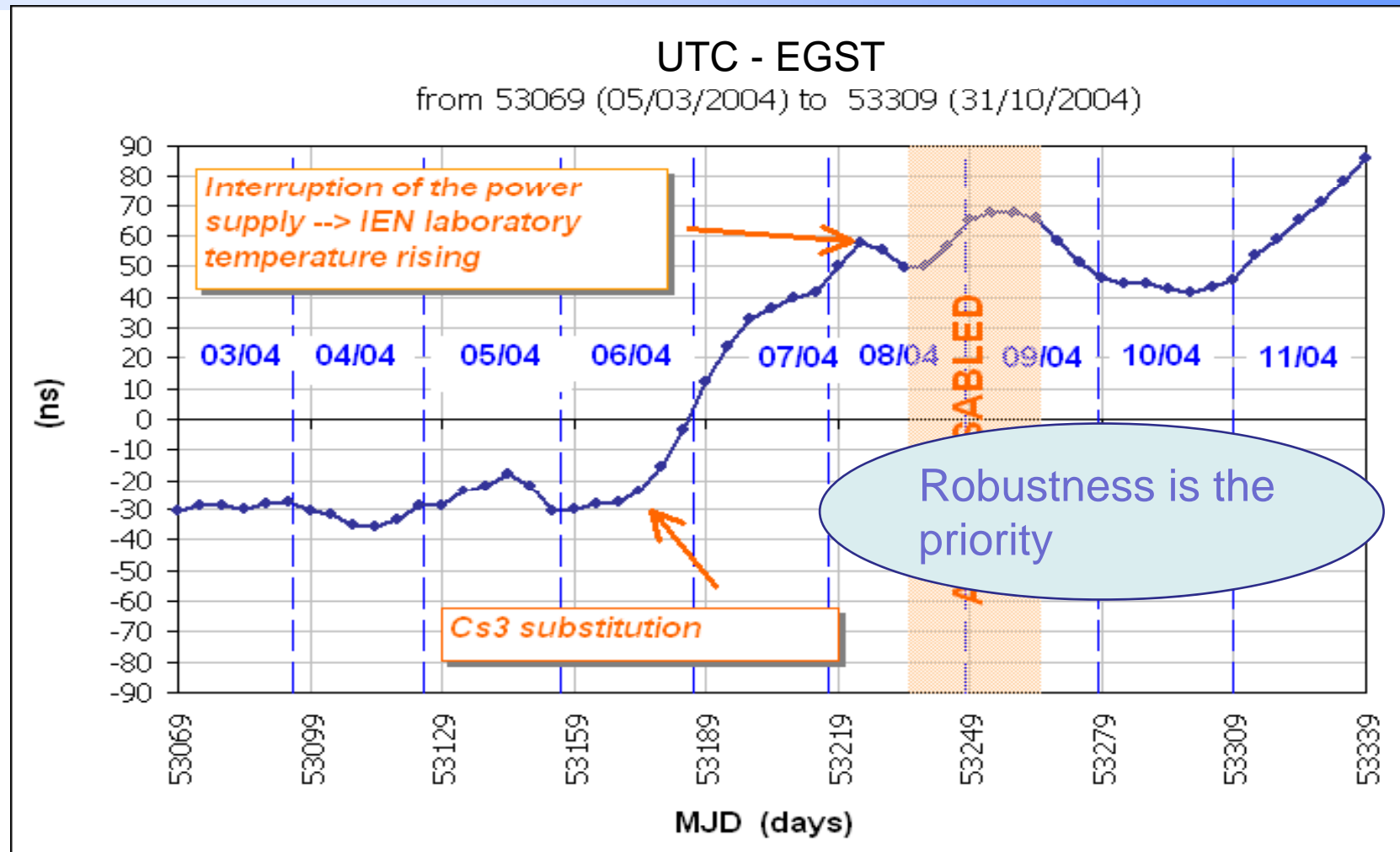
In collaboration with Agenzia Spaziale Europea, Alenia Spazio, Alcatel, ...





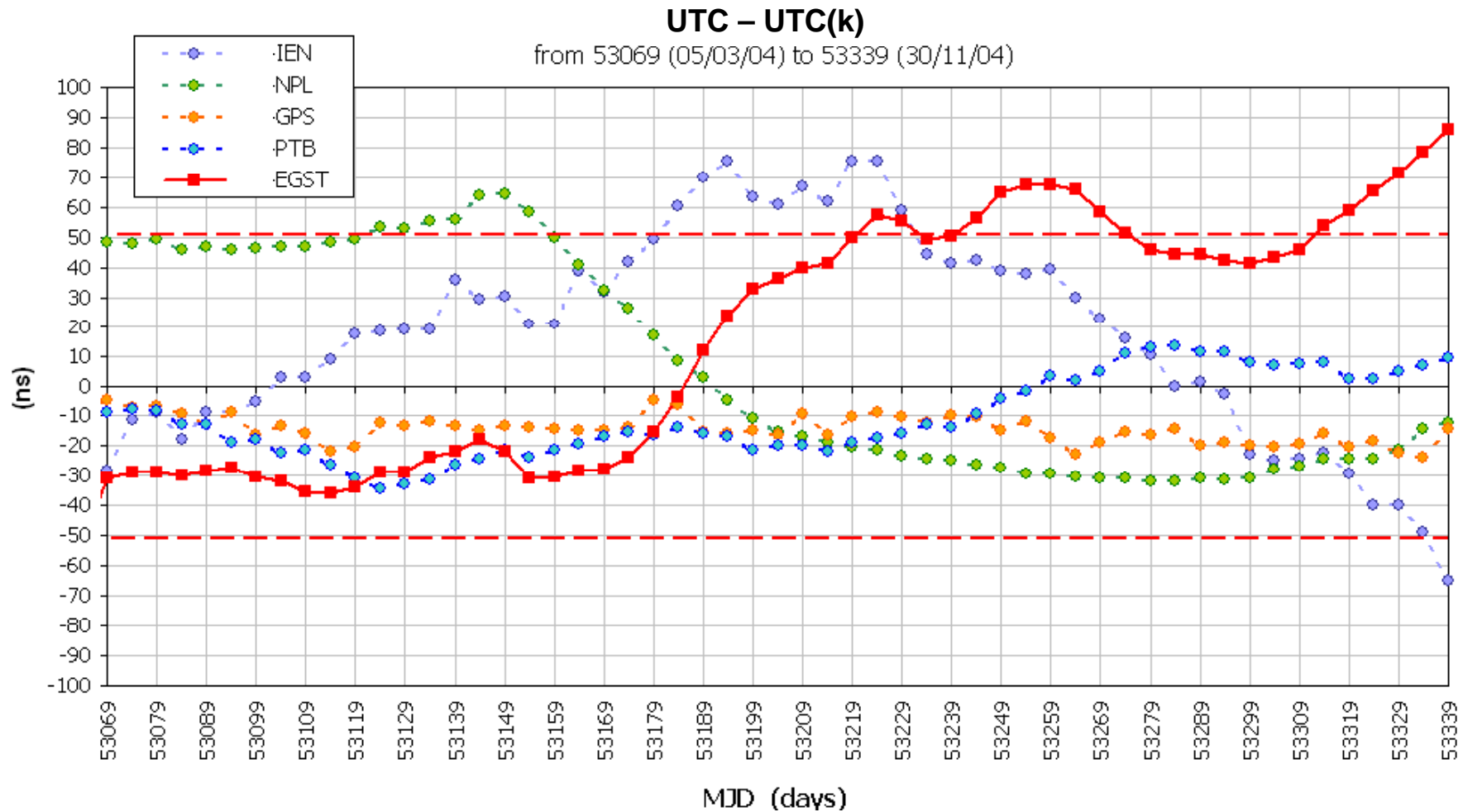


# GSTB-V1 Performances



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  $\pm 50$  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*

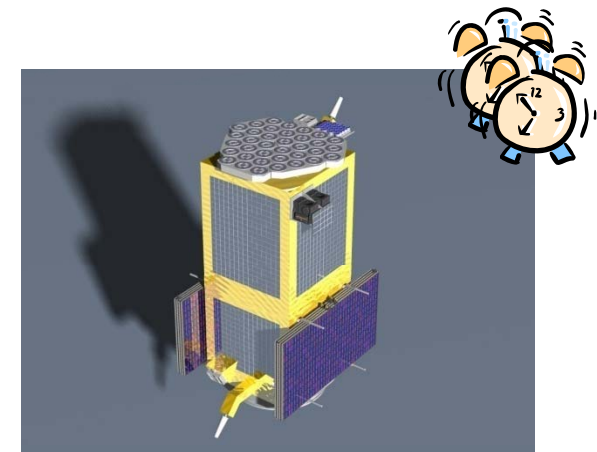
**Galileo In Orbit Validation Experiment**

**GSTB V2**

**2005-2010**



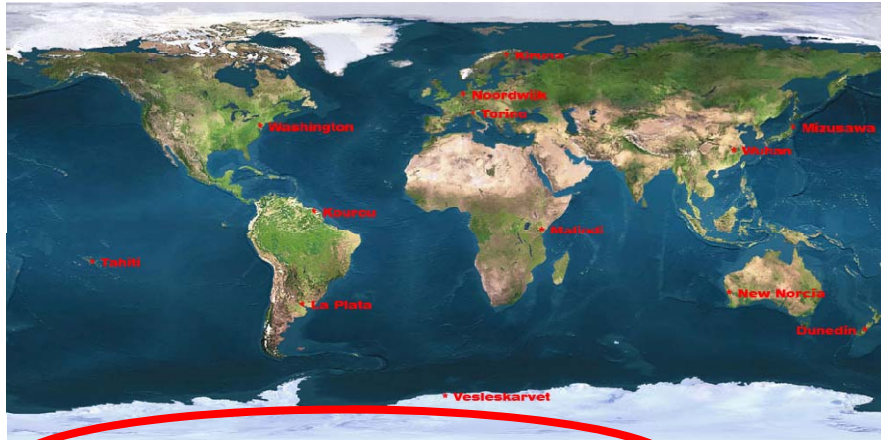
GIOVE A launched on Dec 28, 2005



GIOVE B  
launched April  
27, 2008

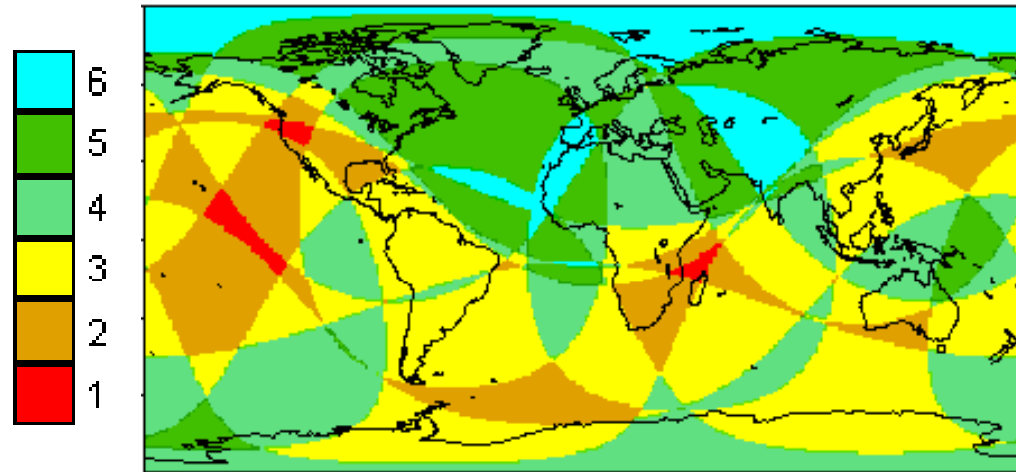


# THE GESS NETWORK



- 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)

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







# THE SENSOR STATION (GESS)



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

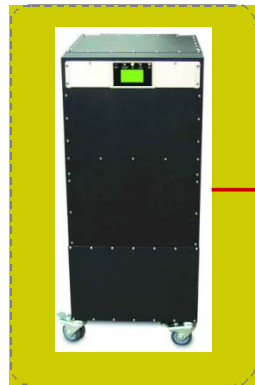
10 MHz frequency signal

1PPS signal

INRIM Time and Frequency Laboratory

☐ Routine activities at INRIM

Free running active H maser



☐ Temperature controlled chamber

PPS Generator



INRIM Meas System



UTC(IT)

Time offset [UTC(IT) - H maser]  
sampling rate: 1 hour

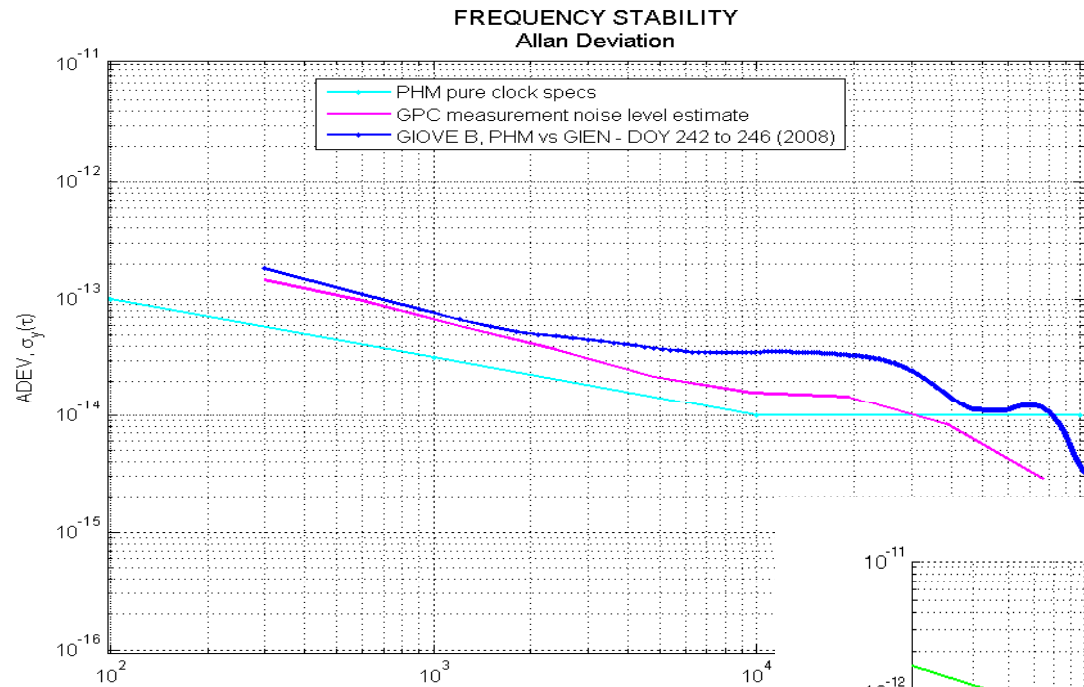
# Galileo GSTB V2 Experimental Satellites

- 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



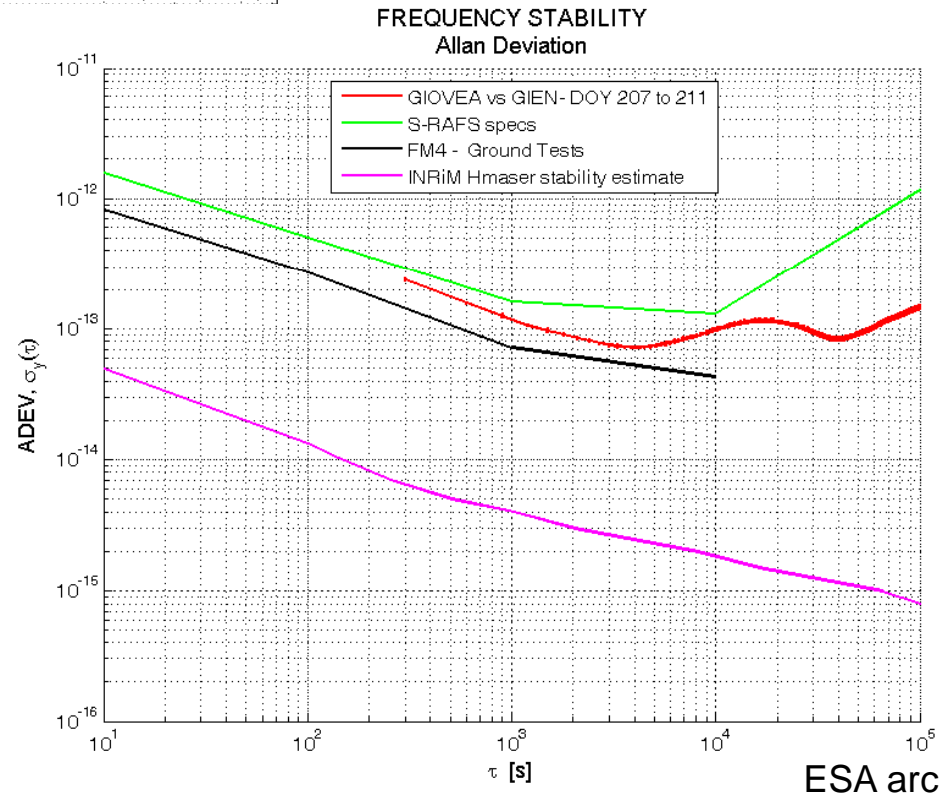
On ground a network of Sensor Station and an Orbit Determination & Time Synchronization processing similar to GSTB V1 with the addition of GIOVE tracking capabilities and Satellite Control Centers

# Passive H Maser (GIOVE-B)

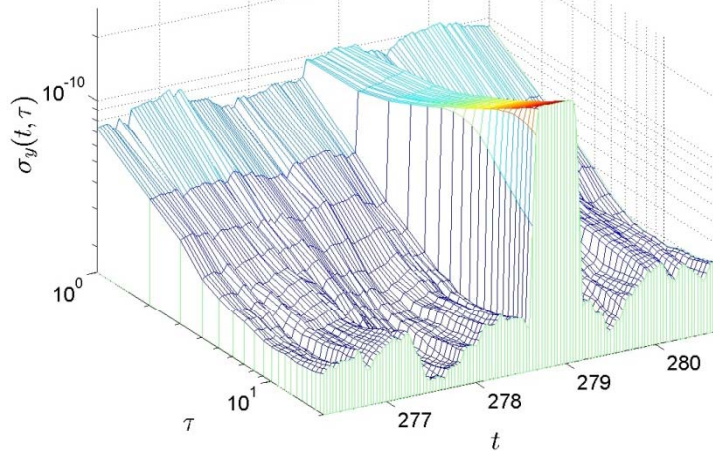


GIOVE clocks

Rubidium (GIOVE A)



Dynamic stability



# http://www.giove.esa.int

ESA - Satellite Applications - Navigation - Galileo - GIOVE - Microsoft Internet Explorer

File Edit View Favorites Tools Help



**GIOVE**  
Galileo In-Orbit Validation Element

European Space Agency

[ESA Home](#) | [Navigation](#) | [Galileo](#) | [Egnos](#) | [GIOVE](#) |

28-Feb-2007 09:13:12 UTC

#### Menu

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#### Welcome to the GIOVE Processing Centre



Welcome to the web pages of GIOVE, the Galileo In Orbit Validation Element.

The GIOVE Processing Centre, located at ESA ESTEC in Noordwijk, conducts experimentation activities using GIOVE's two satellites. The results will support the development of the Galileo IOV system, thereby reducing risk and helping to guarantee the success of the Galileo mission.

#### Announcements

##### January 11

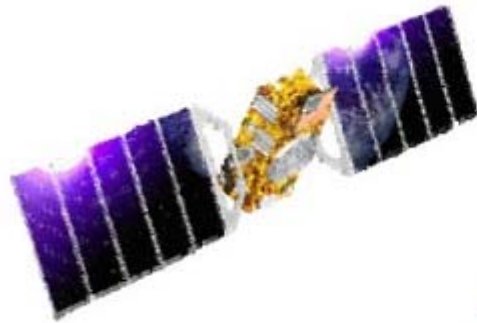
Galileo One Year In-Orbit

##### August 28

First GIOVE A On Board Clock results available

First Satellite Laser Ranging Campaign on GIOVE-A is a success

# Galileo Implementation Plan



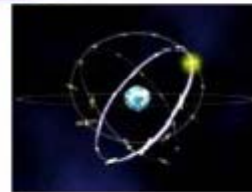
**GIOVE Testbed**  
2 initial test satellites  
**2005 - 2008**



**In-Orbit Validation**  
4 IOV satellites plus  
ground segment  
**2011**



**Open Service, Search & Rescue  
Public Regulated Service**  
18 satellites  
**2014**



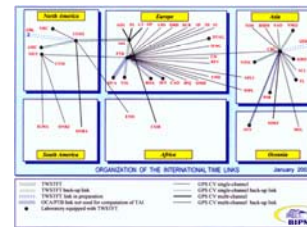
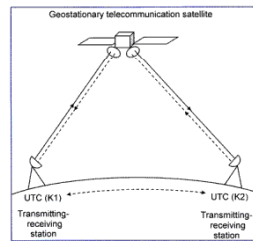
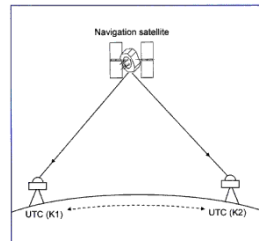
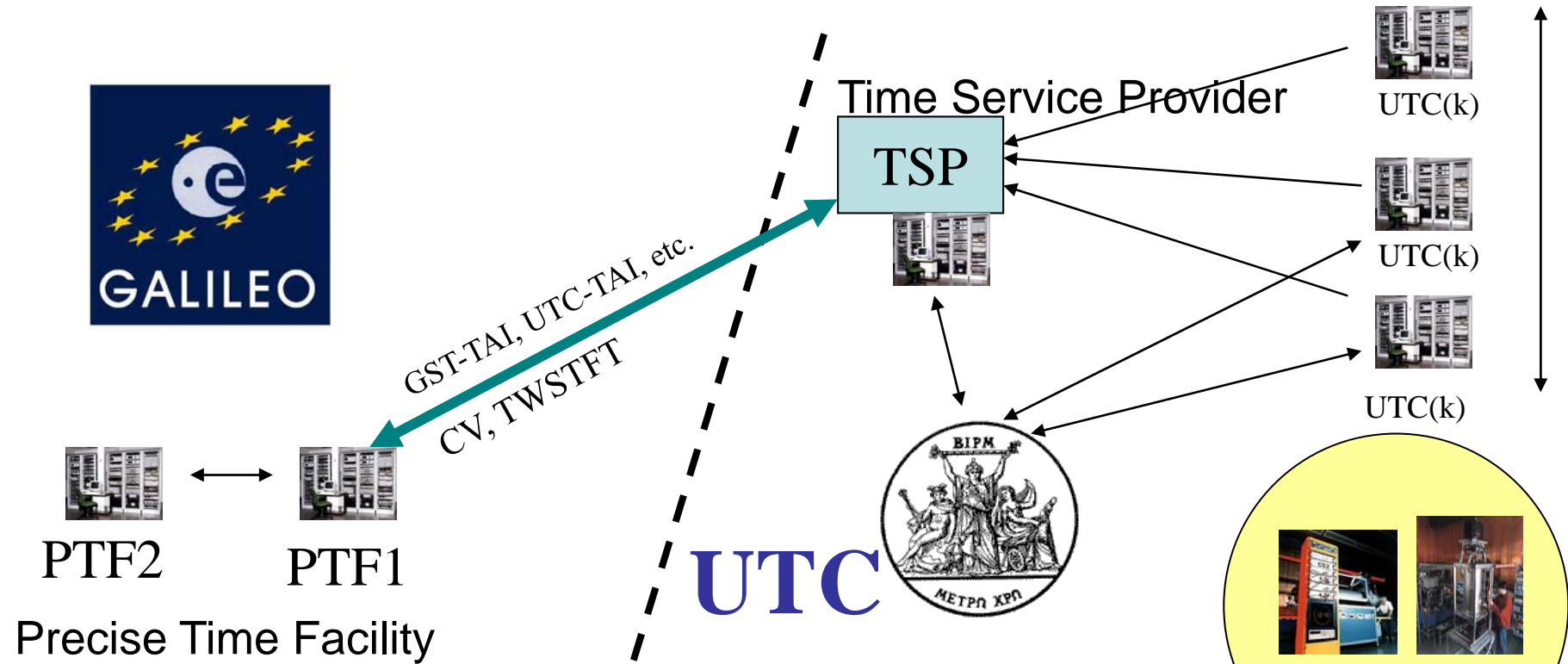
**All services**  
30 satellites

**2016**





# Galileo Time Keeping System Setup



ESA archive



Currently in the

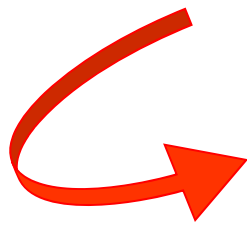
## *Development of the Ground Segment:*

### *2 Galileo Control Centers*

### *2 Precise Time Facilities*

1. Kayser Threde consortium

2. Consorzio Torino Time



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

Time scale algorithms

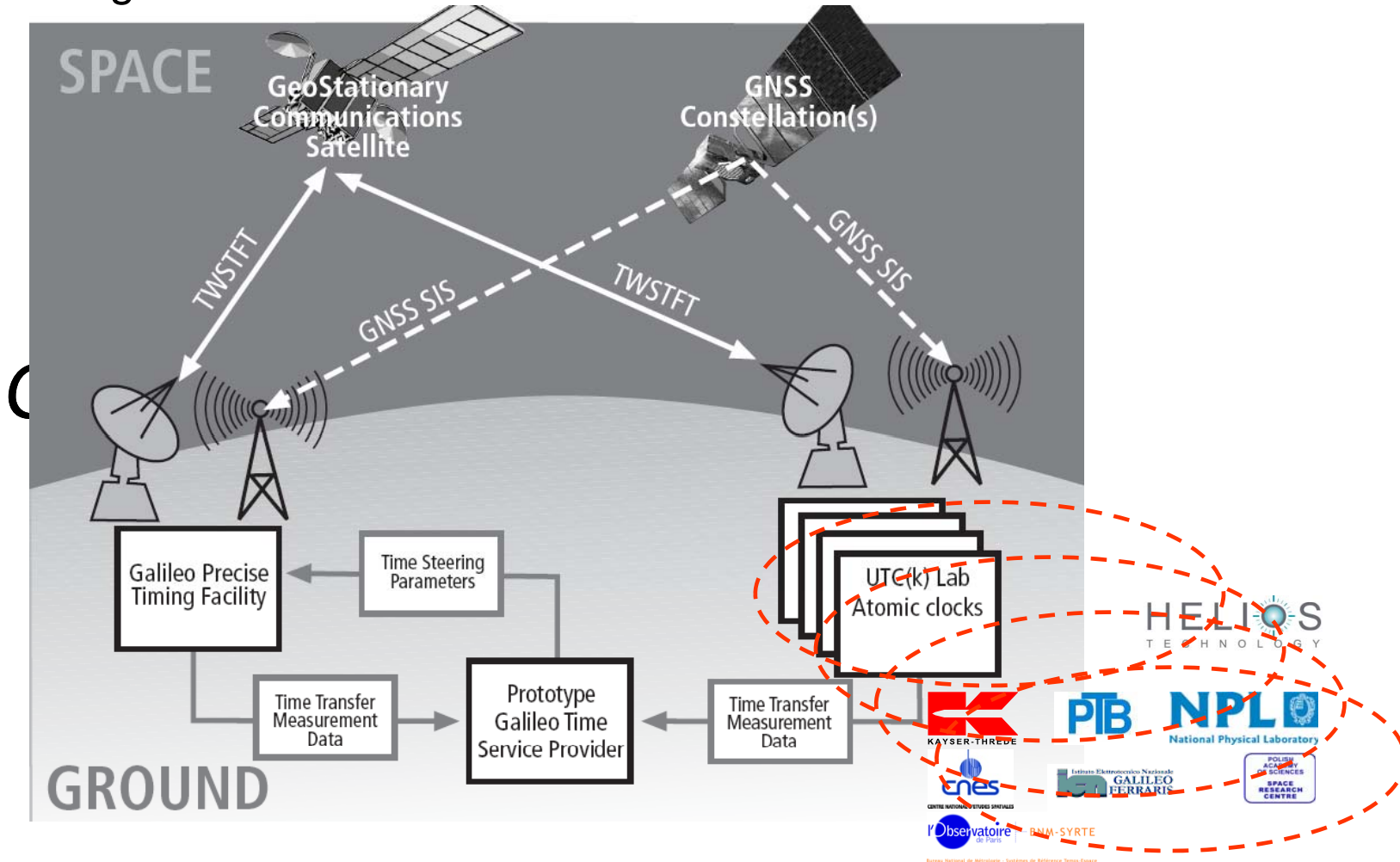


# FIDELITY (2005-2009)

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

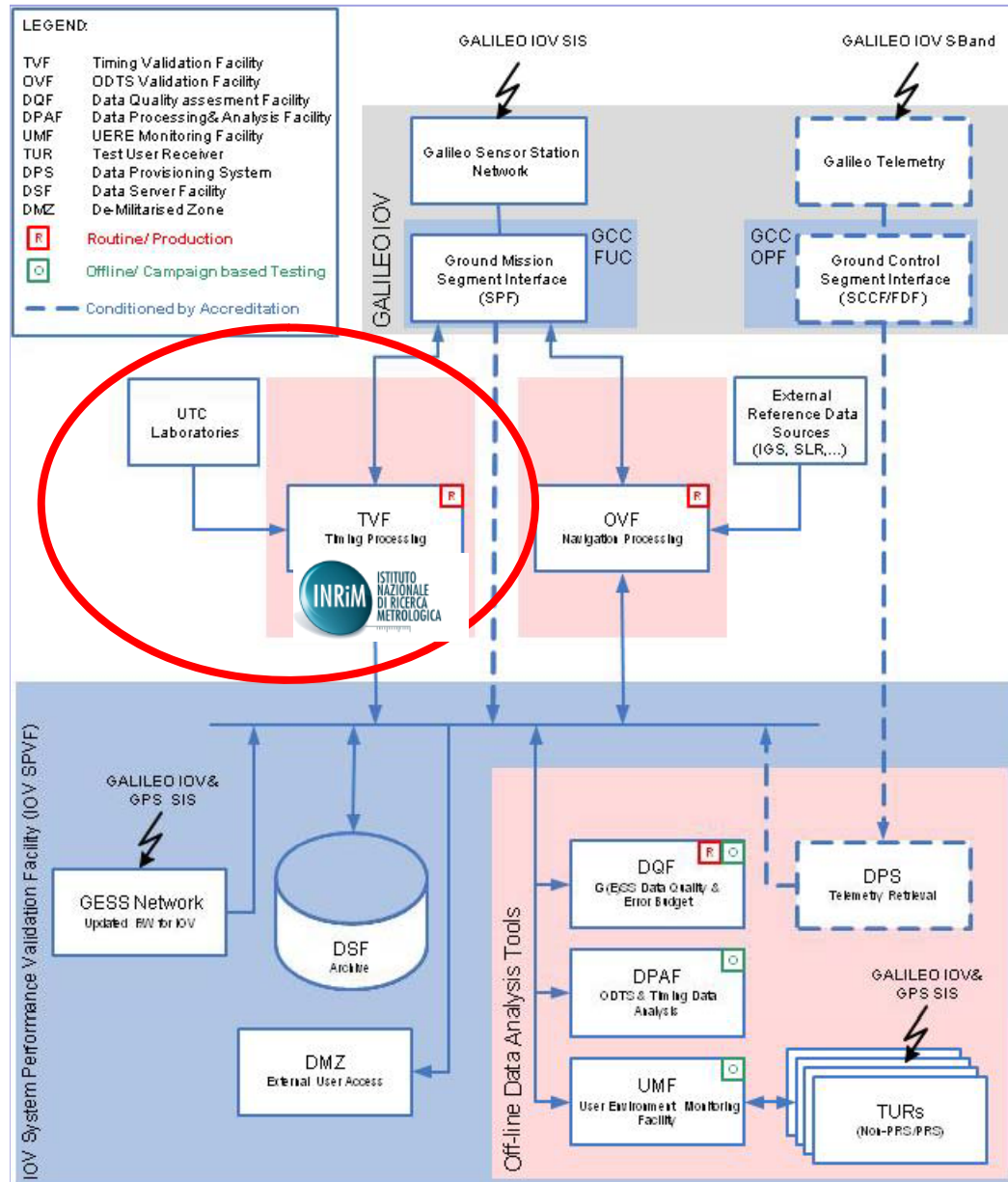
To maintain the Galileo System Time

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**

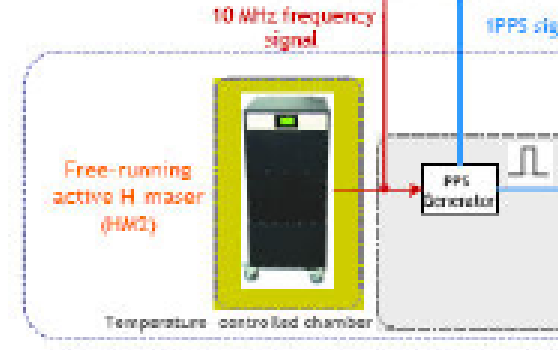
**Geodetic Reference Service**

**provision (Orbits, ERP, IONO, BGD, Tropo,...)**

**Support the GMS-GTSP and GMS-GGSP External Interfaces**

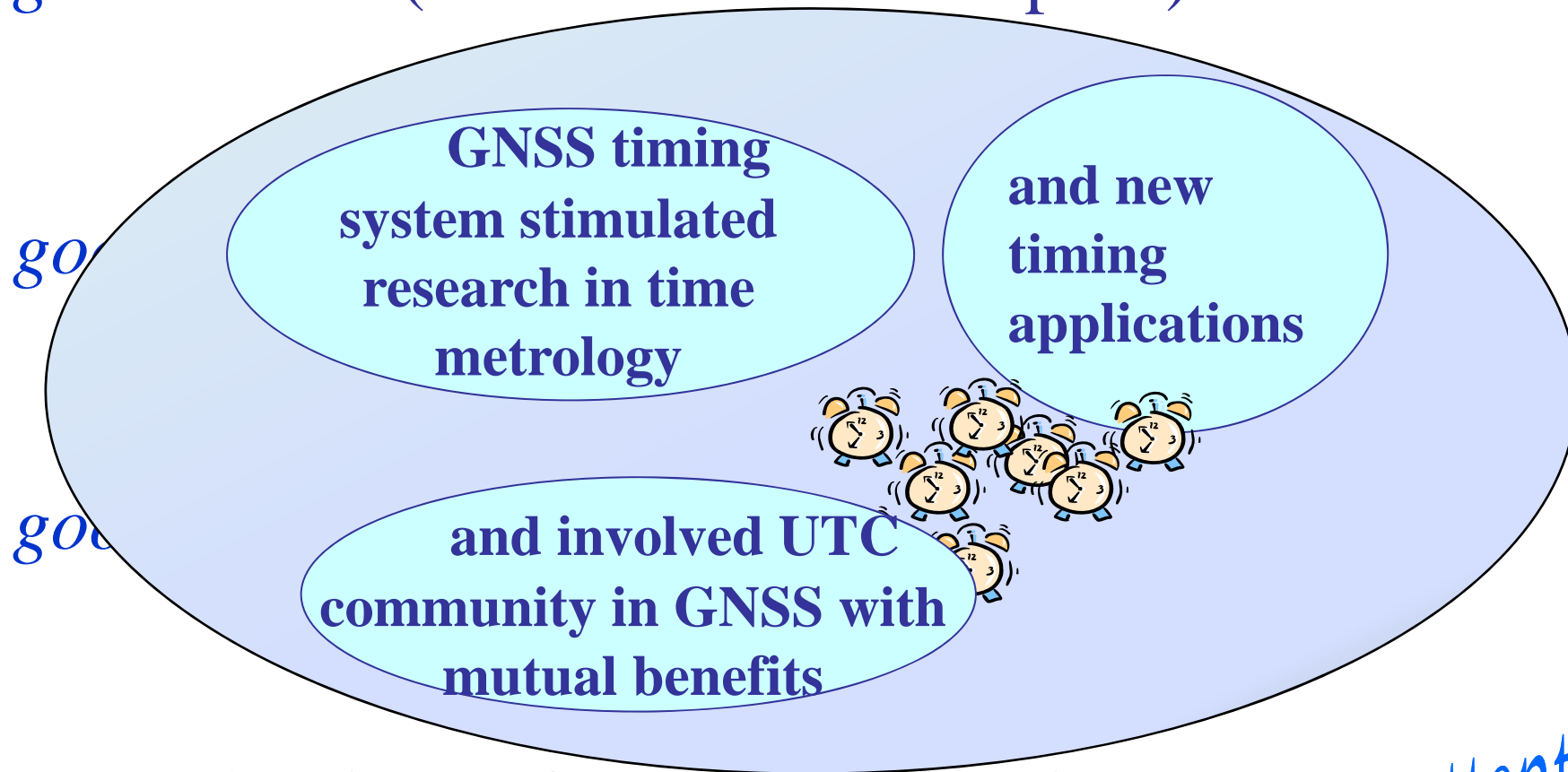


# A visit to INRIM tonight



# Timekeeping and Navigation

*good* clocks (on Ground and in Space)



*good* algorithms for clock evaluation

*Thank you for your attention!*