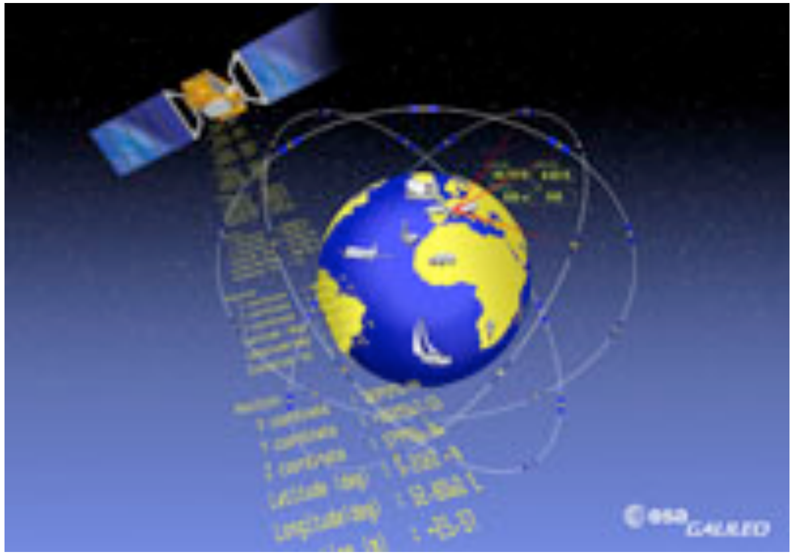
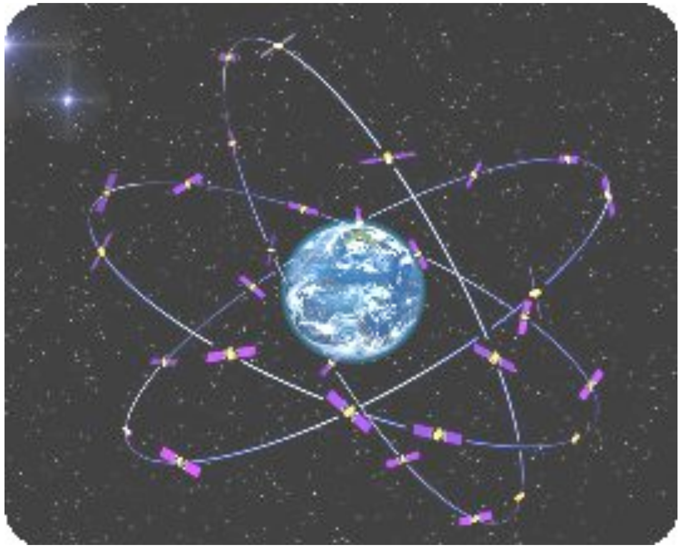
Synchronizing 30 navigation satellites within 1 ns ......



Performances Of GNSS on board atomic clocks

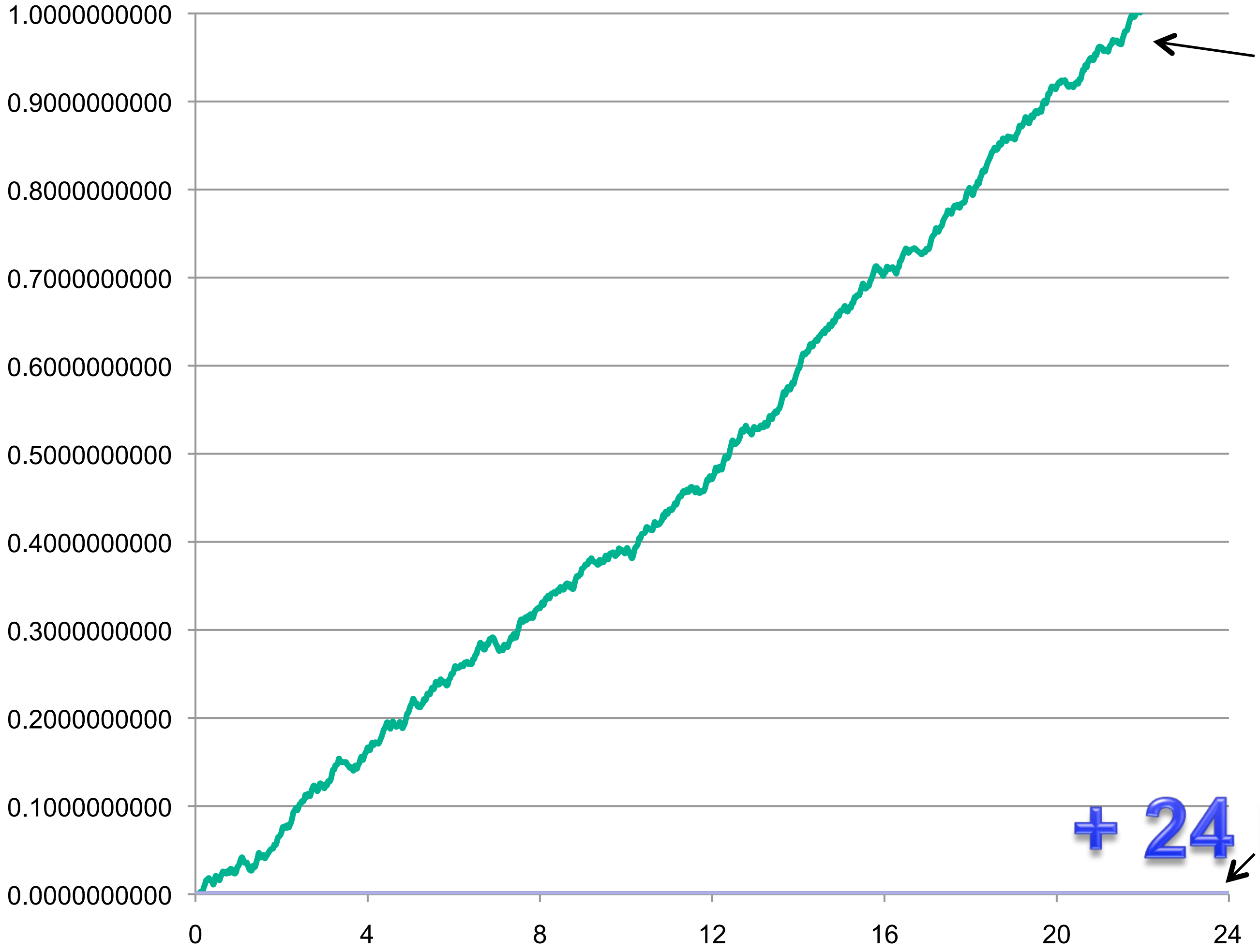
Galileo :



- Project start 1999-2000
- Constellation
  - 30 satellites
  - 3 circular MEOs
  - Altitude 23222km
  - Inclination 56°
- Satellites lifetime12 years
- On board clock model adjust : 100 minutes –> 6 hours
- Navigation precision objective: Metric/sub-metric
- On board Clock stability :→ 1 to 3 ns over 100min-6 hours

What would be the stability of Galileo if equipped with this type of crystal clock ?

Watch type Crystal clock time Stability over 24 Heures:

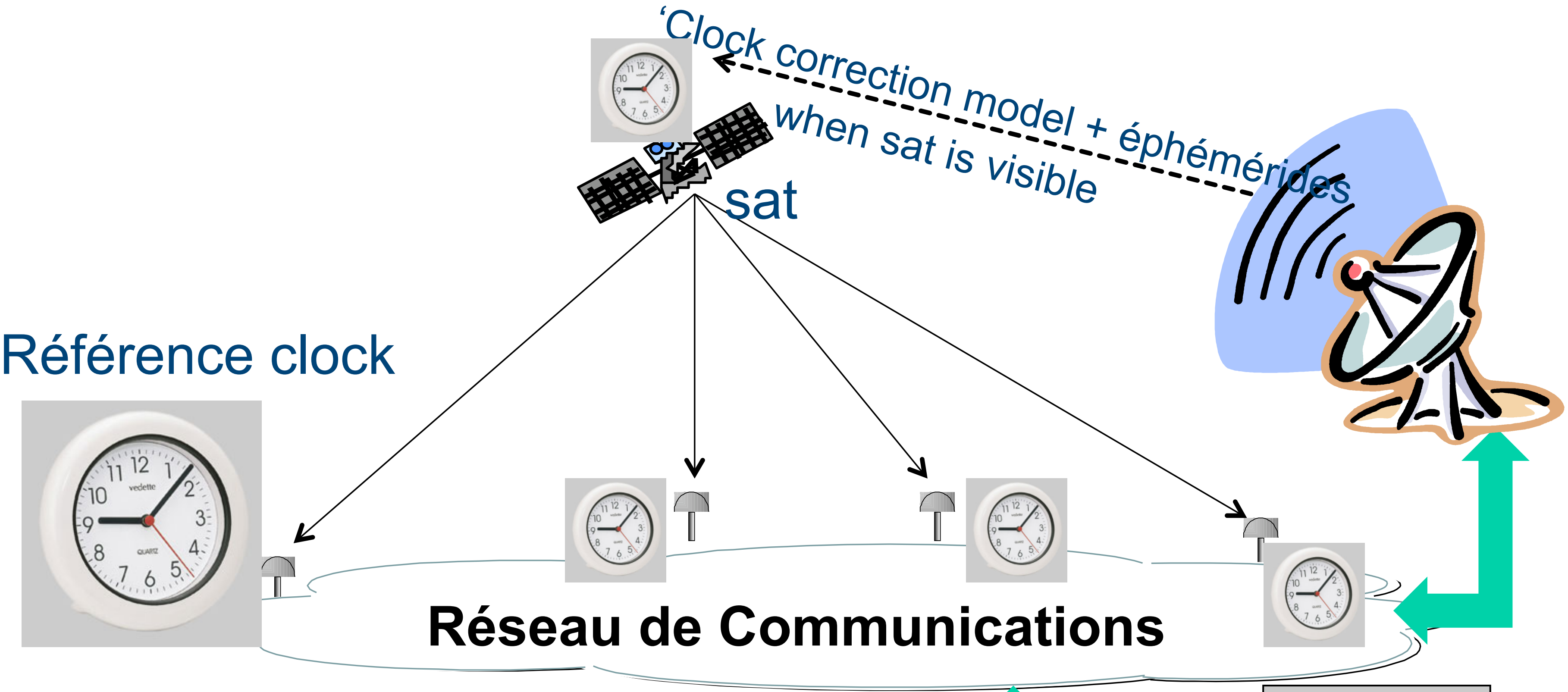


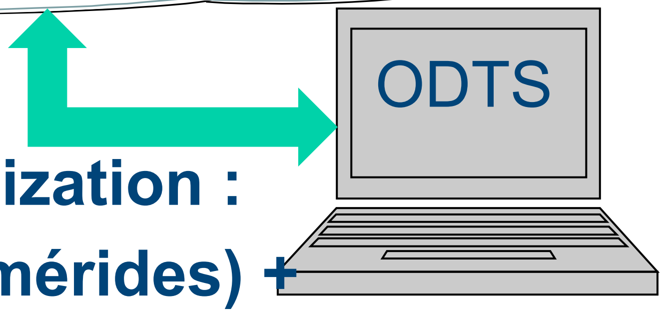
With this type of clock :

The position error with a re-synchronization every 24 hours will be :

300’000 Km !!

But may be less …….

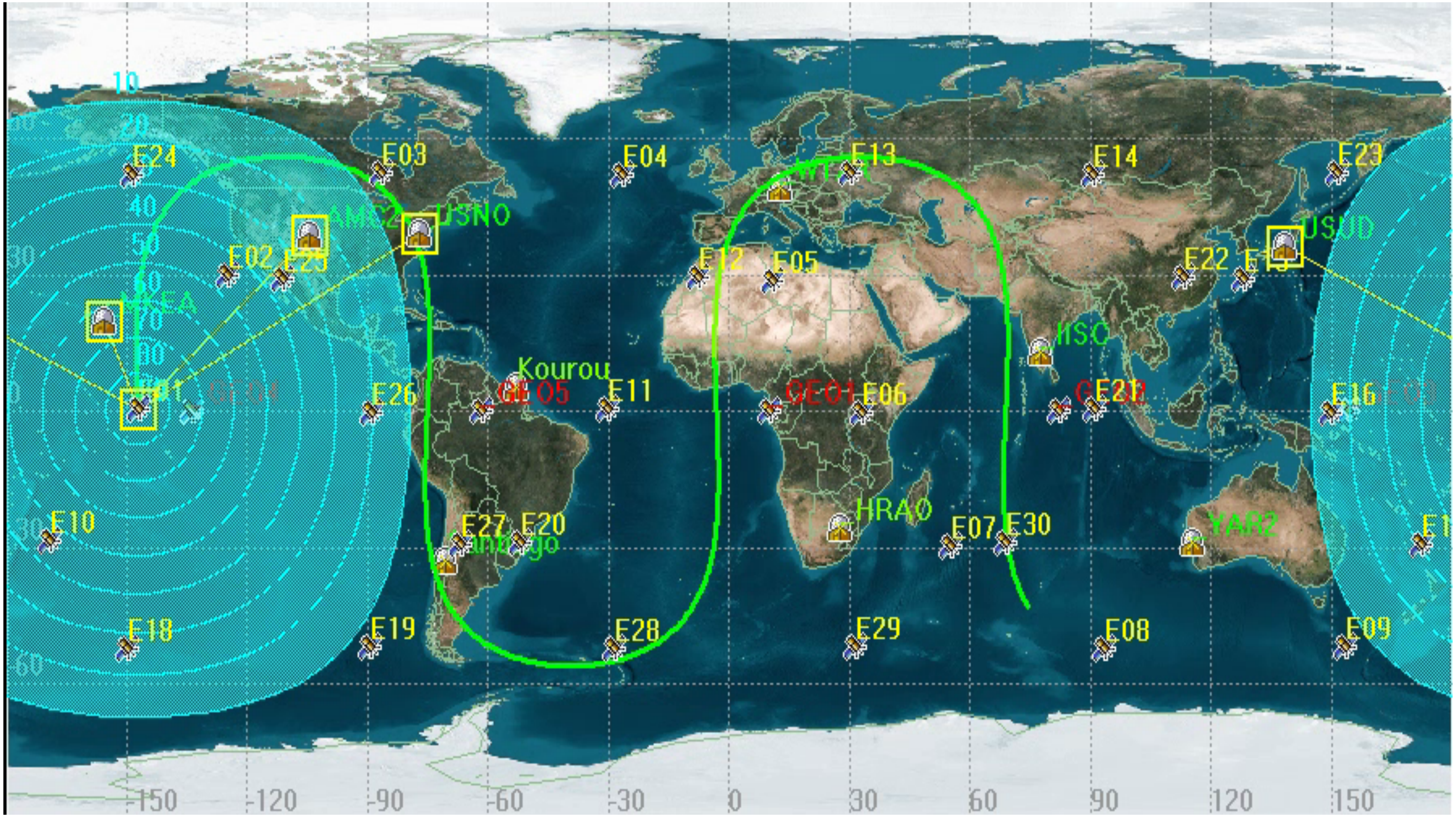




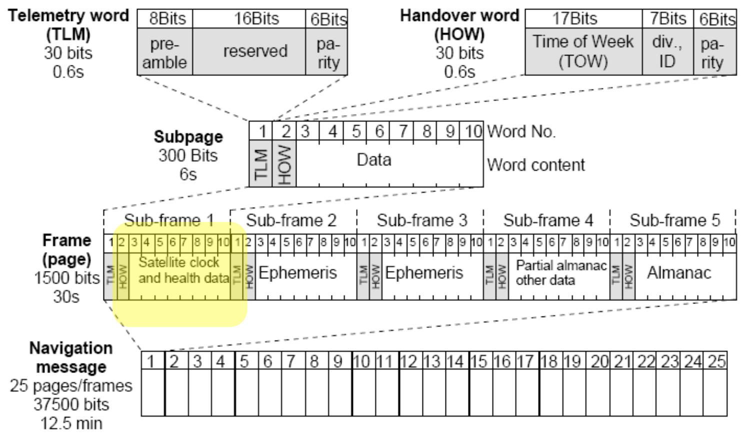
ODTS:

Orbit Determination & Time Synchronization :

Compute the orbit parameters (éphémérides) + clock parameters(clock model)


E24
E03
E04
E13
E14
E23
AMC2
USNO
USUD
E02
E25
E12
E05
E22
MKEA
IISC
Kourou
GEO5
E26
E11
GEO1
E06
E16
E10
E27
E20
HRAO
E07
E30
YAR2
E18
E19
E28
E29
E08
E09
-150
-120
-90
-60
-30
0
30
60
90
120
150

Exemple of ‘clock model’ transmited by the satellite:



CLOCK FOR SATELLITE 2 :

PRN number for data 2

Week number...... 797

Predicted user range accuracy 32

Health of satellite 0

L1 - L2 Correction term 9.31323E-10

Issue of clock data 224

Time of clock data 240704

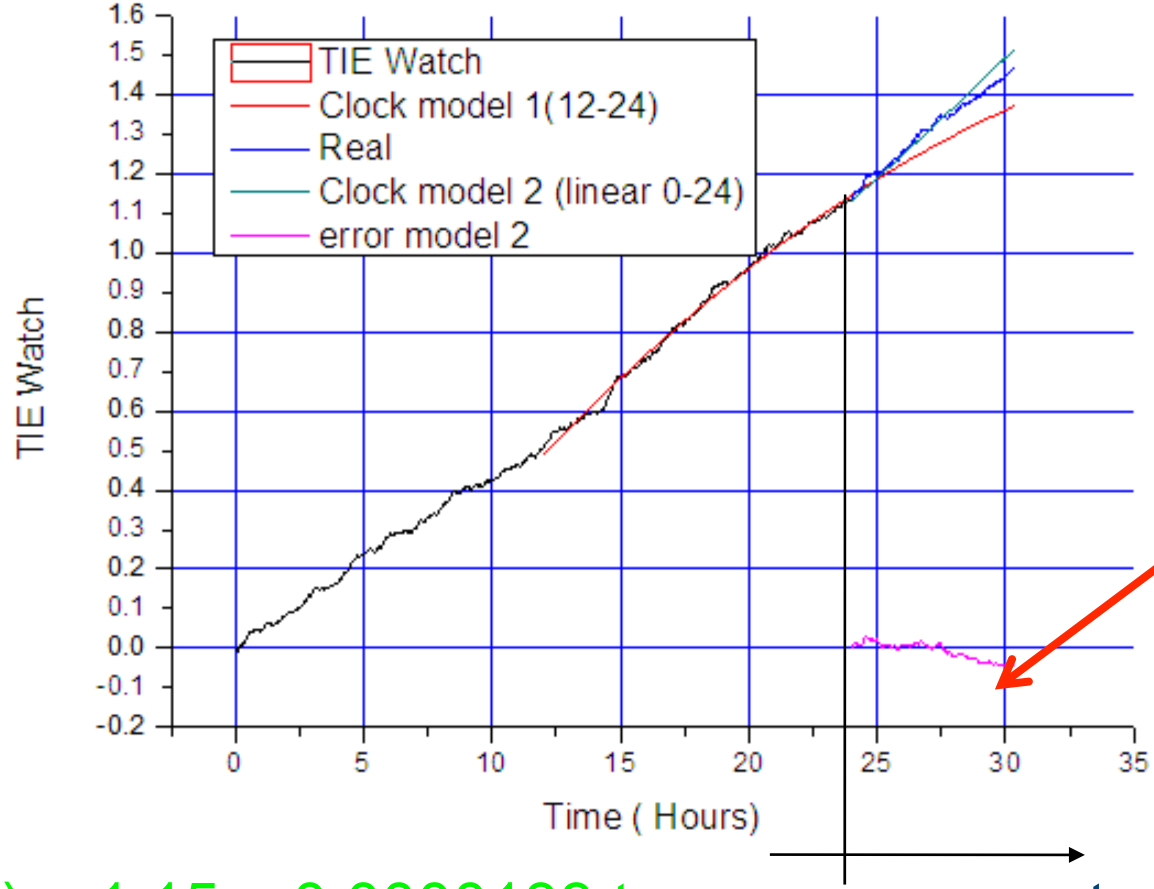
Clock offset .... -0.000158074

Clock drift .... -2.50111E-12

Rate of clock drift 0

$$X(t) = a + bt + ct^2$$

Position error with ‘clock model’ correction’ when using the Crystal clock :



~ 40 ms

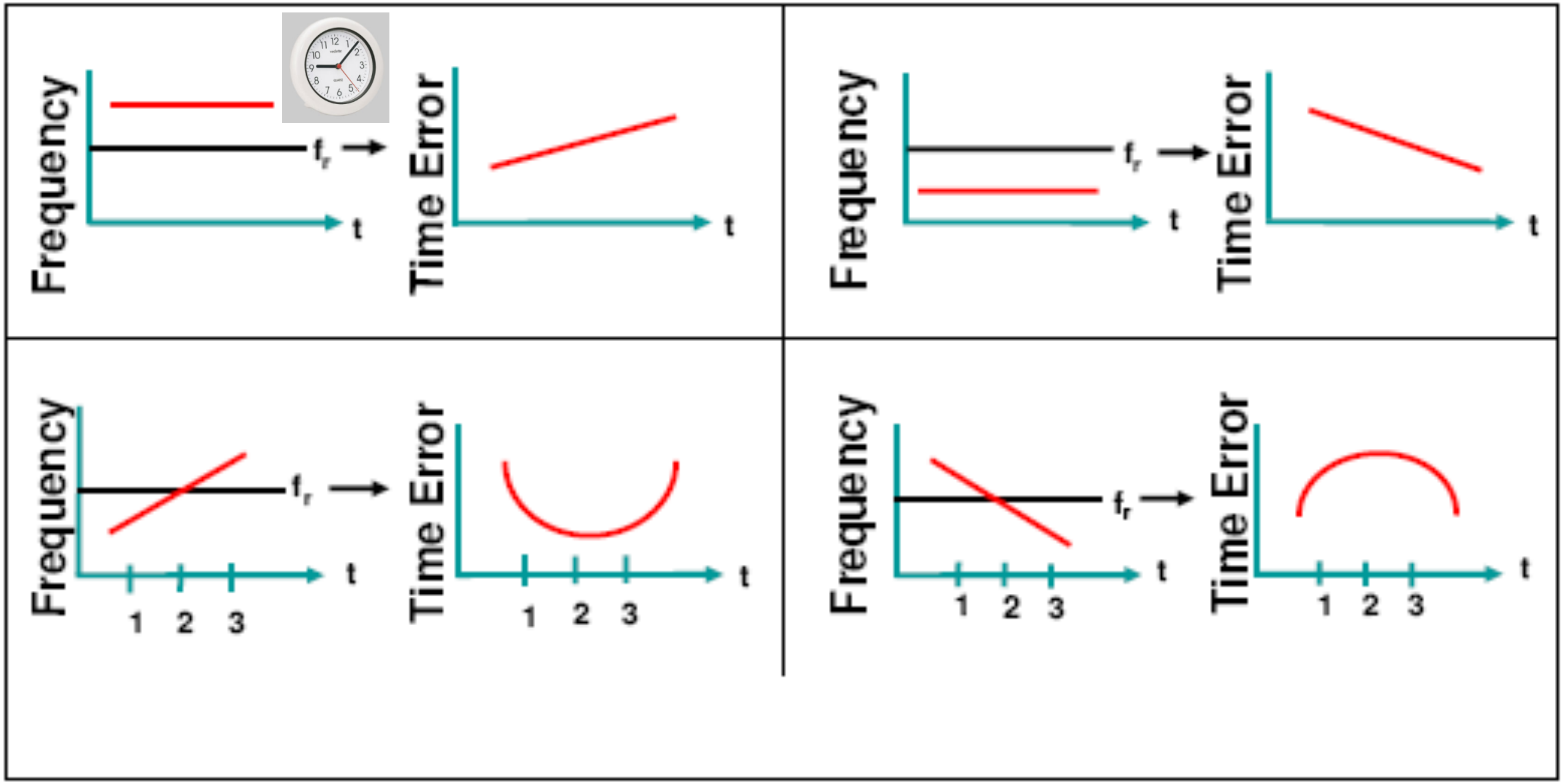
=

~ 12’000 Km

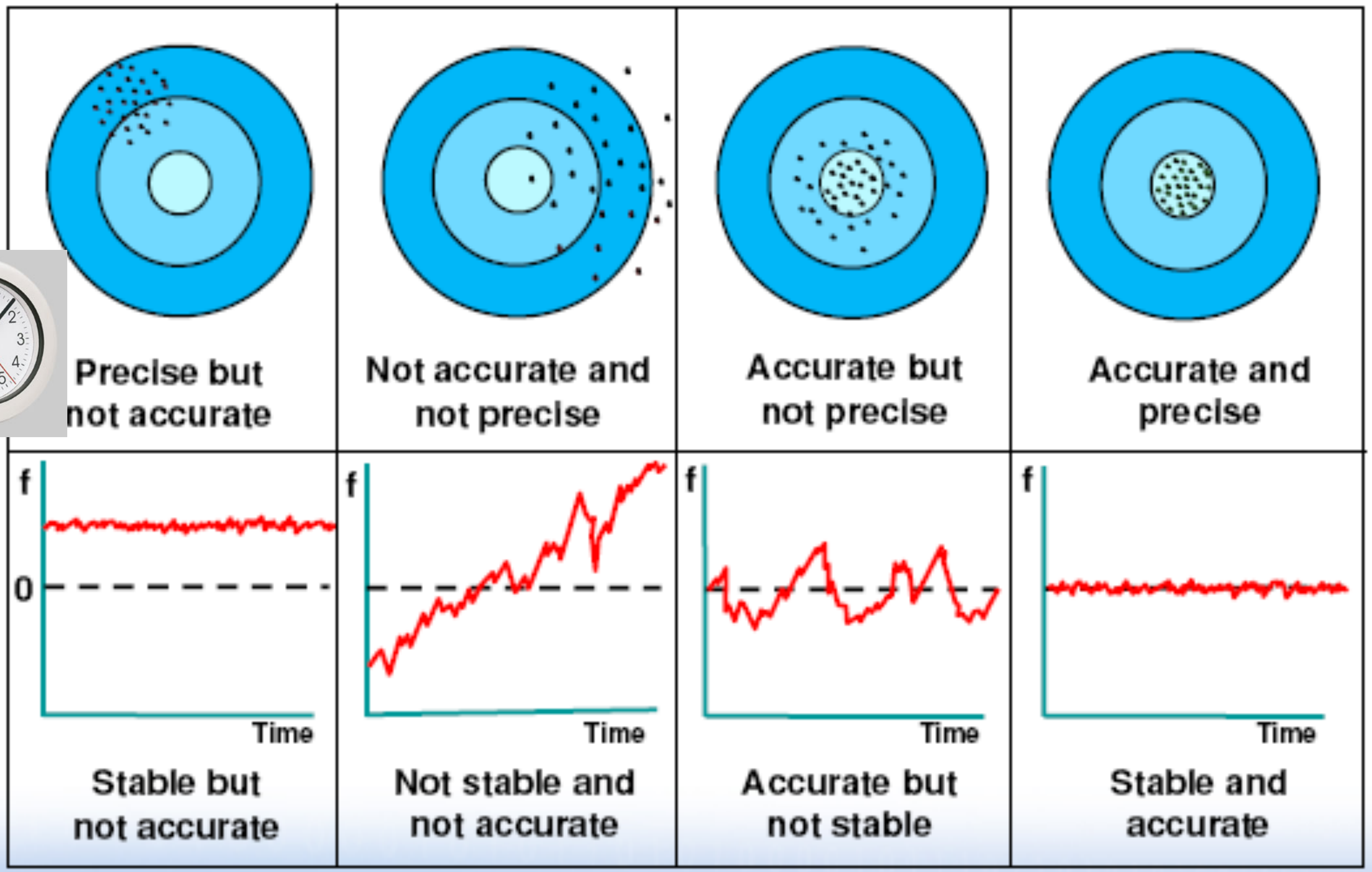
$X(t) = 1.15 + 0.0000133\ t$

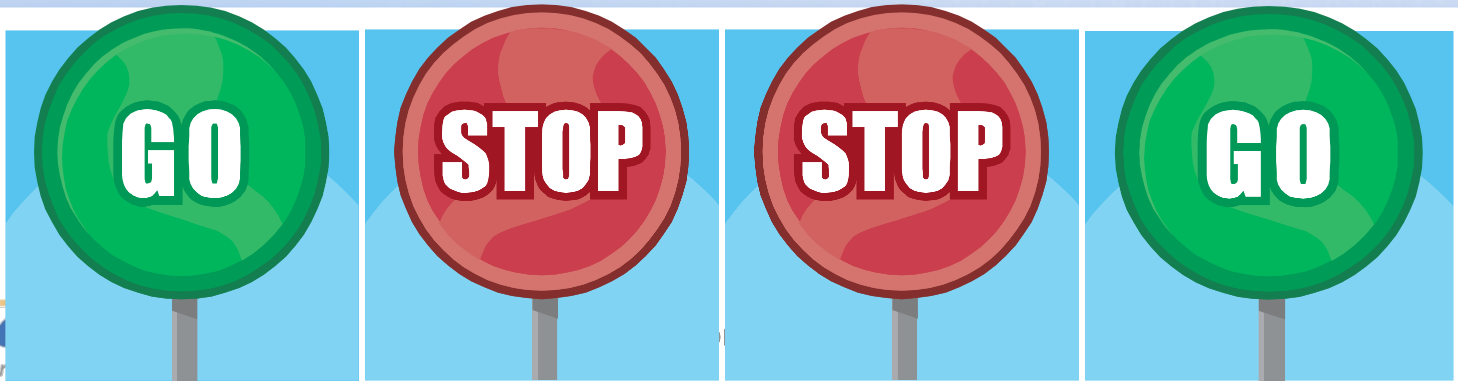
t=0

t

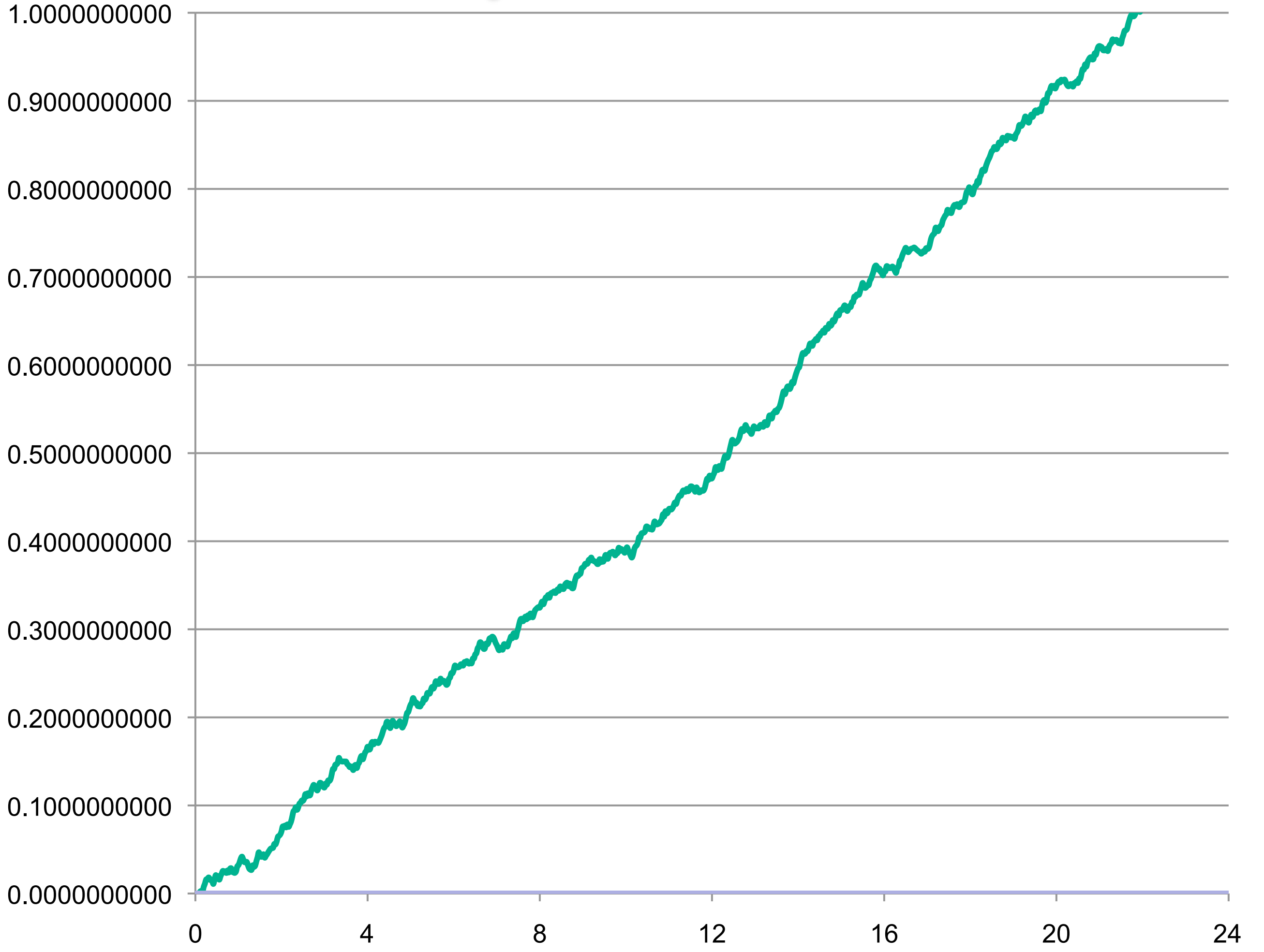


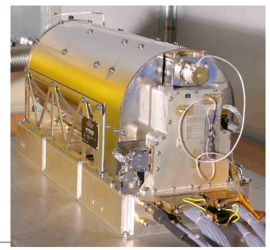
Frequency
f_r
t
Time Error
t
Frequency
f_r
t
Time Error
t
Frequency
f_r
t
1 2 3
Time Error
t
1 2 3
Frequency
f_r
t
1 2 3
Time Error
t
1 2 3


Precise but
not accurate
Not accurate and
not precise
Accurate but
not precise
Accurate and
precise
f
0
Time
Stable but
not accurate
Not stable and
not accurate
Accurate but
not stable
Stable and
accurate

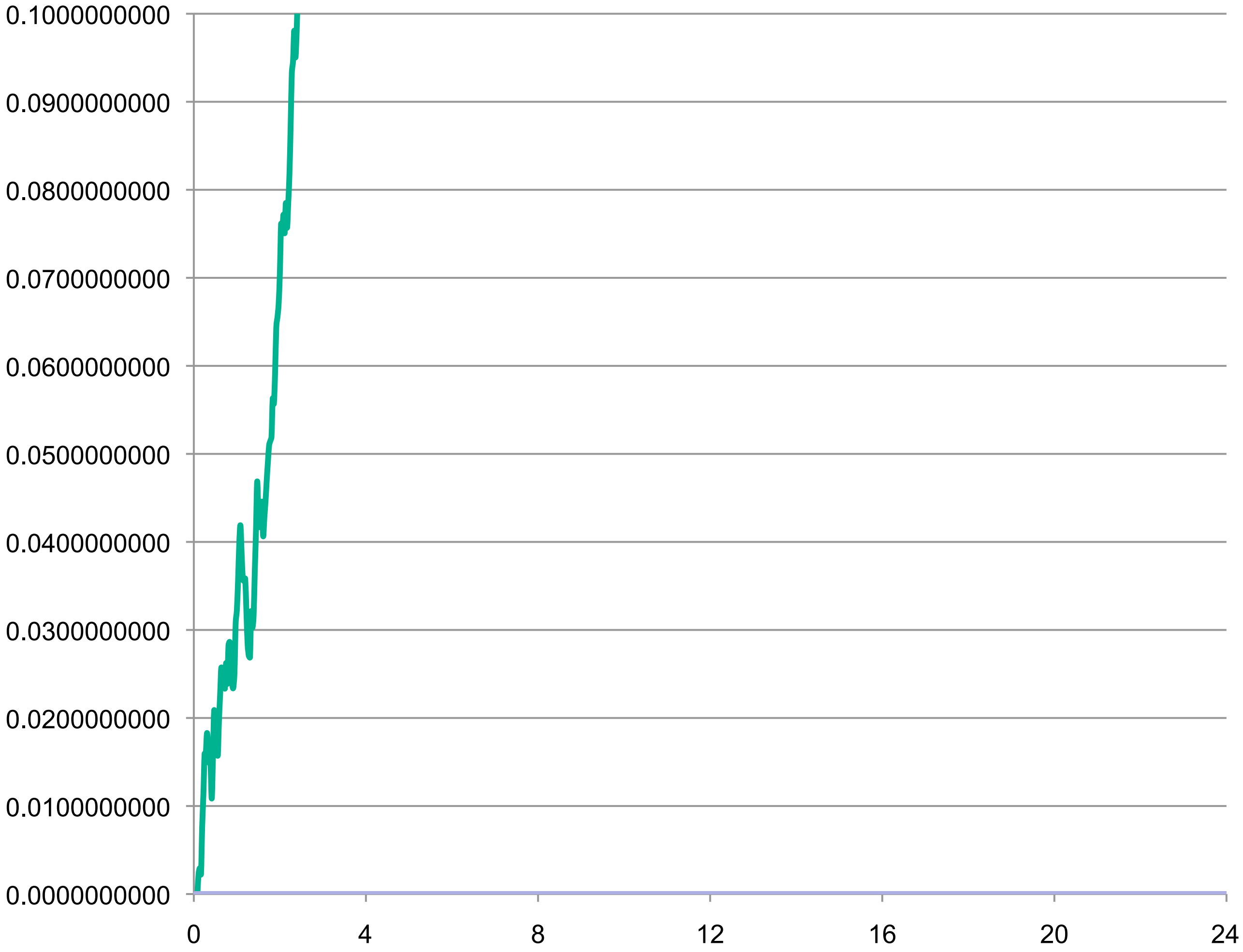

GO
STOP
STOP
GO

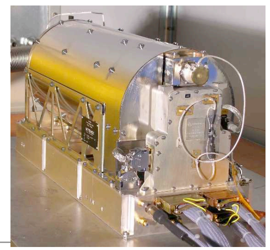
Clocks Comparaison: Scale : + 1 sec



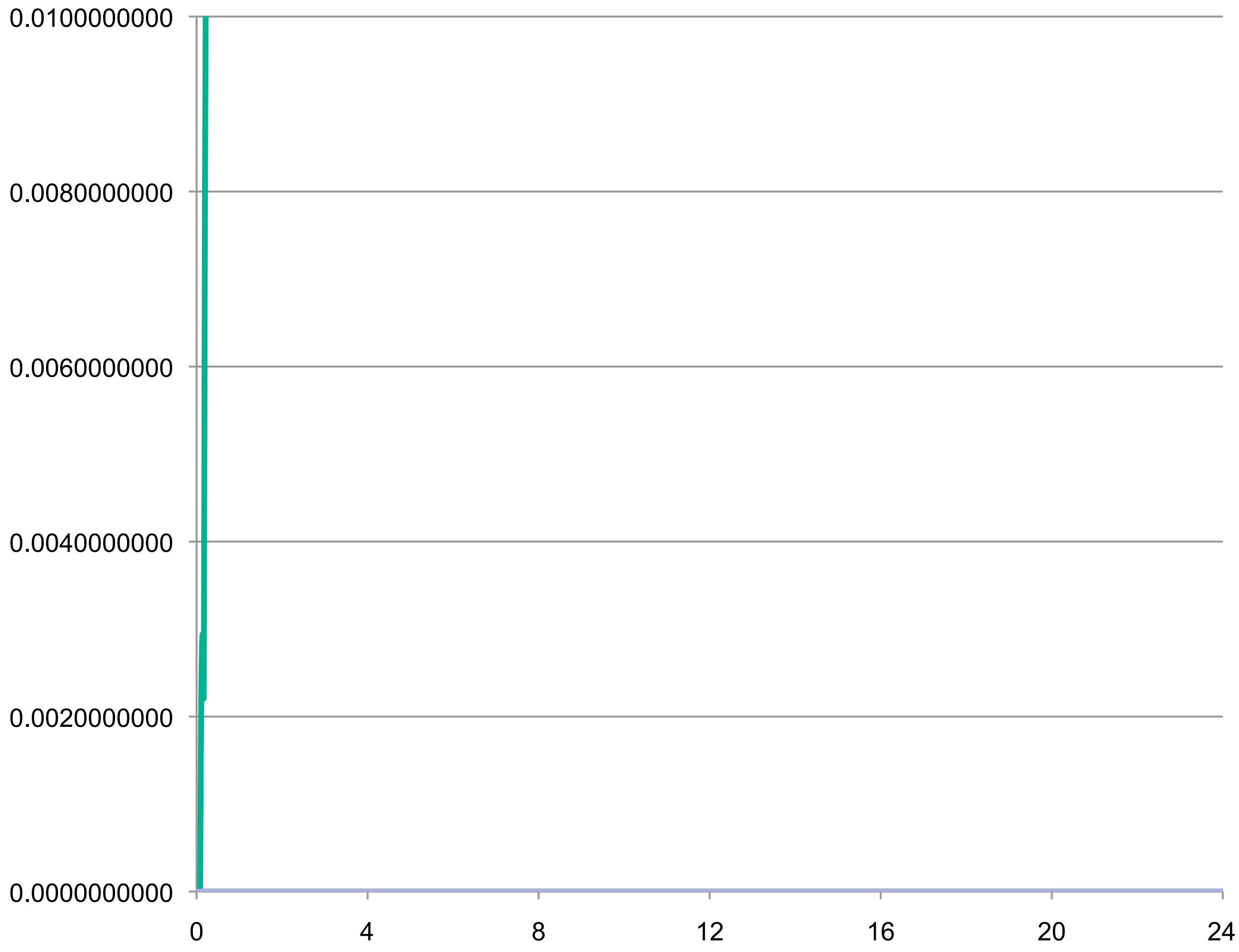


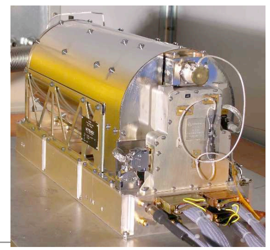
Clocks Comparaison: Scale : : +0.1 sec



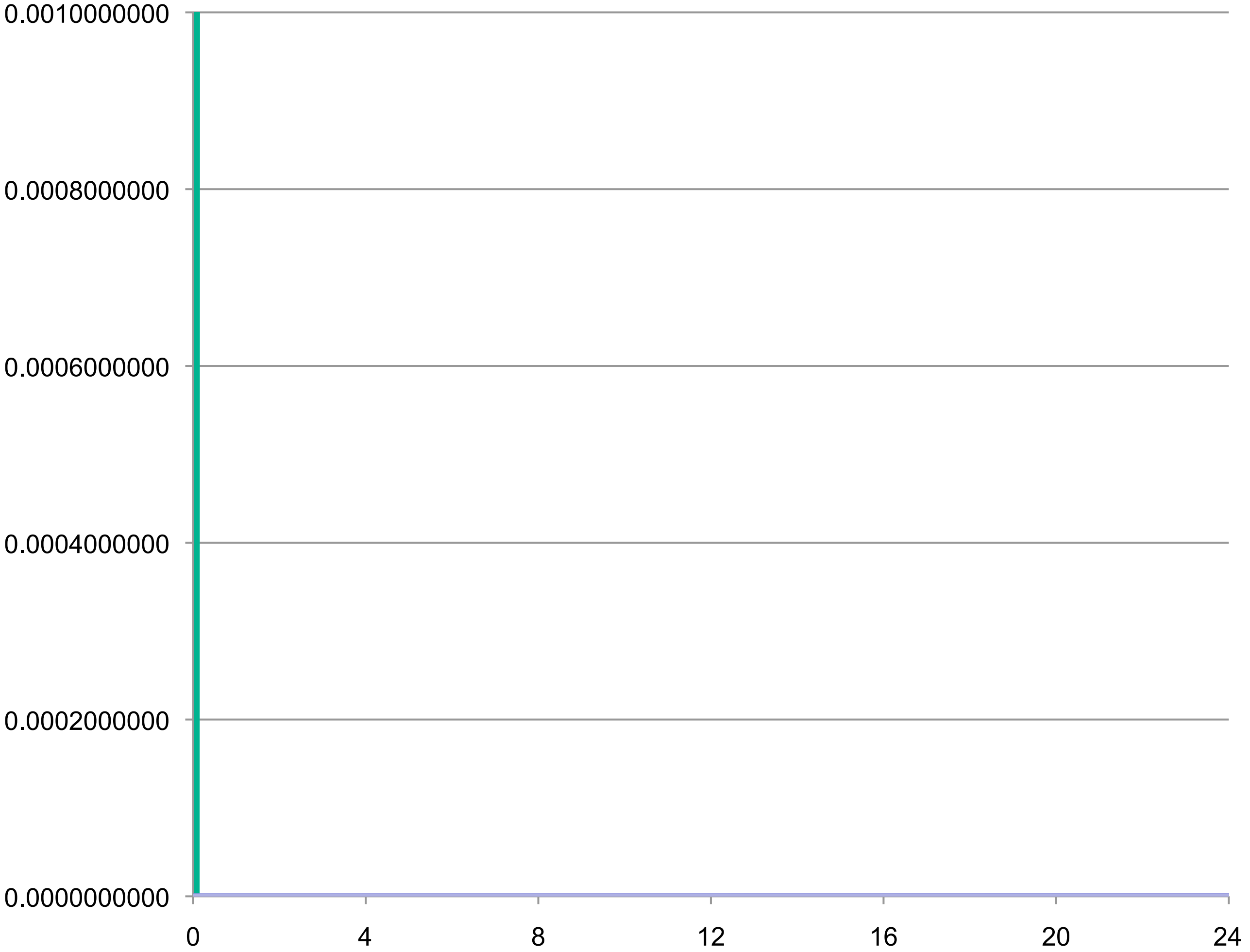


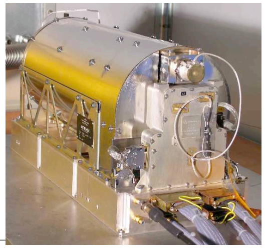
Clocks Comparaison: Scale : : +0.01 sec



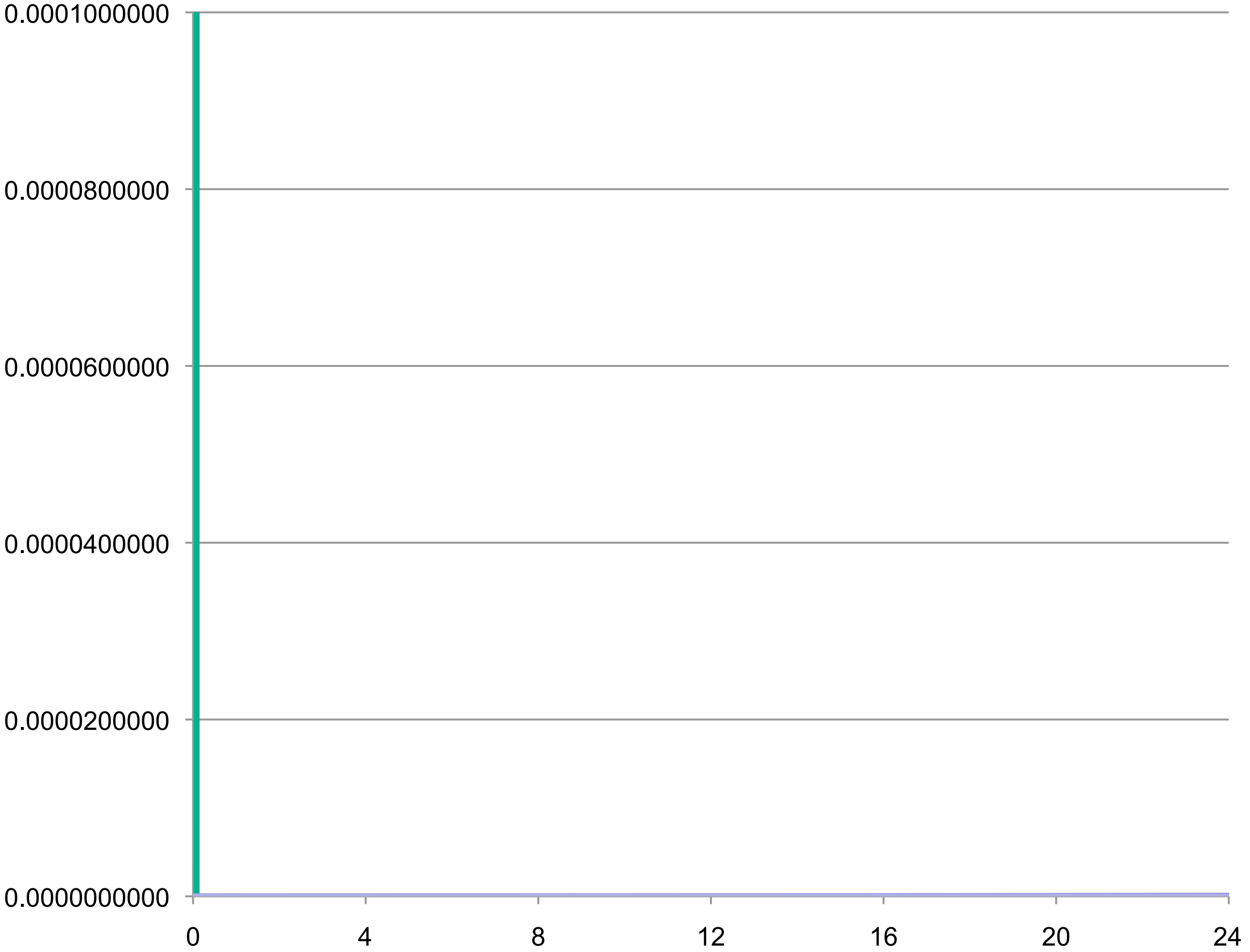


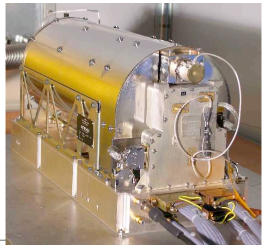
Clocks Comparaison: Scale : : +0.001 sec



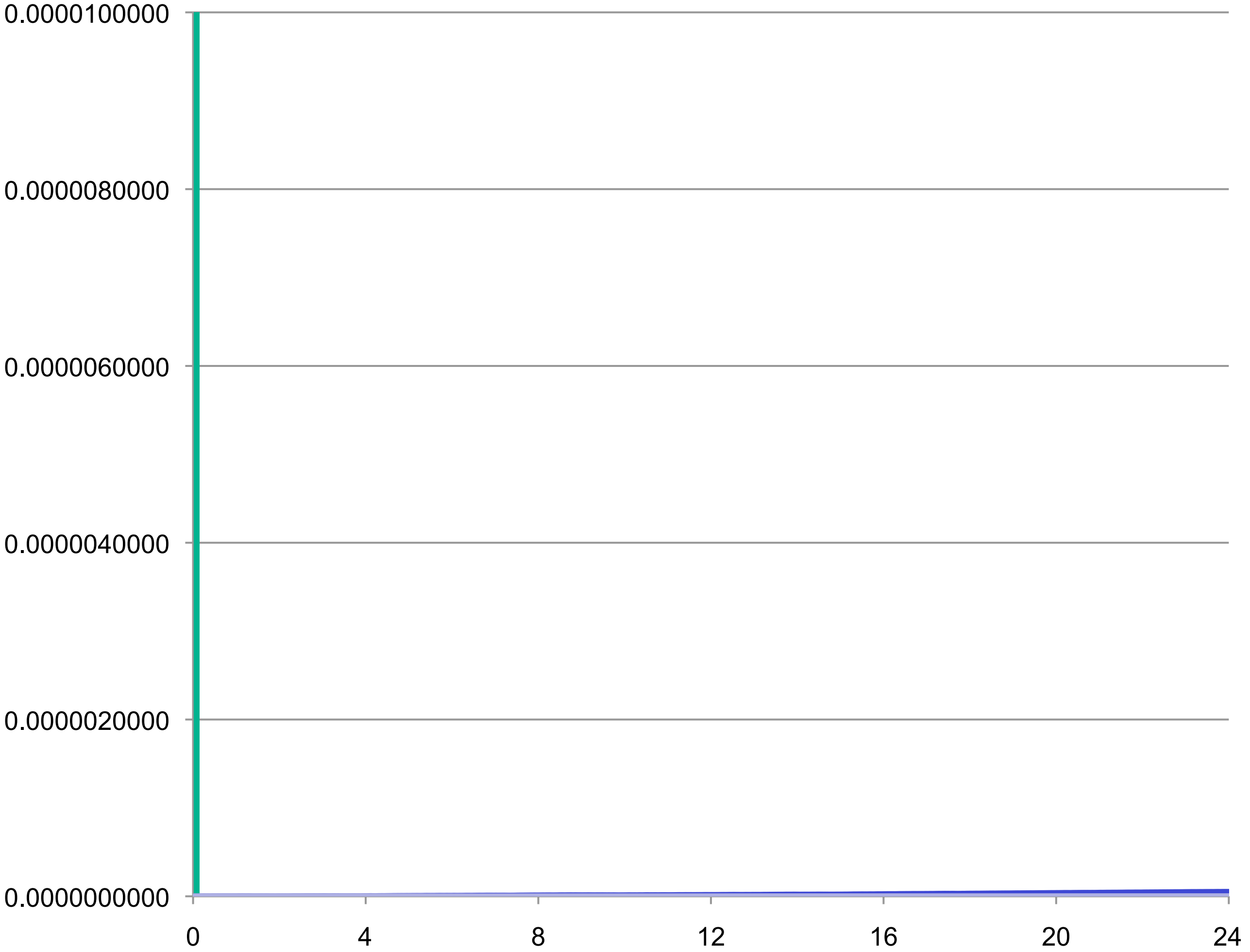


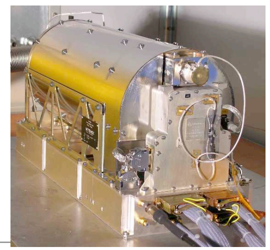
Clocks Comparaison: Scale : +0.0001 sec



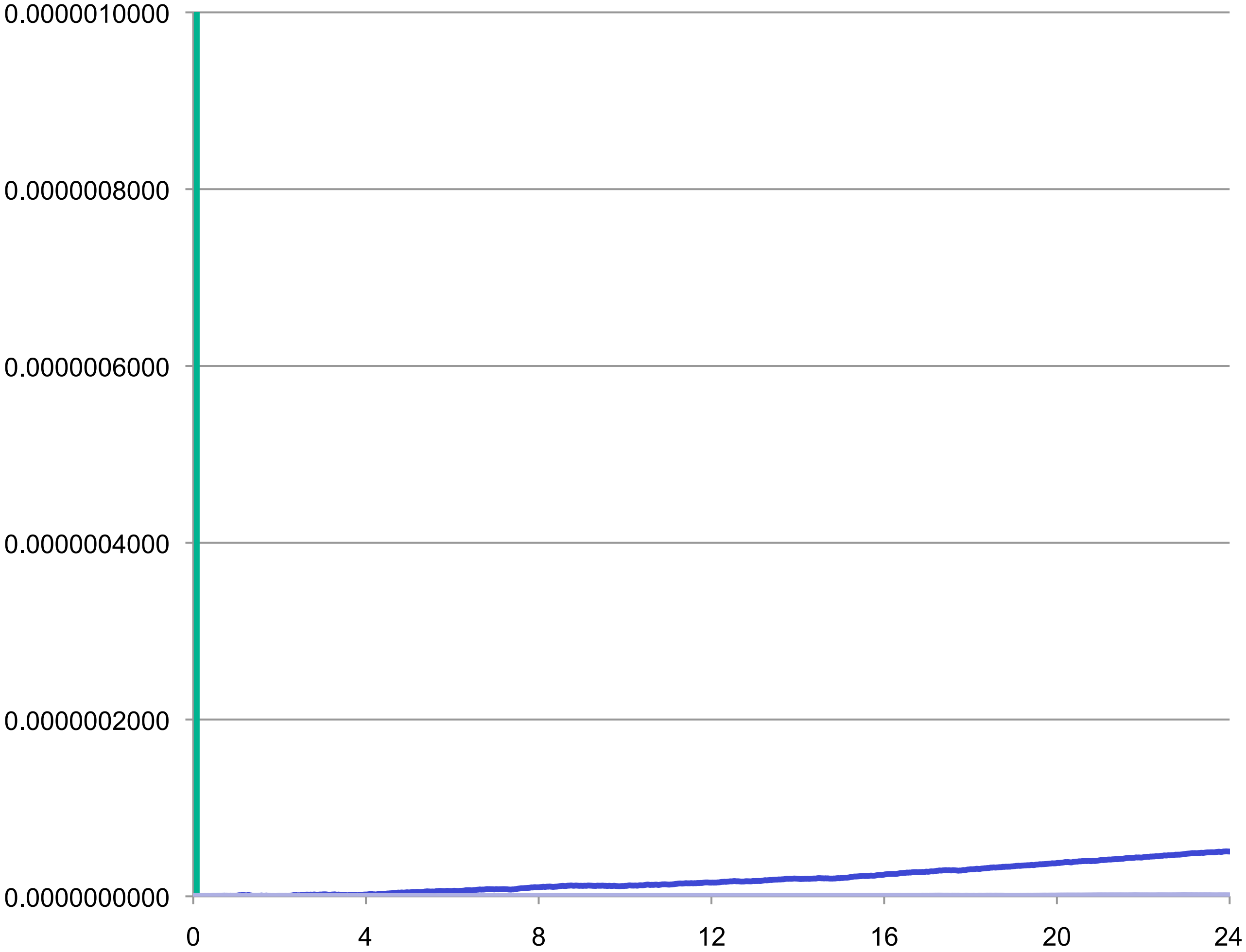


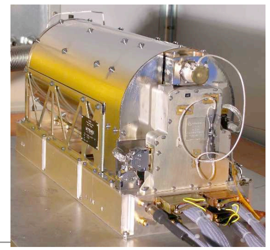
Clocks Comparaison: Scale : : +0.00001 sec



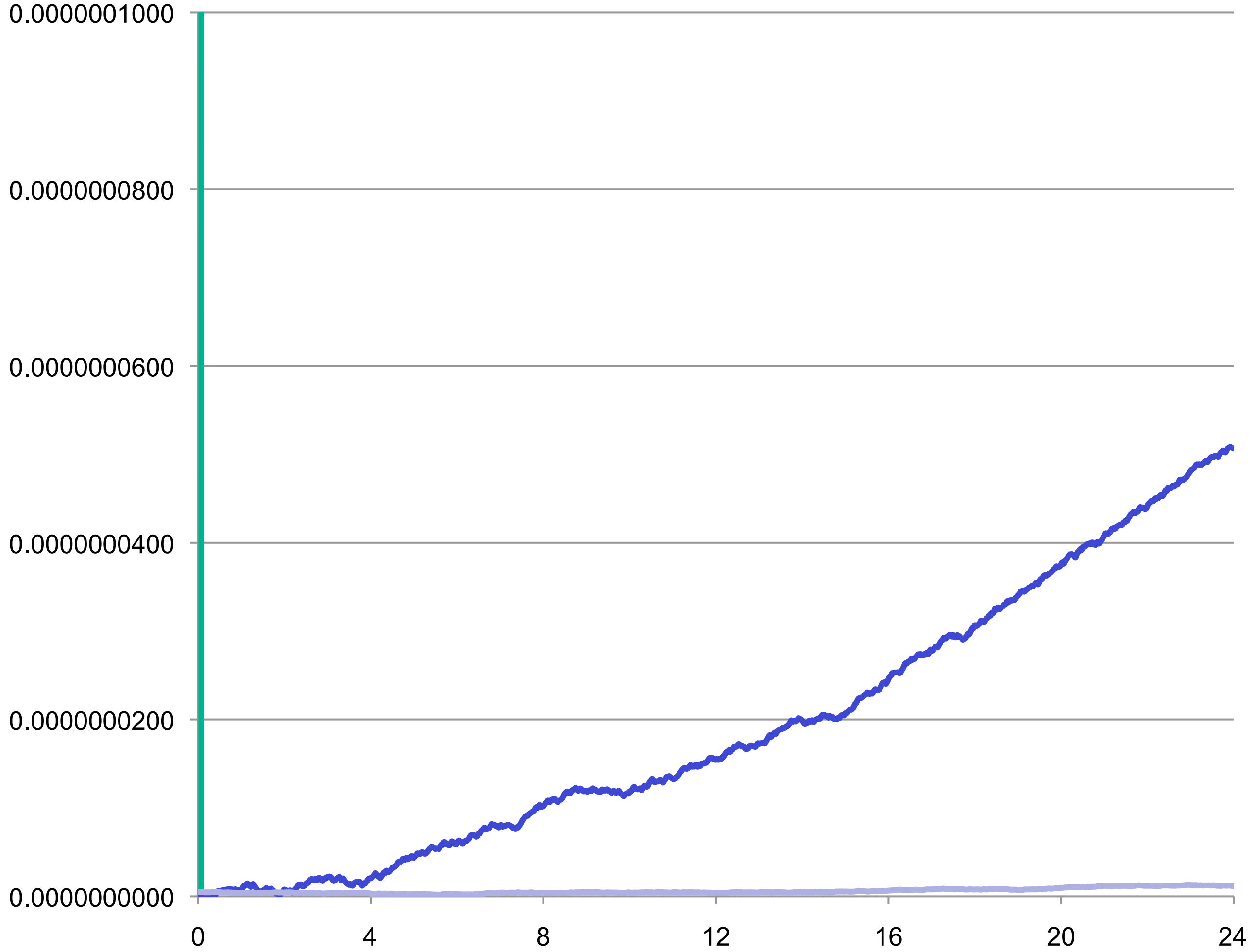


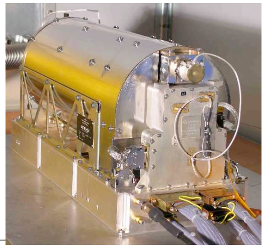
Clocks Comparaison: Scale : +0.000001 sec



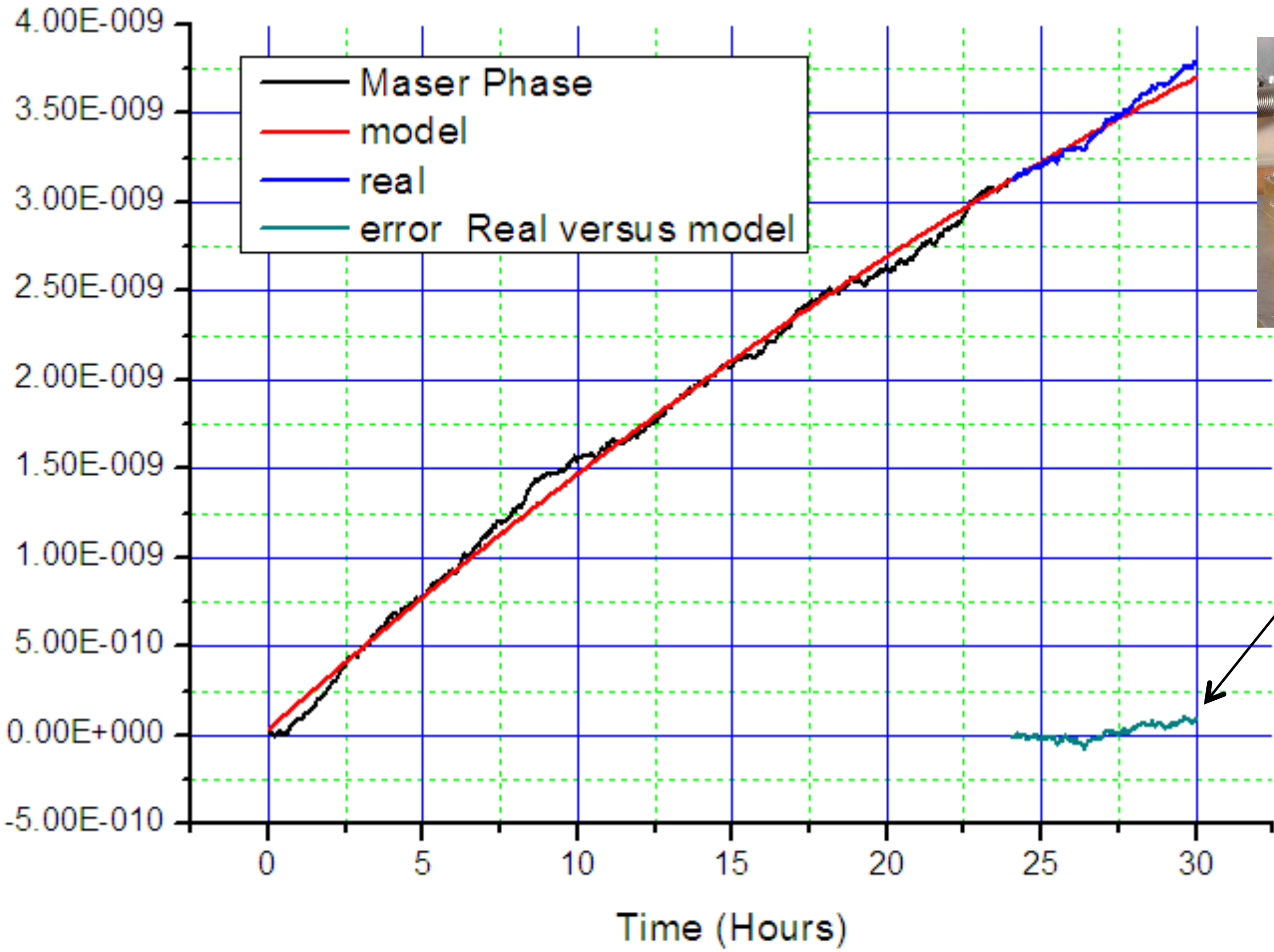


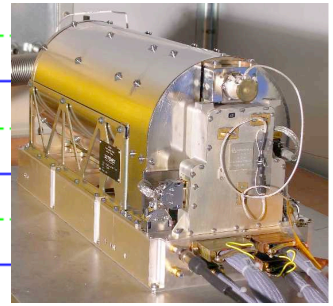
Clocks Comparaison: Scale : +0.0000001 sec





Position error induced by the on board passive maser:

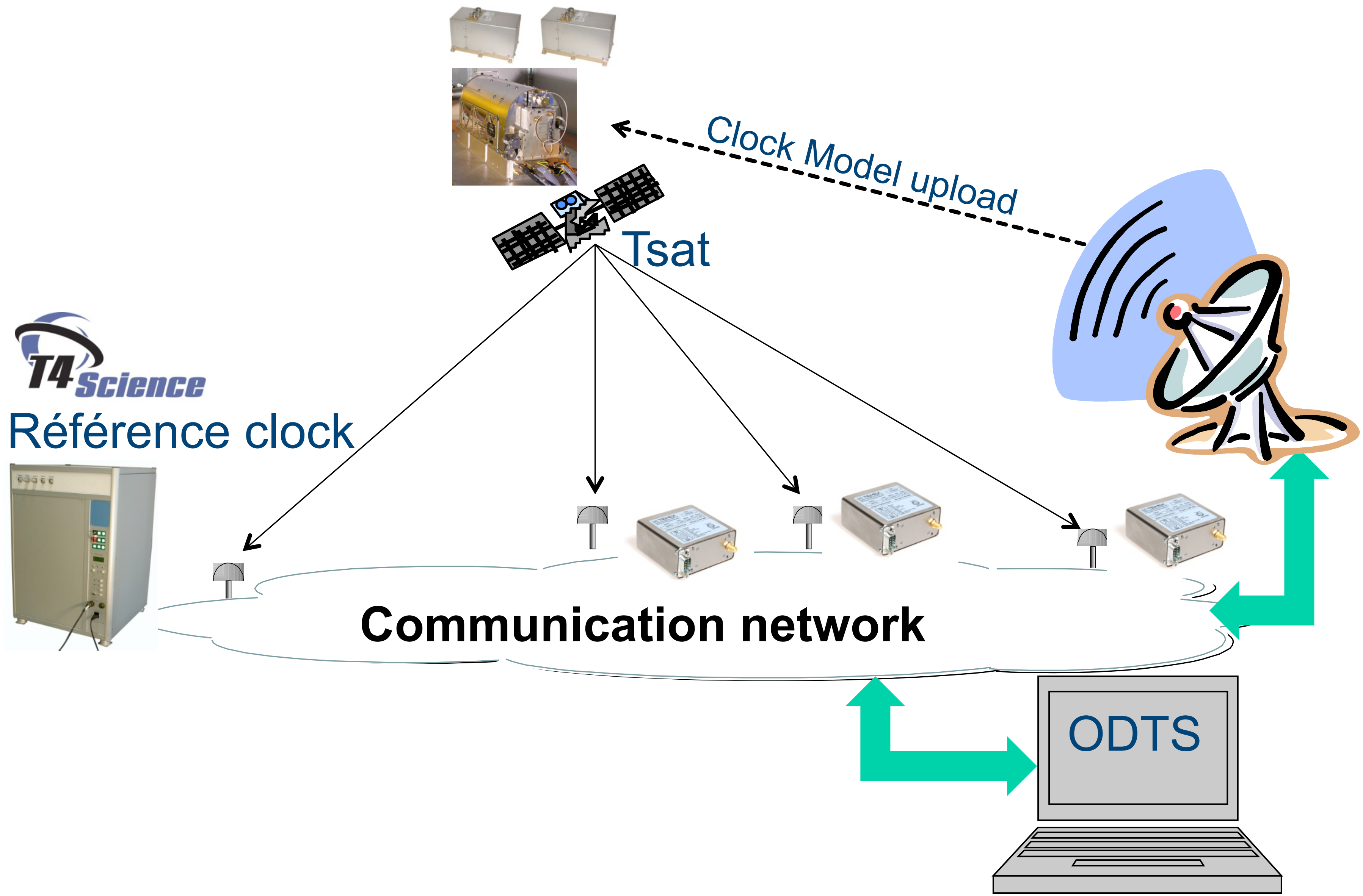




~ 0.1 ns

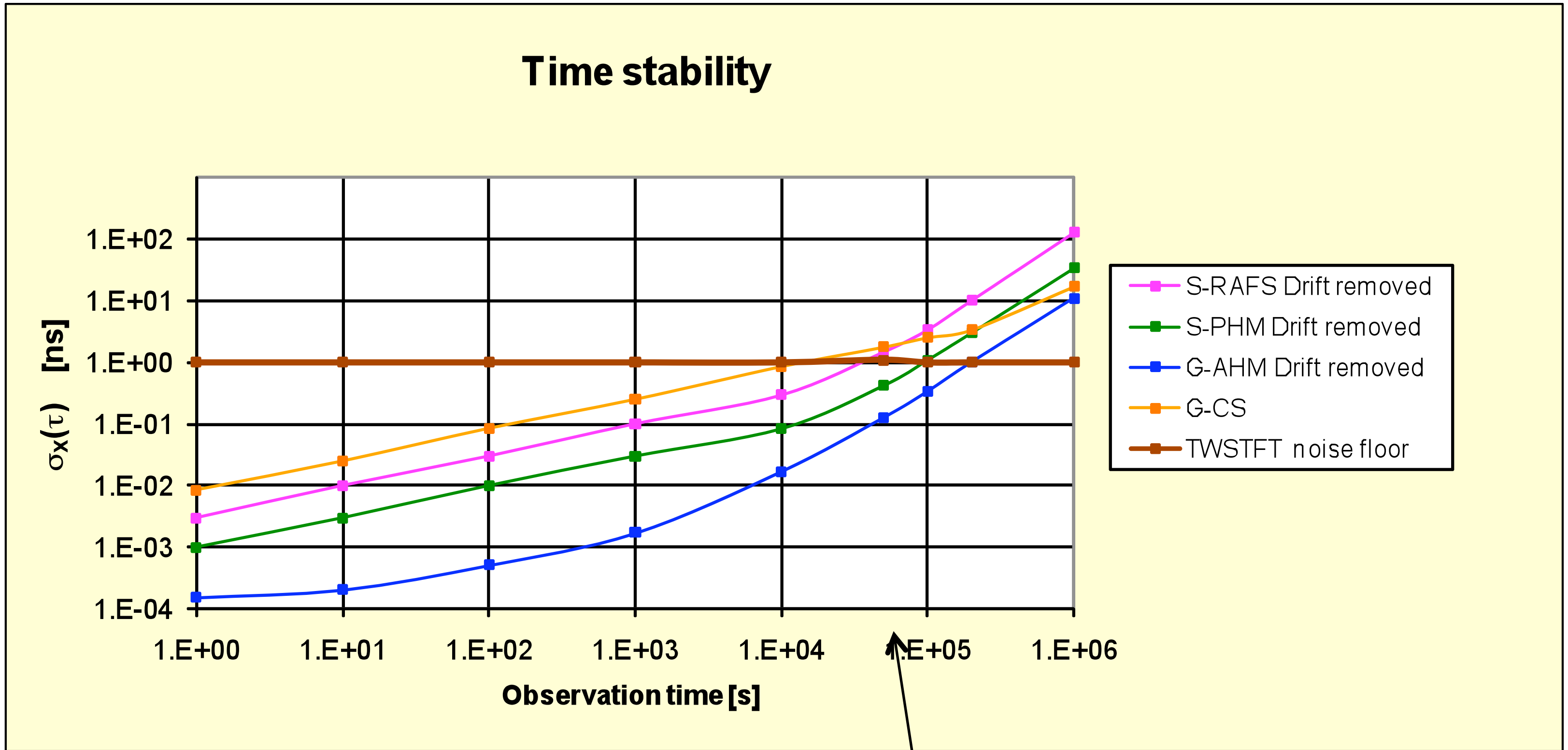
soit

~ 3 cm



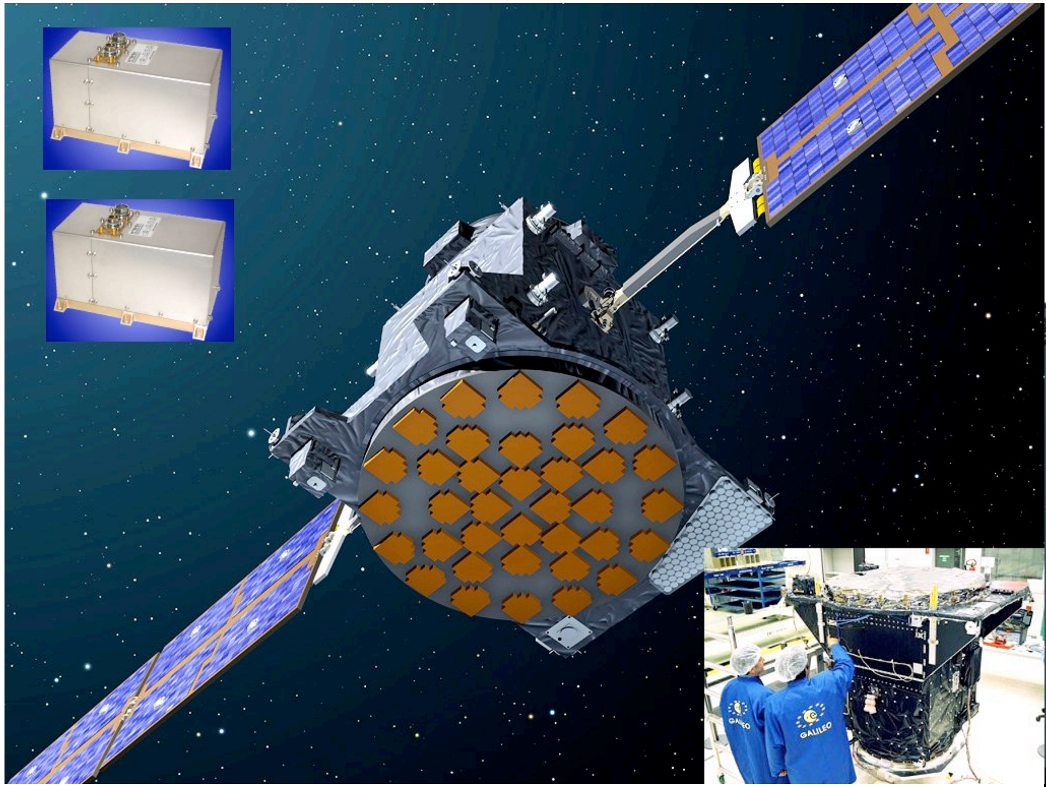
Clock Model upload
Tsat
Référence clock
T4Science
Communication network
ODTS

Stabilité de temps des horloges du système:



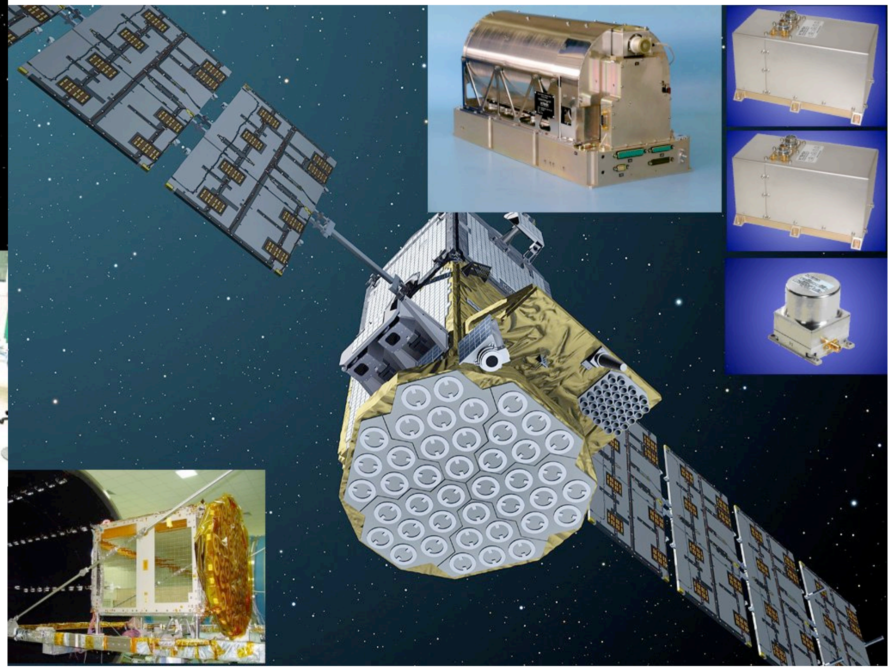
1 jour

GIOVE Satellites



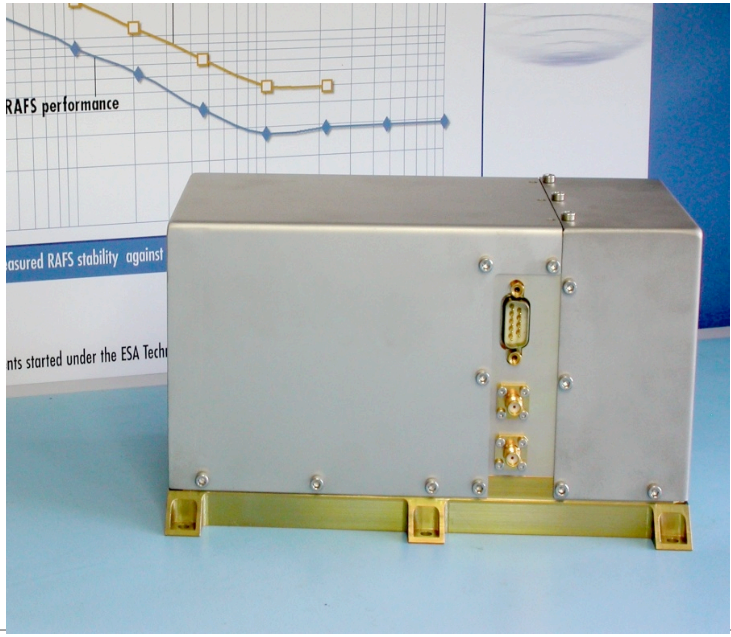
GIOVE A & A2

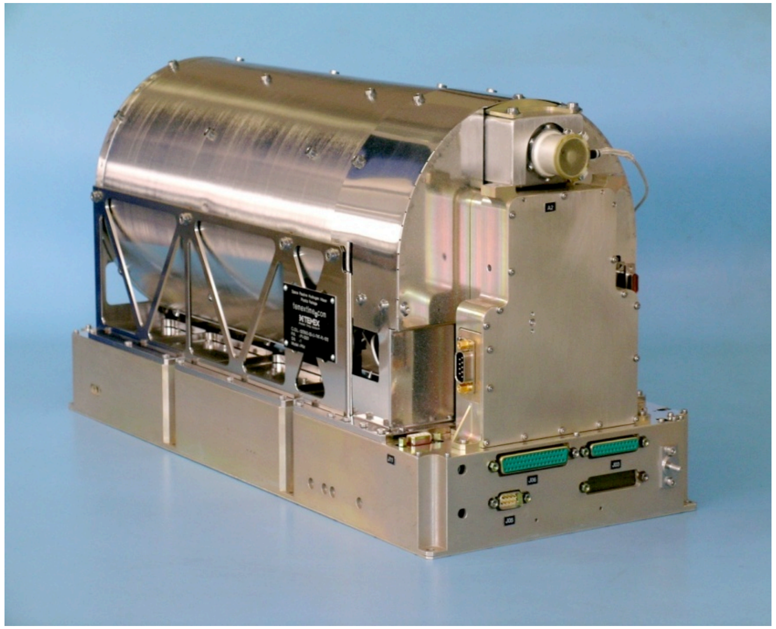
GIOVE B



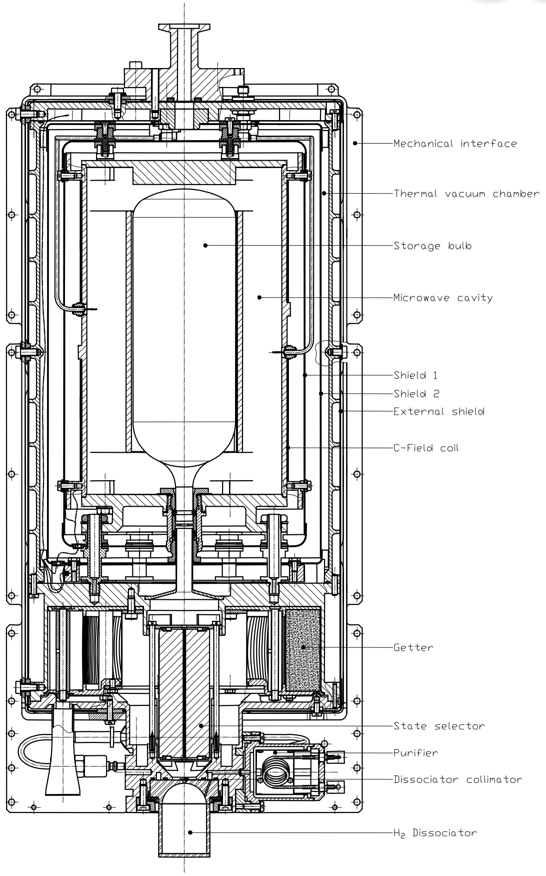
Present Onboard Clocks for Galileo

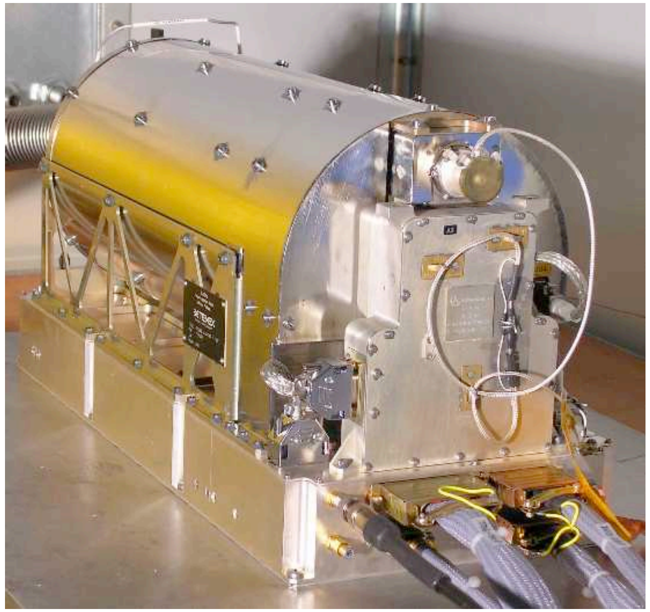
- Two baseline clock technologies
  - Rubidium Atomic Frequency Standard (RAFS)
  - Passive Hydrogen Maser (PHM)





Passive Hydrogen Maser for Galileo





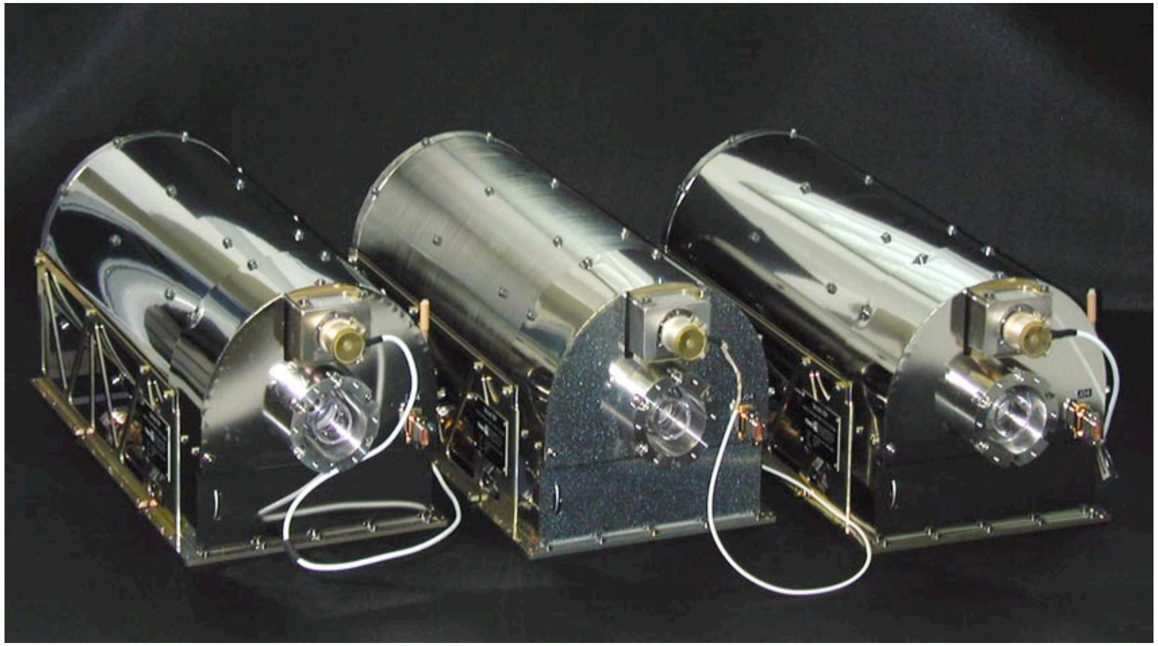
Complete clock
delivered for Giove B sat

Galileo Avionica

PHM Tests & Qualification (1/2)

PHM Industrialisation

- First Main efforts focused on definition of repeatable and reliable manufacturing processes
- Overall structure and design reviewed to increase compactness / robustness. This was done for both EP and PP



- New microwave assembly design to improve the AIT process on the satellite (inclusion of an external vacuum envelope)
- Manufacturing and qualification of 4 EQMs, two of them are under test for *lifetime estimation*

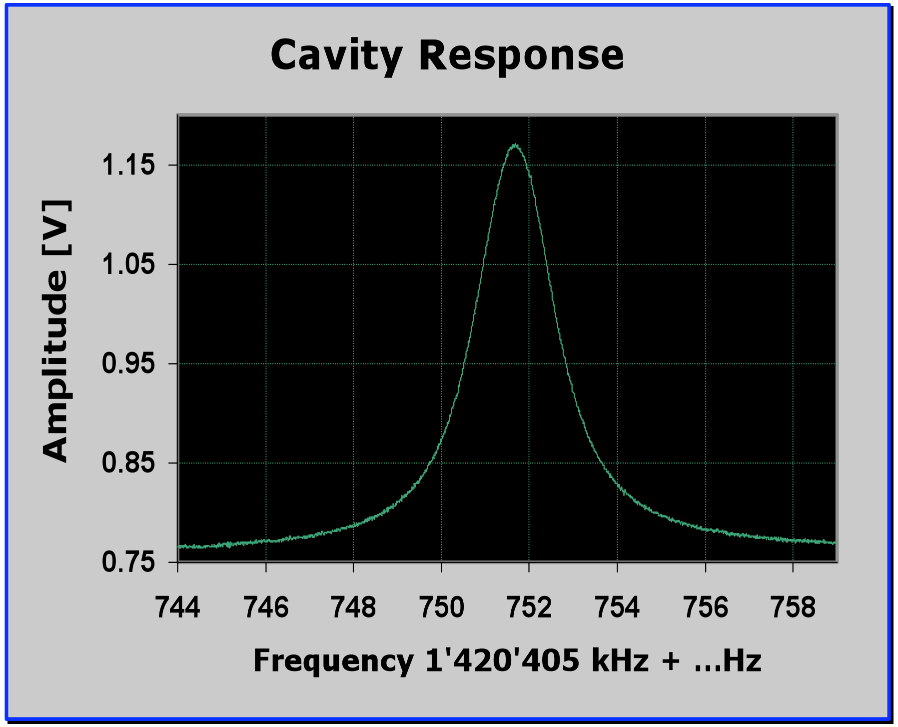
PHM Tests & Qualification

PHM Characterisation

- Exemple of sub-assembly characterisation (Microwave Cavity sub-assembly) with SpectraTime specific measurement system

At nominal operational condition,

- Gain: 3.6 dB
- Line width: 2Hz



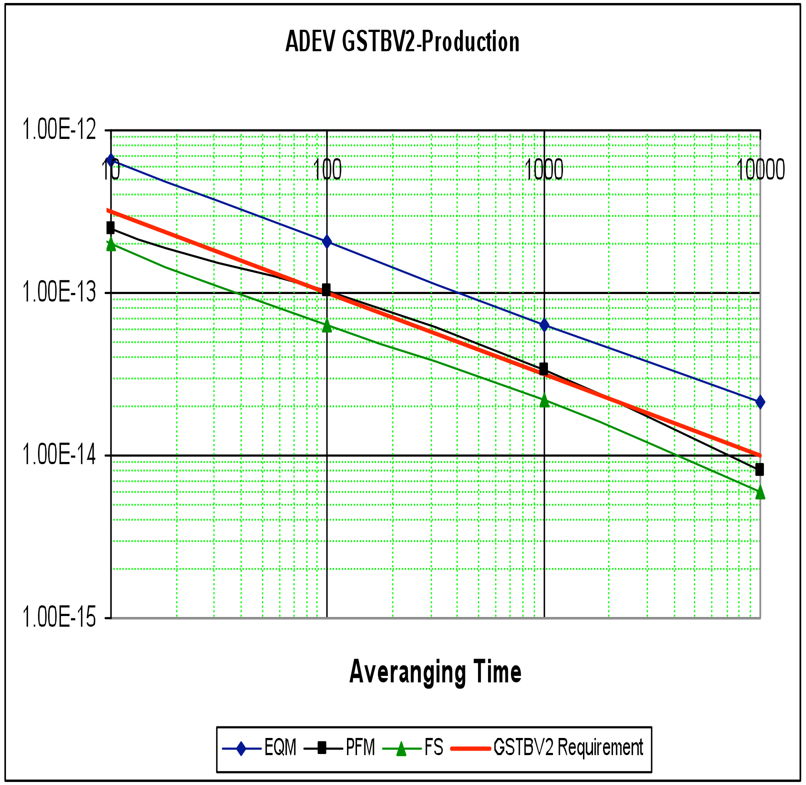
PHM Production Activities

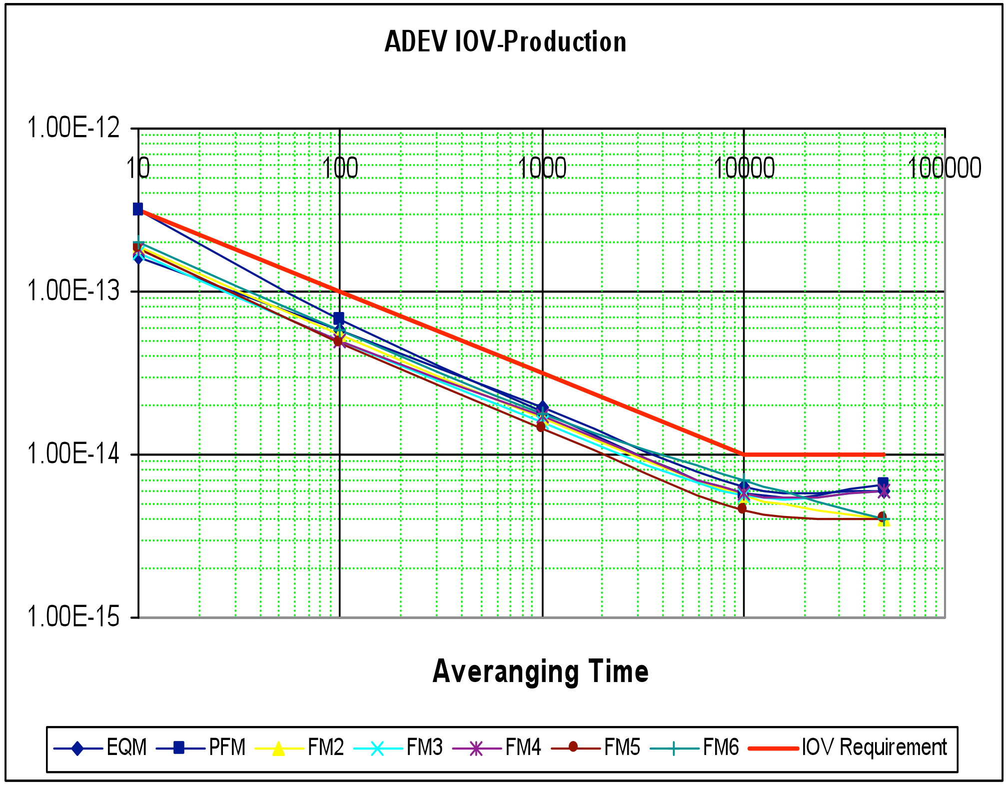
- GSTB-V2
  - 1 EQM clock delivered to Astrium Ltd in Mars 2005
  - 1 PFM delivered in May 2005 to fly on GIOVE-B
  - 1 FM delivered February 2006 as Flight Spare

- In Orbit Validation (IOV)
  - 1 EQM clock delivered after additional qualification tests according to new requirements in April 2008
  - 8 FM clocks under final integration.& testing

IOV Masers versus GSTB-V2

- Performances improvement:
  - Better control on processes and adjustments led to better stability





BUDGET D'ERREURS

Bilan d'erreur typique de Galileo

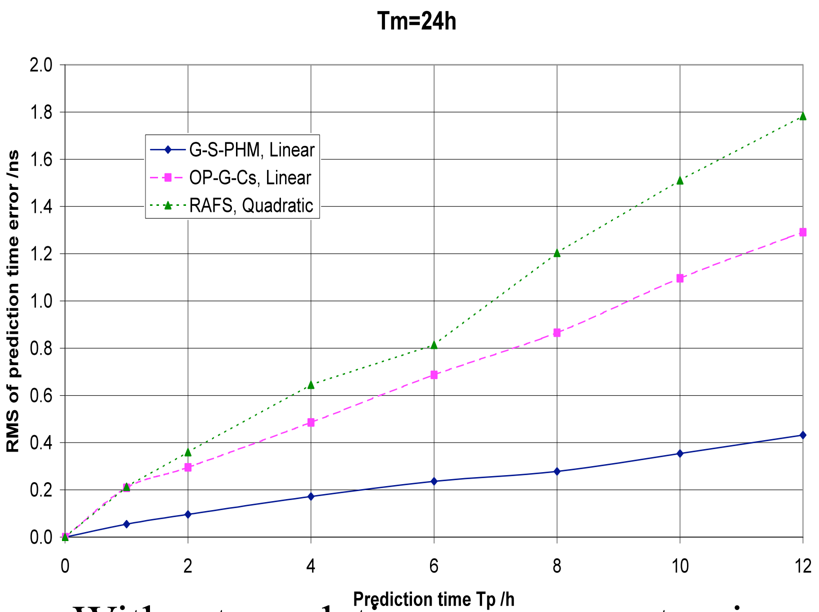
User Equivalent Range Error Budget (UERE)

Utilisateur Bi-Fréquence	
Détermination d'orbite **Synchronisation du temps**	0.65 m
Troposphere & Ionosphère	0.25 m
Multitrajets	0.2 m
Poursuite du récepteur	0.2 m
TOTAL (ΣErreurs Rms)	**0.8 m**
L'UERE est défini pour des angles d'élévation de 30 à 40 degrés	

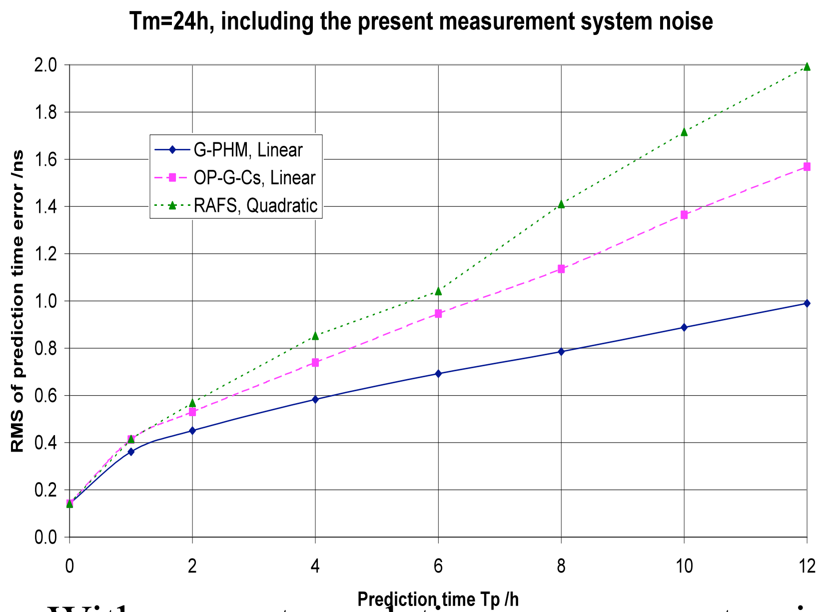
UISBA, Bayonne 17 octobre 2003 27

27

Clocks prediction error Tm=24h

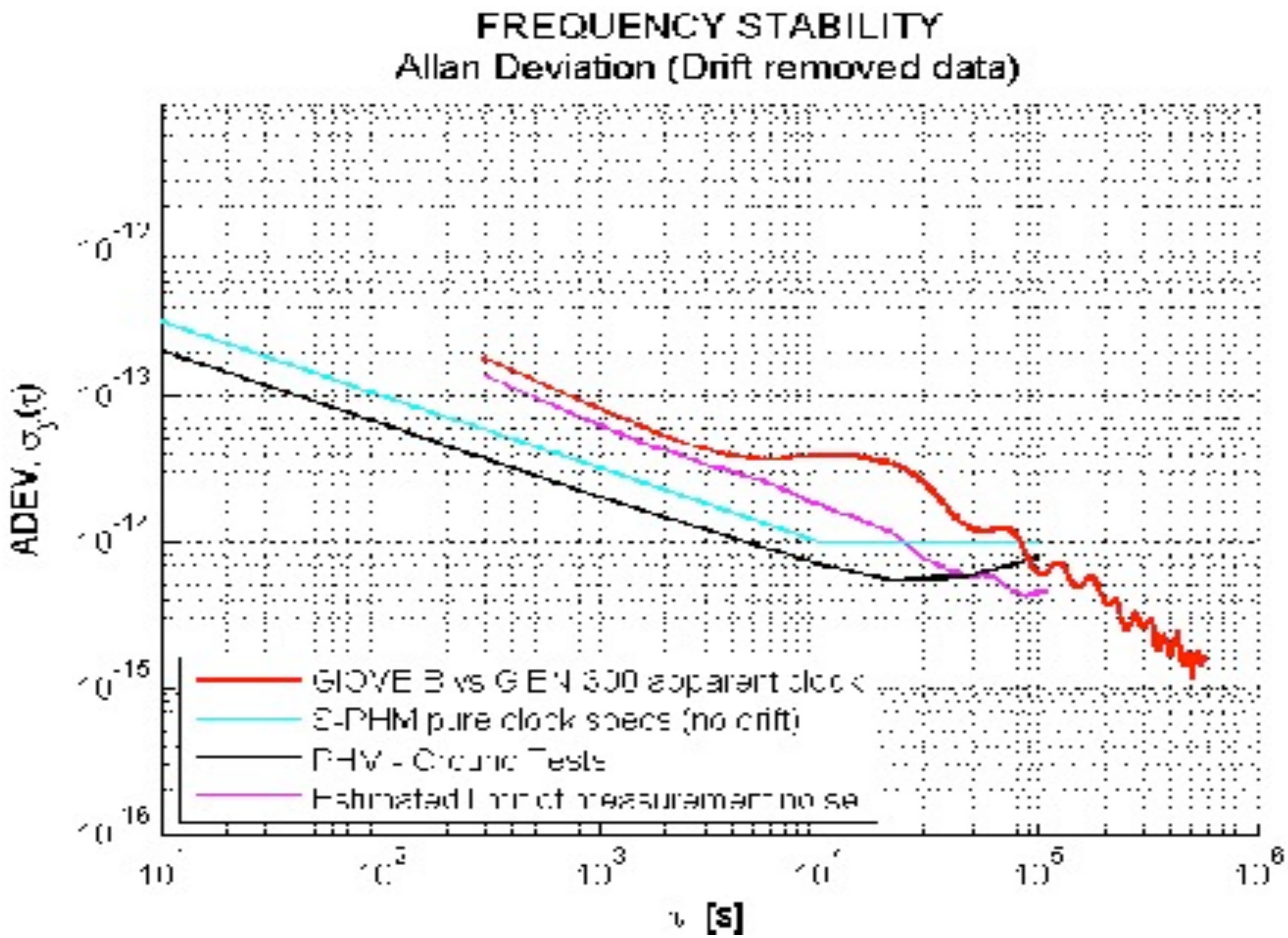


Without geodetic measurement noise

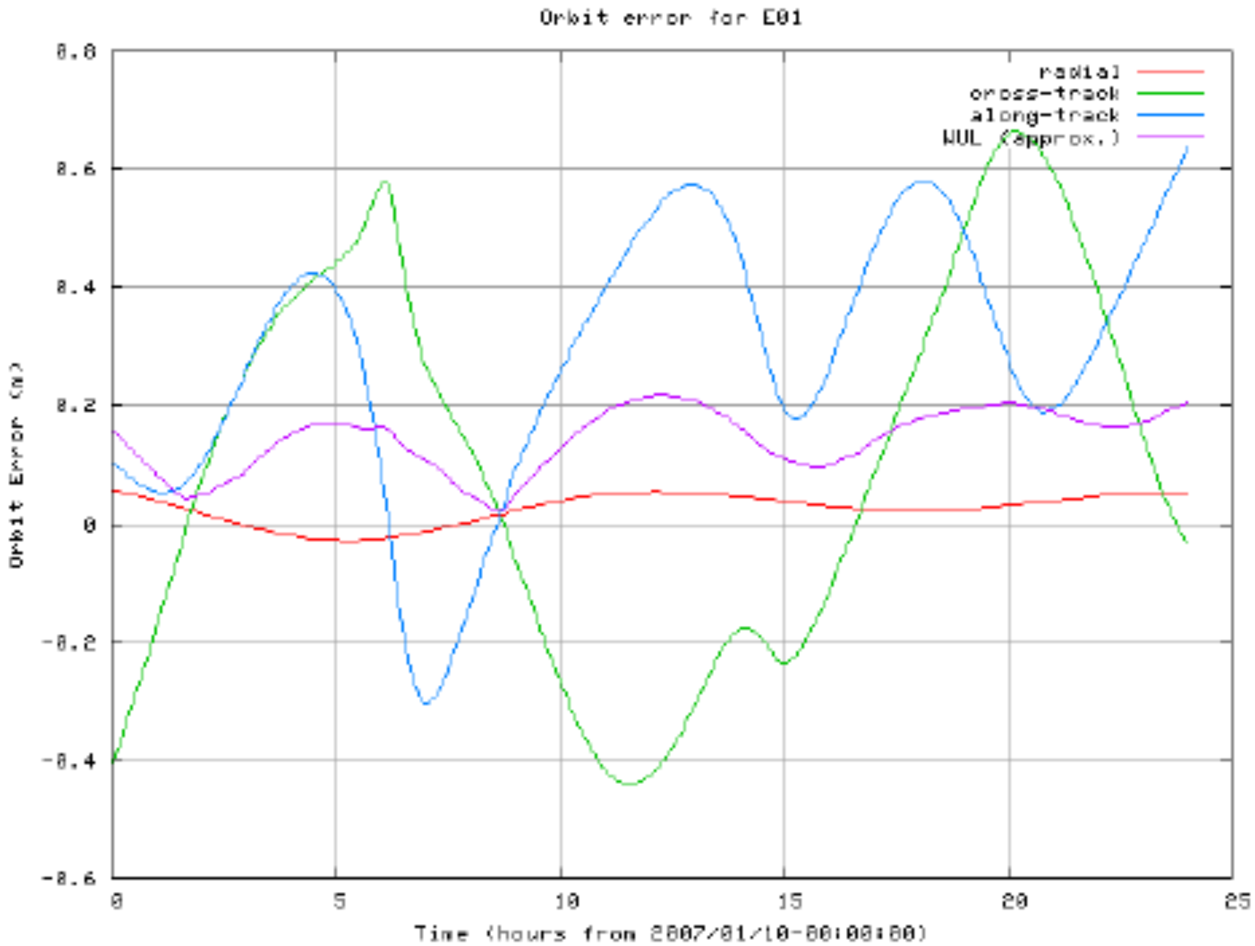


With present geodetic measurement noise

On board clocks are not the limiting factor for precison of satellites navigation systems -> A possible evolution could be to place 'ultra-stables ' clocks in GEO orbit with very precise 2 ways (3 bands) ranging from earth 5GEO_E.wmv

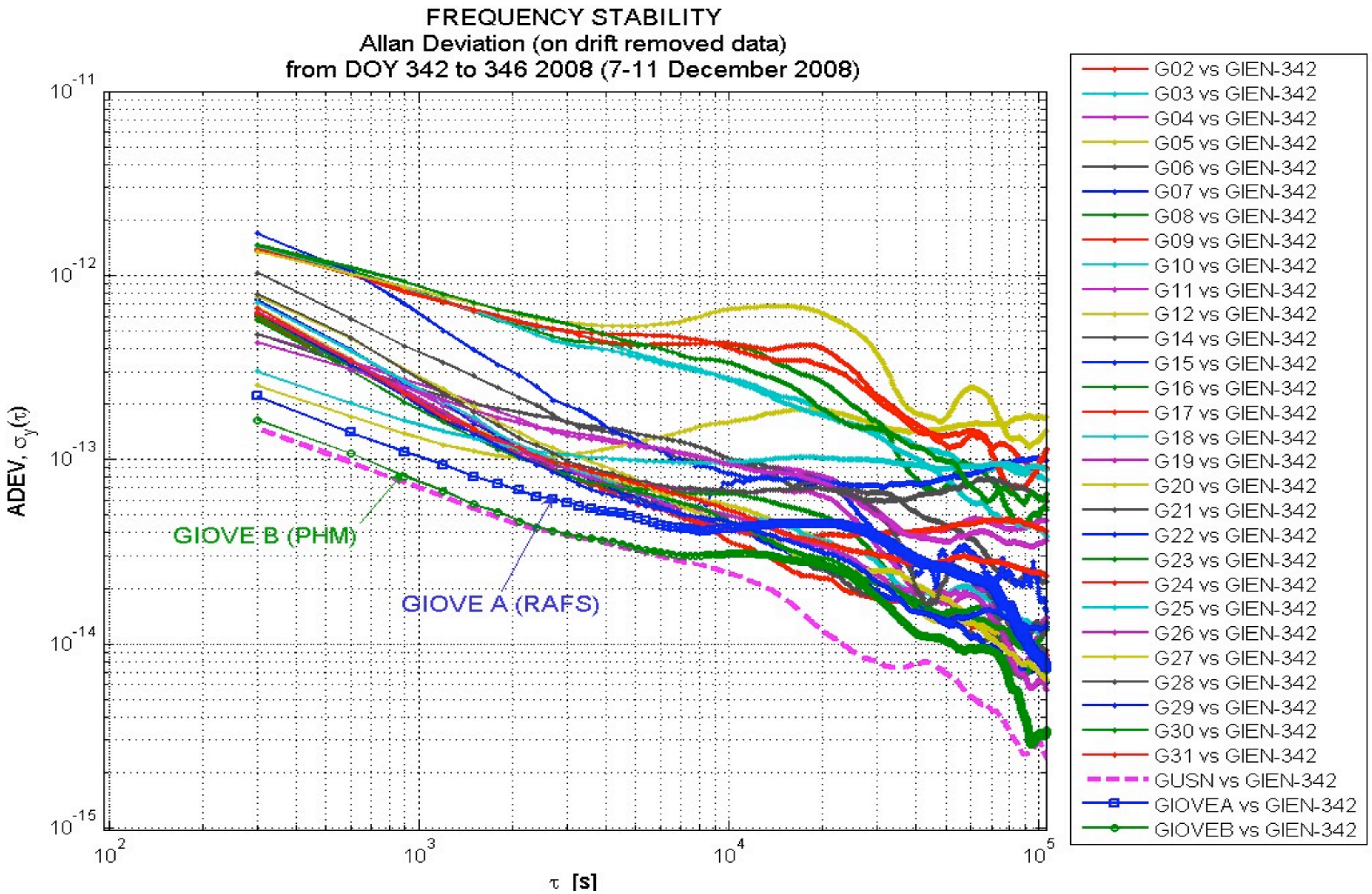


Presented at EFTF 2009 / GMV/ESA



GIOVE orbit prediction error

Source : GMV / ESA



Presented at EFTF 2009 / GMV/ESA

Thanks !

More info about atomic clocks on:

www.spectatime.com

&

www.t4science.com