Space Passive Hydrogen Maser

Performances, lifetime data and GIOVE-B related telemetries

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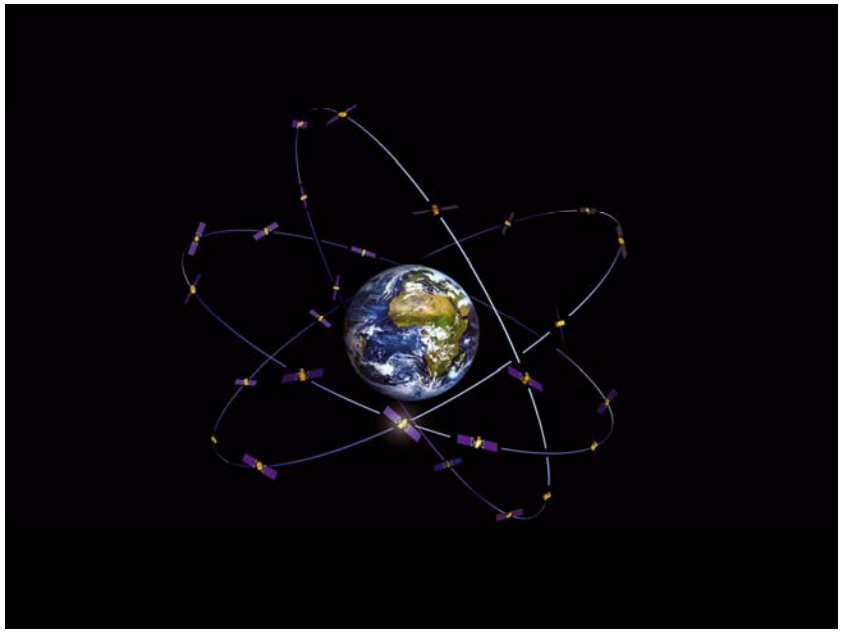
Presentation Outline

- Introduction
- Development & Qualification Activities of PHM
- PHM Activities for the In Orbit Validation
- Lifetime Facilities
- Correlation between Ground and Orbit Data
- Lifetime Ground Data
- Conclusions

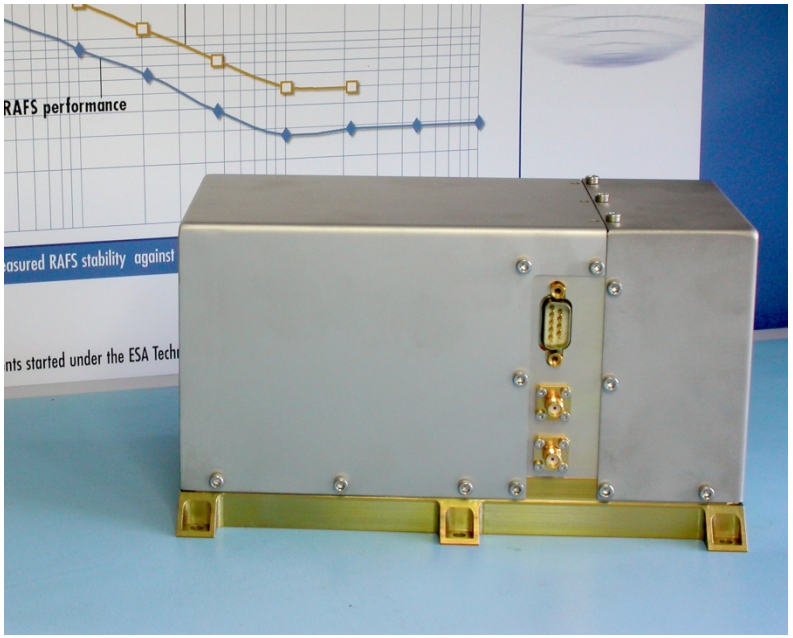
Galileo program description

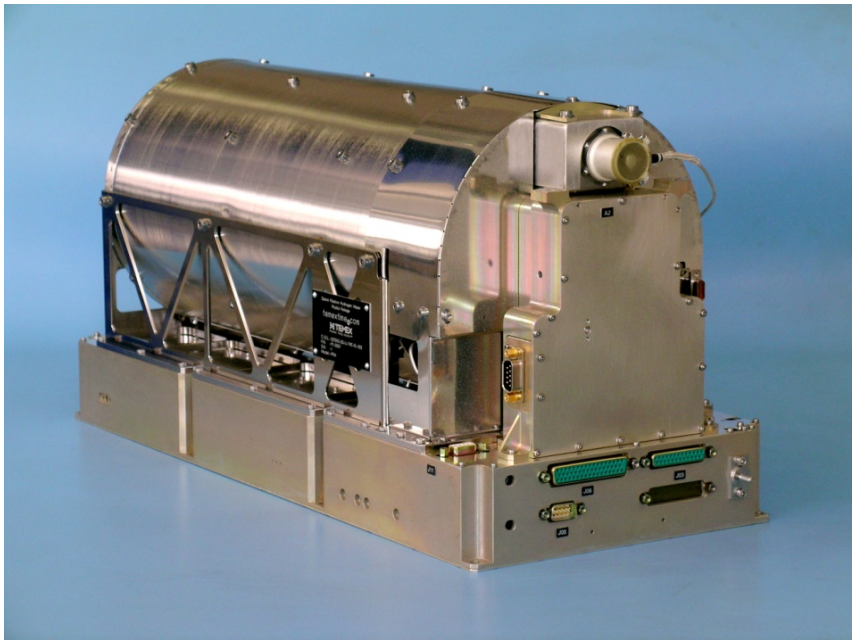
- Global Navigation Satellite System Jointed by EC & ESA
- Constellation
  - 30 satellites
  - 3 circular MEOs
  - Altitude 23’222km
  - Inclination 56^{o}
- Mission life time of 12 years
- Clock model update < 10’000 sec.
- Metric/sub-metric navigation accuracy



Present Onboard Clocks for Galileo

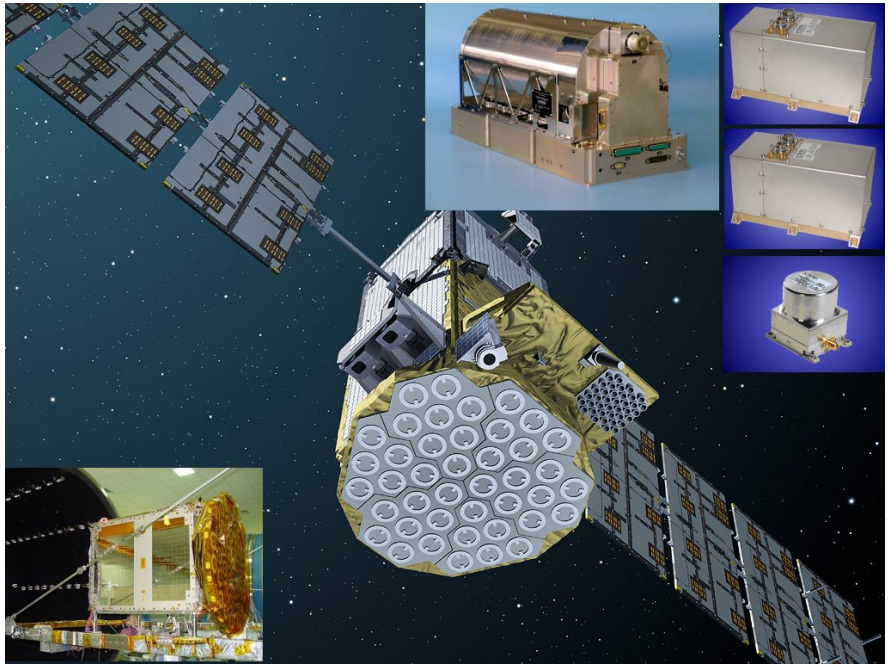
- Two baseline clock technologies
  - Rubidium Atomic Frequency Standard (RAFS)
  - Passive Hydrogen Maser (PHM)





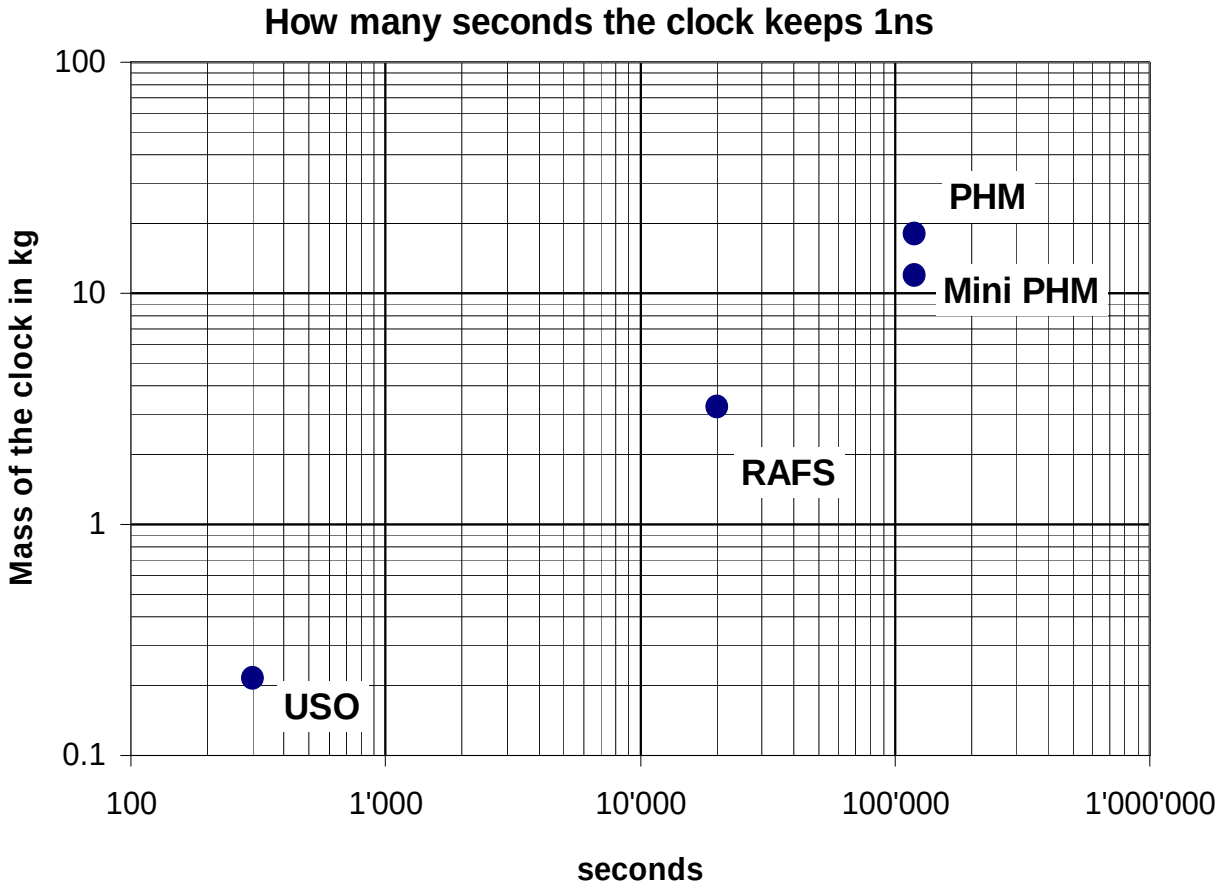
In-progress GIOVE-A and -B

- Two experimental satellites flying
  - GIOVE-A Two RAFS unit (Dec. ’05)
  - GIOVE-B One PHM (PFM) unit and two RAFS units (April ’08)
- Main targets of the satellites
  - Frequency Filling
  - Test of critical technologies (like clocks)
  - Experimentation on Galileo Signals
  - Characterisation of MEO environment
- Mission lifetime of 3 years



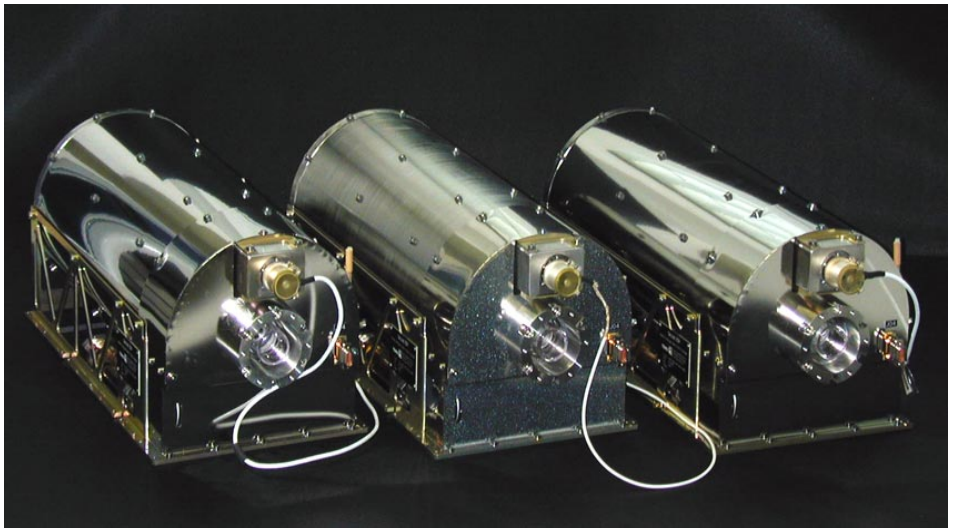
Why use PHM for navigation?

- 1ns equals 30cm of precision
- Minimum 8hrs of operation without relying on ground station



PHM Development Milestones and Industrialisation

- First development activity tailored to navigation applications kicked off in 2000
  - Predevelopment led by Observatory of Neuchatel with Selex Galileo as subco for EP
  - Development achieved in 2003 with a prototype ready for testing
- Industrialisation development kicked off in January 2003
  - Industrial Consortium led by Selex Galileo in charge of the instrument integration and EP design
  - SpectraTime responsible for redesign and manufacturing the PP
- Overall structure and design reviewed to increase compactness / robustness
- Manufacturing and qualification of 4 QMs, two of them are under test for *lifetime estimation*

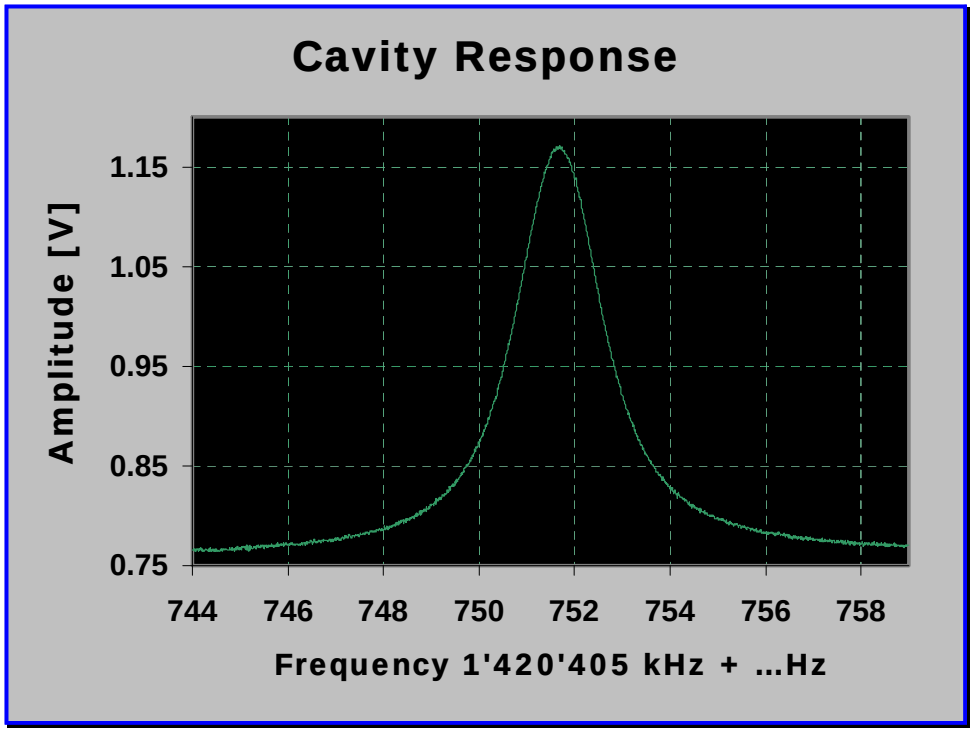


PHM Characterisation

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

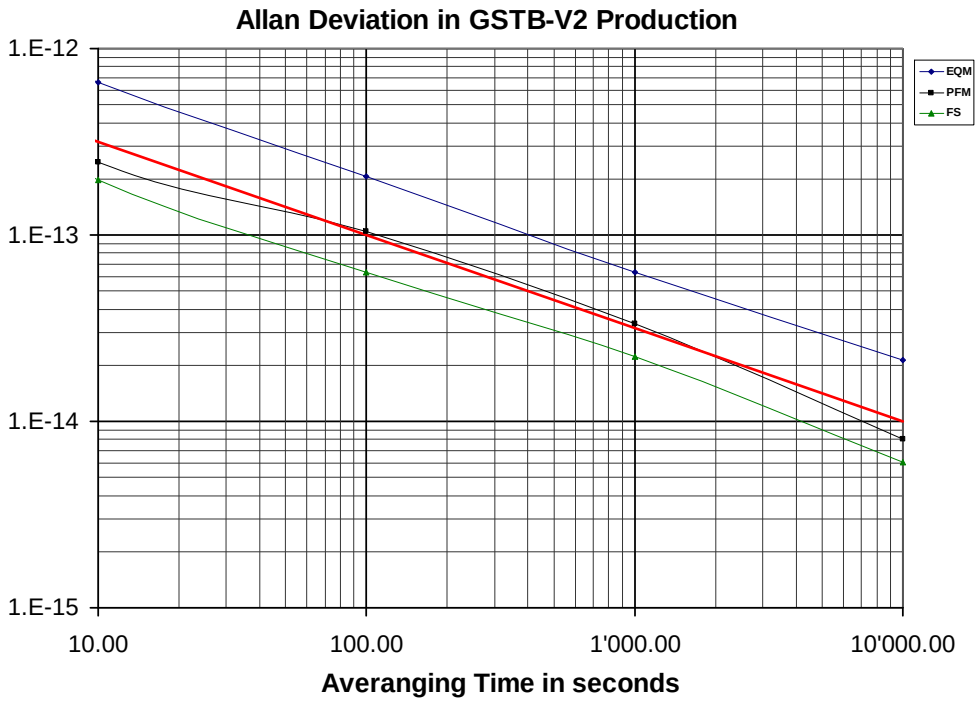
At nominal operational condition,

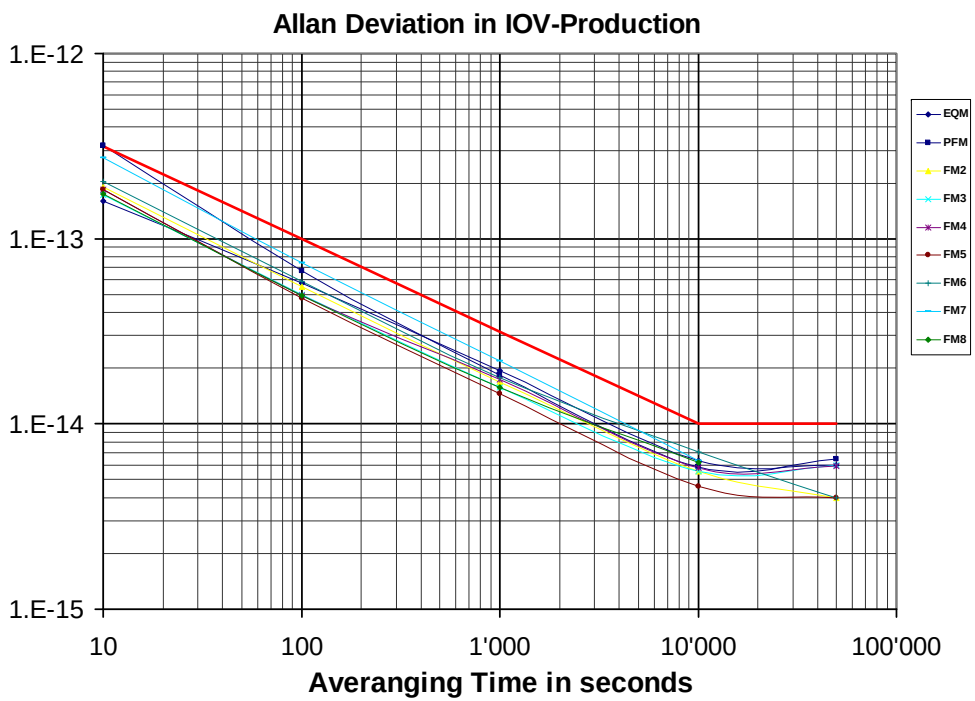
- Gain: 3.6 dB
- Line width: 2Hz @ 1.420GHz



The first 4 IOV satellites vs. GIOVE

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





Lifetime facilities

Lifetime facilities

- The two identical units consist of:
  - **the vacuum chamber with pumping system and gauge**
  - **the base-plate connected with cooling system**
  - **the frequency stability measurement system (2 Picotime)**
  - **the data acquisition system for additional TM (temperatures, pressure, …)**
  - **the PC with automatic control and acquisition system**
  - **the power supply and UPS**

- The common elements are:
  - **the QM lifetime EGSE, i.e. the man-machine-interface support including serial telecommand (TC) generation and main serial TM recording for both units**
  - **the reference frequency system; H-Maser (EFOS C) with GPS monitoring and the frequency distribution unit (common for all the SpT facilities)**

Lifetime facilities

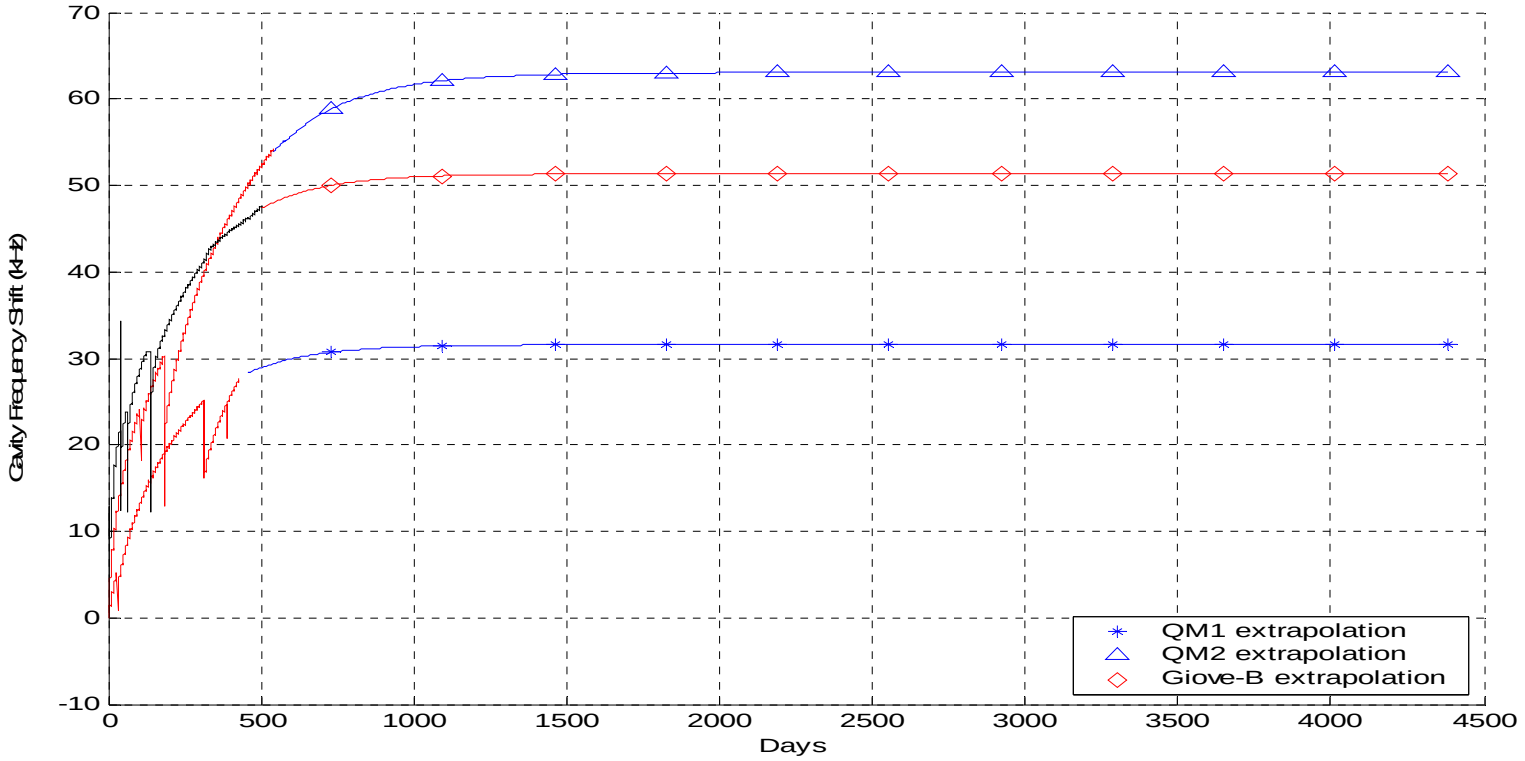
In addition to frequency stability performances, more than 20 parameters are measured. The most relevant are:

- **Atomic signal amplitude**
- **Cavity Varactor voltage**
- **Hydrogen supply pressure and temperature as H_2 consumption indicator**

Lifetime preliminary measurements

Microwave Cavity Ageing extrapolation

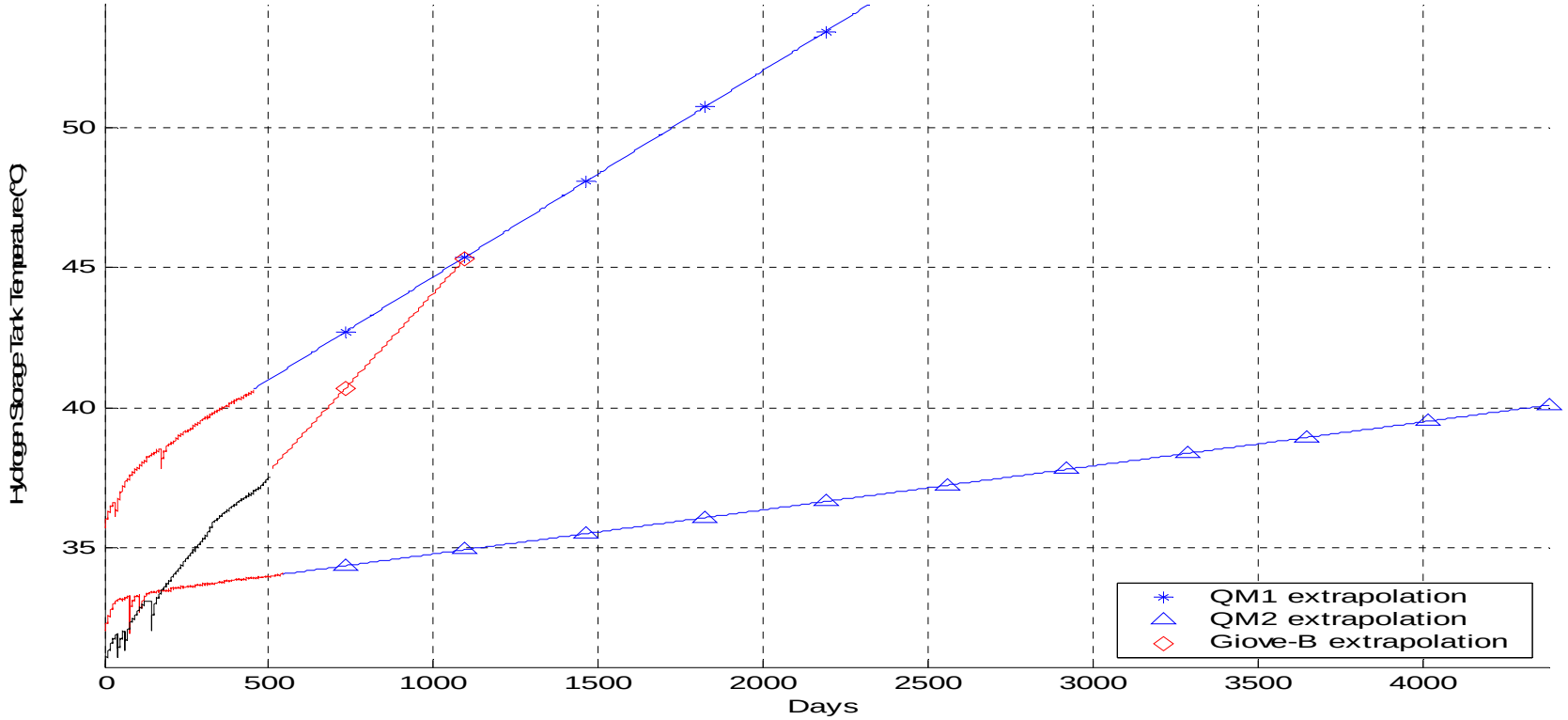
- Image of the microwave magnetron frequency stabilization over time
- Relevant due to the Automatic Cavity Tuning (ACT) function



Lifetime preliminary measurements

Hydrogen Supply Tank Temperature extrapolation

- Use of hydride for small tank volume and low pressure operation (<3 bar)
- Temperature is relevant of the Hydrogen consumption
- Beginning at QM2 all PHM are equipped with new Hydride



Lifetime preliminary measurements

Extrapolation over 12 years for most critical parameters (QM2):

Telemetry	Extrapolation in 12 years
Cavity Frequency Change	< 150kHz
Hydrogen Supply Temperature	~40°C

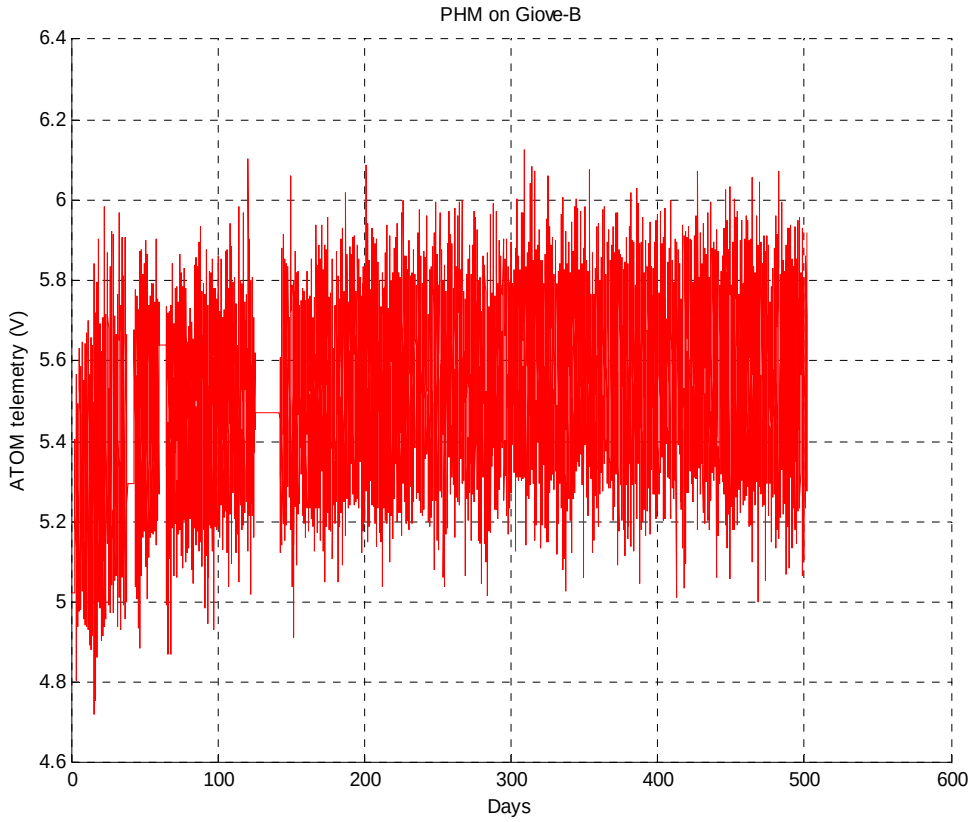
Both parameters stay within expected limits with limited margins as first conclusion. Nevertheless:

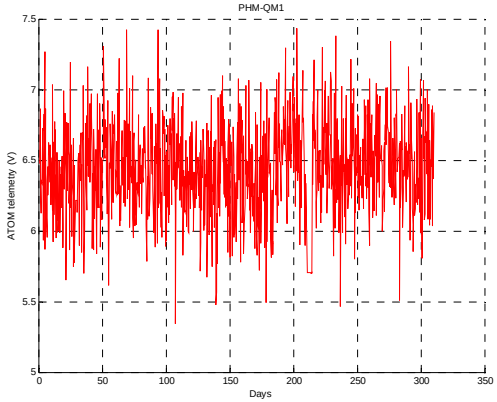
- **Margin for the tank are restored within IOV design by a change of the hydride (lower operational temperature). About 10°C margin.**
- **Cavity frequency shift is <<150kHz which is the worst case value that can recovered acting on the cavity temperature (20kHz per °C) and ACT.**

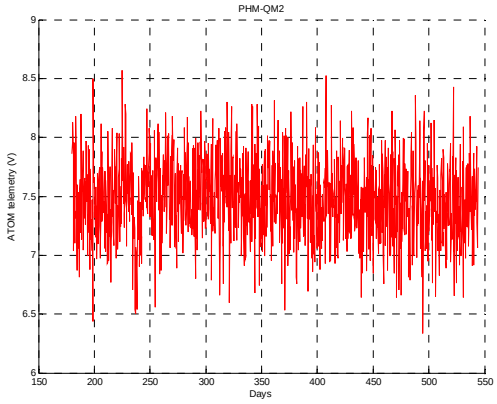
Lifetime preliminary measurements

Atomic Signal Amplitude

– **The most relevant parameter for ageing of the PHM (Teflon coating, dissociation efficiency, microwave cavity quality factor, high vacuum level, pollution, …)**

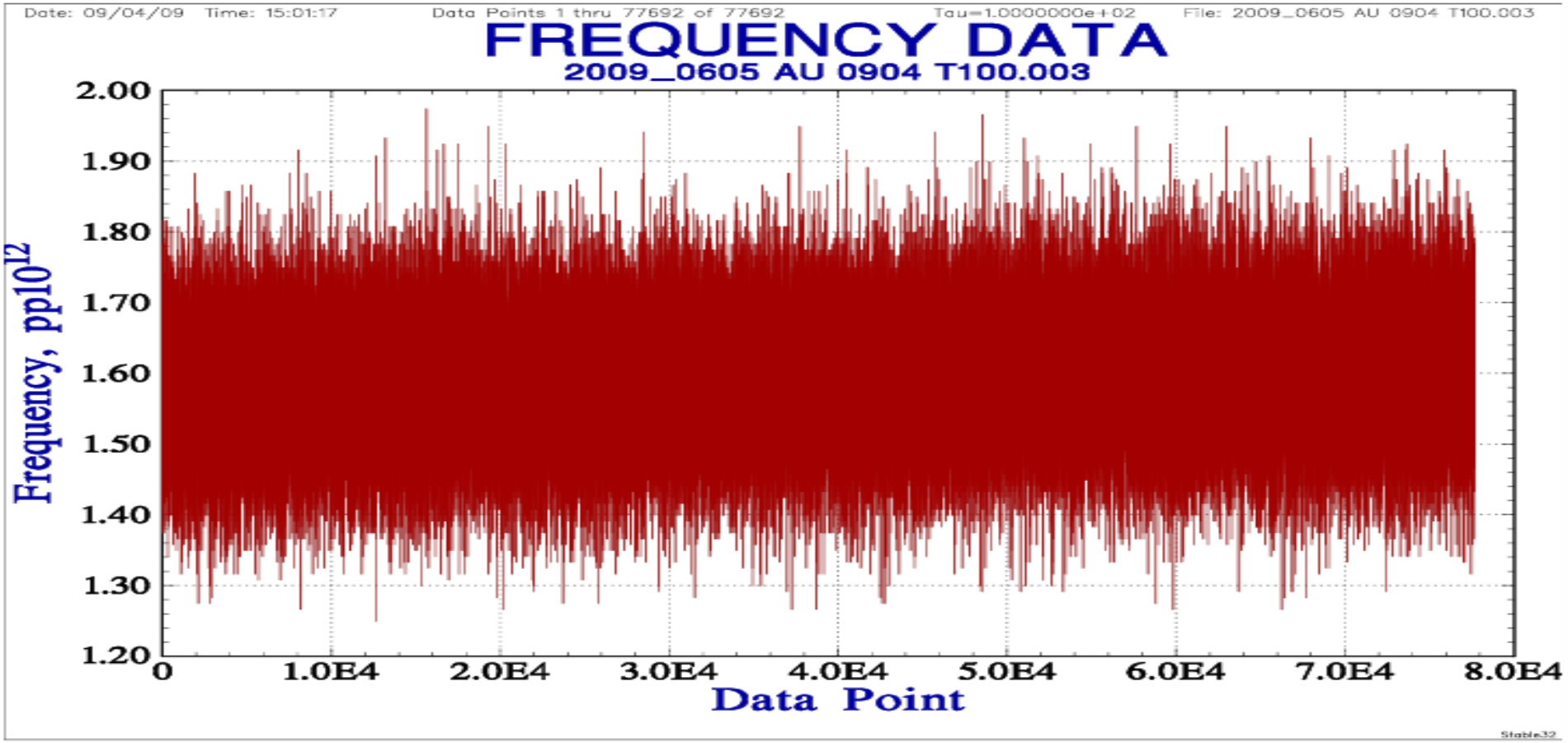






Lifetime preliminary measurements

Frequency Stability Performances (QM1 Lifetime):



Lifetime preliminary measurements

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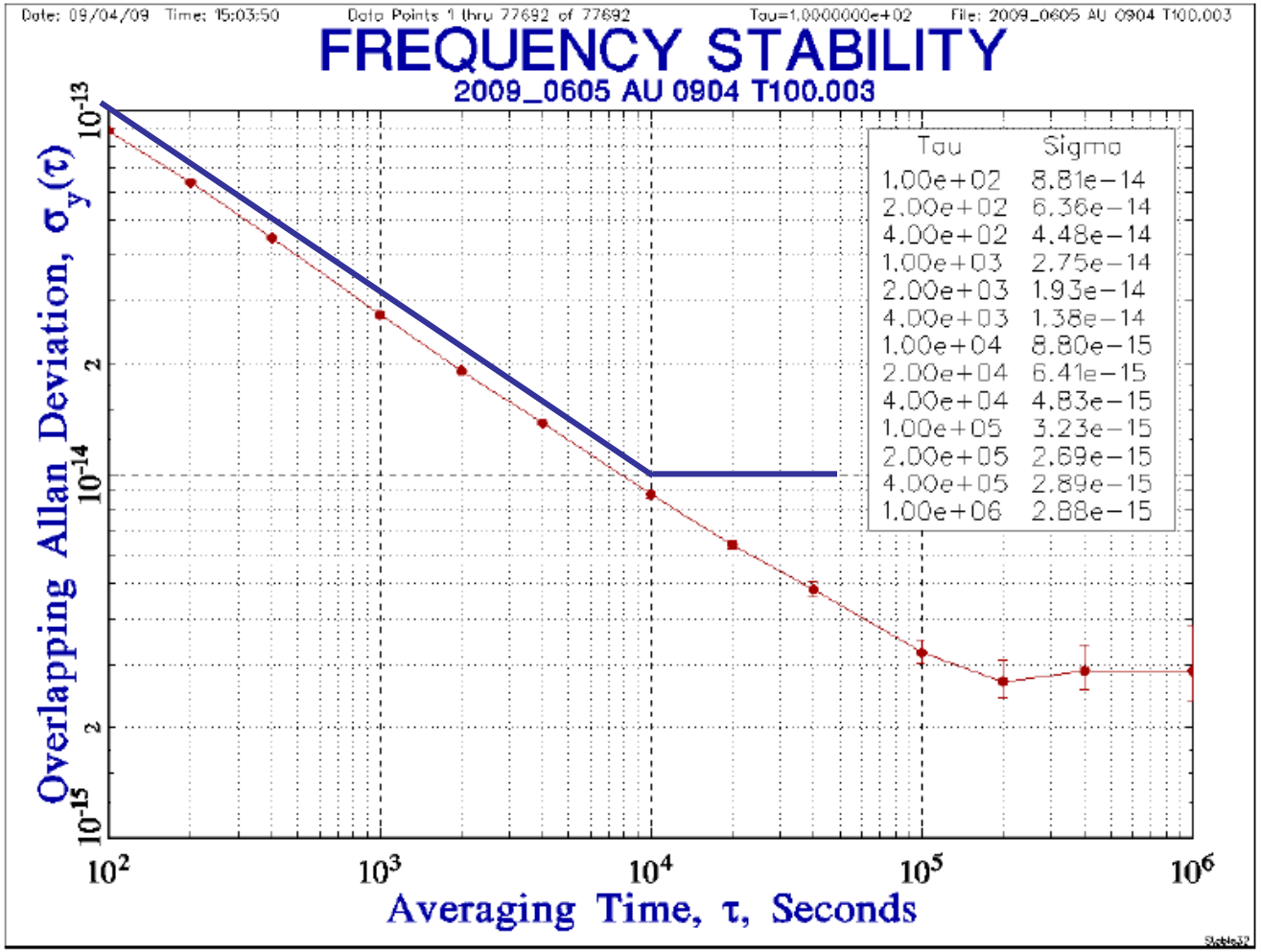

Lifetime preliminary measurements

Typical Frequency Stability Performances:

Parameter	Measurement
Frequency Stability	$<7*10^{-15}$ @ 10‘000sec
Flicker Floor	$<3*10^{-15}$
Drift	$<1*10^{-15}$ / day
Thermal Sensitivity	$\leq 2*10^{-14}$ / °C
Magnetic Sensitivity	$<3*10^{-13}$ / Gauss
Mass	18kg

Lifetime preliminary measurements

The lifetime program has been providing useful results and demonstrating the capability of the PHM to operate for 12 years under vacuum without significant degradation.

The ageing trend observed is in line with prediction of the lifetime program results and is compatible with Galileo 12 years mission.

The performances achieved provide sufficient margins for sub-metric navigation system with long autonomy (up to several days).

The ageing trend observed on ground and the GIOVE-B data confirm that the PHM fully complies with the Galileo mission requirements.

Thank you very much for your attention

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