Swiss Space Atomic Clock Technologies and Applications in Space Science

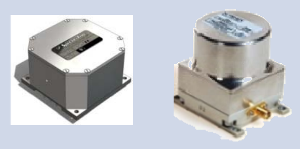
瑞士空间原子钟技术及其在空间科学中的应用

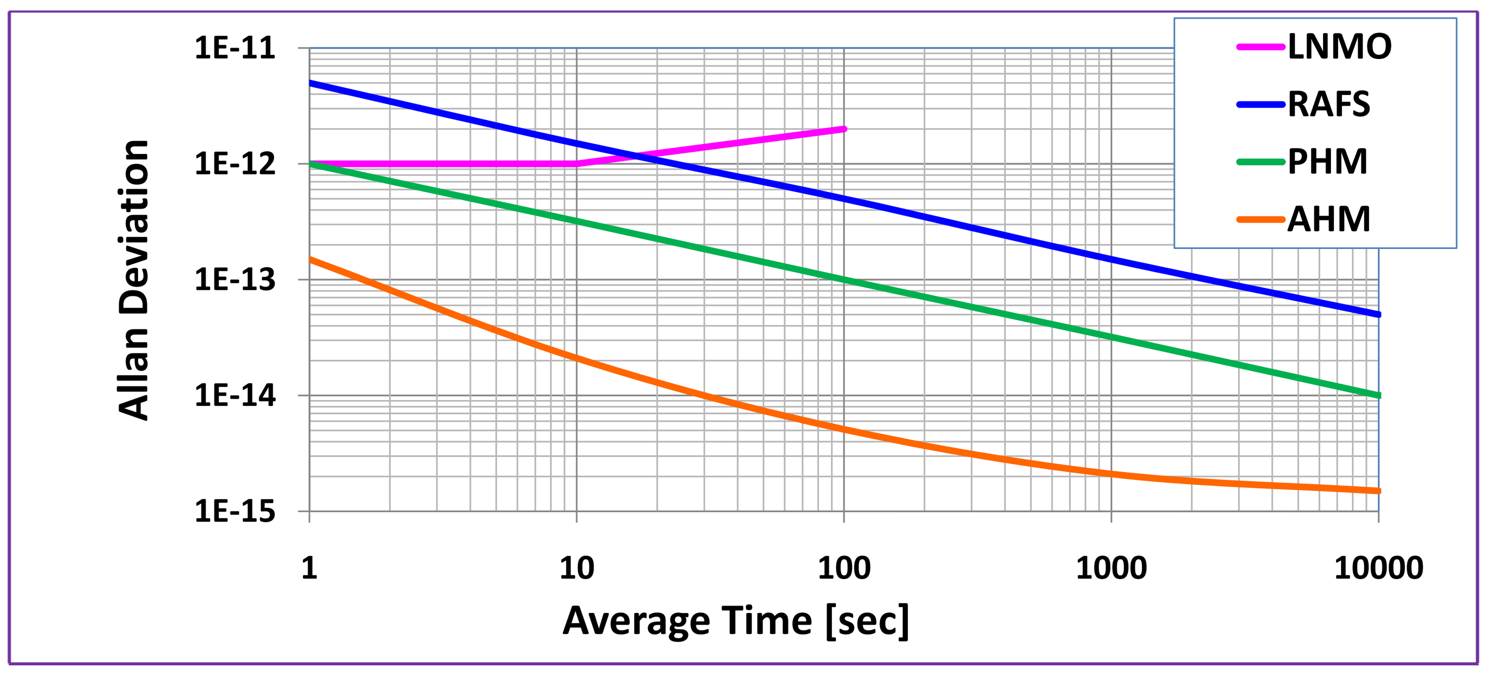
Qinghua Wang*, Fabien Droz, Pascal Rochat, Didier Goujon
Orolia Switzerland Inc., Neuchâtel, Switzerland
*qinghua@spectratime.com

orolia Group

spectratime iPrecision Timing Solutions®

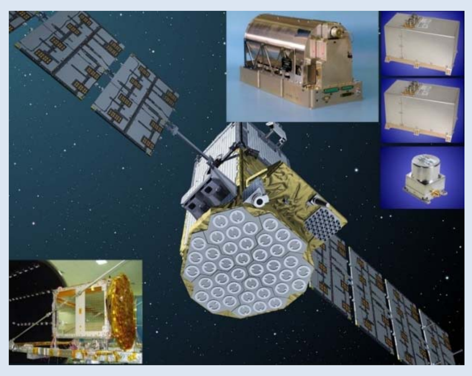
Spectratime Space Products

晶振 Crystal USO Low Noise Master Oscillator (LNMO)	铷钟 Rubidium Atomic Frequency Standard (RAFS)	被动氢钟 Passive Hydrogen Maser PP (PHM)
		
100 g or 210 g Stability $<1\times10^{-12}$ @ 10s	3.3 kg Stability $<5\times10^{-14}$ @ 10'000s	18 kg Stability $<1\times10^{-14}$ @ 100'000s



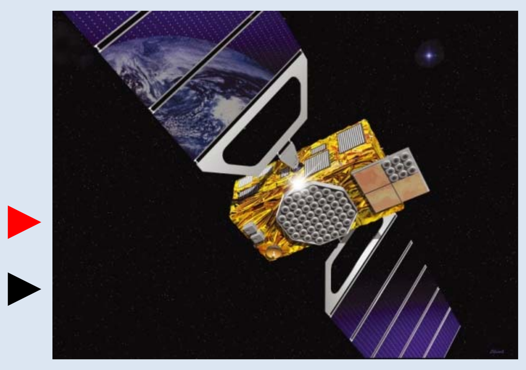
Success Stories in GNSS (Global Navigation Satellite Systems)

Mission lifetime: 12 years

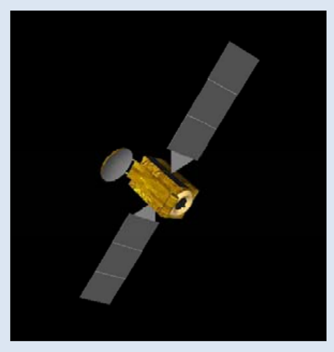


- European Galileo GIOVE-A & B Satellites launched in 2005 and 2008
- 4 RAFS, 1 PHM, 1 USO onboard

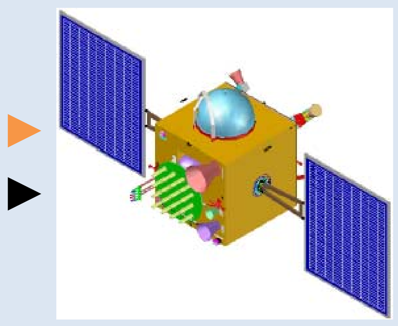
Thanks to PHM, Galileo is flying the most stable clocks ever launched for GNSS !



- 4 European Galileo IOV Satellites launched in 2011 and 2012
- 8 PHM, 8 RAFS, 24 USO onboard



- 11 Chinese Compass (北斗) Navigation Satellites launched from 2009 to 2012
- 20 RAFS onboard



- 1st Indian Regional Navigation Satellite launched in 2013
- 3 RAFS onboard

Space Rb Clock for Remote Sensing

- 9 Chinese DFH (东方红) satellites launched from 2010 to 2013
- 12 RAFS onboard

Design Criteria for Space Atomic Clock

Satisfactory and reliable performance over overall mission life

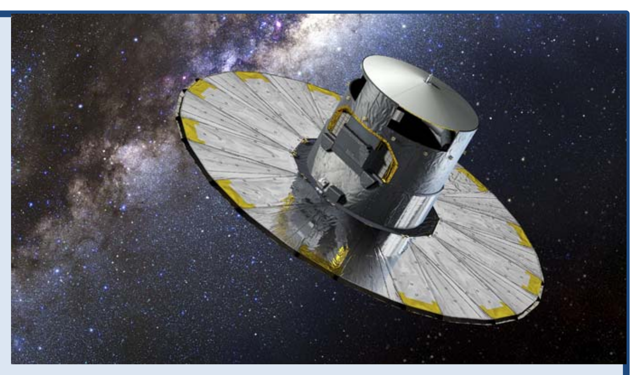
- Meet constraints on mass, volume, and power consumption
- Survive launch environment: shock, acceleration, and vibration
- Survive operational environment
  - vacuum, thermal, EMI/EMC, radiation, magnetic field and other space hazards

Because of their simplicity and reliability, Rb and H atomic clocks are used in various space missions.

Clocks key parameters:

- Short term stability
- Long term drift or drift stability
- Frequency sensitivity to environment (temperature, magnetic field, voltage)
- Reliability figure of onboard elements versus requested Availability figure

Space Rb Clock for GAIA



ESA's billion-star surveyor

Launched: 19.12.2013
Orbit: 1.5 million kilometres from Earth
Mission lifetime: 5 years
Goal:

- Measure the position, motion, brightness, temperature, and composition of each star
- Create the largest and most precise 3D map of the Milky Way

Scientific objectives:

- Galaxy origin and evolution
- Galactic dynamics and distance scale
- Solar System census
- Large-scale detection of all classes of astrophysical objects

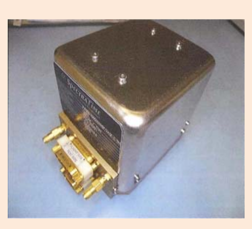
Why Atomic Clocks on-board of GAIA?

Ultimate astrometrical performances of the GAIA mission deeply rely on the accuracy by which the payload data are time stamped on board.

Requirements for the Atomic Clock?

10 ns over 6 hours including all effects cumulated, drift, stability and environmental effect, deduced from expected astrometrical resolution (**a few µarcsec** for the bright stars)

GAIA RAFS Performances:

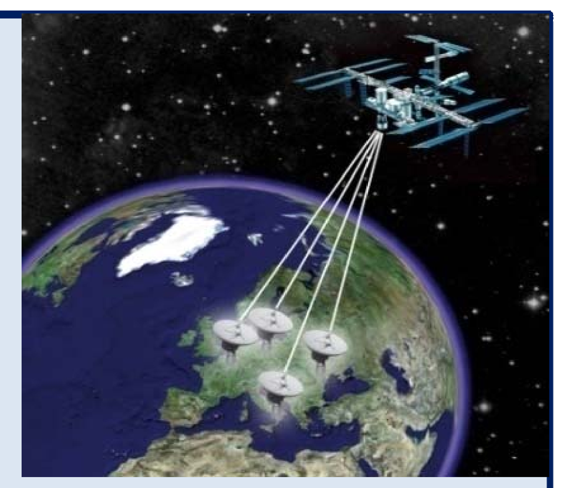


1.2 kg integrated within the Clock Distribution Unit

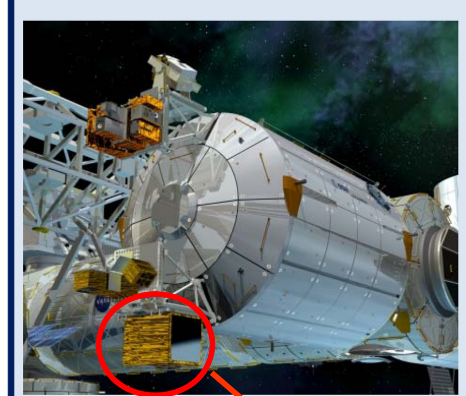
- Clock drift:
  - FM1: -2.4×10^{-13} /day
  - FM2: $+2.0\times10^{-13}$ /day
- Clock stability:
  - FM1: 5×10^{-14} (Flicker)
  - FM2: 4×10^{-14} (Flicker)
- Temperature effect:
  - FM1: -1.7×10^{-14}
  - FM2: -2.6×10^{-14}

Overall MTIE at 6 hours:
FM1:<2.7 ns
FM2:<1.8 ns

Space H-Maser for ACES



Atomic Clock Ensemble in Space



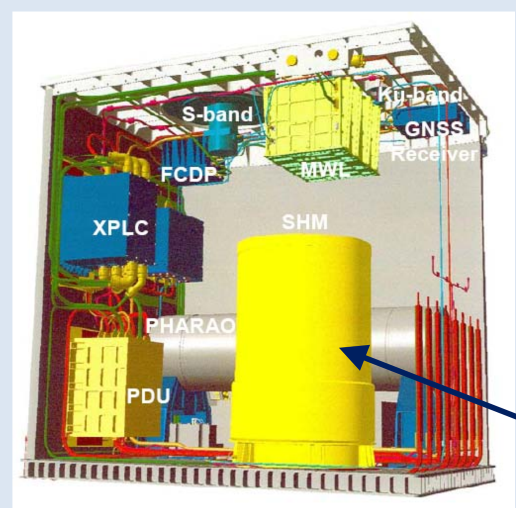
Launch: 2016
On the **International Space Station**
Mission duration: 18 months

Scientific objectives:

- Demonstrate the high performances of a new generation of space clocks
- Achieve time and frequency transfer with stability better than 10^{-16}
- Perform fundamental physics tests (Einstein's general relativity and alternative theories of gravitation)

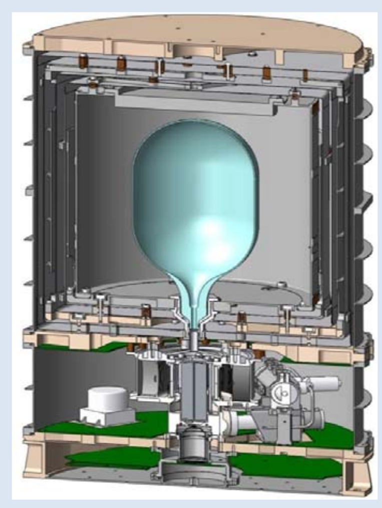
Onboard timescale: Excellent short-term stability of SHM and the long-term stability and accuracy of PHARAO (CNES).

The most precise measurement of time yet – in space



SHM is an Active H-Maser for space applications developed by Spectratime under ESA contract with funding provided by the Swiss Space Office.

SHM EM fully assembled



主动氢钟
45 kg
Stability: 1.5×10^{-13} @ 1s
1.5×10^{-15} @ 10'000s

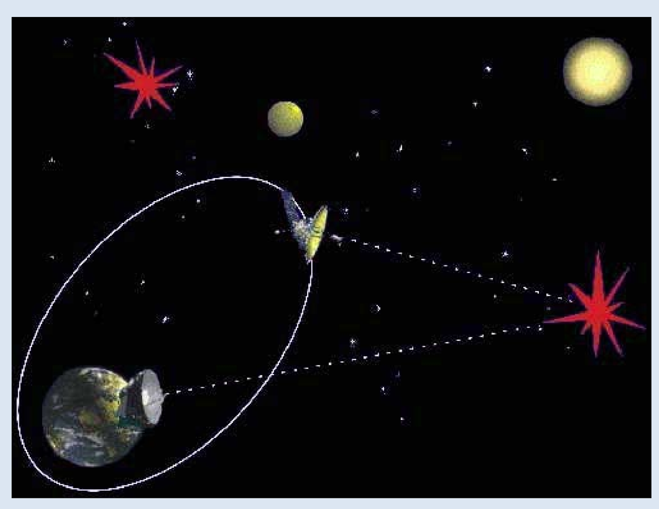
Current status and plan:

- EM phase closed
- PFM manufacturing started
- PFM delivery 2014

ACES

Space Rb Atomic Frequency Standard for RadioAstron

Earth-Space Interferometer with orbit up to 350 000 km



Launched: 18.07.2011
Mission lifetime: 5 years
Goal:

- Investigations of various types of astrophysical objects of the universe with an unprecedented high angular resolution (**up to 1 µarcsec**) in the cm and dm wavelength bands.

Onboard Atomic Frequency Standards:

- Russian Active H-Maser
- **RAFS** - *ESA has provided funding for the development of the onboard RAFS, which has been manufactured by the Neuchatel Observatory (former Rb clock team of Spectratime) in Switzerland.*

We are interested in the provision of the critical payload as onboard high-performance atomic clocks for potential cooperative scientific space missions!

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