

# 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



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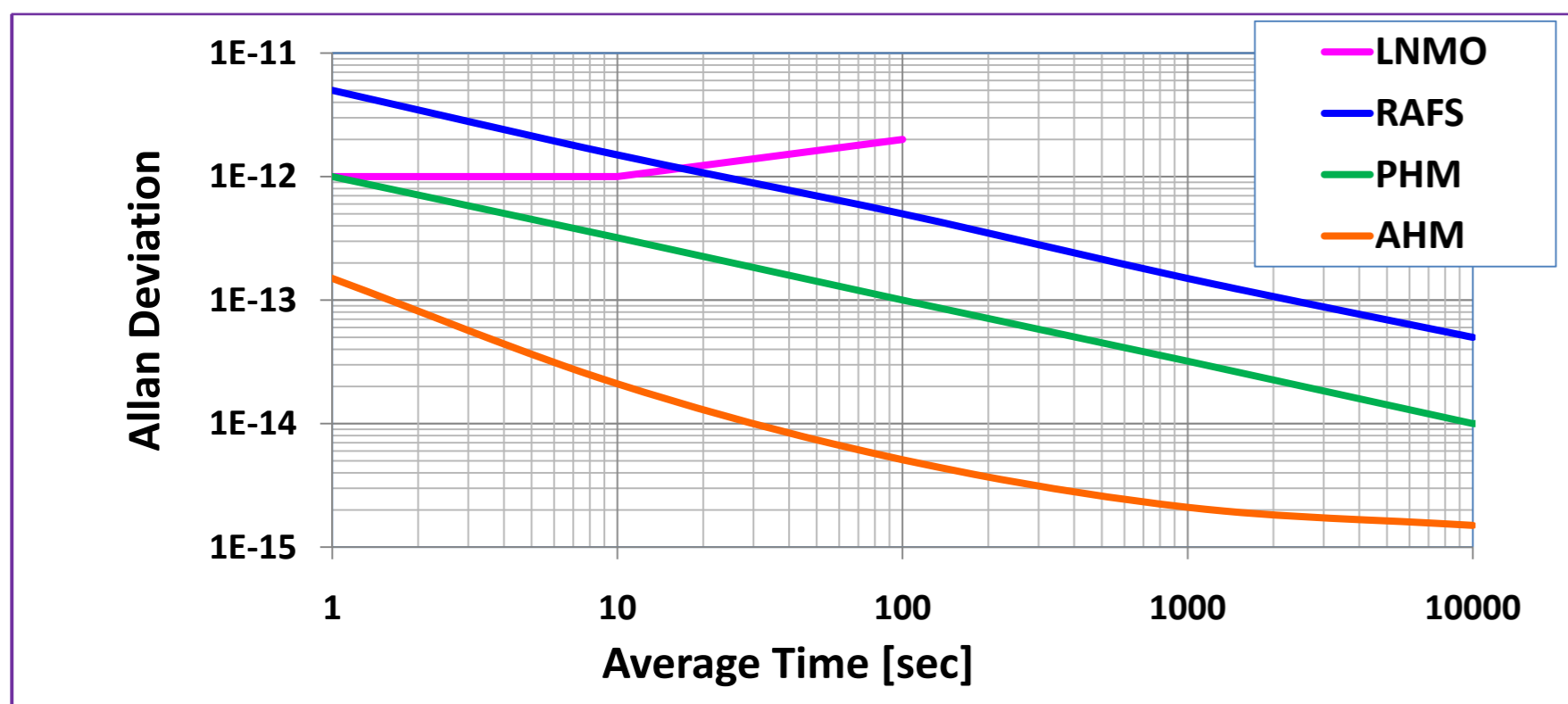
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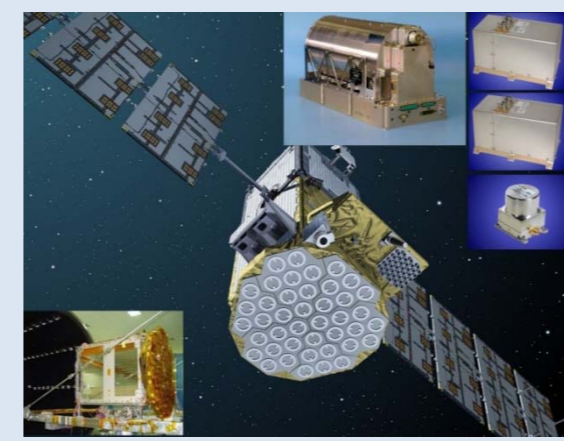


### Spectratime Space Products

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 $<1 \times 10^{-12}$ @ 10s	3.3 kg Stability $<5 \times 10^{-14}$ @ 10'000s	18 kg Stability $<1 \times 10^{-14}$ @ 100'000s



### Success Stories in GNSS (Global Navigation Satellite Systems)

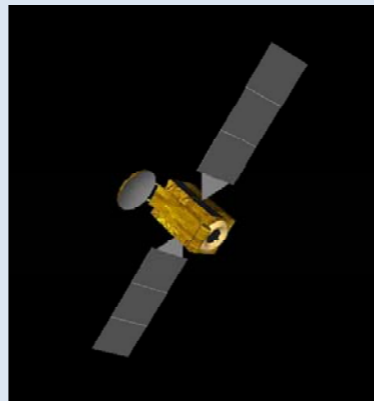


Mission lifetime: 12 years

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

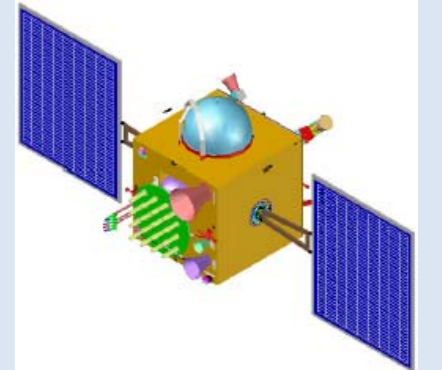
Thanks to PHM, Galileo is flying the most stable clocks ever launched for GNSS!

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  $\mu\text{arcsec}$  for the bright stars)

### GAIA RAFS Performances:

1.2 kg integrated within the Clock Distribution Unit

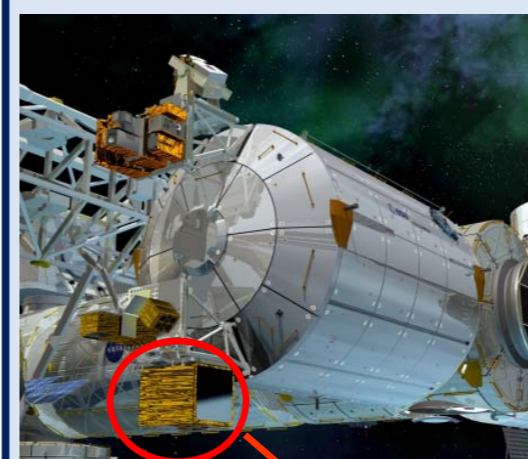
- Clock drift:
  - FM1:  $-2.4 \times 10^{-13}$  /day
  - FM2:  $+2.0 \times 10^{-13}$  /day
- Clock stability:
  - FM1:  $5 \times 10^{-14}$  (Flicker)
  - FM2:  $4 \times 10^{-14}$  (Flicker)
- Temperature effect:
  - FM1:  $-1.7 \times 10^{-14}$
  - FM2:  $-2.6 \times 10^{-14}$

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

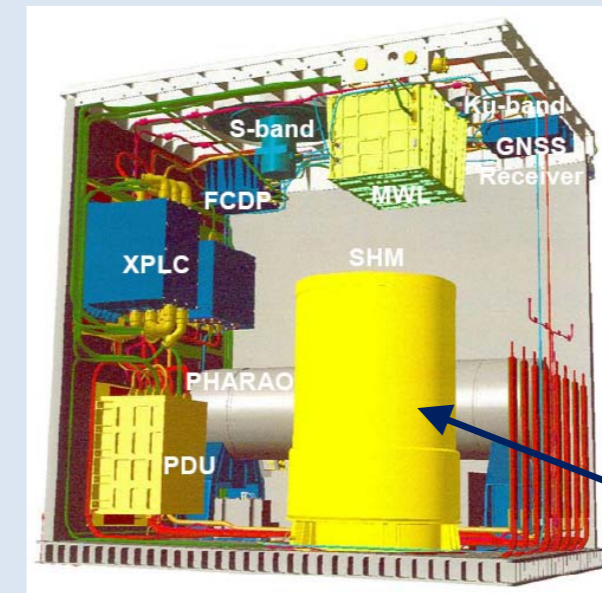
Scientific objectives:

- 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.

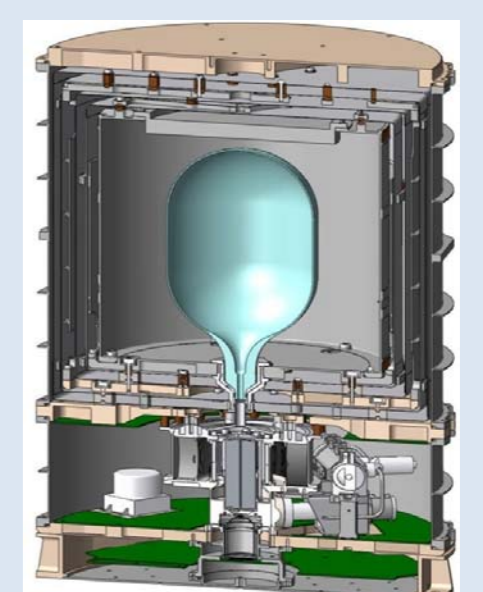


SHM EM fully assembled

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

Current status and plan:

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



### 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  $\mu\text{arcsec}$ ) 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!

我们将竭诚为未来联合空间科学任务提供关键载荷 - 星载高性能原子钟

1st Workshop of Planning for a joint scientific space mission, CAS - ESA, Chengdu (China), 25-26 Feb. 2014

www.spectratime.com