PHARAO SPACE CLOCK

Science team:

l'Observatoire de Paris – SYRTE
LNE – Le progrès, une passion à partager
Laboratoire Kastler Brossel – Physique quantique et applications
PENNSTATE 1855

Prime contractor, AIV:

cnes – CENTRE NATIONAL D'ETUDES SPATIALES

Main manufacturers:

SODERN
THALES
CS – COMMUNICATION & SYSTEMES
EREMS

CNRS
Institut Francilien de Recherche sur les Atomes Froids – IFRAF
ENS – LETTRES – SCIENCES – ECOLE NORMALE SUPERIEURE
UPMC – PARIS UNIVERSITAS

PHARAO clock
Main characteristics

- **Cold cesium atoms prepared by laser cooling techniques**

- **Measurement of the hyperfine frequency resonance (definition of the second) induced by a microwave oscillateur**

- **To frequency locked the microwave oscillator**
- **This oscillator delivers the atomic-referenced signal to lock the Hmaser which provides the continuous ACES proper time.**

Performances objectives of PHARAO:

Frequency stability $\leq 10^{-13}\, t^{-1/2}$ ($<3.10^{-16}$ 1-20 days)

Frequency accuracy $<3.10^{-16}$

Short Term Frequency Stability

Signal to noise ratio of the detected signal

3 main contributions:

Number of detected atoms

Many captured cold atoms with the lowest temperature.

- Laser power, frequency and power noise

Phase noise of the microwave signal

- Microwave synthesis from Ultra-stable quartz oscillator

And the hyperfine resonance linewidth

- Adjustable in microgravity (2 orders of magnitude)
- Limited on ground by gravity

Frequency accuracy

	Correction (10^{-16})	Main Evaluation method	Expected uncertainty (10^{-16})
Quadratic Zeeman effect (magnetism)	-400	Clock measurement	0.2
Black body radiation (thermal photons)	150	Temperature measurement	0.6
Cold collisions (density)	35	Clock Measurement	<2
First order Doppler (phase gradient)	1	Clock Measurement	<1
Microwave spectral purity&leakage	0.5	Measurement Sub-systems	<0.5
Microwave lensing (recoil)	-1	Calculation	<0.5
Total	-214.5		< 3

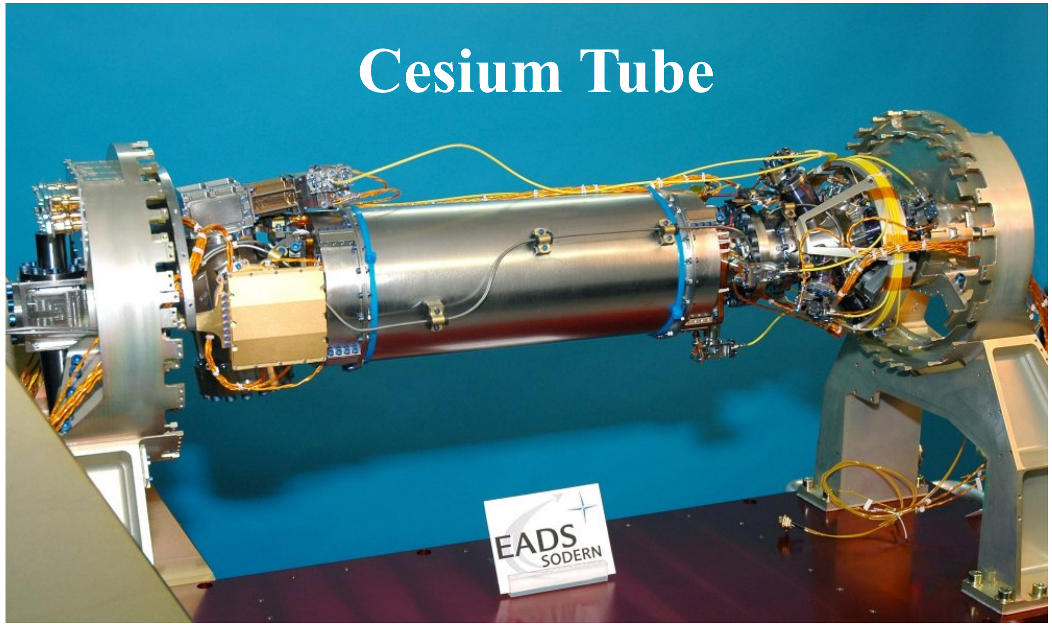
PHARAO development

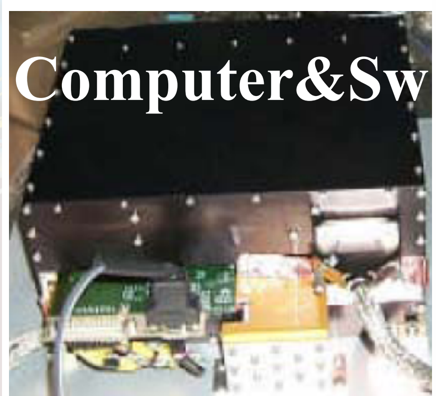
Engineering model (EM): fully operational but not space qualified.

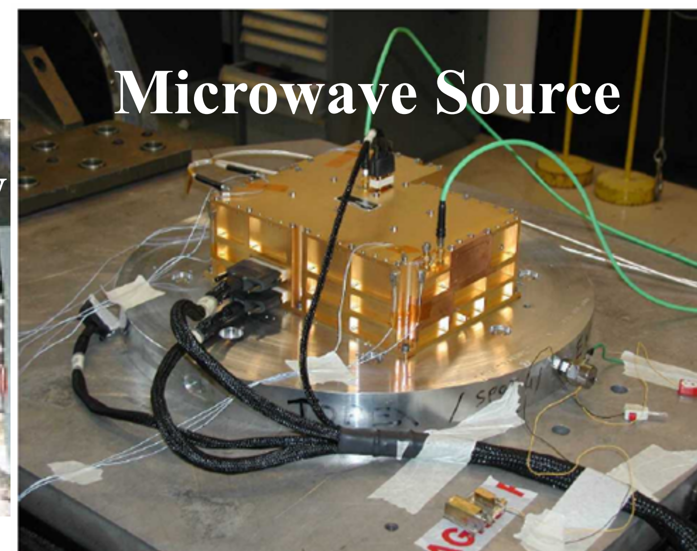
Delivery 2006,
Assembling, Verification, Performances and EMC tests.

On ground, lower performances
larger resonance linewidth

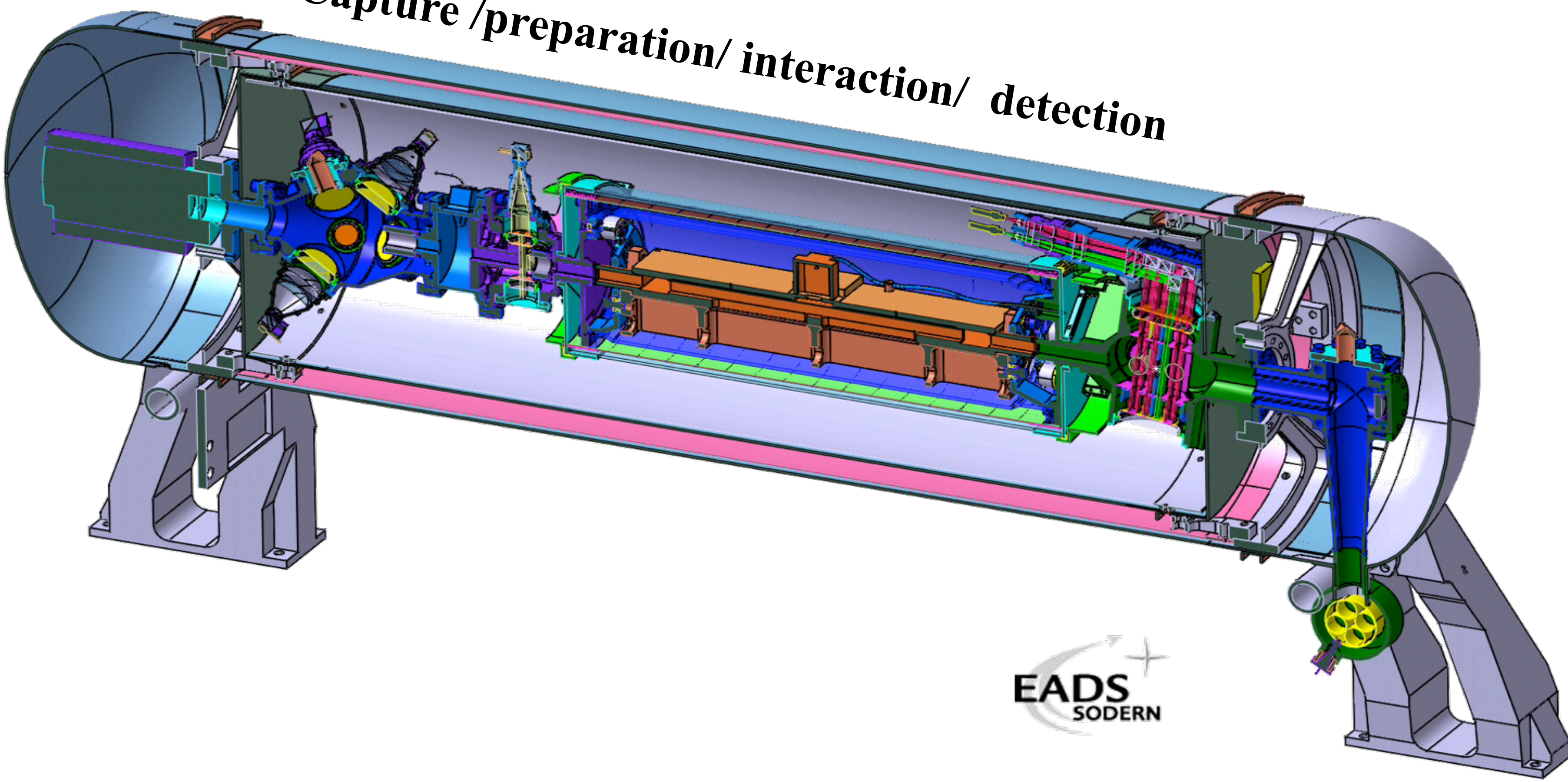
Physical Package



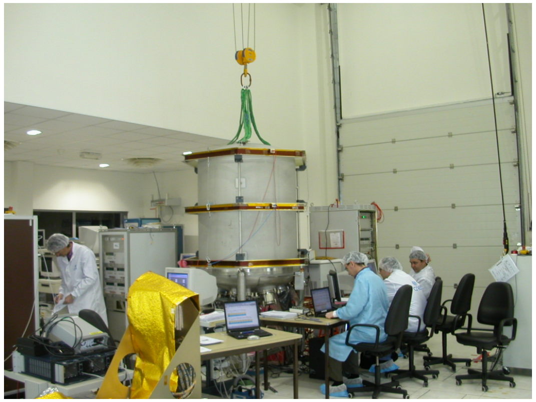


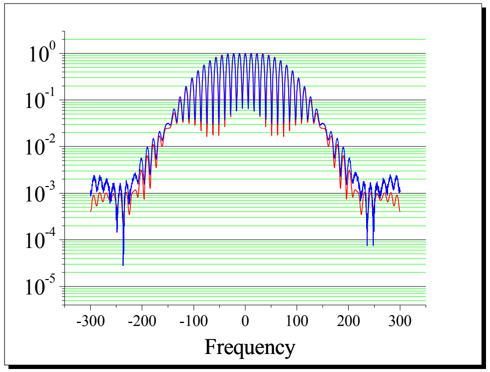


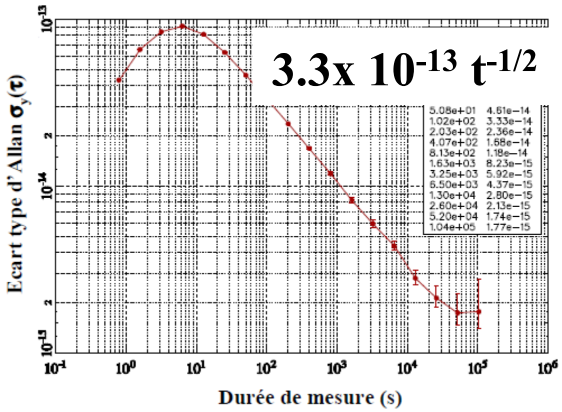
Capture /preparation/ interaction/ detection



PHARAO EM tests: main results







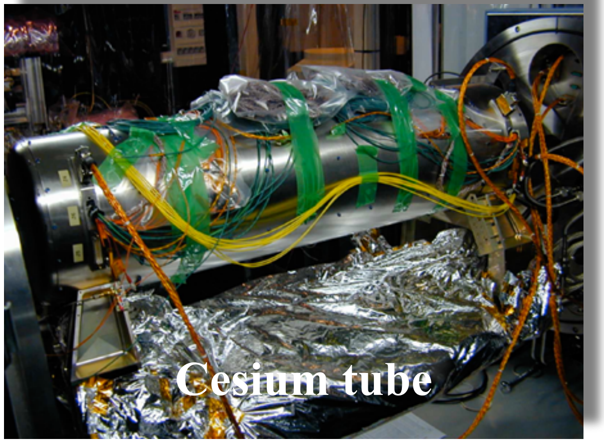
Frequency stability : performances validated

Frequency accuracy: $2x10^{-15}$ but 3 issues:

Magnetic field inhomogenity: Zeeman shift uncertainty 5.10^{-16}
Magnetic field isolation (orbit field): 70 000 (shield and active compensation) 5.10^{-16}
Microwave spectral purity: phase transient : 6.10^{-16}

PHARAO MSTH

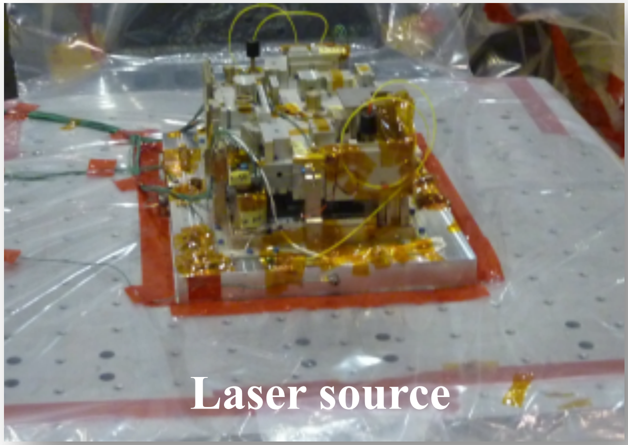
MSTH structural and thermal model: verification of robustness in thermal (-40, +60°C) and in mechanical (~20 grms) environment.



Results

Cesium tube: no margin on mechanical stress
Low temperature accuracy (blackbody)

Laser source:
optical alignments instability for thermal environments



Flight model status

PHARAO Flight Model

Microwave source:

Electronic improvement

- **FM qualified and delivered**
  - Performances measurement
    - **Frequency stability contribution 8.10^{-14} (in microgravity)**
    - **Frequency accuracy contribution $< 5.10^{-17}$**

PHARAO Flight Model

Cesium tube

Mechanical structure

Thermal: best temperature control

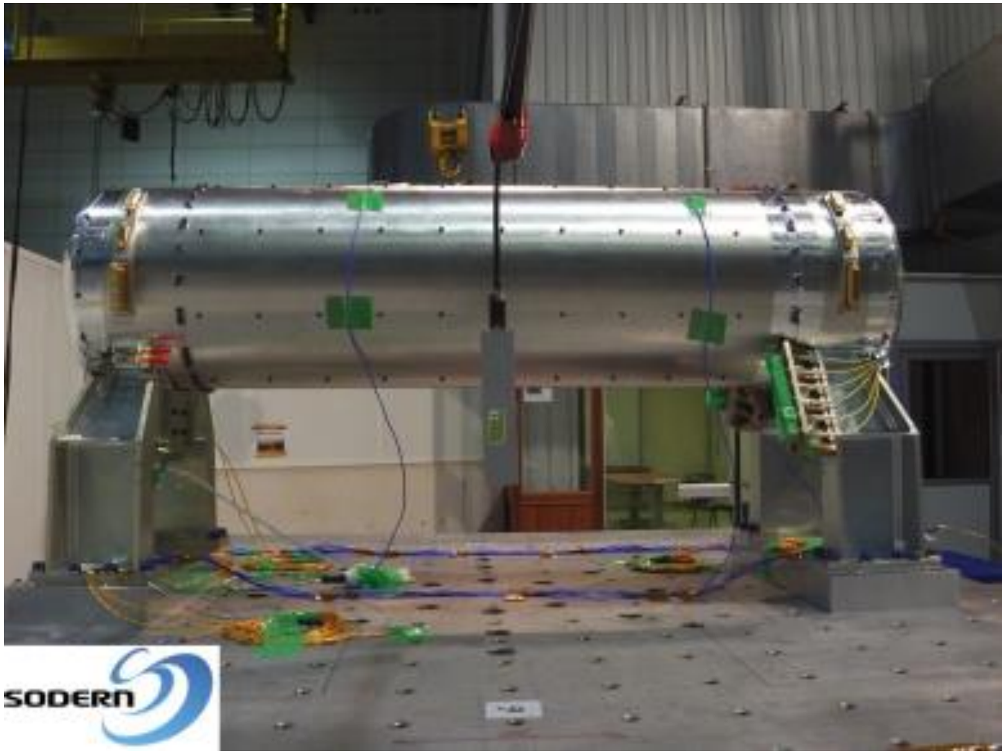
Magnetism

Vacuum level

Cesium tube is qualified and delivered

Assembled with the other EM sub-systems (clock operation)

- No magnetism issues
- Thermal verification in progress



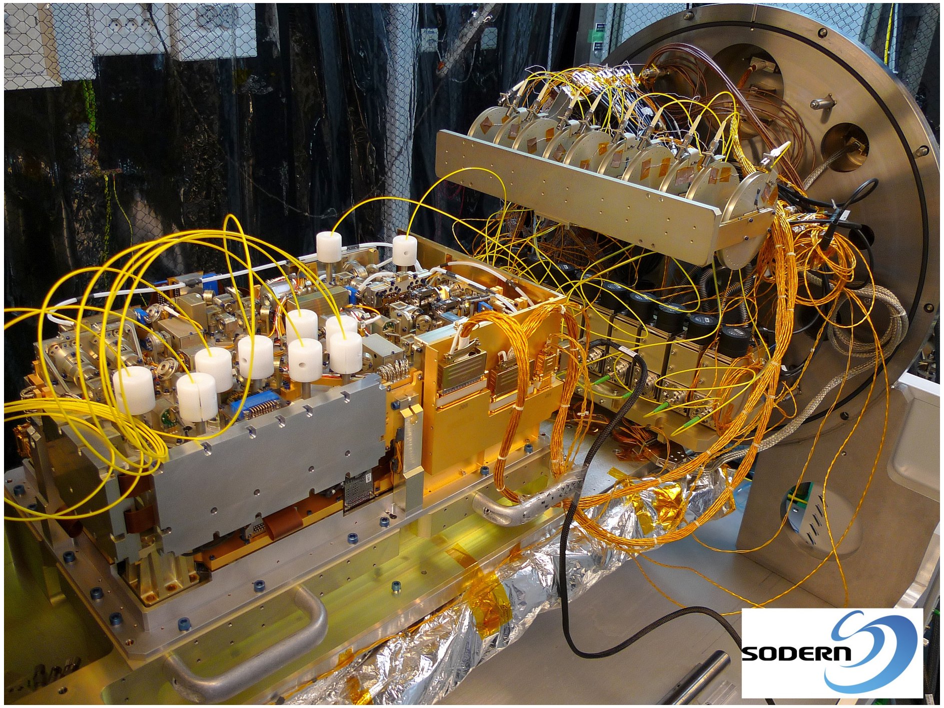
PHARAO Flight Model

Laser source

Better Optical structure

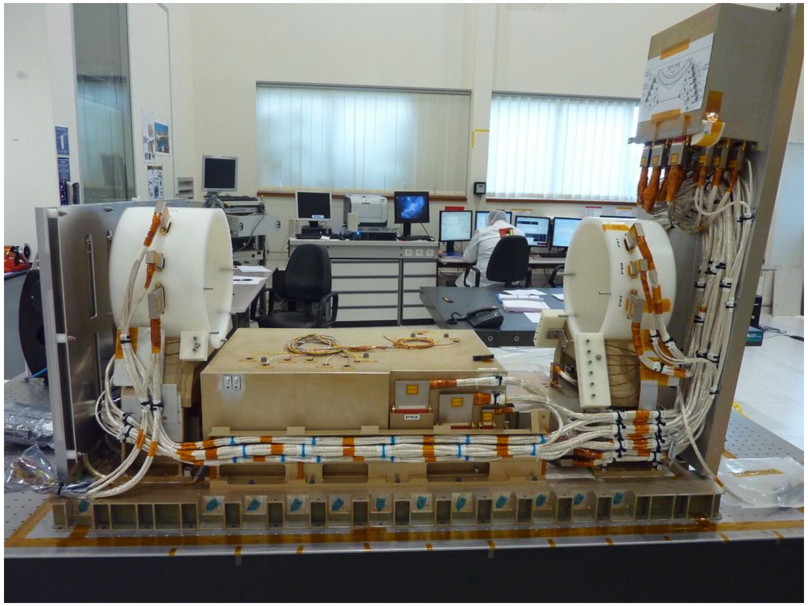
The FM is assembled

- Thermal settings (-40, +40)
- Performances tests in progress
- Qualification tests Nov.



Planning

The Clock flight model will be assembled on january 2014
on ACES baseplate (at CNES)



To perform measurements on

- Cold atom manipulation
- and to measure the two last systematic effects: cold collision and Doppler shift (3 months)

To be delivered to Astrium for the whole ACES payload integration and tests