Status of the ACES/PHARAO mission

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What is ACES: payload, science objectives, …

Status of PHARAO and other ACES instruments

Conclusions
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SUPPORT:
European Space Agency
Centre National d’Etudes Spatiales
Centre National de la Recherche Scientifique
Observatoire de Paris
LNE

CORE INDUSTRIAL TEAM:
What is ACES: payload, science objectives, ...
ACES : Atomic Clock Ensemble in Space

ACES payload on ISS

PHARAO
XPLC
SHM

FCDP
MWL space segment

XPLC : payload computer
PHARAO : Cold Cs atom clock
SHM : Space Hydrogen Maser
FCDP : Frequency Comparison and Distribution Package
MWL : Microwave Link

ACES ground segment

ACES control and mission center

MWL ground terminals

Rencontres de Moriond – La Thuile, 11-18 march 2007
Australia:       UWA, CSIRO (Sydney)  
Austria:          Univ. Innsbruck  
Brazil:            Univ. Sao Carlos  
Canada:            NRC  
China:             Shangai Obs, NIM, NTSC  
Germany:          PTB, MPQ, Univ. Hannover, Univ. Düsseldorf,  
                  TU Muenchen, Univ. Erlangen  
France:            SYRTE, CNES, Obs. Besançon, OCA, LPL  
Italy:              INRIM, Univ. Firenze  
Japan:              Tokyo Univ., NMIJ, CRL  
Italy:              INRIM, Univ. Firenze  
Russia:            Vniftri, ILS Novosibirsk  
Swiss:              METAS, ON  
England:           NPL  
USA:                JPL, NIST, JILA, Penn St. Univ., USNO  
Taiwan:            Telecom research lab  
Int. Agency:       BIPM

Total: 35 Institutes + theory groups  > 280 researchers
THE ACES PAYLOAD ONBOARD ISS

Launch scheduled in 2013 with the Japanese HTV

European Columbus module

ACES Payload

→ Launch scheduled in 2013 with the Japanese HTV
THE ACES PAYLOAD

ASTRIUM

Volume: 1172x867x1246 mm$^3$
Total mass: 227 kg
Power: 450 W
ACES science objectives

- Study of cold atoms physics in space (first cold atom instrument in space !)
- Demonstration of PHARAO and SHM high performance ($\Delta v / v \approx 10^{-16}$)
- Demonstration of MWL high performance (time noise < 10 ps / day)

- Time comparisons between ACES clocks and ground located clocks :
  - T&F metrology, improvement of atomic time scales
  - Test of general relativity :
    - measurement of the gravitational red shift (@ 2 ppm)
    - search for a possible drift of fundamental constants (10^{-16} - 10^{-17} / year)
  - Test of special relativity (preferred frame) :
    - search for a possible anisotropy in light velocity : $\frac{\delta c}{c} < 10^{-10}$
Comparison scenarios

Space clock to ground clock comparison

→ Short comparison sessions (300 s) separated by large dead times

→ A few comparison sessions per day

Uncertainty: 0.3 ps over one ISS pass, 6 ps over 1 day

![Graph showing visibility per day with bars indicating different intervals and their occurrence over 28 days]
Comparison scenarios

Ground clocks comparison in common view

→ Up to 4 simultaneous ground stations in common views

→ Time stability of the ground clock comparison < 1 ps

→ Capability to compare ground clocks with a resolution of $10^{-17}$ @ 1 day
Comparison scenarios

Ground clocks comparison in non-common view

→ Time stability of the ground clock comparison: a few ps

→ Capability to compare ground clocks with a resolution better than $10^{-16}$ @ 1 day

Most distant stations: Paris-Perth

Between 1 and 2 non common views per day within less than 3000 seconds
Several non common views within 10 000 seconds

Overall: less than 10 ps at half day, ie 2 $10^{-16}$
ACES

INSTREMENTS

STATUS
PHARAO sub-systems

- **Microwave source**
  - For the atoms interrogation

- **Cesium tube**
  - For all the atoms/fields interactions

- **Laser source**
  - For radiative cooling and launching, atom state preparation and clock signal detection

- **Computer**
  - For the whole experiment control, data storage and processing
PHARAO sub-systems: the microwave source

EM test with SYRTE cold atom fountain:

\[ \sigma_y(\tau) = 7 \times 10^{-14} \tau^{-1/2} \]

The best result ever obtained with a quartz oscillator
PHARAO sub-systems: the cesium tube

- Ramsey cavity
- Quantum state preparation
- Cold atom source
- Clock signal detection
PHARAO sub-systems: the laser source
PHARAO EM assembly in CNES Toulouse

\[ 4 \times 10^7 \text{ cold atoms} @ 1 \mu K \]

- Laser source
- Cesium tube

\[ \Delta \nu = 5.5 \text{ Hz} \]
→ Frequency stability:

\[ \sigma_y(\tau) = 4 \times 10^{-13} \tau^{-1/2} \]

→ Compatible with \( \sigma_y(\tau) < 10^{-13} \tau^{-1/2} \) in space (\( \Delta\nu < 1 \text{ Hz} \))

→ Frequency accuracy: under evaluation (10^{-15} expected on ground, 10^{-16} in space)
Other ACES instruments status

Feasibility demonstration of SHM is done. EM delivered in 2007

Successful tests of phase comparison and phase lock loop with FCDP EM (in CNES)

Measured noise of MWL/DLL at Ku band: 160 fs at 1 s

Flight antenna tests

Full tests of MWL EM flight segment in March 2007
CONCLUSIONS

→ PHARAO and FCDP EM already delivered
→ The other instrument EM delivered by the end of 2007
→ Many specific studies on the payload (thermal, microvibrations, orbit determination, …)

→ 2007 : a very important step for the project (CNES decision to fund the PHARAO FM)
→ Scheduled launch date : 2013 (mission duration > 18 months)

→ ACES is both a scientific mission and a technology demonstrator for cold atom based missions (validation in space of complex laser systems, UHV equipment, ultrastable RF electronics, …)

→ Precursor of the next generations of atomic quantum sensors for space missions (clocks, accelerometers, gyroscopes, gravity acceleration / potential sensors)

→ Other T/F metrology missions : T2L2 on board Jason 2 (2008)