Time and frequency transfer with a microwave link in the ACES PHARAO mission

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Expected performances

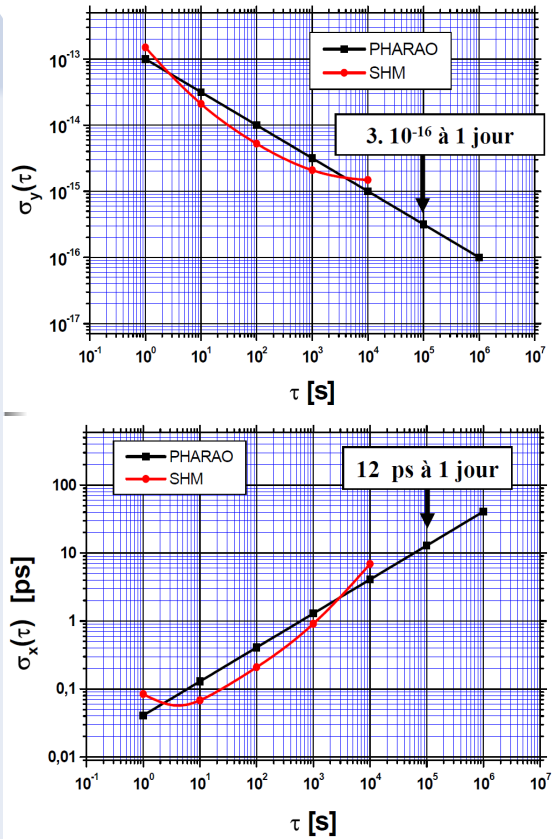
A realization of the second in space (PHARAO) :

- Accuracy better than $3 \cdot 10^{-16}$
- Frequency stability better than $10^{-13} t^{-1/2}$ for t<20 days

A time scale of high stability (PHARAO/HMASER composite clock)

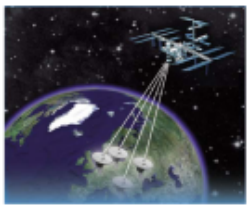
- better than 400 fs @ 300s
- better than 40ps @ 20 days

+ a microwave link (MWL) and a laser link (ELT)

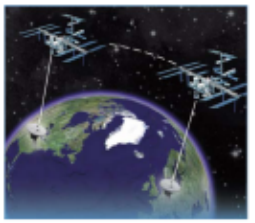


ACES : Main science goals

- Atomic clock and microwave link performances in space environment
- Distant clock comparisons



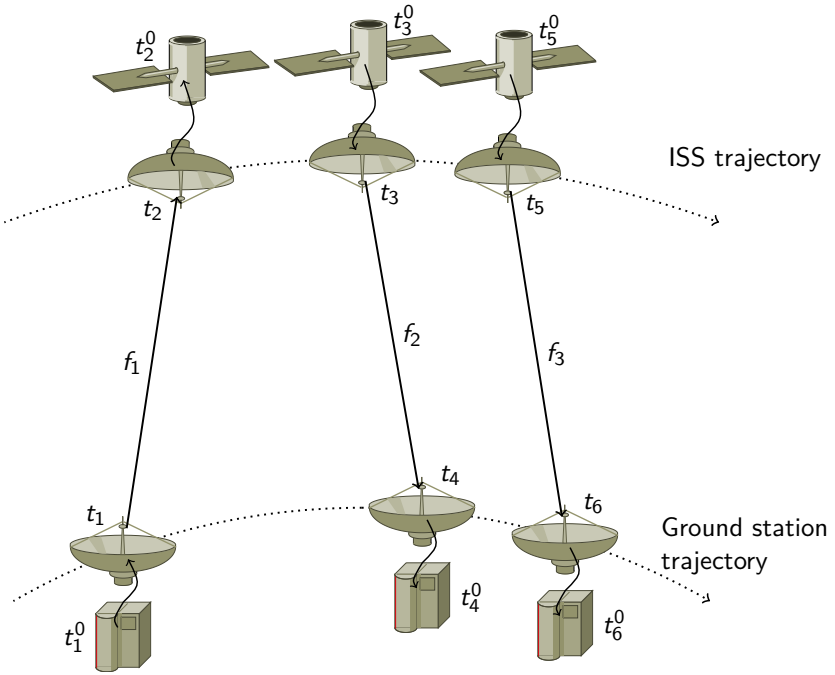
Common view : stability $\simeq$ 0.3 ps @ 300s



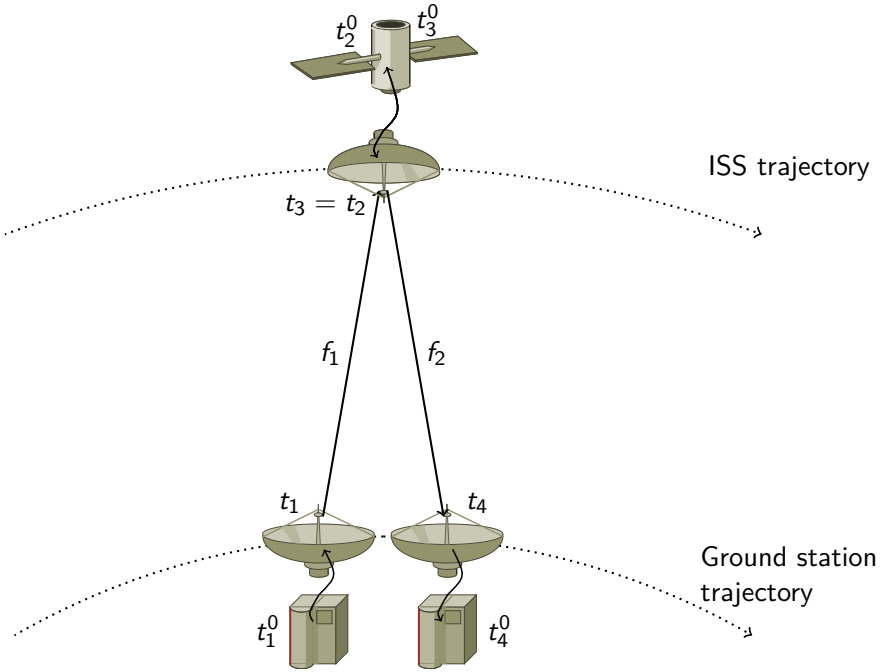
Non common view : stability $\simeq$ 7 ps @ 1 day

- General relativistic redshift test, alternative theories (SME, ...)
- Relativistic geodesy

ACES microwave link setup



General case

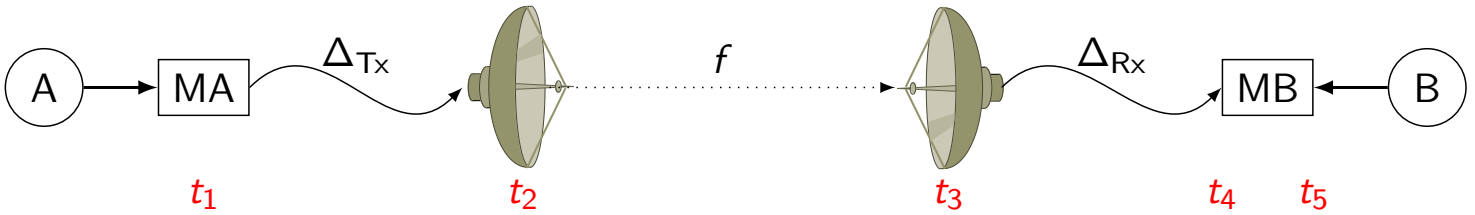


Λ configuration (interpolated)

one measurement each 80 ms on ground and in space

A third frequency (downlink) is used to determine the ionospheric delay.

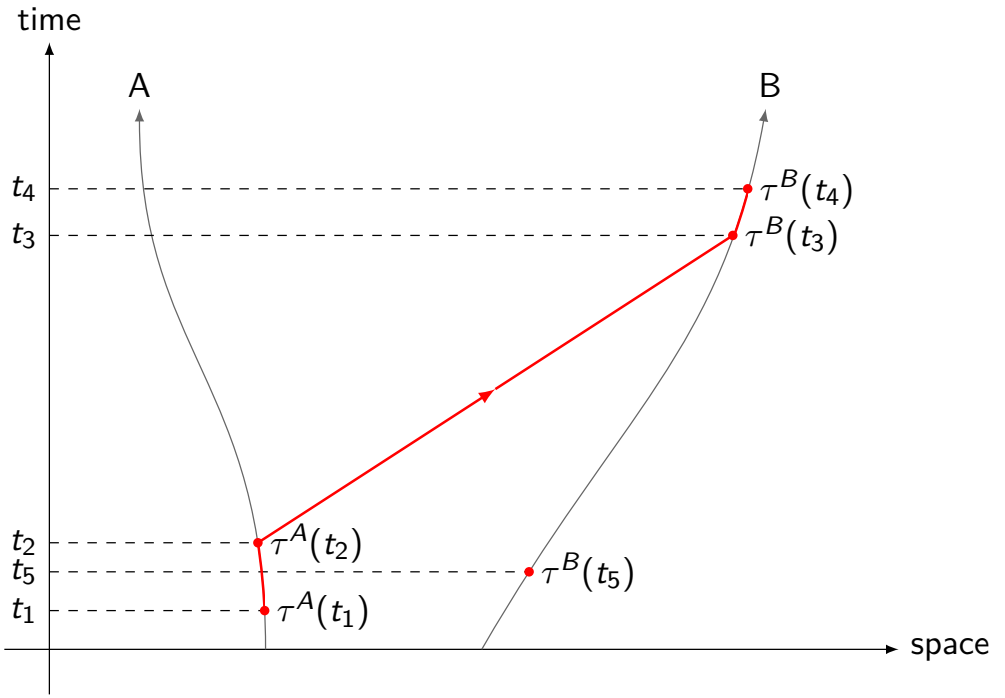
One-way measurements with MWL



One-way measurement setup

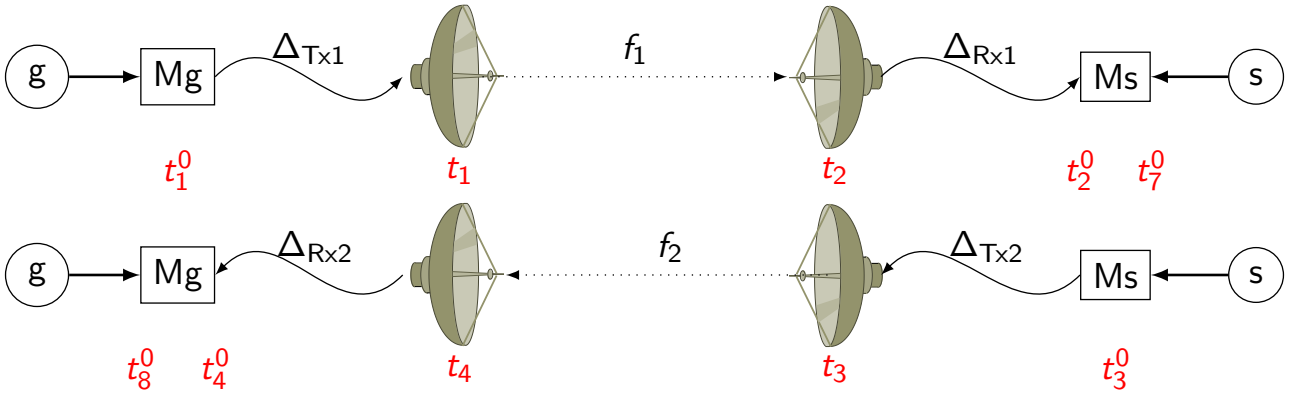
If $\tau^A(t_1) = \tau^B(t_5)$, we define

$$\begin{aligned}\Delta\tau^B(\tau^B(t_4)) &= \tau^B_{\text{prod}} - \tau^B_{\text{rec}} \\ &= \tau^B(t_5) - \tau^B(t_4) \\ &= \tau^A(t_1) - \tau^B(t_4)\end{aligned}$$



Desynchro : $\tau^B(t_4) - \tau^A(t_4) = -\Delta\tau^B(\tau^B(t_4)) - \left[T_{23} + [\Delta_{Tx} + \Delta_{Rx}]^t\right]^A$

Two-way measurements with MWL



Two-way measurement setup (= 2× one-way)

2 observables :

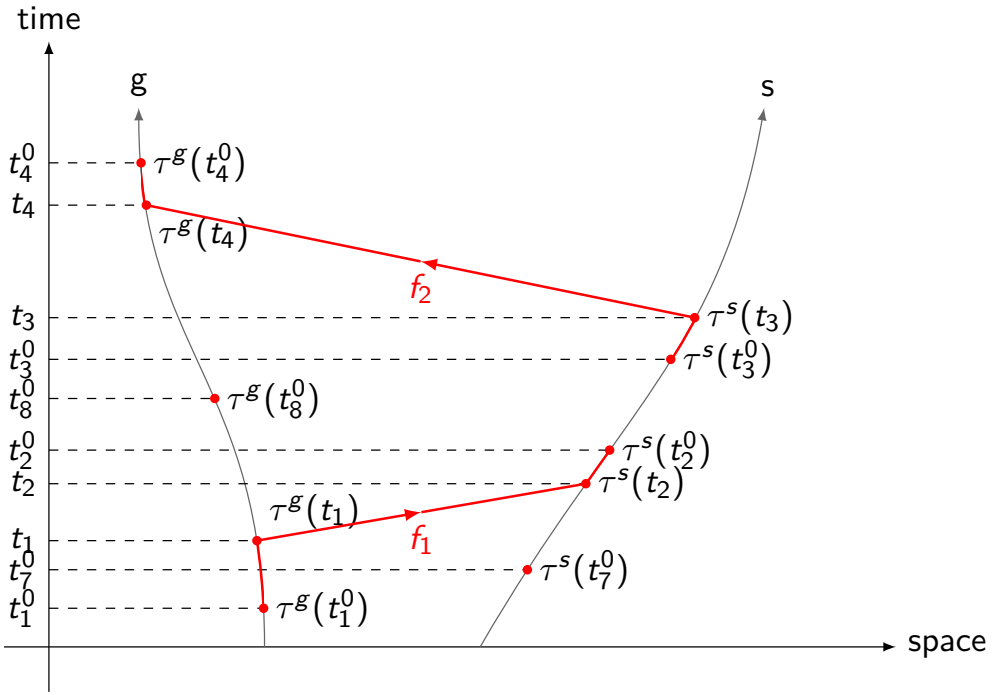
$$\Delta\tau^s(\tau^s(t_2^0)) = \tau^s(t_7^0) - \tau^s(t_2^0)$$
$$\Delta\tau^g(\tau^g(t_4^0)) = \tau^g(t_8^0) - \tau^s(t_4^0)$$

$\tau^g(t_1^0) = \tau^s(t_7^0)$ and $\tau^s(t_3^0) = \tau^g(t_8^0)$

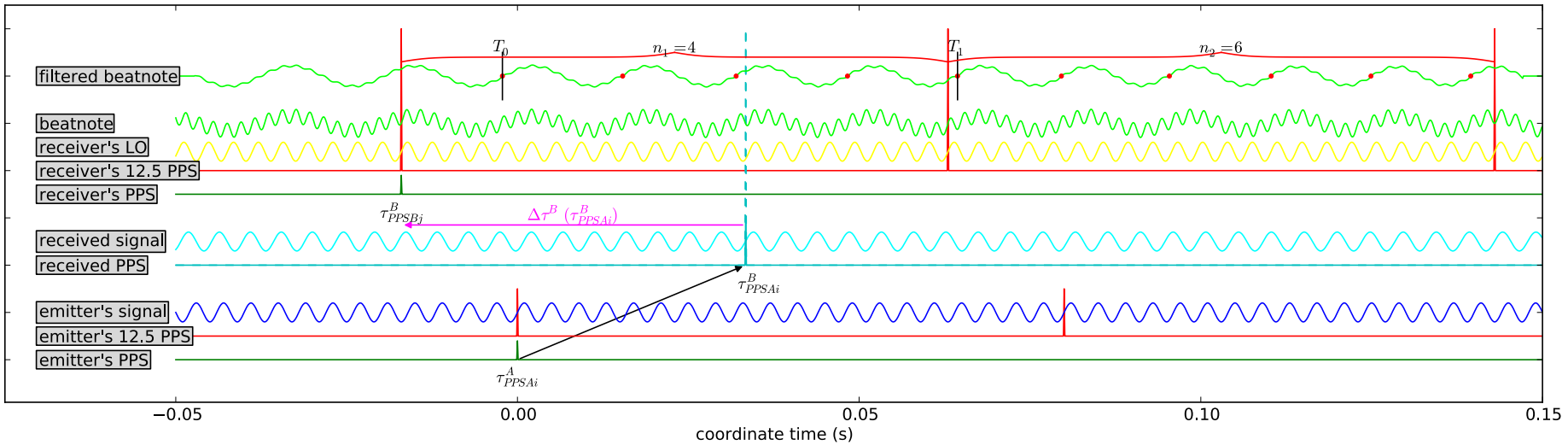
Desynchro :

$\tau^s(t_2) - \tau^g(t_2) =$

$\frac{1}{2}\left((\Delta\tau^g - \Delta\tau^s + [T_{34} - T_{12}]^g + \ldots\right)$



Microwave link measurement principle

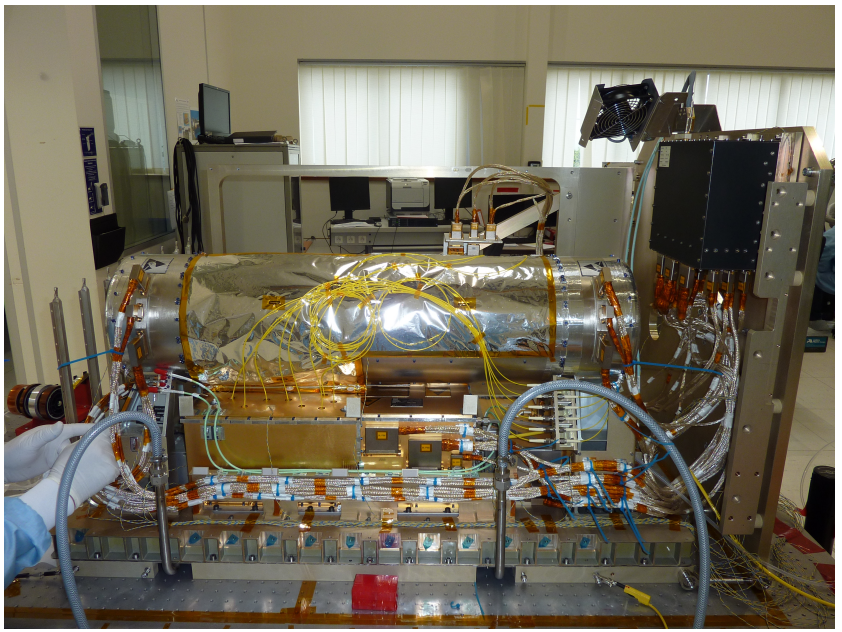


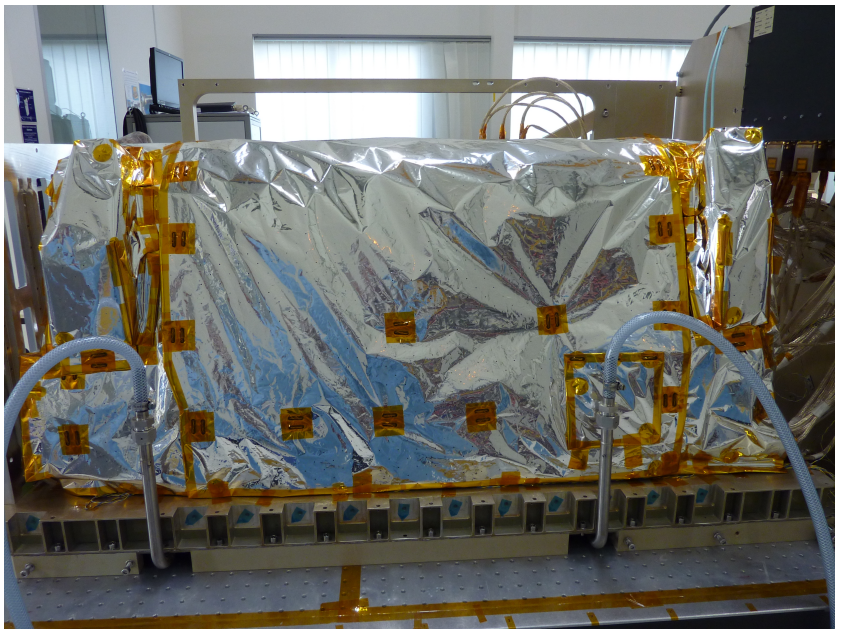
The system generates a beatnote between incoming signal and the local oscillator, then counts the number of zero-crossing for each sample.
Code = 100 MHz (beatnote : 195 kHz)
Carrier = 13.475 GHz / 14.703 GHz (beatnote : 729 kHz)

Ground stations

2 Ground terminals antennas already assembled, electronics under development (to be installed at SYRTE + PTB at autumn 2014).

Flight Segment





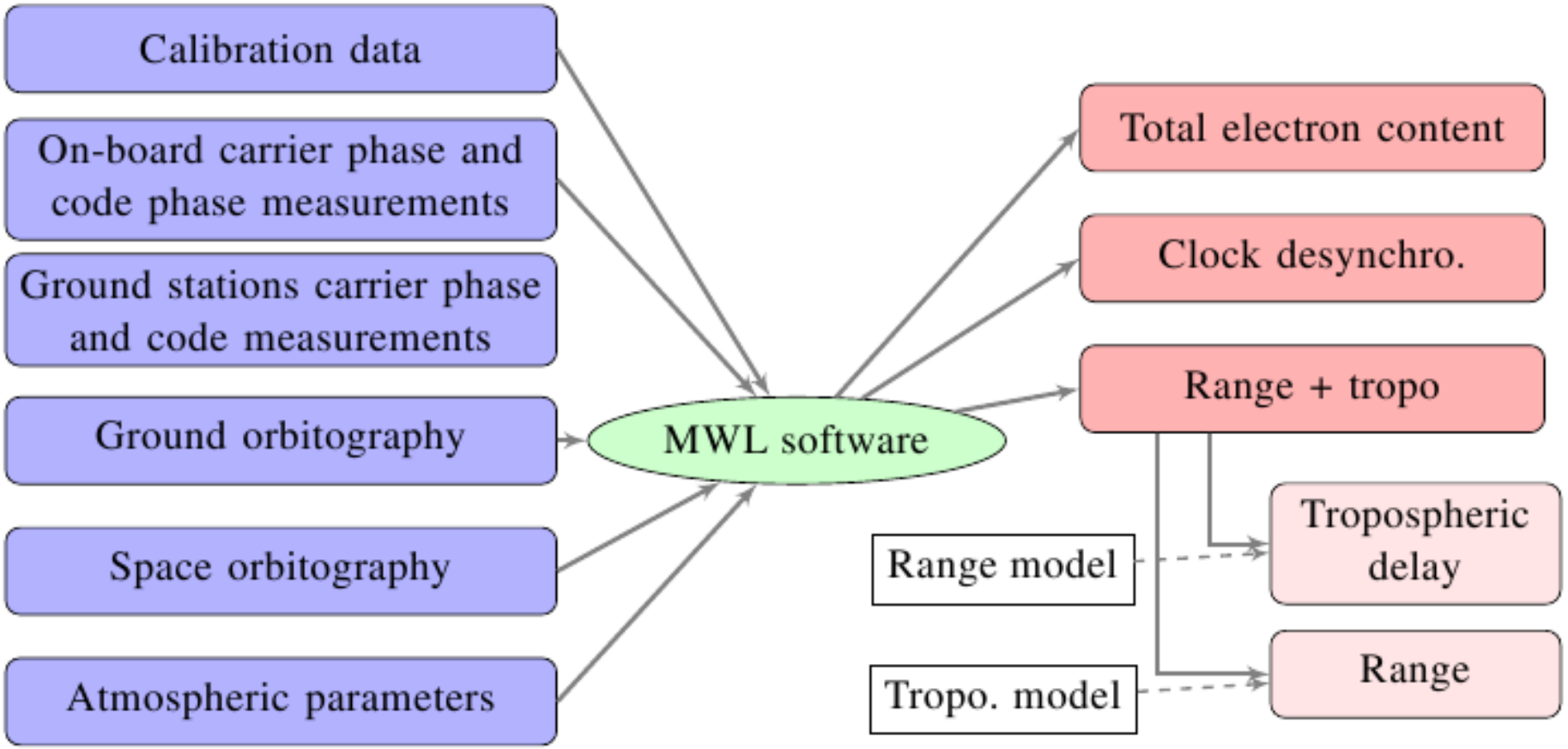
PHARAO : FM integrated, working and is now under validation.

MWL Antenna :
FM delivered

MWL Electronics :
FM in construction

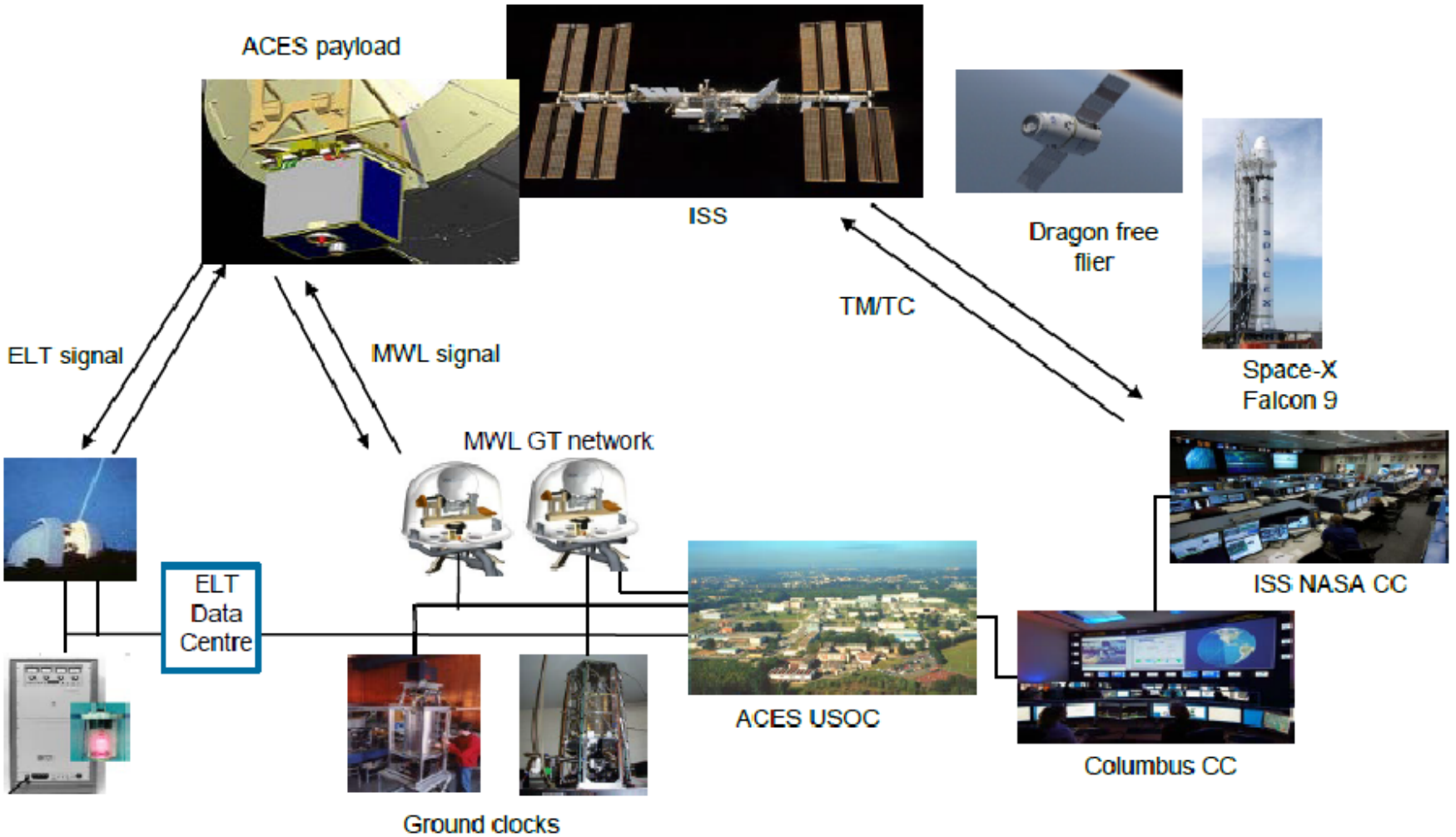
SHM (H-Maser) : pending...

Data Processing

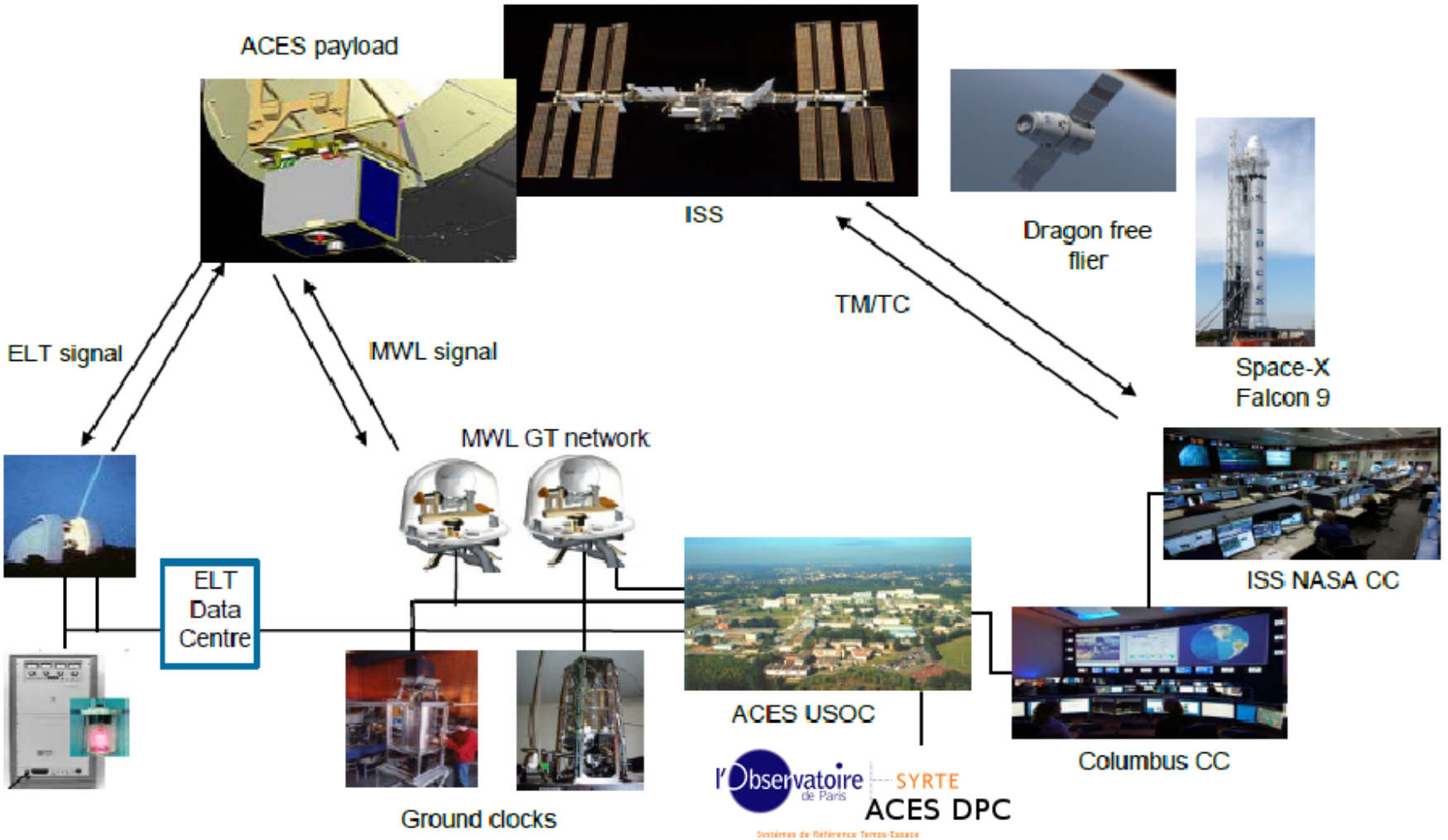


Status : low-level data processing under development at ASTRIUM, high level data processing and scientific analysis under development at SYRTE.

ACES mission components



ACES mission components



Remaining milestones

- ACES flight model integration and tests (SHM last blocking point)
- Ground stations installation (prototypes in SYRTE and PTB end of 2014)
- Data processing chain implementation
- **Launch in may 2016**