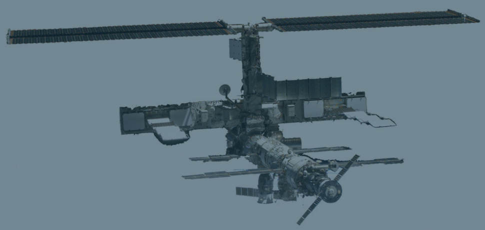
DATA SIMULATION AND ANALYSIS FOR THE ACES/PHARAO MISSION



From QUANTUM 2 COSMOS

Session II

October 2013, 15-17th

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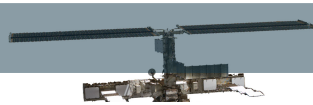
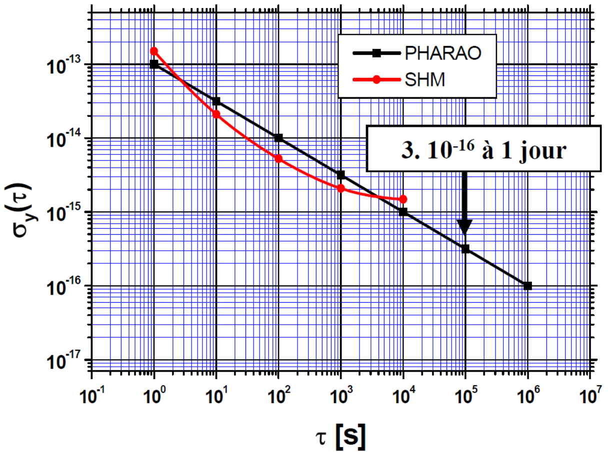
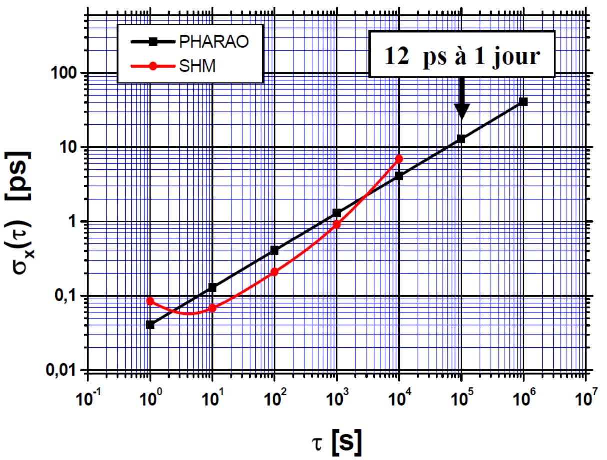
An international metrological space mission

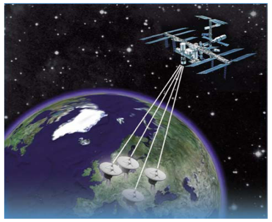


- A time scale in space of **high stability**…
  - better than $\sigma_y = 10^{-13} \cdot \tau^{-1/2}$ (in frequency)
  - better than $\sigma_x = 2.1 \cdot 10^{-14} \cdot \tau^{+1/2}$ (in time)
- …and **accuracy** ~ 10^{-16}
- **International cooperation** of more than 150 people
  - Science: LKB/ENS, SYRTE, PTB, Neuchâtel, UWA, …
  - Space agencies: ESA, CNES
  - Industrial: EADS/Astrium, EADS/Sodern, TimeTech, …





- Main **scientific objectives**
  - Atomic clock and microwave link performances in a space environment
  - Distant clock comparisons
  - Equivalence principle tests
  - Relativistic geodesy

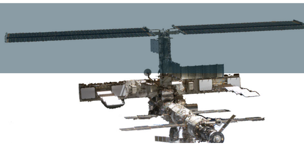


Common view

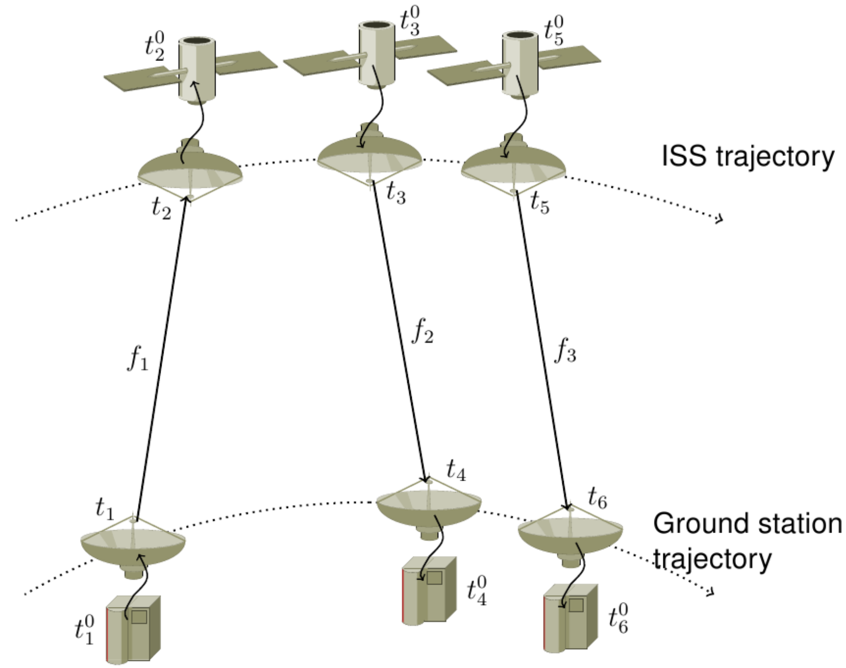
Stability ~ 0.3 ps @ 300 s.

Non common view

Stability ~ 7 ps @ 1 day



- What is a time transfer ? Compare distant clocks to determine their **desynchronisation**
- The MWL :
  - **Three signals** of different frequency (1 up, 2 down)
  - One signal = carrier + code
  - Asynchronous link → choice of the configuration by interpolating
- **ST** (Syrte Team) observables (six):
  - Time difference between the locally generated code/carrier and the received one

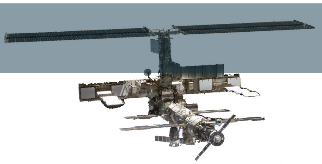


$$f_1 \simeq 13.5\ \text{GHz}$$
$$f_2 \simeq 14.7\ \text{GHz}$$
$$f_3 = 2.24\ \text{GHz}$$

delays

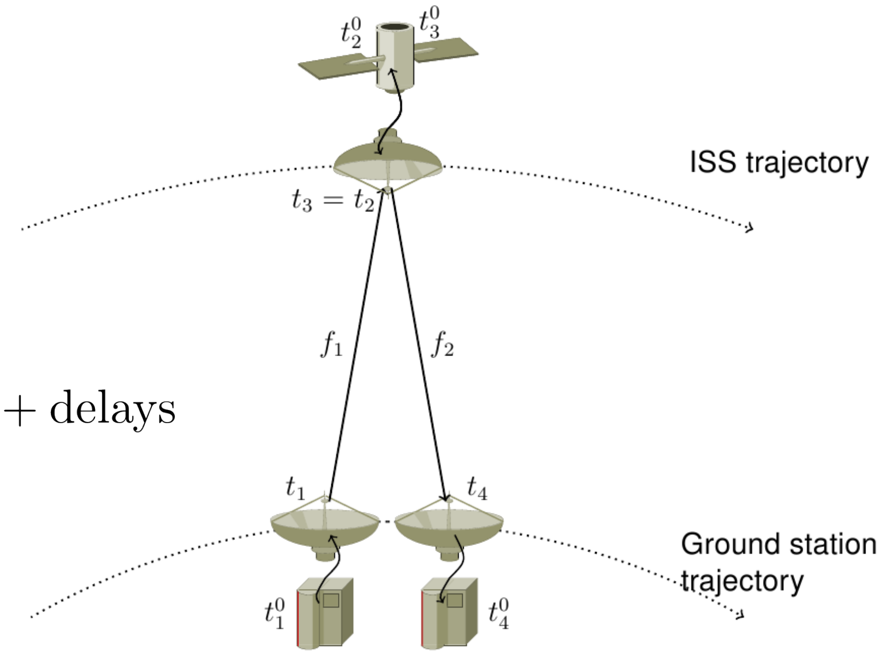
$$\tau^s(t_2^0) - \tau^g(t_2^0) = -\Delta\tau^s - \left[T_{12} + [\Delta_{\mathrm{Tx}} + \Delta_{\mathrm{Rx}}]^t\right]^g$$

Desynchronization | ST observable | Time of flight (from orbitography)

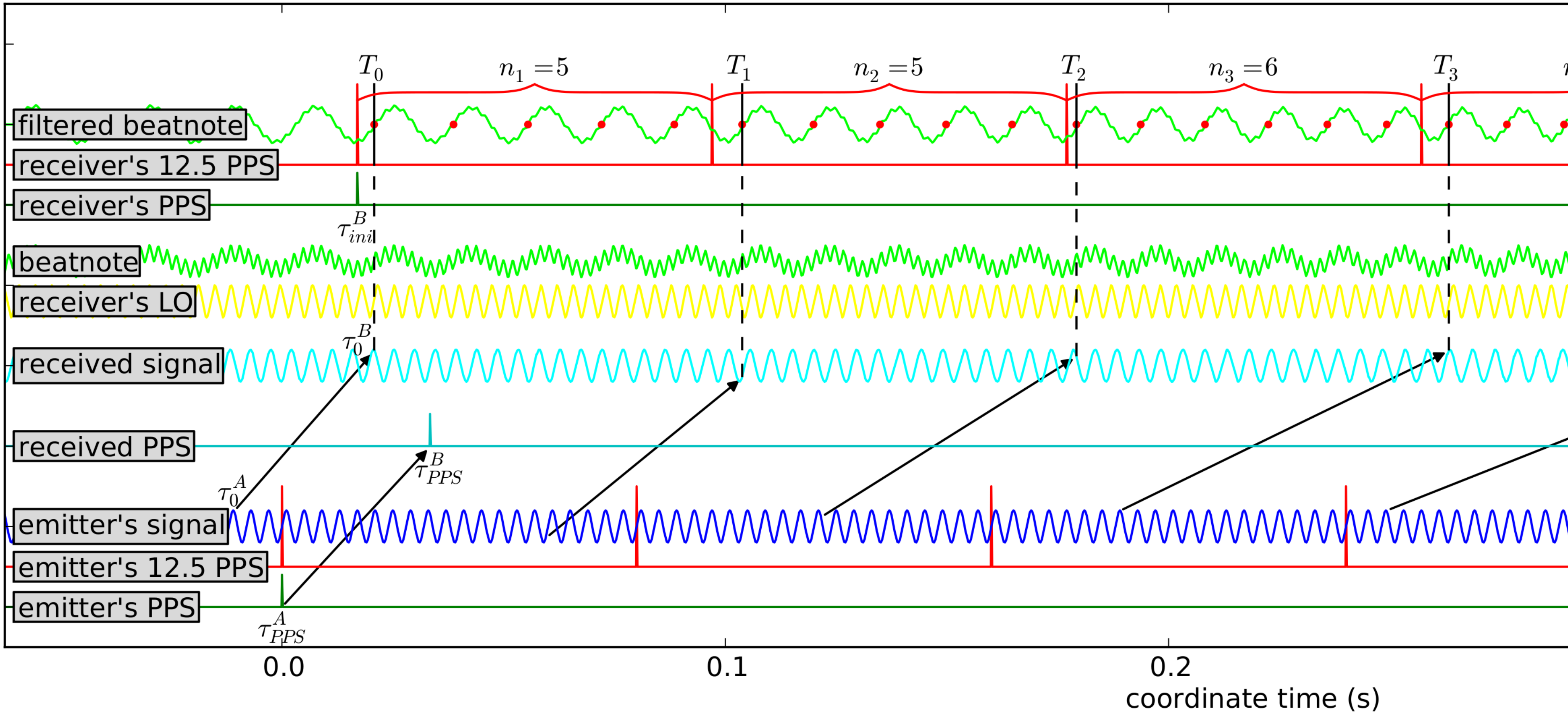


- **Lambda configuration** :
  - Interpolate data so that $t_2 = t_3$
  - Minimize error due to ISS orbitography (Duchayne et al., A&A **504**, 2009)
  - Different from « standard » 2-way configuration

$$\tau^s(t_2) - \tau^g(t_2) = \frac{1}{2}\left(\Delta\tau^g - \Delta\tau^s + [T_{34} - T_{12}]^g\right) + \text{delays}$$

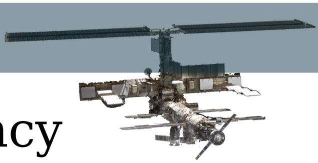


- **Atmospheric electronic content**
  - Ionospheric delay depends on signal frequency and STEC
  - Data from downlinks → STEC



ST observables : time difference between the locally generated code/carrier (= local time of emission) and the received one (in receiver time) → pseudorange

2 methods for recovering ST observables from TT observable : *iterative* and *direct*



- **Accuracy** of ST observables during one passage (for frequency transfer) :

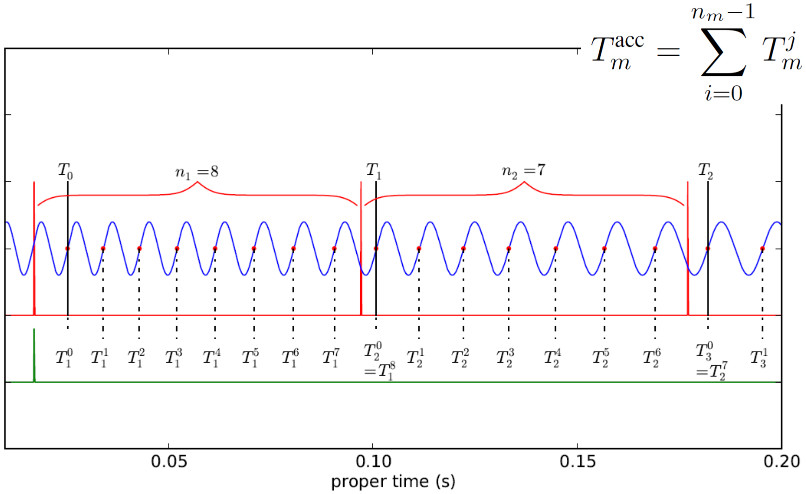
$$\delta(\Delta\tau_m) = \left(\frac{f_{\rm beatnote}}{f_{\rm emission}}\right) \cdot \delta T_m \quad (\delta T_m \sim 10\ \text{ns})$$

$$\frac{195\ \text{kHz}}{100\ \text{MHz}} \cdot 10\ \text{ns} \sim 20\ \text{ps (code)}$$

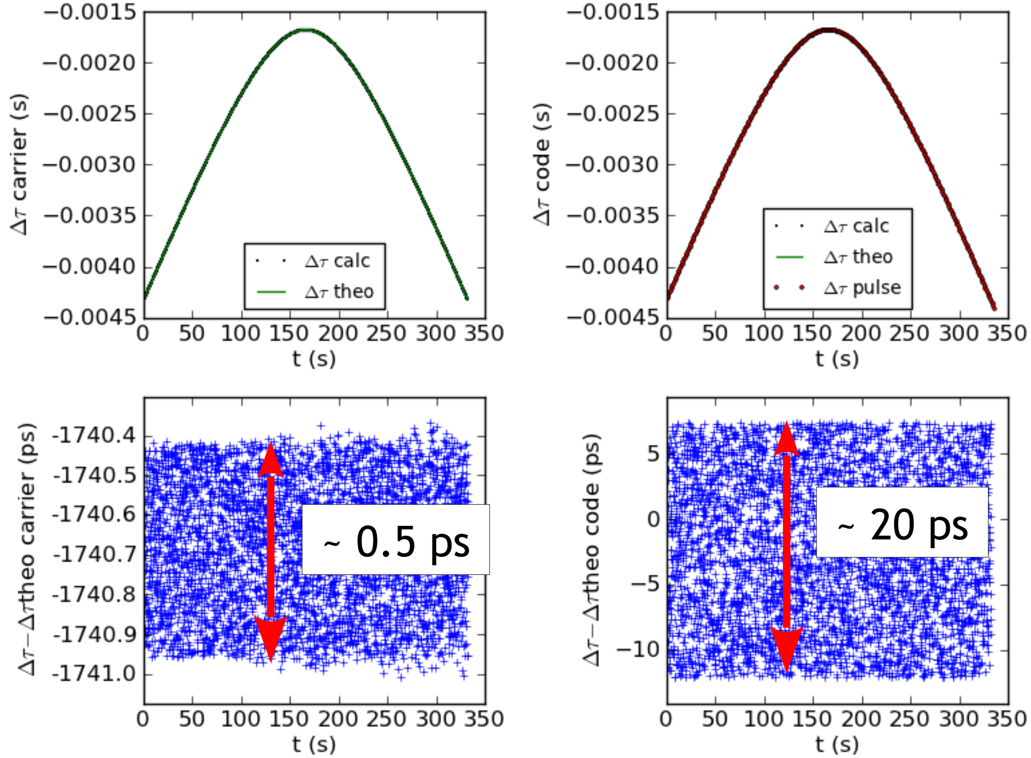
$$\frac{729\ \text{kHz}}{13.5\ \text{GHz}} \cdot 10\ \text{ns} \sim 0.5\ \text{ps (carrier)}$$

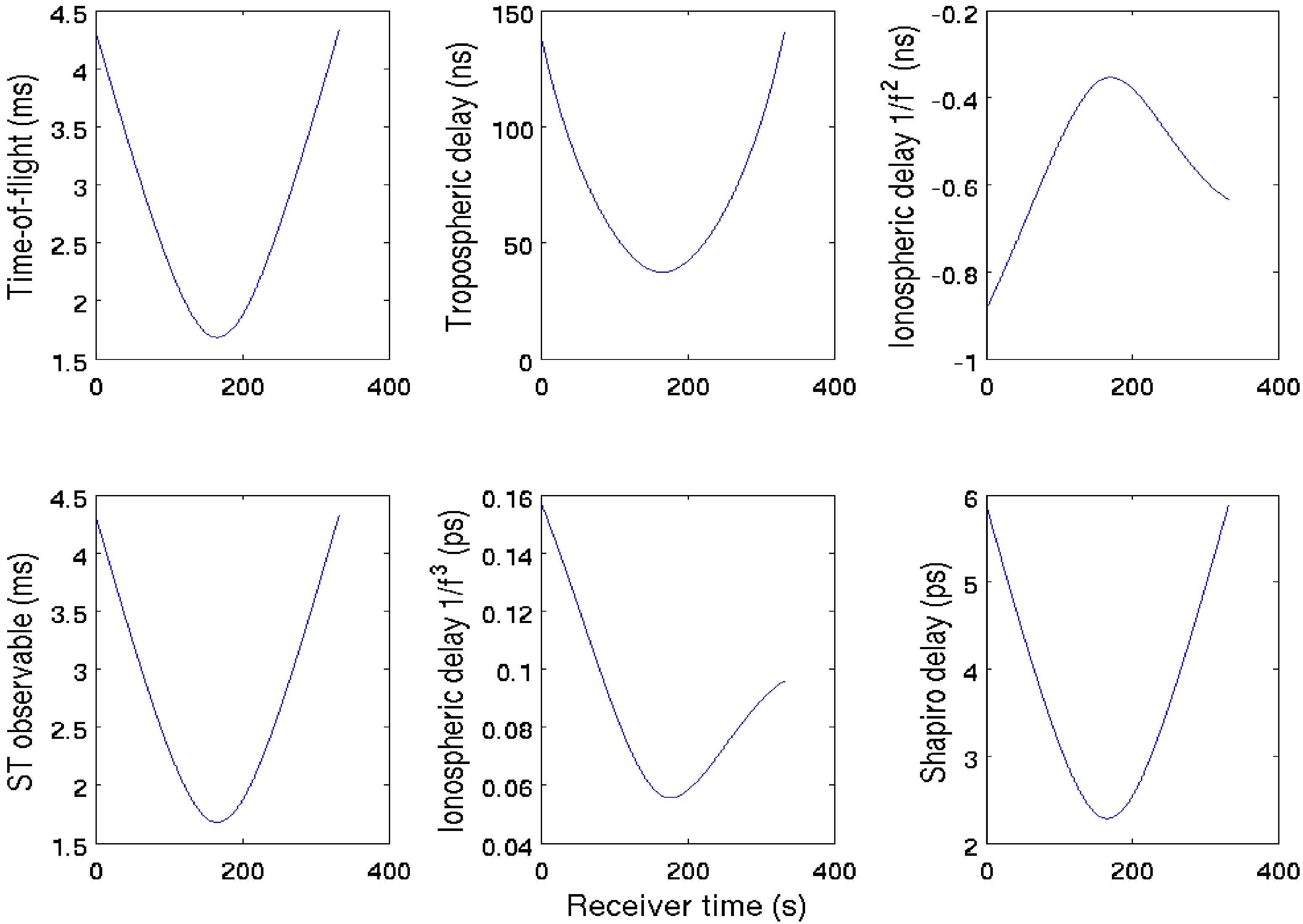
- **Resolve code ambiguity**
  - Iterative method : initial term found by averaging on all PPS
  - Direct method : ambiguity found by fitting the code phase to one PPS
  - code to resolve carrier ambiguity

- Measurement uncertainty can be further decreased by using “accumulated phase latch”, T_{acc}. But in the end S/N dominated by received power

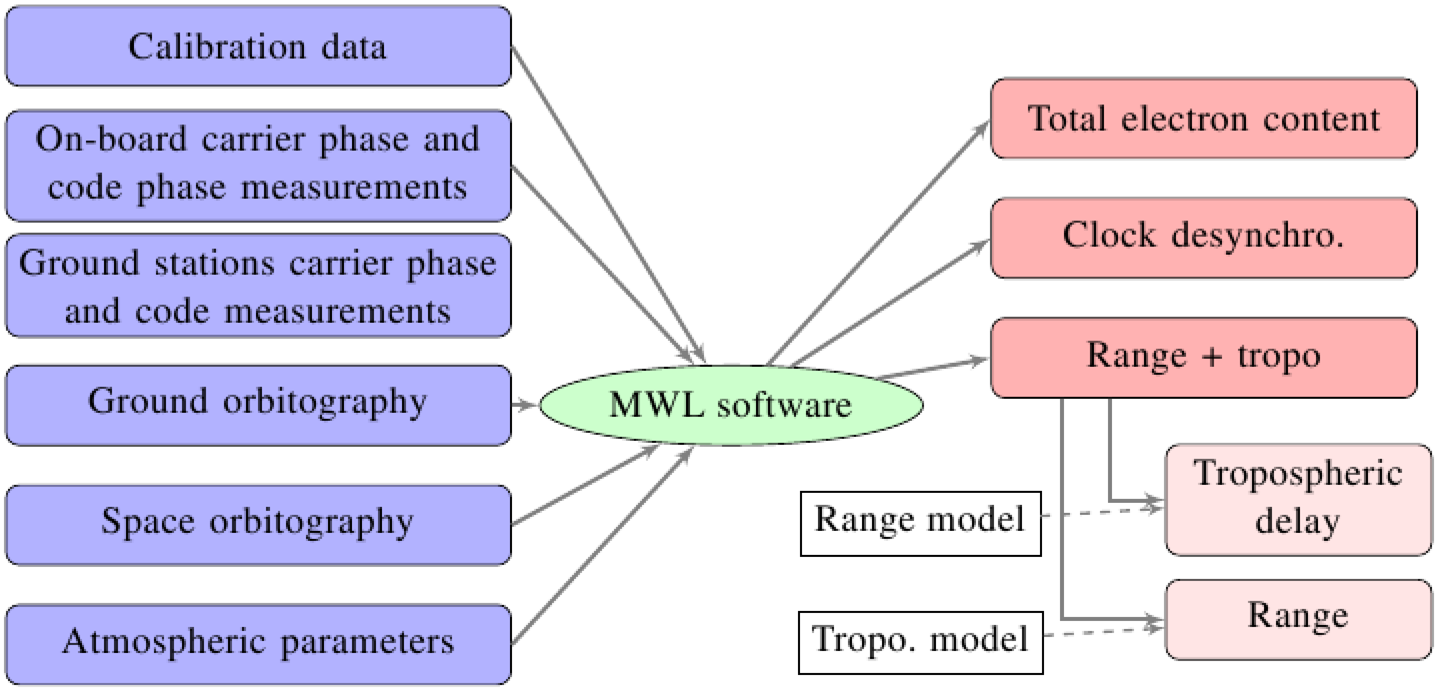


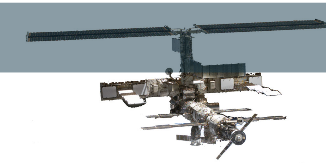
- ISS orbitography + station coordinates in Terrestrial Reference Frame → transform to Celestial Reference Frame (inertial)
- clock modelization for ISS & GS (e.g. noise)
- Solve time transfer between the two terminals
- Generate TimeTech observables & theoretical values
- Test of preprocessing code (from TT 2 ST observables)

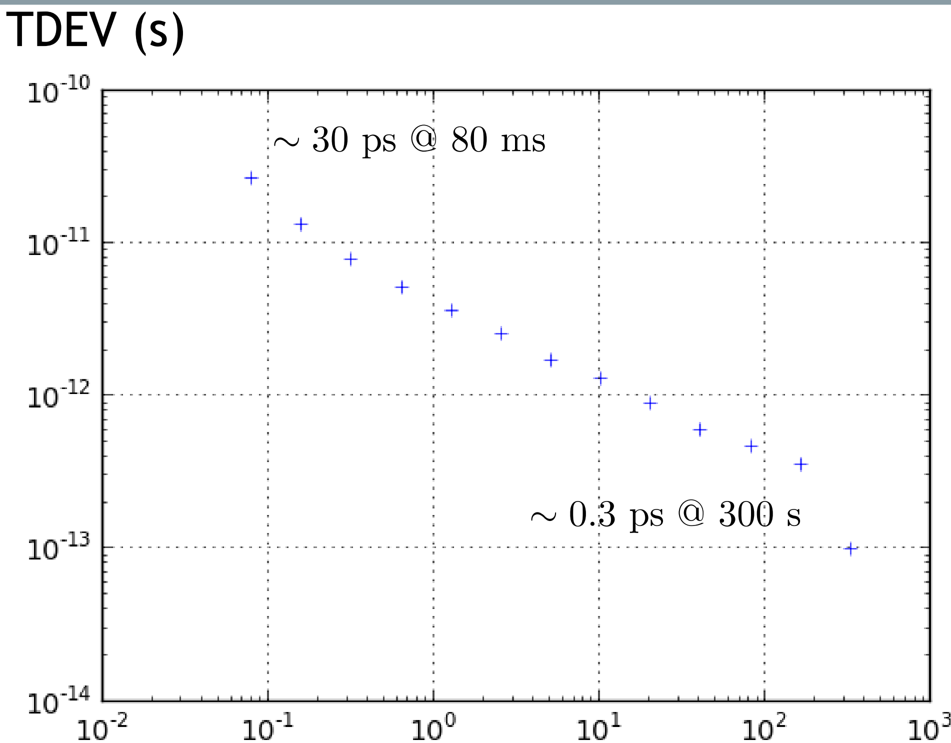



Time-of-flight (ms)
Tropospheric delay (ns)
Ionospheric delay 1/f^2 (ns)
ST observable (ms)
Ionospheric delay 1/f^3 (ps)
Shapiro delay (ps)
Receiver time (s)
0
200
400

- Data analysis : file naming, data classifying, file formats, conventions...
- Inputs and outputs :



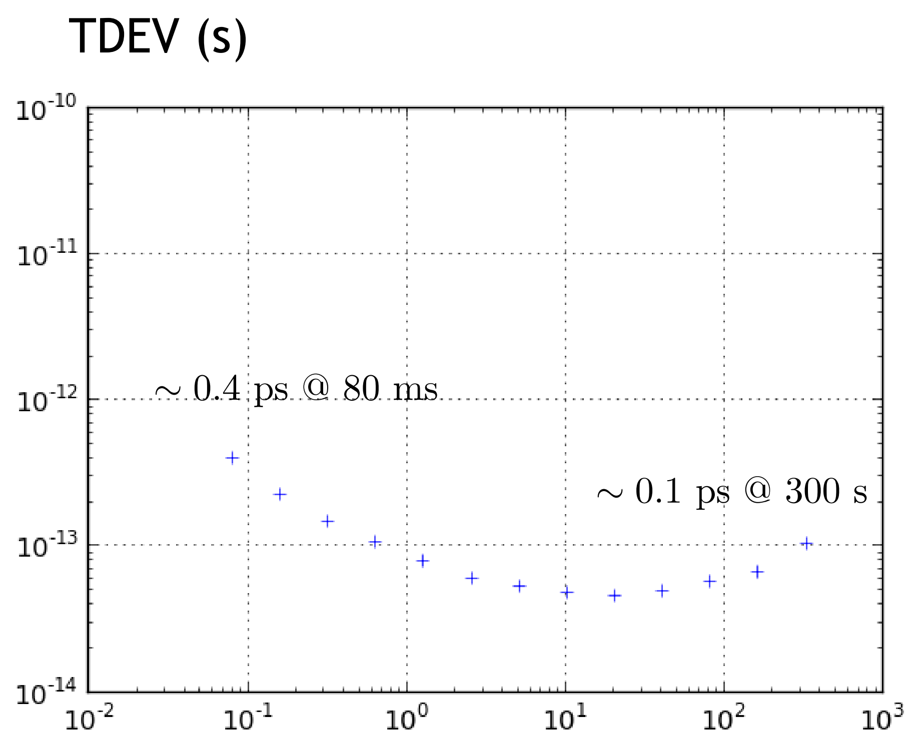




- Space and Ground Terminals are connected to the same clock → null desynchronisation

- 1 way **code** observables

- 1 way **carrier** observables



Scientific analysis: T2L2

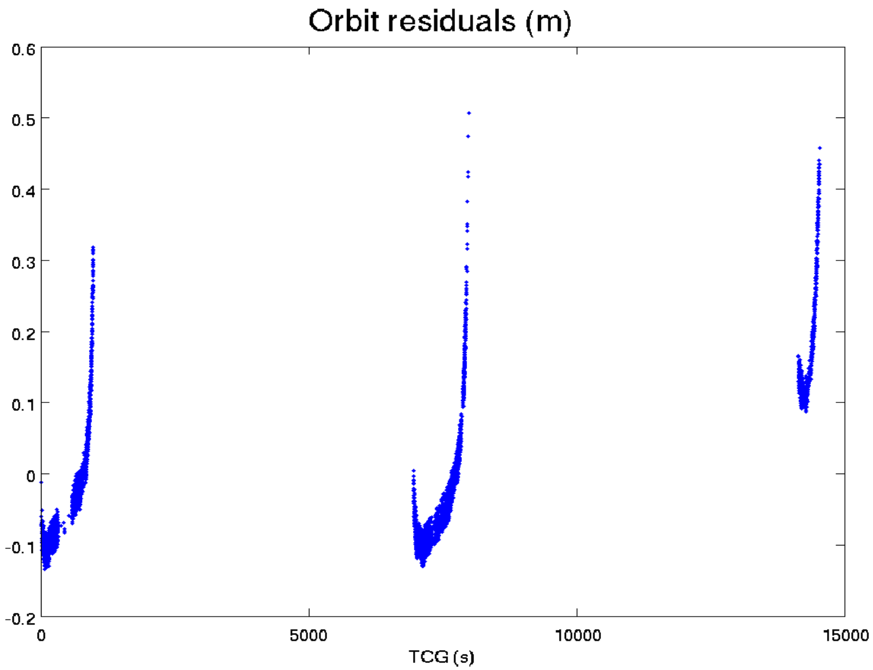
Jason satellite

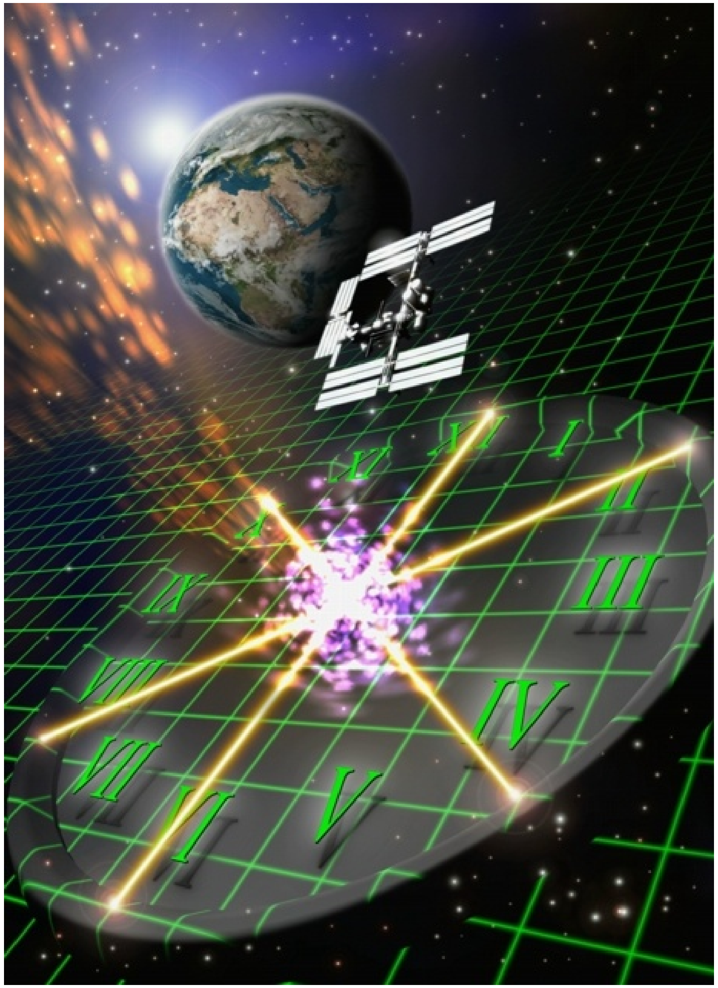
Collaboration with Geoscience Azur (UNS, CNRS-OCA)

Test of Lorentz invariance in the Robertson-Mansouri-Sexl formalism

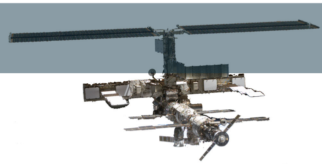
Real data == PROBLEMS → T2L2 is a good occasion to test parts of our ACES analysis code

MEO laser Station @ OCA





- Link between TimeTech observables and Syrte Team observables understood
- Simulation to generate TimeTech observables and theoretical observables
- Software for pre-processing of data finished and tested (+implementation of a new pre-processing method for robustness)
- Data analysis software : design done, writing in progress, first (simple) tests successful
- MWL end to end test in progress (TimeTech)
- Analysis of T2L2 data for science (Lorentz Invariance) and as “test case” in progress



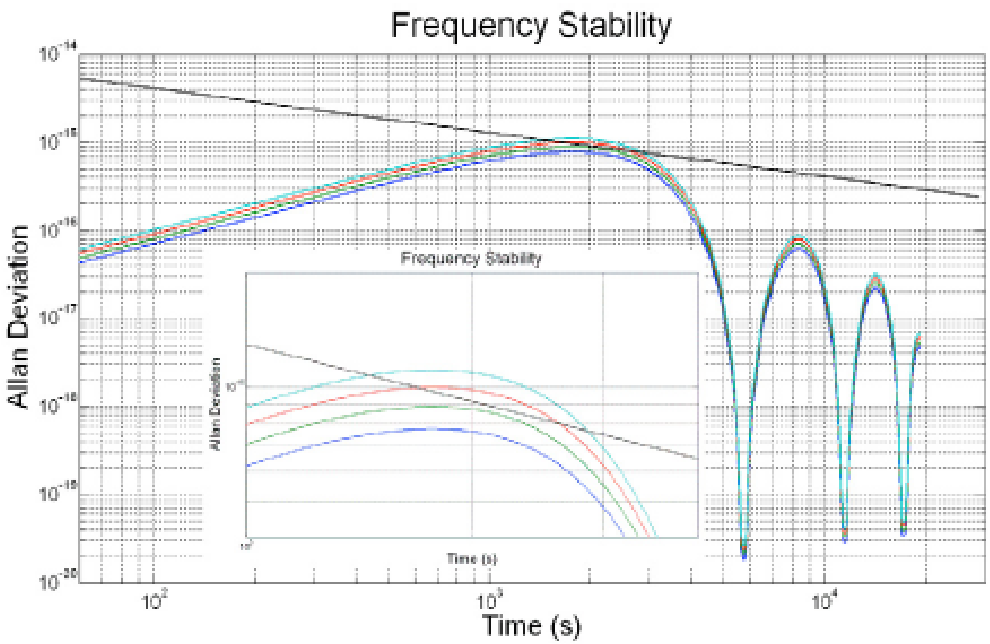


Fig. 7. Modified Allan deviations of the redshift error for $X = 14, 16, 18, 20$ m.

Duchayne et al., A&A 504 (2009)

- « Naive » estimate give 1m for 10^-16 relative accuracy
- Relativistic frequency shift : grav. Redshift + 2nd order Doppler effect → errors partly cancel
- Hill and white noise model give :
  - 8 m for radial errors
  - 16 m for tangential errors
  - 1,4 km for normal errors
  - Plus constraints on the Lambda configuration and calibration delays