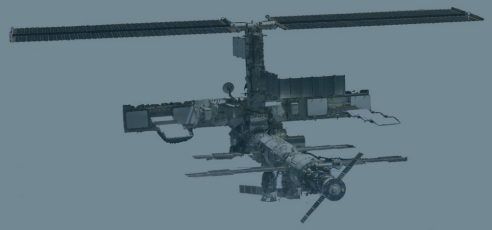
Status of data processing and analysis preparation for the ACES Microwave Link



l'Observatoire de Paris — SYRTE
Systèmes de Référence Temps-Espace
cnrs
LNE Sharing a passion for progress
UPMC SORBONNE UNIVERSITÉS

Journées de la SF2A - session GRAM

Nice

June 2012, 5-8th

Frédéric MEYNADIER

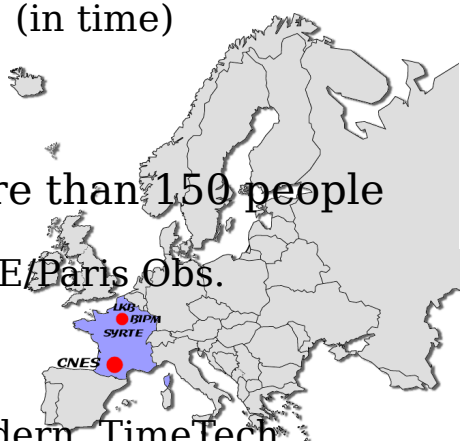
Pacôme DELVA

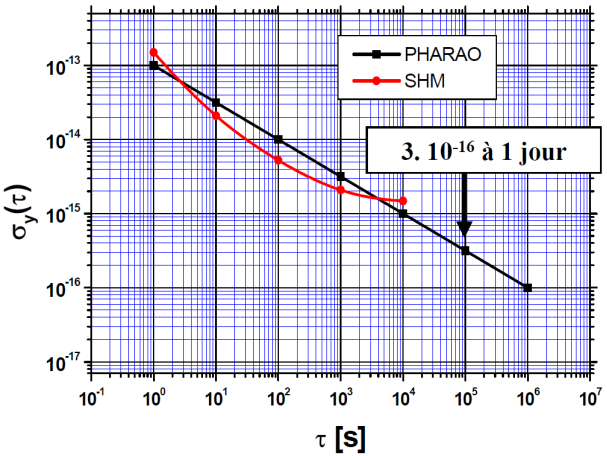
Christophe LE PONCIN-LAFITTE

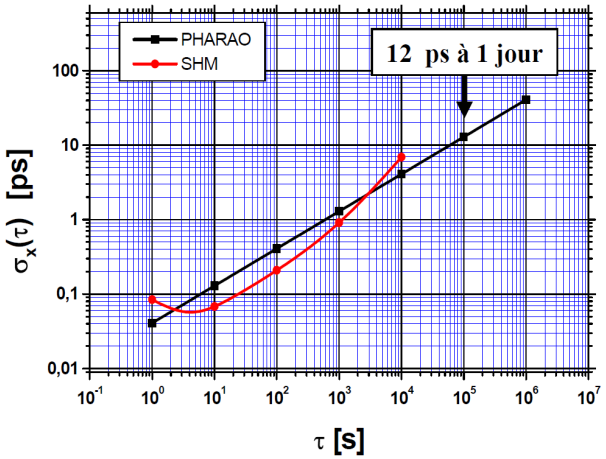
Philippe LAURENT

Peter WOLF

- 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
  - PI: LKB/ENS, Neuchâtel Obs., SYRTE/Paris Obs.
  - 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





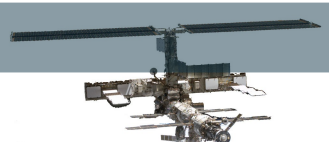


Common view

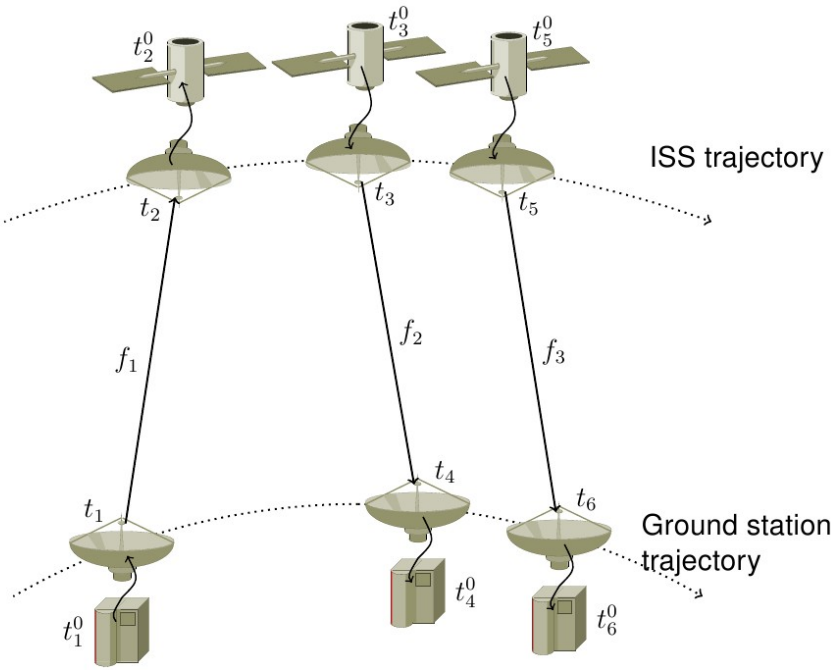
Stability ~ 0.3 ps @ 300 s.

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



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

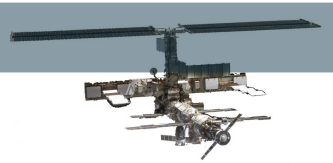
delays

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

Desynchronization

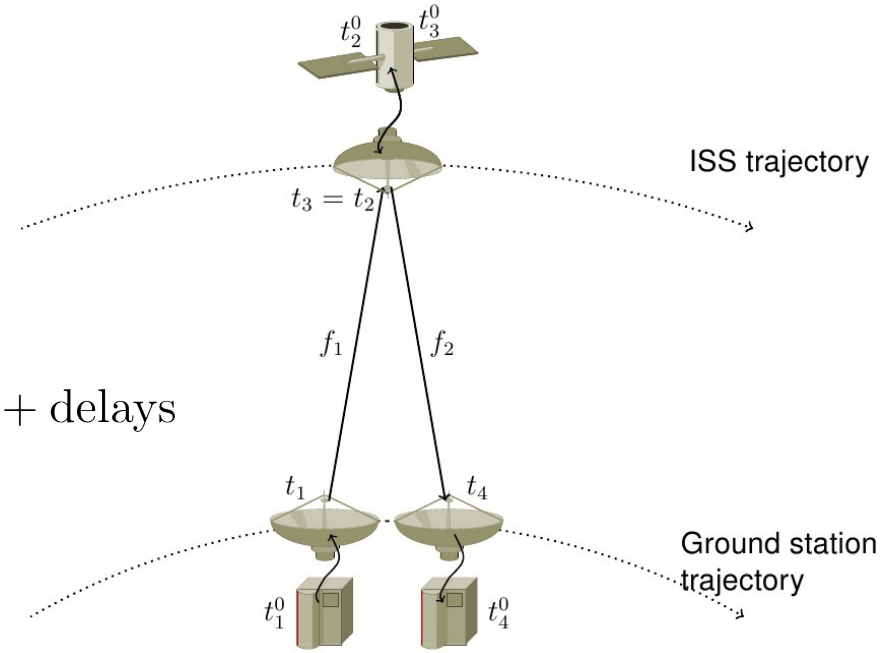
ST observable

Time of flight (from orbitography)

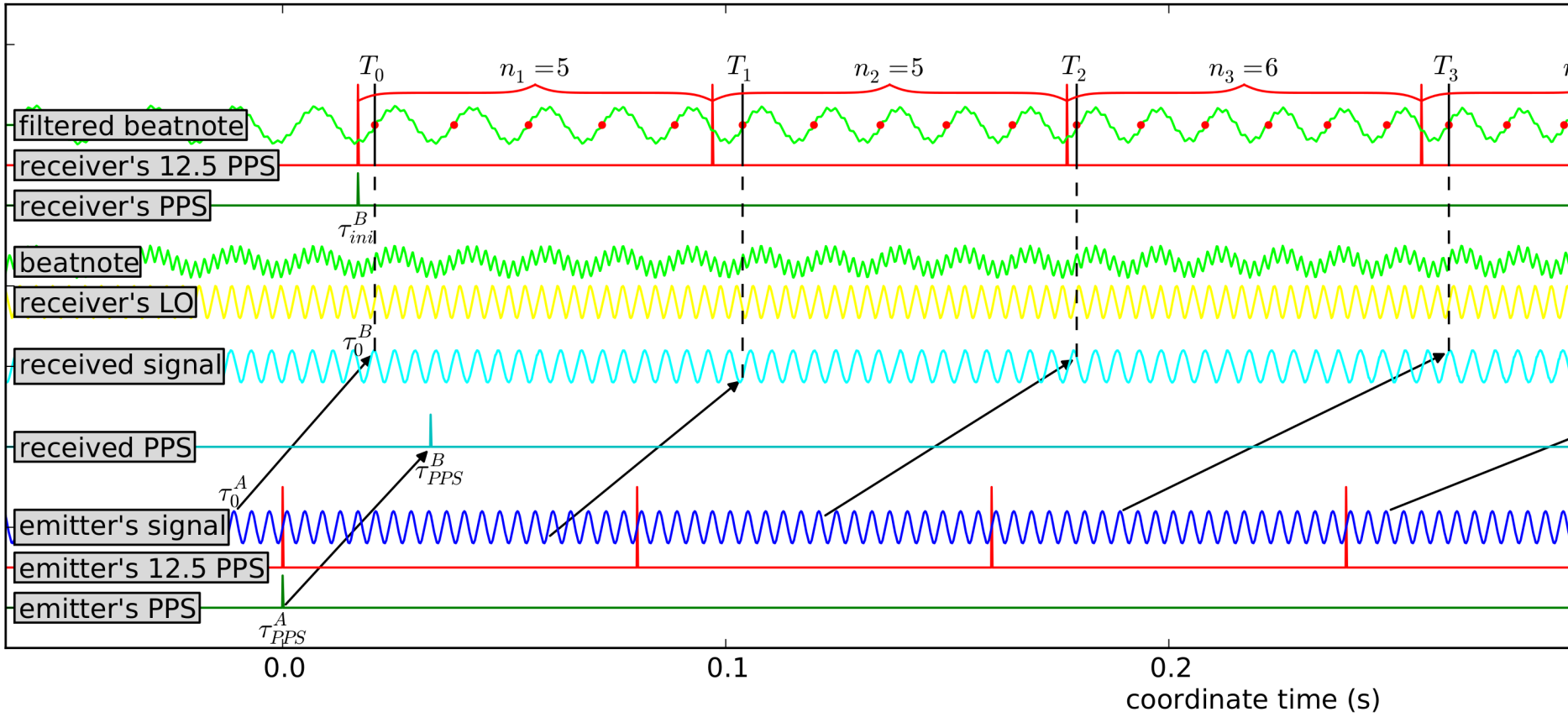


- **Lambda configuration** :
  - Interpolate data so that t_2=t_3
  - Minimize error due to ISS orbitography (Duchayne et al., A&A 504(2), 2009)
  - Different than the 2-way configuration

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

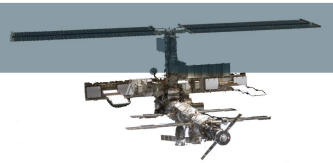


- **Atmospheric electronic content**
  - Ionospheric delay depends on signal frequency and STEC
  - Data from downlinks → STEC



ST observables : time difference between the locally generated code/carrier and the received one (in receiver time)

$$\Delta\tau^B_m(T_m) = \Delta\tau^B_{m-1}(T_{m-1}) \pm \frac{n_m}{f_{\mathrm{emi}}} + \left(\frac{f_{\mathrm{L.O.}}}{f_{\mathrm{emi}}} - 1\right)(T_m - T_{m-1})$$



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

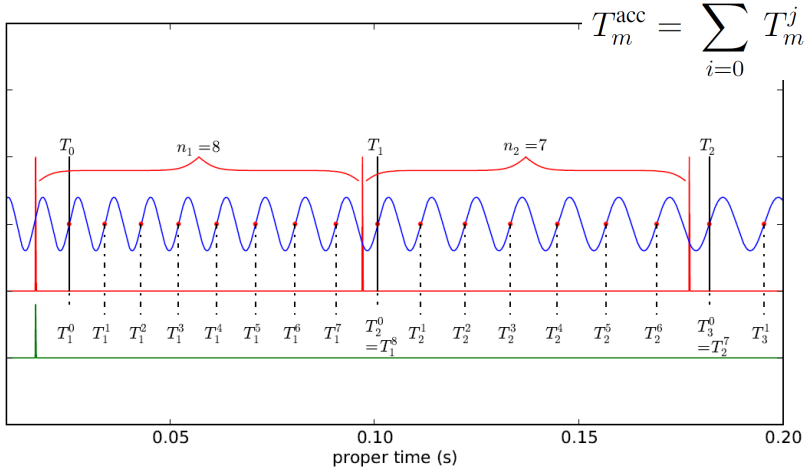
$$\delta(\Delta\tau_m) = \left| \frac{f_{\text{L.O.}}}{f_{\text{emi}}} - 1 \right| \cdot \delta T_m \quad (\delta T_m \sim 10 \text{ ns})$$

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

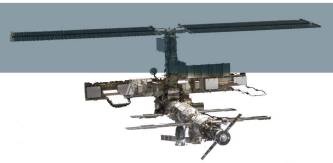
$$\frac{729 \text{ kHz}}{13.5 \text{ GHz}} \cdot 10 \text{ ns} \sim 0.5 \text{ ps (carrier)}$$

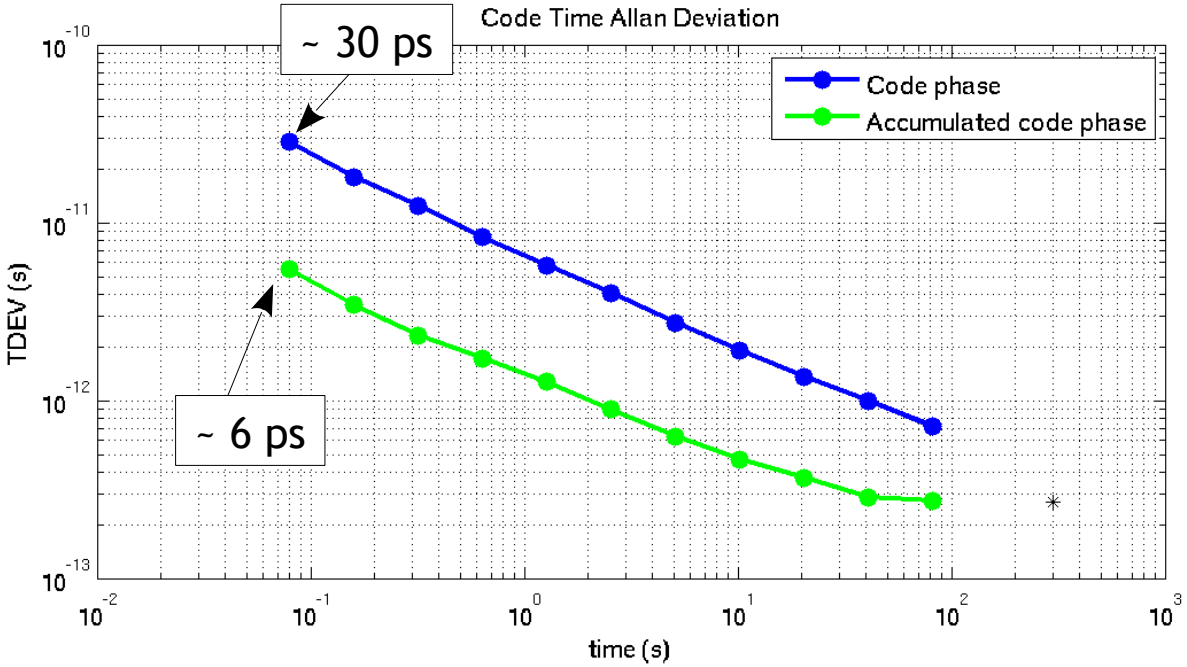
- **Initial term determination** $(\Delta\tau_0)$
  - From PPS which is unambiguously linked to UTC
  - PPS and code are synchronised → precise PPS determination
  - Absolute accuracy on $\Delta\tau_0$ (for time transfer) : 20 ps
  - Problem : bridge the gap between two passages → e.g. need 2 ps for a gap of one orbital period
  - Solutions :
    - accumulated phase latch ?
    - Carrier phase → phase ambiguity...

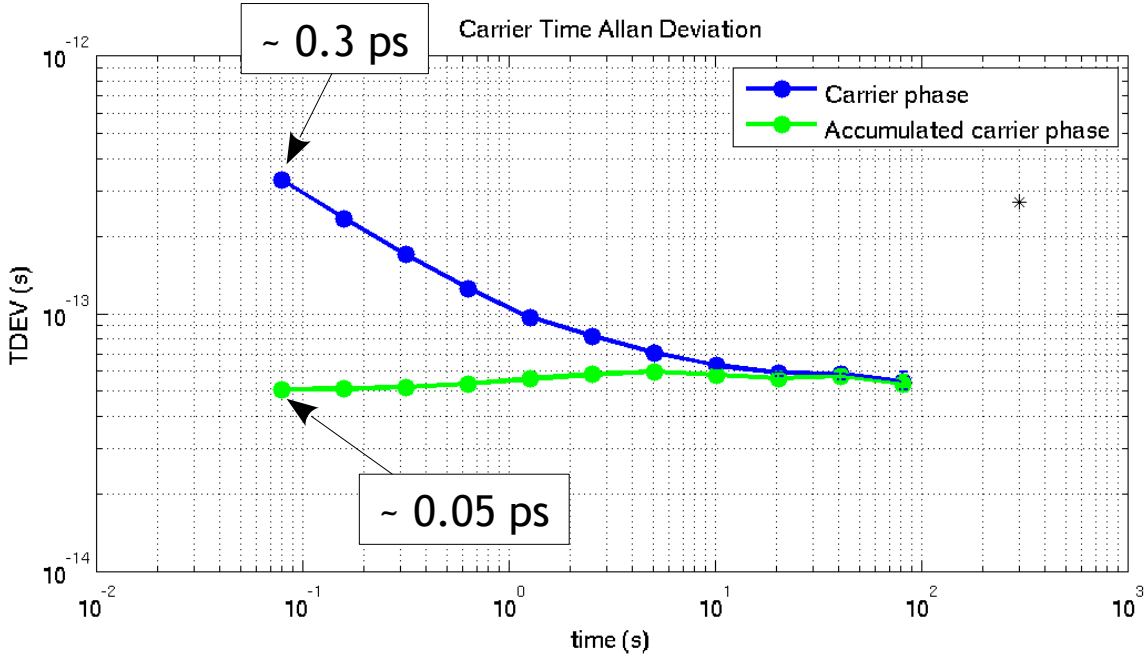
$$T_m^{\text{acc}} = \sum_{i=0}^{n_m-1} T_m^j$$

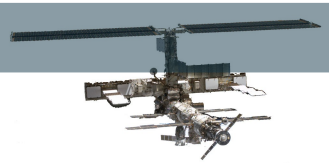


Pre-processing and link performance (2/2)



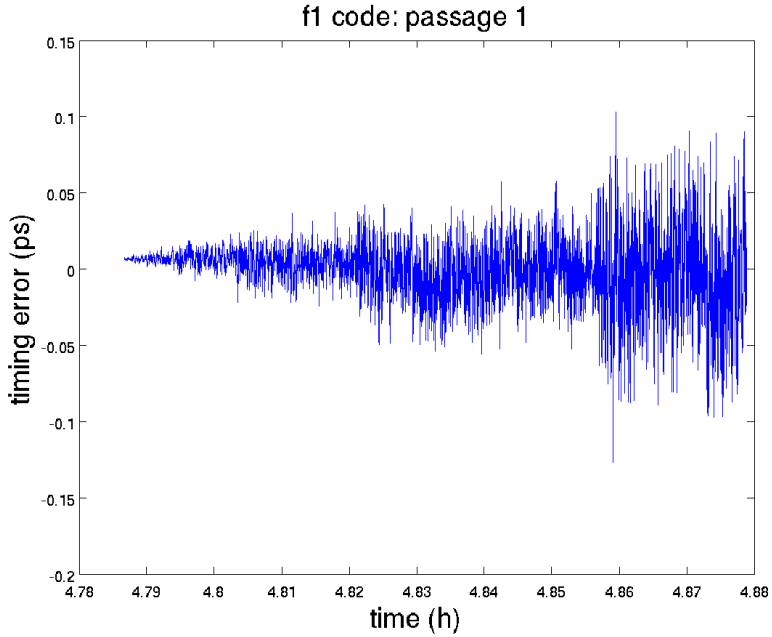




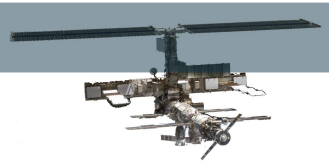


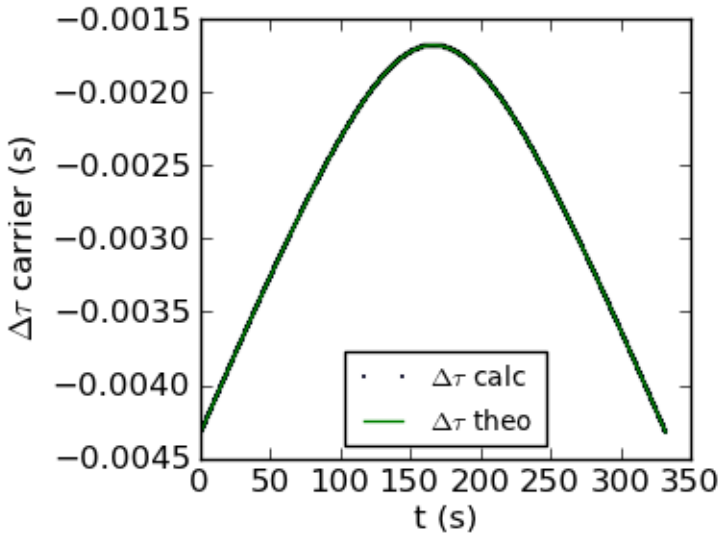
- ISS orbitography + station coordinates in Terrestrial Reference Frame → transform to Celestial Reference Frame (inertial)
- clock modelization for ISS & GS (e.g. noise)
- Solve time transfer between the two terminals
- Generate TimeTech observables & theoretical values

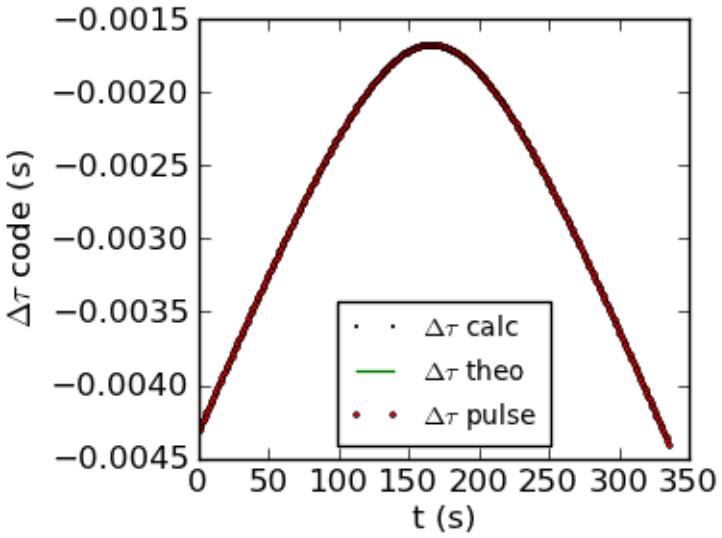
ST observables reconstructed after pre-processing of TimeTech data minus theorical ST observables : residuals are due to cumulated numerical sampling errors

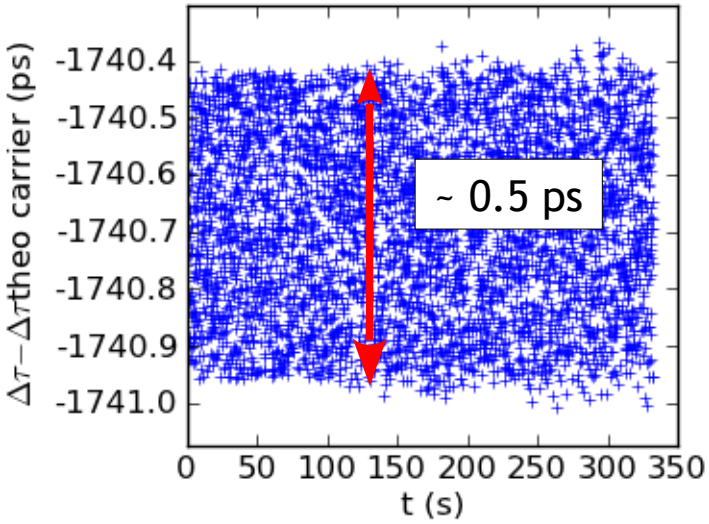


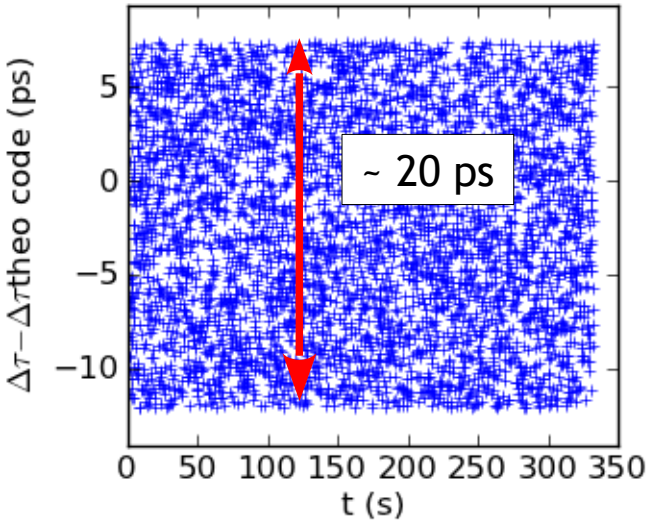
Independant pre-processing

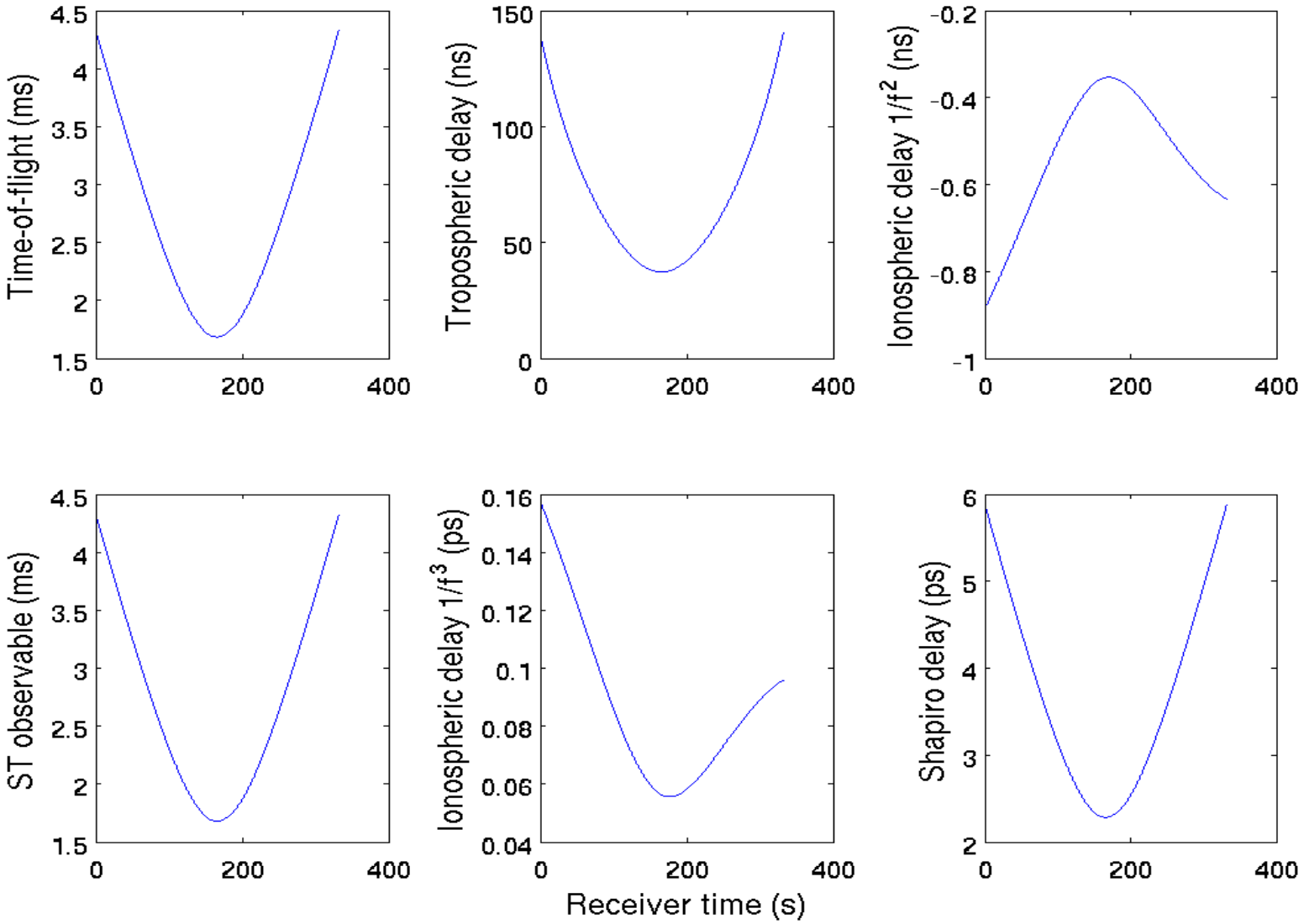


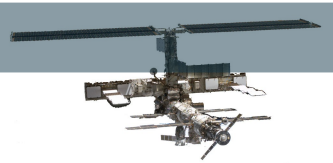




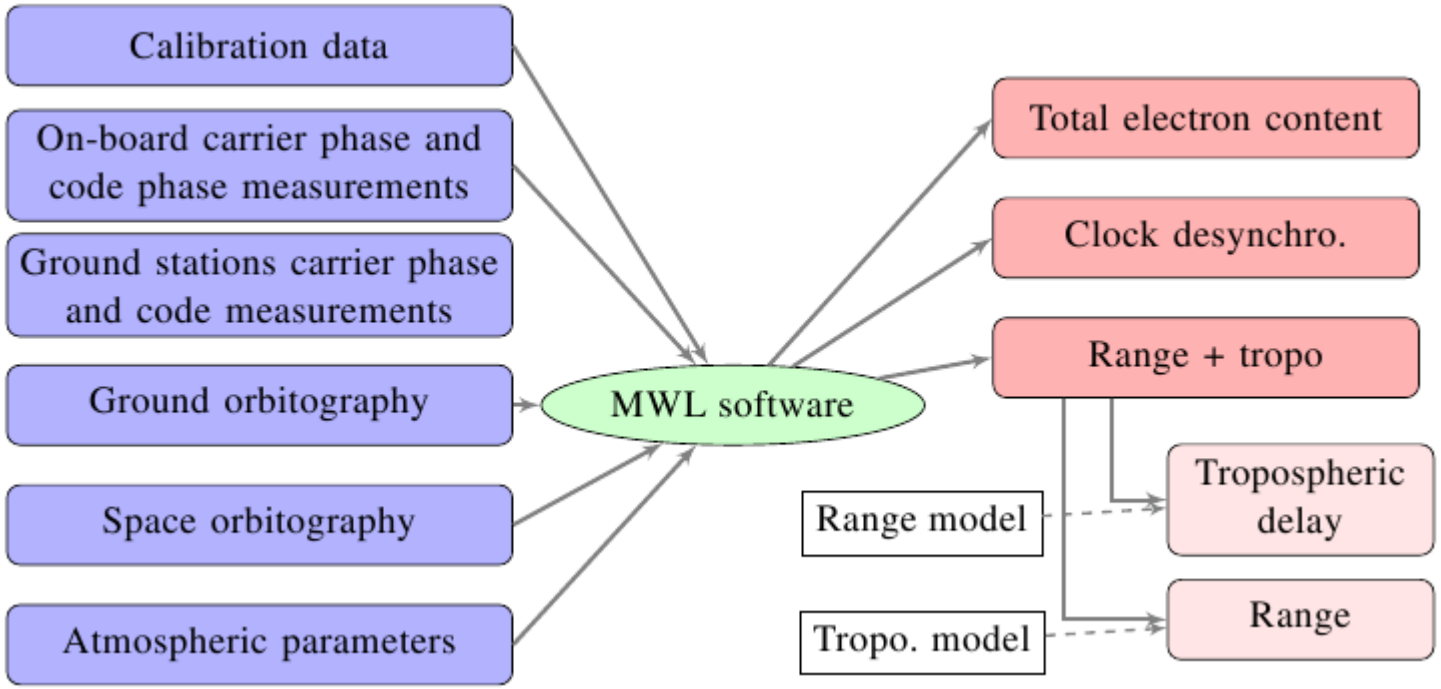




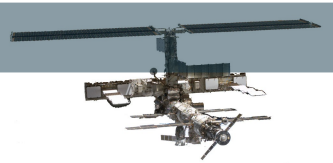

Time-of-flight (ms)
Tropospheric delay (ns)
Ionospheric delay 1/f² (ns)
ST observable (ms)
Ionospheric delay 1/f³ (ps)
Shapiro delay (ps)
Receiver time (s)

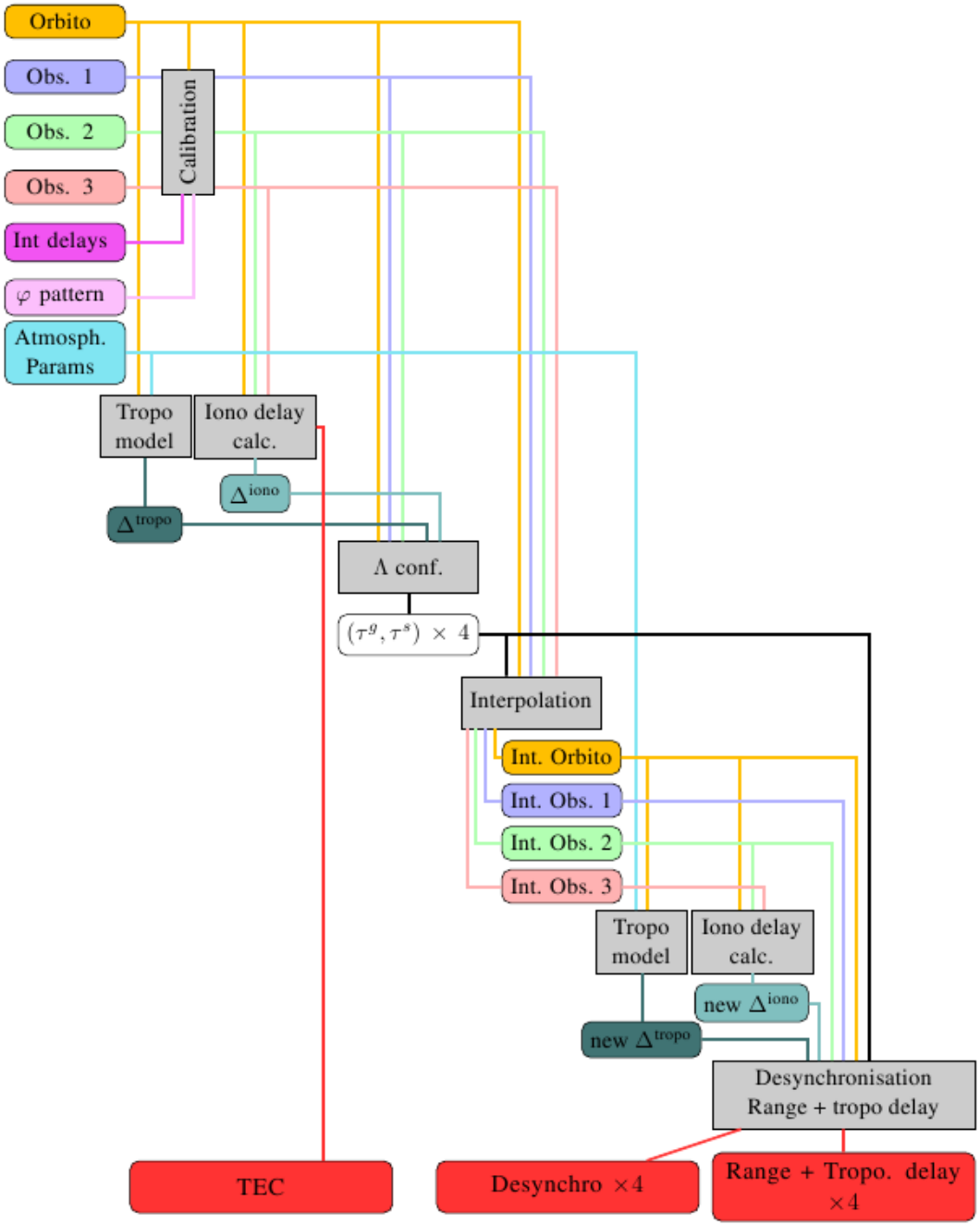


- Data analysis : file naming, data classifying, file formats, conventions...
- Inputs and outputs :

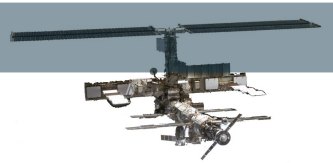


Software design

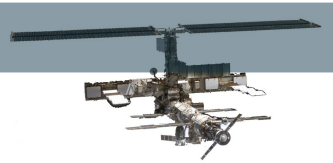




Conclusion



- 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
- Data analysis software : design done, writing in progress
- MWL end to end test in progress (TimeTech)



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THANK YOU