



T2L2 : 6 years in space



CNES : Ph. GUILLEMOT
S. LEON-HIRTZ

OCA : E. SAMAIN
P. EXERTIER
C. COURDE
M. LAAS-BOUREZ
N. MARTIN

SYRTE : M. ABGRALL
J. ACHKAR
D. ROVERA



Mission Objectives

■ Time Transfer experiences :

- ◆ Ground to Space AND ground to ground time transfer
- ◆ Comparison with GPS & Two-Way Time Transfer
- ◆ With a stability in the 10 ps range and a sub ns accuracy

■ 'Monitoring' of the DORIS USO

- ◆ From several 10 of seconds
- ◆ Correlation with CARMEN-2 data (SAA area)

■ Improvement of SLR data for orbitography

- ◆ Using the on-board dates and full rate data
- ◆ Test of 1 way pseudo-range for contributing to POD

■ Fundamental physics :

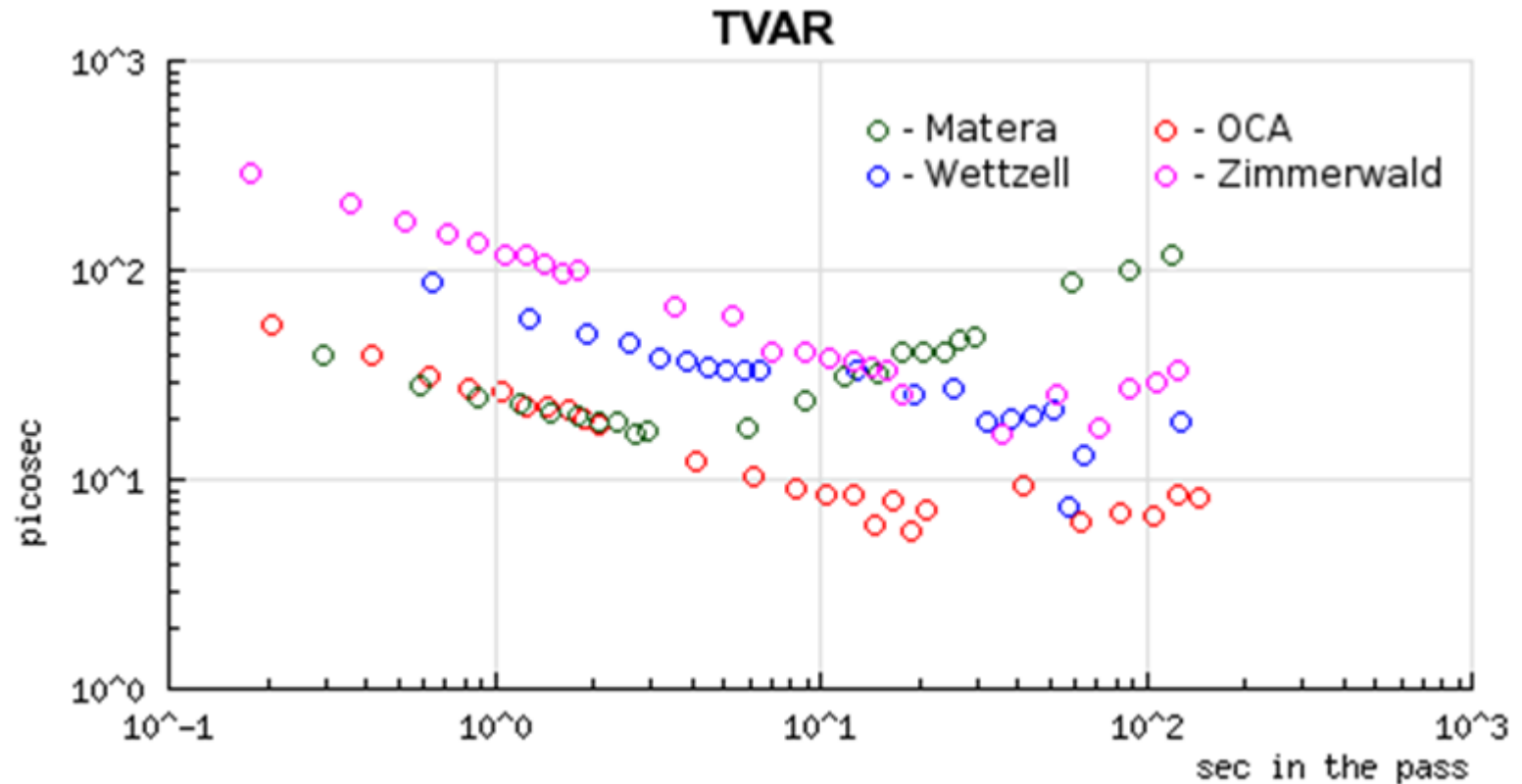
- ◆ Anisotropy of the speed of light at the level of 2.7×10^{-9} (USO limitation)
- ◆ Fine structure constant : Canceled



Stability (1)

■ Short term stability

- ◆ Clearly influenced by SLR/Clock performances
- ◆ Lower than 10 ps from 10 to 100s for the best SRL/Clock



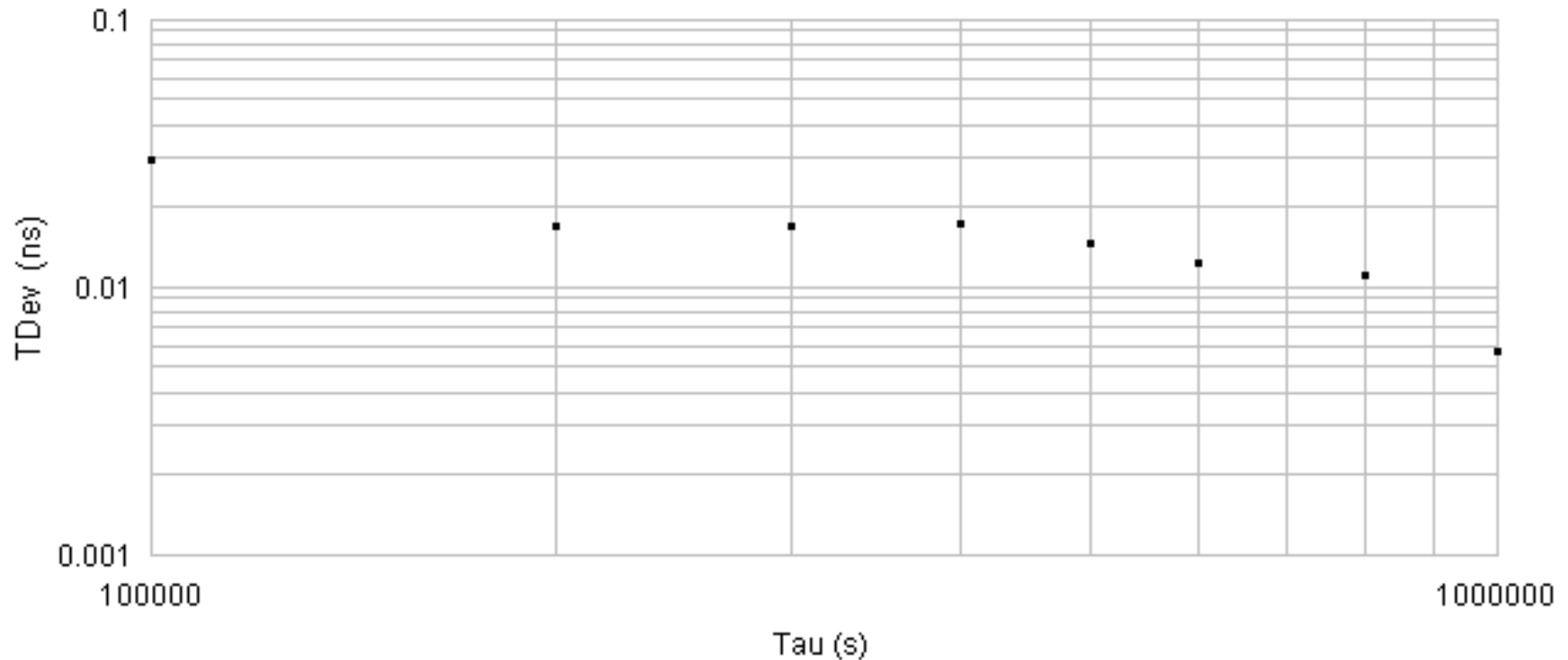


Stability (2)

■ Long term stability

- ◆ Between MéO & FTLRS, common clock
- ◆ Around 10 ps from 1 to 10 days

Allan modifié N° 0 Source : MeO-FTLRs CMS.txt Col N° 0



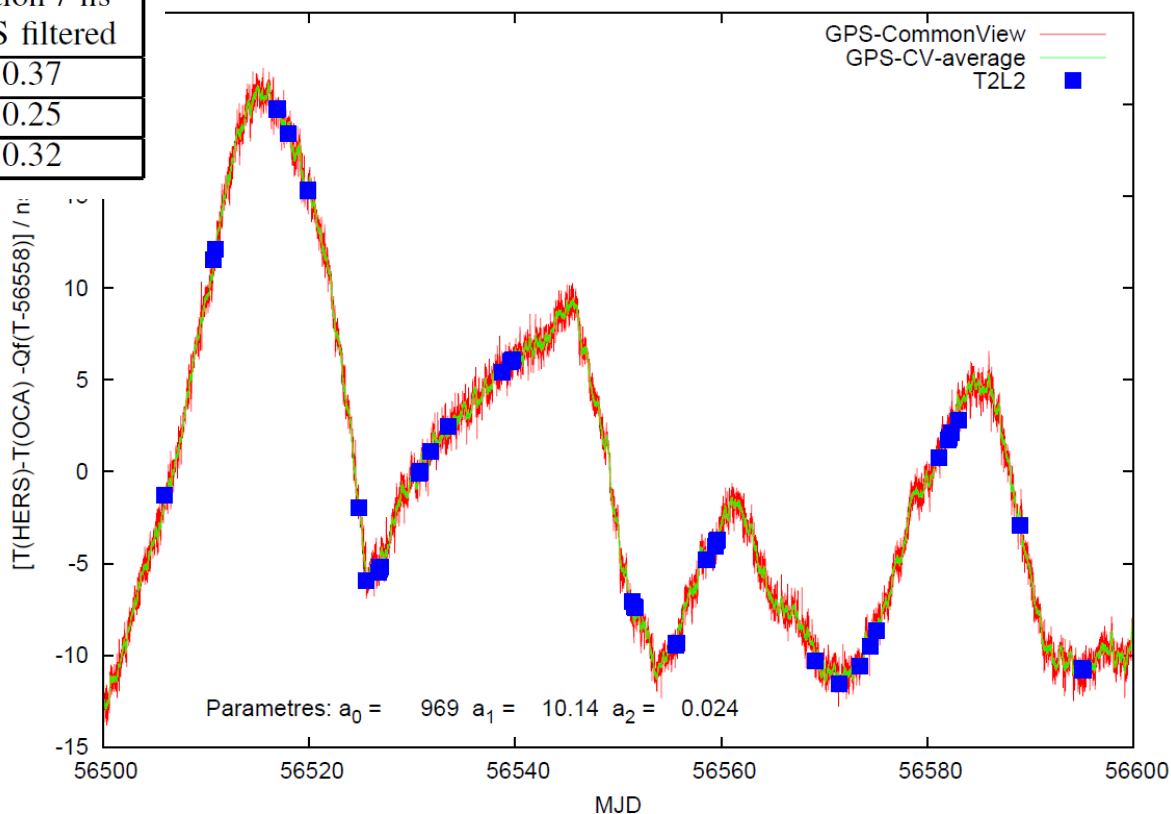


Accuracy

■ Comparison T2L2 / GPS

- ◆ After the calibration of all participating labs
- ◆ Average difference between GPS and T2L2 solution is lower than 300 ps (With a standard deviation of 500 ps, due to GPS)

Link	Number of points	Average ns	Standard Deviation / ns	
			GPS CV	GPS filtered
SGF-OCA	42	0.09	0.49	0.37
OP-OCA	12	0.24	0.48	0.25
SGF-OP	5	0.10	0.32	0.32





Current status

■ Launched in June 2008 with Jason-2 :

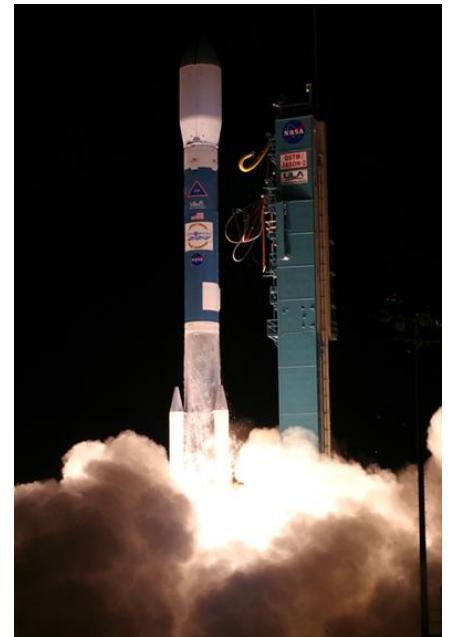
- ◆ About 6 years of continuous operations
- ◆ More than 20 SLR involved with 26000 passes and about 130 millions of laser shots detected
- ◆ All parameters are nominal

■ Data processing

- ◆ CMS is fully operational
- ◆ Data are available on <https://t2l2.oca.eu/>

■ Science objectives :

- ◆ Stability : $< 10 \text{ ps @ } 100 \text{ s}$, $< 2 \text{ ps @ } 1000 \text{ s}$ & $< 10 \text{ ps @ } 1 \text{ day}$
- ◆ Accuracy : $< 300 \text{ ps}$
- ◆ On board clock frequency : few 10^{-13}





Lessons learned

■ T2L2 instrument is clearly a success :

- ◆ It is able to 'see' any SLR
- ◆ It is still working after nearly 6 years in orbit

■ Data processing has been under estimated

- ◆ The development started late in 2007
- ◆ Stabilized and really operational since 2012

■ Ground segment has to be upgraded

- ◆ It is difficult to connect cold atoms atomic clocks with SLR
- ◆ Very few SLR have H-Maser and 'sub ns' ground segment
- ◆ New methods / systems for calibration are mandatory



And now...

■ **Operations of T2L2 are founded until the end of 2014**

- ◆ An extension of the mission for 2 more years is requested by the PI

■ **With new science objectives**

- ◆ Atmospheric propagation and link budget
- ◆ 3D orbitography with LRO
- ◆ Preparation / Contribution to ACES mission : At least with T2L2 observations

⇒ Towards an extended collaboration with ELT ? Upgrade of OCA laser station ?
Data processing ?

■ **It could be also an opportunity to complete initial objectives**

- ◆ Extensive comparison between T2L2 and GPS
 - ◆ Comparison between T2L2 and TWSTFT
- ⇒ Towards new European campaign ? With transportable TWSTFT station ?

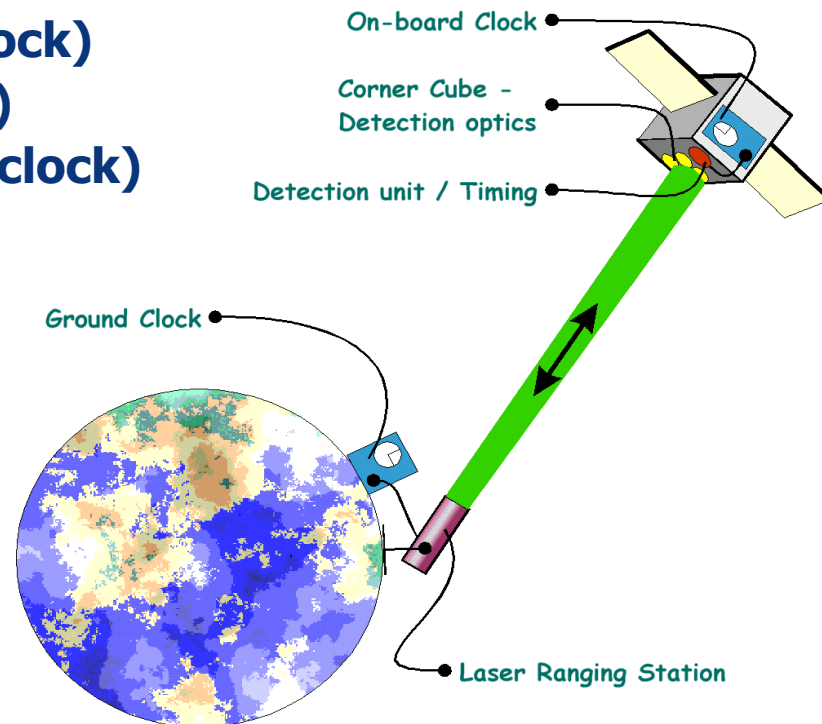
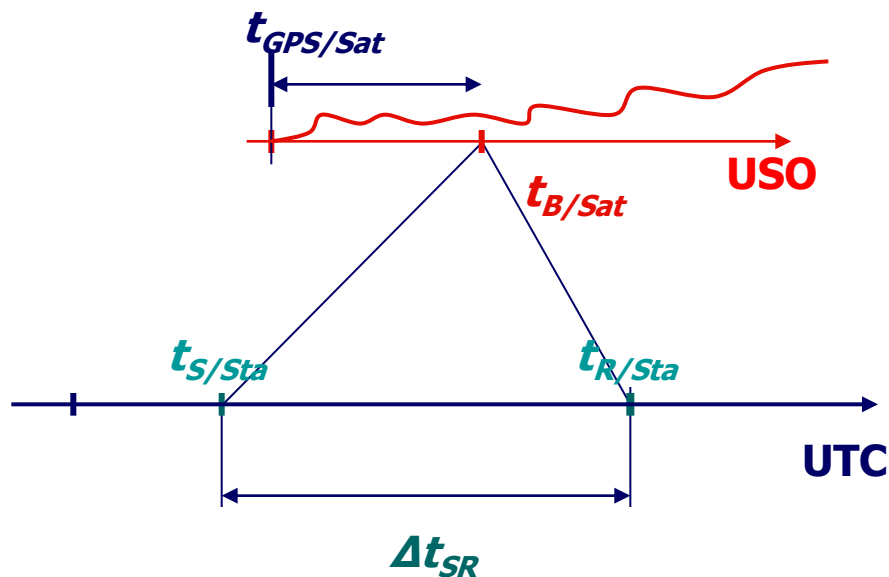




T2L2 Principle

■ Time Tagging of laser pulses emitted from a laser station towards the satellite

- ◆ Start Time at ground station t_s (ground clock)
- ◆ Arrival time at satellite t_B (on-board clock)
- ◆ Return Time at ground station t_R (ground clock)



$$X_A = \frac{t_s + t_R}{2} - t_B + \tau_{\text{Relativity}} + \tau_{\text{Geometry}} + \tau_{\text{Instrument}}$$



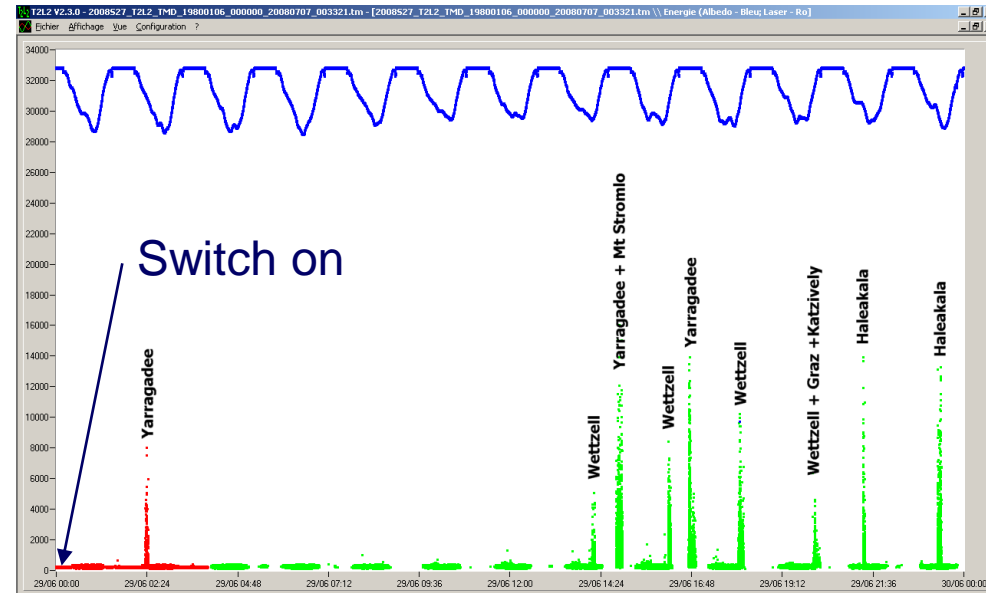
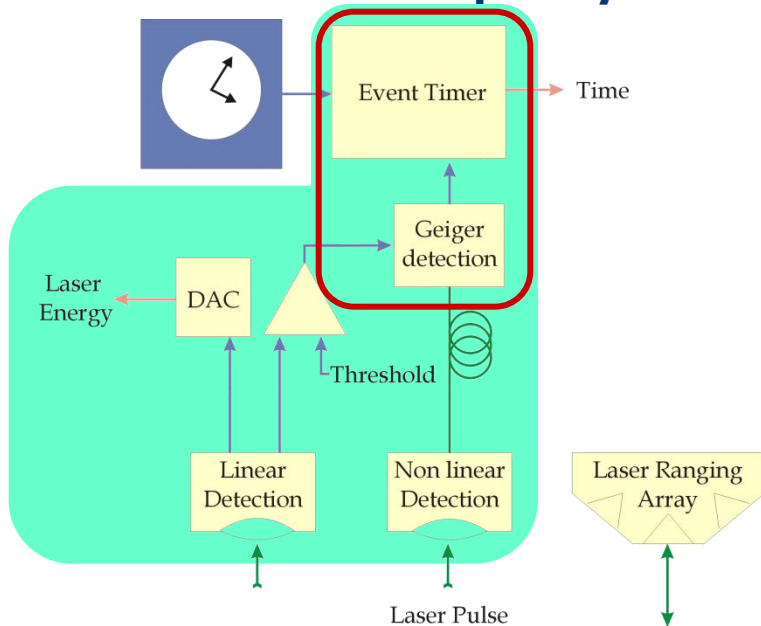
SRL/T2L2 Interface

■ A huge diversity of Satellite Laser Ranging stations

- ◆ Precision of measurements from 100 ns to 1 ps
- ◆ Laser rate from some Hz to some kHz
- ◆ Laser energy from > 1 mJ to > 50 mJ

■ Decision to manage the constraints at the level of the instrument

- ◆ Only "one" interface instead of several interfaces (one per station)
- ◆ Increase the complexity... and 40W & 10 kg





2nd T2L2 International Campaign (2)

■ Experimental setup

- ◆ **Common clock, H-Maser expected, cold atom clock if any**
- ◆ **Calibration campaign of SLR stations with an unique equipment (OCA):**
 - Reference event timer, high speed photo detector coupled with an optical fiber
 - Absolute accuracy ≤ 100 ps

