Time Transfer by Laser Link (T2L2), A way to synchronize laser ranging observatories

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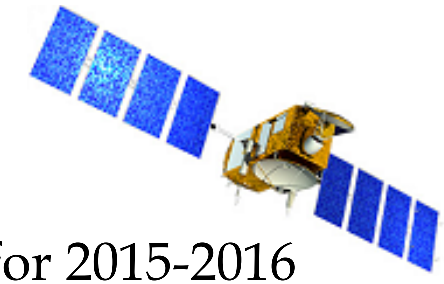
Introduction

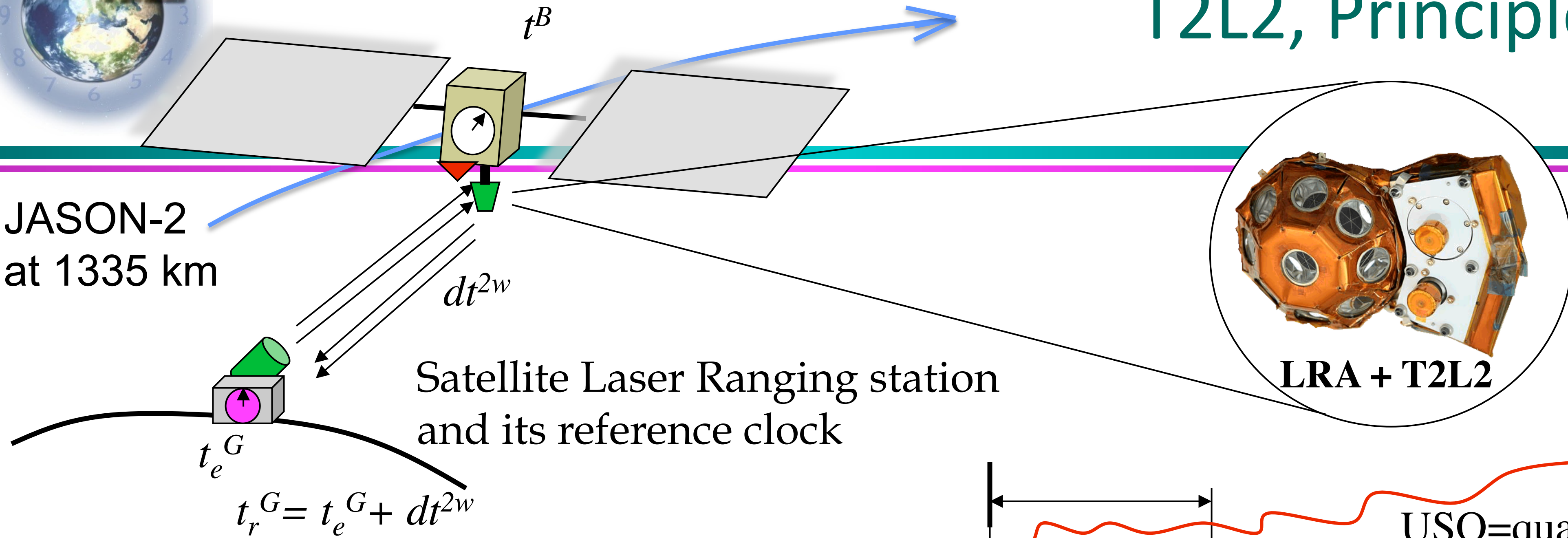


- T2L2, launched on Jason 2 (June 2008) for a 2 yrs mission
  - » see LASSO (1988-1992)
  - » Extending the mission: from 2010 to 2014; now, a proposal for 2015-2016

- Objectives of the project
  - » Métrological (performance, comparaison aux techniques GNSS, au sol)
  - » Scientific (space geodesy, and fundamental physics)

- Summary
  - » Performances, and the role of the laser technology and network
  - » Developements, campaigns, applications
  - » Plan for 2015-2016

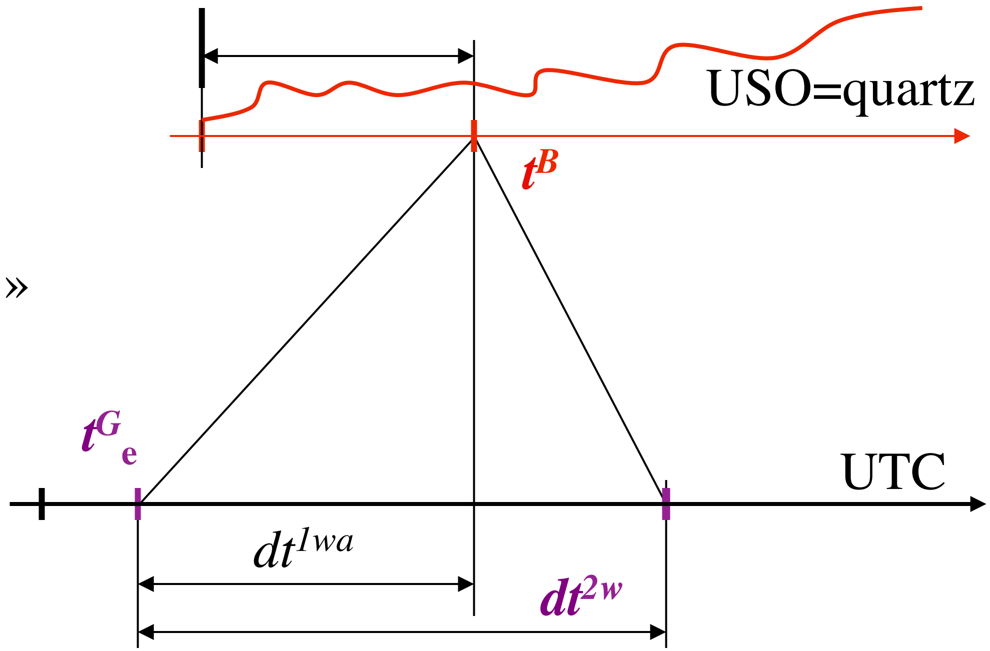
T2L2, Principle



t^G_e, dt^{2w}, t^B : 3 measured quantities: « triplets »
(dt^{1wa} is computed from dt^{2w} /Sagnac correct.)

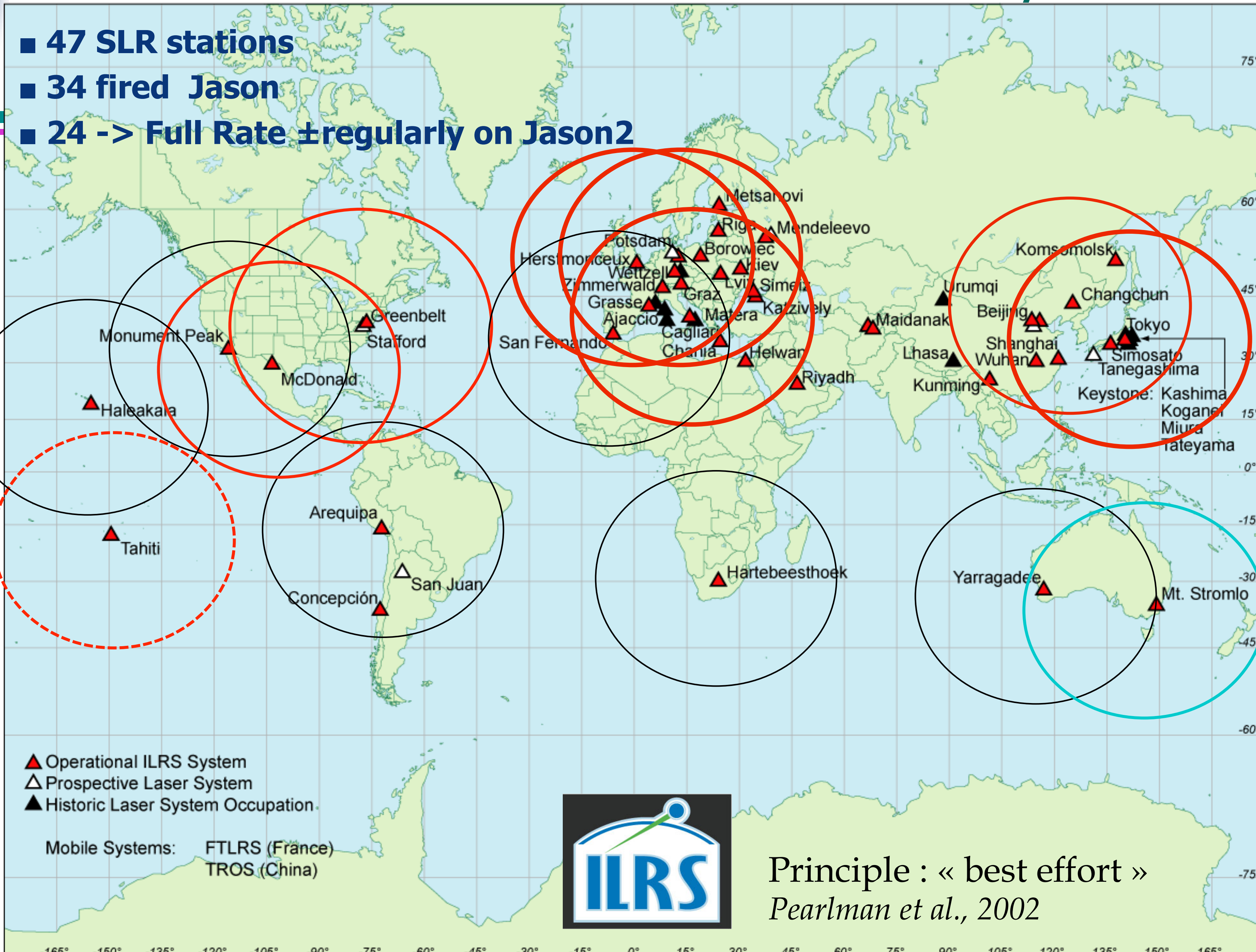
Fridelance et al., 1997; Samain, et al., 2008, Exertier al., 2010

$$\Delta = t_B - \frac{t_e^G + t_r^G}{2} + \tau_{\mathrm{Relativity}} + \tau_{Intern-delays} + \tau_{Instrument}$$



SLR stations involved in T2L2 /Jason2

- **47 SLR stations**
- **34 fired Jason**
- **24 -> Full Rate ±regularly on Jason2**



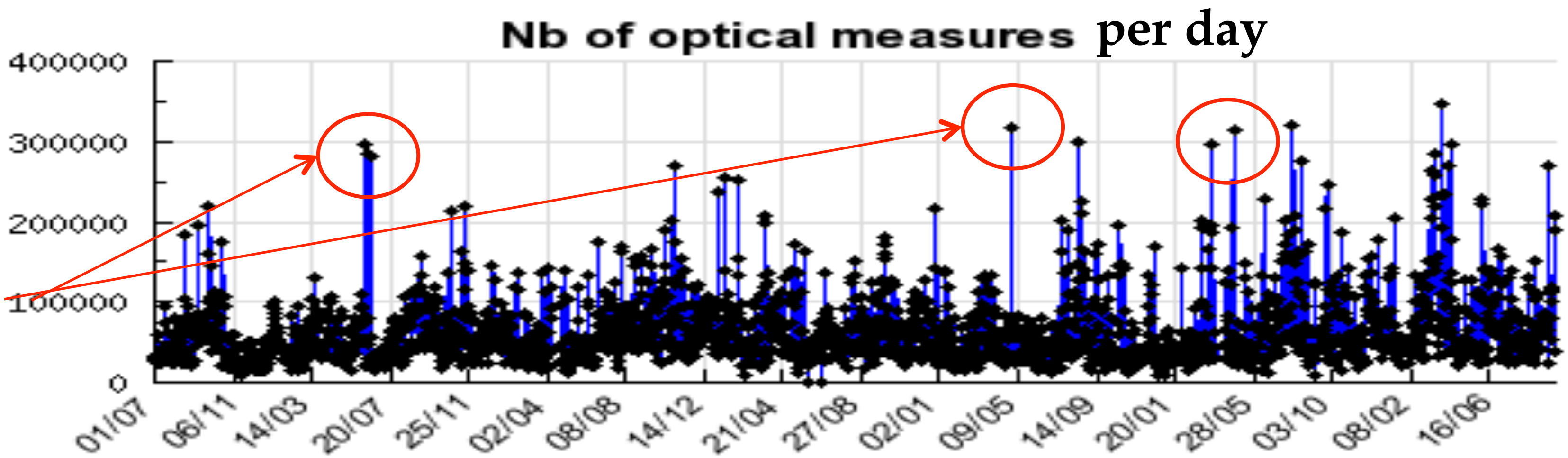
Principle : « best effort »
Pearlman et al., 2002

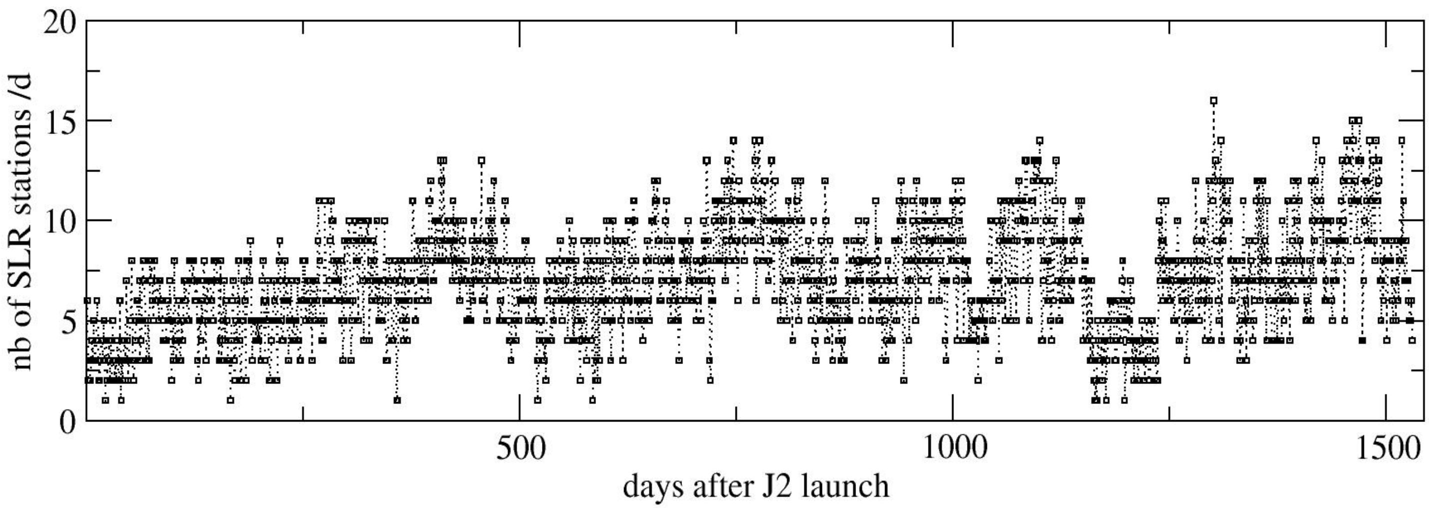
ILRS network for Time Transfer

SLR station	time transf. @ 1s	stab. @ 60 s
1824,1873,1893	~ 85 ns	-
7080: Mac Donald	< 1 ns	6-8 ps
7090: Yarragadee	~ 50 ns	2-3 ns
7105: Greenbelt (*2014*)	< 1 ns	30 ps
7237: Changchung	< 1 ns	4-5 ps
7308: Tokyo	< 1 ns	4-5 ps
7810: Zimmerwald	< 1 ns	6-8 ps
7824,7824	~ 50 ns	2-3 ns
7840: Hx	< 1 ns	6-8 ps
7845: Grasse	< 1 ns	6-8 ps
7941: Matera	< 1 ns	6-8 ps
8834: Wettzell	< 1 ns	6-8 ps
7501,7110,7119,7124,7403	~ 50 ns	2-3 ns
FTLRS : 7822, 7828, 7829	< 1 ns	6-8 ps

Data, from 2008

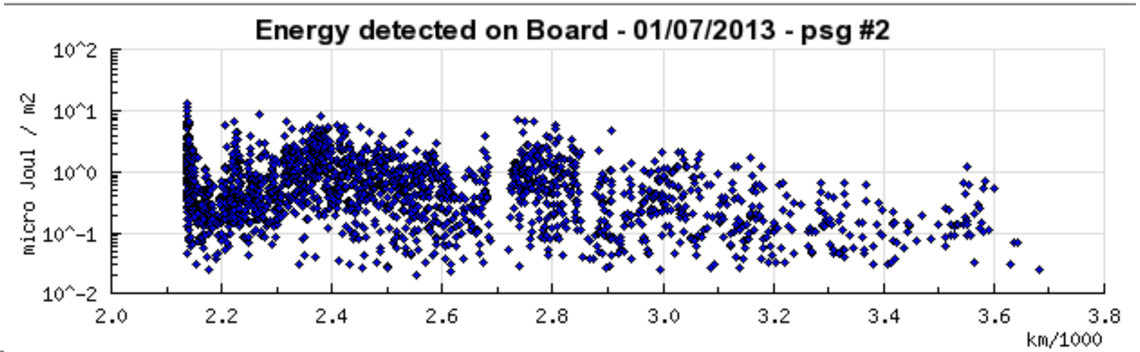
kiloHz systems

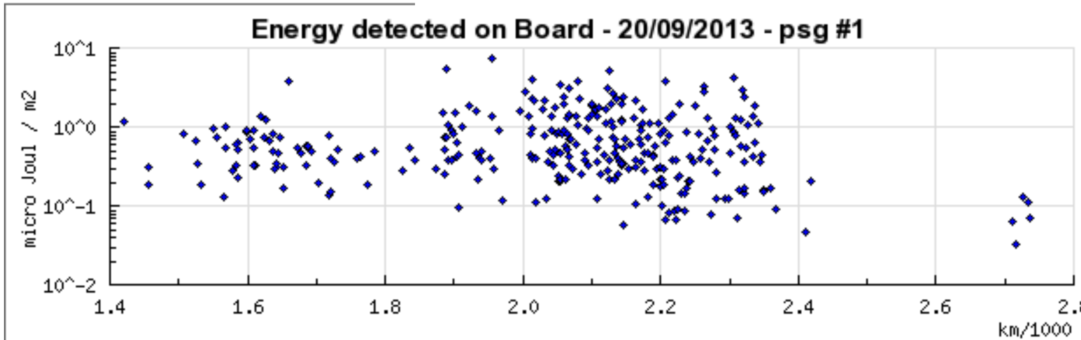




Tracking capability

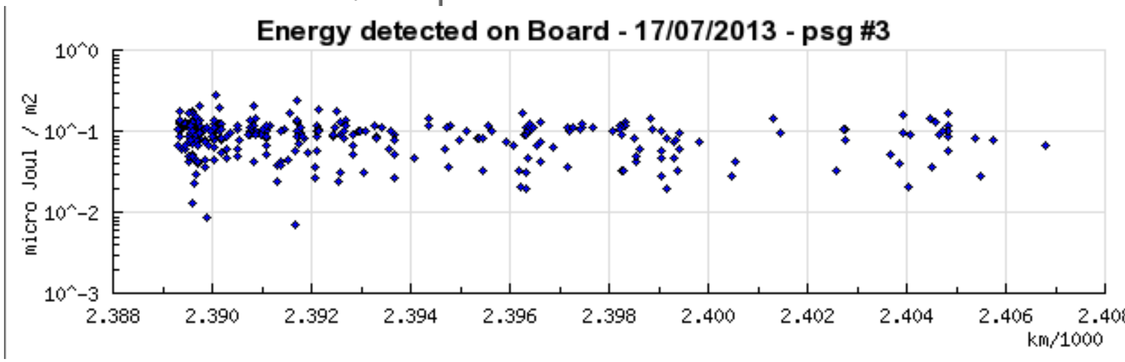
7845, Grasse
SLR-LLR, 10Hz, 160 mJ
1.9 µJ.m^{-2}





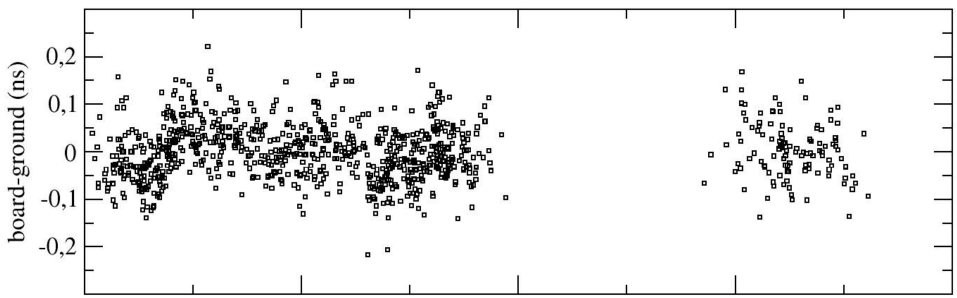
7828, Obs. Paris
FTLRS, 10Hz, 20 mJ
0.35 µJ.m^{-2}

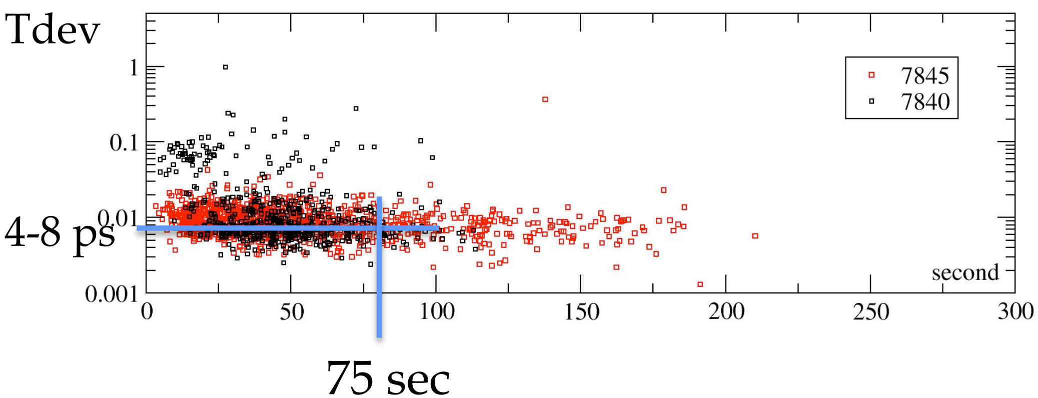
7237, Changchun
kiloHz laser
0.1 µJ.m^{-2}

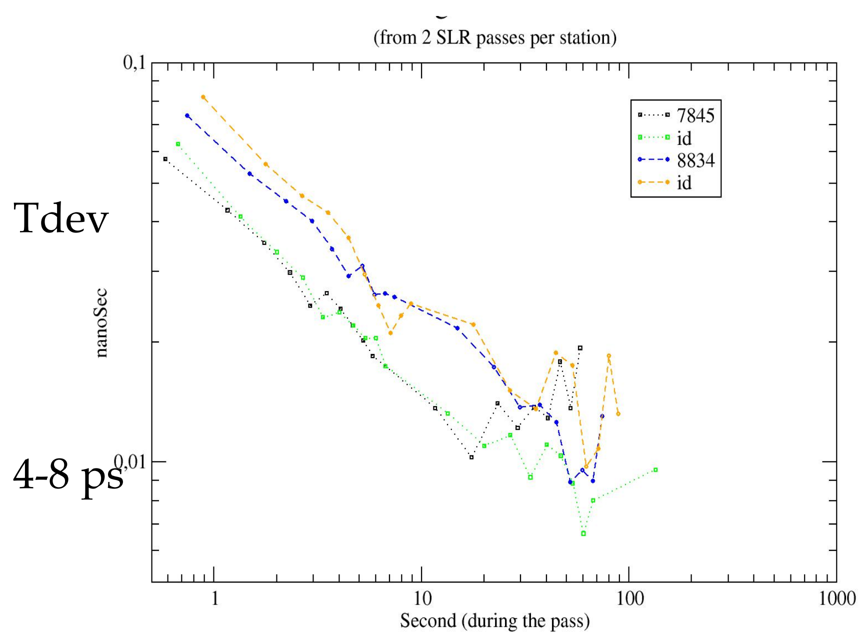


Time transfer from ground to space

Residuals of time transfer equation after removing of a frequency biais (USO) :
~35 ns /seconde (0.01 ns/sec /day)





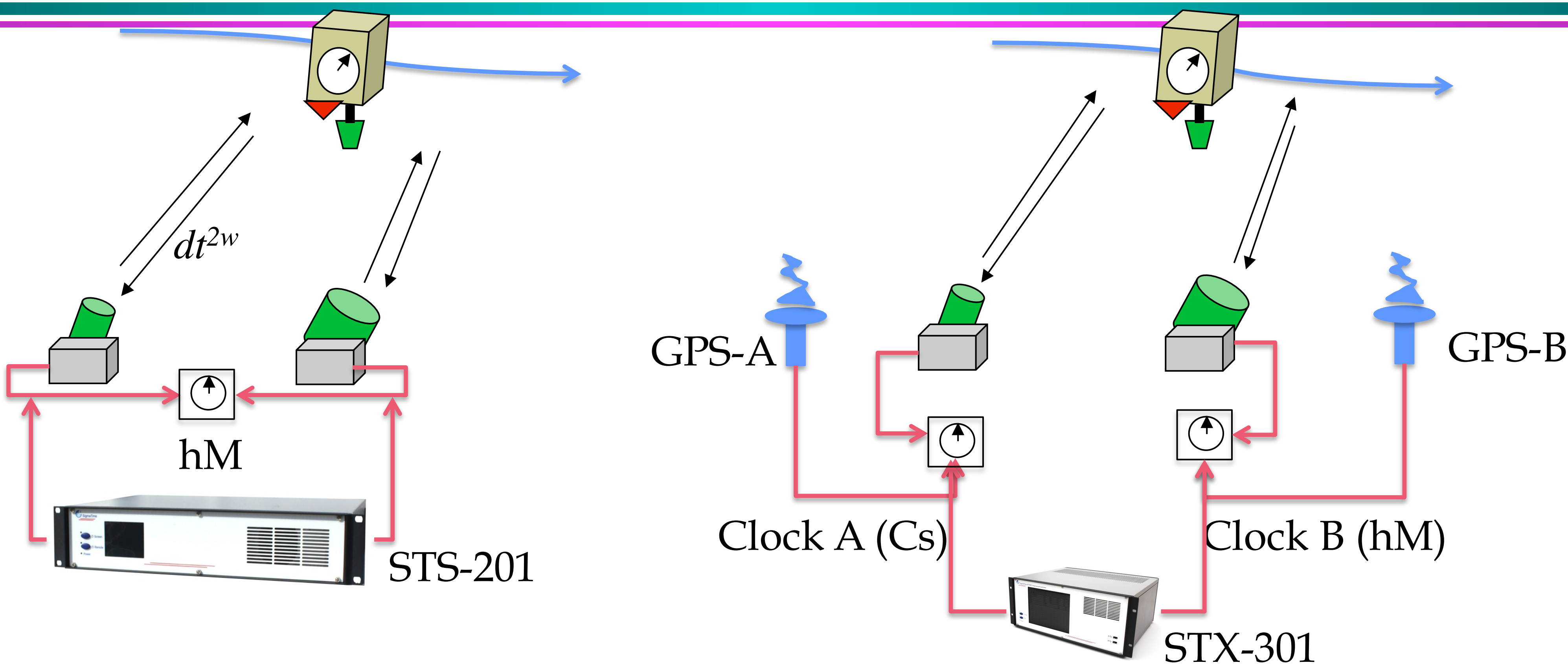


Best performances : 4-8 ps @ 75 sec deduced from a multi-yr analysis
Exertier, et al. Adv. Sp. Res., 2010

The impact of technological progress

● Laser		
» Role of mobile systems	Laser - TF labo.	*Degnan, J., 1997*
» Pulse energy and width	stability, acquisition	
» Detectors	noise, accuracy, efficiency	
● Cloks and timers		
» Better clocks (h-maser, cesium, etc.)	stability 0.1-1000 s	*SLR*
» Picosec. resolution (1 -> ~50ps)	timing	*community*
● Accuracy & Stability		
» Laser link (calibration)	~ 10 ps	
» Ground links (& calibration)	< 100 ps (stability 10ps @1d)	*Panek, et al., 2013*
» Ground timers		*Prochazka et al., 2011*
»		*Samain et al., 2011*
» Clock frequency	~10^{-13} (H-maser)	
		Kodet, 2014; Mao, 2014
● GNSS calibrated links to reach TAI/UTC	~ 100 ps	*Rovera et al., 2014*

Experiments of type -1 and -2

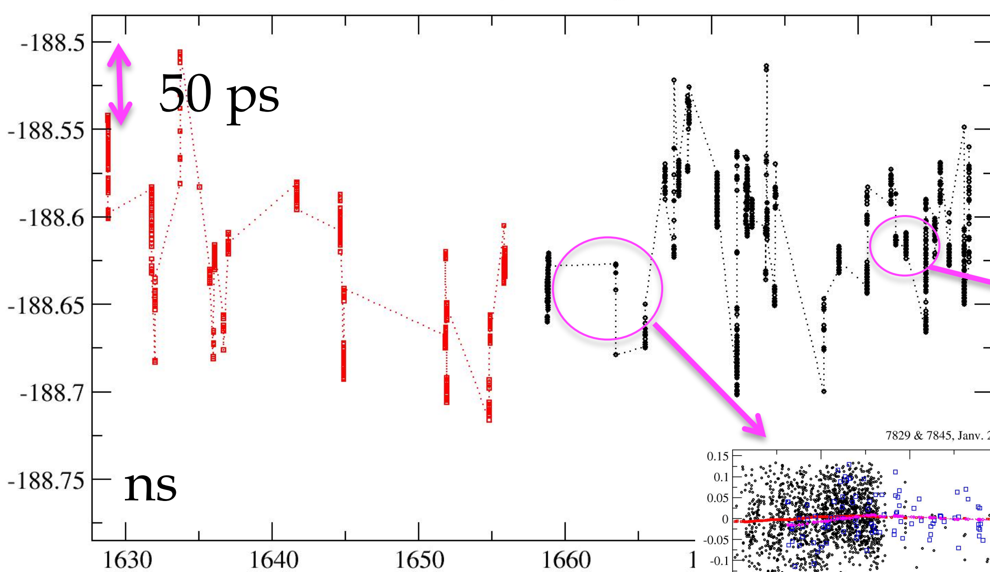


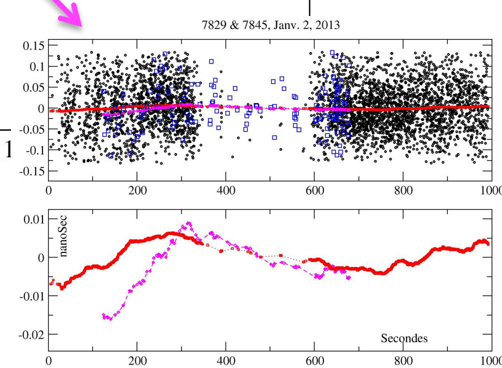
Samain et al., 2010

Experiments on the **same site,** Grasse, with 2 SLR stations, 2 GPS antennas, and time & frequency laboratory (metrology, clocks, cables, etc.). Plus equipment (STX) for exactness and STS for stability

Type -1

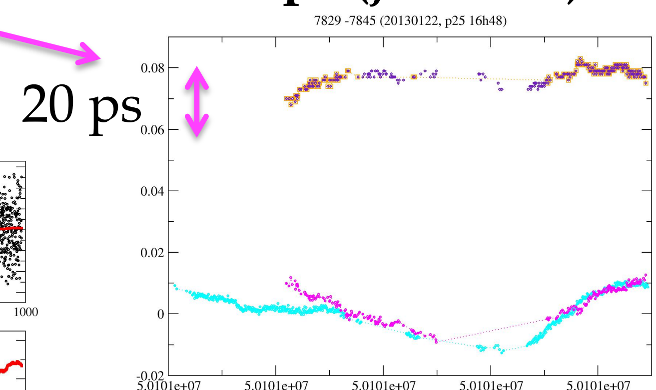
- Exp. -1 : stability (short & long terms)
  - » satellite in common view, same clock on the ground (h-maser), 2 independant SLR systems (FTLRS and MeO)
  - » STS201 for monitoring the stability (cables...)





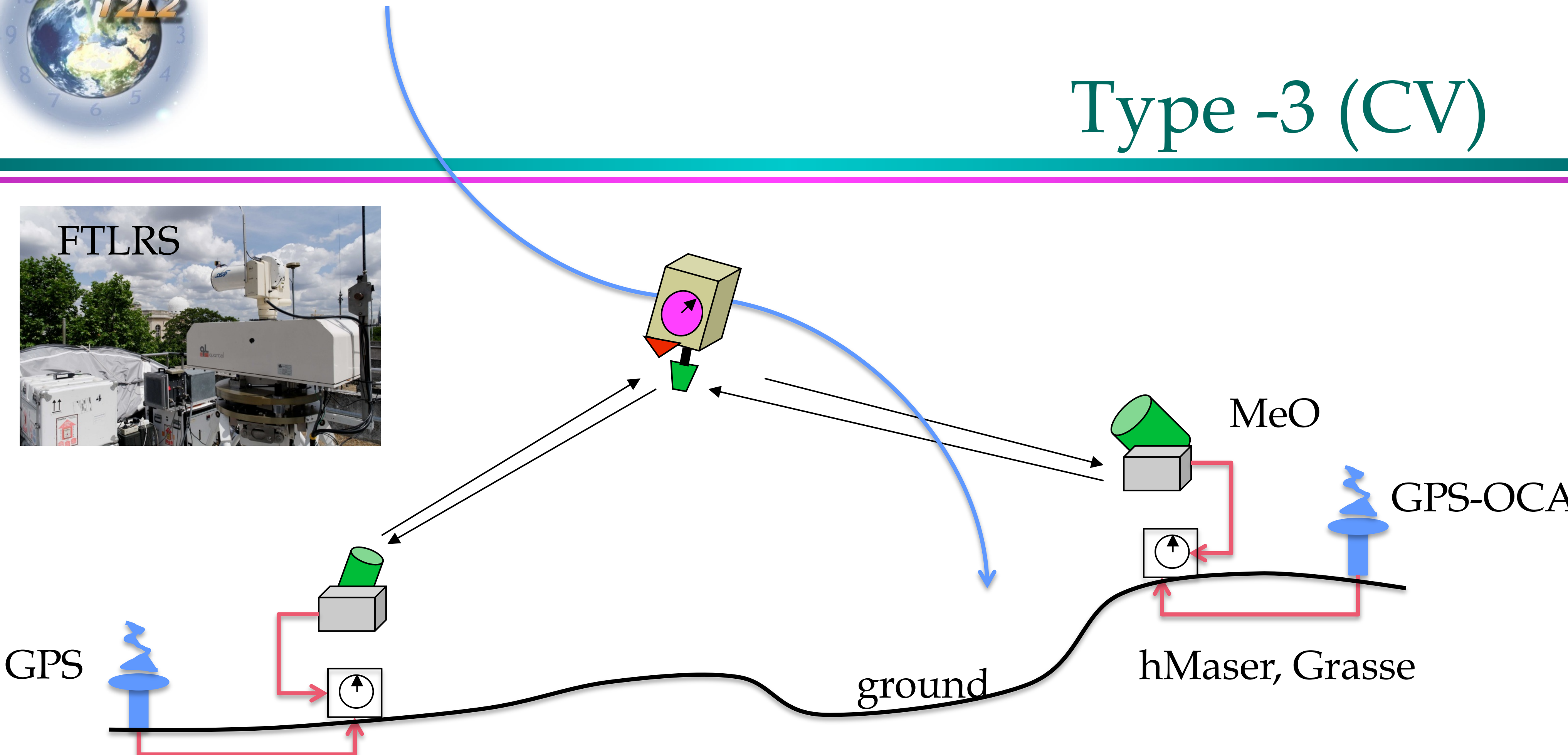
CAL = 188.5 ns :: T2L2 = 188.6 ns

≠ 0.108 ns ± 36 ps (dec. 2012)
≠ 0.048 ns ± 31 ps (jan 2013)



Samain et al., to be submitted in Metrologia

Type -3 (CV)



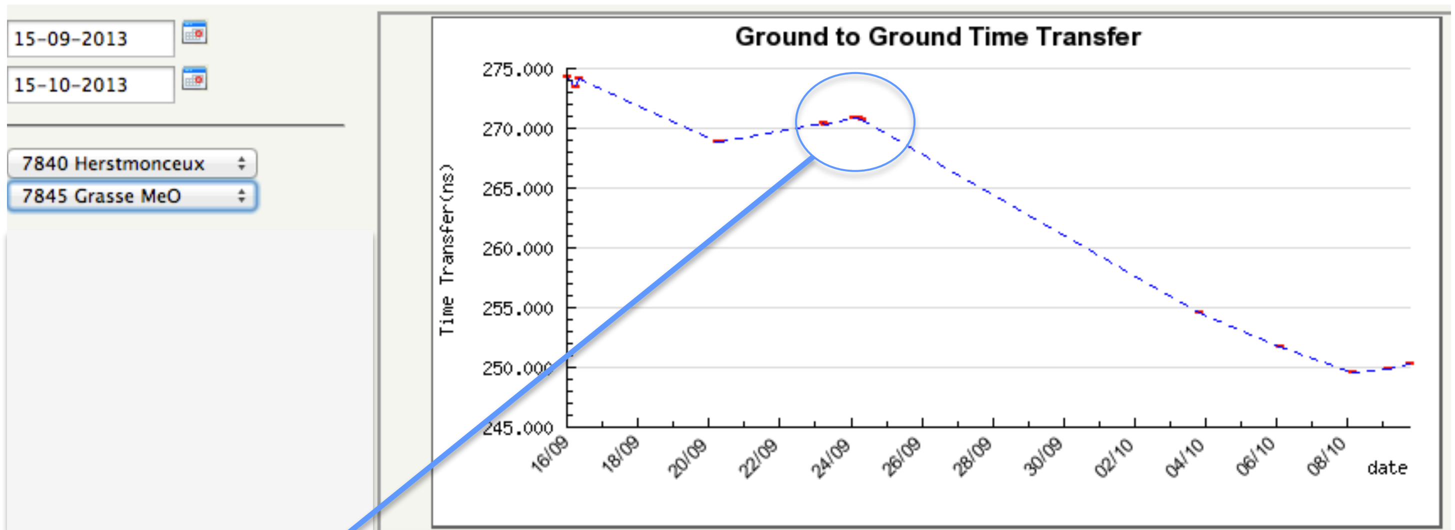
hMaser: Paris **(FTLRS)**, Hertsmonceux, Wettzell, and Grasse

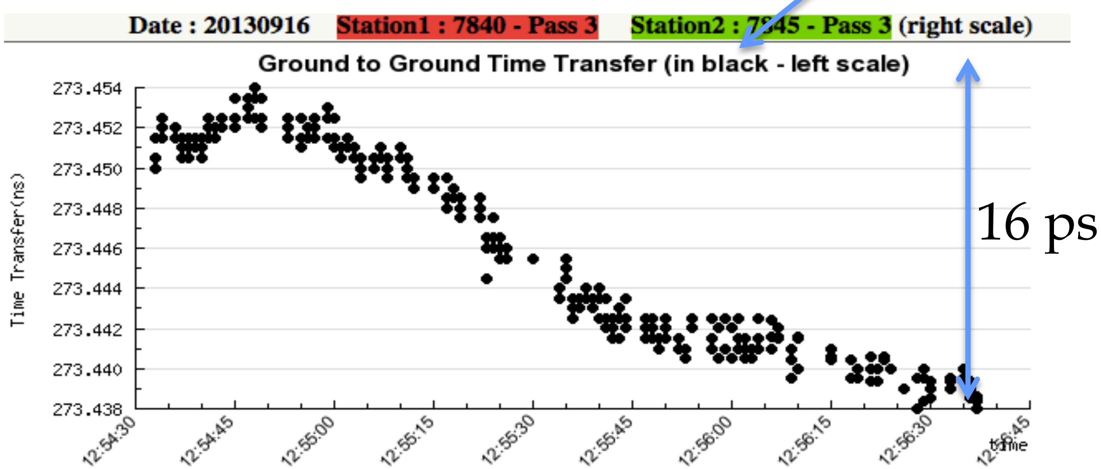
Experiment between Grasse and european observatories (SLR stations), and FLTRS as a mobile equipment; plus GPS, and CALibration campaigns.

Configuration, CV.

Sept.-Oct. 2013 :

A dedicated monitoring between :
Grasse, Paris
Hertsm., Wettz
SLR's + h-masers





Time transfer between h-masers

Example: Grasse and Herst. (UK)

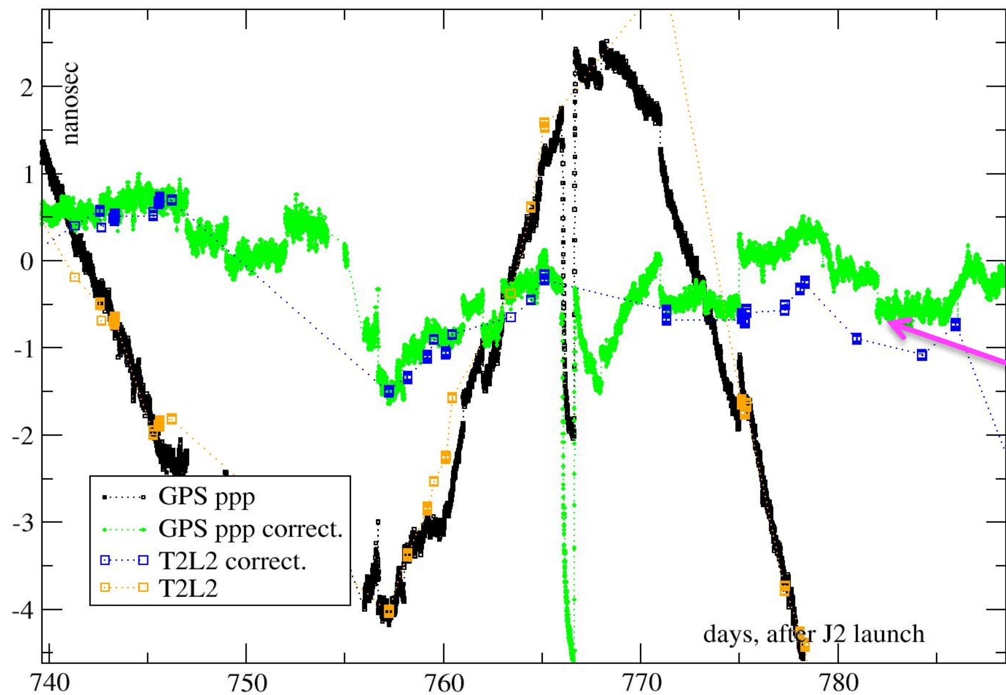
-> CALibration made by:
(R.Sherwood, JM Torre, E Samain, C Courde, 2013)

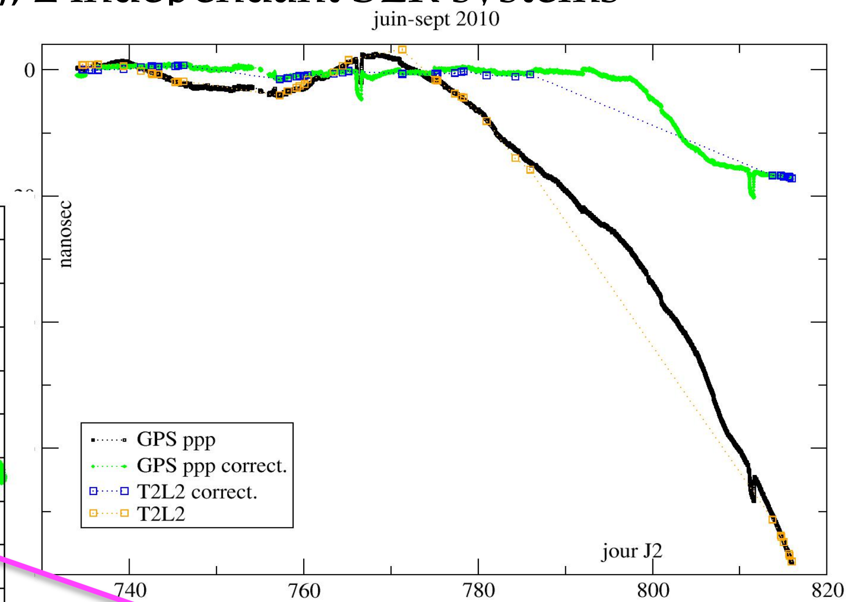
Time transfer by Laser => RF link

Stability (long term, summer, 2010)

» Satellite in common view, 1 hMaser clock (OParis) and hMaser (3.2 10^{-15}/d) +FOM (Grasse), 2 independant SLR systems (FTLRS and MeO), plus 2 GPS

» Need for Gravitational shift of : 1.3 10^{-13}



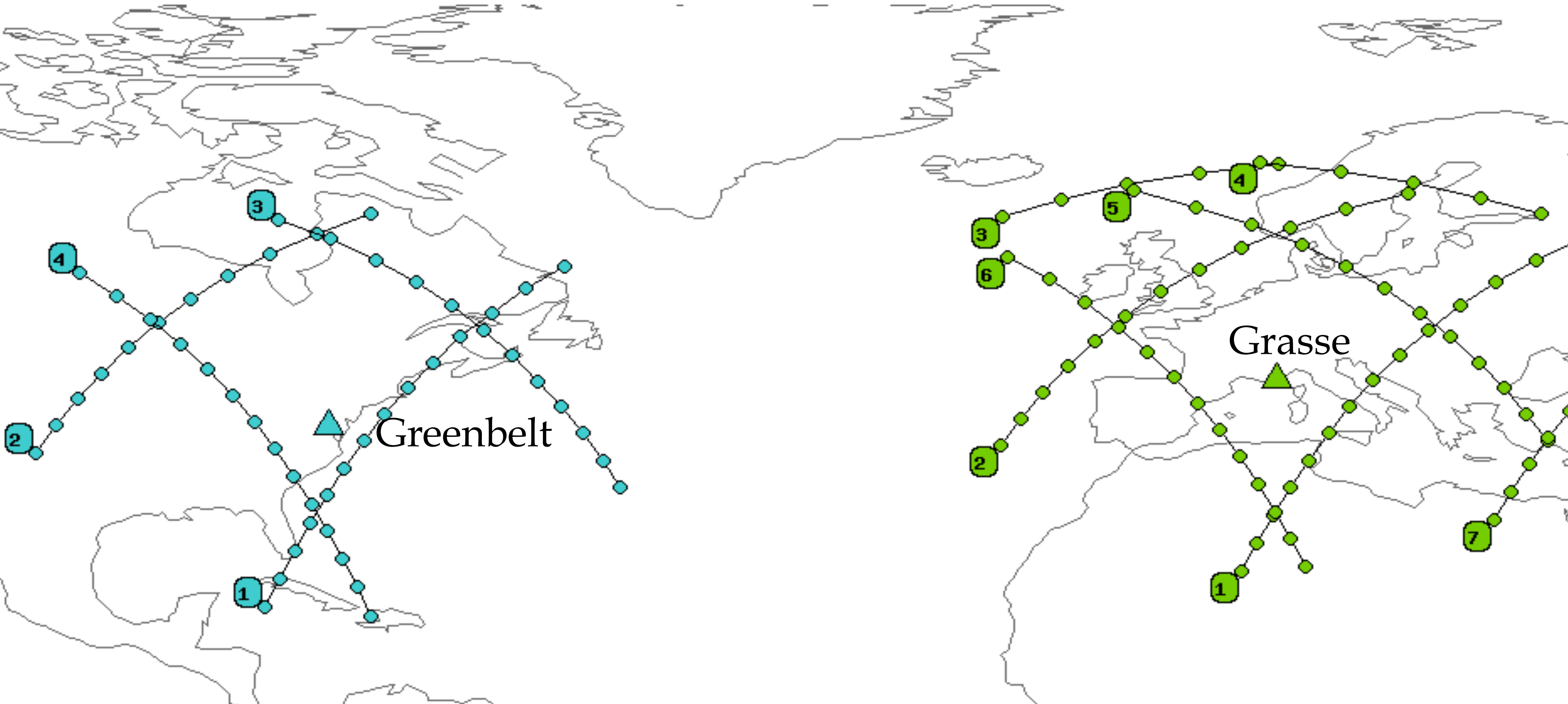


PARIS - GRASSE
GPS-CP ambiguities

Guillemot et al., 2013

Configuration, non CV.

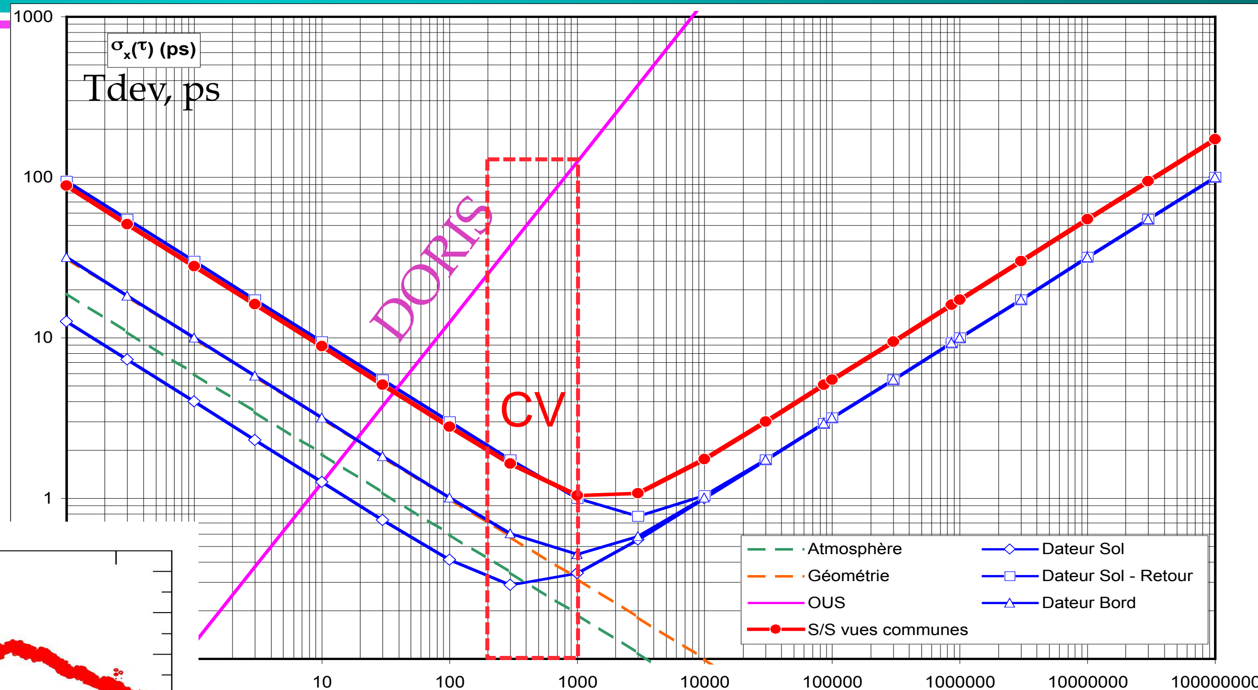
Jason-2 pass over N.Atlantic, Oct. 17 2013

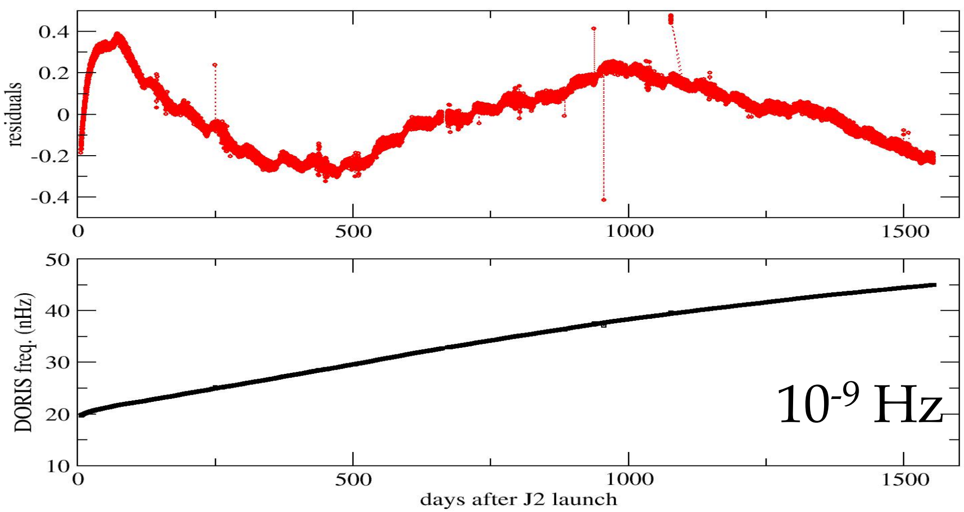


DORIS USO (oscillator)

Performances of the DORIS oscillator (quartz)

2-3.10^{-13} @ 1000 s





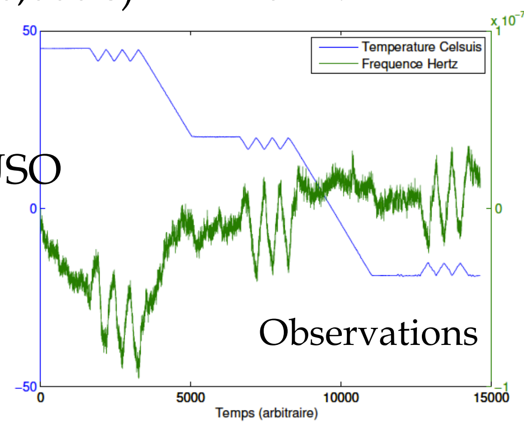
Monitoring of the relative bias frequency: 0.01 10^{-9} / d

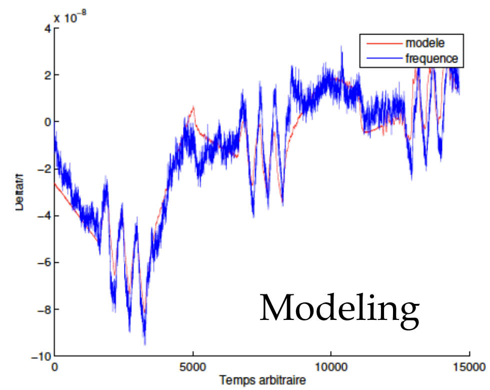
Bias => tens of µsec / 1000s

Guillemot, et al., EFTF 2009

Time transfer by Laser => DORIS

- Long term
  - > 1 month- few years : monitoring of the USO / T2L2 : aging and space environment
  - Interest for Jason-like mission (with DORIS, see Lemoine&Capdeville, 2006, Willis et al., 2004)
  - T2L2 provides: on board data (GPS-USO) and time transfer data (H-maser's – OUS)
  - => 10^{-11} => a few 10^{-13}
- Short term
  - 1000 s – 1 d
    - Orbitography /Jason2, and IDS positioning => 10^{-12} ~ 0.3 mm.s^{-1} *(Willis et al., 2004)*
    - On-board : DIODE (navigator ,CNES) => id. *(Jayles et al., 2010)*
    - Time transfer in non Common View (10,000 s) => 10^{-13} ?
    - Fundamental Physics
- Tests on ground before the launch of DGXX-S USO
  - Temperature / Frequency
  - Radiations





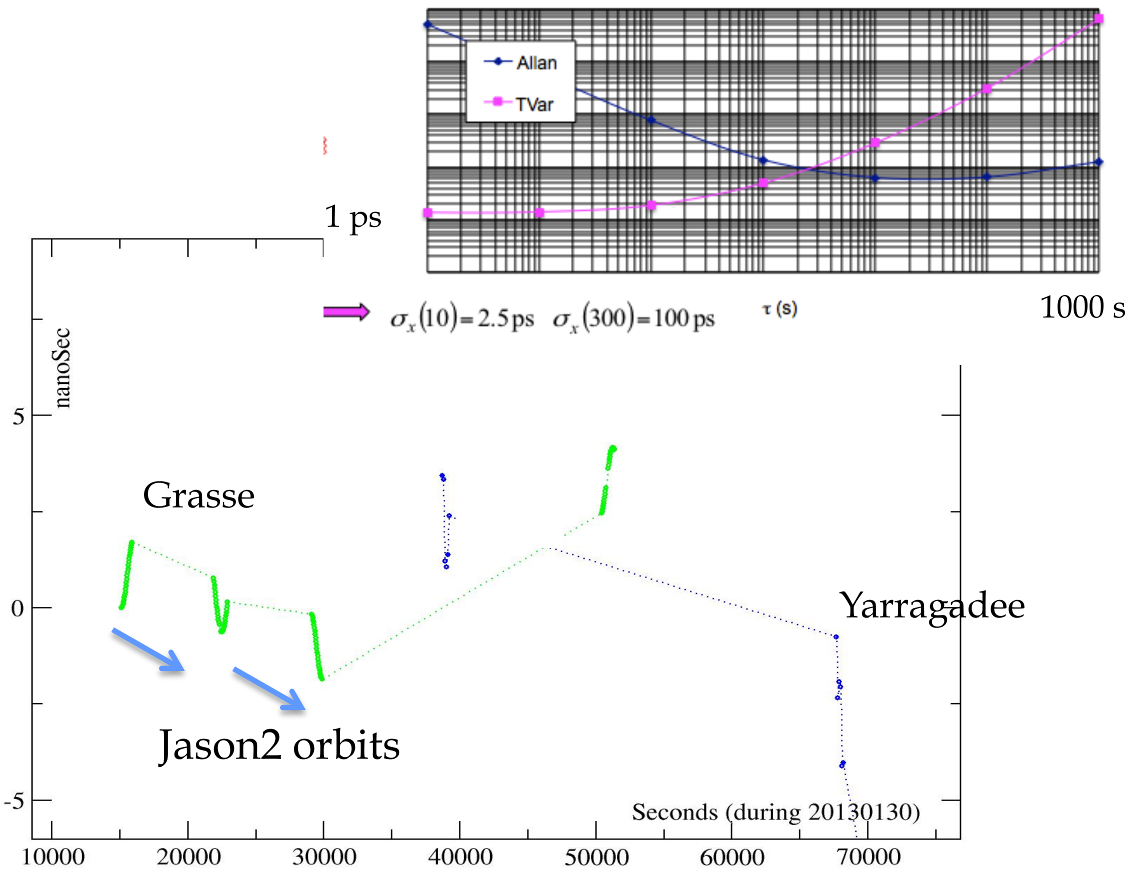
Time Transfer in non Common View

USO monitoring / T2L2-SLR's
-> model (approx. 2.10^{-13})

-> integration over time
(1 orbit. revolution ~6600 s)

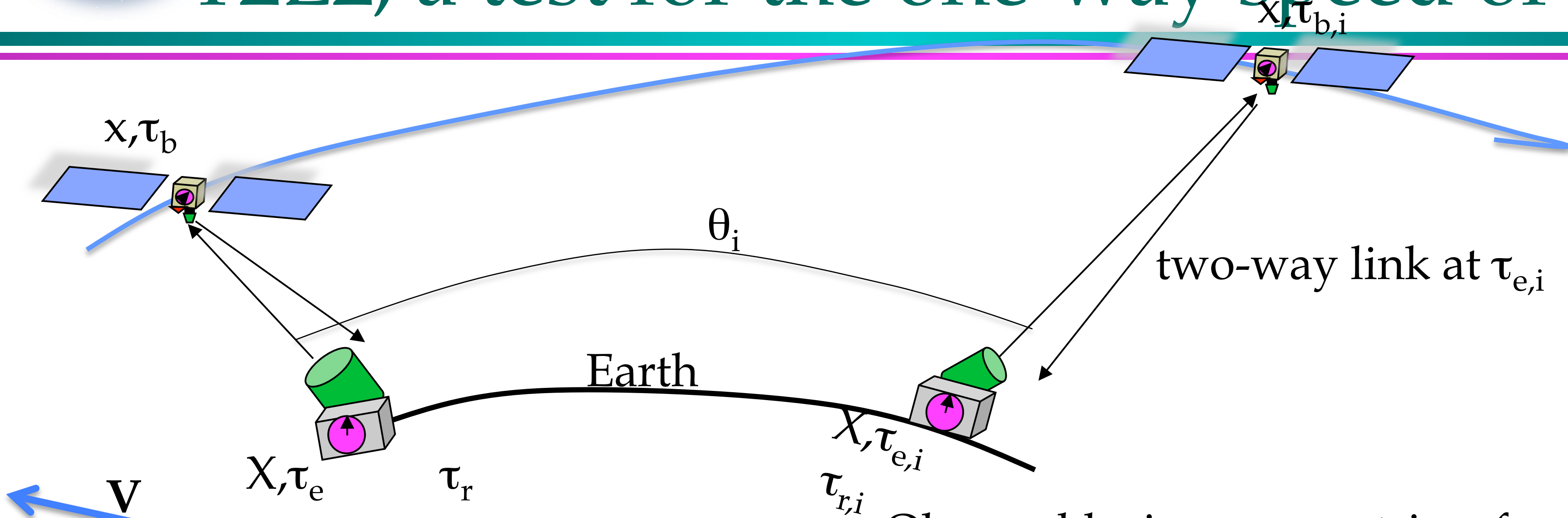
-> Performance:
0.3-0.5 ns / 900 s
2-3 ns / 12h

$\Rightarrow$ Modeling the USO frequency
with Temperature effects



=> Need time CALibrations at several SLR stations

T2L2, a test for the one-way speed of light



Observable, in a geocentric reference frame

(*Mansouri & Sexl, 77*) => kinematics

V earth as a preferred direction in space (CMB): V << c

First « framework » by (*Krisher, 1990; Will, 1992*)

$$[\ (\tau_{b,i} - \tau_{e,i}) - (\tau_{r,i} - \tau_{b,i})\ ] - [\ (\tau_{b,1} - \tau_{e,1}) - (\tau_{r,1} - \tau_{b,1})\ ] + \Delta_{1,i} \sim 2.A\ (\cos\theta_i - \cos\theta_1)$$

Same study with the previous LASSO experiment (*Veillet & Fridelance, 93; Petit & Wolf, 94*) at the picosecond level; and expected performances for the PRARE and T2L2 systems (*Wolf, 1995*):

=> $\Delta\phi / \delta\tau$ = 2-3 10^{-9}

Plans for 2015-2016

- Better characterization of the USO on the long term (yrs)
- Campaigns on intercontinental distances => Tokyo, Mac-Donald, Greenbelt, and Europe
- Access to all the database, via CDDIS & EDC (CRD format, at least) and our web pages
- Synergy between the projects T2L2 /Jason2 and LRO (current missions) and ELT
  - Methods and analysis, comparisons and synchronizations
  - 1-way ranging
  - Comparisons T2L2 / ACES (MWL and ELT)

Thank You