OCA –UMR GeoAzur

Grasse – FRANCE

M. Aimar, D. Albanese, P. Exertier, D. Feraudy, M. Furia, H. Mariey, G. Martinot, JL. Oneto, J. Paris, F. Pierron, M. Pierron, R. Rigard-Cerison, E. Samain, J.M. Torre, H. Viot

CNES

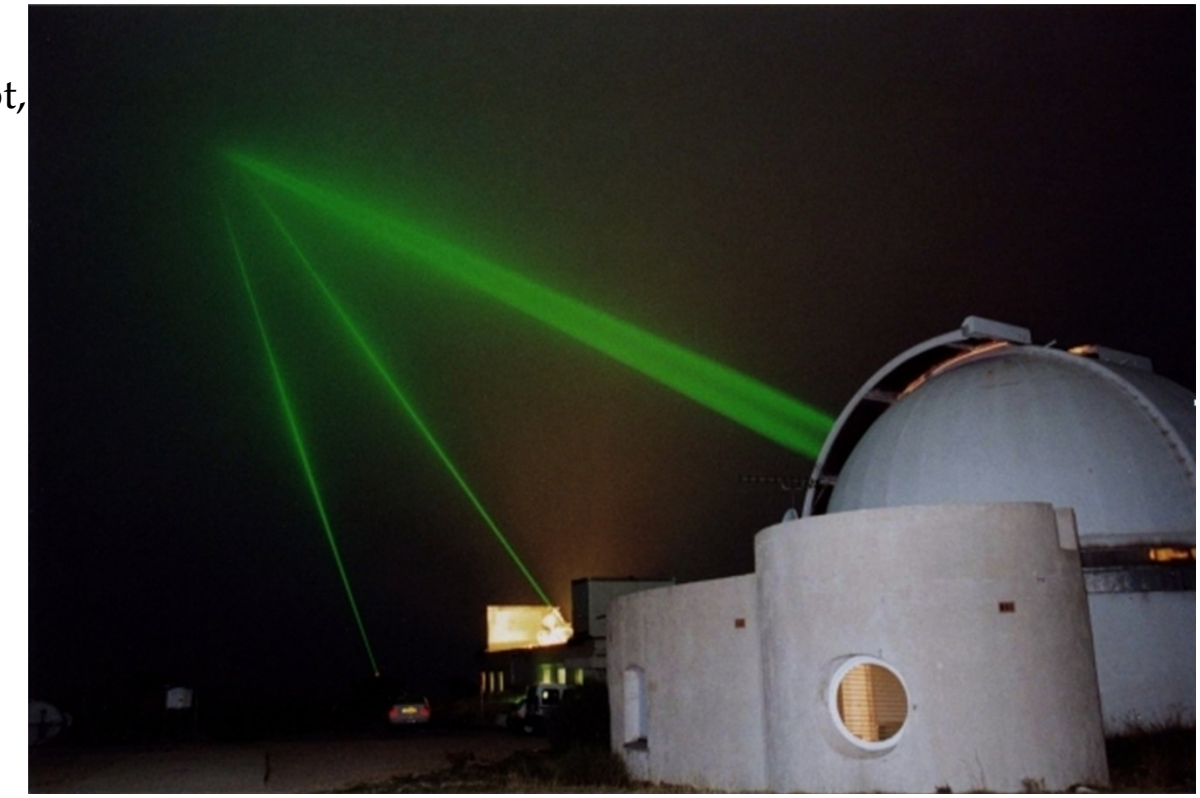
Toulouse-Paris – France

P. Guillemot, S. Leon, C. Jayles

OP

Paris– France

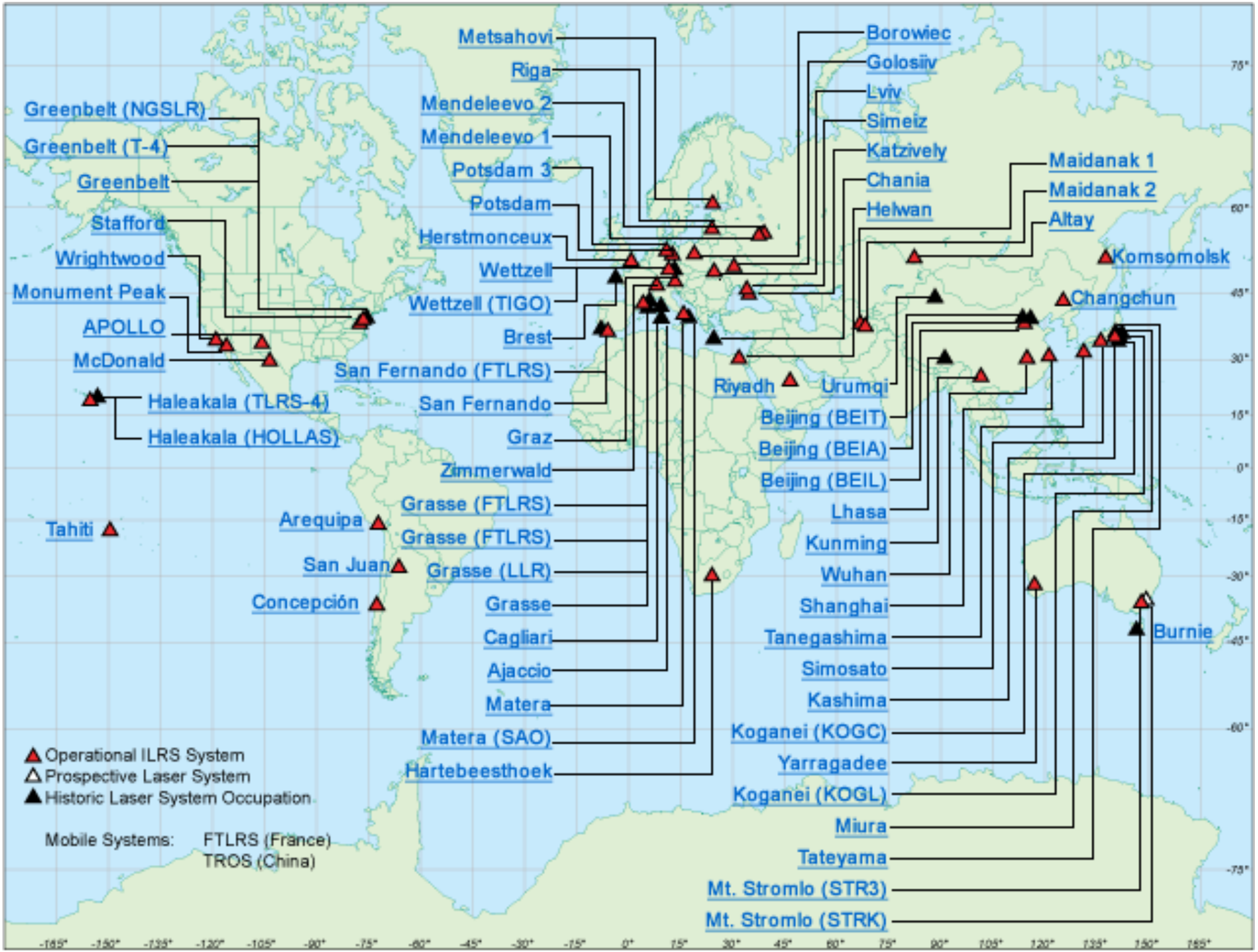
J.Achkar, K. Djeroud, P. Laurent, D. Rovera



Télémétrie et transfert de temps par lien laser

Télémétrie Laser

- Détermination de la distance par mesure du temps de propagation d'une impulsion laser
- Définition du mètre : distance parcourue par la lumière dans le vide en 1/c seconde
- Impulsion laser ps : modulation gaussienne dans la bande des 20 GHz d'une porteuse optique (532 nm)
- Avantages
  - » Bande passante élevée permet des mesures à l'échelle millimétrique
  - » Insensible à l'effet Doppler
  - » Incertitude liée à la distance : centimétrique
  - » Longueur d'onde optique permet de manipuler des faisceaux avec une divergence de l'ordre du µ radian
- Inconvénient
  - » Sensibilité à la météo

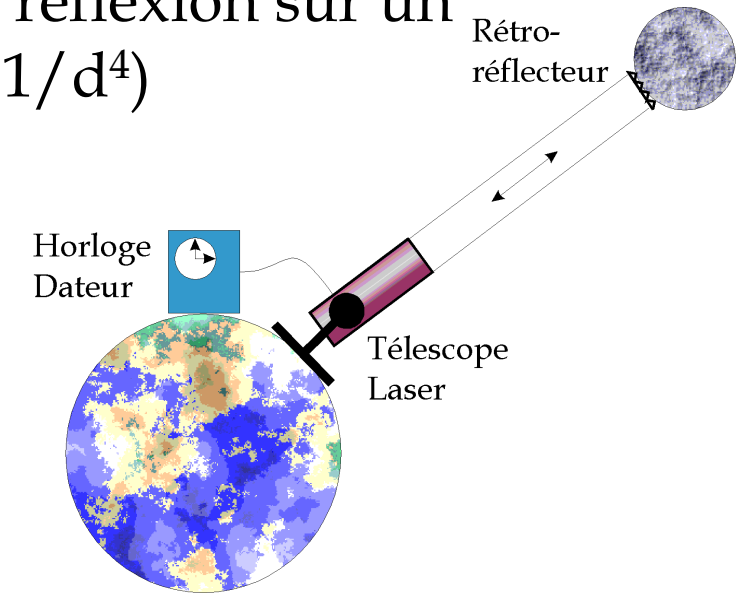

Metsahovi
Riga
Mendeleevo 2
Mendeleevo 1
Potsdam 3
Potsdam
Herstmonceux
Wettzell
Wettzell (TIGO)
Brest
San Fernando (FTLRS)
San Fernando
Graz
Zimmerwald
Grasse (FTLRS)
Grasse (FTLRS)
Grasse (LLR)
Grasse
Cagliari
Ajaccio
Matera
Matera (SAO)
Hartebeesthoek
Borowiec
Golosiiv
Lviv
Simeiz
Katzively
Chania
Helwan
Riyadh
Urumqi
Beijing (BEIT)
Beijing (BEIA)
Beijing (BEIL)
Lhasa
Kunming
Wuhan
Shanghai
Tanegashima
Simosato
Kashima
Koganei (KOGC)
Yarragadee
Koganei (KOGL)
Miura
Tateyama
Mt. Stromlo (STR3)
Mt. Stromlo (STRK)
Maidanak 1
Maidanak 2
Altay
Komsomolsk
Changchun
Burnie
Greenbelt (NGSLR)
Greenbelt (T-4)
Greenbelt
Stafford
Wrightwood
Monument Peak
APOLLO
McDonald
Haleakala (TLRS-4)
Haleakala (HOLLAS)
Tahiti
Arequipa
San Juan
Concepción
Operational ILRS System
Prospective Laser System
Historic Laser System Occupation
Mobile Systems: FTLRS (France)
TROS (China)

Stations laser France

- Station Fixe MeO
  - » Calern France
  - » Telescope 154 cm
- Station Mobile FTLRS
  - » Calern France / mobile
  - » Telescope 13 cm
  - » 300 kg
- Station MOBLAS 8
  - » Tahiti
  - » Telescope 76 cm
- Station Mobile 2
  - » REseau Sismologique et GéodésIque Français
  - » Telescope 40 cm

Télémétrie laser 2 voies

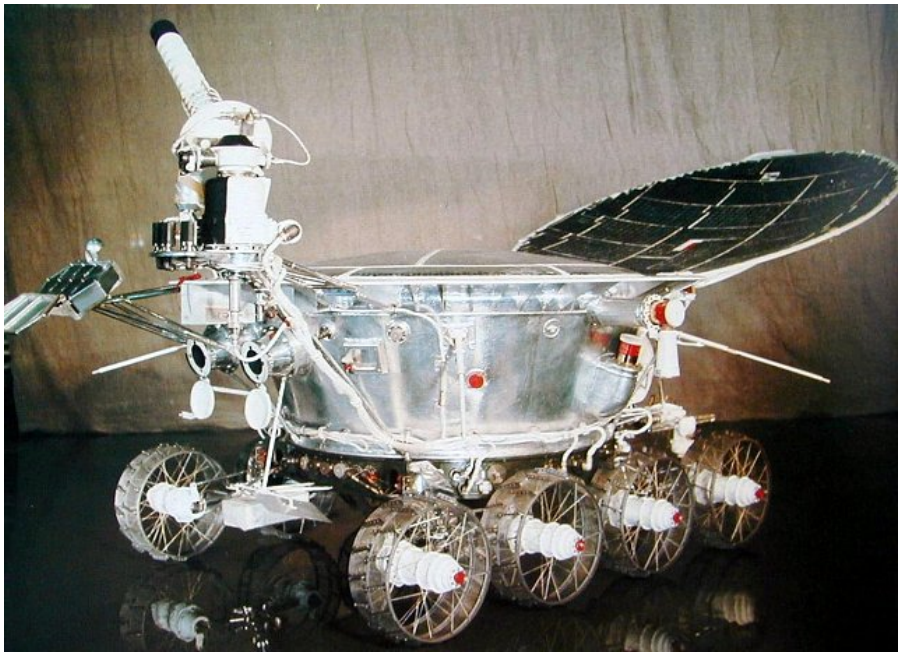
- Mesure du temps aller retour après réflexion sur un ensemble de coin de cube (bilan en $1/d^4$)



- Objectifs scientifiques
  - » Géodésie
  - » Systeme de référence
  - » Sélénophysique
  - » Physique fondamentale
  - » Altimétrie

- 37 cibles mesurées de 400 km à la Lune
- 20 nouvelles cibles à l'horizon 2015

Cibles



Luna 17

GPS

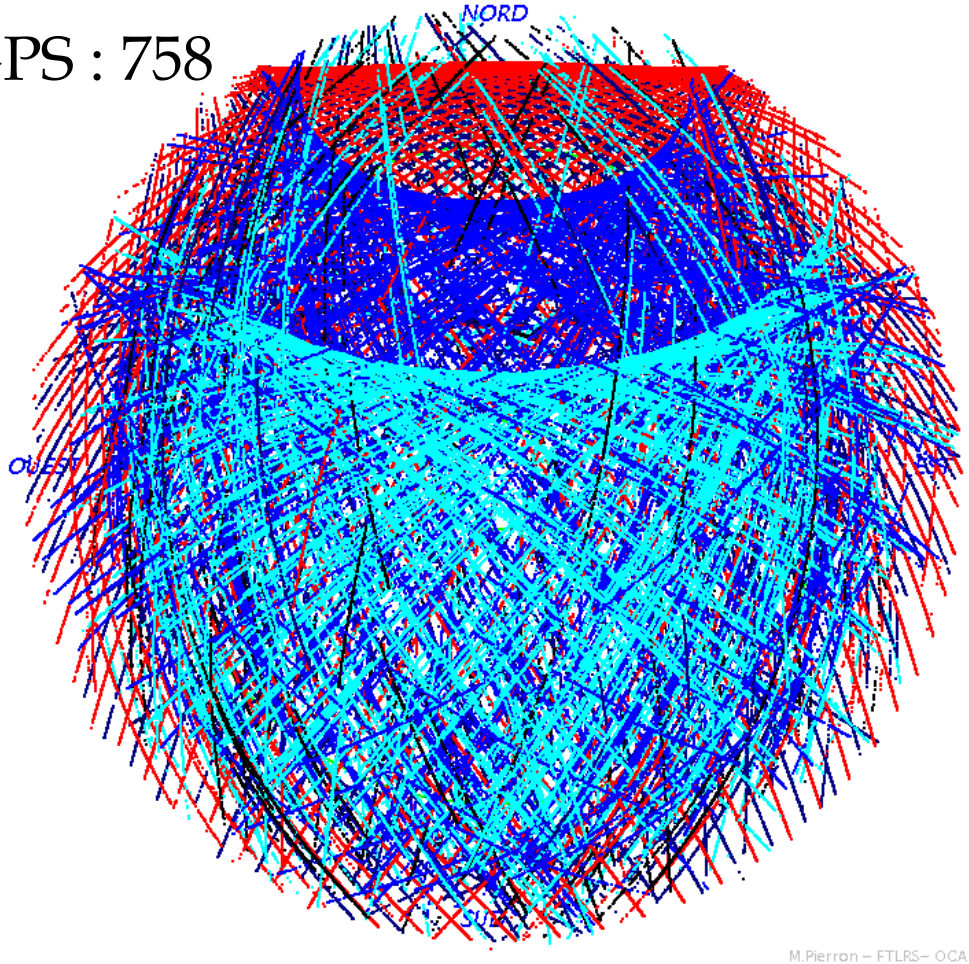
Blits

Larets

Télémétrie laser
Stations MeO OCA (depuis 07/08)

- Lageos 1&2 : 608
- Glonass, Etalon GPS : 758
- Leo : 1749
- Apollo XV : 43
- Apollo XI : 3
- Apollo XIV : 1
- LRO : 25 (6 h)

- Total : 3187



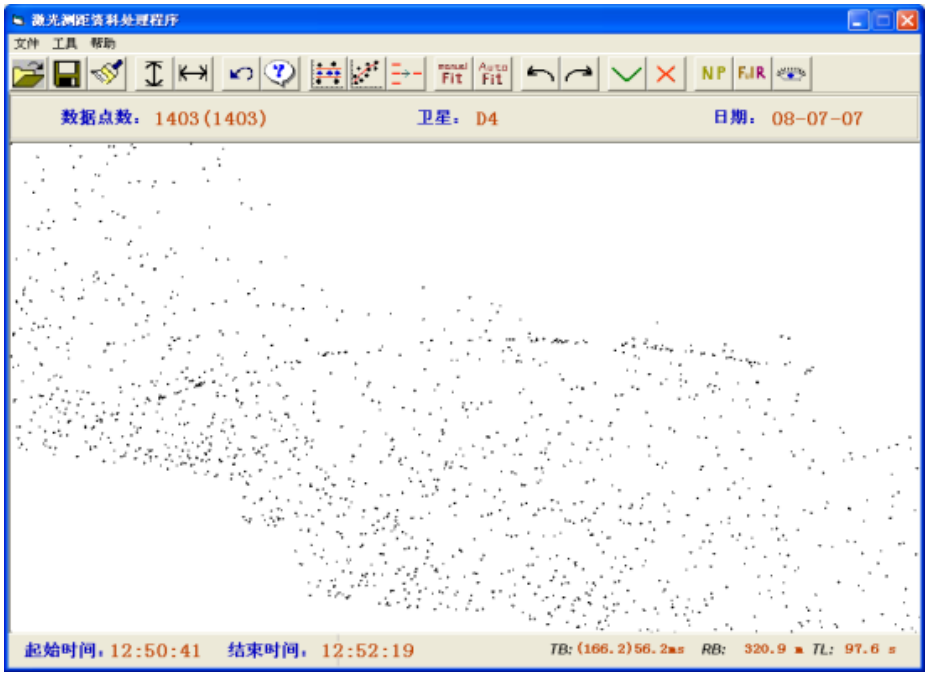
Nombre de Passages

total: 3115 ~ 53372 NPs

ajis	26 pass.	~ 522 NPs
blit	87 pass.	~ 714 NPs
cmp1	95 pass.	~ 341 NPs
cry2	54 pass.	~ 1069 NPs
env1	72 pass.	~ 1500 NPs
ers2	67 pass.	~ 1413 NPs
eta1	100 pass.	~ 316 NPs
eta2	108 pass.	~ 382 NPs
gl02	123 pass.	~ 447 NPs
gl09	58 pass.	~ 193 NPs
gl10	31 pass.	~ 96 NPs
gl15	114 pass.	~ 421 NPs
gl18	23 pass.	~ 91 NPs
gl20	77 pass.	~ 244 NPs
gova	78 pass.	~ 281 NPs
govb	118 pass.	~ 416 NPs
gp35	7 pass.	~ 28 NPs
gp36	117 pass.	~ 419 NPs
grca	15 pass.	~ 470 NPs
grcb	9 pass.	~ 191 NPs
jas1	283 pass.	~ 9733 NPs
jas2	655 pass.	~ 25167 NPs
lag1	341 pass.	~ 3617 NPs
lag2	267 pass.	~ 3026 NPs
lart	22 pass.	~ 224 NPs
lrol	40 passages	
pba2	6 pass.	~ 185 NPs
star	57 pass.	~ 865 NPs
stel	43 pass.	~ 503 NPs
tadx	11 pass.	~ 252 NPs
tera	11 pass.	~ 246 NPs

Télémétrie non coopérative

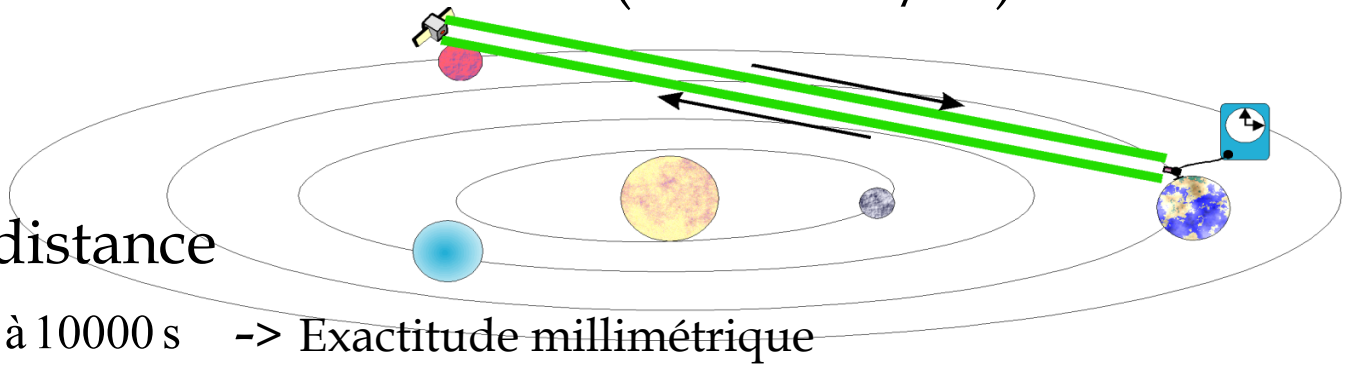
- Télémétrie sur cibles non équipées de coin de cube
  - » Débris lanceur
  - » Satellite fin de vie
- Objectifs
  - » Orbitographie
  - » Déplacement de débris
- Acteurs
  - » Chine
  - » Australie
  - » France (MeO)



Série obtenue par la station de Shanghai sur le lanceur Russe (ID 1987-38B) ; Altitude 900 km

Télémétrie laser 2 x 1 voie par transpondeur optique

- Mesure indépendante du temps aller et retour avec une station laser aux 2 extrémités du lien (bilan en $1/d^2$)



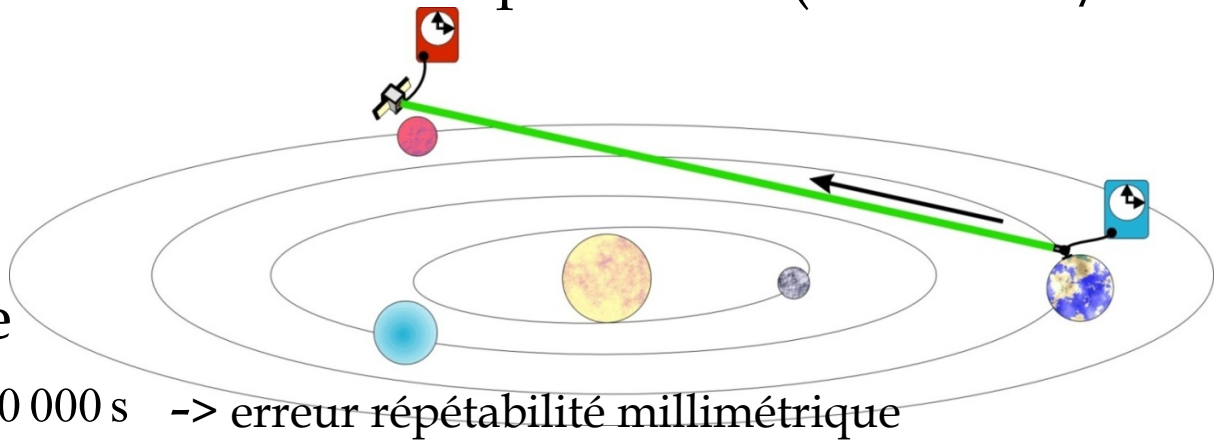
- Incertitude en distance

$\delta l = \sigma_x(\tau)\, c\,;\ \tau \sim 1000 \text{ à } 10000\ s$ -> Exactitude millimétrique

- Terre – Mercure : 23,964,675,433.9 m +/- 0.1 m
  - » Sonde MESSANGER ; MLA : Mercury Laser Altimeter
  - » Goddard Geophysical Astronomical Observatory
- Terre – Mars
  - » Sonde MGS ; MOLA : Mars Orbiter Laser Altimeter
  - » Goddard Geophysical Astronomical Observatory

Télémétrie laser 1 voie par Lecture horloge

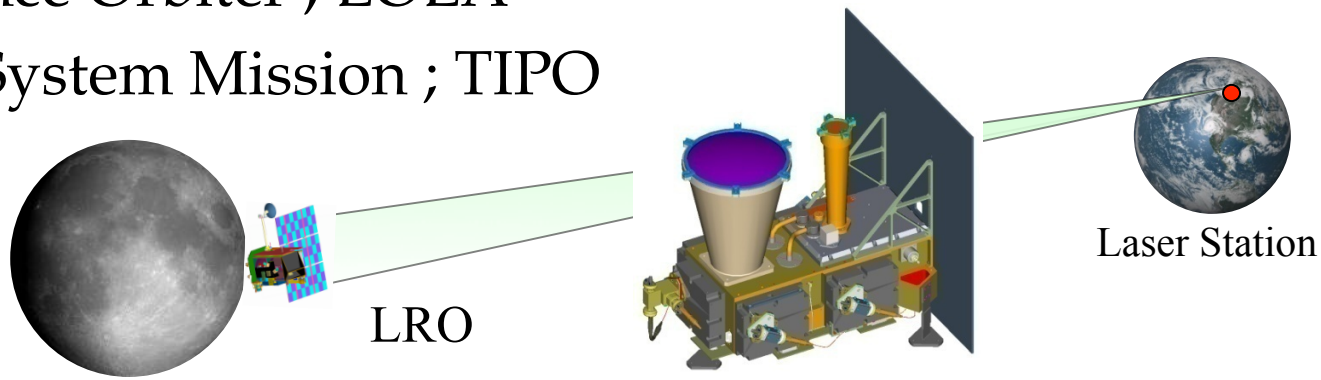
- Mesure simple du temps aller, déduite de la date de départ et de la date d'arrivée d'impulsions émises depuis le sol (bilan en $1/d^2$)



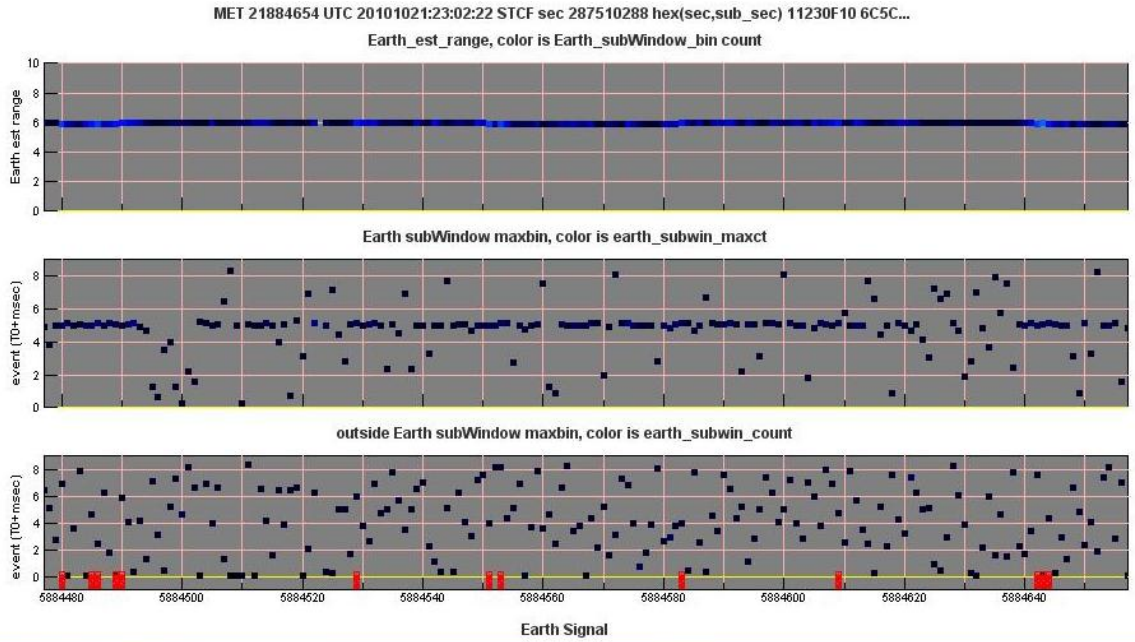
- Incertitude en distance

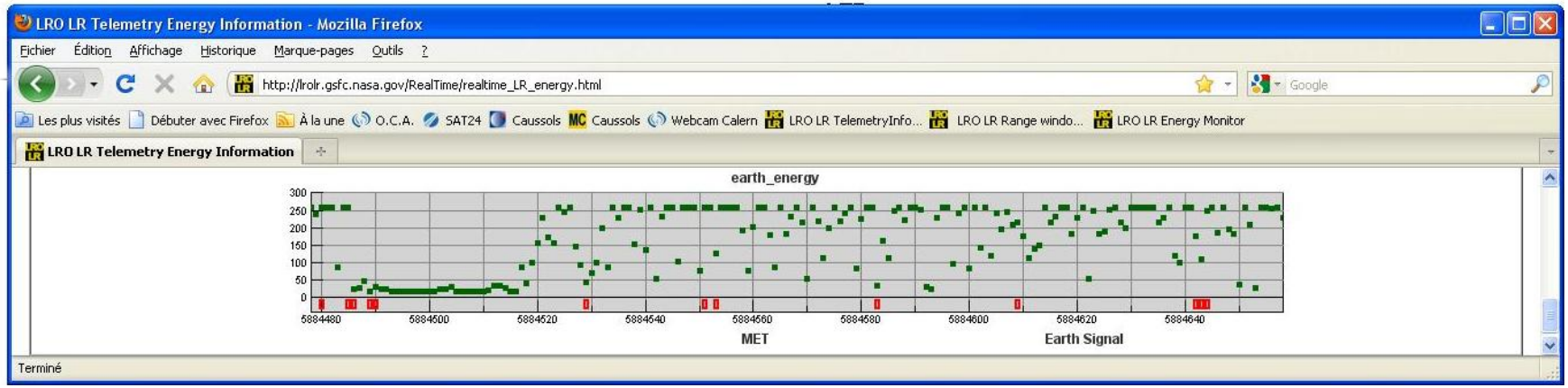
$\delta l = \sigma_x(\tau)\, c\,;\, \tau \sim 100\,000$ à $1\,000\,000$ s -> erreur répétabilité millimétrique

- Luna Reconnaissance Orbiter ; LOLA
- OSS : Outer Solar System Mission ; TIPO



Observation LRO
Passage commun Zimmerwald - Calern

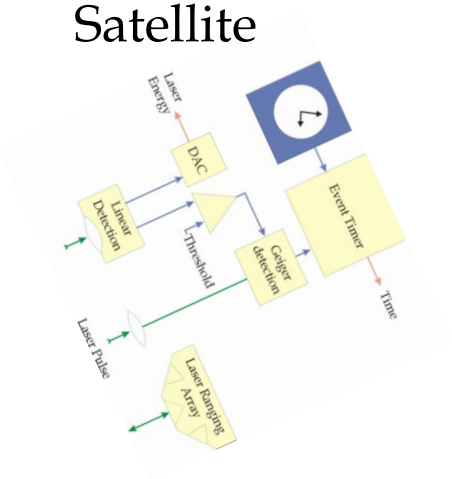




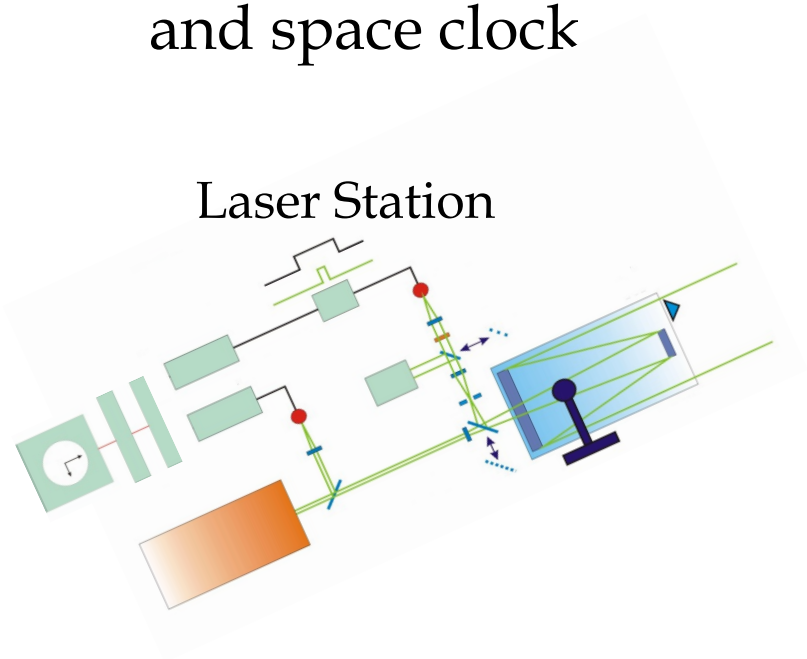
Transfert de temps par lien laser

- 2 way technique based on the timing of optical pulses emitted (and received) by a laser station and received by a space segment
- Ground : T_{start} T_{return} Space : T_{board}
- From these 3 dates : phase between the ground and space clock

Satellite



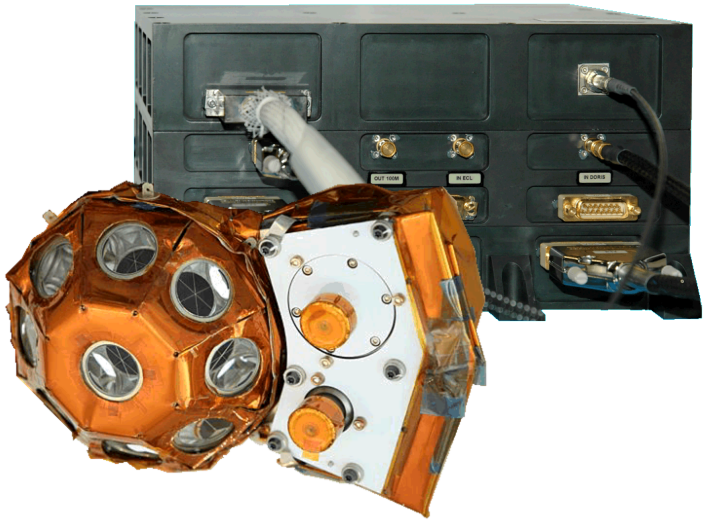
Laser Station



- Time Transfer by laser Link sur Jason 2 (2008) : T2L2
- Laser Time Transfer sur Compass (2007) : LTT
- European Laser Timing sur ACES (2014) : ELT

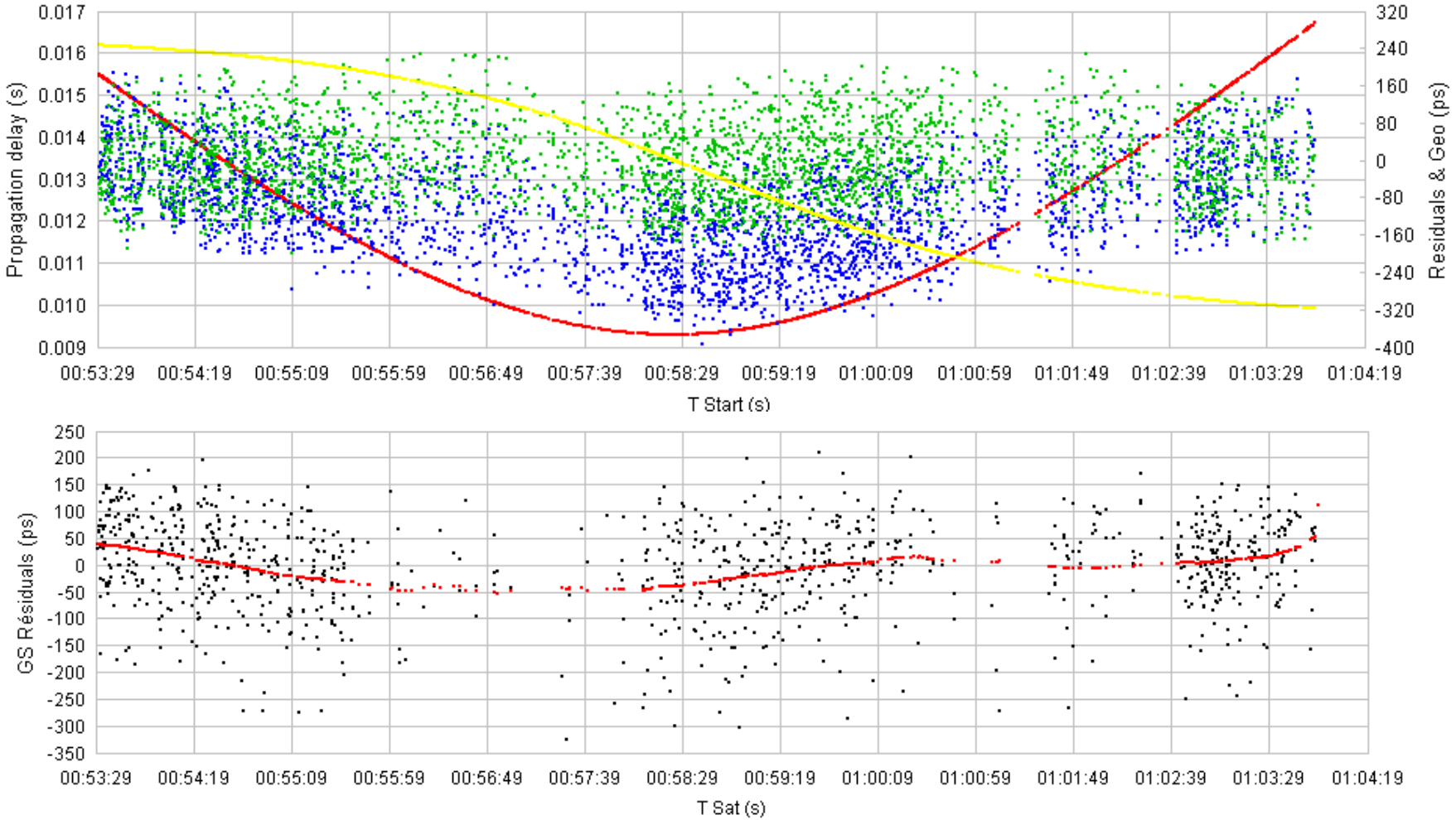
T2L2 Status

- 30 months of continuous operation :
  - » 50 millions of “luminous” events recorded
  - » No aging of the instrument
  - » No degradation of the performances
  - » All parameters are nominal

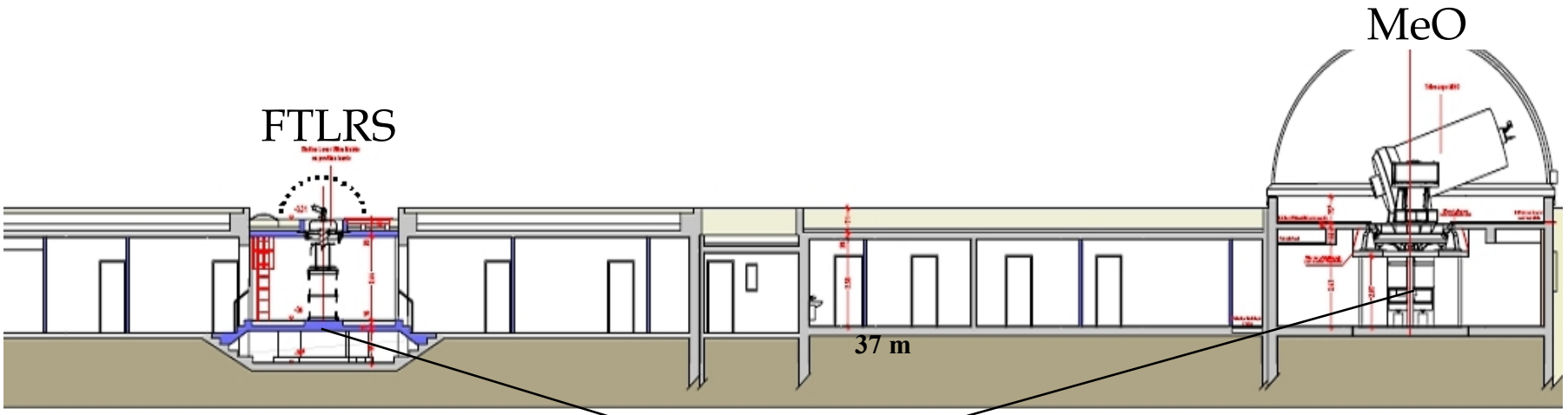


- Exploitation :
  - » CNES has decided to extend operations of T2L2 until the end of 2012
  - » Possibility of post 2012 operations will be studied mid 2012

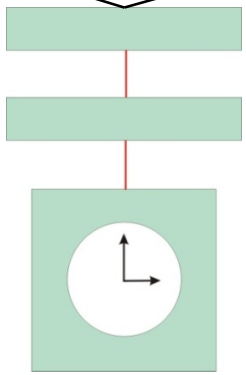
Space to ground time transfer
Japan 7308 NICT 21/10/09



Ground to ground time transfer Collocation between MeO-FTLRS (1)

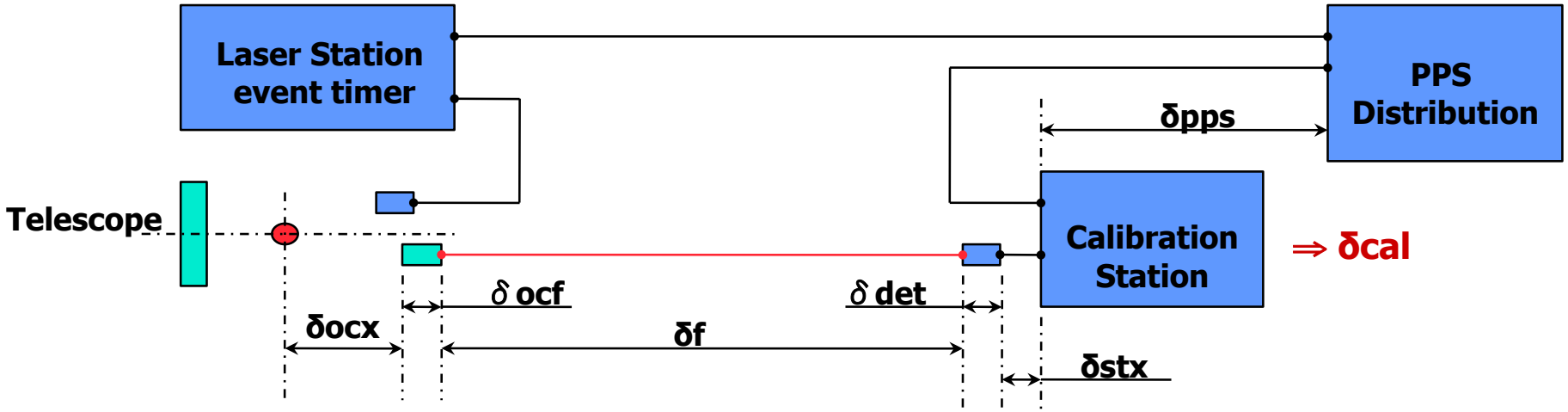


- Common Clock distribution T4S HMaser
- Cancellation of the clock noises



Ground to ground time transfer Collocation between MeO-FTLRS (2)

- Absolute Calibration Global Scheme

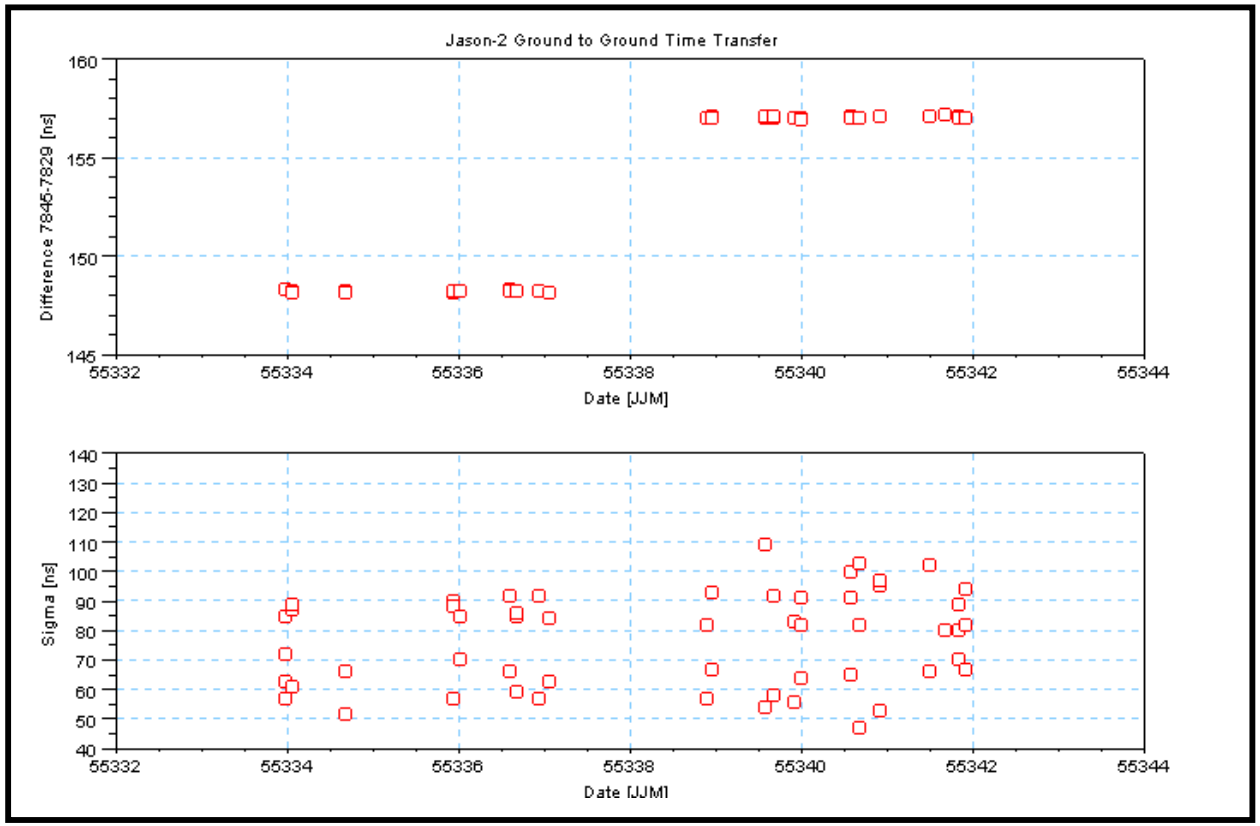


- After calibration, laser events are corrected with :

$$\delta T_i = \delta cal_i - (\delta ocx_i + \delta ocf + \delta f + \delta det + \delta stx) + \delta pps$$

$$\delta T_{1,2} = \delta cal_2 - \delta cal_1 - (\delta ocx_2 - \delta ocx_1)$$

Ground to ground time transfer Collocation between MeO-FTLRS (3)

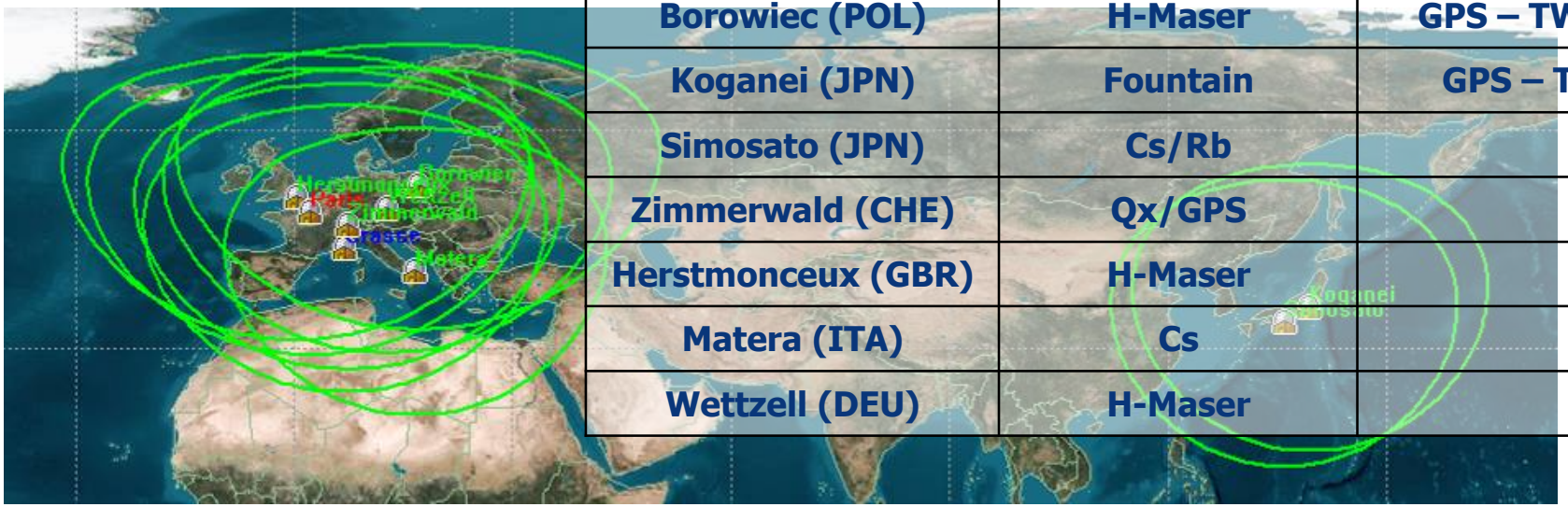


- Difference between absolute calibration : 157.030 ns ± 50 ps
- Difference between Jason2 passes : 157.075 ns ± 75 ps
- Error: 45 ps

2nd T2L2 International Campaign (1)

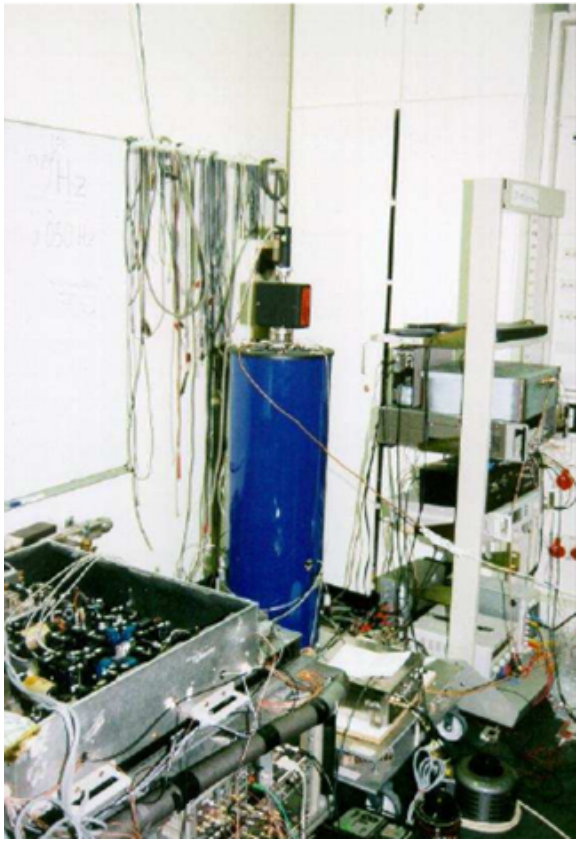
- Objectives :
  - » Short and long term stability of the time transfer
  - » Comparison between T2L2 and TWSTFT and GPS time transfer

Site	Clock	Time Transfer
Caussols (FRA)	**Fountain + HM**	**GPS – TWSTFT Europe**
Paris (FRA)	**Fountain + HM**	**GPS – TWSTFT Europe**
Borowiec (POL)	**H-Maser**	**GPS – TWSTFT Europe**
Koganei (JPN)	**Fountain**	**GPS – TWSTFT Asia**
Simosato (JPN)	**Cs/Rb**	**GPS**
Zimmerwald (CHE)	**Qx/GPS**	**GPS**
Herstmonceux (GBR)	**H-Maser**	**GPS**
Matera (ITA)	**Cs**	**GPS**
Wettzell (DEU)	**H-Maser**	**GPS**



2nd T2L2 International Campaign (2)

Structure pour l'installation de FTLRS a l'Observatoire de paris



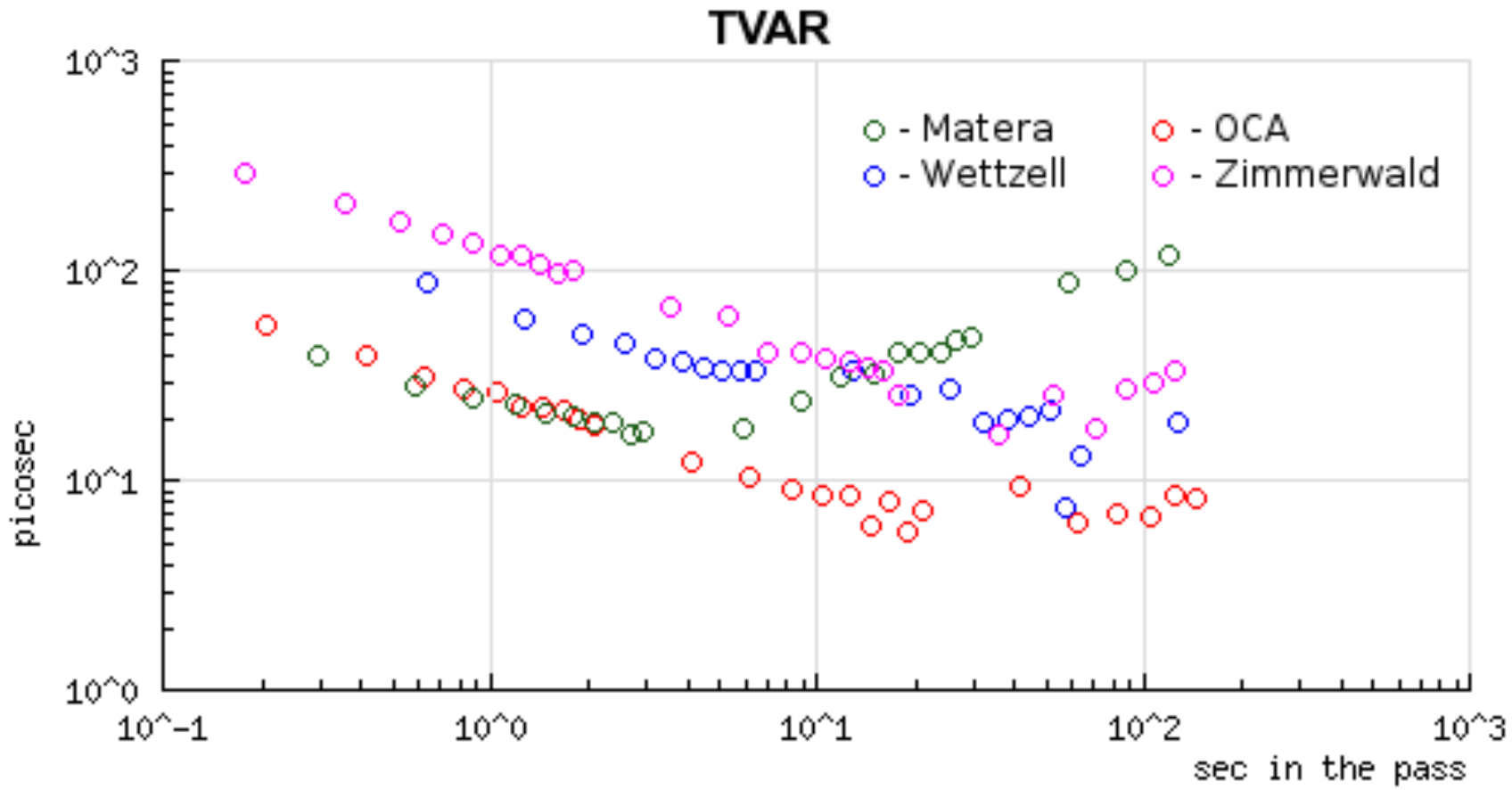
Fontaine atomique mobile a l'OCA

2nd T2L2 International Campaign (3)

- Observation planning : 4-5 passes per day above each station
  - » In common view configuration above Europe or Asia
  - » One common orbit between Europe and Asia per day
- Synthesis of the activity : 1.155 passes, 650 in common view !

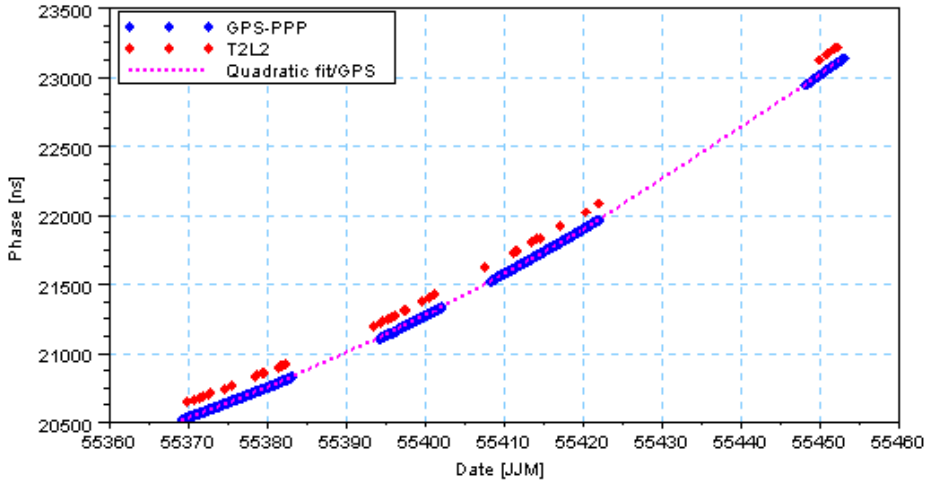
Site	Passes with triplets	% of triplets	Passes with triplets in Common View : ~645 passes					
			Paris	**Zimmerwald**	**Grasse**	**Matera**	**Wettzell**	**Simosato**
Herstmonceux (GBR)	**169**	**20**	**47**	**14**	**87**	**33**	**19**	
Paris / FTLRS (FRA)	**140**	**9**		**22**	**88**	**43**	**36**	
Zimmerwald (CHE)	**85**	**34**			**35**	**27**	**21**	
Grasse (FRA)	**350**	**14**				**77**	**58**	
Matera (ITA)	**190**	**89**					**38**	
Wettzell (DEU)	**167**	**71**						
Koganei (JPN)	**29**	**34**						**5**
Simosato (JPN)	**25**	**70**						

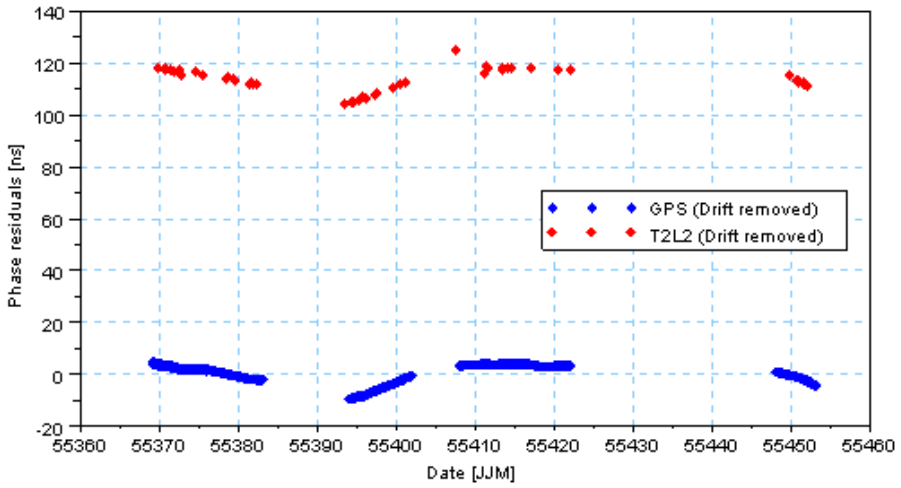
2nd T2L2 International Campaign (4)



2nd T2L2 International Campaign (5)

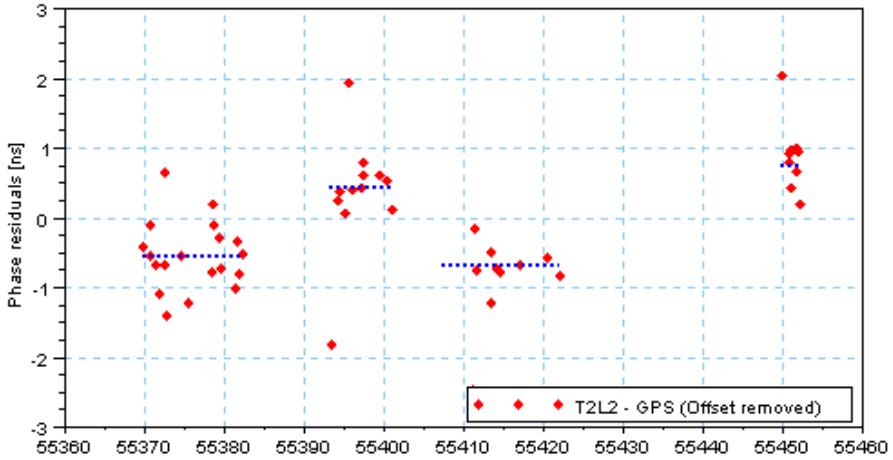
- Carrier phase time transfer method using ambiguity resolution on zero-difference measurements[1] (λ_c = 0.356758 ns)
- Comparison with GPS Common View : OP – OCA Link
- Same behaviour / trend of GPS & T2L2 data (Same polynomial removed)

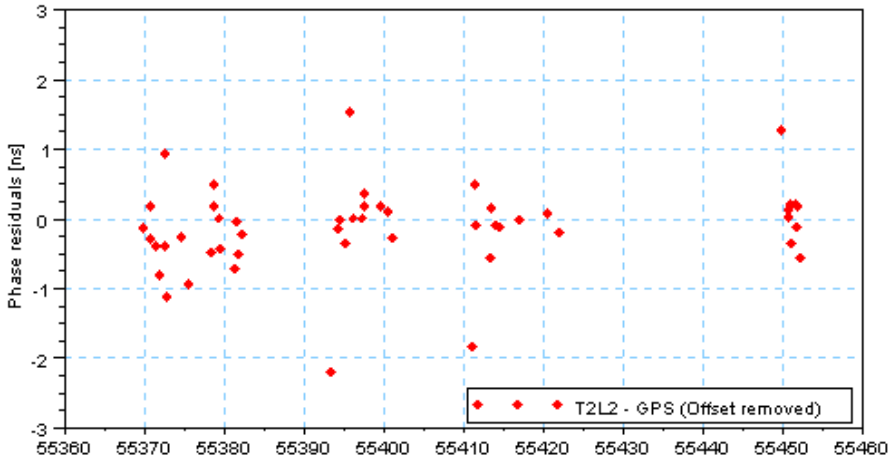




[1] "GPS carrier phase time transfer using single-difference integer ambiguities" - J. Delporte, F. Mercier, D. Laurichesse, O. Galy, International Journal of Navigation and Observation, Hindawi Publishing Corporation, Volume 2008, Article ID 273785.

2nd T2L2 International Campaign (6)





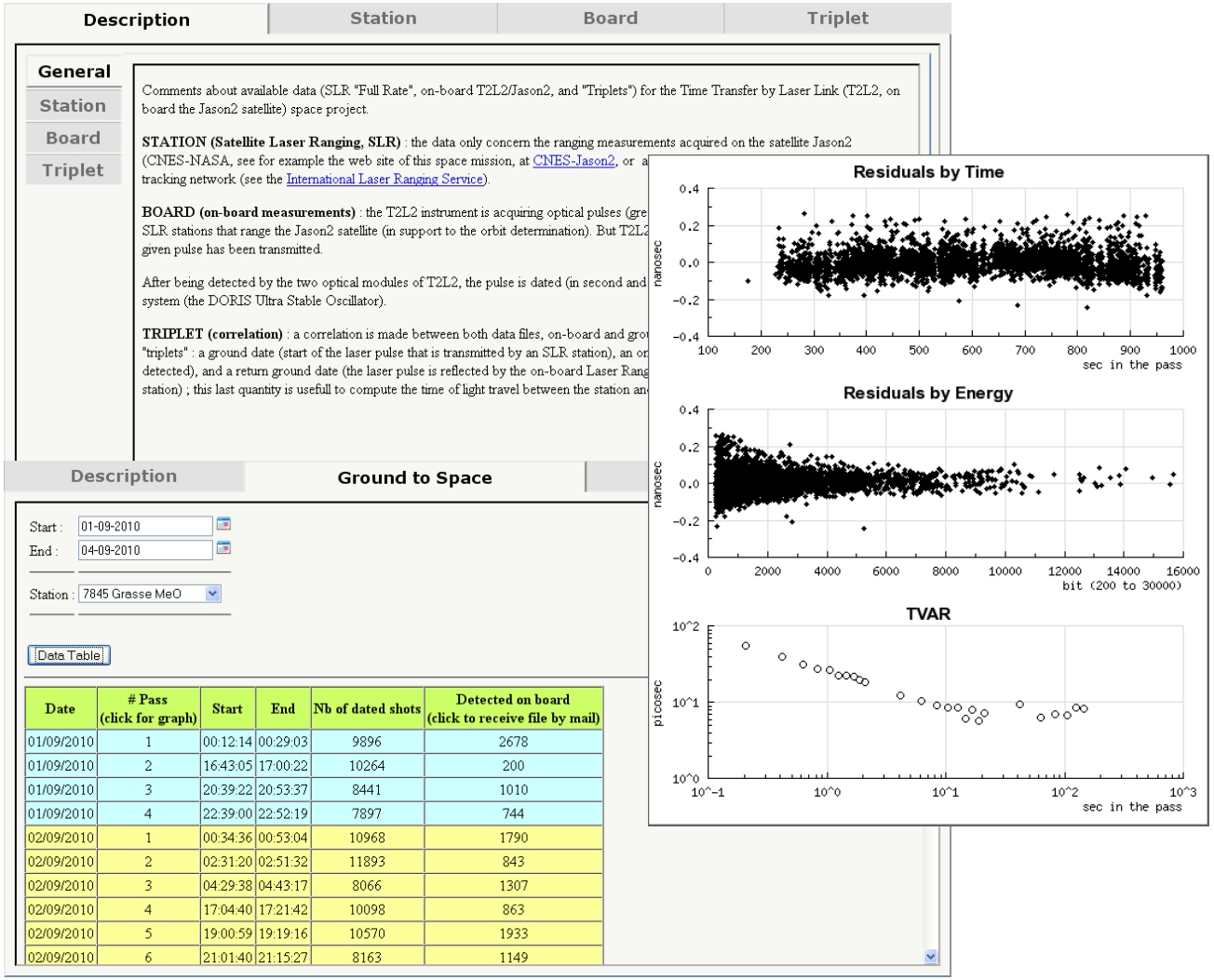
- Mise en évidence des Widelane Jump
- T2L2 – GPS résiduals : 0.3 ns rms

Conclusion

- La Télémétrie laser est une technique pérenne qui a été mise en œuvre depuis bientôt 50 ans
- Perspectives dans le domaine des mesures de distance à l'échelle du système solaire
- Des nouveaux projets dans le domaine du transfert de temps
- Instrument T2L2 :
  - » En orbite depuis 30 mois
  - » Performance nominale
  - » Phase d'exploitation étendue jusqu'à fin 2012

Web

http://www.oca.eu/heberges/t2l2/home.htm



Date	# Pass (click for graph)	Start	End	Nb of dated shots	Detected on board (click to receive file by mail)
01/09/2010	1	00:12:14	00:29:03	9896	2678
01/09/2010	2	16:43:05	17:00:22	10264	200
01/09/2010	3	20:39:22	20:53:37	8441	1010
01/09/2010	4	22:39:00	22:52:19	7897	744
02/09/2010	1	00:34:36	00:53:04	10968	1790
02/09/2010	2	02:31:20	02:51:32	11893	843
02/09/2010	3	04:29:38	04:43:17	8066	1307
02/09/2010	4	17:04:40	17:21:42	10098	863
02/09/2010	5	19:00:59	19:19:16	10570	1933
02/09/2010	6	21:01:40	21:15:27	8163	1149