T2L2/Jason2: first results of ground to ground TTcampaigns in common view

CMS T2L2, OCA-GRGS & CNES
Exertier, P., Minazzoli O., et al.

summary

• T2L2, instrument and principle
• Ground Segment (ILRS network of SLR stations)
• Exploitation:
  – goals
  – CMI (CNES, Toulouse) & CMS (OCA, Grasse)
• Data
• Results
  – « triplets » extraction from on board data files
  – performances & noises
  – time transfers
• Conclusion, current and future campaigns
Jason2 mission
(launched June, 20 2008)

- Ocean altimetry -> mean sea level and ocean topography at the cm level; on-board instruments:
  - Radar altimeter Poseïdon 3
  - Measurement of water vapor along the radar
  - Positioning & orbitography
    - Doris (plus Ultra Stable Oscillator)
    - GPS
    - Laser (LRA)
- Orbit
  - Altitude 1336 km, $i = 66^\circ$, $P = 6800$ s
- Satellite pass over ground SLR station
  - Distance max in common view: 6500 km
  - Interval between 2 passes: $2h < T < 14h$
  - 3 - 6 passes /day
T2L2, principle

retro-reflectors: LRA

clock: Doris USO

detector
T2L2, space segment

- **T2L2**
  - electronic for Datation & Gestion
  - optics: Linear Detection (energy) AND Non-Linear detection (date)

- Equipments available on Jason2:
  - LRA: Rétro reflector
  - USO (from DORIS): Clock
Ground Segment

- 47 SLR systems
- 34 fired on Jason1 & 2
- 24 are regularly firing on Jason2
- -> 22 are currently involved in the T2L2 experiment
Principle of TT

$t^T_{\text{sta}}, dt^{TR}, t^R_{\text{sat}}$ : measured quantities = « triplet »

(dt$^T$ is then computed from $dt^{TR}$)

\[ X_A = \frac{t_S + t_R}{2} - t_B + t_{\text{Relativity}} + t_{\text{Atmosphere}} + t_{\text{Instrument}} \]
Goals

• Validation of optical Time Transfer (TT)
  ▪ validation of the experiment itself
  ▪ estimation of the time stability and exactness
  ▪ demonstrate the feasibility of the « one-way ranging » technique (as with TIPO)

• Scientific applications
  ▪ metrology in the time&frequency domain
    ◦ synchronisation of remote clocks (which performances reach the best current cold atom time systems)
    ◦ inter comparisons of T-Freq links as the existing Two Way & GPS techniques
  ▪ characterisation of the on-board DORIS Ultra Stable Oscillator
  ▪ fundamental physics
Expected stability & noises

- Validation of the optical link:
  - $\sigma_x^2(t) = (28 \cdot 10^{-12} \cdot t^{-1/2})^2 + (17 \cdot 10^{-15} \cdot t^{3/2})^2 \quad t_0 = 0.1 \text{ s}$
  - $\sigma_y(t) = 0.4 \cdot 10^{-13} t^{-1/2}$ for $\tau > 10000 \text{ s}$
  - Incertitude < 100 ps
DATA

Measured arrival energy
Laser pulses

albedo

## SLR (laser) stations

<table>
<thead>
<tr>
<th>STATION</th>
<th>CNTRY</th>
<th>CONTACT</th>
<th>LASER</th>
<th>TIMER</th>
<th>CLOCKS</th>
<th>GPS TIME</th>
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<tbody>
<tr>
<td>MLRS</td>
<td>USA</td>
<td>Jerry Wiant</td>
<td>200ps</td>
<td>UTT</td>
<td>Quartz</td>
<td>TAC</td>
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<td>HERSTMONCEUX</td>
<td>UK</td>
<td>Graham Appleby</td>
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<td>Thales</td>
<td>GPS + Maser</td>
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<td>ZIMMERVALD</td>
<td>Suisse</td>
<td>Werner Gurtner</td>
<td>100 Hz 30ps</td>
<td>Riga</td>
<td>Quartz</td>
<td>True Time</td>
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<td>GRAZ</td>
<td>Autriche</td>
<td>Georg Kirchner</td>
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<td>Quartz</td>
<td>HP</td>
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<td>MATERA</td>
<td>Italie</td>
<td>Giuseppe Bianco</td>
<td>40ps</td>
<td>Honeywell T.</td>
<td>Cesium + Maser</td>
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<td>LVIV</td>
<td>Ukraine</td>
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<td>150ps</td>
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<td>Borowiec</td>
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<td>URUMQI (mobile)</td>
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<td>Guo Tangyong</td>
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<td>Rub. + Cesium</td>
<td>CNS</td>
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<td>Chris Moore</td>
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<td>EOS</td>
<td>Quartz + Cesium</td>
<td>True Time</td>
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<td>ROA</td>
<td>Espagne</td>
<td>Jorge Garate</td>
<td>100 ps 5 Hz</td>
<td>Rubidium</td>
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<td>Alemagne</td>
<td>Ulrich Schreiber</td>
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<td>Thales</td>
<td>Maser + Cesium</td>
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<td>France</td>
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<td>Cesium + Maser</td>
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<td>Riga</td>
<td>Rubidium</td>
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</table>
Involved Stations & detected laser pulses

T2L2/Jason-2: available SLR data
(up: nb of stations, down: nb of data)

Nb stations /day

Nb on-board data /day

Laser telemetry / computed orbit

JASON-2 SLR residuals (Full Rate for T2L2)

MOE orbit (Oct., 1 to April, 15 2009)
Estimation of the time of flight & corrections

• Time of flight: measured by SLR stations, but:
  – Sagnac (rot. Terre), 1ps /dist. ±300m
  – noises: laser (pulse width), detection (diode), chronometry, LRA (optical corr.)
  – geometrical corr. LRA <-> T2L2\textsubscript{BONL} & T2L2\textsubscript{BOLI}

• Computed time of flight (if necessary) with:
  – « MOE » orbit, tropospheric corr. (meteo param. measured at ground), relativistic corr.
  – angles for on-board instrument model (incidence, aand azimut in the \( \text{XYZ}_{\text{SAT}} \) reference frame
Extraction of triplets from both data sets (board and ground)

Number of data sets detected on board
Up: 7090, Yar - down: 7840, Hx & 7810, Zim

% : nbre of pulses detected by T2L2 /nbre od SLR data emitted from the ground
ground to space TT

T2L2, time transfer (from June to Sept.)
(rms of date comparisons: board-ground)
# classes of TT performances

GPS:

- PPS on-board (/1 sec): 0.15 µsec & Δf/f = 3.10^{-11}  
  1µsec : *a priori*

SLR stations (and clocks):

- « classe » 100ns:
  Arequipa, Tahiti, Yaragadee, Hartebeeshoek, Greenbelt, McDonald, MtPeak, Wettzell-1  
  50 ns

- « classe » 1-2ps:
  Grasse (MeO & FTLRS), Herstmonceux, Matera, Wettzell-2, Chagchun-2, Koganei  
  < 350ps

- « classe » intermédiaire:
  Changchun-1, FTLRS(Ajaccio), Zimmerwald, Mt Stromlø  
  < ± 1-5 ns
7845 - Grasse (Cesium)

TT ground-board, T2L2/Jason2 Oct. 3, 2008

7845 (1 pass, true measures and synthetic (green))
8834 - Wettzell (Maser-H)

Time stability, measured by T2L2 on one pass of the SLR station of Wettzell, Germany (H-Maser), compared to the on-board DORIS USO (quartz) : 40 ps @ 1 s and 7 ps @ 30 s.

For integrated times >30 s : limit due to DORIS with : 5 ps @ 30 s and 10 ps @ 100 s.

![Graph](image-url)
Conclusion

• 1 year of data processed (ground and board)
• improvements of: filtering, corrections, and stabilisation of the data processes (level 1: a priori dates by GPS)
• extraction of triplets (level 2): require 1 μsec a priori (=> local model of the USO / few days)
• few SLR passes with the required performances, but more and more since April 2009:
  – 4 stations in EUROPE: 7ps @ 30 s
  – Koganei (Japan), and Borowiec (Poland): in October for compar. /Two-way & /GPS
  – October 2009: Obs. Paris (FTLRS) - OCA Grasse (MeO)
• Energy & fine instrumental model (hardware): to be developed
• Physics: to be tested