CNES

Toulouse – France

P. Guillemot: System Engineer

S. Leon: Program

I. Petitbon: Project Manager

OCA –UMR Gemini

Grasse – FRANCE

E. Samain: Prime Investigator

D. Albanese: Optics

F. Baumont: Time

B. Chauvineau: Fond. Physics

P. Exertier: Data Analysis

O. Minazzoli: Fond. Physics

JL. Oneto: time

F. Para: Instrumentation

J. Paris: Software

F. Pierron: FTLRS

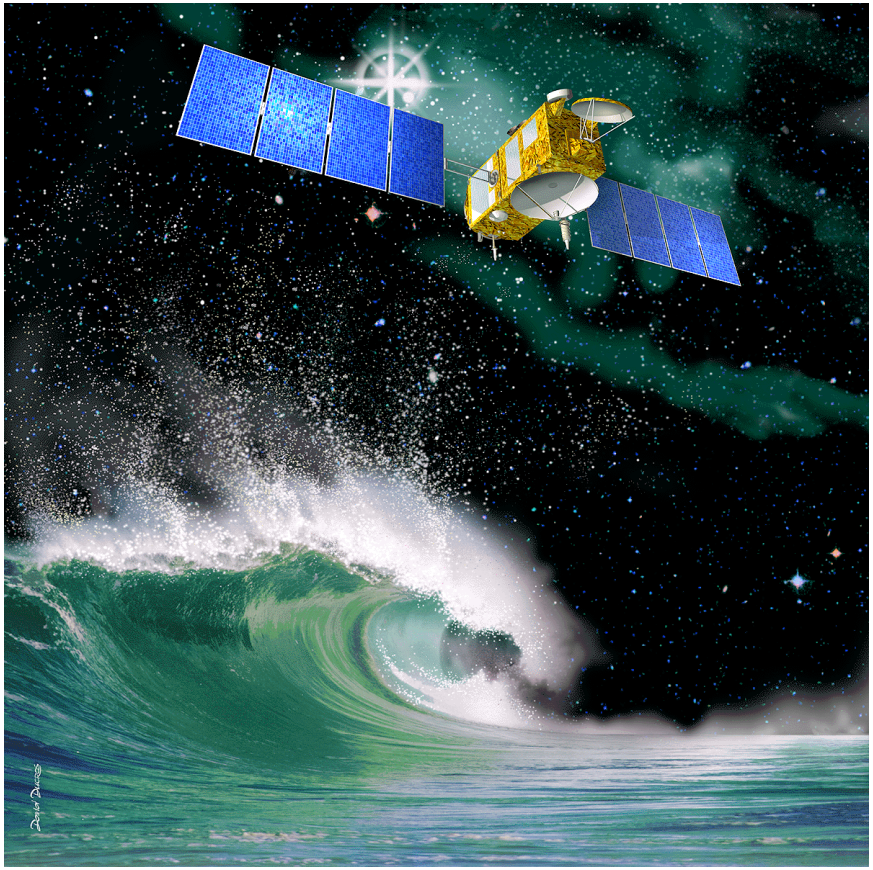
J.M. Torre: Laser sations ILRS

P. Vrancken: Test benches

T2L2 First Results

Space segment
T2L2 on Jason 2

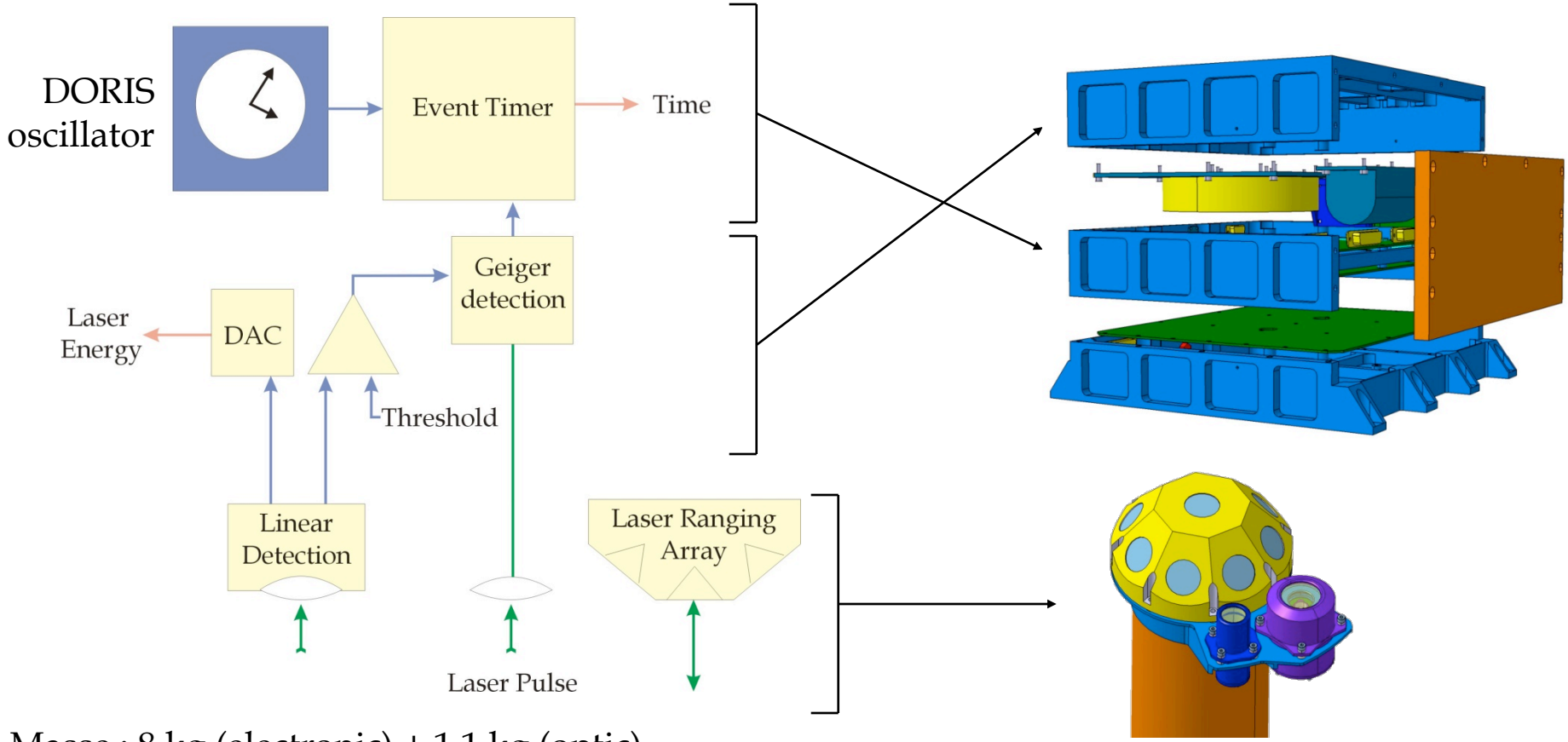
- Millemetric sea altimeter
- Native instruments
  - Altimeter : Poseïdon 3
  - Water vapor measurement
  - Orbitography: Doris, GPS, Laser
- Passenger instruments
  - Radiation: Carmen 2, LPT
  - Time Transfer by Laser Link: T2L2
- Orbit
  - Altitude 1336 km, i = 66°, P = 6800 s
  - Max distance in a common view mode : 6500 km
  - Single pass: ~1000s
  - Time interval between pass 2h < T < 14h
  - 3 to 6 passes per day



T2L2 Space instrument Development plan

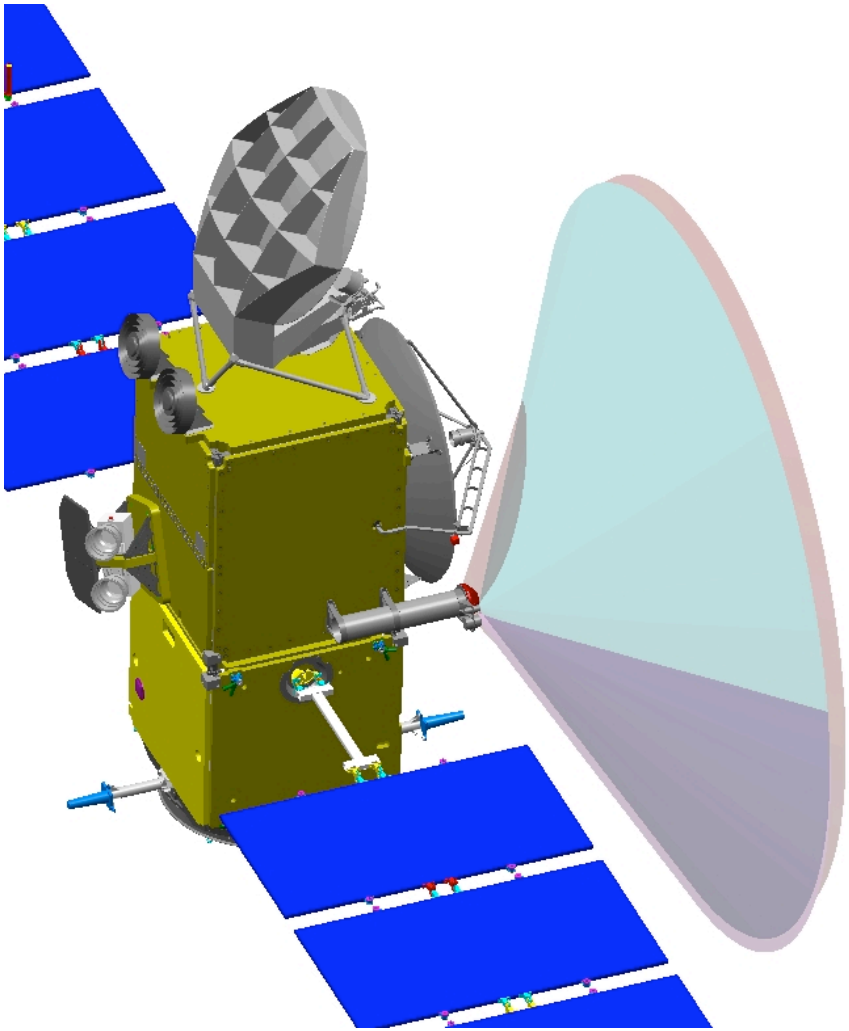
- B C D Phase: 09/2005 → 12/2006
- T2L2 integration on Jason 2: 05/2007
- Jason 2 launch: 06/08
- Exploitation: 06/2008 → 06/2010 → … 2013

T2L2 Space Instrument Synoptic

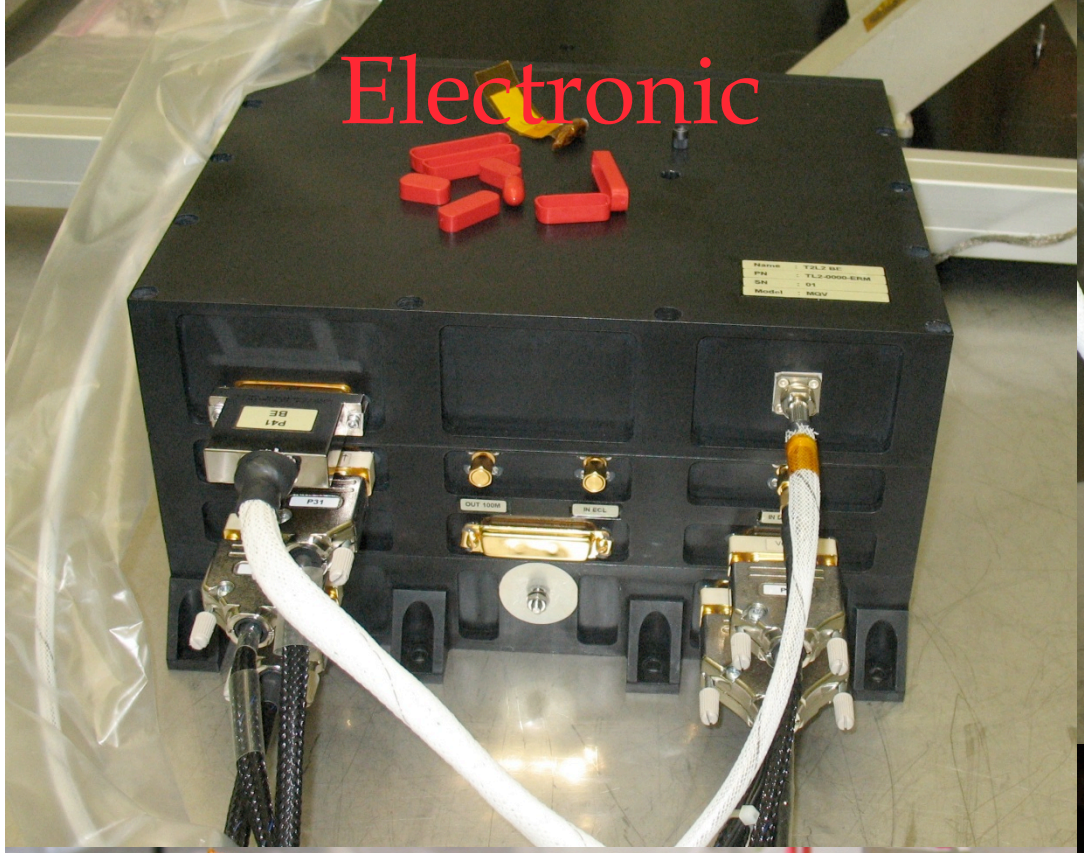


- Masse : 8 kg (electronic) + 1.1 kg (optic)
- Power Consumption: 42 W
- Volume : 270x280x250 mm^3 // Ø 30x95 // Ø62x100

T2L2
External payload



- From Space: +/- 55° for both T2L2 detection and LRA
- From ground: 5° in elevation (no atmosphere uncertainty)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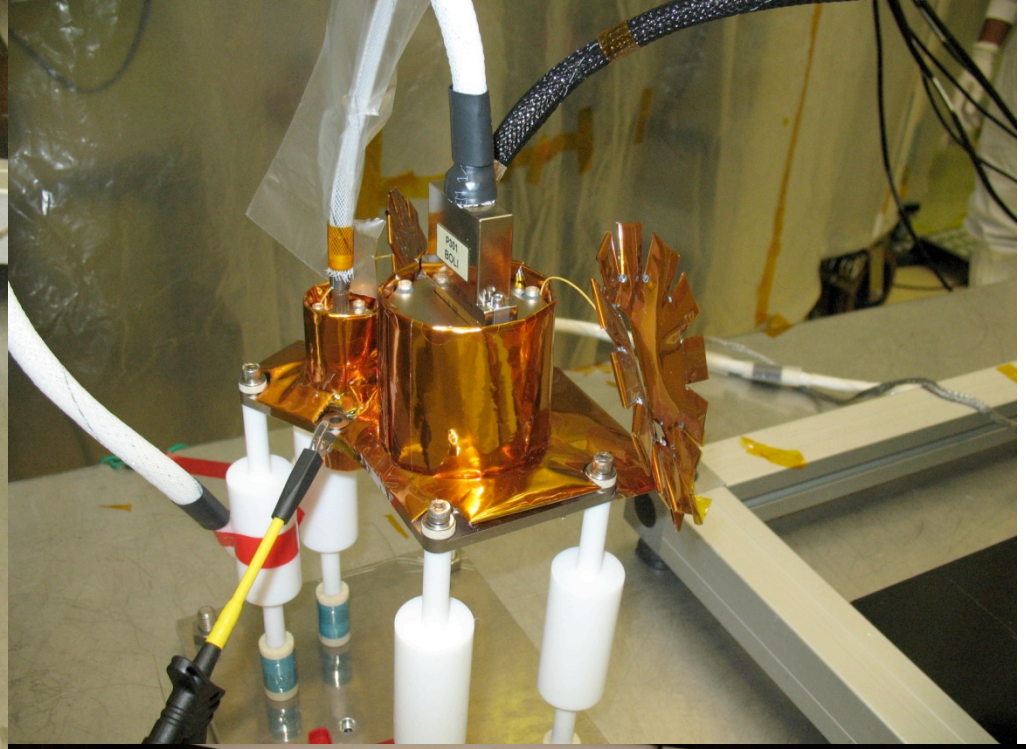
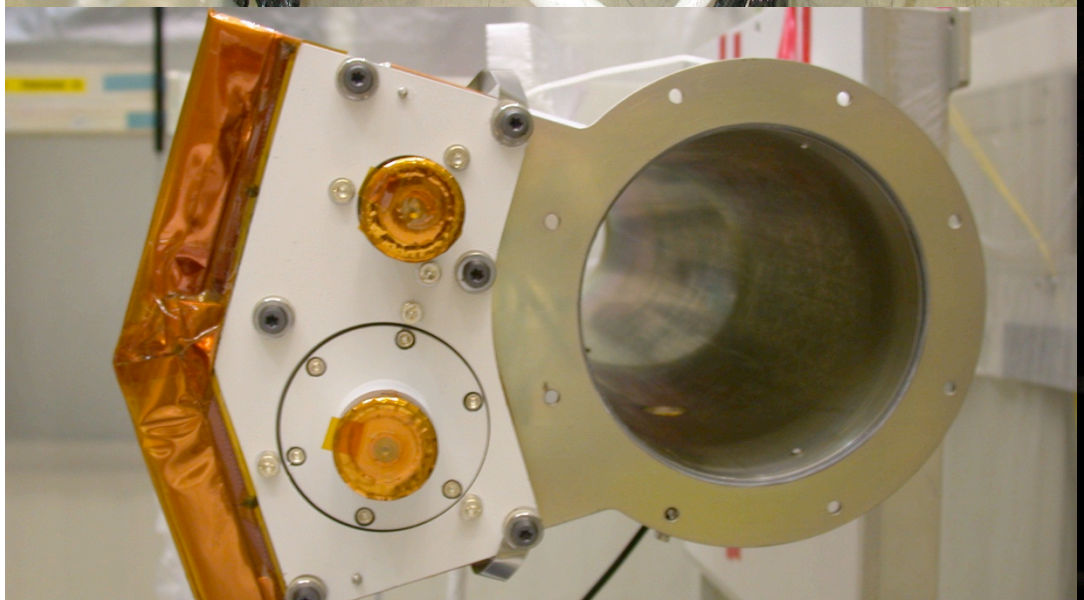
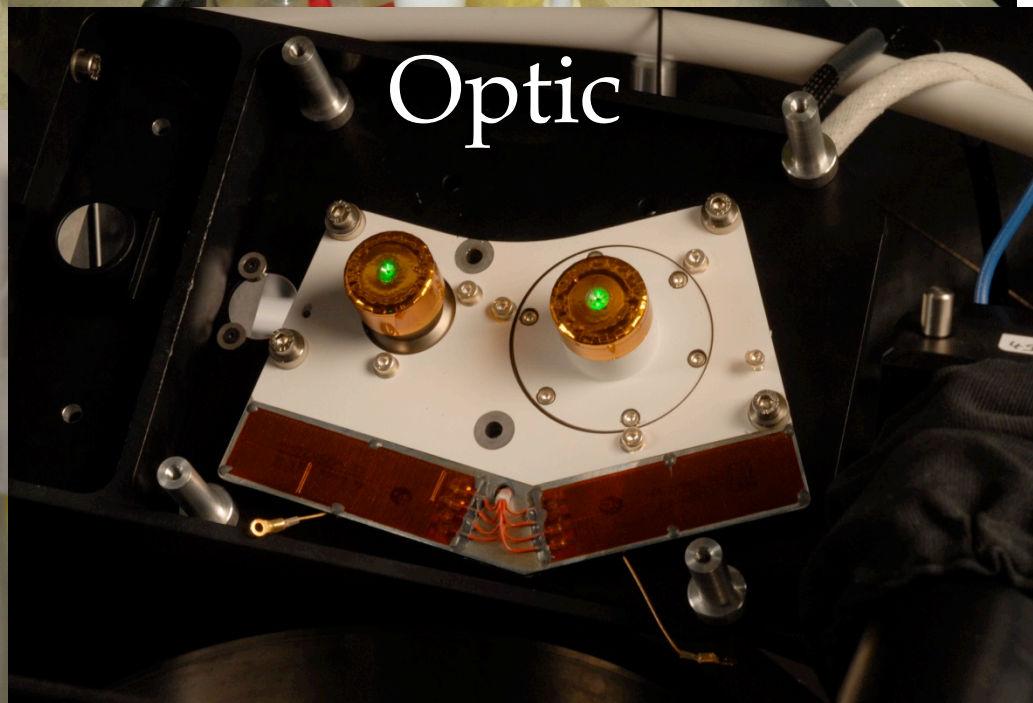
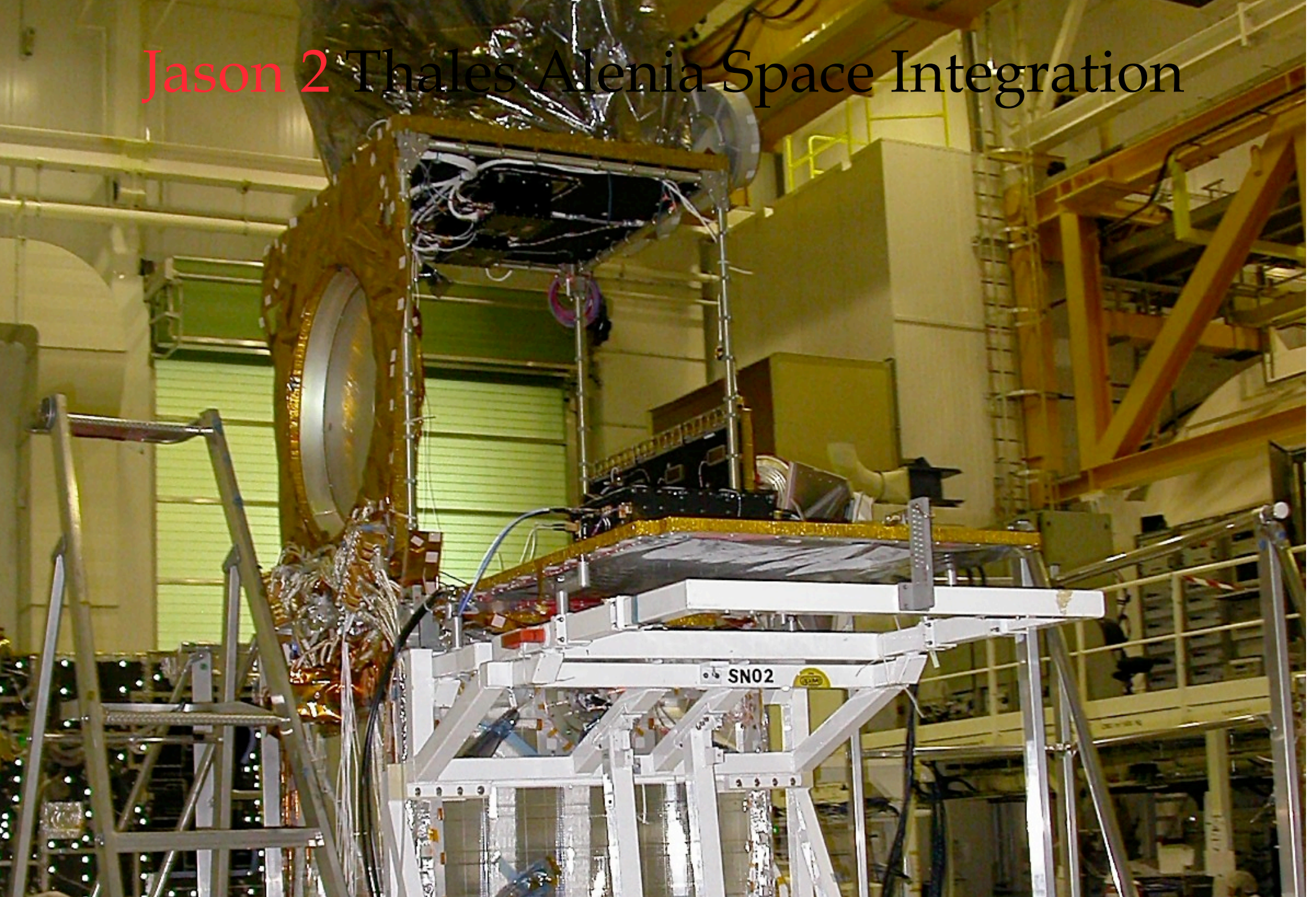
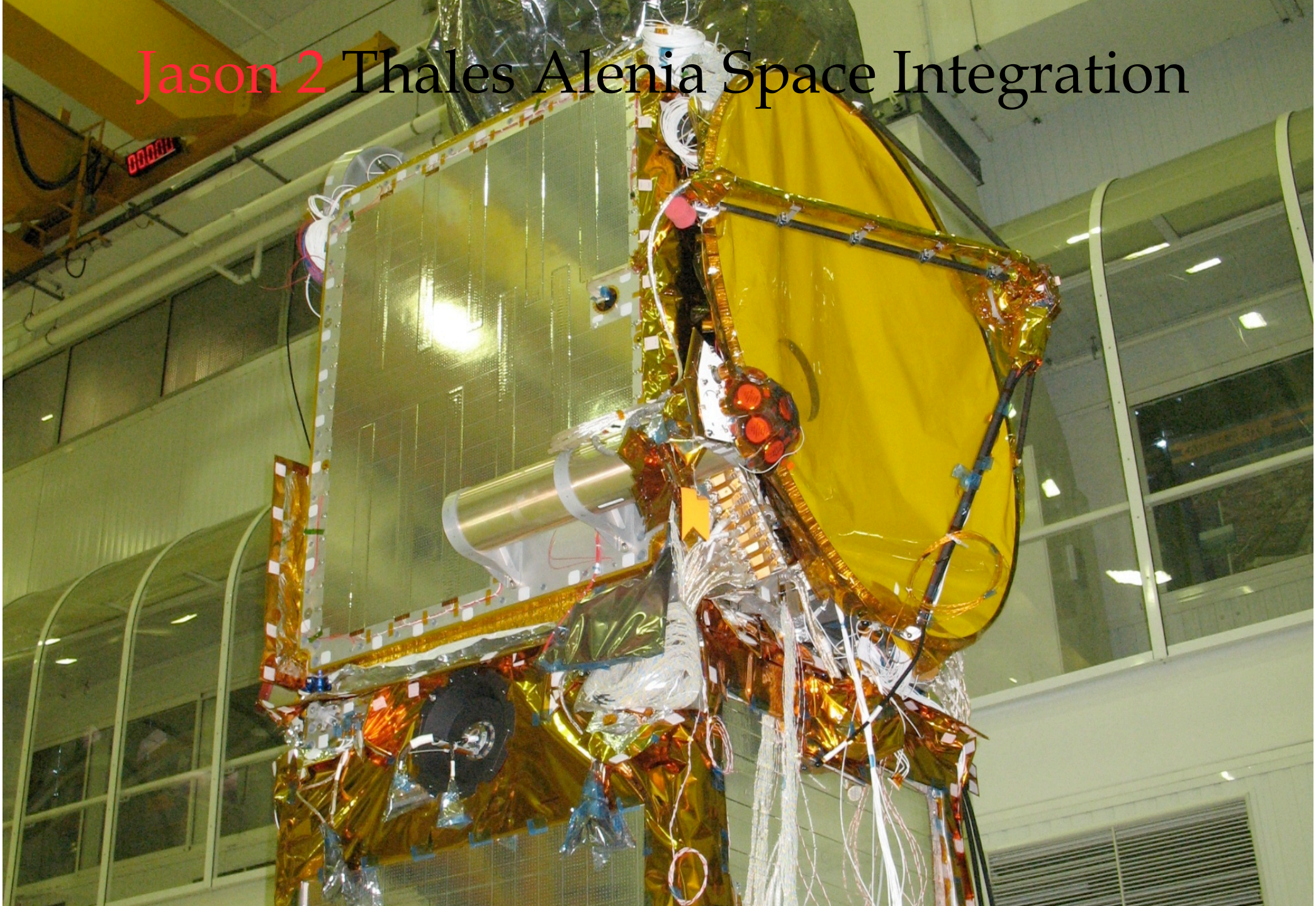


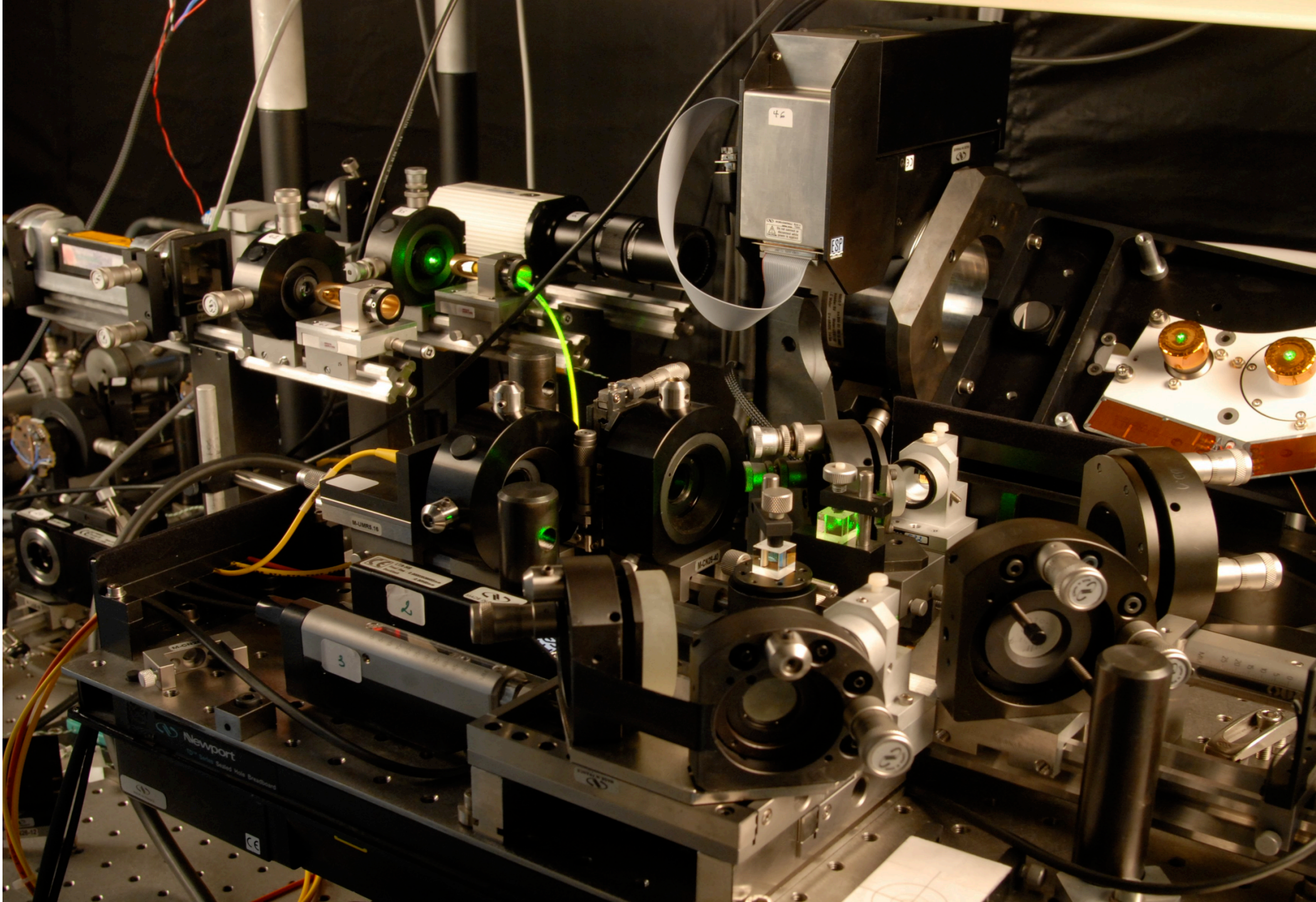


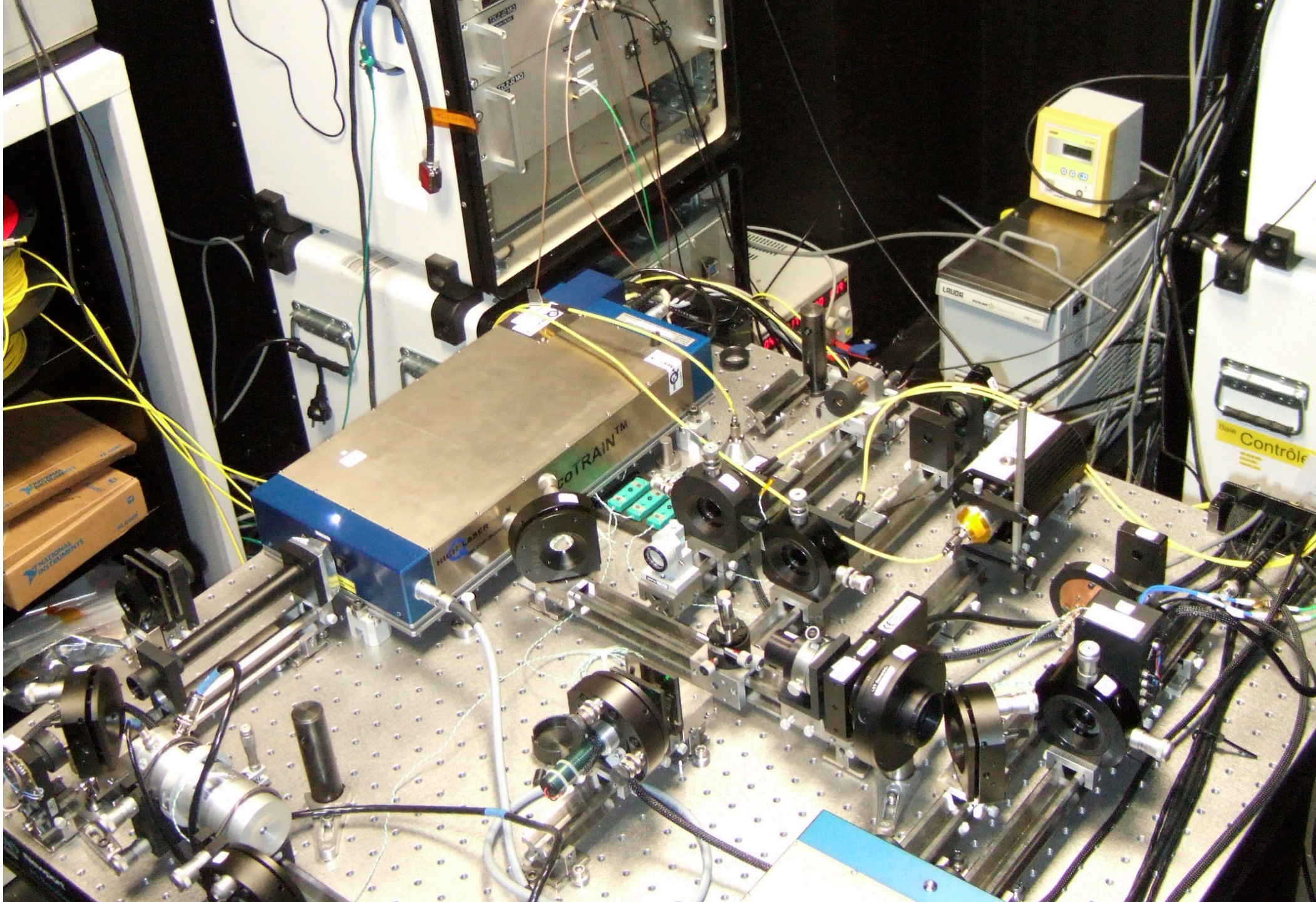

Optic

Jason 2 Thales Alenia Space Integration




Jason 2 Thales Alenia Space Integration


Newport

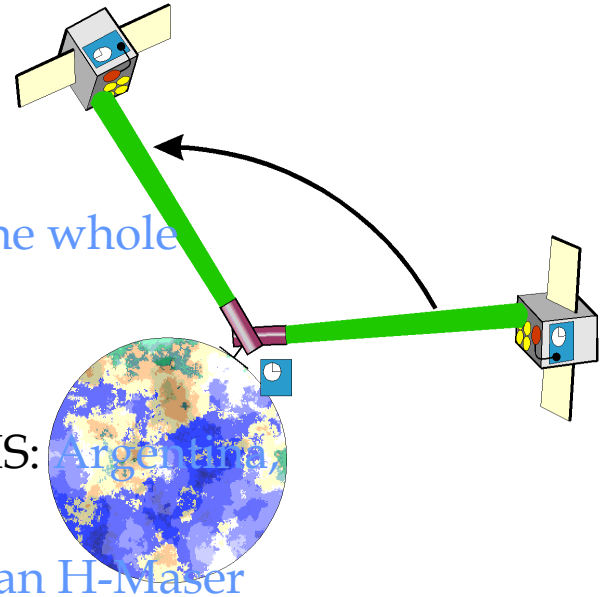

COTRAIN™
LAUDA

Laser Station Mission 1

- T2L2 Validation
  - » Colocation, Grasse, Maidanack, Postdam, Simeiz and Katzively
  - » Common view - Ultra stable Clocks: Matera, Herstmonceux, Poznan, Wentzell , Observatoire de Paris
  - » Non Common View: Europe, China, Australia, USA
- Microwave Link Comparison: TWSTFT-GPS
  - » France Caussols OCA
  - » Austria Gratz TUG (TBC)
  - » Spain San Fernando ROA
  - » Poland Poznan AOS
  - » Observatoire de Paris (FTLRS)
  - » PTB (TROS) (TBC)

Mission 2

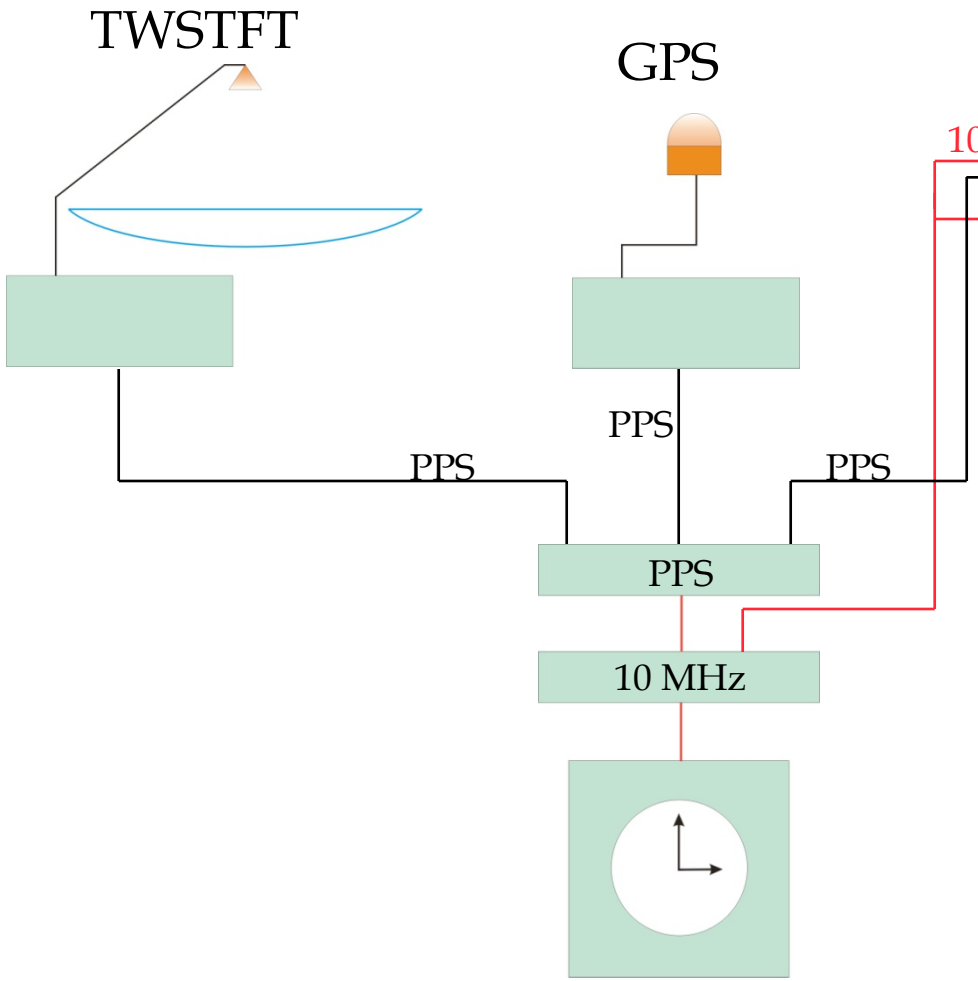
- Fundamental Physics
  - » Anisotropy of c: Matera, Hersmonceux, Grasse
  - » Interplanetary one way laser ranging demonstration: the whole network
- DORIS
  - » Characterization of the onboard quartz oscillator DORIS: Argentina, Guyanne
  - » One way laser ranging: Any laser station connected to an H-Maser
- Link Budget
  - » Any station having a good telescope and a well qualified laser beacon



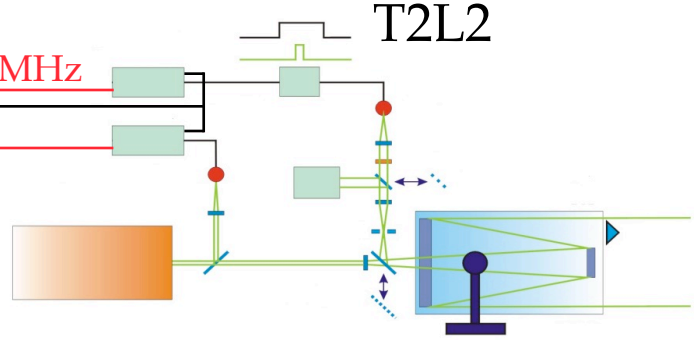
Laser sations Requirements

- Wavelength : 532.1 +/- .5 nm
- Event timer connected to the clock
- CRD Full Rate data : Upload to EDC
- No synchronization required
- Laser pulse Energy
  - Min: 1 mJ σ_θ = 10 µrad
  - Max: 1 J σ_θ = 5 µrad
- Pulse width 10 ps up to 500 ps (FWHM)
- Mono pulse or semi train
- Microwave link comparison: Time tag the start pulses with an accuracy of 100 ps (OCA calibration campaign)

Calibration : Start Epoch with an accuracy of 100 ps



Optical time tranfer
T2L2



- Delay between the optical pulse at the cross axe of the telescope and the electrical reference coming from the Time and frequency lab

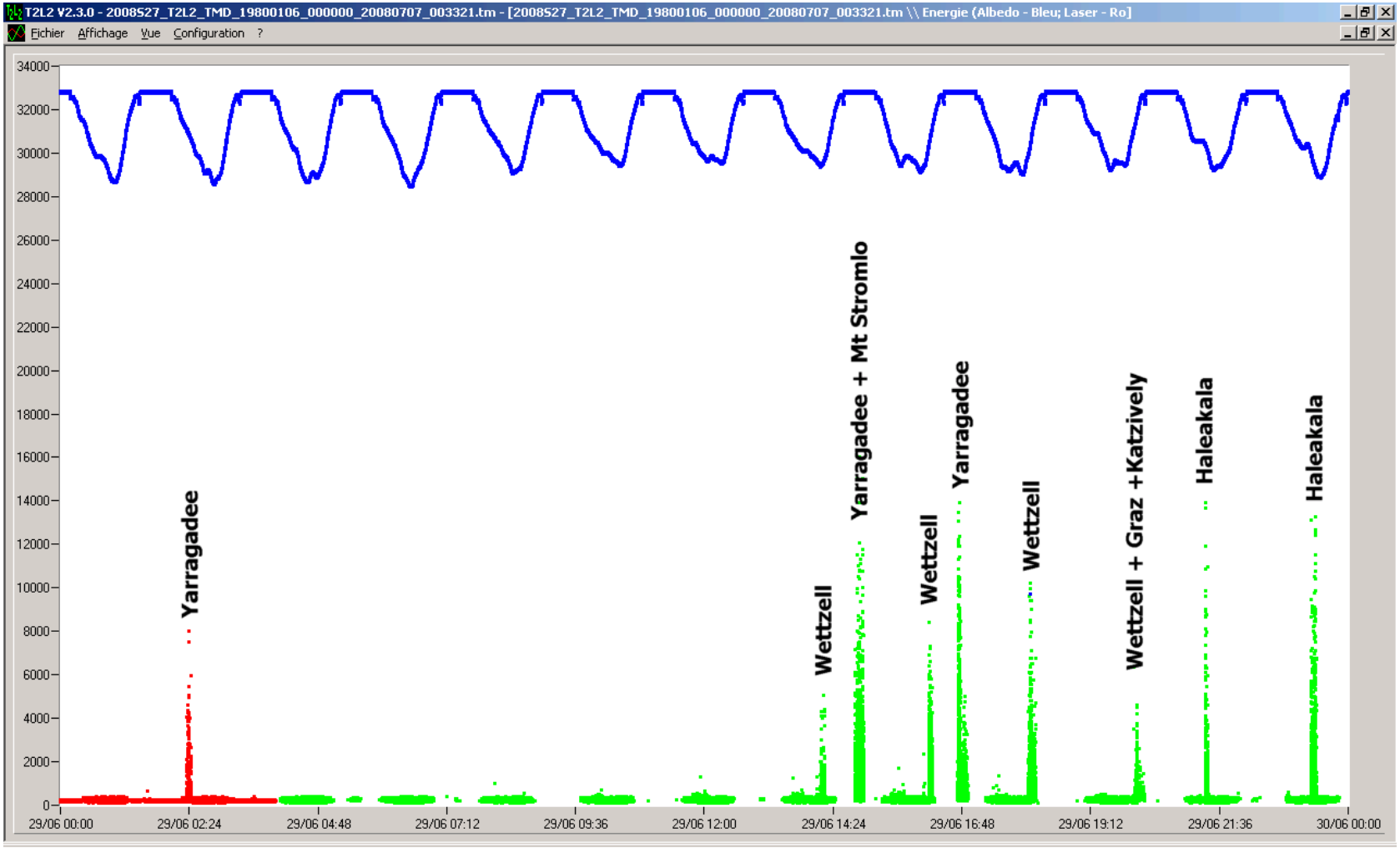
T2L2 Calibration station

- OCA Sub picosecond Event timer
  - Precision and linearity: 0.6 ps rms
  - Dead Time: 120 ns
  - Continuous repetition rate: 800 kHz
  - 3 channels, 3 inputs per channel
  - Onboard synthesizer 10 MHz to 100 MHz
- High speed photo detection (optical fiber)
  - Ultra high speed logic: 25 GHz
  - High speed photo diode (FWHM = 18 ps)
  - Computation of the absolute global delay with an uncertainty < 50 ps

Start

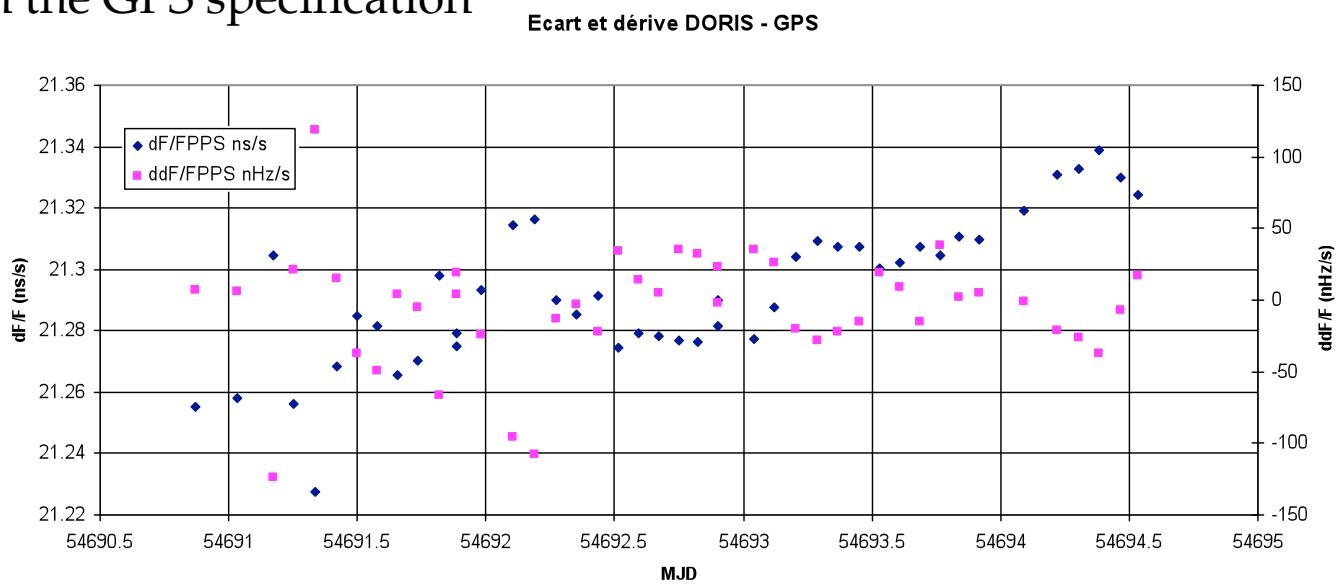
- Launch :
  - 20 june 2008
  - FromVandenBerg
- On
  - 5 days after the launch
- First echo recorded
  - 29 June 2008

First laser pulse detection



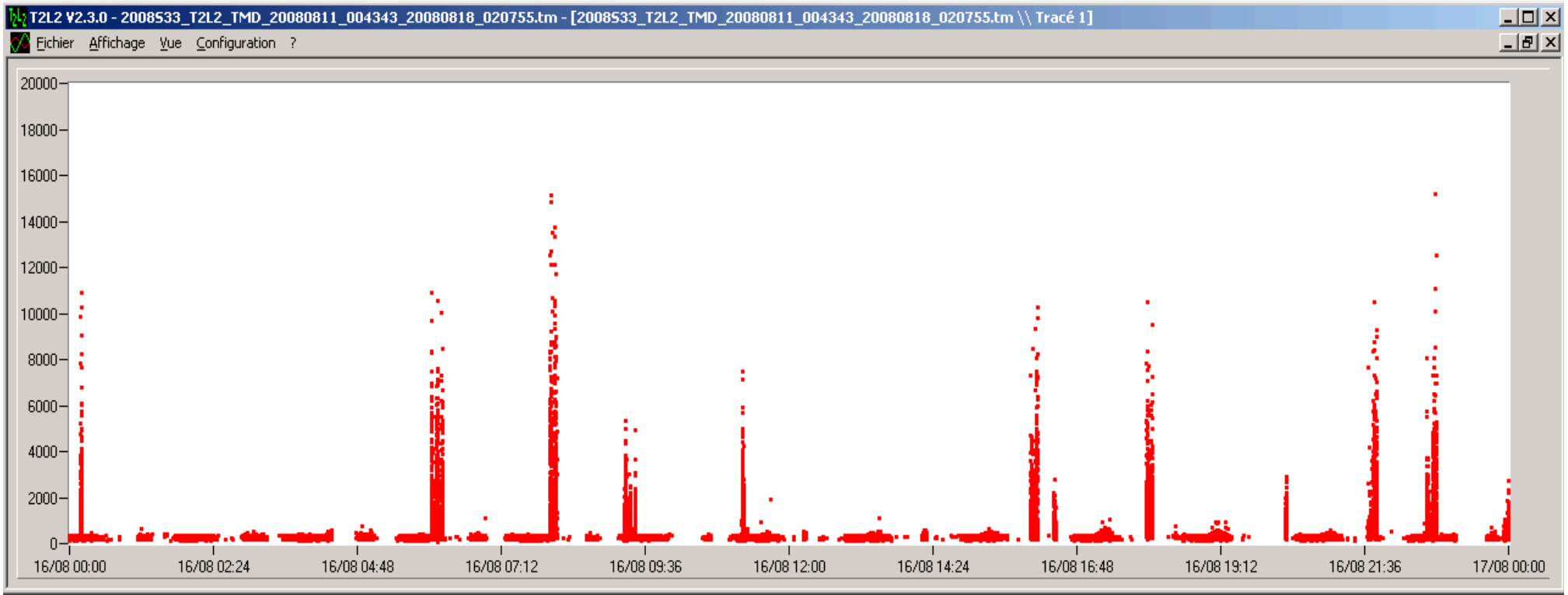
Event timer

- Onboard timing
  - ≈ σ = 1.5 ps rms
  - » In agreement with ground measurement
- Timing from Proteus PPS
  - ≈ σ = 0.3 µs rms
  - » Frequency shift DORIS 20 10-9
  - » In agreement with the GPS specification

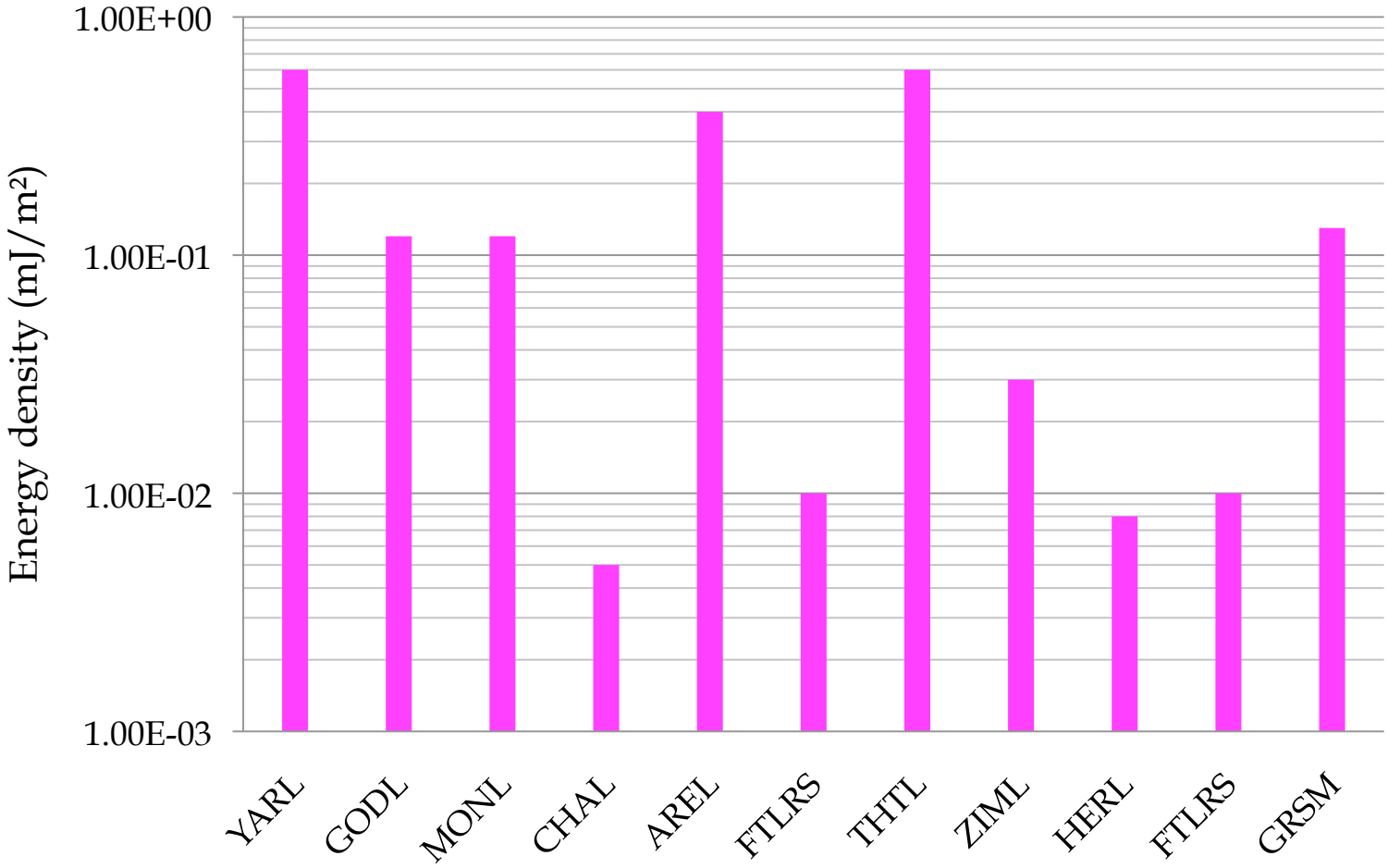


Energy measurement

- Up to now the energy measured is inside the dynamic of the instrument
- As compared to the maximum recorded (YARL) the margin is a factor 3

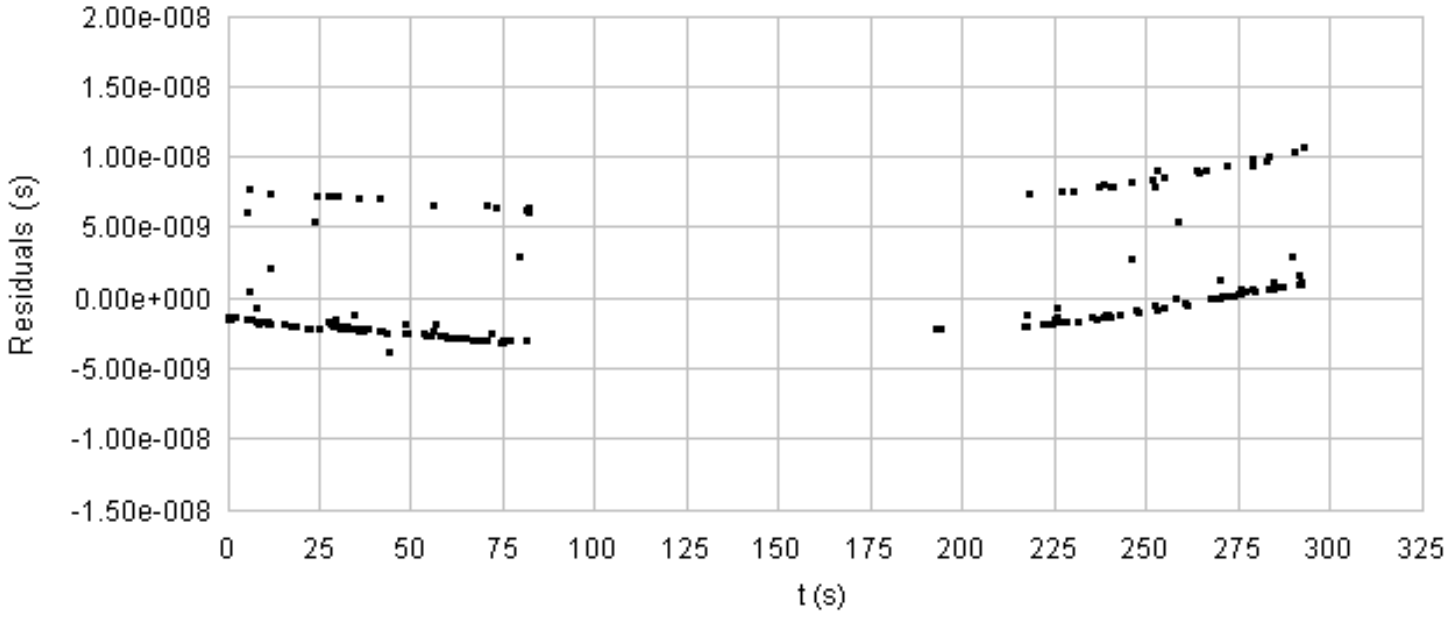


Maximum Energy in the satellite plane



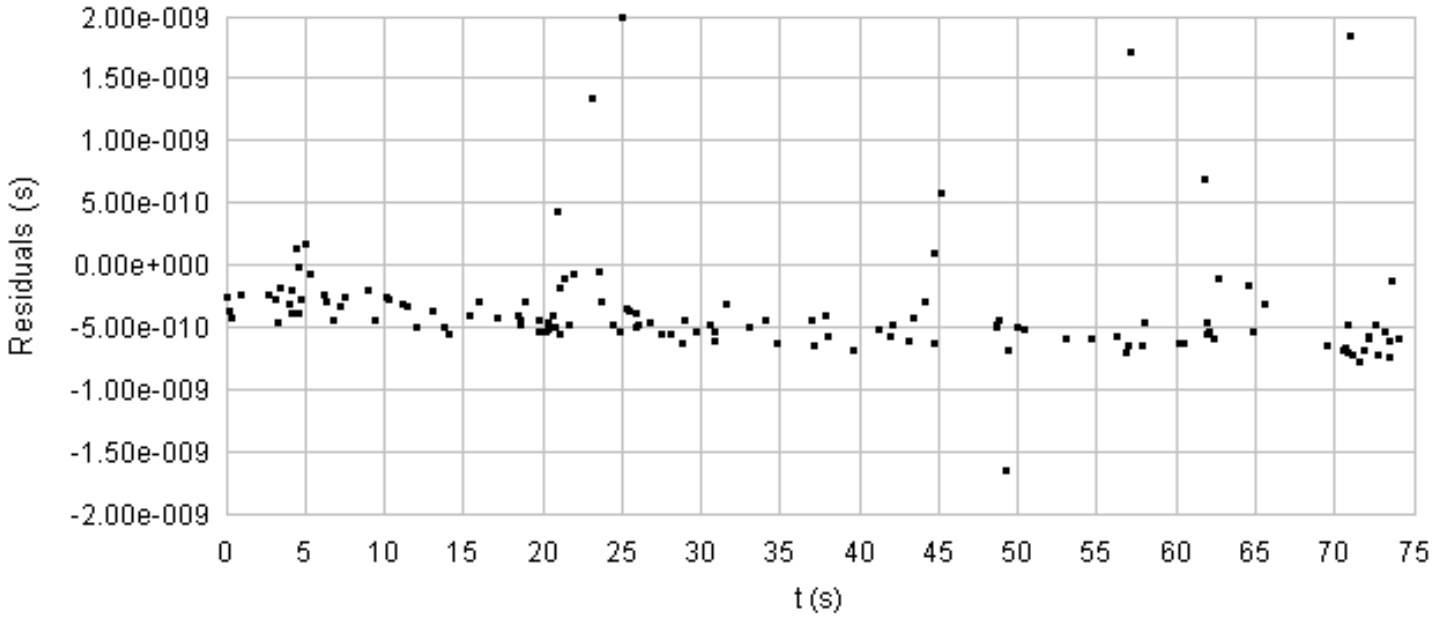
Time Transfert Ground-Space Herstmonceux

- Ground Station: Herstmonceux
- Ground Clock:
- No Sagnac correction
- Polynomial fit order 1(frequency shift between Doris – Cesium)



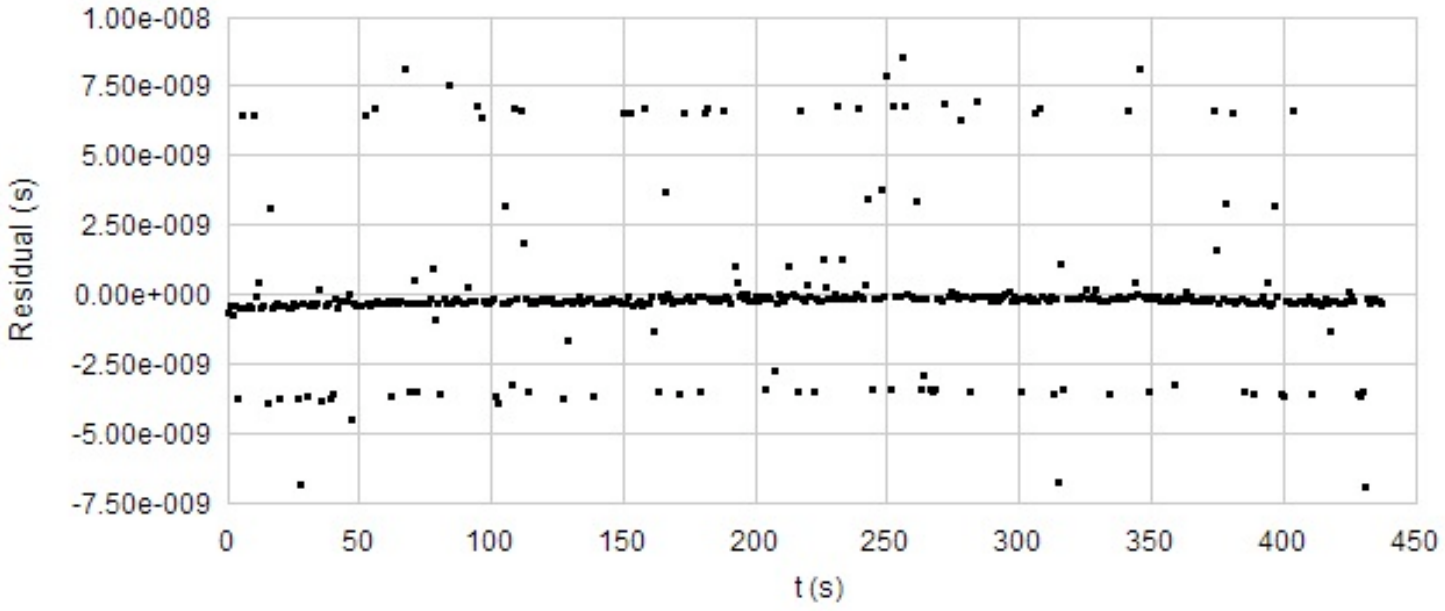
Time Transfert Ground-Space Changchun

- Ground Station: Changchun 7237
- Ground Clock: Quartz + GPS
- No Sagnac correction
- Polynomial fit order 1(frequency shift between Doris – Cesium)



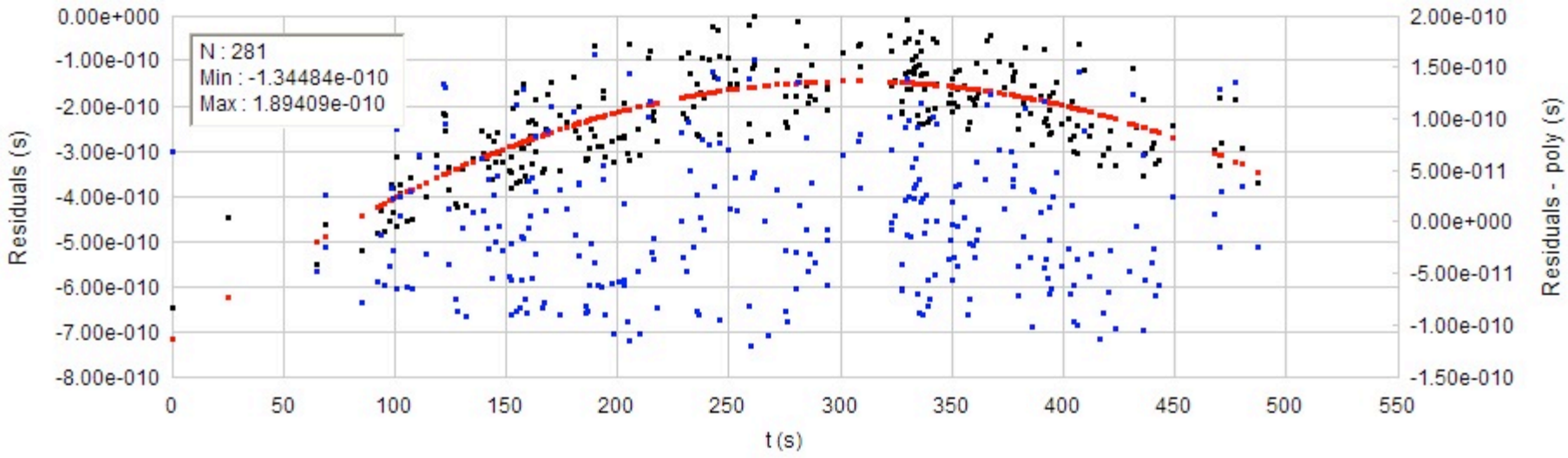
Time Transfert Ground-Space FTLRS

- Ground Station: FTLRS
- Ground Clock: HP5071A
- No Sagnac correction
- Polynomial fit order 1(frequency shift between Doris – Cesium)



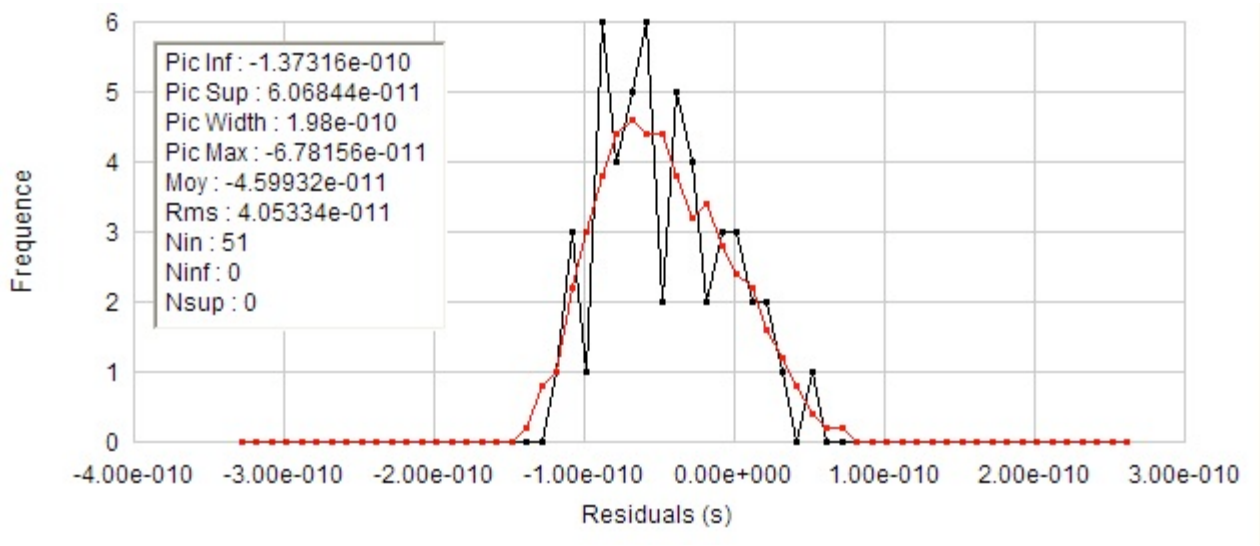
Time transfer
DORIS - FTLRS

- Polynomial fit (Sagnac)
- Filter on the distribution



Transfert de temps Sol – Espace FTLRS

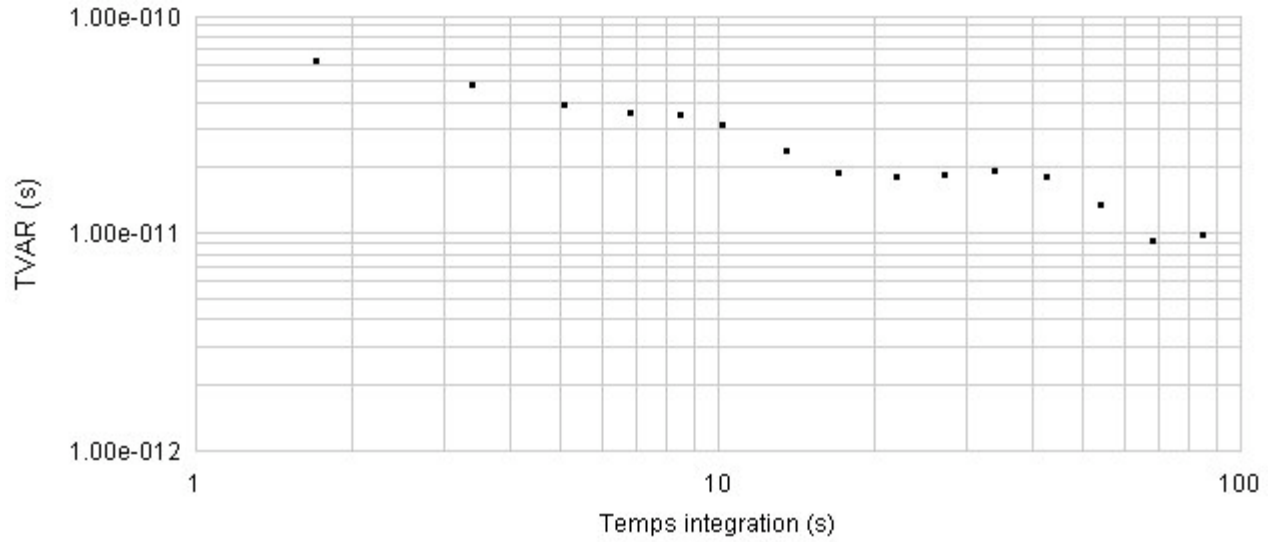
- Energy distribution on one octave (energy)



- σ = 40 ps rms

Transfert de temps Sol – Espace FTLRS

- Time variance



- τ_0 = 1.7 s
- - Order 2 polynomial
- σ_x @ 100 s = 10 ps

Summary - Conclusions

- Very short development plan: 18 month for the BCD phase
  - » In accordance with specifications
- **Jason 2 launch: June 2008**
- Exploitation during at least 2 years up to 5 years
- Laser community
  - » Up to now 15 laser stations are ready to run
  - » Event timer upgrade
  - » FULL RATE DATA in the CRD format
  - » Calibration process for time scale comparison
- **We need a large implication of laser stations for the succes of that experiment**
- **Many thanks to every laser stations that have already made an effort for the project**

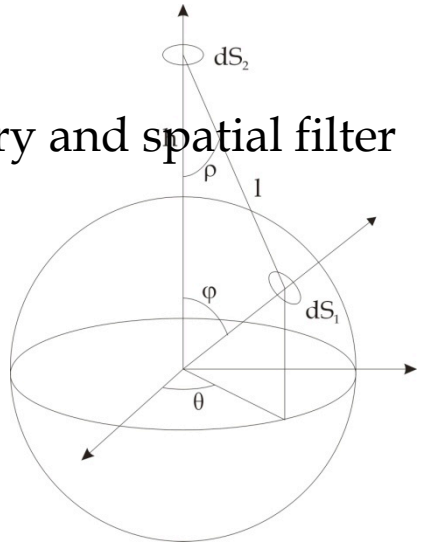
THANKS

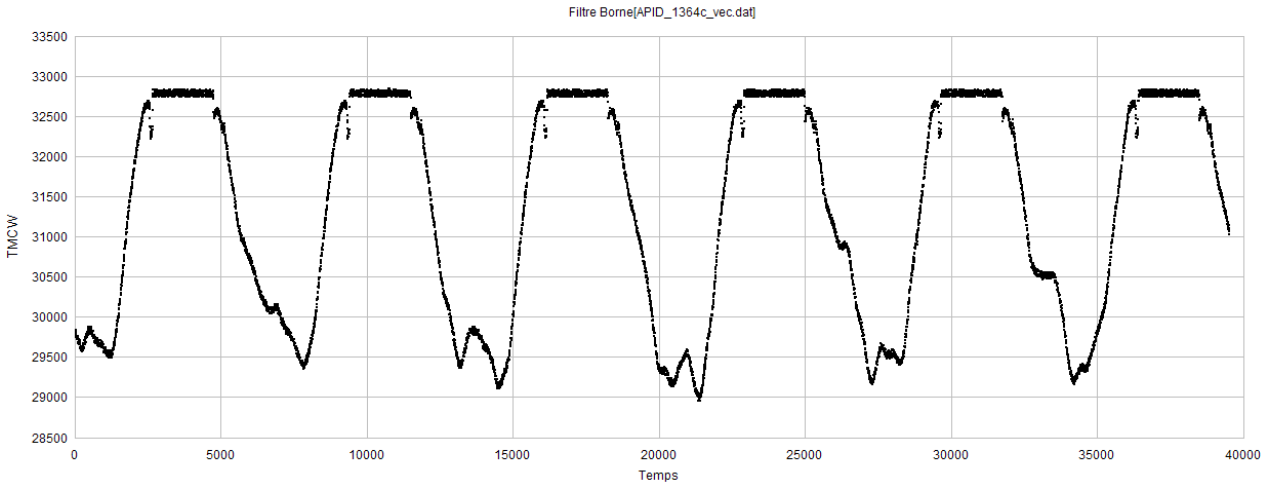
Solar flux

- Solar flux from the earth
  - ≈ $\Phi_T = I \,.\, Al \,.\, Ms \,.\, S_d$; M_S : Sun direct= 18.9 W/m², I : Geometry and spatial filter

$$I = 2\int_0^{\varphi_M}\left(\frac{\cos^2\rho\,.\sin^2\rho}{\tan\varphi} - \sin^3\rho\,.\cos\rho\right)T(\rho)\,.d\varphi$$

  - » T(ρ) = Radial filter profile
  - » Al : Earth Albedo

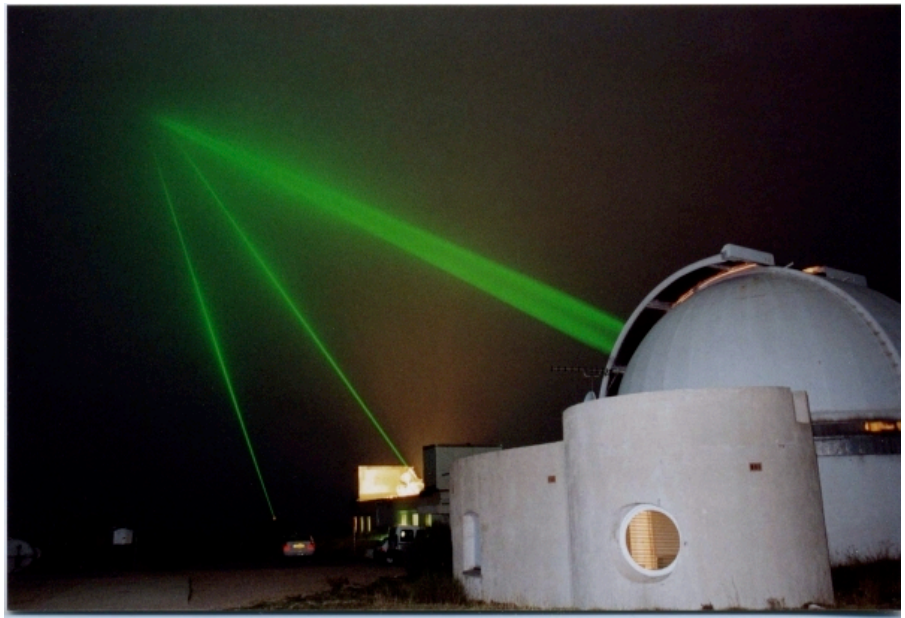




$$Al = \frac{k_{ML} TM_{CW} T_0}{M_S I} = 0.21$$

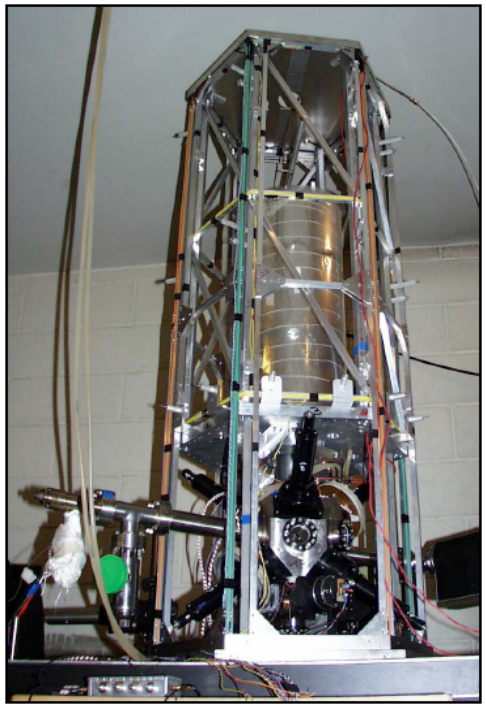
T2L2 Validation
Colocation

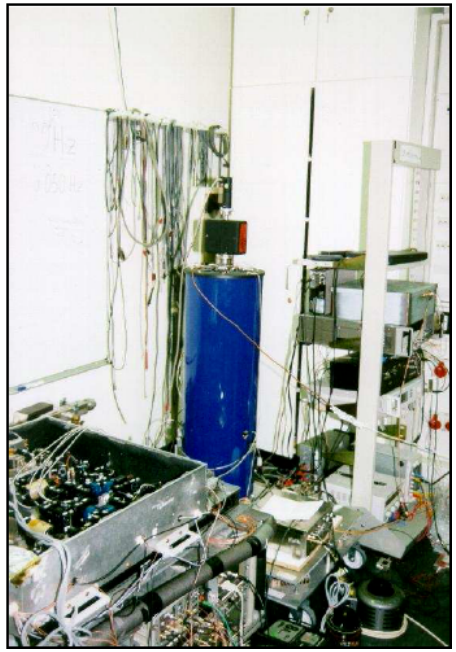
- Time Transfer between stations located at the same place
- The link will use an unique clock at ground
  - » The noise of both the space clock and the ground clock will disapeared
  - » Systematical effects : the same geometry, the same atmosphere
- Observation Campaign
  - » France: OCA MeO and FTLRS
  - » Russia: Maidanack 1 & 2
  - » Germany : Potsdam 1 & 3
  - » Ukraine: Simeiz and Katzively



T2L2 Validation
Common view – Ultra stable Clocks

- Time transfer in common view between ultra stable distant clocks
  - » Hydrogen Masers
  - » Atomic fountain
  - » Cesiums
  - » Optical clocks



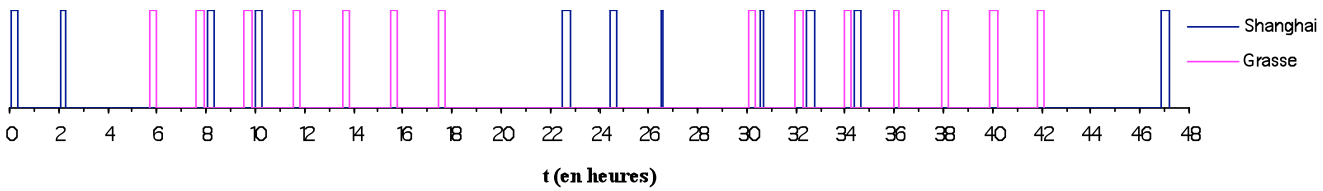


T2L2 Validation
Common view - Ultra stable Clocks

Country	Laser Station	Time & Freq	Clocks	link
France	Caussols OCA	OCA	FOM OP	Direct
France	Paris OP (FTLRS)	OP	FO1 &FO2	Direct
Germany	Wentzell IFAG	IFAG	H-M ; Cs ; Rb	Direct
Poland	Poznan AOS	AOS	H Maser ; Cs	Direct TBD
Switzerland	Zimmer. AIUB	Berne METAS	FO ; H-M; Cs	Fiber TBD
Austria	Gratz	TUG	TBD	Direct Fib.
Italy	Matera MLRO	MLRO	H-M	Direct
England	Herstmonceux	NERC	H-M 2009	Direct
Spain	San Fernado ROA	ROA	H-M ; Cs	Direct

T2L2 Validation
Non common view: France – China

- Pass
  - » Over 10 days : 29 passes
  - » Time interval between pass : 606 s (5° elevation)

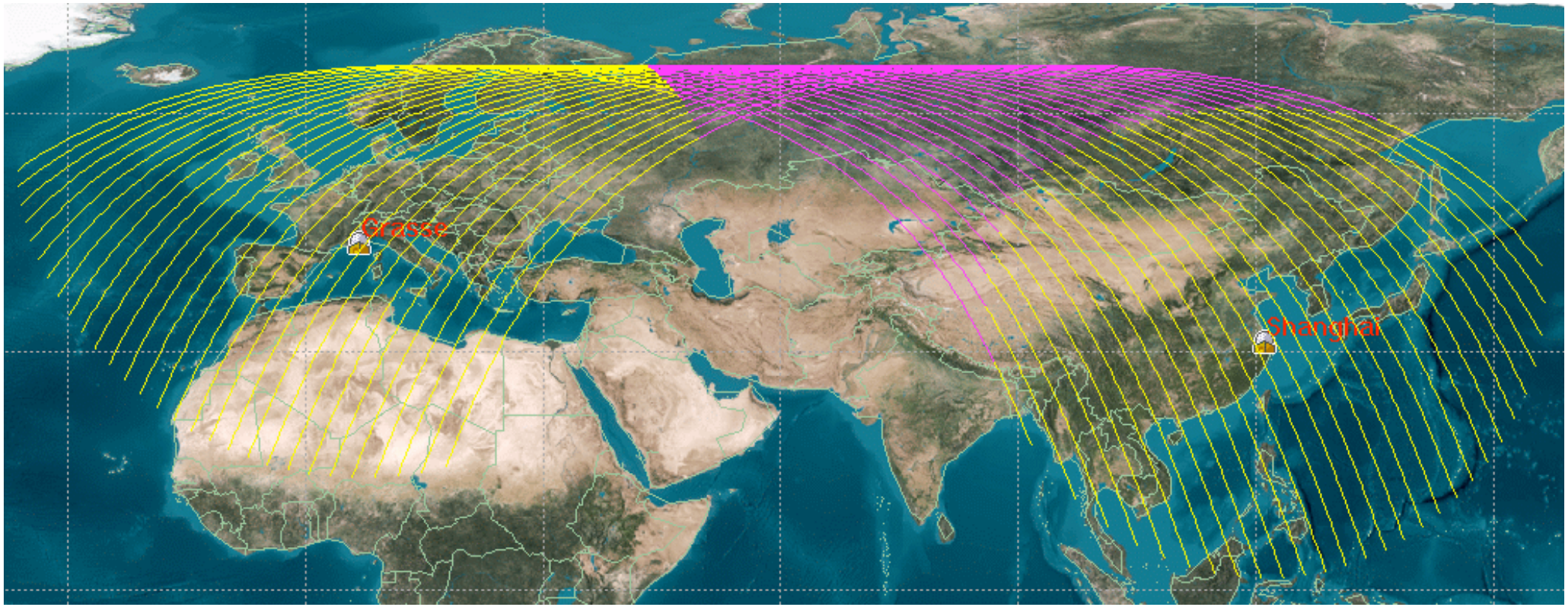


- Doris noise
  - ≈ $\sigma_x(600)$ = 300 ps

Passage	Durée (sec)		Intervalle (sec)
	Grasse	Shanghai	
1	1146	1041	563
2	1029	1101	540
3	1015	600	708
4	1140	1118	540
5	955	993	565
6	1101	847	622
7	1107	1146	531
8	881	779	621
9	1141	1003	574
10	1051	1122	535
11	824	218	823
12	973	483	754
13	1146	1098	546
14	980	1038	554
15	1078	778	645
16	1121	1142	533
17	905	867	597
18	1132	959	587
19	1072	1136	532
20	840	506	709
21	923	325	821
22	1148	1073	553
23	1005	1073	546
24	1050	697	673
25	1132	1133	536
26	930	936	578
27	1119	907	603
28	1091	1143	531
29	860	664	655
Moyenne	**1031 ±104**	**894 ±263**	**606 ±86**
Max.	**1148**	**1146**	**823**
Min.	**824**	**218**	**531**

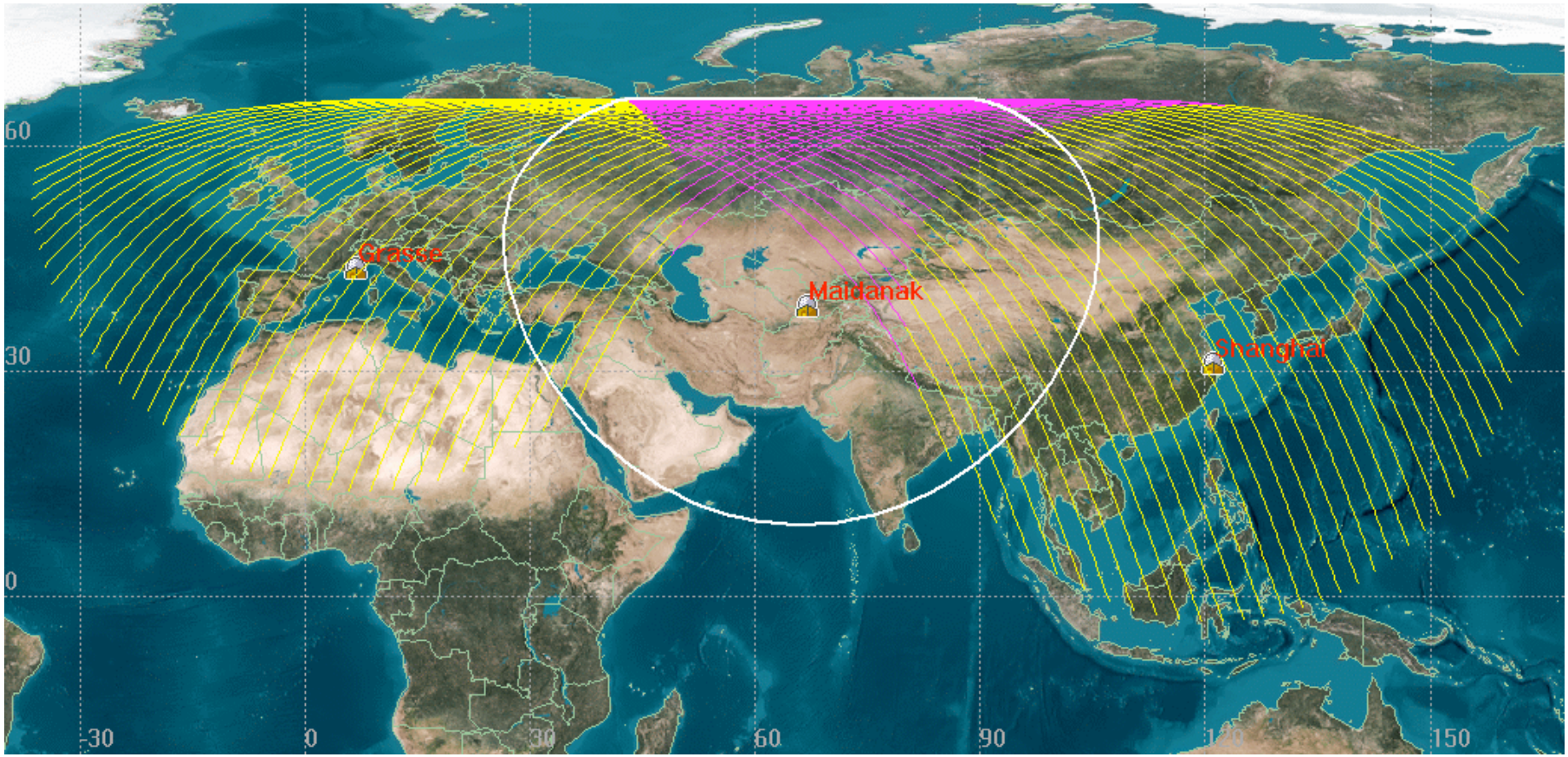
T2L2 Validation

Non common view: Grasse – Shangai



T2L2 Validation

Non common view: Grasse – Shangai



T2L2 Validation
Non common view: Grasse – Shangai

- Track the space clock with :
  - Maidanak (Russia)
  - Mendeleevo 2 (Russia)
  - Simeiz (Ukraine)
  - Katzively (Ukraine)
  - Riyadh (Arabia)

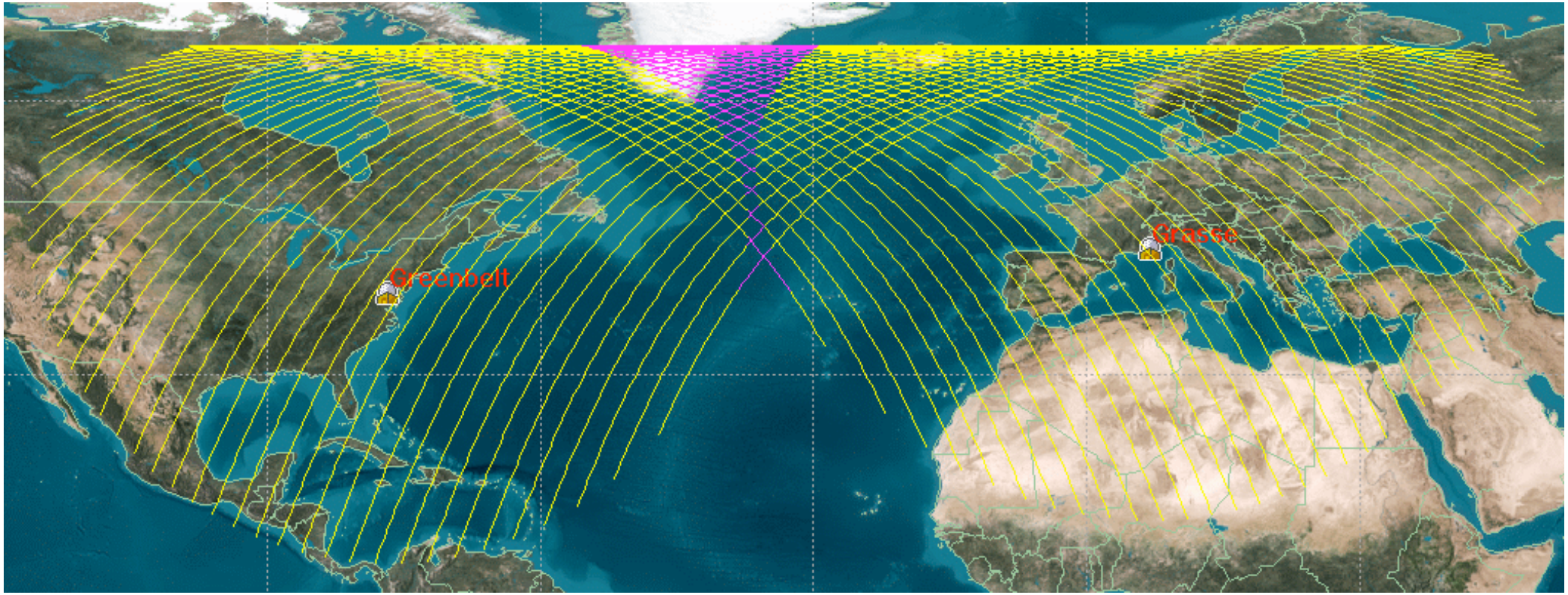
⟹ Equivalent to a common view transfer

T2L2 Validation
Non common view: Europe – USA

- Time transfer between France and Grennbelt
  - » OCA – Greenbelt : dead time : 20 seconds @ 5 °

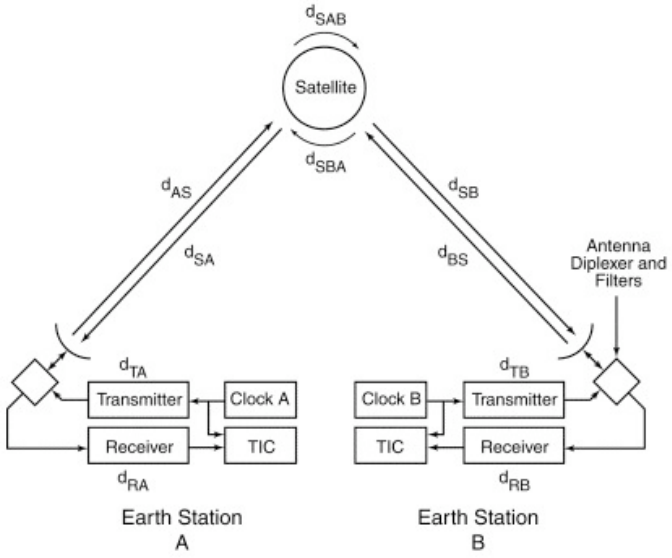
⟹ Negligible degradation as compared to a common view transfer

Non common view
GRASSE – Greenbelt (20 s)



MicroWave Time transfer comparison TWSTFT and GPS

- 4 european laboratories having both laser and TWSTFT - GPS
  - » France Caussols OCA
  - » Austria Gratz TUG
  - » Spain San Fernando ROA
  - » Poland Poznan AOS
- 2 mobile laser stations
  - » FTLRS (French)
  - » TROS1 (China)
- 2 mobile TWSTFT stations
  - » TUG
  - » TimeTech



TWSTFT and GPS Time transfer Calibration

- Determination of the delay between :
  - The instant materialized by the PPS signal at the reference location of the lab
  - The instant materialized by the laser pulse at the reference point of the station (axe crosses of the telescope mount)
- Calibration of the start time of the laser pulses
  - Absolute accuracy: 100 ps
  - Relative accuracy (long term time stability) : 10 ps
- Calibration campaign with an unique equipement (OCA):
  - Reference event timer
  - Single photon detector coupled with an optical fiber
- Each participating laser station will be calibrated defore or during the microwave comparison campaign

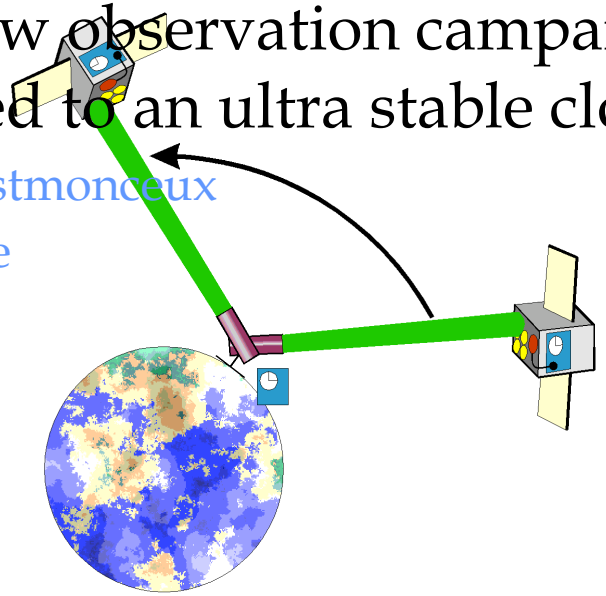
TWSTFT and GPS Calibration campaign

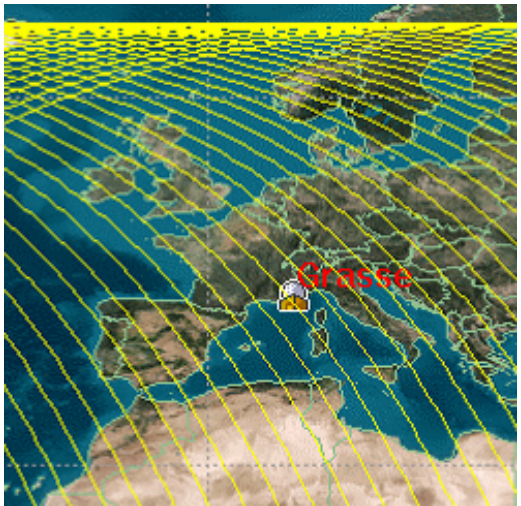
- A first 2 months campaign in june 2008 between :
  - OP via FTLRS
  - OCA (connected to Mobile Atomic fontain syrte)
  - TUG
  - ROA
  - AOS
- A second 2 months campaign in 2009 between :
  - China, Xian : National Time Service Center via TROS mobile station
  - OP connected to Mobile stations
- A permanant long term campaing between
  - OCA
  - TUG
  - ROA
  - AOS

Fondamental Physics
Anisotropy of the speed of light δc/c

- Determination of the variation of c through different laser orientation propagation

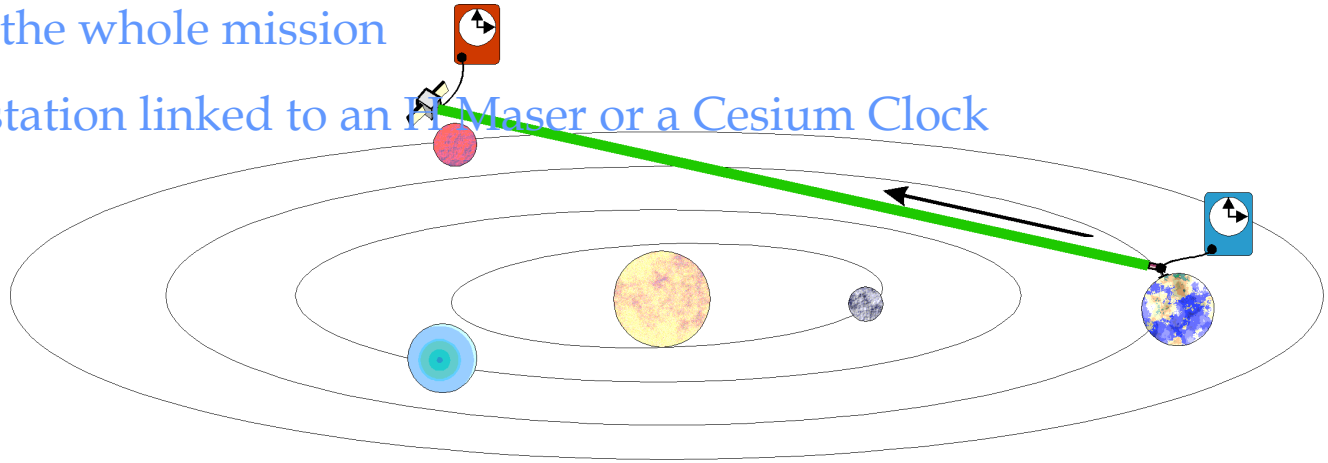
- Common view observation campaign with 3 laser stations linked to an ultra stable clock (H Maser)
  - » England Herstmonceux
  - » France Grasse
  - » Italy Matera





Fondamental Physics
Interplanetary one way laser ranging

- Comparison of the one laser ranging deduced from the time delivered by both the space and ground clocks with the classical two way laser raging
- Campaign
  - During the whole mission
  - Every station linked to an H Maser or a Cesium Clock

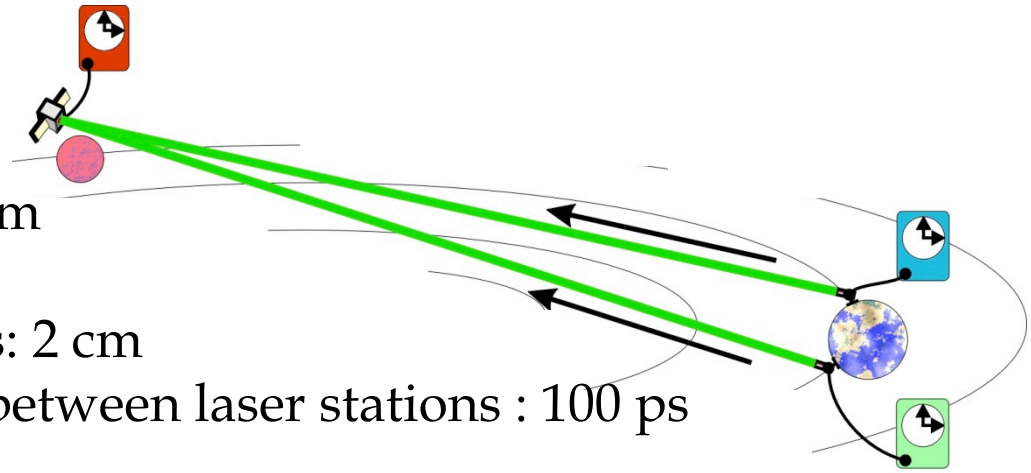


DORIS

- Characterization of the onboard quartz oscillator DORIS
  - » Correlation between onboard radiation measurement (LPT and carmen) and frequency noise
  - » Observation campaign
    - – Continuous campaign with every station linked to an H Maser or a Cesium Clock
    - – Dedicated Campaign for the SAA : South Atlantic Anomaly
      - Argentina San Juan + H Maser
      - Guyane Kourou (FTLRS)

- One way laser ranging telemetry
  - » Fake echoes computation from the onboard dates
  - » One way laser ranging : Corner cubes signature cancellation
  - » Observation campaign
    - – Every station linked to an H Maser or a Cesium Clock

3 D localization
LRO-LOLA – Interplenatary missions



Distance between Earth Moon ~ 400 000 km
Base at ground ~ 1000 km
Differential precision between laser pulses: 2 cm
Time synchronization measured by T2L2 between laser stations : 100 ps

Angular determination: 4 10^{-8} rd = 15 cm @ 400 10^{3} km

- Observation campaign
  - »Zimmerwald - Metas
  - »OP FTLRS
  - »OCA FOM

Link Budget

- The linear photo detection of the space instrument will permit to measure
  - » the energy density received for each laser pulse
    - Dynamic : 80 dB
    - Threshold : 0.1 fJ ; S = 0.05 mm²
  - » The solar flux retrodiffused by the earth
- Link budget validation
- Speckle contrast
- Observation campaign
  - » Laser station having calibrated laser beam (Gaussian shape and energy density)