European Laser Time Transfer (ELT) and Laser Safety for the ISS

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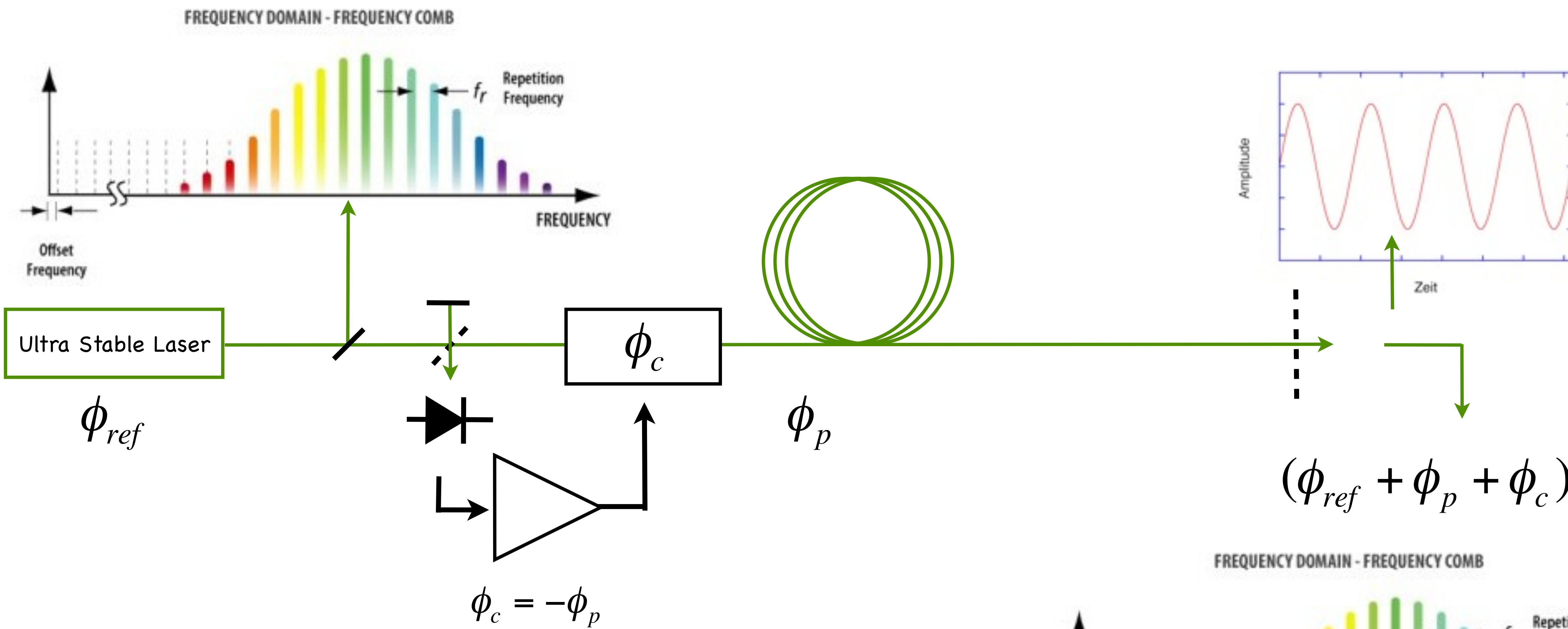
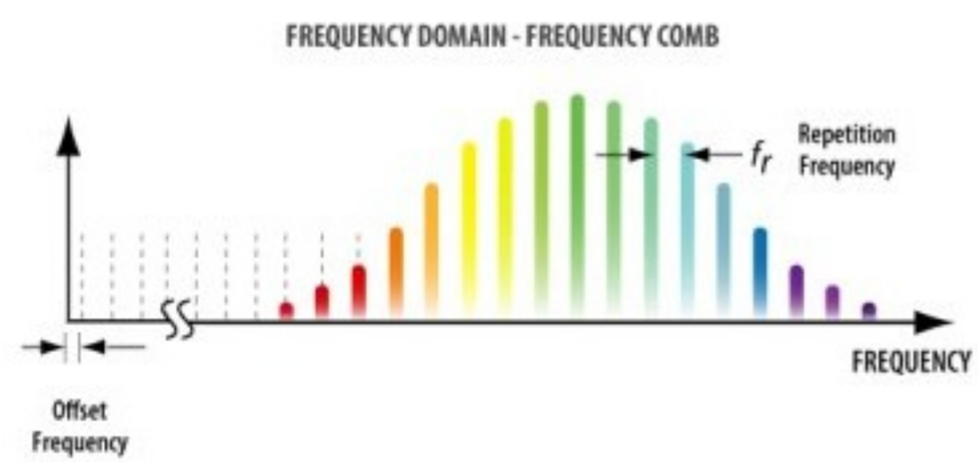
The methods of optical time transfer have been proposed and pioneered by the French group (Exertier, Samain et al.) in Grasse. As a result T2L2 was launched on Jason 2 and demonstrated the viability of this technique. With the Atomic Clock Ensemble in Space (ACES) a follow up mission for the exploitation of time transfer is in preparation at ESA. While the USO of Jason 2 drifts significantly, ACES will provide a stable reference for non common view time comparison. The ILRS has been confronted with challenging tracking restrictions several times in the past. With ACES at the Columbus module of the ISS the challenge of guaranteed eye safety at all times during SLR laser activities is given. This talk reviews the requirements and the currently proposed procedure.

Laser ~~Time~~ Frequency Transfer





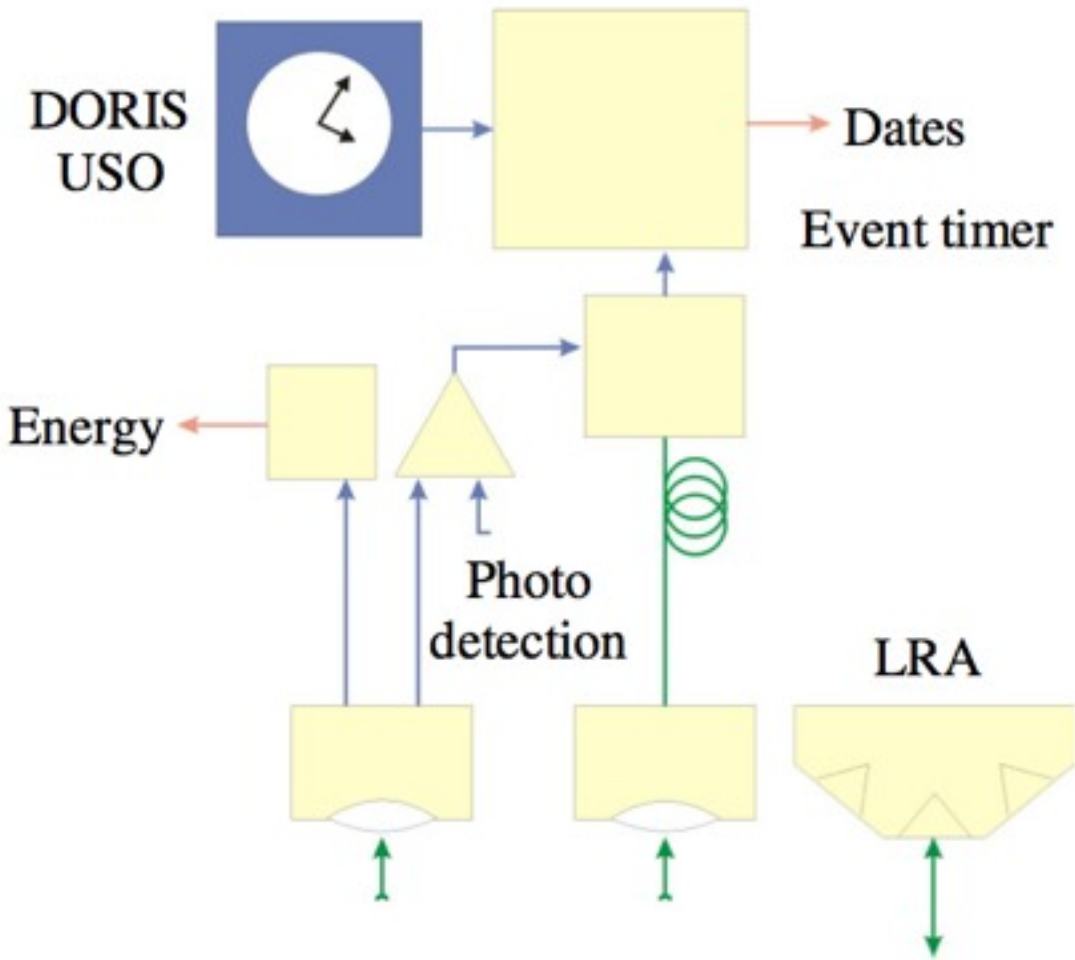
- Why the fuss with going optical?
- The 2-way concept does not work in the electrical regime
- Method resilient to interference and is shown for distances over 900 km.

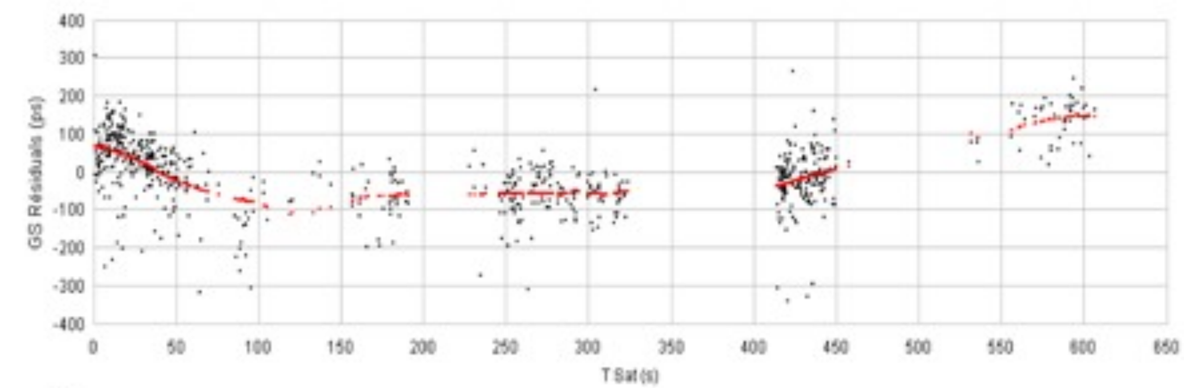
Frequency and Time

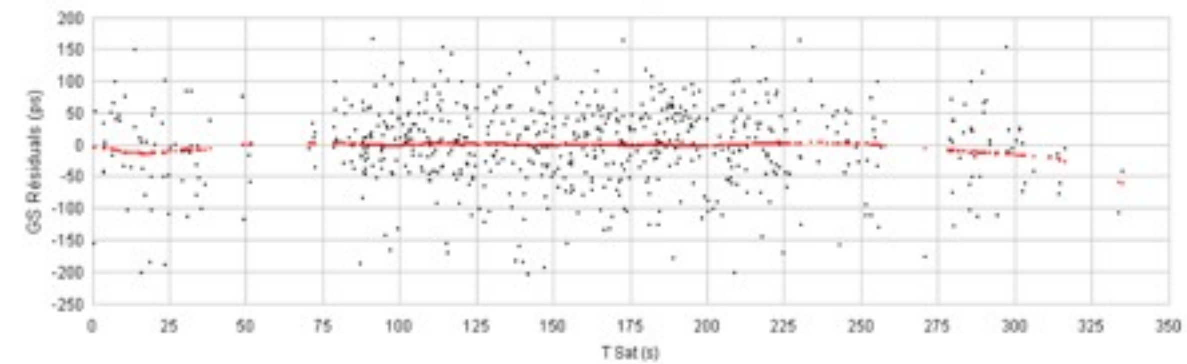
- A frequency comparison provides access to clock stability but not to a comparison of time scales (offset unknown)
- Time transfer requires a broad bandwidth channel
- SLR (short laser pulses) is ideal for time transfer, also because atmospheric delays (dispersion) are predictable
- T2L2 has demonstrated the viability of SLR for time transfer impressively

Time Transfer by Laser Link T2L2: First Results

E. Samain, P. Exertier, Ph. Guillemot, F. Pierron, D. Albanese, J. Paris, J.-M. Torre, I. Petitbon, S. Leon







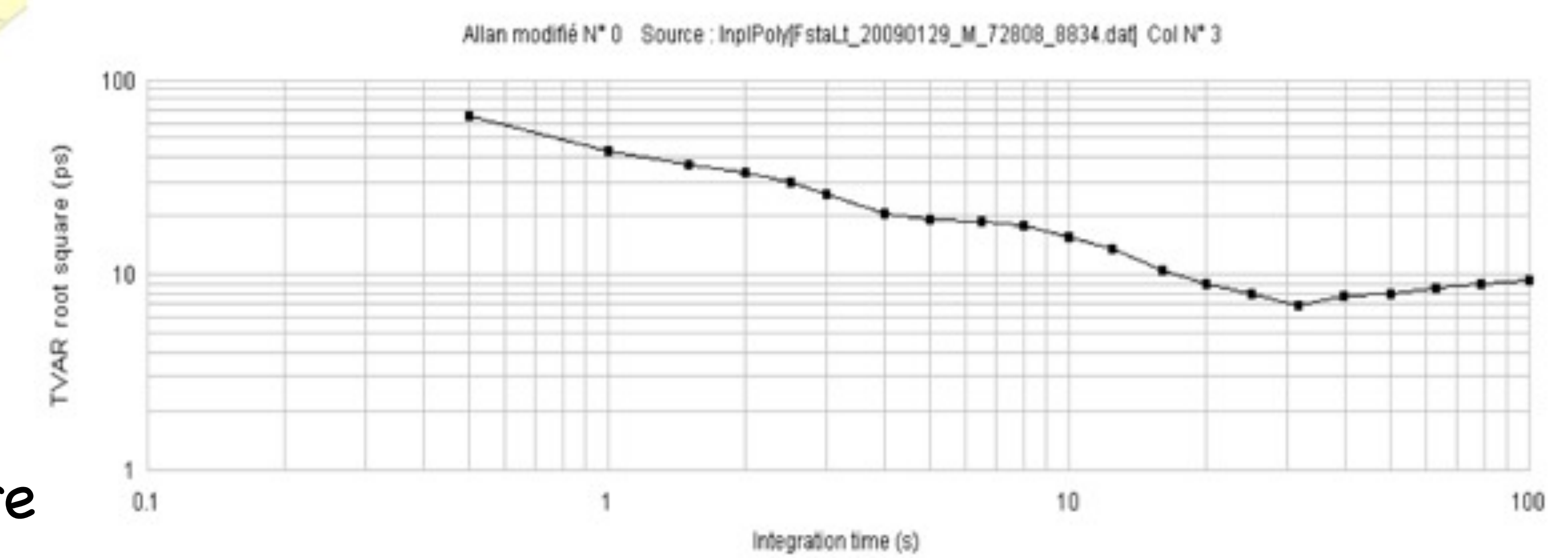


Figure 10: Time stability measured by T2L2 of the Wetzell's H-Maser compared to the T2L2's DORIS oscillator

Concept works well, however there are limitations due to USO drift

Characteristics of ACES

- ACES is a distributed system designed to disseminate a high stability and accuracy clock signal.
- It consists of a space payload generating the ACES atomic frequency reference and a network of ground terminals connected to high-performance atomic clocks on ground.
- A GNSS receiver installed on the ACES payload and connected to the on-board time scale will provide orbit determination of the ACES clocks.
- The ACES clock signal will be compared to ground clocks using two separate links: a time and frequency transfer link in the microwave domain (MWL) and an optical link (ELT). These comparisons will enable fundamental physics tests and applications in different areas of research.
- During the science phase, a clock signal with frequency resolution of about $\Delta f/f \approx 10^{-15}$ will be available to ground users.
- These measurements will test general relativity and seek for new interactions beyond the standard model.

Science Objectives in Space Geodesy

- The laser link will perform comparison of distant clocks, both space-to-ground and ground-to-ground, to frequency uncertainty levels well below 10^{-16} after a few days of integration time.
- Because of the high-stability of the ACES clock signal, non-common view comparisons of clocks across intercontinental distances will be possible with ELT.
- The optical link also finds interesting applications in the distribution of the ACES time reference and in the synchronization of geodetic observatories.
- Combined with MWL performance, ELT will contribute to the characterization and crossed-comparison of two different time transfer and ranging systems.
- Optical versus dual-frequency microwave measurements also provide useful data for the study of atmospheric propagation delays and for the construction of mapping functions at three different wavelengths.

ACES

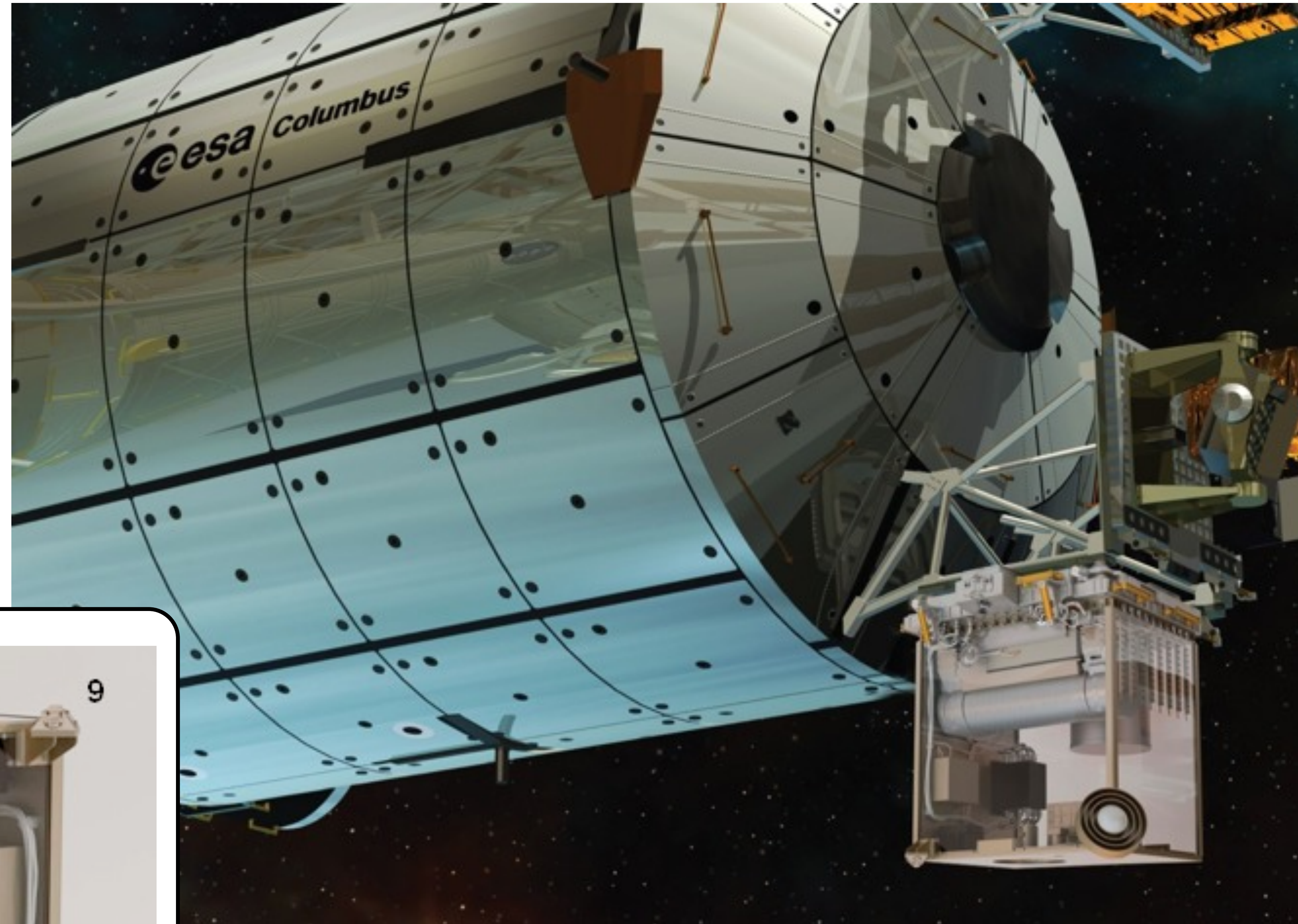
S127E011186

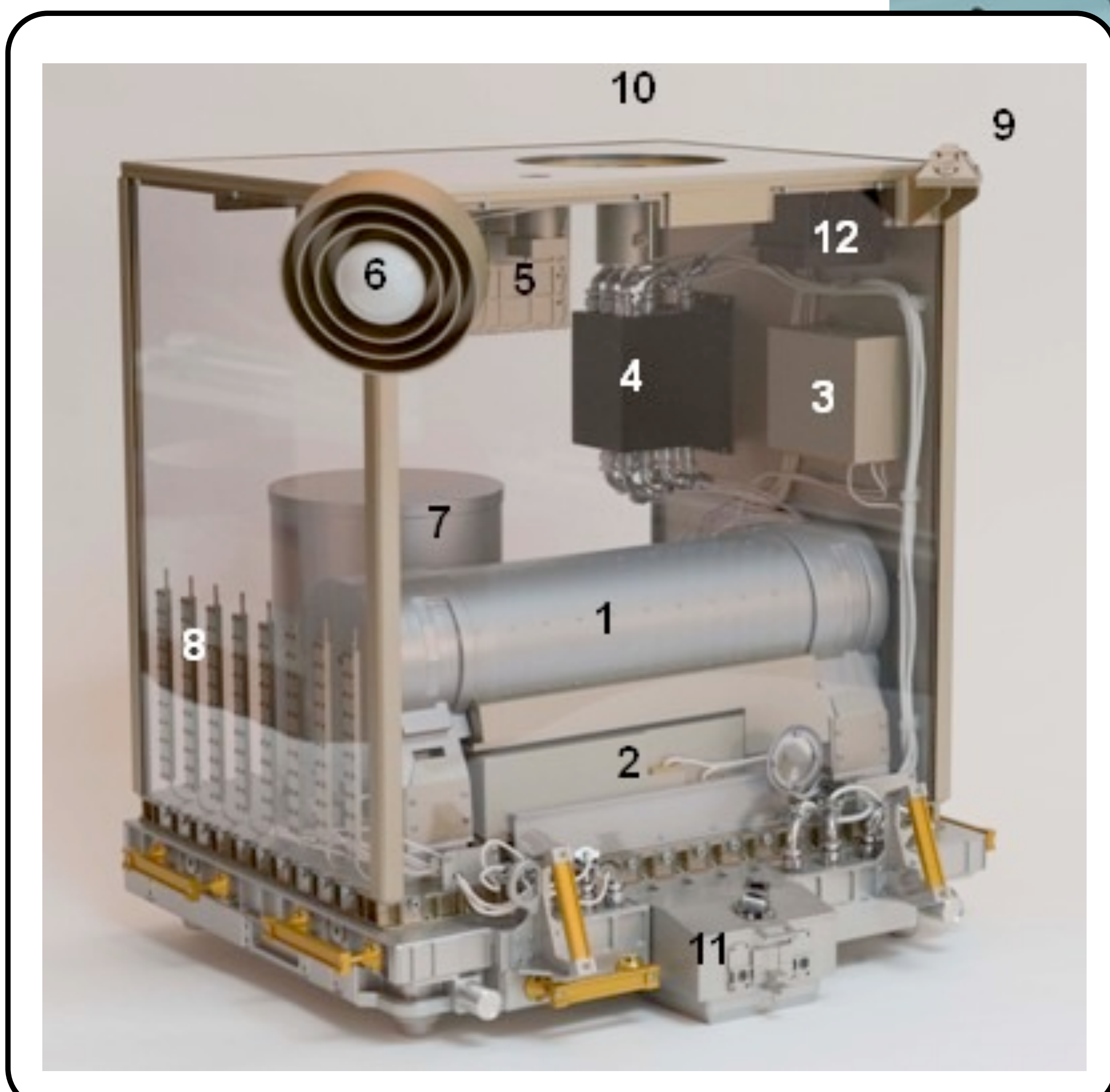
launch date: July 2016

European Laser Time Tansfer (ELT)

Two atomic clocks; a μ-g environment Cs fountain clock and a H-maser. Synchronization with the ground timescales are done by microwave and laser link, aiming at 25 ps and accuracy for the time comparison.

ACES





1. PHARAO Cesium Tube
2. PHARAO Laser Source
3. PHARAO computer
4. XPLC
5. MWL
6. GNSS Antenna
7. Space hydrogen Maser
8. Heat pipes
9. Laser corner cube reflector
10. MWL antennae
11. CEPA
12. ELT

The payload has a volume of about $1 m^3$ and a mass of ~362 kg.

Optical Time Transfer

- Severe limitations on power and weight
  -> small detector; no dedicated timer
- Single Photon detection @ satellite and ground
  (ND6 onboard attenuation)
- Ranging to ISS - New Domain for Laser Safety

Laser Safety in SLR

- Local (operator) Safety: (HV, slewing telescopes, eye-safety) see poster LEB
- In-Sky-Safety: outside operator, tracking radar, aircraft transponder, camera, flight control radar data
- Target Safety (sensor integrity, operator)

Laser Safety in SLR

- Ranging Elevation Mask, beam power limitation, scheduling, Go/no-Go flag
- In-Sky-Safety: outside operator, tracking radar, aircraft transponder, camera, flight control radar data, no-flight zone (eg. ED-R 59 in Wettzell)
- Target Safety (sensor integrity, astronauts)

Example: WLRS (old laser)

Parameter	Quantity
Wavelength	532 nm
Laser Energy per shot (at laser output)	0.1 - **50** mJ
Pulse Width	80 ps
Transmission through telescope	0.63
Transmission through atmosphere (max)	0.75
Minimum Range to ISS	380 km
Laser Beam Divergence (half angle)	**25** - 200 μrad
Atmospheric turbulence induced beam Divergence (half angle) typical	15 μrad
Diameter of Laser Spot at ISS	19 m
Total area illuminated at ISS	284 m^2
Energy density	8.3e-9 J/cm^2
Interlock	Go/ no Go Flag (as defined by ILRS)
MPE (2^{nd} Harmon. Nd:YAG < 100 ps)	7.2e-8 J/cm^2

Target Safety in SLR

The WLRS is always eye-safe for the crew of the ISS with a safety margin of one order of magnitude

ELT requires a carefully balanced link budget, since we operate at single photon level both in space and on ground (ELT detector attenuation: ND6)

Parameter	**Quantity**
Laser Energy per shot	0.1 mJ
Laser Beam Divergence (half angle)	200 μrad
Energy density at Columbus Module (TCA)	2.3e-13 J/cm^2
MPE (2nd Harmon. Nd:YAG < 100 ps)	7.2e-8 J/cm^2

Target Safety in SLR

How to ensure mission objectives AND target eye safety?

1. IR part of laser power is measured continuously

2. Measurement voltage is inverted, causing high power values and power failure to give similar (low) voltage readings

3. Low voltages are considered unsuitable for the mission objectives and potentially unsafe

4. Ranging activities are suspended

5. A mechanical switch senses actual beam divergence settings and ranging cannot commence when the switch is not activated (hardware inhibit)

Summary

- ELT for ACES builds on the success story of T2L2 and was adjusted to fit into payload margins
- ELT system requirements make it an interesting but also challenging target
- Ground segment (good clock) and safety requirements make it a target for only a few SLR stations
- The ILRS needs to develop a procedure to properly handle the ranging restrictions