Starting the communication between ELT data centre and ILRS stations

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ABSTRACT

The ELT (European Laser Timing) link designed for the ESA mission Atomic Clock Ensemble in Space (ACES) follows T2L2 (Time Transfer by Laser Link) and LRO (Lunar Reconnaissance Orbiter) as an experiment to transfer time into or from space with pulsed laser signals. The main objective of ELT is to demonstrate that an accuracy of 50 ps, with a perspective of 25 ps, can be achieved. This would allow a calibration of the ACES microwave link and the synchronization of clocks, both space-to-ground aand ground-to-ground up to 50 ps (25 ps as goal). As the detection principle and the target properties change from T2L2 to ELT, the operation of ILRS stations has to take safety and synchronization issues into account.

1 Introduction

Comparison of an ultra-stable time scale in space with ground clocks allows tests of crucial aspects of Einstein's theory of relativity, such as the gravitational red-shift and the Local Lorentz Invariance (LLI). The best measurement of the gravitational redshift was performed by Vessot et al. in 1980. LLI has been tested by using GPS clocks in an experiment similar to the one planned by ACES [Wolf and Petit 1997]. The stability and accuracy of the ACES clocks and links will allow to significantly improve existing results. The ACES time scale will additionally contribute to the generation of international time scales (UTC and TAI). "Relativistic" geodesy will be pushed forward to demonstrate the possibility of performing local measurements of geopotential differences by using clocks on the ground. ACES [Cacciapuoti 2009] will establish a time scale in space with stability accuracy of 10^{-16}. The frequency comparison and distribution package which combines the short-time stability of an active hydrogen maser (1.5 10^{-15} at 10^4 s integration time) and the long-time stability of a laser-cooled caesium clock called PHARAO (fractional frequency stability of $10^{-13}\,\tau^{-1/2}$) will guarantee this performance.

The main space-to-ground time and frequency transfer system is a microwave link (MWL) with a capability of a time stability of 0.3 ps at 300 s and 7 ps at 1 day integration time. The accuracy of time transfer will be 100 ps.

An alternative to time transfer via MWL will be tested in the European Laser Timing (ELT) experiment. For this link, short laser pulses fired towards ACES by a laser ranging station will be time tagged with respect to the ground time scale at their emission (t_{start}). Once detected in space they are time tagged in the ACES time scale (t_{stop1}). The returned signal from the retroreflector to the SLR station will again be registered in the ground time scale (t_{stop2}). For each laser pulse, the offset between the ground and the space clock is the difference between the time a ground observer expects the laser pulse to be at the ISS in the ground time scale and the time t_{stop1} as it was registered at the ACES module. The corrections that have to be taken into account are due to short term fluctuations in the atmosphere, geometry (the laser reflecting point does not coincide with the detection point) and relativistic effects.

$$\tau_{offset} = \frac{t_{stop2} + t_{start}}{2} - t_{stop1} + t_{relativity} + t_{atmosphere} + t_{geometry}$$

The ELT payload consists of a corner cube retroreflector, a SPAD detector [Procházka 2010] and an event timer. The gating of the SPAD detector is locked to the 100 pps signal (1000 pps in discussion) from the ACES clock. A verification test on the ground has been completed by Schreiber et al. (2010).

In contrast to T2L2 [Fridelance et al. 1997] the detector onboard ACES works in single photon mode. It is therefore necessary to guarantee a very low photon flux at the ACES detector, as otherwise the accuracy would be limited due to the time walk effect. ELT will have similar long-time stability as the MWL, namely 7 ps at 1 day, limited by the ACES clock. The short-time precision is however limited by the repetition rate of the laser pulses (2 kHz for the best stations) to 4 ps at 300 s integration time.

2 SLR station requirements and the role of a data centre

The specific requirements of a SLR station for the ELT experiment arise from the target properties and the detection mode. The target, the ACES module, will be installed on the International Space Station (ISS), at the nadir-pointing location of the Columbus External Payload Facility (CEPF). The attitude and orbit behaviour of an extended object like the ISS cannot be predicted with sufficient accuracy over a long time, so the SLR stations participating to ELT will have to handle predictions every 90 minutes. Due to manned operation of the ISS, some safety issues have to be taken into account. A flag will indicate if laser firing to ACES is allowed and has to be checked before starting a ranging session. A shutter has to be installed which blocks the laser in case of loss of energy control. To ensure single photon detection mode at the ISS, ground stations will have to appropriately control and adjust the laser energy received at ACES. An attenuation of 10^{13} at the ELT detector will allow two-way tracking as well as single photon one-way ranging. The detector will be gated at 100 Hz, synchronously to UTC. The stations have thus to control the laser firing times with respect to the predicted times with an accuracy of 100 ns.

To demonstrate the high accuracy of the optical pulsed time transfer, the SLR stations have to provide full-rate data with start times of laser firing with picosecond resolution, they have to consider single photon mode tracking on ground as well as they need to keep modifications to system configuration to the minimum. SLR stations with nominal laser fire rates greater than 100 Hz should take advantage of their full two-way ranging capability.

As not many stations have experience with active hydrogen masers or frequency standards with comparable stability, the ELT data centre will provide information about precise time-keeping and distribution on ground station. This can be achieved for instance by organizing a workshop dedicated to the station operators. E-mail and world wide web are other media that the data centre will use for the communication with SLR stations.

3 Conclusions

ELT is challenging experiment, in particular for what concerns the operation of SLR stations. ACES is planned for launch in the 2015-2016 timeframe. To get the ILRS stations ready until then, the ELT data centre will coordinate efforts and distribute all the necessary information. To identify the needs of the stations a questionnaire has been worked out together with the T2L2 data centre and it has been send to the SLR stations operators. The feedback received through the questionnaire will help planning for the next steps.

References

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