esa Human Spaceflight
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ACES: ATOMIC CLOCK ENSEMBLE IN SPACE

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13. Disposition of GSCB:
14. Concurrence of Interface Partners For ELT DS________________________________ ____________ Signature Date

1. Introduction

1.1. Scope

This document describes the data format and file names, which are exchanged between the SLR tracking stations and the ELT Data Center during ELT operation. It explains the measurement principle and the resulting actions that must to be taken at the ground stations to allow for a successful tracking of the ISS with optimal time synchronization between the clock system on the ACES module and the clocks on ground. This document **does not** describe the actions taken by the ground stations to fulfill the laser safety regulations.

1.2. Purpose

This document informs the management of the SLR ground stations about the actions that must be taken to successfully track the ELT detector on-board of the ACES module mounted on the ISS.

1.3. Documents

RD-01: CAD-CI-CE2311-4469-CNS
RD-02: Consolidated Laser Ranging Data Format (CRD) Version 2.01
RD-03: Consolidated Laser Ranging Prediction Format Version 2.00

2. ELT on ACES

The European Laser Timing (ELT) Experiment will allow synchronization of ground clocks with the Atomic Clock Ensemble in Space (ACES). The synchronization works with short laser pulses with a wavelength of 532 +/-0.1 nm, as usually used in Satellite Laser Ranging (SLR). The measurement principle is a combination of the typical two-way ranging, in which laser pulses are send to satellites equipped with retroreflectors and the echo detected again on ground. This is a time of flight measurement, where the range is extracted. On board the ACES module, an avalanche photodetector registers the arrival times of part of the laser pulse. The clock desynchronization is the difference between the time of reflection in the ground time scale and the time of detection in the ACES time scale. The detector on-board is gated regularly 10 to 100 times a second according to the ACES time scale and is active until a noise or a laser photon triggers the avalanche process. The background light is very high at daytime, so the gate window may not remain open for longer than 100 ns. This fact makes a highly accurate timing necessary.

3. The ELT Data Center

The ELT Data Center is responsible for the data processing, the coordination between ESA and the ground stations as well as the organization of the exchange of data. For this purpose, the ELT Data Center has a close cooperation with the Eurolas Data Center (EDC) of the International Laser Ranging Service (ILRS). The data products delivered by the SLR stations will be collected by EDC. Therefore, the stations connect to EDC as usual. The ISS predictions in cpf format will be available on the EDC server as well. The data is available in a password-protected area. EDC further distributes the data to ESA and the ELT Data Center.

4. Data exchange between stations and ELT Data Center and formats

SLR typically produces two data products on a regular basis. One is the so called fullrate data product, a collection of all returns measured to one satellite within one pass. This file records the laser firing epoch together with the time of flight until the laser pulse is registered again on the station. The second data format is a collection of normal points. The measurements are already bundled here, which makes orbit determination more convenient. The EDC collects these two data formats together with a third one. For time transfer not only the fire epochs, where also returns are registered on ground are of interest, but all other fire epochs, too. It is possible that returns will be detected in space while no photons were registered on ground. The ILRS has developed the data format called frf for that purpose.

The naming of the files should be handled according to the conventions used in the ILRS:
The ILRS document **RD-02** describes the data format used for data exchange.

The SLR stations need to know the position of the object in order to track it in advance. The orbit information is provided in the consolidated laser ranging prediction format (cpf). The description of the data format can be found in the ILRS document **RD-03**. The file is named in the following way:

aces_cpf_ yymmdd_nnnvv.src

- aces: mission id
- _: delimiter
- cpf: data type/format
- _: delimiter
- yy: year of observation epoch start time
- mm: month of observation epoch start time
- dd: day of observation epoch start time
- _: delimiter
- nnn: ephemeris version number.
- vv: version number within the day.
- .: delimiter
- src: prediction provider code, 3 characters long

The accuracy of the predictions directly influences the possibility of the SLR stations hitting the gate window of the on-board detector. For this reason, ESA provides a prediction of the ISS every 90 minutes. It is the responsibility of the stations to use the newest predictions available.

For transponder missions such as ELT, an additional header entry is foreseen in the prediction format. Header H4 delivers the offset and drift of the on-board clock. As the gate opens in the ACES time scale and the stations usually operate in UTC(k), the two time scales have to be converted to each other. Due to the Theory of Relativity, a moving clock not located on the geoid will drift away from UTC(k). With the two parameters offset and drift, a conversion between the two time scales can be performed with the necessary accuracy. The convention is to use the parameters in the form of equation 1.

$$t_{UTC(k)} = t_{ACES} + (t_{ACES} - t_0) \cdot 10^{-15} \cdot drift + offset, \quad (1)$$

with t_{UTC} time in UTC, t_{ACES} ACES time, t_0 time for which offset and drift are determined.

Header 4:

Header type 4 Transponder information
1-2 A2 Record Type (= "H4")
F12.5 Pulse Repetition Frequency (PRF) in Hz
F10.4 Transponder transmit delay in microseconds
F11.2 Transponder UTC offset in microseconds
F11.2 Transponder Oscillator Drift in parts in 1015
F20.12 Transponder Clock Reference Time (seconds, scaled or unscaled)

Important for each participating station is to know an estimate of UTC(k) to UTC.

5. Safety first

Docking manoeuvers regularly take place on the ISS when another crew or equipment is brought on board. As laser light may disturb the docking, tracking is not allowed while these manoeuvers happen. A go/nogo flag is used to handle this issue. It is the responsibility of the station to retrieve the flag from EDC right before tracking a pass of the ISS. The validity of the flag is 5 minutes, so if requested just before the start of a pass the flag will be valid for the whole pass and a new retrieve is not necessary. The file name of the go/nogo flag is
aces.gng.

Data format example for ICESAT:

```
ICESAT 0300201 8201 0 nogo 20110221T114350
```

6. Handling of time at the station

The stations have to control different parameters on ground in order to be able to hit the gate window on the detector in space. First of all the time offset of ACES to UTC (see section 4) and the time offset of the station itself to UTC. With GNSS time synchronization an accuracy of about 10 ns is possible. The stations should aim at such an accuracy. While the gate on-board will open 100 times a second maximum, kilohertz two-way ranging is welcome, as this makes the adjustment of the orbit more relaxed. For the 100 Hz one-way measurements, the fire epoch has to be calculated according to the orbit prediction, the UTC offsets, the laser delay times within the atmosphere calibration factors, and delays of the laser to the fire event, if necessary. In addition, a calibration of the one-way delay of the laser pulse at the station could be helpful. A discussion with Ivan Prochazka on that topic may be helpful (ivan.prochazka@fjfi.cvut.cz).

The most critical part are the predictions. Even predictions prepared every 90 minutes may be too bad to allow ranging at daytime. Therefore, an analysis of the two-way ranges for a time bias of the ISS is mandatory and has to be considered when firing the laser. We recommend using real-time sharing of time biases so that the information of prediction uncertainty can be disseminated within the community.

To access all available status messages, connect to AIULI3.UNIBE.CH port 7810 with, e.g., TELNET command:

```
telnet aiuli3.unibe.ch 7810
```

Example:

```
-------------------------------------------------------------------------------------
--
Graz 2008-01-24 15:24:10 Lageos2 CUR 11k HTS5241 0.000
Zimmerwald 2008-01-24 15:24:00 DWN
Yarragadee 2008-01-24 15:24:07 Calibrate CUR 391
Potsdam-3 2008-01-24 15:24:01 OUT
Wettzell 2008-01-24 15:24:05 BeaconC CUR 0 HTS5231 0.000
San_Fernando 2008-01-24 15:24:12 Calibrate LST 871
MLRO-Matera 2008-01-24 15:23:45 BeaconC CUR 213 SGF5241 0.000
Herstmonceux 2008-01-24 15:24:15 Lageos2 CUR 642 SGF5241 0.000
```

In order to make optimal use out of time synchronization, a common clock experiment with GNSS time transfer should be aimed at. For such experiments, distributing time on calibrated cables is mandatory.

7. Handling of laser intensity at the station

The accuracy of the ELT experiment depends on the station to maintain the single photon mode on the ISS. To make one-way and two-way tracking in the optical possible, the on-board detector is diminishing the laser intensity by a factor of $1x10^7$. Even with this high attenuation, the one-way ranging may not be in single photon mode. The attenuation is tuned such that a single photon ranging in the two-way measurements will result in a single photon ranging at the ISS. Thus, ensuring a signal photon mode on ground will result in a single photon mode in space, when performing the attenuation of the laser beam rather at the outgoing than on the incoming branch.

8. Issue with multi-retroreflectors on ISS

For docking manoeuvers, the ISS has installed retroreflectors on many positions. Some of these reflectors will also reflect photons coming from ground. Ranging to the ISS will result in more than one trace on the range gate window. Even the trace of the ACES reflector should be dominant, any automated reduction of the gate window to the first detected returns may not be extracting the right returns. The ELT Data Center provides a piece of software based on Matlab or Octave for extracting the returns of the ELT reflector. If this cannot be implemented in your ranging software, please ensure that you are sending unfiltered fullrate data to the Data Center, where all returns are captured. We can also provide an algorithm for extracting the returns so you can implement this feature your own. Please contact the ELT Data Center for more information (anja.schlicht@tum.de).

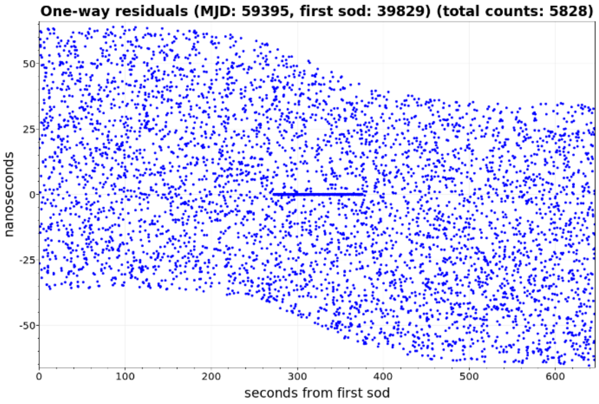
9. Quick-look response from ELT Data Center

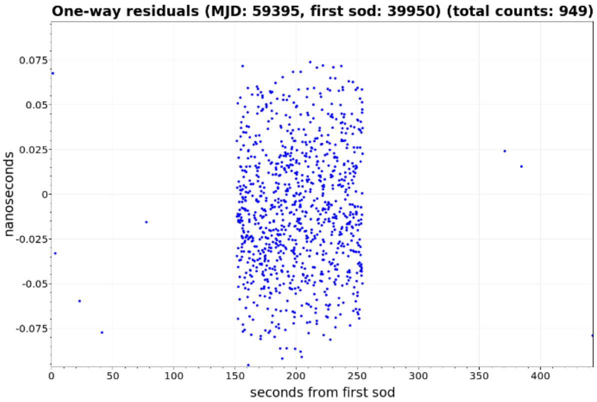
The tracking station do not get an immediate response from ACES if they managed to hit the gate window. To give the station operators the possibility to correct for desynchronization sources, the Data Center will analyze the data as soon as one-way data is downloaded from the ISS and the two-way measurements are available from the stations. So please send the measurements as soon as possible to EDC. This analysis is preliminary and only serves as a quick-look on the data. The operator can see if you managed to hit the gate at all, if the return rate is much too high, if the full pass is tracked and if the analysis we did is correct. The communication between the Data Center and the stations observer is via email. The stations should inform the Data Center about the relevant mail address. The address of the Data Center is elt@sgd.lrg.tum.de .

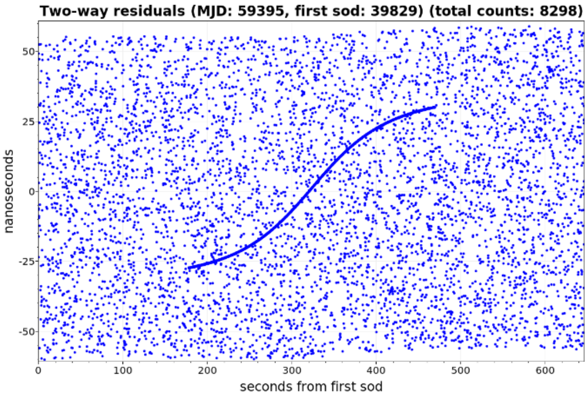
The processing report will look like this:

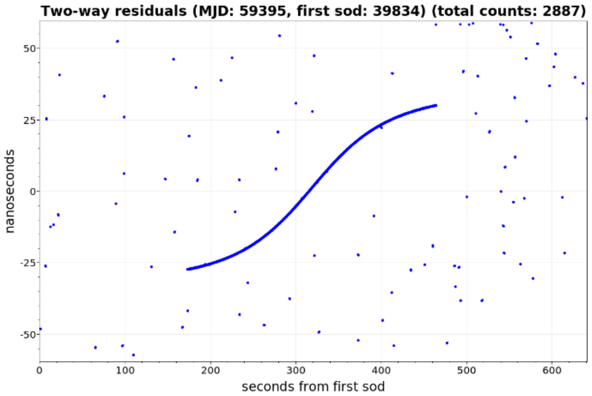
```
Dear ELT participant,

thank you for sending your measurements rapidly.
In a quick-look analysis we estimated
the mean time offset to ACES as: 14.6ps
the standard deviation as: 36.0ps

Kind regards,
the ELT-DC team
```

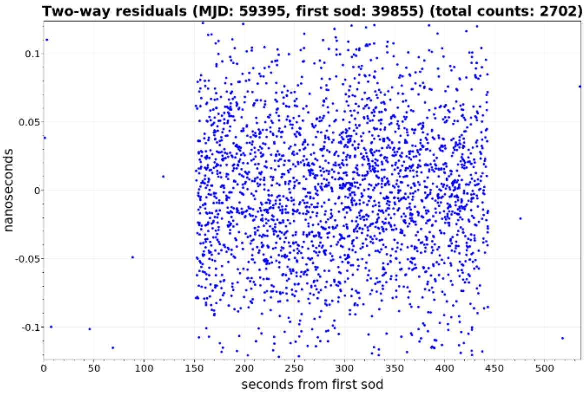
The appended zip-file contains all the plots of the analysis:

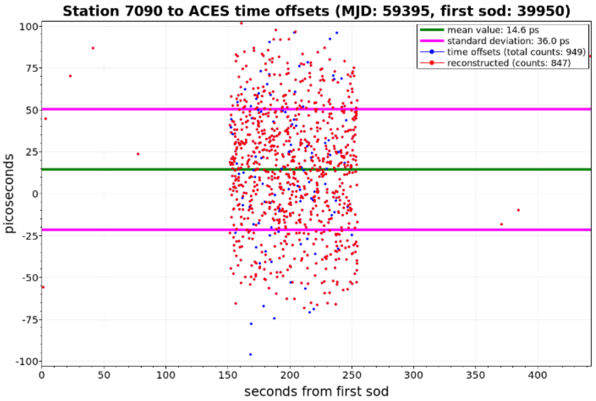

One-way residuals (MJD: 59395, first sod: 39829) (total counts: 5828)


One-way residuals (MJD: 59395, first sod: 39950) (total counts: 949)


Two-way residuals (MJD: 59395, first sod: 39829) (total counts: 8298)


Two-way residuals (MJD: 59395, first sod: 39834) (total counts: 2887)


Two-way residuals (MJD: 59395, first sod: 39855) (total counts: 2702)


Station 7090 to ACES time offsets (MJD: 59395, first sod: 39950)

The first row of figures shows the analysis of the one-way data from the residual plot to the detected returns. The second row shows the analysis of the two-way data from the residual plot to the first filtering. In the last row on the left, the extracted two-way returns with a short-arc orbit estimation correction are shown. The figures on the right hand side in the last row shows the analysis of the time transfer. The real triplets are shown in blue, where the start epoch is available together with the one-way and two-way returns, and in are red the so called reconstructed triplets, where only the start epoch and one-way return are available and the two-way returns are estimated by the short-arc estimation of the orbit.