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ACES MWL DATA ANALYSIS CENTER AT SYRTE

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Abstract. The ACES-PHARAO mission aims at operating a cold-atom caesium clock on board the International Space Station, and performs two-way time transfer with ground terminals, in order to allow highly accurate and stable comparisons of its internal timescale with those found in various metrology institutes. Scientific goals in fundamental physics include tests of the gravitational redshift with unprecedented accuracy, and search for a violation of the Lorentz local invariance.

As launch is coming closer we are getting ready to process the data expected to come from ACES Microwave Link (MWL) once on board the International Space Station. Several hurdles have been cleared in our software in the past months, as we managed to implement algorithms that reach target accuracy for ground/space desynchronisation measurement.

I will present the current status of data analysis preparation, as well as the activities that will take place at SYRTE in order to set up its data processing center.

Keywords: General Relativity, Atomic Clocks, Tests of Fundamental Physics, Relativistic Time and Frequency Transfer, Data Analysis, Space Mission

1 Introduction

This talk reports on the current status of the ACES-PHARAO mission preparation at SYRTE, where our team is currently building a Data Analysis Center (SYRTE-DAC) for ACES Micro Wave Link (MWL). This preparation spans a long time range, hence this status report follows several previous ones, e.g. Meynadier et al. (2012) which describes the mission in general as well as measurement principle.

2 The SYRTE DAC

The need for a specific Data Analysis Center appeared gradually in the last couple of years. As ground segment implementation unfolded, it became clear that the initial plan (i.e. full processing chain running on CADMOS premises with little or no operator interaction) would be difficult to achieve, because of the complexity of some of the processing required to reach ACES goals.

It was thus requested by ESA that SYRTE should take on from CADMOS for the scientific stages of data processing and analysis, and would then return processed results within the ACES archive. This is illustrated on Fig. 1.

Figure 2 shows the location of the MWL ground terminals across the world. ACES Ground Segment will process their data up to the L2/L3 level on a routine basis. ACES Investigators Working Group (IWG) will then prioritize which data will be further processed, and SYRTE DAC will then proceed accordingly, generating the L4 data that contains physical values of interest for the community (i.e. desynchronisation between round and space clocks and some by-products, namely Total Electron Content (TEC) of the ionosphere and pseudo-ranges).

The core software of the DAC has been developed at SYRTE for roughly ten years, from the very first ideas and prototype codes, to the present python code that powers data processing (whose implementation began in 2011). Simulation software has been developed in parallel, taking care to isolate has much as possible both

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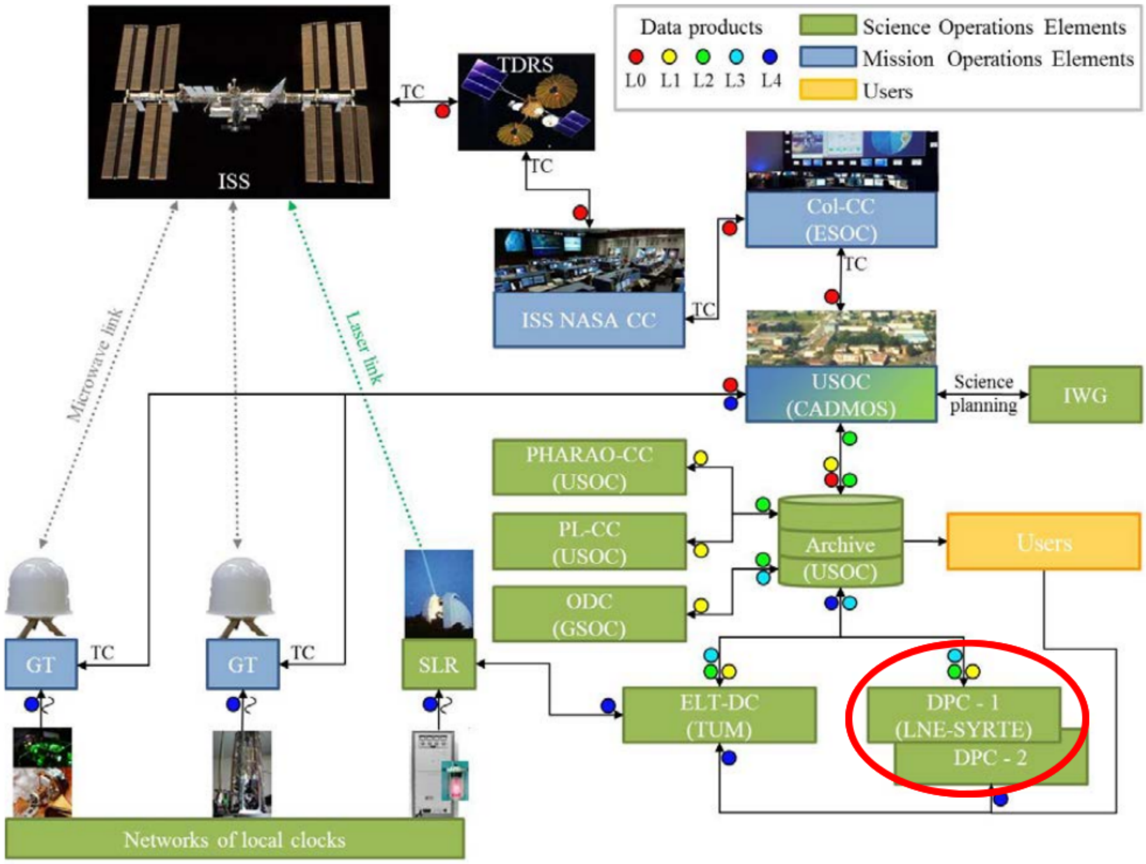

Fig. 1. The ACES ground segment organization. Red ellipse highlights the position of the Syrte DAC within the processing chain. Note that SYRTE will also host a ground Terminal (GT) but there will be no direct connection between DAC and GT, all data will go through CADMOS archive and SYRTE GT will be just another GT from DAC perspective.

codes (different languages, different developers). Our simulation is now the most complete simulation software for MWL data, and serves as benchmark for other pieces of software developed for the ground segment by the industrial contractor (Airbus D&S). It is highly flexible and allows to test almost any imaginable configuration, realistic or not, while mimicking as well as possible the kind of data that we expect to receive at the L1 level.

3 Processing of simulated data

Figure 3 shows typical results from our analysis software, when fed with simulated data. In this context we can compare the input values to the output and determine what errors are introduced by the measurement principle and its implementation. Note that, in the absence of any other noise, we are limited by the measurement method which is based on counters, which introduces a truncation in the measured values. Signal is composed of a carrier carrying a code : both can be used for measurement, the code giving absolute desynchronisation values with a 20 ps spread, while carrier has only 0.5 ps spread but have an offset which will be unknown (but constant as long as the MWL is switched on).

One of the major breakthroughs in the past year as been the implementation of a method which allows to recover this “unknown but constant” offset between successive ISS visibility period, enabling us to reach the expected specifications. This achievement is demonstrated on Fig. 4.

In the end, we have now demonstrated our ability to simulate data for long durations (more than expected ACES uninterrupted run durations, i.e. 20 days at most), and recover desynchronisation and other parameters at the expected level through data analysis. Work is ongoing to encapsulate the core software into an integrated DAC infrastructure which will automatize as much as possible the data analysis, easing the mandatory validation

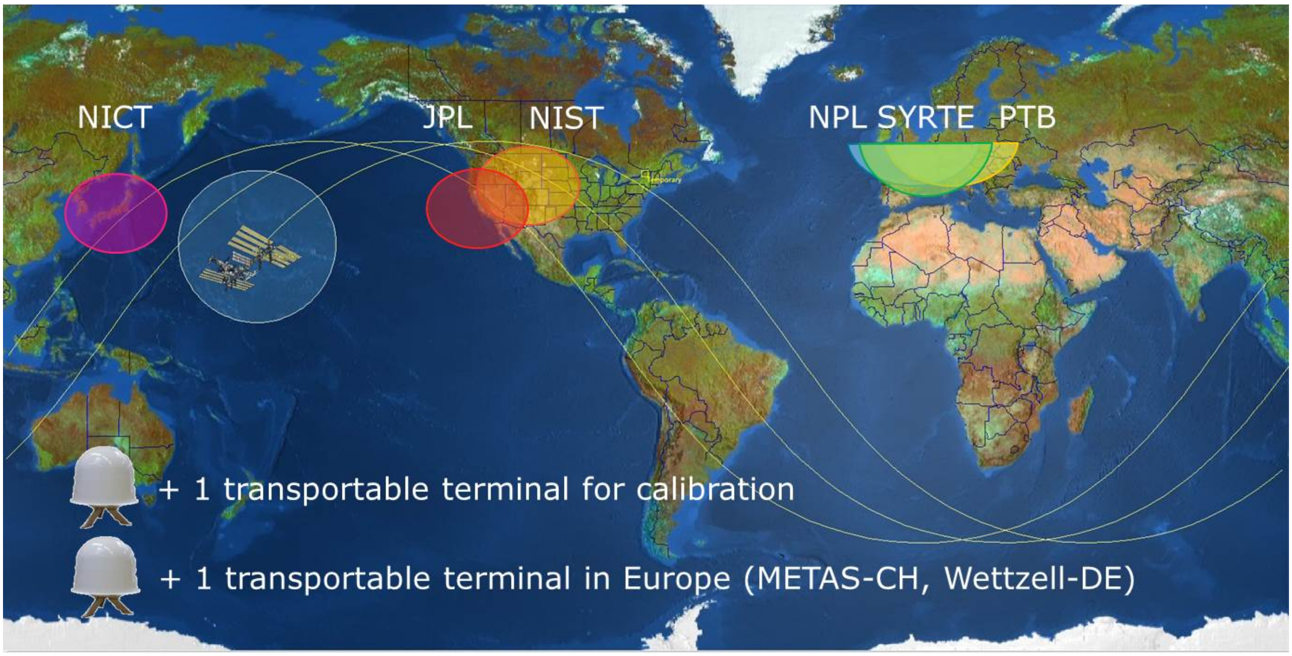

Fig. 2. Location of ACES MWL ground terminal, with visibility zones of the ISS showing possibilities for common-view operations (source : ESA)

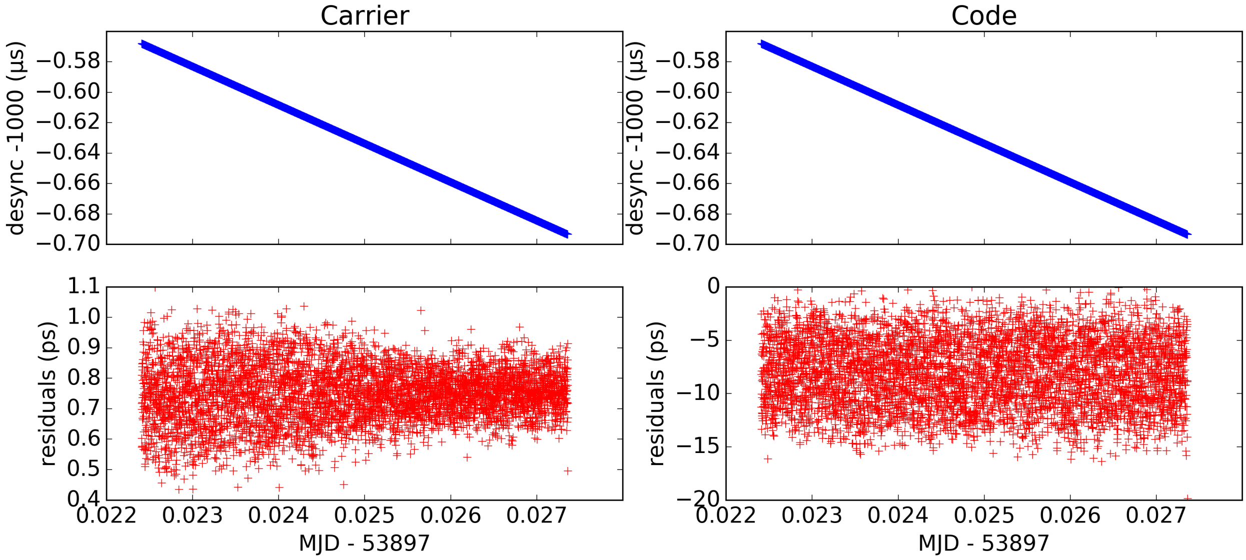

Fig. 3. Typical output from the analysis of simulated data. Top = input theoretical values of desynchronisation, bottom = residuals between those values and the ones coming out of the analysis. Noise caused by counter quantization (no other noise source simulated here), so this is the noise floor of this mesurement.

steps that will be performed while in flight.

4 Estimation of ISS position uncertainty impact

Our simulation/analysis combination can also be used to assert the impact of various factors on the measurement. A first application is to measure the impact of ISS orbitography uncertainty. First theoretical estimates (Duchayne et al. 2009) pointed out that this was a major contributor to the global error on desynchronisation determination, and Duchayne (2008) proposes a method to cancel it at first order by interpolating data such

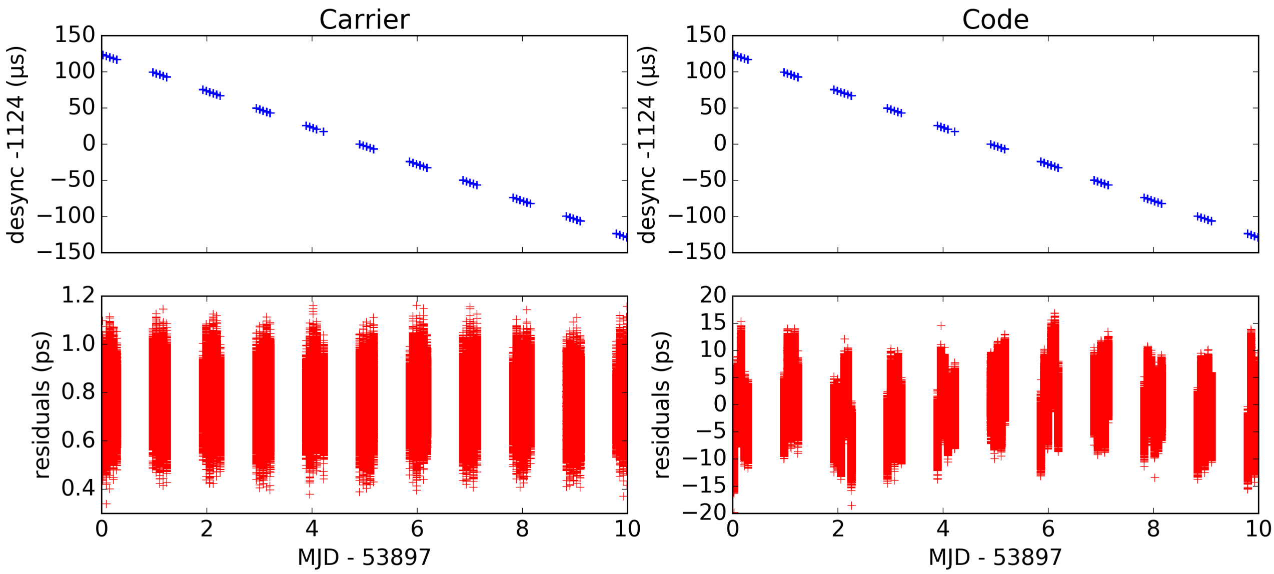

Fig. 4. 10 days ($\simeq$ 50 ISS passes) of data. Drift in desynchronisation corresponds to what is expected from General Relativity. For each pass, code data mean residuals stay within $\pm$10 ps but shows jitter, whereas carrier data residuals stay within a few tenths of ps around a common arbitrary offset.

that downlink signal leaves the ISS exactly as the same time as the uplink signal arrives (dubbed "lambda configuration").

In 2006 a study on ISS orbit determination used positioning data from 2 devices, one being the regular position and attitude sensor (SIGI), the other one being a more precise GNSS receiver. By combining both measurements we were able to estimate the position uncertainty we should expect from SIGI measurements, and also were able to generate synthetic orbitography with tunable yet realistic uncertainty. By feeding the correct orbitography to our simulation, then using its modified counterpart for the analysis, we were able to show how our limited knowledge of the ISS position can impact the ACES measurements.

Our conclusion is that even a factor 10 on the ISS position uncertainty will still allow to be well within specifications as long as individual desynchronisation determination is concerned. More details will be available in an article that is currently submitted.

5 Conclusion

The Syrte DAC core software is now close to completion, and we are currently setting up the infrastructure that will run it. Next step is to implement the interface with the main database at CADMOS and ensure smooth operation. This task is under way and should be operational as soon as the rest of the ground segment is.

However we expect a lot of adjustments to become necessary when real data comes out of scheduled end-to-end tests. Those first batches of real data are eagerly wanted to finish the validation of this work and fine-tune the DAC for the operational phase of the ACES-PHARAO mission

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