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# THE ACES OPERATIONAL CONCEPT: HOW TO TURN THE ISS INTO A HIGHLY ACCURATE SPACE-TIME PROBE.

**Abstract**

Aces (Atomic Clock Ensemble in Space) is an ESA mission in fundamental physics based on a new generation of clocks operated in the microgravity environment of the International Space Station. ACES will be launched and installed on the international station Columbus external platform facility. The operations implementation concept is under fine tuning.

The ACES mission foresee to have the frequency reference distributed on ground by a link in the microwave domain and used to compare distant clocks. These comparisons will allow ACES to perform tests of the Einstein's theory of general relativity including an accurate measurement of the gravitational red-shift, a search for time variations of fundamental constants and tests of the Standard Model Extension. ACES also develops applications in different areas of research including geodesy and Earth observation.

The flight segment, installed on-board of the ISS, comprises two atomic clocks: PHARAO (Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbite), a primary frequency standard developed by CNES and based on laser cooled caesium atoms, and SHM (Space Hydrogen Maser), an active hydrogen maser for space applications. The two clocks are compared and locked one to the other by means of the Frequency Comparison and Distribution Package (FCDP) in order to generate an on-board time scale combining the short-term stability of SHM and the long-term stability and accuracy of PHARAO. The on-board time and frequency reference is distributed via a dual-frequency Micro Wave Link (MWL) to ground sites situated all over the world.

On the ground a set of Micro Wave Link Ground Terminals (MWL GT) installed at ground sites and linked to a local time reference generated by different types of atomic clocks. The ground clocks can also be compared one to other using the common view technique, when two or more ground terminals are simultaneously in visibility of ISS, or, for distant terminals, using the non-common view technique thanks to the very high stability of the ACES on-board reference time. In addition, an optical laser link between the flight segment and the ground allows performing time and frequency comparisons between the on-board time reference and various Satellite Laser Ranging (SLR) stations that are coordinated by the European Laser Timing (ELT) Data Centre.

The system is designed to accommodate up to 35 MWL ground terminals, however currently only 8 are provided. Six terminals are located at universities or institutes: three in Europe, one in Japan and two in the United States. In addition, 2 mobile terminals are provided to allow fine calibration of the fixed ground terminals and also to be used for some specific scientific experiments. The ground terminals are linked to the flight segment using a two-way microwave link (Ku band) and a one-way S-band downlink which is used to determine the ionospheric correction to be applied to the ground data. The planned mission duration is 18 months with the possibility to extend it for other 18 months. During the first 6 months, the performances of the PHARAO and SHM clocks in space will be characterised. The PHARAO target performance is $7 \cdot 10^{14} \cdot \tau^{1/2}$ for the frequency stability and $10^{-16}$ for the frequency accuracy. In the second part of the mission, the on-board clocks will be run in an optimal configuration and compared to the ground based clocks operating both in the microwave and the optical domain.

CADMOS, the ISS operational control Centre USOC (User Support and Operations Centre) owned by CNES and located in Toulouse, France, is the ACES Mission Control Centre and carries out ACES operations in the frame of the Columbus Operations integrated team.

This paper presents the detailed operational concept that introduces ACES into the ISS operational process and operates the ACES flight and ground segments.