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ABSTRACT

Since 2008, the SOLAR package on the ISS has been active in collecting the solar output in earth orbit combining three instruments ranging from the far UV to the infrared. The solar output is an essential parameter for earth atmospheric photochemistry and earth climate. The scientific objectives and results are described by the Principal Investigators in various publications (for example: G. Schmidtke et al (2006). While a short summary of the already achieved science in 2008, 2009 and the first part of 2010 will be given, this presentation will insist on the possibilities given by the ISS and especially COLUMBUS to exterior payloads devoted to the observation of the earth.

Real operations will help understand the actual advantages and disadvantages of the ISS in terms of target pointing, telescience operations and possible use of crew resources.

INTRODUCTION

The SOLAR payload consists of 3 instruments complementing each other to allow measure the solar flux throughout virtually the whole electromagnetic spectrum - from 17 nm to 3000 nm - in which 99% of the solar energy is emitted. The instruments are mounted on a Coarse Pointing Device for accurate Sun pointing and are controlled by a Control Unit. The scientific instruments are:

SOVIM (SOlar Variable & Irradiance Monitor) covers near UV, visible and thermal regimes (200 nm - 100 µm)

SOLSPEC (SOLar SPECctral Irradiance measurements) covers the 180 nm - 3000 nm range with high spectral resolution.

SOL-ACES (SOLar Auto-Calibrating EUV/UV Spectrophotometers) measures the EUV/UV spectral regime (17 nm -220 nm) with moderate spectral resolution.

The SOVIM and SOLSPEC are the upgraded versions of instruments that have already accomplished several orbital flights without failure. Significant refurbishment was nevertheless planned to enable the instrument to meet the ISS requirements (safety, reliability and mission duration) and to improve the instrument performance, utilising the experience gained from the past missions. SOL-ACES is a new development instrument.

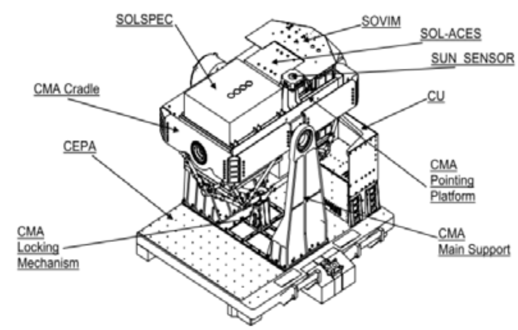

Figure 1. Solar payload overview.

The Coarse Pointing Device is a multi-purpose system that has the function of keeping the supported instruments pointed to a target (e.g.: to the Sun), compensating for the orbital motion of the ISS. During each observation orbit, the Coarse Pointing Device keeps the instruments pointed to the Sun during an observation period of about 15 minutes per orbit. The Coarse Pointing Device provides a movable frame, which can rotate around two axes, thanks to a cardanic type mechanism. The motion is controlled in closed loop, using a sun sensor located on the moving frame, brushless motors and encoders mounted on each axis. The control loops for the two axes are implemented in the software running on the Control Unit. The maximum range of the Coarse Pointing Device angular motion is +/- 25° around the axis compensating for the seasonal variation of the ISS orbit inclination,

Proc. 'ESA Living Planet Symposium', Bergen, Norway
28 June – 2 July 2010 (ESA SP-686, December 2010)

and +/- 40° around the axis compensating for the ISS orbital motion.

The pointing accuracy is +/- 1 degree; the pointing stability is 0.3 deg over 10 seconds.
During launch and re-entry, the Coarse Pointing Device mechanism is locked in both the degrees of freedom by means of an electrically-actuated pin; the pin is retracted only when the payload is on-orbit, in its operational location, such that the pointing function can be operated. From a structural/mechanical point of view, the Coarse Pointing Device is designed such that it can take all launch and re-entry loads due to the acceleration and vibro-acoustic environment typical of the Space Shuttle, acting on its structures and payload.
The Coarse Pointing Device is developed in two versions, one for the SOLAR payload and one for the EXPORT payload. Each version has different instruments accommodation and mess carrying capabilities. For SOLAR the maximum mass carrying capability is 75 kg.

A second Coarse Pointing Device exists as it was also designed for the astronomical payload SPOrt (Sky Polarisation Observatory) which was abandoned in 2005 in favour of studies of the cosmic background using free-flyers, this CPD could be used for earth observations as it can also be targeted at geolocated coordinates.

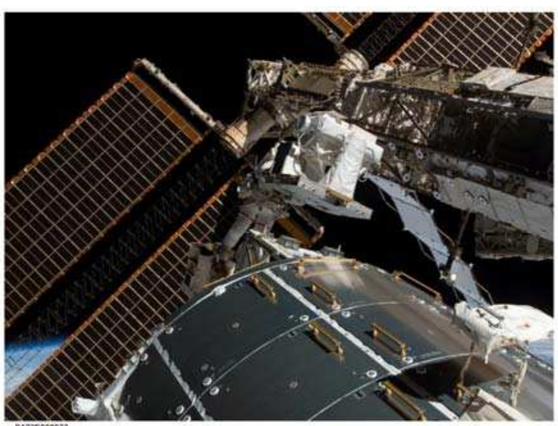

Figure 2. Solar installation EVA (NASA image).

2. OPERATIONS.

After successful launch of STS 122, SOLAR has been installed on Columbus on February 15th, 2008. From the moment SOLAR has been powered on, the Operation team had to ensure 24/7 on console duty as per ESA requirement. All activities were performed in accordance with Col-CC (Columbus Control Centre) Joint Operations Interface Procedures and with coordination with Col-OC (Columbus Operations Coordinator). After a few weeks of operation, it became clear that the operational constraints followed by Col-CC and based on the operation of Columbus as a system were limiting the SOLAR operations in ensuring sustainable support to this scientific mission – planned at that time for 1.5 year and now extended by 3 years. In view of real-time issues, some adjustments to the operational concepts were made in concert with the Col FCT (Columbus Flight Control Team), ESA and the PIs (principal investigator) to ensure the most effective support for the mission.

The performed operations satisfied the requirement as the sun source was observed at each observation opportunity, the source non-availabilities were more important than was expected before launch. These resulted from the sun astronomical ephemeris but also from non nominal attitudes before the solar panels became fully optional. They resulted also from the securing of external payloads during dockings, EVA's and manoeuvres. After commissioning, the operations of the CPD and payload were mainly nominal. Two of the instruments: SOLSPEC and SOLACES performed as scheduled after, unfortunately, the SOVIM instrument had to be switched off after about one year of operation due to a power conditioning problem internal to the instrument. Crew intervention was limited to SOLAR installation and a very few troubleshooting actions in the commissioning phase, crew action can however always be requested in the case the normal remote commanding channels are disabled. The crew has the advantage of having full command capability and uninterrupted monitoring. In earth observations, target monitoring by the crew would be an asset in cases where exceptional events have to be recorded.

3. CURRENT STATUS AND AVAILABILITY.

The availability of a sun observing mission is first limited by the sun visibility window. This is related to the ISS beta angle which relates the position with the ISS orbital plane and which varies slowly over time. These requirements lead to periods where no solar observations can be performed, in the case of this payload, the requirements of the PI's are satisfied as they search for long term trends and do not require continuous recording. The situation would be different if space weather objectives were the main drive of the solar observations, then not only the restrictions on angles imposed by the platform would have to be eased but also the orbit would have to be modified to have a permanent sun visibility. The ISS has unfortunately a fixed orbital plane and an altitude range limited by its stability and access between 350 km and 500 km, these constrains cannot be relaxed.

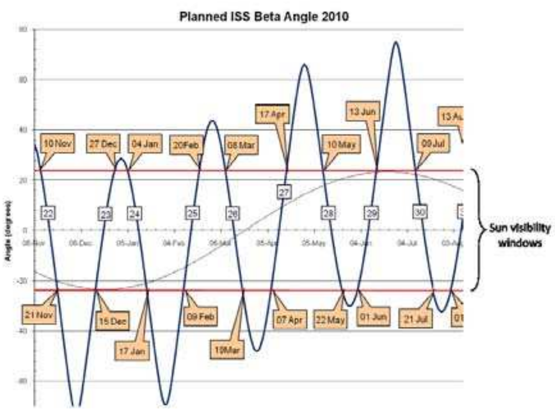

Figure 3. This figure shows the times of nominal solar availability during the first semester of 2010. These curves have also direct significance for atmospheric observations using solar occultations.

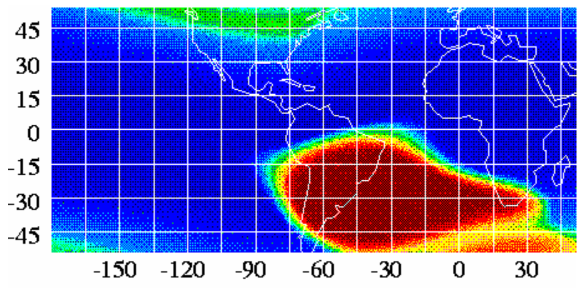

Figure 4. The South Atlantic anomaly (ROSAT image), the South Atlantic anomaly is a supplemental reason of non availability for sensitive instruments, in this plot, it clearly covers the Amazonia region which has special significance for various earth observations programmes.

Moreover, the ISS in its construction period, which is far from over, generates itself interruptions, in particular, when supply spacecrafts as the shuttles, PROGRESS, SOYUZ or ATV's arrive at the ISS, payloads have to be put in standby modes due to the use of thrusters and the release of gases which could be dangerous to the optics, the same is true for EVA's especially if these involve manipulation of the external circuits of coolants. In the first years of operation, it happened also that the station attitude was non nominal as electrical problems implying the solar panels were constraining the orientation. In the beginning of the mission, the commissioning proved to be slower than expected as by definition, a real integrated test can only be performed in flight despite all the pre-flight tests organised by the space agencies and the THALES-ALENIA prime contractor of the platform.

Solar activity has been minimal from 2008 until the middle of 2010 and was not a cause of unavailability but the ISS crosses the South Atlantic anomaly (Fig. 4) and for sensitive electro-optical devices this could also become a restriction.

The result of this is that it is difficult now to establish a complete balance of availability; it is certainly inferior to the more the 95 % availability achieved by the SCIAMACHY payload on ENVISAT. The scientific objectives of SOLAR have been achieved by adapting the operations to the circumstances. The methods used have an importance for future earth observations, the ISS due to the availability of operation centres and even crew has a very superior capability on more automatic satellites by allowing scientific replanning if necessary.

Rigid planning and strict sequences in procedures do not provide the necessary freedom and flexibility to react on scientific results and adapt upcoming activities in view of current results. Planning for such activity should therefore be as flexible as possible whilst still adhering to agreed operational concepts.

In the specific case of SOLAR, the SOLACES instrument is using Command Schedules (CS). A Command Schedule is a dedicated pre-programmed time-ordered sequence of time tagged commands to be sent to the SOLAR instruments or the CPD system. The Command Schedules length is defined by the scientist. Some last for 5 orbits then stop, others last longer than 30 orbits. The scientists have the option to repeat the CS automatically until a command to stop them is sent by ground. Until the CS or sequence of CS to be executed is known, it is not possible to exactly predict when one will stop and commanding will be needed to restart the next one. It is impossible to know two weeks in advance when commanding will be needed either because the sequence of CS is not known or because scientists have specific requests based on latest results. Earth observations as the targets have constant variations should request even greater flexibility.

4. EARTH OBSERVATIONS FROM THE ISS

The orbit of the ISS is inclined at 51.63° and misses the high latitudes; its altitude varies between 350 and 450 km according to operational needs. It is permanently manned and since 2010, its optical windows have been supplemented by the cupola, a set of optical windows for both observation and operation purposes. The ISS has also a number of external locations which can accommodate instruments as the present CPD installed on COLUMBUS and supporting SOLAR.

The orbital situation is perfect for an extensive study of land and atmosphere in the lower latitudes and has an exceptionally good cover of Africa. Operations should relate to specific problems as biomass burning and hydrography.

Fig. 4: an example of Central African observation from the ISS : ISS photograph, May 16, 2002, centred near 8.6 degrees south latitude, 27.4 degrees east longitude. This image shows a simultaneous start of several fires in the dry season in Katanga for trash and burn agriculture. This image was not planned and was taken in an astronaut initiative (NASA document).

Fig. 5: NASA- UCSD Earth-Kam image of SUMATRA (439393 Time Taken (GMT) 2009/293/04:55:02). This image was requested by a Japanese school and can be related to observation of coastal changes after the 2004 Tsunami. The Earth-Kam is an imager used on the ISS for educational purposes.

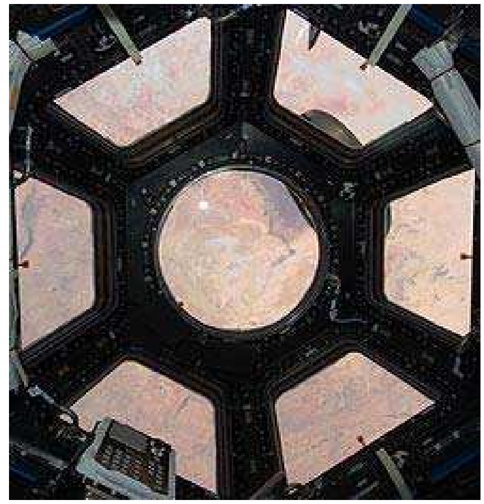

Fig. 6: One of the first images obtained through the ISS cupola, an ancient hydrographic network in the Sahara appears on the image..(image taken by a hand-held camera) (NASA document).

5. CONCLUSIONS

The International Space Station has been until now largely unused for earth observation, its successes in other sciences as microgravity and life sciences are a good argument to consider its use for earth and space sciences in the frame of its recently decided extended to 2020 and later mission.

6. REFERENCES

Brantschen, S., De Smet, L. and Michel, A., SOLAR payload Operations: Achieving Flexibility to support a Long Term Science Mission, AIAA 2010-1951, Space Ops. 2010 Conference proceedings, AIAA, 2010.

Schmidtke, G., Fröhlich,C.and Thuillier, G.: ISS-SOLAR: Total (TSI) and spectral (SSI) irradiance measurements, *Advances in Space Research*, number 37, page 255-264, 2006

7. ACKNOWLEDGMENTS

The authors thank the European Space Agency (ESA) Directorate of Human Spaceflight (D/HSF) and the Belgian Science Policy Office (BELSPO) (ESA Prodex and other programmes) for their funding. B.USOC is part of the Services & Operations Division of the Belgian Institute for Space Aeronomy (IASB-BIRA).