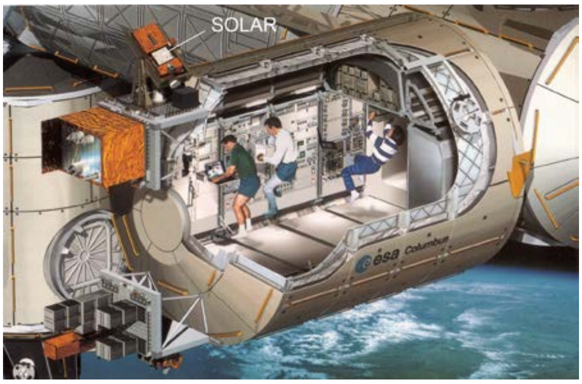
SolACES

Summary

SolACES (SOLAR Auto-Calibrating EUV / UV Spectrophotometers) monitored (quasi) continously the Extreme UV (EUV) and UV radiation of the sun in the wavelength range between 17 and 220 nm during a nearly 9-years measurement campaign onboard the International Space Station (ISS). The instrumnt was launched on 7. February 2008 together with ESA's Columbus module. As part of the SOLAR space science instrument package SolACES is mounted into a Coarse Pointing Device (CPD) on the Columbus External Payload Facility (CEPF). The CPD compensated for the ISS orbital orientation changes and pointed SolACES together with the two other solar science payloads of SOLAR, the Solar Variability and Irradiance Monitor (SOVIM, Switzerland) and the Solar Spectrum Measurement instrument (SOLSPEC, France) at the sun. This allowed simultaneous and complementary measurements of all three instruments. While SOVIM served to determine the total irradiance over the whole solar spectrum, SOLSPEC obtained measurements of the spectral irradiance longward of the SolACES range and overlapping with it (SOLSPEC wavelength range: 180 nm to 3 μm).

The primary science goal of SolACES was to observe the absolute (spectral) irradiance (the solar "constant" in physical units) of the full disk of the sun in the EUV / UV range and its variations with time. The spectral resolution of these measurements varied between 0.5 and 2 nm depending on the wavelength in the spectrum. A novel feature of SolACES, improving all similar space experiments from the past, was its capability to auto-calibrate the instrument repeatedly during the whole mission at regular intervals. This accounted for the inevitable efficiency changes (degradations) of the instrument, and allowed EUV flux measurements with an up to now unprecedented absolute radiometric accuracy of better than 10%. So far, EUV flux measurement uncertainties were typically of the order of 20 to 400% or more.



Apart from its primary goal of monitoring the solar EUV / UV radiation, SolACES aimed at a number of scientific goals as well as applications in satellite operations and technology. The main goals comprised questions from the fields of solar-terrestrial relations, solar physics, stellar astrophysics (comparison between the sun and stars), and the monitoring of the ISS (atmospheric) environment. In particular, basic measurements were expected to substancially improve the thermospheric / ionospheric models of the Earth's atmosphere. Applications of the anticipated results of SolACES are the improvement of forecasts of satellite and space debris orbits, as well as new models for telecommunication via satellites and satellite navigation (space weather).

The development of the SolACES instrument was mutually funded by DLR (55%), ESA (25%), and the Fraunhofer-Gesellschaft (20%), the launch to the ISS being responsibility of ESA. In addition to the development phase, DLR has also financially supported the mission preparation, operation and data reduction phases.

The SolACES science team is led by the Principal Investigator from the Fraunhofer Instiute of Physical Measurement Techniques (IPM) in Freiburg, Germany, which is responsible for the development and the operation of the experiment. Members of the team come from the Kiepenheuer Institute for Solar Physics, Freiburg, the Institute for Meteorology, Univ. of Leipzig, the Astrophysical Institute Potsdam (AIP), DLR / DFD, Neustrelitz (all Germany), Space Environment Technologies, Los Angeles, CA (USA), the Lab. for Atmospheric and Space Physics (LASP), Boulder, CO (USA) , the Space Science Center (SSC) of the University of Southern California, Los Angeles, CA (USA), the Service d'aeronomie, Verrières-le-Buisson (France, SOLSPEC), and the Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center (PMOD / WRC), Davos (Switzerland, SOVIM).

Science Background and Objectives

SolACES comprised the experience of work of more than 40 years in the very complex field of space EUV / UV spectroscopy related to solar-terrestrial relations. Since all the other pioneering groups of the first generation in space research have ceased working in the meanwhile, SolACES was the first experiment to accomplish the inevitable requirement of re-calibrating its spectrometers in-flight repeatedly at rate of minimum twice per month. If not re-calibrated, the measured variability of the solar irradiance cannot be separated from variations caused by the efficiency changes and degradations of the spectrometers. These depend on various surface effects, temperatures variations, angle of incident radiation and other effects, leading to time and wavelength dependent efficiency functions.

SolACES achieved its auto-calibration capability by using two tri-current ionisation chambers, filled with the gases Ne, Xe and NO, as primary detector standards, and silicon diodes as secondary detector standards. The ion currents measured at the chambers are directly related to the incoming solar photon fluxes determined in wavelength subranges being selected by 43 different filters.

The primary goal of SOLAR was the (quasi-) continuous measurement of the solar "constant" in order to separate solar effects from human influence on climatology. In addition to this, modelling of changing VIS-UV-EUV emissions in dark spots and the surrounding active areas on the sun was one of the topics of SolACES in solar physics. It is intended to apply these models to past and future integral space measurements of the solar constant.

Beyond the primary SOLAR science goals SolACES was expected to contribute to other science areas of strongest interest, because the EUV radiation by the sun is THE primary energy source for the thermospheric / ionospheric (T/I) system of Earth's atmosphere. Thus, most of the T/I processes are controlled by the solar EUV radiation which strongly changes on short-term (solar flares), medium-term (solar rotation), and long-term time scales (solar cycle). However, due to the technological challenges before SolACES this important energy source was not known to a level of accuracy that is required for today's state of science (aeronomy of the thermosphere and ionosphere, solar physics, interplanetary and planetary physics), and - even more serious - to the requirements in applied fields such as navigation (especially the GPS technology), drag analysis of the ISS and satellites, radar measurements and telecommunication.

In the past, the given radiometric accuracies of solar EUV flux measurements in the important spectral region of less than 100 nm ranged from 20% up to 400% and even more. Thus, the goal of SolACES to lower this level to <10% meant a strong improvement. Uncertainties lower than 5% have been reached depending on the specific sub-wavelength range. This progress has been achieved by introducing for the first time an auto-calibrating system with a very high absolute and statistical accuracy. In view of the on-going US missions TIMED and SORCE that neither have this in-flight re-calibration capability, nor the high statistical accuracy, SolACES has contributed with new results in a number of different fields of space science and its applications. In particular, SolACES and SOLAR gained new results in the following fields:

- (Quasi-) continuous **monitoring of the solar** EUV / UV **radiation** (more than 15 spectra per day)
- Radiometrically accurate determination of the **solar EUV / UV spectral irradiance** between 17 and 220 nm

- Modelling of the solar EUV / UV spectral / total irradiance
- Modelling of the **terrestrial thermosphere and ionosphere**
- Determination of solar EUV / UV **indices**
- Semi-empirical modelling of **active regions of the sun**
- Spectroscopy of hydrogen emissions of active regions
- Investigation of **solar-terrestrial relations**
- Investigation of **solar-stellar connections**
- Aspects of **space weather** (impacts on satellite telecommunication and navigation)
- Interactions of solar EUV radiation with the ISS
- **ISS environment** changes with solar activity
- **EUV / UV space instrumentation** and its calibration
- Cross-calibration with other EUV space instrumentation

In order to cooperate with the most important groups working in all these fields the Principal Investigator of SolACES has initiated the international **TIGER** (Thermospheric-Ionospheric GEospheric Research) program in coordination with the SCOSTEP (Scientific Committee On Solar-TErrestrial Physics) and the COSPAR (Committee on Space Research) international organisations.

Key Characteristics of the SolACES Development and Operation

- Start of Development: November 1998
- Start of Mission: 7. February 2008
- Launcher: Space Shuttle (NASA)
- Place of launch: Cape Canaveral
- Nominal mission duration: 18 months
- Mission duration: until February 2017
- Orbit characteristics: ISS orbit (altitude ~400 km)
- Mission Control Center: B.USOC (Belgium)
- Observation schedule: max. 20 minutes per orbit

Key Instrument Characteristics

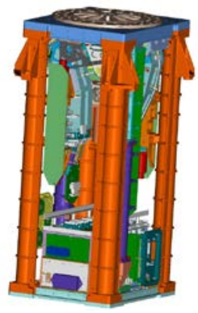
- Mass: 23.0 kg (SolACES instrument)
- Size: 25 x 29 x 60 cm^3
- Electrical power consumption: < 25 W (typ.), 60 W (max.)
- Data rate: ~1.0 kbit/s
- Spectral range: 17…220 nm (EUV / UV)
- Spectral resolution: 0.5…2 nm

SolACES Payload Description and Measurement Principle

SolACES used two twin spectrophotometers with four different diffraction gratings and channel electron multipliers as detectors, and two ionization chambers equipped with photodiodes, to detect the inciding EUV / UV radiation and to perform the in-flight calibration. A common filter wheel for the spectrometers and the ionization chambers, containing 43 different thin film metallic and crystal filters, served to select the spectral bandpasses during the calibration procedure.

Standard spectrophotometric measurements were carried out using the spectrometers without any filters to obtain one or two EUV / UV spectra per orbit, integrated over the full disk of the sun (i.e. more than 15 spectra per day will be recorded).

The auto-calibration procedure was executed at regular intervals during the mission phase. During the procedure, the transmissions of the filters were determined by comparison of spectrometer measurements with and without filters. Absolute EUV / UV fluxes integrated over each of the selected filter bandpasses were then obtained by ionization chamber measurements. Taking into account the actual filter transmissions, these flux determinations were then used to derive calibration factors for the standard measurements.



During all standard measurements and calibrations the accurate pointing towards the sun had been ensured by the CPD.

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Status: May 2017