

# International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

*Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny*



## *OPSys: optical payload systems facility for space instrumentation integration and calibration*

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icso proceedings



## OPSys: Optical Payload Systems facility for space instrumentation integration and calibration

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### ABSTRACT

The Optical Payload System (OPSys) is an INAF (Italian National Institute for Astrophysics) facility hosted by Aerospace Logistics Technology Engineering Company (ALTEC SpA) in Turin, Italy. The facility is composed by three clean rooms having different cleanliness levels, a thermo-vacuum chamber (SPOCC, Space Optics Calibration Chamber) with a motorized optical bench and several light sources covering the range from the extreme ultraviolet to the red light wavelengths. The SPOCC has been designed having in mind the very stringent requirements of the calibration of solar coronagraphs and the suppression of the stray-light. The facility and the optical performances will be described here. The calibration campaign performed on Metis space coronagraph will be reported as a case study.

**Keywords:** Payload calibration facility; coronagraphs; optical calibrations; space instrument; vacuum chamber

### 1. INTRODUCTION

The on-ground calibration plays a crucial role on the development process of space instrumentation. The overall instrumental performances are in most cases dependent of the quality and accuracy of these calibrations. The Italian National Institute for Astrophysics (INAF) have developed the Optical Payload System (OPSys) facility for the AIV (assembly, integration and verification) activities and the calibration of optical instrumentation. The facility is hosted by the Aerospace Logistics Technology Engineering Company (ALTEC S.p.A) in Turin, Italy. The facility environment is controlled in terms of temperature/humidity and cleanliness (see par. 2). In the cleanest part of the lab, is located the optical bench. This is part of the so called Space Optics Calibration Chamber (SPOCC), described in the paragraph 3. The OPSys has been used for the integration and calibration of the Metis instrument, the coronagraph on board the ESA/Solar Orbiter mission. The calibrations performed on this coronagraph will be reported in the par. 4 in order to show how the facility can be used.

### 2. The OPSys facility

The OPSys facility consists of a controlled area of about 100 m<sup>2</sup>. As depicted in Figure 1, the laboratory is composed by three different rooms with different cleanliness level:

→ The “Grey room” classified as ISO-8 following the ISO 14644-1 standard (see Figure 2a). This room of about 50 m<sup>2</sup> hosts:

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- The SPOCC pipeline;
- The SPOCC pumping section;
- The SPOCC light sources;
- The controller of the SPOCC optical bench;
- The SPOCC thermal system control and monitoring;
- The SPOCC vacuum system monitoring system;
- The SPOCC control workstation;
- The OGSE/EGSE storage area;
- The operator desk.

The dedicated instrument controllers are positioned here during the activities. Moreover in this area is performed the cleanliness of the items to be introduced in the clean rooms.

→ The “ISO-7 Clean room”. (see Figure 2b) This room of about 35m<sup>2</sup> is dedicated to support the activities performed in the ISO-5 Clean room. The equipments of this area are:

- The optical bench allows to perform optical activities (if the cleanliness level expected are compatible with this environment);
- The laminar flow bench, guarantying the ISO-5 cleanliness level;
- Two closets for the storage of “clean” materials;

The SPOCC cover is placed in this area when open.

→ The “ISO-5 Clean room” (see Figure 2c), of about 11m<sup>2</sup> host the SPOCC optical bench and is the place where the AIV and the calibration activities are performed. The cleanliness level is guaranteed by 12 HEPA filters.

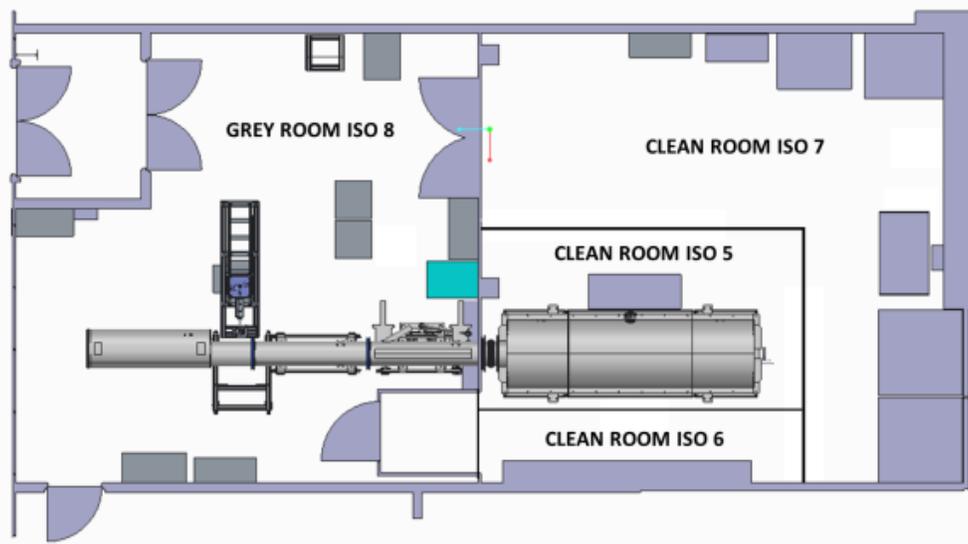


Figure 1. The OPSys laboratory and the layout of the SPOCC chamber

All the environments are controlled and continuously monitored in terms of temperature, relative humidity and particle contamination. In the last years several improvements has been introduced with respect to the original facility configuration described in [1] especially in terms of cleanliness control and monitoring.



Figure 2 : OPSys facility rooms: (a) ISO-8 grey room; (b) ISO-7 clean room; (c) ISO-5 clean-room

### 3. The Space Optics Calibration Chamber (SPOCC)

The SPOCC is the optical test and calibration vacuum chamber housed in the OPSys facility. The vacuum calibration chamber was designed for performing integration and verification activities on optical payload. However, thanks to its features, the chamber is extremely adaptable for performing the following activities:

- pre-flight qualifications of generic items (on-board computers, data handling, flight items, etc..) where a specific vacuum environment is required;
- pre-flight qualifications of scientific instruments and sensors, optical pointing devices, solar panels sensitive to their alignment;
- calibration and verification of scientific optical instruments;
- integration, calibration and verification of solar telescopes.

The SPOCC is composed of the following four main sections:

- Sun-simulator section, hosting the source and the Sun-simulator optics. The first 2050 mm of this section has a diameter of 600 mm, while the following 500 mm has a diameter of 400 mm.
- Removable pipeline section, a cylindrical segment with a length of 1850 mm and a diameter of 400 mm.
- Pumping section, where the pumping system is installed. This section have a diameter of 400 mm and a length of 1850 mm.
- Test section, consisting of a cylindrical chamber made of two semi-circular halves split along the chamber longitudinal axis. The top half can be removed to access the optical bench inside the bottom half. The test section is equipped with an optical table with five stepper motors allowing tilts and translations on the table plane.

The main optical features of the calibration chamber consist of a Sun simulator, a light trap and a variety of baffles (see *Figure 3* and *Figure 4*).

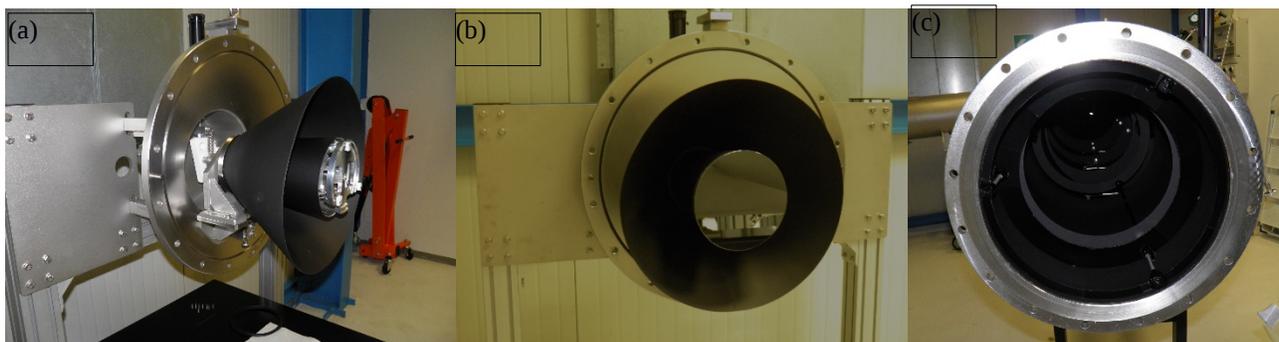


Figure 3: Space Optics Calibration Chamber optical features: (a) light trap, (b) off-axis parabolic mirror, (c) baffles

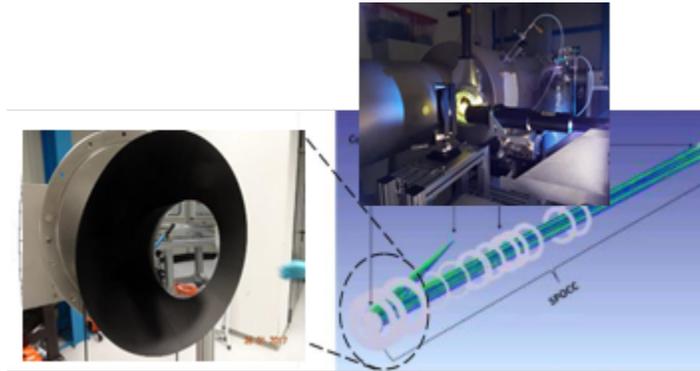


Figure 4: Optical Payload Calibration Chamber ray tracing

The SPOCC solar simulator is an off-axis parabolic mirror focusing the light incoming from a source. The mirror within the chamber is coated with a SI/Mo multilayer having an Ir-Mo capping layer, designed for operation in the visible and UV, and at an EUV wavelength of  $\lambda = 30.4 \text{ nm}$  at  $4.93^\circ$  incidence. Its diameter is of 165 mm with a curvature of about 400 mm. A dedicated mechanism allows movements along the directions perpendicular to the mirror optical axis. Due to the flexibility of this system, it is possible to simulate a collimated beam with the Sun divergence at the Earth-Sun distance (i.e. 1 AU), up to 0.5 AU, or a focused beam with Sun divergences corresponding to closer distances to the Sun. The spectral reflectivity of the collimator is plotted in Figure 5.

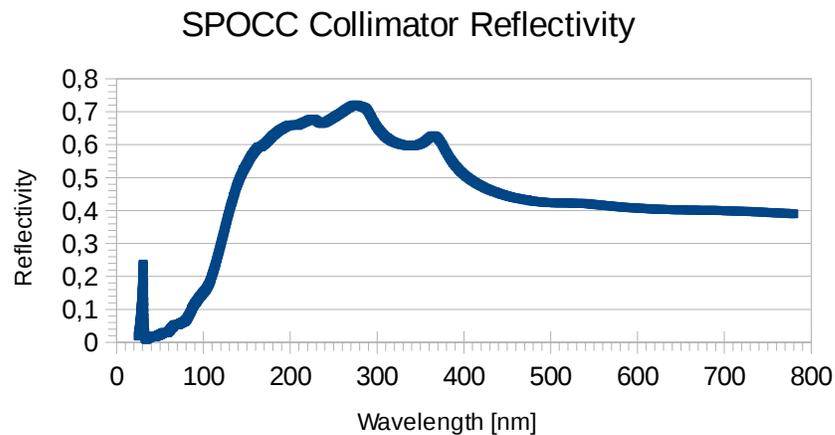


Figure 5: The SPOCC collimator reflectivity

Due to the off-axis mirror optical features, the SPOCC allows performing tests in the visible and in the ultraviolet light spectrum. Consequently, a variety of light sources is present in the OPSys facility: a monochromator working in the wavelength range from 30 nm to 1200 nm can be coupled with an hollow cathode source for performing test in UV and EUV light, a VUV Lyman Alpha source and, the Illumination System in Visible Light (ISVL). Moreover, a suitable vacuum equipment permits to change the light source without compromise the vacuum level previously established in the test chamber. For interfacing the visible light source, the chamber has been provided with a 101.6 mm fused silica optical window with two anti-reflection coated surfaces optimized in the  $500 \div 700 \text{ nm}$  interval and able to sustain a delta pressure of 1 atm. The off-axis parabolic mirror inside the calibration chamber is surrounded by a light trap consisting of two concentric cones coated with VEL-BLACK<sup>®</sup>, that guarantees 99.95% absorption in the visible range.

As a result, the computed level of brightness of the light trap is less than  $10^{-11}$  time the source brightness. This minimizes the probability of entering stray-light rays to exit back into the chamber toward the payload under test. To the aim at further improving stray-light suppression, a series of baffles has been inserted along the pipeline. The purpose of these baffles is to suppress rays coming from the edge of the mirror. Moreover, the SPOCC inside wall has been painted with Aeroglaze<sup>®</sup> Z306, characterized by a low level of volatile emissions.

The SPOCC optical features guarantee the minimum possible level of stray light inside the chamber. In order to allow the stray light rejection measurements down to  $1 \times 10^{-9}$  a suitable visible light source has been developed. The Illumination System in Visible Light ISVL [2] has the purpose of simulate the Sun disk. Two re-imagers are used to properly operate ISVL, namely the IC re-imager (IC, infinite conjugated) and the FC re-imager (FC, finite conjugated). Figure 6 shows the ISVL layout. The optical performances of the source are reported in [2].

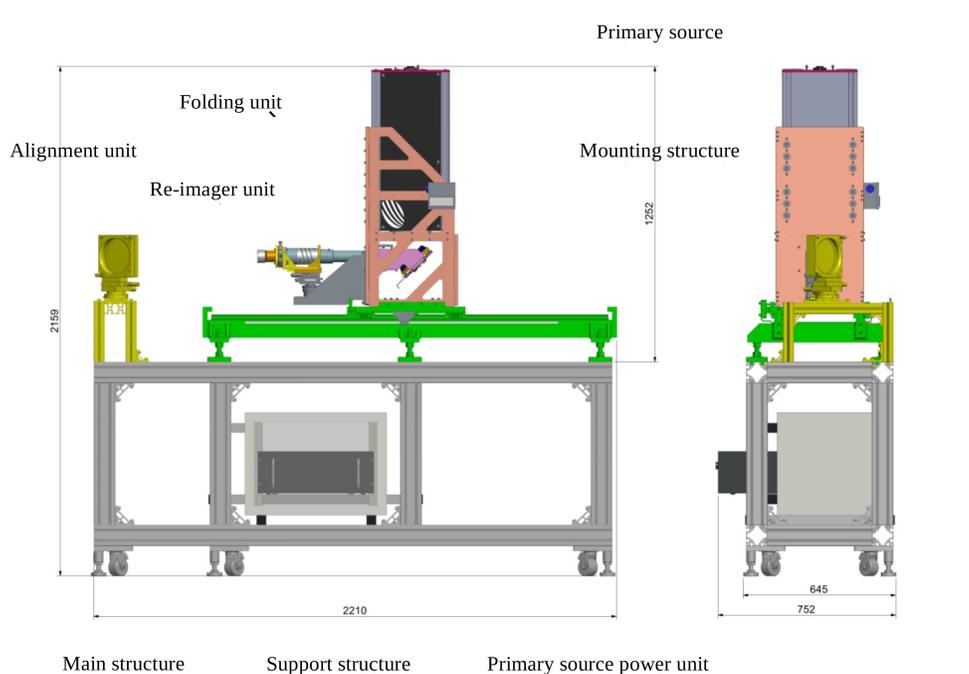


Figure 6 : ISVL Layout

The optical bench inside the SPOCC is made of aluminum profile and its dimensions are 900 mm x 3500 mm, that is the maximum useful planar surface (see Figure 7). Due to the dimensions of the SPOCC test section, the optical bench can host instruments high, at least, 550 mm.

The main feature of the optical bench is the possibility to tilt it in pitch and yaw and to translate it perpendicularly to the chamber longitudinal axis. As the matter of the fact, the SPOCC bench is provided with two groups of actuators located near its edges. The actuators are servo-controlled by a remote workstation hosted in the ISO 8 clean room. Table 1 reports the optical bench performances in terms of maximum allowed translations and rotations.

Table 1: Optical bench performances

<b>Translation</b>	Vertically (y-axis) left front total stroke	34 mm
	Vertically (y-axis) right front total stroke	40 mm
	Vertically (y-axis) rear total stroke	71 mm
	Laterally (x-axis) front total stroke	40 mm
	Laterally (x-axis) rear total stroke	101 mm
<b>Tilt</b>	Yaw (x-z plane)	$\pm 2^\circ$
<b>Tolerances in translation</b>	Resolution	25 $\mu\text{m}$
	Stability (over 1 hour)	125 $\mu\text{m}$
	Accuracy	125 $\mu\text{m}$
	Repeatability	50 $\mu\text{m}$
<b>Tolerances in the angular motion</b>	Resolution	0.3 arcmin
	Stability (over 1 hour)	20 arcsec
	Accuracy	1 arcmin
	Repeatability	0.6 arcmin

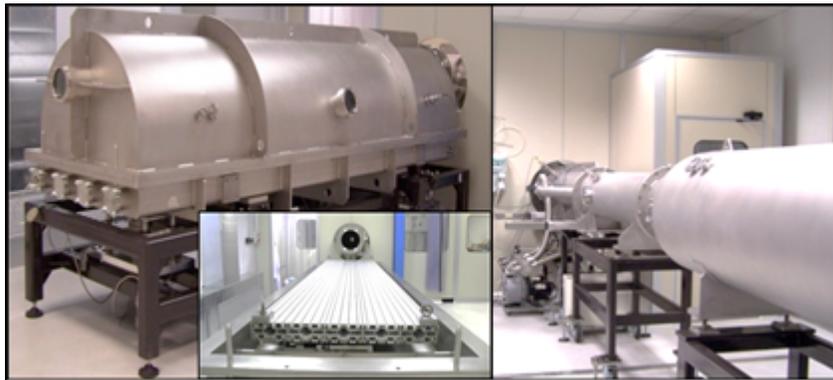


Figure 7: Space Optics Calibration Chamber and its optical bench

The SPOCC vacuum subsystem is a two-stages pumping system; it is composed of two tri-scroll pumps of 500 liters/minute each and two turbo-molecular pumps of 2000 liters/second each.

The tri-scroll pumps bring the pressure from atmosphere to  $1 \cdot 10^{-2}$  mbar in about half hour. As a consequence, the air contained in the chamber passes from the viscous or laminar to the molecular regime. At that point, the turbo molecular pumps can be safely turned on. The SPOCC pumping system reaches a pressure of  $1 \cdot 10^{-6}$  mbar after 24 hours in dynamic vacuum condition hampered by the outgassing from the internal coating of the chamber, when the cold trap is used. It is also possible to isolate the chamber from the pumps by closing two servo-controlled gates-valves.

Six vacuum gauges (two thermocouples for the low vacuum, two cold-cathodes for the high vacuum and two full range gauges) monitor the internal SPOCC vacuum level. These sensors are distributed along the SPOCC in order to keep under control the vacuum level in each section of the chamber. An example of the pressure plot is shown in Figure 8.

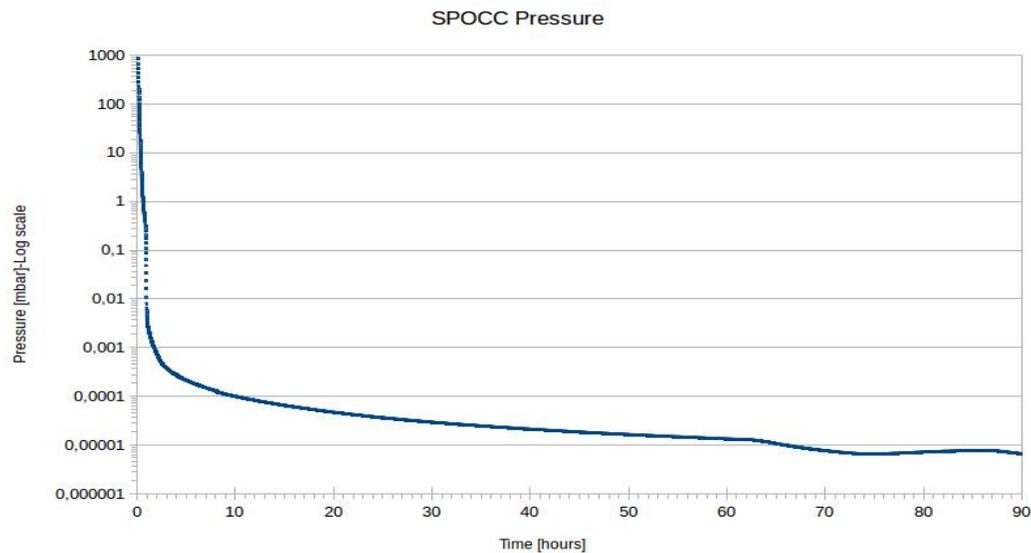


Figure 8: SPOCC vacuum plot when the cold trap trap is not used

The SPOCC is equipped with a thermal subsystem consisting mainly of a cold plate cooled by a LN<sub>2</sub> pipelines system and used as cold trap for contamination. A copper bar connects the cold plate to six removable thermal straps that can reach the cold spots (if any) of the optical payload under test.

The temperature at the interfaces, on the cold plate and along the copper bar are real-time monitored and controlled through a dedicated control panel.

#### 4. The Metis instrument assembly and calibrations

Metis is the coronagraph of the ESA Solar Orbiter mission and it will acquire, for the first time, simultaneous imaging in the visible light (580-640 nm) and in the Ly- $\alpha$  line (121.6 nm) of the solar corona [3]. The integration and the calibration activities on the Metis coronagraph have been performed in the OPSys facility.

Here are listed the main calibrations performed on the Metis coronagraph are [4], [5], [6], [7] and [8]:

→ Visible Light Channel:

- Detector dark current characterization;
- Point Spread Function (PSF) [3];
- Vignetting;
- Radiometric;
- Polarimetric;
- Stray light.

→ UV Channel:

- Detector dark current characterization;
- PSF and radiometric in analog mode;
- PSF and radiometric in photon counting mode.

## 5. Conclusions

The OPSys facility located at ALTEC SpA has been designed to be a solar instruments test facility. Nevertheless, due to its features, it is extremely adaptable to test a variety of contamination sensitive optical payloads.

The SPOCC can recreate environmental conditions representative of space and, with its motorized optical bench, permits to perform tests considering different line-of-sight of the instrument, preserving the vacuum conditions. Its thermal subsystem offers the possibility to control the temperature of sensitive parts of the instrument under test.

In the frame of future space missions, the OPSys facility could represent a suitable laboratory in which perform the integration and the calibration activities on a variety of space flight instruments and optical payloads.

## ACKNOWLEDGMENTS

This work has been supported by the Italian Space Agency – ASI - under contract to the co-financing National Institute of Astrophysics (INAF) Accordo Addendum I/013/12/0 and under the contract to the industrial partners: ASI-ATI N. 2013-057-I.0.

ASI prime contractor for the Metis project has been OHB-CGS that delivered the opto-mechanical design, the electronics and the software. Thales Alenia Space Italy was responsible for the instrument integration and alignment activity. The VLDA assembly was provided by MPS under Contract 2013-058-I.0 with the Italian Space Agency (ASI). The UVDA assembly was provided by MPS as German contribution to Metis thanks also to the financial support of DLR (grant 50 OT 1201). The primary and secondary mirrors were provided as Czech contribution to Metis; the mirror hardware development was possible thanks to the Czech PRODEX Programme.

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