International Conference on Space Optics—ICSO 2012

Ajaccio, Corse

9–12 October 2012

Edited by Bruno Cugny, Errico Armandillo, and Nikos Karafolas

Conceptual design of a stray light facility for Earth observation satellites

Y. Stockman

M. L. Hellin

S. Marcotte

E. Mazy

et al.

International Conference on Space Optics — ICSO 2012, edited by Bruno Cugny, Errico Armandillo, Nikos Karafolas
Proc. of SPIE Vol. 10564, 1056402 · © 2012 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309193

Conceptual design of a stray light facility for earth observation satellites

Y. Stockman*, ML Hellin*, S. Marcotte*, E. Mazy*,

* *Centre Spatial de Liège - Université de Liège, Avenue du Pré-Aily, 4031 Angleur, Belgium*
e-mail address ystockman@ulg.ac.be

J. Versluys**, M. François***, M. Taccola***, A. Zuccaro Marchi***

** *OIP Sensor Systems, Westerring 21, B-9700 Oudenaarde, Belgium.*
*** *ESTEC – European Space Agency, Keplerlaan 1, NL-2200 AG Noordwijk ZH, The Nederlands*

Abstract — With the upcoming of TMA or FMA (Three or Four Mirrors Anastigmat) telescope design in Earth Observation system, stray light is a major contributor to the degradation of the image quality. Numerous sources of stray light can be identified and theoretically evaluated. Nevertheless in order to build a stray light model of the instrument, the Point Spread Function(s) of the instrument, i.e., the flux response of the instrument to the flux received at the instrument entrance from an infinite distant point source needs to be determined.
This paper presents a conceptual design of a facility placed in a vacuum chamber to eliminate undesired air particles scatter light sources. The specification of the clean room class or vacuum will depend on the required rejection to be measured. Once the vacuum chamber is closed, the stray light level from the external environment can be considered as negligible. Inside the chamber a dedicated baffle design is required to eliminate undesired light generated by the set up itself e.g. retro reflected light away from the instrument under test. This implies blackened shrouds all around the specimen.
The proposed illumination system is a 400 mm off axis parabolic mirror with a focal length of 2 m. The off axis design suppresses the problem of stray light that can be generated by the internal obstruction. A dedicated block source is evaluated in order to avoid any stray light coming from the structure around the source pinhole. Dedicated attention is required on the selection of the source to achieve the required large measurement dynamic.

I. INTRODUCTION

The Centre Spatial de Liege (CSL) has been involved since twenty years in the characterization and evaluation of stray light for space instruments (ref [1] to [5]). Today CSL is developing a new facility for the stray light characterization of small earth observation satellites. Stray light issues are tackled in different ways. For large payloads deep stray light analysis is carried out, tests at subsystem are performed or partial illuminations are also envisaged. For small EO satellite, it is possible to perform an end to end test to evaluate the stray light characteristic of the instrument.

II. TEST FACILITY REQUIREMENTS

For an optical system, the stray light contributions may be summed as In-field Stray light (IFS) and Out-of-field Stray light (OFS). The major stray light contributions are:
- the effects of mirror roughness,
- the effects of dust on the mirrors,
- the scattering induced by the aperture stop,
- the effects of ghosts,
- the stray light due to Sun and Moon, or any intense light source out of the FOV.

The facility will not be able to directly identify the sources of stray light listed here above, but it will verify that the stray light contribution for along track angles (taken in absolute values) larger than 10 arc degrees or for across track angles larger than 25 arc degrees are negligible, and to confirm the dominant contributor to stray light. For example in the case of PROBA V that will be the first tested payload in this facility, the major in field stray light contributor is the aperture stop. The models indicate that aperture stop contribution to stray light is close to flat with respect to any angular contribution and extend typically on +/-9 arc degrees in the along direction and +/-22.5 arc degrees in the across direction. The mirror roughness and dust contributions are indistinguishable in practice and bear a strong angular variation from the incident direction.

III. TEST FACILITY CONCEPT DESCRIPTION

A. Stray light test facility overview

The facility is in a clean room to eliminate undesired air particles scatter light sources and to allow to work with space hardware. To cope with this, the stray light facility is developed in a vacuum chamber. The baseline is to use the vacuum chamber closed, in such a way that the stray light levels from the external environment are negligible.
Inside the chamber dedicated baffle design is studied to eliminate undesired light generated by the set up itself e.g retro reflected light away from the instrument under test. This implies blackened shrouds (with AZ603 or MAP) inside the facility.

The proposed illumination starts from a 400 mm off axis parabolic available at CSL. The off axis design suppresses the problem of stray light generated by the internal obstruction. A dedicated block source is developed to avoid any stray light coming from the structure around the source pinhole as well as the fold mirror.
The GSE consists in a rotation of + /- 180 ° and tip tilt from - 10 ° to + 10 °.
Dedicated attention is required on the selection of the source to achieve the large required measurement dynamic range and to the stray light analysis. This is basically the only way to guarantee that there is no residual stray light coming from the facility itself.

A general design of the facility is presented in Figure 1. The facility consists in the following items:

1) the vacuum chamber
2) the collimator in an auxiliary chamber
3) the source pack
4) the rotating table
5) baffle design

Each of these subsystems will be described here after.

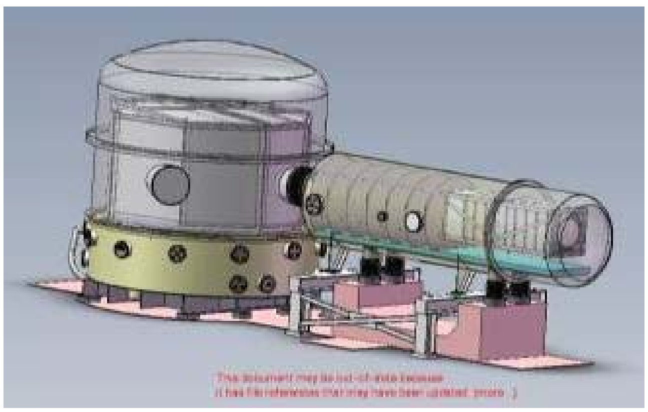


Figure 1. Stray light facility general overview

B. The vacuum chamber

The set up is implemented in FOCAL 3 facility. FOCAL 3 (acronym of Facility for Optical Calibration At Liège) is composed of two stainless steel vessels located in a class 10 000 clean room (following US standard: FED-STD-209E): one main vertical cylindrical chamber of 3 m diameter and 2.8 m height and an auxiliary horizontal axis of 1.2 m diameter and 5 m length. The stray light test set-up is developed in a Class 100. Two optical benches are installed respectively in the main chamber and in the auxiliary chamber. Both benches are put on the same seismic block which is actively controlled thanks to 5 air cushions.
Focal 3 chamber will be used at air. Literature and CSL experience indicated that up to 10^{-8} air scattering is not an issue. Primary pumping is foreseen when measurements down to 10^{-10} need to be achieved.

C. The collimator

The collimator consists in a 400 mm off-axis parabola with a 2 m focal length. It will be placed in the auxiliary chamber as far as possible from the tested payload (about 5 m). A stainless steel truss supports the parabolic mirror cell and the focal plane. The truss is in stainless steel and is black painted with MAP PU1 and backed (see Figure 2.).

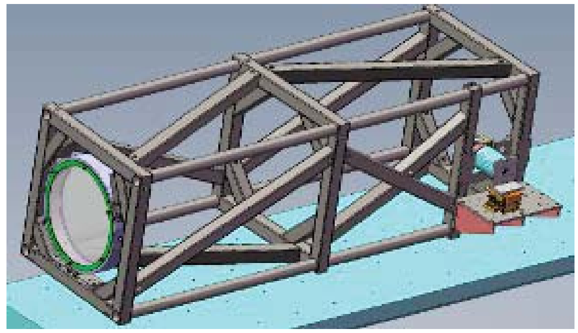


Figure 2. Collimator truss and source pack interface

1) The collimator baffling

The collimator baffling is divided in two parts. A first baffling of the truss (see Figure 3.) consists in a set of 2*4 black MAP PU1 Aluminum sheets to close the side of the truss. These sheets have 10 additional vanes.
A second baffling (see Figure 4.) is placed in the auxiliary chamber to hide the visibility of the metallic parts of the vacuum chamber with respect to the instrument. It consists of a set of 7 black MAP PU1 Aluminum sheets with an aperture of 440 mm.

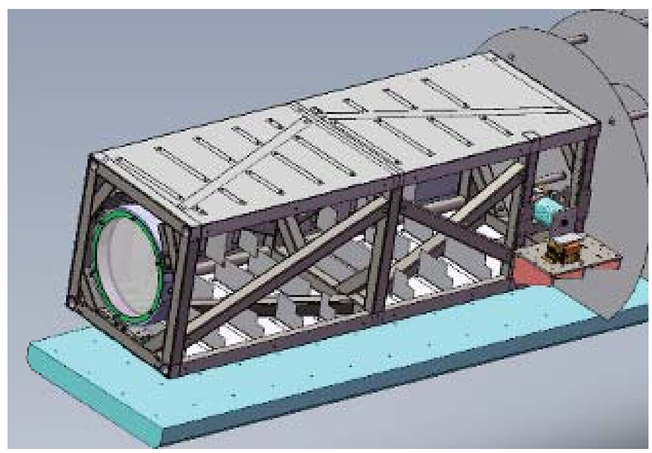


Figure 3. Collimator trust baffling

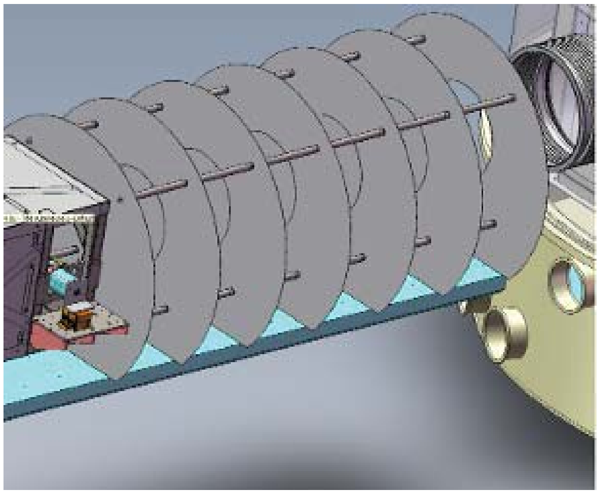


Figure 4. Auxiliary chamber baffling

D. The source pack

The Source pack requires several items. In a first time it needs an adequate baffling to avoid stray light in the FOV coming from the source itself. Secondly it necessitates a strong source since very low level of stray light wants to be detected. To fulfill this, two sources are used, one plasma source with a 230 µm core Optical Fiber (OF) for IFOV and one NIR 20W laser diode with a 600 µm core OF for OFOV measurements. To manage the great dynamic range an attenuation system is also implemented. This is controlled with monitoring detectors.

E. Source baffling

This baffling is a critical part of the set up for the IFOV stray light performances. The goal is to have a system able to illuminate only one single pixel and to get a level lower than 10^{-8} in the neighbour pixels. It is required that this level of 10^{-8} is achieved after a few (2 - 4) arcminutes. Since this is very difficult to measure, the requirements are demonstrated by analysis.
The source baffling has 2 main objectives. A first is to avoid any stray light coming from reflection of parts close to the source or backscattered to the source; a second is to limit the output beam F_{number} in order to avoid illumination of the parabolic mirror mount which is in direct view with the tested instrument.

To minimize these stray light contributions, a light trap is placed in face of the source pinhole (see Figure 5.) For the folding mirror care is taken on the scratch and dig and the micro roughness (less than 1 nm RMS) to minimize the scattering. For the remaining backscattered light if any, a light trap, like a pyramid in black glass, is placed around the source pinhole. The top of the pyramid has a hole of 400 µm for the IFOV test. The pyramid is in Schott NG1 black glass, to get a good absorption of the residual back scattered stray light. The pyramid shape is designed to reflect the ~4% specular reflected beam in the cylinder light trap. The cylinder around the pyramid is designed as a light trap such that no stray light is coming out the baffle.
Since there are two sources (for IFOV and OFOV test), the baseline is to use only one identical focal plane for the in and out field of view stray light with 2 different pyramids. The only thing to change in the pyramid design is the output hole for the fiber: instead of a 400 µm hole a 800 µm is drilled and another optical fiber with a other feedthrough is used.
To go from one pyramid to the other, the mechanical pyramids are designed to allow the replacement with an accuracy better than 50 µm interface. Nevertheless, no motorized units will be used, so that to change the source, it will be requested to open the auxiliary chamber.

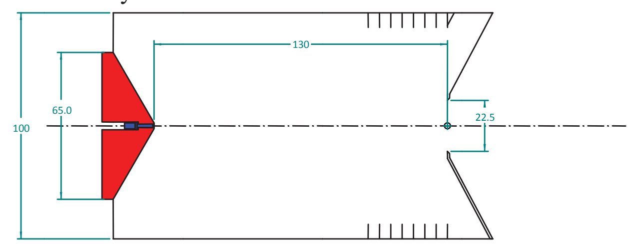


Figure 5. Light trap model

F. Visible source

The baseline is to use fiber coupled source with the highest brightness possible. The proposed source presents a spectral integrated stability of 0.018% 1σ standard deviation. The fact that it is a fibered source allows to put all the heating parts and potential stray light source outside the chamber and to feed the focal plane only with a 230 µm optical fiber.

G. Laser diode source

A NIR 20W laser diode pigtailed into a 600 µm optic fiber is used for OFOV measurements. The laser diode characteristics are summarized in table 1.

CW output power:	20 W
Fiber core diameter:	Φ 600 µm
Numerical aperture:	NA 0.22
Central wavelength:	808 ± 4 nm
Spectral width:	< 3 nm
Manufacturer:	Thomson-CSF

Table 1: Laser diode characteristics

H. Attenuation and coupling system

The attenuation and coupling system is sketched in Figure 6. The aim of this system is to allow attenuation of the source outside the chamber. It is realised with an achromatic afocal system (x1 magnification) into which Neutral Density Filter are introduced.

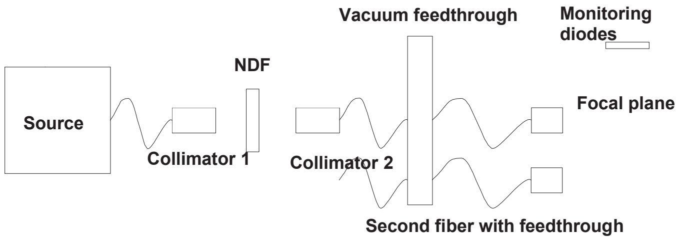


Figure 6. Source pack layout I/F

I. Monitorings

1) Flux stability monitoring

Since long integration time is required, the flux intensity will be monitored. This will be realized with a vacuum compatible detector able to measure 10^{-4} beam intensity variation.
The detector will be placed outside the useful beam and will collect a small part of the collimated beam (see Figure 7.).

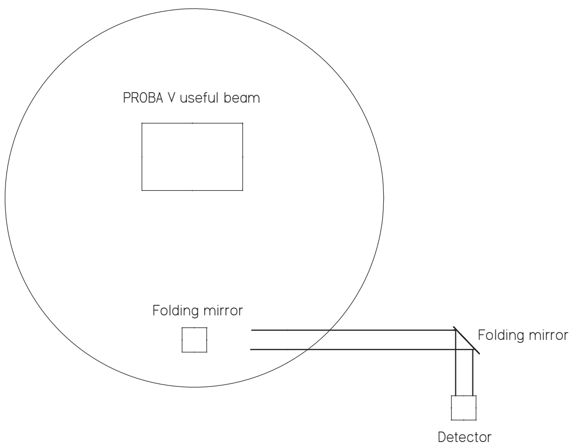


Figure 7. Monitoring detector

2) Stray light level monitoring

To control any residual light inside the chamber during the test and the movements of the payload in the different FOV, a PMT working in counting mode is placed inside the black chamber. The PMT is fixed to the shroud and only the photo sensitive face is inside the chamber. The PMT is positioned at the level of the payload and behind it (see Figure 8.)

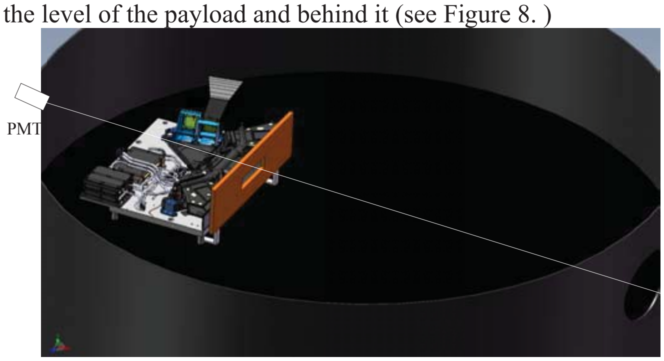


Figure 8. Straylight PMT Monitoring detector and chamber shrouds. The orange front panel is also blackened (e.g. metal black sheet)

IV. BAFFLE DESIGN

One of the most critical parts in the design of the stray light facility is to get rid of all internal stray light coming from reflection of the wall of the chamber or retro reflection from the tested item.
To limit this stray light, it is proposed to put the payload in a black box as large as possible: the chamber surrounded by black painted walls. Additionally a payload baffle in front of the entrance aperture is set (orange baffle in Figure 8.) to avoid back reflection to the focal plane.

A. Facility baffle design

The wall of internal tent is painted in black with MAP. Front part of the tent is also painted in black.

Figure 9. Facility baffling drawing and before painting

A black painted Kapton foils make the link between the MGSE and the facility baffles, allowing MGSE rotation without interference.

B. Payload baffling

A small baffle is put at the level of the entrance payload primary baffle to block any remaining light coming from the collimator outside the baffle aperture. Care is taken on this baffle since it receives the full beam of the collimator and this

baffle should retro reflect light as less as possible. Black velvet is proposed since this material presents the lowest hemispherical reflection.
This rectangular baffle will leave the whole SI baffle illuminated.

V. MGSE Mechanical Ground support Equipement

The MGSE is the same as the one developed for the PROBA V calibration ([6]). The rotating table is a XMM heritage that was used to calibrate the XMM Newton Mirror Modules. The table is able to support more than 1 ton. The angular range is +/- 200°, with a resolution lower than 5 arcsec. To achieve the along track angle, a Tip Tilt table inherited from the Planck Primary reflector cryo characterization is used and is interfaced on the rotating table. The motors have a stroke of 200 mm allowing to achieve a range of +/- 13 arcdegrees. The coders on the translation motor have a resolution of 2 µm, that will allow a tilt position with a resolution of 1 arcsec. Figure 10. gives a picture of the MGSE during calibration.

Figure 10. Mechanical Ground Support Equipement

VI. Payload requirements

In order to perform the alignment of the tested payload with respect to the line of sight of the collimator, it is required to have an alignment cube that materializes the orientation of the LOS of the tested payload. The proposed way to proceed is to:

a) sight the collimator pinhole with a theodolite,
b) integrate the Payload on the MGSE,
c) perform an auto collimation on the payload alignment cube with the help of the MGSE,
d) adjust the payload position with respect to the alignment cube localization versus payload line of sight.

VII. OGSE stray light performances

A. *Radiometric budget*

With the selected source the achieved radiance levels at the output of the collimator are about 4000 W/m².sr.µm, which is about 4 to 5 decades brighter that the L1 ground luminance level. The 3 to 4 additional decades can be accessed by changing the integration time and keeping a SNR lower than 10 (this is pending on the detector performance of the tested payload). So, in practice a level of 10^8 can be achieved.
To achieve the 10^{10} level for out of field stray light measurement, the laser diode is used. With the 20W laser diode, this level is easily achieved (up to 10^{12} is possible with the same assumptions as here above).

B. *Stray light simulation*

The stray light facility is modeled in FRED® non sequential ray tracing software. The model considers the F3 vacuum chamber and the auxiliary chamber with their optical benches with a specular metallic reflection. All the baffles are considered MAP PU1 painted and diffused. The BRDF model used is presented in Figure 11.

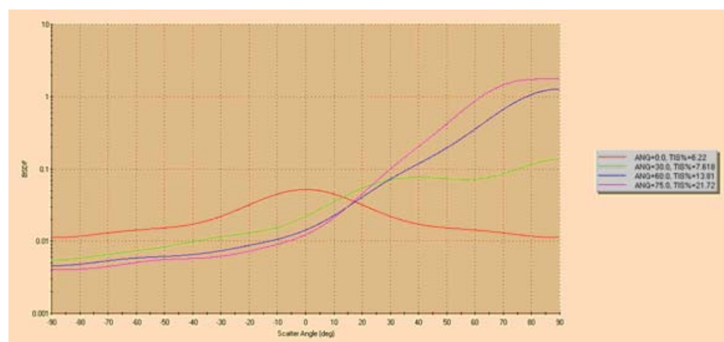
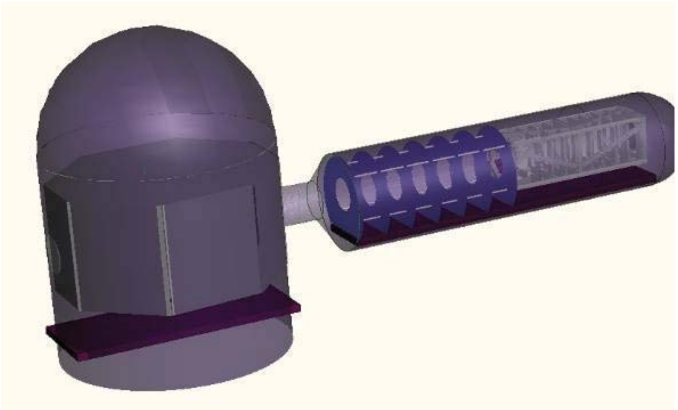


Figure 11. MAP PU1 paint BRDF profiles

The Raytracing model with and without vacuum chamber is presented in Figure 12.



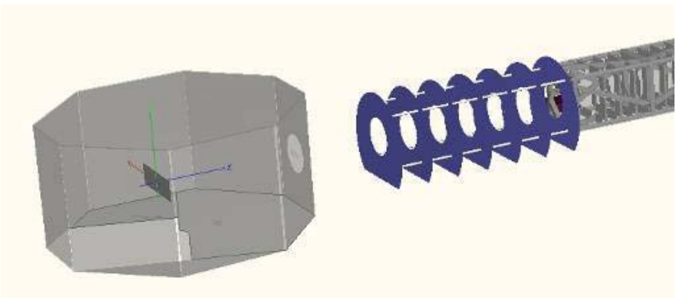


Figure 12. Raytracing model with (top) and without (bottom) vacuum chamber

The tested instrument is summarized by its front panel (assumed coated with MAP PU1 paint). The detector is a 50 x 200 mm² rectangle corresponding to the entrance baffle size of the payload. This can be enlarged until its stays within a diameter of 300 mm.
The collimator model consists into:

- The FPA with its light trap (see Figure 13.)
- The truss with all additional baffles (see Figure 14.)
- The optics (i.e. parabolic mirror and fold mirror).

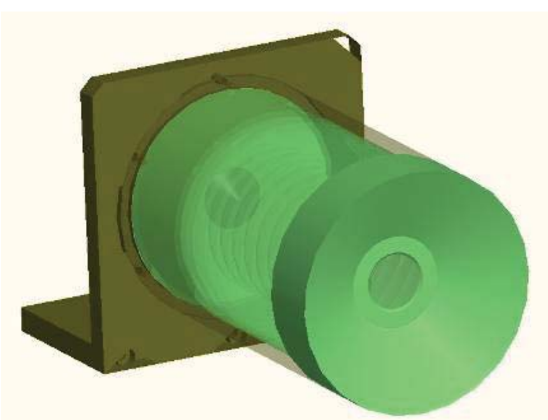


Figure 13. FPA assembly model

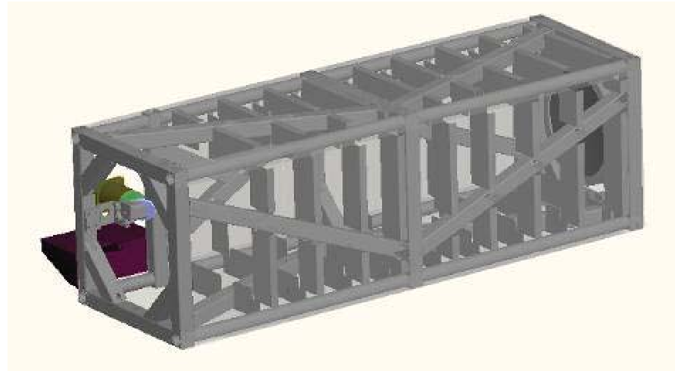


Figure 14. Collimator model

1) Stray light performances

The stray light performances are analyzed in terms of nearfield and farfield contributions:
For the nearfield contributions, we have first the stray light induced by optical surfaces scattering due to particulate contamination on the mirrors (parabolic mirror and fold mirror) and the microroughness: 1.2 nm for parabolic mirror and 0.4 nm for fold mirror. Additionally to this the stray light induced by the collimator FPA assembly and the one induced by the payload baffle are considered.
For the farfield contributions the stray light induced by the payload baffle and the one induced by air dust are computed.

For the optical surface particulate contamination stray light contribution, it is considered that both parabolic mirror and fold mirror are assumed contaminated between CL250 and CL100 surface cleanliness (according MIL-1246C standard). Both situation have been computed and are presented in Figure 15. It indicates that a class 100 is mandatory to stay within the requirements.

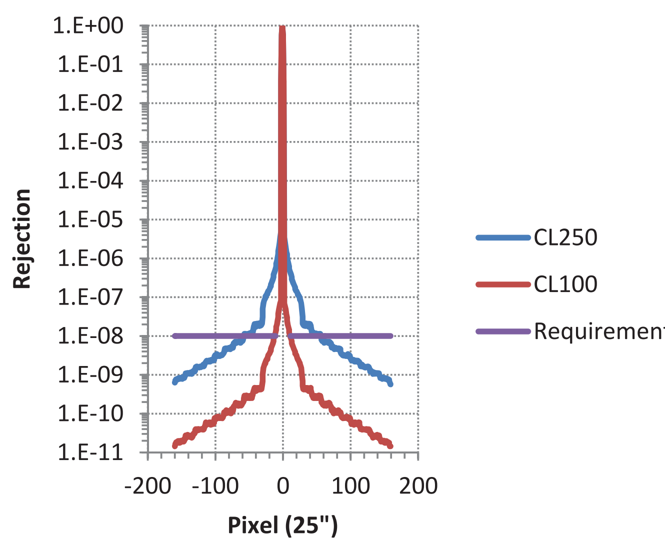


Figure 15. Impact of optical surface cleanliness on nearfield stray light FPA

The stray light contribution coming from the mirrors micro roughness has not yet been computed. It will be performed using a Harvey model or similar.

For the FPA assembly stray light contribution, it is assumed MAP PU1 black paint coating for the FPA assembly. With these assumptions the FPA assembly stray light contribution is lower than 10^{-10} (see Figure 16. for the intensity level and Figure 17. for the intensity pattern).

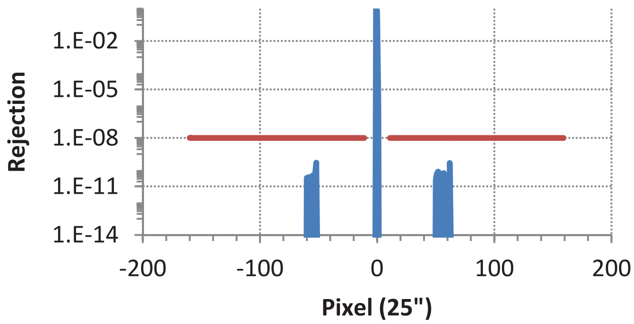


Figure 16. Impact of FPA assembly on nearfield stray light

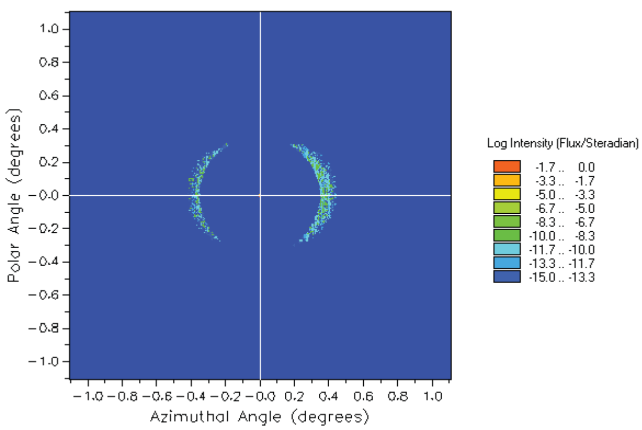


Figure 17. Stray light angular pattern at SI level from the FPA assembly

The Payload baffle near field stray light contribution is linked to the Φ300 mm entering beam into the facility baffle that hits the payload baffle and is diffused into the auxiliary chamber and the F3 chamber. Backscattering towards this baffle and the tested instrument induces stray light that has been computed and is presented in Figure 18. for the intensity and Figure 19. for the intensity pattern.

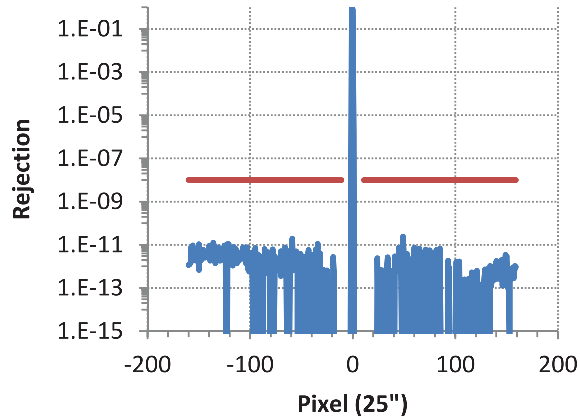


Figure 18. Impact of payload baffle diffusion onto the nearfield stray light

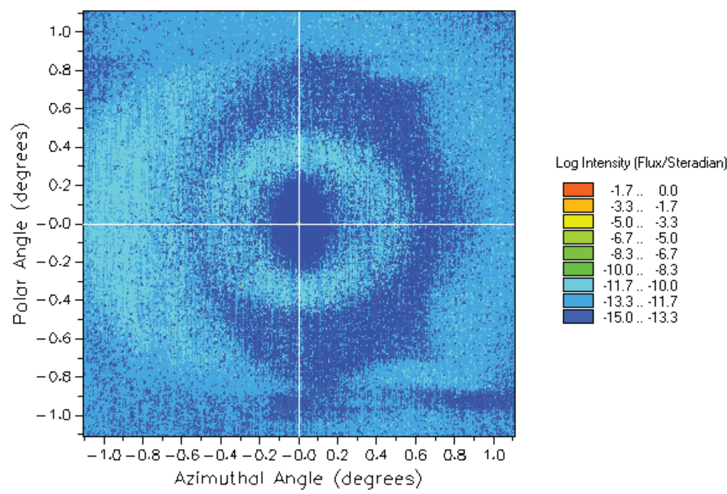


Figure 19. Stray light angular pattern at SI level from the payload baffle diffusion

Payload baffle far field stray light contributions are not yet computed but the stray light level for far field should stay below 10^{-11}.

VIII. TEST PHILOSOPHY

The major difficulty is to perform the stray light calibration with the flight detectors, since basically it is required to illuminate one pixel with and intensity 10^{8} much higher that its neighbor. Several problems can occur, does the detector survive to a level 10^{8} more intense than its detection level, is there no cross talk from the saturate pixel to the neighbor one. The proposed test philosophy is to not illuminate the central pixel directly with a powerful beam. The assumption is that usually for earth observation multi spectral imager, a line detector oriented across track is used. With this type of configuration it is possible to illuminate a fictive pixel along track with an intensity as high as needed, unless the stray light contribution does not damage the actual pixel. Nevertheless, it is required to measure the incident flux.

The measurement philosophy will be as follow. The measured pixel is illuminated with an attenuated flux close to three quarter to pixel saturation level. This represented the I0 level. The next step consists to illuminate a fictive pixel by sighting up or down along cross, and to increase the signal. The increase of signal is monitored by two detectors to be able to monitor correctly the 8 orders of magnitude. The signal is recorded by all the pixels of the line. The next step consists to move by two fictive pixels (from the nominal position) along track and to record the signal once again. This is repeated as many times as needed to cover the requested FOV where the stray light needs to be measured. At the end of the process, by assembling the adequate line, a PSF is recorded, where only the central line is missing except the central pixel.

IX. CONCLUSIONS

Stray light characterization of Earth Observation satellites has become a growing necessity to guarantee the mission success.

To fulfill this, a new stray light test facility is under development at CSL. In this paper we have demonstrated that the ability to measure PSFs at below 1E-10 should be possible from the visible till the Near Infra Red. The facility will be able to test payload of several 100 of kg with FOV of +/- 300 arc degrees across track and +/- 15° along track. Using a square allows to reverse these capacities. The acquired data will not allow to identify each of the stray light source mechanisms; it provides the integrated PSF taking into account all the contributors. Nevertheless the big advantage of this stray light test facility is its ability to measure In field stray light. The measurement will not only be used for the final acceptance of the instruments but also for removing the stray light contribution from the in flight data images. This is possible since a particular test philosophy is proposed allowing to test the payload with it final detectors. A spectro imager module of PROBA V (a Belgium Earth observation satellite ref [6]), will use the facility to carried out the stray light calibration of the instrument.

ACKNOWLEGMENTS

This development would not have been possible without the help of the Belgium GSTP program and particularly to the PROBA V program.

REFERENCES

[1] Y. Stockman, I. Domken, H. Hansen, JP. Tock, T.A. Decker, A. Rasmussen, A.F.J. den Boggende, J.W. den G-Herder, F. Paerels, D. de Chambure, P. Gondoin, "XMM Flight Modules with Reflection Grating Assembly and X-ray baffle testing", SPIE Vol 3444, San Diego 1998.

[2] J.Y. Plesseria, E. Mazy, J.M. Defise, P. Rochus, E. Lemmens, D. Vrancken, Optical and mechanical design of a straylight rejection baffle for COROT, Proc. SPIE **5170** (2003)

[3] JY.Plesseria, E. Mazy, JM. Defise, P. Rochus, A. Magnan, V. Costes, "Straylight analyses of the external baffle of COROT", International Conference on Space Optics – ICSO, Toulouse 2000.

[4] J.M. Defise, J.P. Halain, E. Mazy, P. Rochus, R.A. Howard, J.D. Moses, D.G. Socker, R. Harrison, G.M. Simnett, "Design and Tests for the Heliospheric Imager of the STEREO Mission", Proc SPIE **4853** (2003)

[5] E. Mazy, J.P. Halain, J.M. Defise, P. Rochus, R.A. Howard, J.D. Moses, C. Eyles, R. Harrison, "Design and Performances of the Heliospheric Imager for the STEREO Mission", Proc. SPIE **5962** (2005)

[6] Y. Stockman, ML Hellin, A. Zuccaro Marchi, M. Taccola, J. Versluys, M. François, E. Mazy, "Conceptual design of a straylight facility for earth observation satellites" ICSO 2012

[7] A. Zuccaro Marchi, M. Taccola, J. Versluys, D. Beghuin, Y.Stockman, R. Kassel, M. François, I. Torralba Elipe, "PROBA V Multispectral Imager: Status" ICSO 2012.