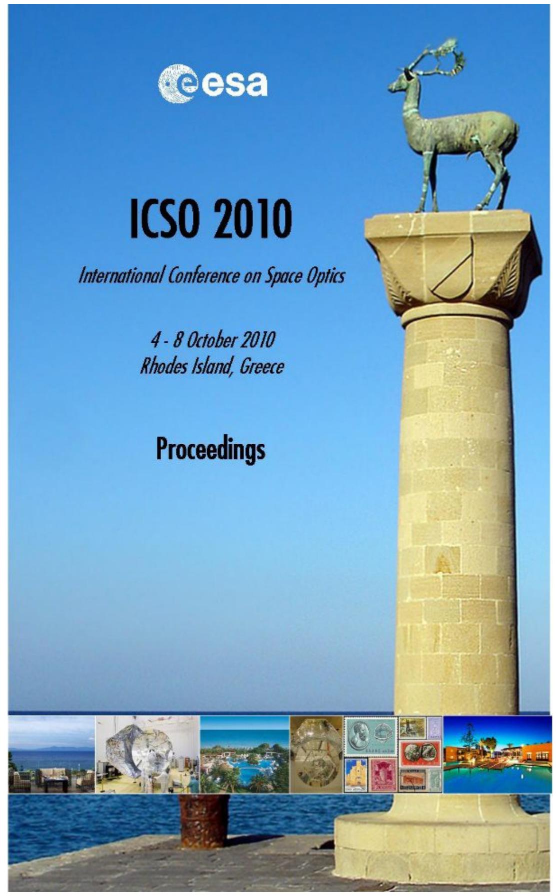
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

Edited by Errico Armandillo, Bruno Cugny, and Nikos Karafolas



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International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny, Nikos Karafolas, Proc. of SPIE Vol. 10565, 105650B · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309106

BAFFLES DESIGN OF THE PROBA-V WIDE FOV TMA

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I. INTRODUCTION

Proba-V payload is a successor of the Vegetation instrument, a multispectral imager flown on Spot-4 and subsequently on Spot-5, French satellites for Earth Observation and defence. The instrument, with its wide field of view, is capable of covering a swath of 2200 km, which, in combination with a polar low Earth orbit, guarantees a daily revisit.
The lifetime of Spot-5 expires in early 2013, and to ensure the continuity of vegetation data, BELSPO, the Belgian Federal Science Policy Office, supported the development of an instrument that could be flown on a Proba type satellite, a small satellite developed by the Belgian QinetiQ Space (previously known as Verhaert Space).
The challenge of this development is to produce an instrument responding to the same user requirements as Vegetation, but with an overall mass of about 30 kg, while the Vegetation instrument mass is 130 kg. This development had become feasible thanks to a number of new technologies that have been developed since the nineties, when Vegetation was first conceived, namely Single Point Diamond Turning fabrication of aspherical mirrors and efficient VNIR and SWIR detectors.

The Proba-V payload is based on three identical reflective telescopes using highly aspherical mirrors in a TMA (Three Mirrors Anastigmat) configuration. Each telescope covers a field of view of 34^{o} to reach the required swath.

One of the challenges in the development of the PROBA-V instrument is the efficient reduction of stray light. Due to the mass and volume constraints it was not possible to implement a design with an intermediate focus to reduce the stray light. The analysis and minimization of the in-field stray light is an important element of the design because of the large FOV and the surface roughness currently achievable with the Single Point Diamond Turning.

This document presents the preliminary baffle layout designed for the Three Mirrors Anastigmatic (TMA) telescope developed for the Proba-V mission. This baffling is used to avoid 1st order stray light i.e. direct stray light or through reflections on the mirrors. The stray light from the SWIR folding mirror is also studied. After these preliminary analyses the mechanical structure of the TMA is designed then verified in term of vignetting and stray light.

II. INSTRUMENT DESCRIPTION

The optical design of the Proba-V telescopes involves only reflective elements assembled in a TMA telescope which allows a significant reduction of mass and complexity for a multispectral imager with a wide field of view. However the mirrors are off-axis and aspherical bringing manufacturing and alignment difficulties. The optical layout is presented in Fig. 1.

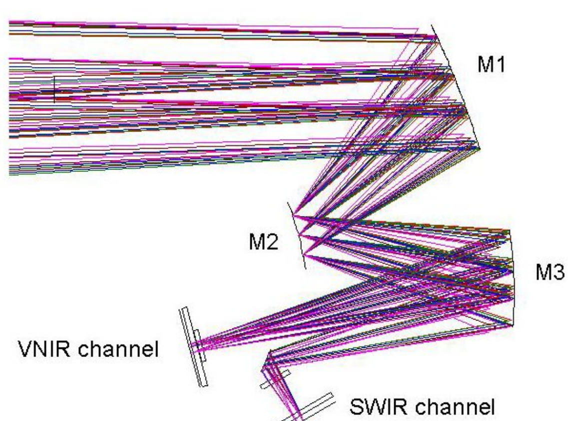


Fig. 1. Optical design of the Proba-V TMA

The instrument is composed of 3 TMA telescopes. Each TMA contains 4 spectral bands : 3 bands in the visible range (462.5 nm, 655 nm, 842.5 nm) and one band in the SWIR spectral range (1600 nm). Each telescope covers a field of view of 34° and their optical axes are positioned at 34° to cover a large field of 102°. The concept of the instrument with the 3 TMAs is presented in Fig. 2.

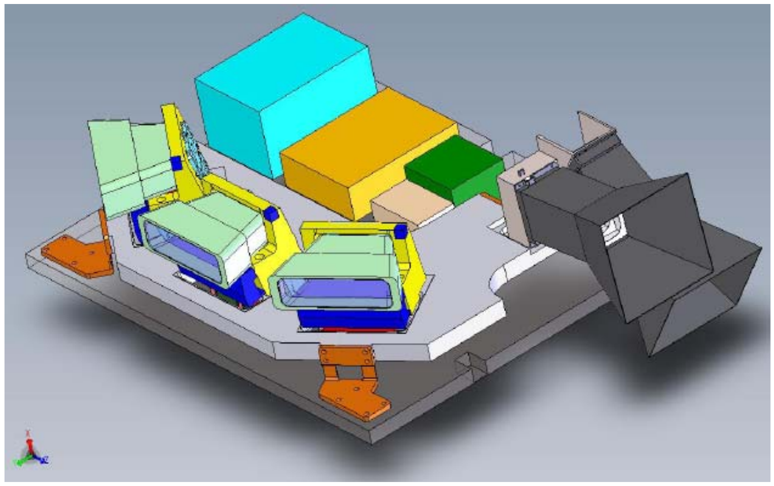


Fig. 2. Concept of the Proba-V instrument

III. FIRST ORDER STRAY LIGHT ANALYSIS

A. Baffles design

The aim of the baffles design is to block the out-of-field light which could enter the instrument and reach the detector, directly or through one or several reflections on the mirrors. This 1st order analysis didn't consider vanes on the baffles and diffusion on M1 of out-of-field light.

The preliminary baffle layout is presented in Fig. 3. It comprises 7 baffles: 1 at the entrance aperture of the instrument and 6 placed inside the instrument. An aperture stop is also placed at the level of the secondary mirror.

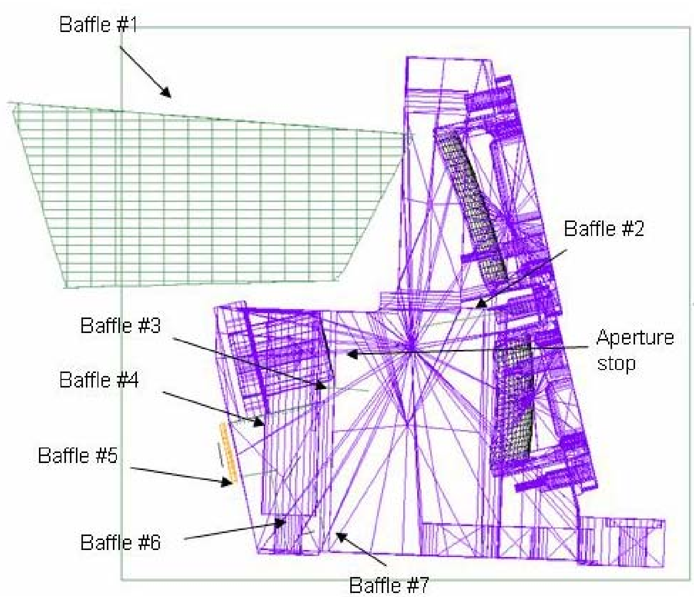
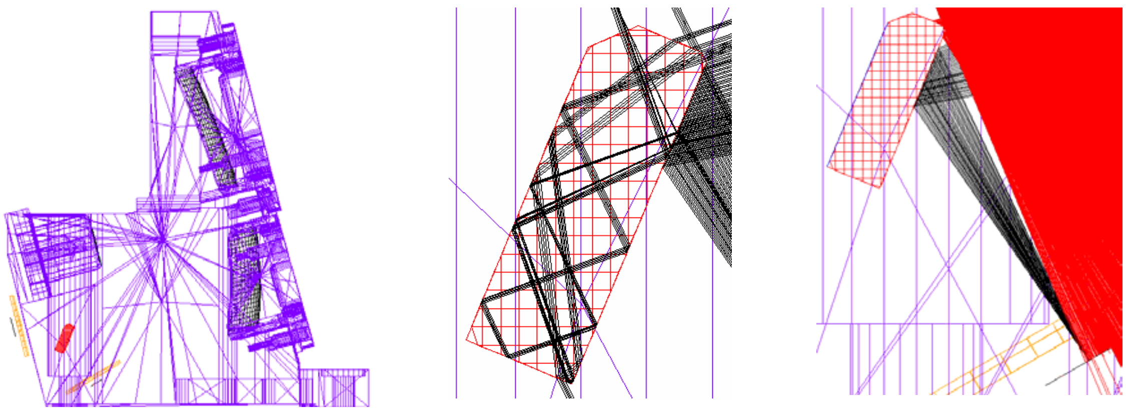


Fig. 3. Proba-V TMA preliminary baffles layout

The baffle #1 is placed at the entrance of the instrument. Its role is to limit the out-of-field light that could directly reach the mirrors. The combination of the baffles #1 and #2 stops the direct view of the M3 mirror through the instrument entrance. The length of the upper side of the entrance baffle is defined to stop the light which could directly reach the M3 mirror and that could not be stopped by the lower side of the entrance baffle and by baffle #2. Some out-of-field light can also reach the M2 and M3 mirrors after reflecting on M1. This cannot be totally avoided but the length of the lower side of baffle #1 has been chosen in such a way that this straylight is stopped by the baffle #3 after reflecting on M3. The baffle #3 is placed below the M2 mirror and stops the direct view of the M1 mirror by the VNIR detector. The baffle #4 is a critical location where reflection or diffusion on the M2 structure can occur and bring stray light to the VNIR detector which is very close. Vanes will be placed at this location. The baffles #5 and #6 are placed near the focal planes to isolate the detectors from each other. The baffle #7 avoids a direct view to the SWIR detector from the M1 or M3 mirrors.

B. SWIR mirror stray light

The SWIR folding mirror is made of BK7 with a reflecting coating on its front side (which is the one used for the SWIR channel). The back side of the mirror (in front of the VNIR focal plane) is black coated. It is shown (in red) on the left part of Fig. 4. The stray light by reflection, transmission and scattering on the mirror have been analysed by scanning the field of view between the SWIR and VNIR channels. The results show no critical path by reflection or transmission (giving rise to internal reflections inside the mirror as shown in the central image of Fig. 4). On the other side it was found that the scattering on the small chamfer on top of the mirror was sending light directly on the SWIR focal plane (right part of Fig. 4). The angle of the chamfer was thus modified to avoid this stray light.



(a) (b) (c)

Fig. 4. (a) SWIR folding mirror (in red) (b) Stray light by reflection and transmission (c) Stray light by scattering

IV. FINAL OPTO-MECHANICAL DESIGN

After the first order stray light analysis the mechanical structure of the TMA has been designed and a verification of this structure in term of stray light has been performed. A view of the final 3D model is presented in Fig. 5.

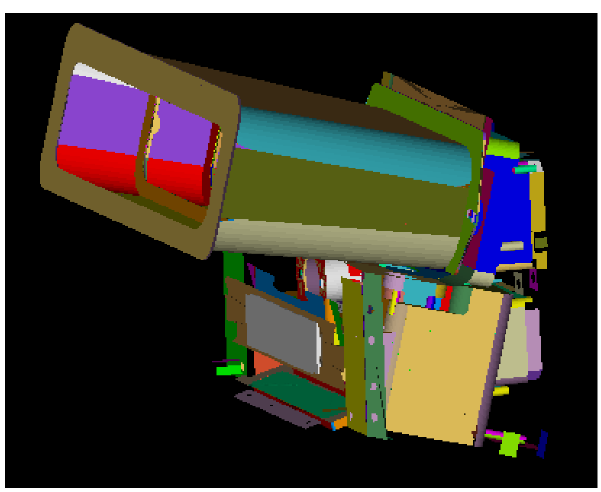


Fig. 5. 3D view of the TMA with the final opto-mechanical design

It is first verified that the mechanical design introduces no vignetting of the useful light beam, which was the case.

Then a search for critical surfaces is performed. These are surfaces that are directly seen by the detector and that are directly illuminated by light coming in the TMA. It was found that the aperture stop and its structure was a critical element giving straylight on the whole detector by specular or diffuse reflection. The Fig. 6 shows the useful beam and the scattered light from the aperture stop structure falling on the SWIR detector.

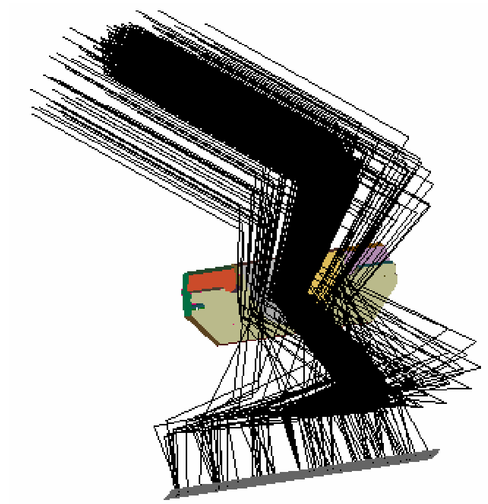


Fig. 6. Straylight generated by the aperture stop structure

To reduce this stray light some grooves structures to be applied on M2 support and acting as light traps have been analysed. They are shown on Fig. 7. The three first light traps are linear grooves in one or two directions and circular holes. For these three cases the stray light level cannot go lower than 50 % of the incident light on the light trap. The fourth sample is composed of triangular grooves allowing to suppress all flat area in the plane of the sample. With this sample the stray light level is lower than 5.3 % so 10 times better than with the 3 first samples.

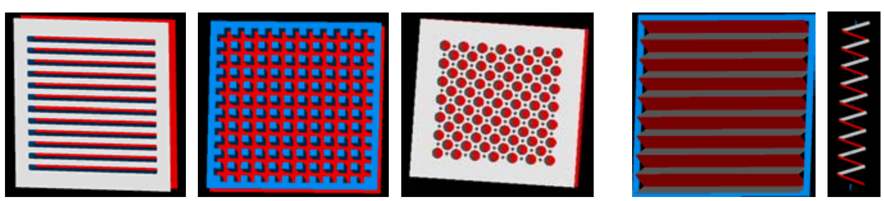


Fig. 7. Examples of light traps

In addition the stray light inside and outside the FOV are computed together and plotted on a PST (Point Source Transmission) curve. This curve is obtained by dividing the stray light level by the useful signal level (= flux in the zero FOV spot). For this analysis the structure around M2 and the aperture stop are considered diffusive with the BRDF model of Chemglaze Z306 (and no light trap) and the rest of the structure is specularly reflective with a reflectivity of 1%. These computations are carried out for the two channels, SWIR and VNIR for a FOV across and along track. As example the PST across track in the SWIR channel is presented in Fig. 8. For angles larger than 32° (and smaller than -32°), the stray light is smaller than 2.10^{-5}. It is smaller than 1.10^{-9} after 71°. The PST along track is presented in Fig. 9. For angles smaller than -20° and larger than 10°, the PST is smaller than 1.10^{-7}.

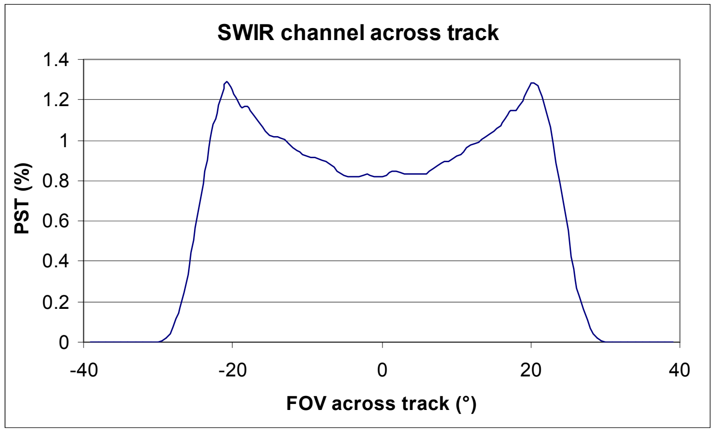


Fig. 8. PST across track in SWIR channel

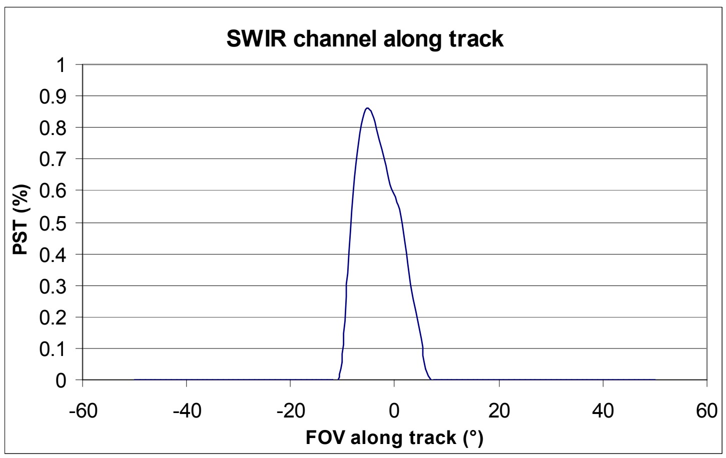


Fig. 9. PST along track in SWIR channel

V. CONCLUSIONS

The first order stray light analysis performed on the TMA telescope for the Proba-V mission has been presented.

As a first step a baffling design is analysed. Seven baffles are proposed to avoid out-of-field stray light on the detectors coming directly or through reflections on the mirrors. The possible stray light by reflection, transmission or scattering on the SWIR folding mirror has also been studied.

From these first results an opto-mechanical design of the TMA has been proposed. This design was verified in term of vignetting by the baffles and stray light inside and outside the FOV. This analysis showed no vignetting but indicated that the aperture stop structure was a critical item giving stray light on the detector after diffusion on the mechanical part around M2. Light trap samples to be applied on M2 structure have been analysed and the sample composed of triangular grooves showed a stray light level lower than 5.3%.

Finally the stray light from the structure inside and outside the FOV was presented as PST curves.

Despite it is well known that the micro-roughness of the mirrors have an important impact on the in-field stray light this aspect has not been aborded in this article because it is still under investigation.