INTEGRAL Optical Monitoring Camera Stray-Light Design

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ABSTRACT

The Optical Monitor Camera (OMC) is a part of the scientific payload of the INTEGRAL spacecraft, scheduled to be launched in 2001. The OMC is an imager that will monitor star variations in the V-band in a 5 x 5° field of view. It is required that the instrument detects object of +19.7 magnitude within the FOV. This requires highly sophisticated baffling techniques to provide attenuation up to $10^{-4.5}$. To obtain such performances, the design of each sub-element is optimized to fulfil very stringent stray-light requirements. The stray-light sources are discussed and performances are simulated with a 3D ray-tracing model.

Keywords: baffles, stray-light

1. THE OMC INSTRUMENT

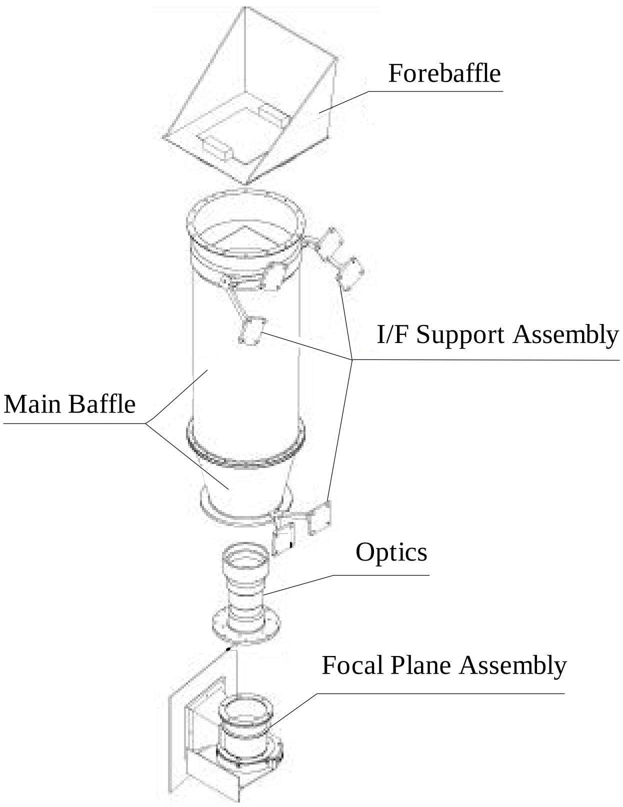

Figure 1: The OMC instrument

The ESA scientific mission INTEGRAL (The International Gamma-Ray Astrophysics Laboratory) is dedicated to the fine spectroscopy and fine imaging of celestial gamma-ray sources in the energy range 15 keV to 10 MeV with concurrent monitoring in the X-ray (3-35 keV) and optical (V-band) energy range. The INTEGRAL spacecraft is scheduled to be launched in 2001.

The Optical Monitoring Camera [[1]] is a 20 kg class instrument mounted on the top of the INTEGRAL payload module. A 6 lens telephoto optical system is imaging stellar objects on a CCD detector mounted in a Focal Plane Assembly (FPA). An optical baffle affords the necessary reduction of stray-light. A once-only deployable cover protects the optics from contamination during ground operations and early operations in orbit. The figure 1 shows the design of the OMC instrument. The main optical requirements are listed in table 1 [[2]].

Aperture size :	50 mm diameter
Field of View (FOV) :	5 x 5 arcdeg square
Pixel size :	13 x 13 µm²
	17.6 x 17.6 arcsec²
Spectral range :	V-band centred at 550 nm
Sensitivity :	19.7 visual magnitude (mv)

Table 1: OMC optical requirements

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2. STRAY-LIGHT DESIGN

1. FOV – UFOV definition

The FOV is defined by the science objectives of INTEGRAL: it is a 5 x 5 arcdeg² square cone. The objects of interest can lie anywhere in the FOV. To reach the stringent stray-light attenuation requirements, the OMC is equipped with an optical baffle. However it remains a range of viewing angles, outside the FOV, where the baffle efficiency is low and where the optical system can collect direct light. Any object in this region can provide an unwanted light flux in the optics. For this reason, the envelope of these viewing angles is called the unobstructed field of view (UFOV). This viewing angles range is a characteristic of the optical baffle. The stray-light suppression outside the UFOV is obtained with the external baffle, while inside the UFOV, we rely on the design of the optics mount and the FPA to damp the unwanted light which enters the lens barrel. The UFOV of OMC is defined by a ± 10 arcdeg² square cone. It results from a trade-off of several factors: allocated accommodation on the platform, acceptable baffle length and compromise between the diameter and the vanes aperture size.

2. Stray-light sources and requirements

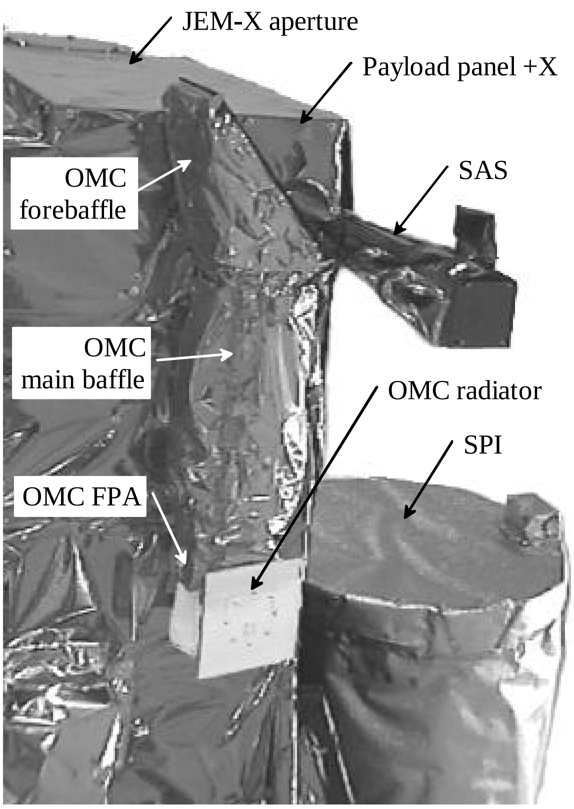


Figure 2: OMC view on the Structural and Thermal Model Payload Module of INTEGRAL

To allow faint sources detection (up to mv = 19.7 outside the galactic plane and mv = 18 inside), it is necessary to minimize the amount of unwanted light.
Bright sources inside the UFOV can produce stray-light with internal reflection in the lens barrel that can reach the detector. Inside the FOV, the ghost images introduces by internal reflections in the optics are discussed in [2].
Other light sources outside the UFOV can only produce stray-light with internal multiple reflections through the main baffle and the lens barrel. The attenuation of such light is more important than sources inside the UFOV because very bright sources could appear in these viewing angles.

The overall baffling of the instrument must also provide high attenuation against other important stray-light sources such as the Sun light and spacecraft elements. The Sun has an elevation lower than 50 arcdeg in the OMC reference system (figure 1) and an azimuth around the –Z direction of ± 5 arcdeg. Direct reflections on the payload and diffraction on the forebaffle edge can also produce stray-light in the OMC baffle. Although the instrument is located at a top position on the platform, two elements of the payload can be considered as candidates for stray-light sources as shown in the figure 2: the +X panel of the payload module (PLM) structure and the SAS. All these elements are thermally protected with Kapton MultiLayers Insulation (MLI).

All the elements of the instrument have been designed to improve to the attenuation of stray-sources:
- the forebaffle designed for the Sun light and the Payload module (PLM) stray-light sources suppression;
- the main baffle designed for reduction of stray-light sources outside the UFOV;
- the lens barrel and the FPA design for the attenuation of stray-light sources inside the UFOV.

Taking into account the V-filter included in the optics [2] and the instrument transmission, the flux from these stray-light sources at the detector level has to be lower than 10^{-19} W/pixel (assuming Sun type stars) to allow faint objects detection up to mv = 19.7. This assumes that at least 70 % of a point object energy is focalized on one pixel of the CCD as described in [2].

3. OMC baffling design

The main baffle is used as the main structural element of the instrument, holding the optics and the FPA. It provides also the required reduction of stray-light far from the FOV. The baffle is a cylinder equipped with a set of internal vanes that are designed to improve the efficiency of light suppression by multi-reflections on diffusive black surfaces. Preliminary studies readily indicated that a two-stage external baffle would be required. It is made with a tube and a conical part to link the tube and the lens barrel interface. The overall baffle surrounds the lens barrel for structural purposes. The overall envelope of the external baffles was imposed by the payload envelope, mass resources and accommodations on-board the platform. The figure 3 describes the "optical" design of the main baffle.

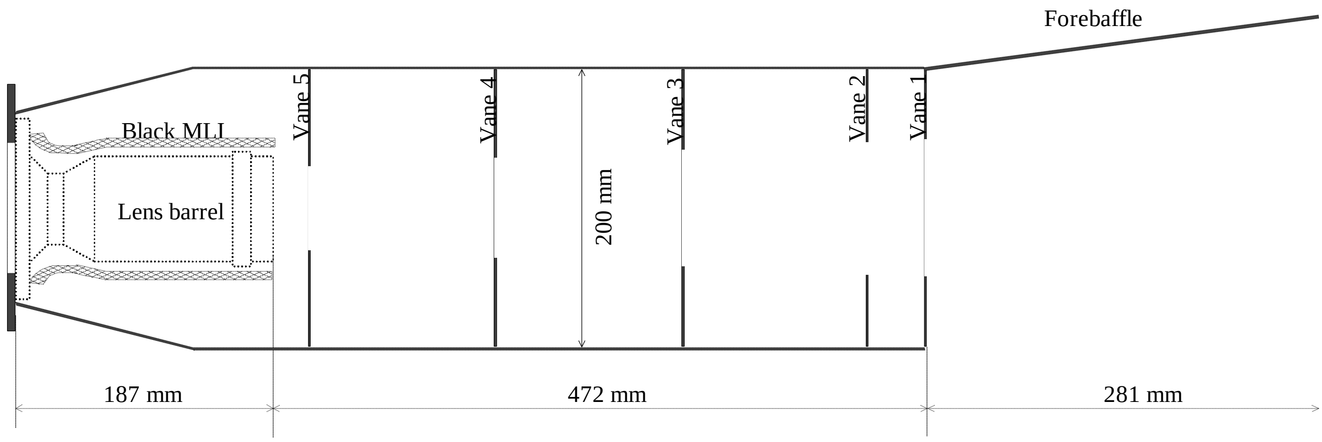
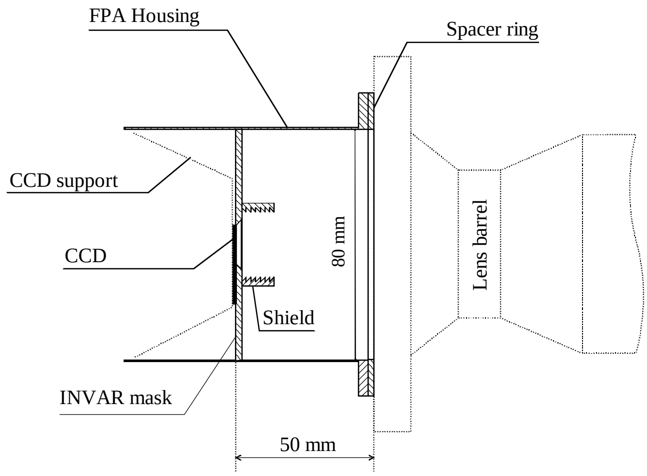


Figure 3: Main baffle and forebaffle design

The vane apertures are optimized according to the circular optics pupil and the square FOV. Their theoretical resulting shapes are rounded squares. To simplify the manufacturing, they are defined as square aperture vanes. Their number and location from the lens barrel entrance are optimized to limit the stray-light at the first order [3]: all the main baffle surfaces have at least a null view factor with the lens barrel or the baffle entrance. The aperture edges of each vanes are also optimized to reduce the view factor and to ease the manufacturing (avoiding sharp edges) and coating [4]. The main baffle material is an aluminium alloy coated with black anodizing.

An additional forebaffle is used to keep the main baffle entrance and the cover mechanism in the shadow of the Sunlight. It consists of a 280 mm height square base skirt tube shown in figure 1. The material is an aluminium alloy covered, on the inner face, with black Kapton MLI ($\alpha = 0.92$).

The lenses are mounted in a cylindrical lens barrel [2]. It is made in Titanium alloy coated with blue anodizing. Although this coating is not the most suited for stray-light reduction, its technology and its application are well known. The internal aperture stop is a critical item because it stops a large part of internal unwanted light in the lens barrel. It is treated with a black chromium coating that provides a good efficiency for light shade. For thermal purposes, the lens barrel external face is covered with MLI and for stray-light purposes, the last layer of this one is made of black Kapton in order to trap the light between the lens barrel and the baffle.



The CCD is mounted in the FPA which supports its cooling radiator and its local electronics. It is made of Invar with black chromium coating on the internal faces. As shown in the figure 4, a black coated Invar plate is masking half of the detector, leaving free a 1024 x 1024 pixel image area. To protect the detector from radiations, a circular Invar shield surrounds the detector above the mask. For stray-light purposes, the internal face of this shield is manufactured with edges towards the detector to reduce reflections towards the detector. The edge of the mask above the detector area is also optimized to limit view factor.

Figure 4: FPA optical description

3. STRAY-LIGHT PERFORMANCE ANALYSIS

1. Black coating measurements

To avoid a complete 3D BRDF measurement of each coating used in the instrument, well-known BRDF models were adapted to match the total hemispheric reflectance (R) and the diffuse reflectance (DR) measurements performed at CSL facilities. The figure 5 summarizes the main results of these measurements.

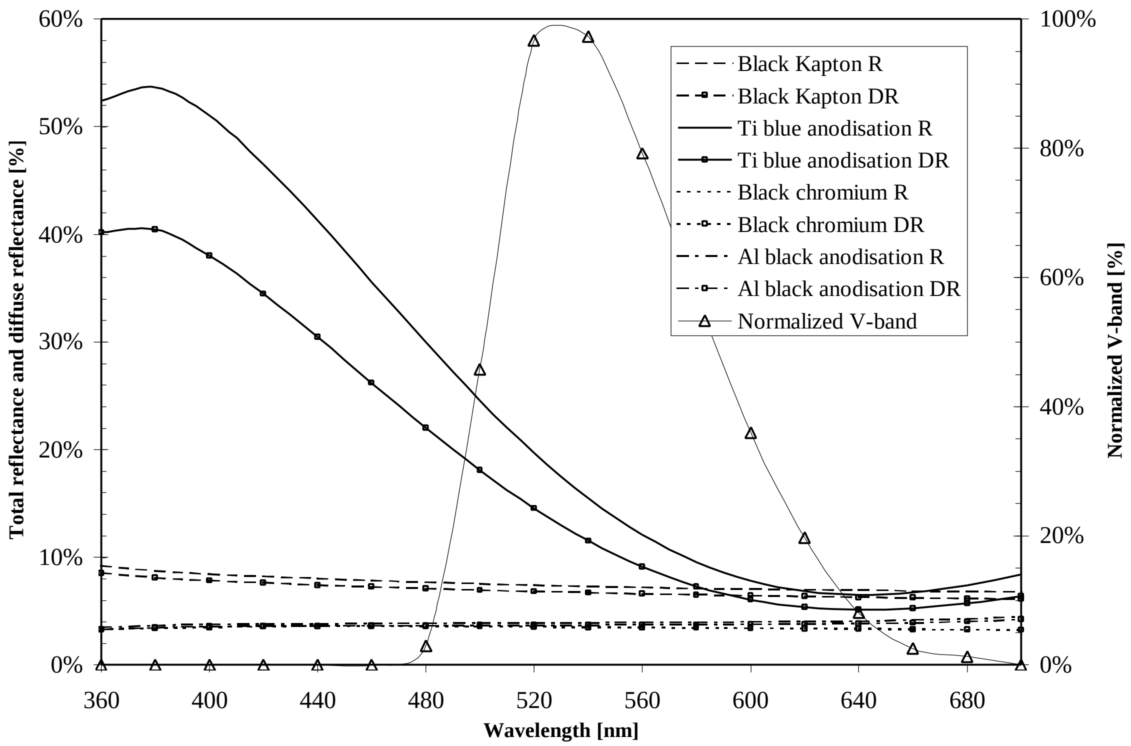


Figure 5: Spectral reflectance (R) and spectral diffuse reflectance (DR) of black chromium on Ti alloy, black Kapton MLI, blue anodisation on Ti alloy and black anodisation on Al alloy. V-band spectral transmission.

It is shown that the blue anodizing on Ti alloy has a specular behavior similar to a Harvey model [5] with adjusted parameters. On the other hand, the three other coatings are similar to a black anodizing on aluminium alloy model [6]. All these adjusted models have been introduced in a 3D ray-tracing model.

2. Ray-tracing models

A 3D ray-tracing model of the instrument has been developed (see figure 6). All the internal surfaces of the instrument with their associated coatings are included in the model. Primarily the model is utilized to evaluate the impact of stellar bright sources by using ray-tracing from sources at the infinite.

To study the impact of the sun light reflected by the payload, a rough model of the spacecraft has been developed. The stray-light produced by the spacecraft elements is evaluated with the complete model of the instrument combined with the payload model, as illustrated in figure 8.

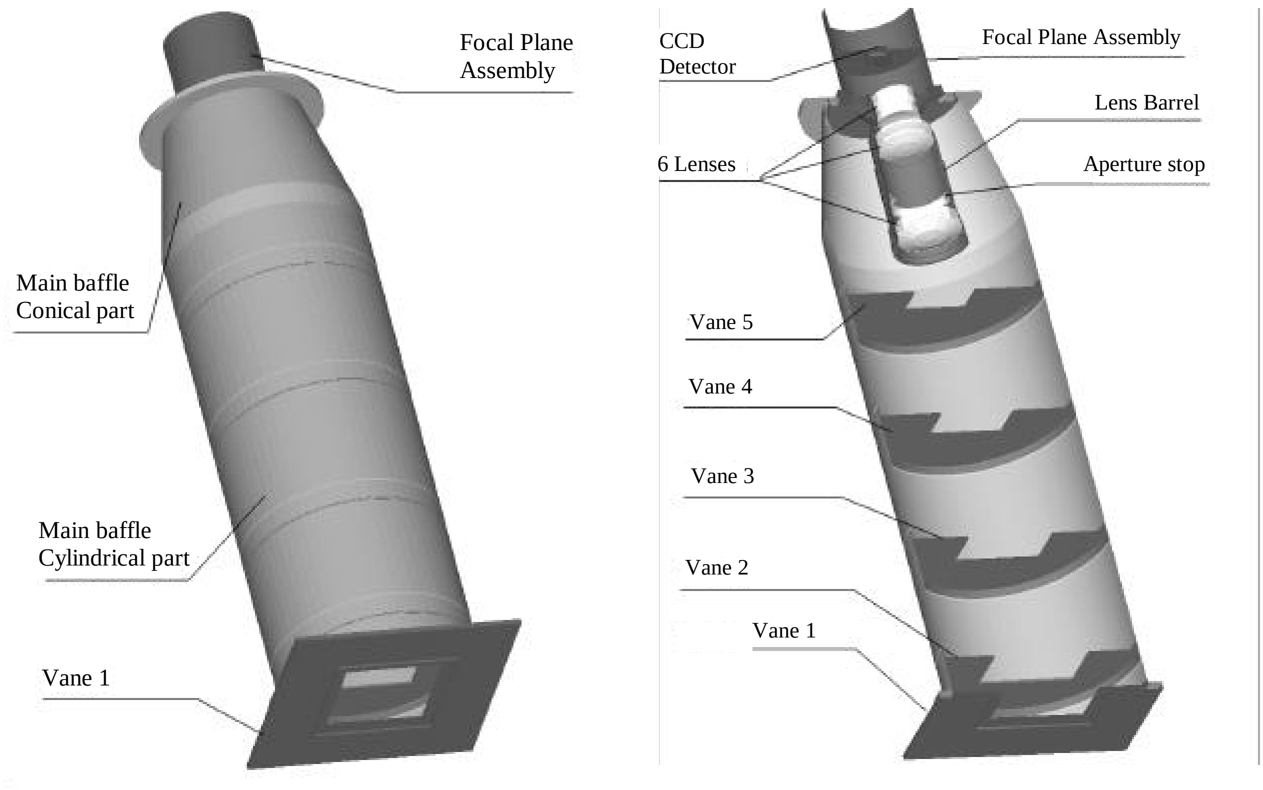


Figure 6: Views of the OMC ray-tracing model

3. UFOV and FOV stray-light analysis

The stray-light sources inside the UFOV are closely dependent with the scientific program of the INTEGRAL mission: near the galactic plane, the number of bright objects inside the UFOV is more important than outside the galactic plane. The figure 7 shows the results of the simulation giving the stray-light flux reaching the detector area, that was confirmed to be uniformly spatially distributed on all the pixels, in comparison with a +19 mv object in the FOV focalized on a single 13 x 13 µm² pixel.

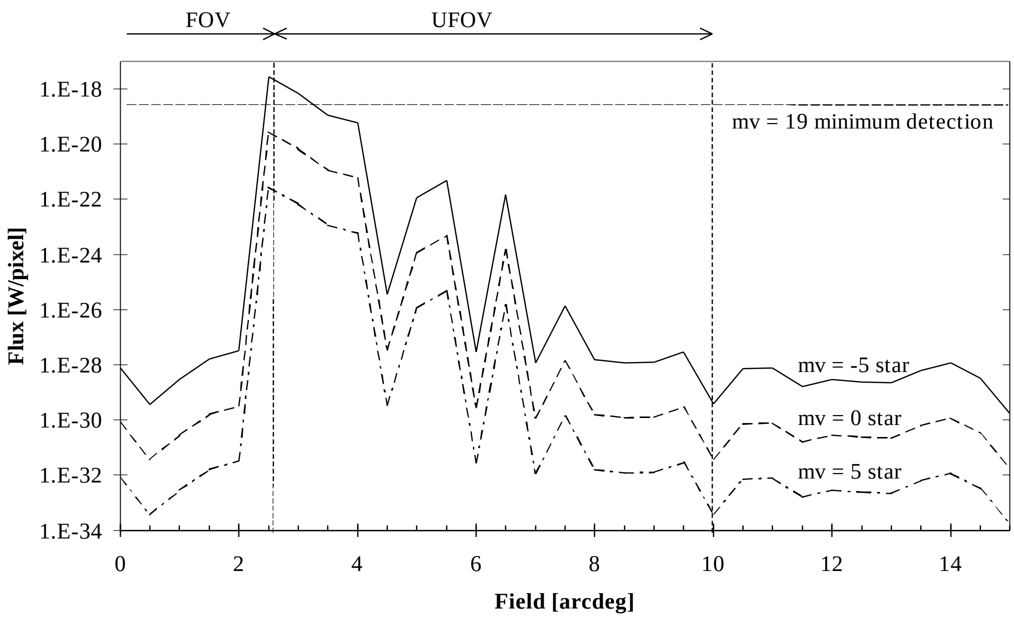


Figure 7: Stray-light from external stellar objects

Inside the FOV, the unwanted light flux reaching the detector pixels area is largely below a mv +19 object focused on a single pixel. The internal aperture stop in the lens barrel is very efficient in this case.

A maximum stray-light flux appears just outside the FOV (< 4 arcdeg). For these viewing angles, unwanted light flux can strike the detector area through direct reflections on the shield and the edge of the mask in the FPA. In this range, bright objects have to be lower than mv = -4. For viewing angles larger than 4 arcdeg, the stray-light flux decreases slowly as bright objects move away from the FOV.

Outside the UFOV, the main baffle provides adequate efficiency and shades light largely below +19.7 mv objects in the field of view.

4. Payload module stray-light analysis

The figure 8 illustrates the global model used for ray-tracing studies, including the main stray-light sources from the payload and other instruments, particularly the +X panel of the payload module structure and the SAS. Both are covered with MLI (α = 0.51).

The stray-light contribution of the potential payload module elements is limited by the view factor between the element and the Sun, by the view factor between the element and the forebaffle entrance, by the optical properties of the MLI and by the OMC instrument attenuation for rays sources located on these elements.

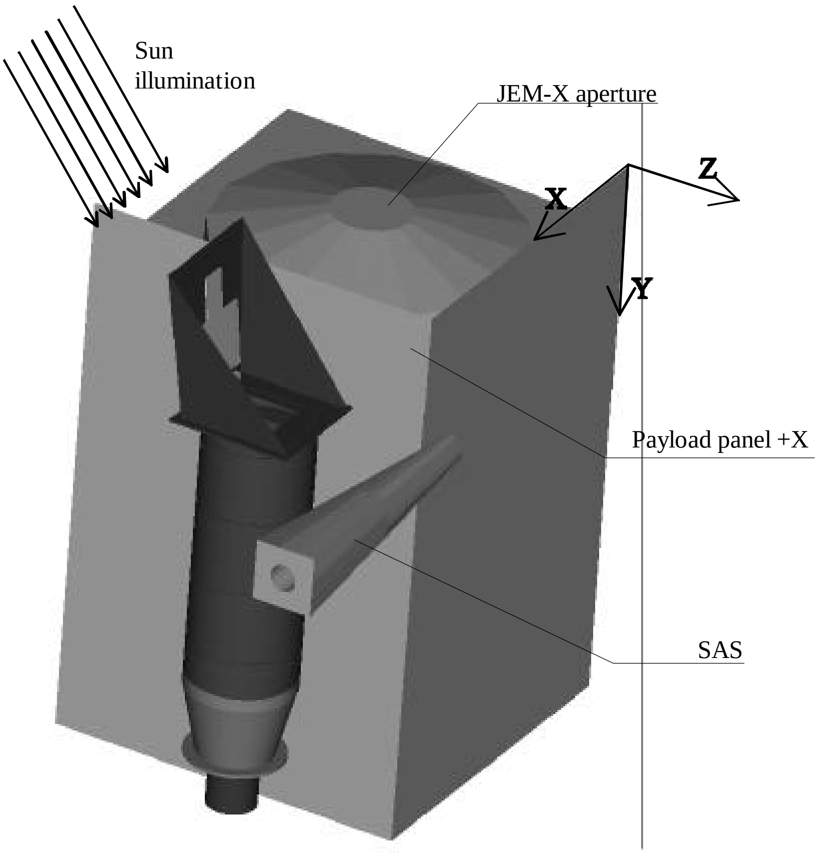


Figure 8: 3D view of the ray-tracing model with the payload stray-light sources

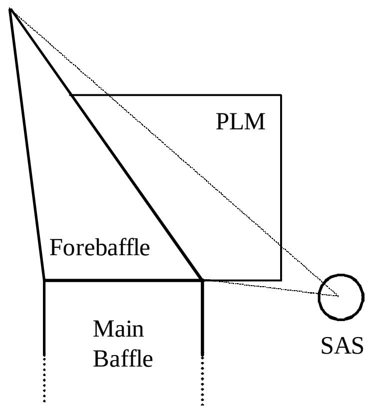


Figure 9: View factors computations

In the case of the +X panel of the payload module, the view factor with the Sun is very small due to the grazing incidence (< 5 arcdseg) of Sun light on this panel. The factor between the panel and the baffle entrance is computed with the assumption of a rectangular forebaffle entrance and an equilateral triangle representing the payload top corner as shown in the figure 9.

On the contrary, the SAS has a high view factor with the Sun since it is nearly normaly illuminated by the Sun.

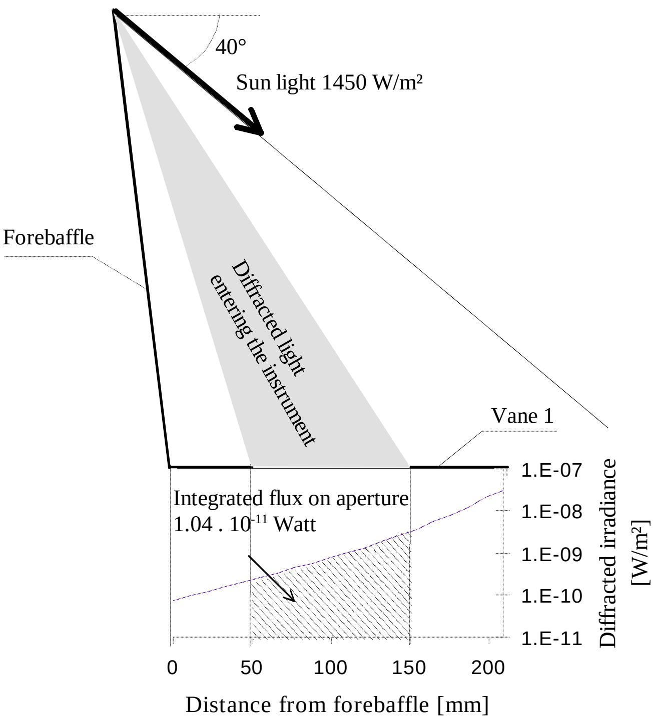
The table 2 summarizes the results of this analysis.

	PLM contribution	SAS support contribution
OMC baffling attenuation	$1.2 . 10^{-16}$	$1.0\ \ 10^{-17}$
Optics transmission	72 %	72 %
MLI reflection	49 %	49 %
Sun light flux in V-band	$2.6 . 10^{-2}$ W	3.52 W
View factor	0.306	0.058
Stray-light Flux reaching the CCD	$3.4 . 10^{-19}$ W	$7.2 . 10^{-19}$ W

Table 2: Stray-light results from the payload

The analyses indicate that the payload stray-light flux reaching the focal plane is uniformly distributed on the detector area, with a value of 10^{-25} W/pixel. These stray-light sources are negligible in comparison to the minimum detectable objects (mv=19.7, flux≈10^{-19} W/pixel) and to the continuous diffuse background due to zodiacal light

5. Direct solar flux analysis



The forebaffle is used to keep the baffle entrance in the shadow of the solar flux. But a small amount of solar flux can reach the baffle entrance with the diffraction by the edge of the forebaffle. A theoretical analysis has been developed using Kirchoff-Fresnel propagation laws [7]. The results are illustrated in figure 10. As much as the diffracted light angle is far from the direct direction, the irradiance decreases. The integrated flux entering into the main baffle entrance is 10^{-11} W. Taking into account the associated attenuation by the instrument for sources located on the forebaffle edge, the flux reaching the detector area is lower than 10^{-16} W, uniformly distributed on the CCD.

Figure 10: Results of the diffraction analysis. The output is the integrated flux entering the instrument aperture after diffraction by the forebaffle edge.

4. CONCLUSIONS

The OMC instrument has been designed and optimized to allow the faint object detection up to 19.7 mv stars. The potential stray-light sources are discussed and a 3D ray-tracing model is built to simulate the effect of these sources and improve the baffle design. The table 3 summarizes the stray-light flux on the CCD, compared to the faintest object flux in the FOV (10^{-19} W/pixel) that needs to be detected by the OMC. In each case, conservative assumptions were used.

Sources	Stray-light flux
Stars inside the FOV	< 10^{-28} W/pixel
Stars inside the UFOV	< 10^{-19} W/pixel for a mv = -4 star
PLM panel reflected Sun light	< 10^{-25} W/pixel
SAS support reflected Sun light	< 10^{-25} W/pixel
Sun light diffracted by the forebaffle	< 10^{-23} W/pixel

Table 3: OMC baffling stray-light performance summary

The results of table 3 demonstrate that an efficient baffling system has been designed to reach the faint object detection goal. The main concern remains the contribution of very bright objects (mv < -4) at the border of the FOV.

The stray-light studies will be regularly updated during the further developments of the OMC instrument and the INTEGRAL payload around OMC, to optimize the faint detection performance.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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