XMM Optical Monitor

MULLARD SPACE SCIENCE LABORATORY
UNIVERSITY COLLEGE LONDON

Author: Mark Cropper

ATTENUATION FACTORS FOR THE ^{XMM}OM BAFFLE

DOCUMENT: XMM-OM/MSSL/TC/0005.01   15-Nov-90

CHANGE RECORD

ISSUE	DATE	PAGES CHANGED	COMMENTS
draft	25-Oct-90		
1	15-Nov-90	2,3,4	Comments from RAL included

1 Introduction

This document provides an estimate of the attenuation required from the ^{XMM}OM baffle.

2 Sources of background light

^{XMM}OM is such a powerful instrument despite its small aperture because the background flux is so low. The principal sources of background are the zodiacal light, diffuse Galactic background (especially in the UV), possibly geocoronal light in the UV, and scattered light from the sun, Earth and Moon.

The scattered light is (within the parameters available to us) within our control. If we take the starting point that the scattered light must be less than the average zodiacal light background (say at an ecliptic latitude of 45°, ecliptic longitude of 90° – the ecliptic longitude = sun angle is always between 70° and 110° in ^{XMM}OM), then it is possible to specify the maximum levels of scattered light the detectors may see.

Both the zodiacal light and the scattered light components have the same spectrum as the sun, G2V. This makes an intercomparison easy. Zodiacal light background is tabulated in various sources, for example Levasseur-Regourd & Dumont (1980) (*Astronomy & Astrophysics*, **84**, 277), or Allen (1973) (*Astrophysical Quantities 3rd ed.*) in terms of the equivalent flux from a $V = 10$th magnitude G2 star per square degree. At this ecliptic latitude and longitude the zodiacal light is equivalent to 81 such stars per square degree. If the detectors in ^{XMM}OM see an area of sky 1024 arc sec on a side, then the total intensity seen over this area is:-

$$81 \times (1024^2)/(60^4) = 6.55$$

The scattered light must therefore be at a level substantially lower than 6.55 $V = 10$th magnitude G2 stars. For this discussion we adopt an intensity of 1.0 $V = 10$th magnitude G2 stars.

3 Sun

In XMM the sun angle α is always $70° \leq \alpha \leq 110°$, and it is always guaranteed that the aperture of the ^{XMM}OM will be in shade from the spacecraft door. Except for this door no other structures are in front of the baffle aperture. Hence the scattered light contribution from the sun will probably be negligible; however, checks must be made on the validity of this conclusion since there will be contributions from scattered light from edges on the spacecraft structure and from diffraction.

4 General formulation

The scattered light contribution can be calculated in several ways, but is conveniently done as follows:-

The V magnitude of the sun is -26.74, a factor of 36.74 V magnitudes more than a $V = 10$ mag G2 star. The ratio of intensities is therefore

$$10^{36.74/2.5} = 4.97 \times 10^{14}.$$

This is the intensity seen at the distance of the Earth from the sun in units of $V = 10$ mag G2 stars.

This is intercepted by a sphere (the Earth or Moon) of radius R_s and a projected cross section πR_s^2. Were the Earth to scatter all of this light isotropically, at a distance of R_d this intensity would be reduced by a factor

$$\frac{R_s^2}{4 \times R_d^2}.$$

However, some of the light is absorbed, and that which is scattered is not scattered isotropically and this ratio must therefore be modified. This is dealt with in a standard way by normalising the scattered flux to that seen from the sun point, *i.e.* the scattered flux is reduced by a factor $p\phi(\alpha)$ where p is the albedo of the fully illuminated sphere and $\phi(\alpha)$ is the dependence of the albedo on the angle between the sun and the spacecraft subtended at the centre of the sphere α, normalised to unity at $\phi(0°)$. The ratio is therefore rather

$$p\phi(\alpha)\frac{R_s^2}{R_d^2}.$$

So far the effect of the viewing angle θ between the optical axis and the centre of the sphere has not been considered. The projected area of the baffle aperture depends on the viewing angle as $\cos\theta$ for $0 \leq \theta \leq \pi/2$ and is zero for $\theta > \pi/2$.

The scattered light S_b immediately within the baffle opening in units of $V = 10$ mag G2V10 stars can therefore be formulated as follows:

$$S_b = 4.97 \times 10^{14} \times \frac{p\phi(\alpha)\cos(\theta)R_s^2}{R_d^2}$$

where
p is the albedo of the fully illuminated sphere
α is the sun angle
θ is the angle to the centre of the sphere
$\phi(\alpha)$ is the dependence of the albedo on sun angle and $\phi(0°) = 1.0$
R_s is the radius of the illuminated sphere
R_d is the distance of the sphere.

Were all the scattered light focussed on the detector, the attenuation required would be $F = 1/S_d$ to reach the level of 1 G2V10 star. However, this is not the case. Only a certain fraction f_1 reaches the hole in the primary mirror, and of that, only a further fraction f_2 reaches the detector directly. In addition, some of the f_1 which misses the detector directly is scattered in the rear compartment and eventually reaches the detector, adding a further component, f_3. Therefore the scattered light in the baffle aperture S_b, given above must be modified to give the final flux on the detector S_d by including these fractions as

$$S_d = S_b f_1(f2 + f_3(1 - f2))$$

Unfortunately it is not possible to specify in general terms what the fractions f_1, f_2 and f_3 are, since these are intrinsic to the baffle design, and the mechanical arrangement and surface coatings within the rear compartment of the telescope module. What *is* clear, however, is that the overall baffle attenuation factor is then

$$F = \frac{1}{S_d} = \frac{1}{S_b f_1(f2 + f_3(1 - f2))}.$$

For any particular ray to the detector, if the albedo of the baffle surface coating is ϵ and the required attenuation factor is A then the number of reflections n can be calculated from

$$\epsilon^n = A \Rightarrow n = logA/log\epsilon.$$

5 Earth

The Earth will be the major contributor to the scattered light seen by the XMM OM , because it is closer to XMM than the Moon and has a higher albedo. The albedo is, however, variable, depending on the cloud cover and the proportion of land-mass to sea in the illuminated hemisphere. According to Allen (1973) the geometric albedo p of the fully illuminated Earth ($\alpha = 0°$) is 0.37. If we assume, as a first order estimate, that the Earth scatters as a perfectly diffusing sphere (Lambert Law), then it is possible to calculate $\phi(\alpha)$. If γ is the angle from the sun-point (reaching 90° at the terminator) then the illumination falls off as $\cos\gamma$, the area illuminated increases as $\sin\gamma$ and the projected area of the scattering element varies as $\cos\xi$ where ξ is the angle between the normal through the element and the spacecraft subtended at the centre of the sphere. This in turn can be calculated in terms of γ and η, where η is the azimuthal angle about the illumination axis from the vertical as $\cos\xi = \cos\gamma\cos\alpha - \sin\alpha\sin\gamma\sin\eta$. The contribution from all these elements can be integrated as

$$\int_0^{\pi/2}\int_{\beta_1}^{\beta_2} \sin\gamma\cos\gamma(\cos\gamma\cos\alpha - \sin\alpha\sin\gamma\sin\eta)d\eta d\gamma.$$

β_1 and β_2 are the limits for the azimuthal integration. Only elements for which $\xi \leq \pi/2$ should be included, thus from above, for which $\sin\eta \geq \cot\gamma\cot\alpha$. When evaluated for $\alpha = 0°$ the integral yields $2\pi/3$, which is a factor $2/3$ of the illumination from a fully illuminated disk π, as is expected for a Lambert Law scatterer. In order to normalise this to unity at $\phi(0°)$ the integral must be normalised by the factor $3/2\pi$ to give $\phi(\alpha)$. The integral is most conveniently evaluated numerically, giving the following table:

α	$\phi(\alpha)$	α	$\phi(\alpha)$	α	$\phi(\alpha)$
0°	1.000	50°	0.708	110°	0.166
5°	0.996	60°	0.609	120°	0.109
10°	0.985	70°	0.508	130°	0.065
20°	0.944	80°	0.410	140°	0.034
30°	0.881	90°	0.318	150°	0.015
40°	0.800	100°	0.236	160°	0.004

We can substitute the minimum operating altitude of 40000 km for R_d and the radius of the Earth, 3618 km for R_s. If for example we assume a fully illuminated Earth at this altitude, 45° from the optical axis, the factors can all be put together to calculate the effective intensity at the ^{XMM}OM as

$$S_b = 4.97 \times 10^{14} \times 0.37 \times 1.0 \times \cos(\pi/4) \times 6318^2/40000^2 = 3.24 \times 10^{12}$$

$V = 10$ mag G2 stars.

6 Moon

The calculation for the Moon proceeds in a similar way to that for the Earth with the difference that the radius of the Moon (1738 km) is smaller than that of the Earth, and the minimum distance of XMM to the Moon is 304000 km. The albedo p of the fully illuminated Moon is 0.067 and $\phi(\alpha)$ is conveniently tabulated in Allen (1973) and is given below:

α	$\phi(\alpha)$	α	$\phi(\alpha)$	α	$\phi(\alpha)$
0°	1.000	50°	0.288	110°	0.041
5°	0.929	60°	0.225	120°	0.027
10°	0.809	70°	0.172	130°	0.017
20°	0.625	80°	0.127	140°	0.009
30°	0.483	90°	0.089	150°	0.004
40°	0.377	100°	0.061	160°	0.001

If we assume a full Moon 45° from the optical axis then $\phi(90°) = 1.0$, and the effective intensity is therefore

$$S_b = 4.97 \times 10^{14} \times 0.067 \times 1.0 \times \cos(\pi/4) \times 1738^2/(304000^2) = 7.70 \times 10^8$$

or more than three orders of magnitude below that from the Earth.

7 Attenuation required

To reduce the scattered light from the full Earth at 40000 km and 45° from the baffle axis to the required level of 1.0 $V = 10$ mag G2 stars, an overall attenuation factor of

$$F = \frac{1}{3.24 \times 10^{12}} = 3.09 \times 10^{-13}$$

is required.

8 Other factors

The spacecraft door must be included in any of the scattered light calculations. Although this shades the ^{XMM}OM baffle aperture from sunlight, it also potentially scatters Earthlight and Moonlight into the aperture. The quantity of scattered light depends on the coating on the inside of the door, which might benefit from some vertical relief since most of the scattered light will be incident at grazing angles.

The baffle will not produce any attenuation on the optical axis, and some offset greater than the field of view has to be assumed in order for the necessary number of reflections to take place within the baffle. This minimum number depends on the baffle design, so it is not appropriate to address that here, but this will produce a constraint on the observing programme, in the minimum angles θ_{min} to both the Earth and Moon. Likewise, other bright sources (such as planets and bright stars) will contribute to the scattered light seen by the detectors if these are viewed at angles which are less than the minimum viewing angle of the baffle. The effect of these sources must still be evaluated.

Irregularity and contamination of the optical surfaces will scatter light into the field of view of the detectors. The relative importance of this component will translate into a cleanliness and roughness specification for these surfaces.

9 Conclusions

It is clear from the calculations appropriate to the scattered Earthlight that a substantial attenuation factor is required in the baffle system to achieve acceptable levels of scattered light. Scattered Moonlight is less important. In addition the design of the spacecraft door will be important in minimising the scattered light.