Avoidence of Planets by OM

XMM-PS-TN-27

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Written by: R. Much

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1 Introduction

1.1 Scope

The performance of the OM MIC detector exhibits local degradation after an exposure to bright objects. The illumination of the detector by planets can damage the detector. This TN discusses the measures required to avoid illumination of the OM detector by planets.

1.2 Documentation

References

[1] ESA. XMM Experiment Interface Document (part A). RS-PX-0016 Issue 6, ESA/PXP, February 1996.

[2] Allen C.W. Astrophysical Quantities. , The Athlone Press, 1973.

[3] Breault Inc., Hunt R. Stray Light Design and Analysis Optical Monitor Telescope. XMM-OM/MSSL/SP/0089.1, MSSL, 1996.

2 Bright Source Limit and Baffle Performance

The performance of the OM MIC detector exhibits local degradation after an exposure to bright objects. In general two cases must be considered, firstly a source within the OM FOV directly illuminating the detector, and secondly, a bright source located outside the FOV. Sources located outside the FOV can produce straylight which is scattered into the OM focal plane. The attenuation of the photon flux from the source is mainly determined by the straylight rejection performance of the OM baffle.

The actual value of the brightness limit for sources located inside the OM FOV is not yet defined. The value depends on the measured performance of the FM detectors. However measurements with test tubes in the development phase have indicated, that a limit is likely to be $\sim 10^{th}$ mag or fainter in the V-band.

The OM baffle straylight rejection has been calculated by Breault Inc [3]. The study has shown that point sources that have an off-axis angle of one degree or greater will not produce any ghost images. Nevertheless straylight will indirectly reach the focal plane. The amount of straylight scattered into the focal plane is determined by the OM baffle straylight rejection performance, which is characterised by the point source normalised intensity transmission curve (PSNIT). The value of the PSNIT is the irradiance on the detector divided by the irradiance entering the system, where the plane used for measuring the entering irradiance is perpendicular to the point source angle.
The PSNIT was calculated as a function of the off-axis angles Θ. Fig. 1 shows the PSNIT as function of the source off-axis position for two different azimuth angles. The azimuthal dependence of the PSNIT is negligible. The difference between the curves of the two azimuth angles is small especially at small off-axis angle, which we consider here. For a source position with an offset angle of 1 degree the irradiance is already reduced by 10^{-4}, at 3.5° the irradiance is attenuated by $\sim 2 \cdot 10{-}6$, which corresponds to ~ 14 mag.

For the full understanding of the Breault report [3] further clarification is required. The PSNIT diagram shown was between a factor 4 to 6 off from the total power scattered into the focal plane listed in Table 20, 22, 24 and 26. In order to achieve reliable estimates this inconsistency should be resolved.

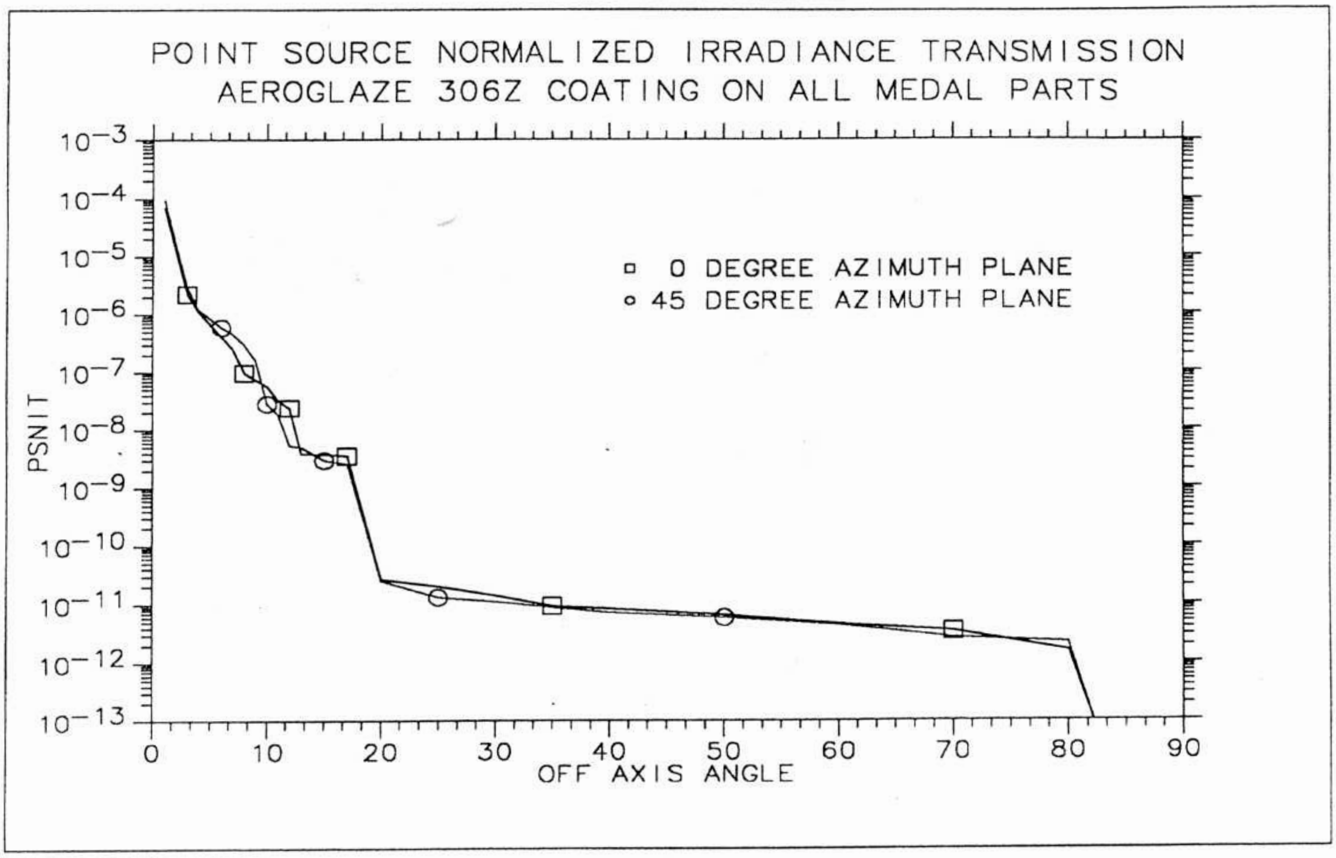

Figure 1: The point source normalized intensity transmission curve as function of the offset angle Θ for two azimuth angles [3].

An insufficiency of the report is the lack of a description of the geometrical shape of the scattered light in the focal plane. It is not reported, whether the straylight is structured or diffuse and whether hot spots are possible. This information is essential before the final avoidance angle is defined. Meanwhile the worst case assumption has to be made, that the straylight is structured and has a point source appearance.

3 Measures of Avoidence

Planets change their position on the sky. A simple catalogue interface is not sufficient to avoid planets in the OM FOV. There are two methods available to exclude a sky patch with a planet from being observed.

1. A patch of the sky is not included into the DBOB (data base of observable bins) for a given time interval.
   If a sky area is not included into the DBOB at a given time, the patch of sky

cannot be observed by XMM at this time. The SGS uses the DBOB to preselect the observations and to generate a shortlist of observations which are considered for scheduling. The selection is underconstrained, i.e. observation with a pointing direction towards an only partially open skybins is included into the shortlist.

2. A flight dynamics provided tool will allow to monitor the position of a limited number of solar system objects (15 TBC) within the SGS. The SGS can calculate the distance between the relevant object and the XMM pointing direction and the instrument pointing direction (TBC). It will become a task of the mission planner to decide whether the observation can be performed with all instruments at a given time. It will be possible to exclude individual instruments from the observation.

It should be mentioned that the OM obscuring bar mounted on the B-filter is sized to obscure point like objects. As the planets appear as extended sources, the bar cannot be used to avoid the illumination of the detector by the planet.

4 Characteristics of Planets

4.1 Assumptions

For the purpose of this note several approximations were made:

1. The orbit of the planet is assumed as circular, i.e. the eccentricity of the orbits is set to zero.
2. The inclination of the planets' orbit with respect to the ecliptic is set to zero degree.
3. The visible part of the planet is always assumed as a disk.

The first assumption simplifies the calculation, as the distance between a planet and the sun becomes a constant. Assumption two reduces the problem from three to two dimensions and the third assumptions allows to easily estimate the surface brightness.

4.2 Estimating the Brightness of the Planets

Beside the fact that planets change their position on the sky, they change their distance to the Earth and their apparent size. The (integrated) brightness of a planet changes with distance to Earth as $\frac{1}{d_{p2e}^2}$. Within the made assumptions the surface brightness of the planets is independant of the distance of the planet from the Earth and remains constant.

Fig. 2 illustrates the definition of the different geometrical parameters. The dashed dotted line indicates the XMM viewing direction. The planet is marked as a black spot.

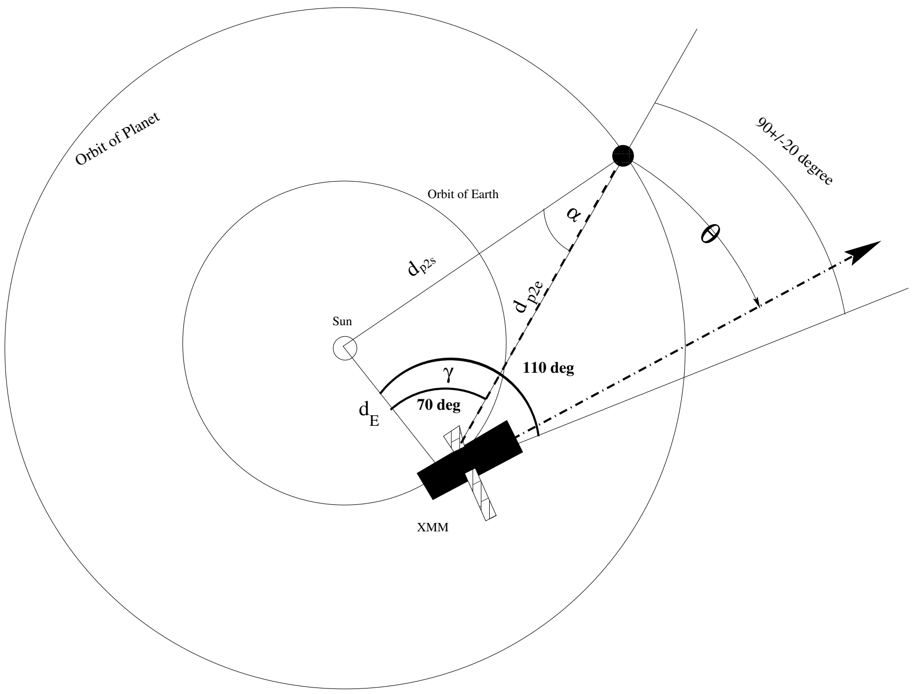

Figure 2: Illustration of the geometry of the XMM viewing direction, the position of a planet and the position of the Sun.

The planet is offset from the XMM viewing direction by the offset angle Θ. The valid range for the XMM sun-aspect angle γ is indicated. The distances between Sun and Earth (d_E), the Sun and the planet (d_{p2s}) and the distance between Earth and the planet (d_{p2e}) are indicated by lines.

Table 4.2 lists the parameters for the different planets, namely the radii of the planets r_p in km, their average distance from the sun d_{p2s}, the phase law $\Phi(\alpha)$ applicable for each planet and the brightness V(1,0), which is the (theoretical) brightness of a planet at a distance of 1 AU from both the Sun and the Earth at phase angle $\alpha = 0$.
Note that Mercury and Venus are not listed, as their angular separation from the Sun as seen from the Earth never exceeds ± 28 degree and ± 48 degree respectively. The line of sight of the XMM telescope is constrained to remain at 90 ± 20 degree away from the sun direction [1], i.e. the sun aspect angle γ is constrained to the interval from 70 degree to 110 degree (cf. Fig. 1). Therefore the position of the inner planets can never coincide with the XMM viewing direction.

The integrated brightness of the planets are approximated with the relation [2]:

$$V_{tot} = V(1,0) + 5 \log \left(d_{p2s} \cdot d_{p2e} \right) + \Phi(\alpha) \tag{1}$$

with

planet	radius planet r_p [km]	avg. distance to sun d_{p2s} [AU]	brightness V(1,0)	phase-law[2] $\Phi(\alpha)$
Mars	3394	1.52	-1.52	$+0.016\alpha$
Jupiter	71880	5.20	-9.40	$+0.014\alpha$
Saturn[1]	60210	9.54	-8.88	$+0.044\cdot$L$-2.6\cdot \sin B + 1.2 \cdot \sin^2 B$
Uranus	26150	19.2	-7.19	$+0.001\alpha$
Neptune	24750	30.1	-6.87	$+0.001\alpha$
Pluto	1084	39.4	-1.0	-

[1] the Saturnicentric ring longitude difference L of Sun and Earth was set to the phase angle α for simplicity and the the latitude B of the Earth was set to 0 degree.
[2] α in degree

Table 1: List of Planetary Parameters [2]

d_{p2s}	is the distance between sun and planet (in AU)
d_{p2e}	is the distance between Earth and planet (in AU)
α	is the phase angle between Sun and Earth seen from the planet (in degree)
$\Phi(\alpha)$	is the phase law, i.e. the change of planet brightness with phase angle
V(1,0)	is the theoretical visual brightness of a planet at a distance of 1AU from both the Sun and the Earth ($d_{p2s} \cdot d_{p23}$=1) and phase angle zero ($\alpha = 0.$)

An estimate of the surface brightness V_{surf} is obtained by dividing the integrated brightness V_{tot} by the apparent size of the planet's disk:

$$V_{surf} = \frac{V_{tot}}{r_\phi^2 \cdot \pi} \tag{2}$$

The apparent disk radius r_ϕ (in arcsec) is obtained by the formula:

$$r_\phi = \frac{r_p}{d_{p2e}} \cdot \frac{\pi}{180} \tag{3}$$

with

r_p	is the radius of the planet (in km)
d_{p2e}	is the average distance of the planet to the Earth (in km)

The distance Earth-planet d_{p2e} is approximated with

$$d_{p2e} = \sqrt{d_E^2 + d_{p2s}^2 - d_E \cdot d_{p2s} \cdot \cos\left(180° - \gamma - \arcsin\left(\frac{d_E \cdot \arcsin\gamma}{d_{p2s}}\right)\right.} \tag{4}$$

with

d_E	is the Astronomical Unit
d_{p2s}	is the average distance of the planet from the Sun
γ	is the solar aspect angle, (the angle between the XMM pointing direction and the sun)

The apparent disk size of the planets was calculated for the three solar aspect angles 70°, 90° and 110° . The areas are listed in Table 4.2.

planet	apparent disk area [arcsec^2]		
	γ=70°	γ=90°	γ=110°
Mars	29	52	94
Jupiter	1036	1184	1353
Saturn	224	241	259
Uranus	11	11	12
Neptune	4	4	4

Table 2: Apparent disk area (in arcsec^2) of the planet for different solar aspect angles γ

5 Brightness of Planets

The integrated brightness of the planets V_{tot} (unit: mag) was calculated for the valid range of the XMM sun aspect angle (70°$\leq \gamma \leq$110°) with equation (1) using the parameters from Table 4.2. The surface brightness V_{surf} (unit: mag/arcsec^2) was derived with equation (2). Both values, V_{tot} and V_{surf}, were converted into OM count rates in the V-filter, assuming the planets have a solar type spectrum and the detector has a zero deadtime. The derived brightness and count rates are listed in Table 3.

In general the planets become brighter with increasing solar aspect angle. Therefore it is sufficient for the definition of the avoidence cone only to consider the case of γ=110°. The surface brightness of the planets Mars, Jupiter and Saturn are by far exceeding the brightness limit of OM. Even their surface brightness is 3 mag above the tentative OM bright source limit.

planet	V$_{tot}$ [mag]			cts$_{tot}$[mag/arcsec^2]			V_{surf} [mag/arcsec^2]	cts_{surf} [cts/arcsec^2]
	γ=70°	γ=90°	γ=110°	γ=70°	γ=90°	γ=110°		
Mars	0.94	0.35	-0.33	1.1E7	1.9E7	3.5E7	4.6	3.6E5
Jupiter	-1.99	-2.11	-2.28	1.6E8	1.8E8	2.1E8	5.6	1.6E5
Saturn	1.23	1.17	1.07	8.3E6	8.8E6	9.6E6	7.1	3.7E4
Uranus	5.68	5.64	5.60	1.4E5			8.3	1.3E4
Neptune	7.93	7.91	7.89	1.8E4			9.4	4.4E3
Pluto	brightness in opposition: 14.9 mag						-	-

Table 3: Brightness of planets in the operational range of XMM

6 Avoidence of Planets

The definition of avoidence cones around the planets is driven by the amount of light reaching the focal plane. This is a function of the brightness of the planet (Tab. 3), the straylight rejection performance of the baffle (Fig. 1) and the shape and size of the straylight image in the focal plane. The latter is not known and the conservative approach is adopted, that the image is point like.

For Jupiter an attenuation of $10^{-}6$ is needed to reduce the number of photons reaching the focal plane to an acceptable level, i.e. to several hundreds counts per second. This is achieved with an avoidance cone of 4.5 degree. For Mars an avoidence cone of 3.5 degree (attenuation by 10^{-5}) is sufficient and Saturn requires an avoidance by 2 degree (attenuation by 10^{-4}).
Neptune and Uranus have a brightness comparable to *usual* bright stars. The avoidance criteria for normal bright stars could be applied, i.e. the two planets are supposed to be located outside the operational OM FOV and for observations with these planets inside the FOV, the filter wheel is moved into the blocked position. However as the baffle performance for small off-axis angles is not known, an off-axis angle of at least $1°$ is required at the moment.

While the avoidence angles for Mars, Jupiter and Saturn are of the size of the smallest DBOB bins ($2°$x$2°$), the off-set angles required for Neptune and Uranus are only half the DBOB binsize. It is proposed to avoid Mars, Jupiter and Saturn at the DBOB level (option 1 in section 3), while Neptune and Uranus are treated procedurally (option 2 in section 3).

No constraint on the operation will be imposed by Mercury, Venus and Pluto. The brightness of Pluto is fainter than the OM bright source limit. Mercury and Venus are already excluded from being observed by the constraint on the XMM sun aspect angle.

7 Summary

In general the conclusions made are hampered by the fact that the straylight rejection performance is not known for offset angles less than $1°$, i.e. when the bright source is located just outside the OM FOV, and by the fact that the MIC respone to bright and medium bright extended sources has not been investigated so far.

- Mercury and Venus lie outside operational range of XMM and do not impose an additional constraint.
- Pluto is fainter than the tolerable OM brightness limit and does not impose an additional constraint.
- Mars, Jupiter, Saturn should be excluded at the DBOB level.

- Mars, Jupiter, Saturn will be avoided by a half-cone angle of $3.5°$, $4.5°$and $2°$ respectively.
- Saturn, Uranus and Neptune will be handled procedureally by the mission planner with the flight dynamics angular separation tool.
- Saturn, Uranus and Neptune are treated as bright sources, i.e. they will be kept outside the OM FOV, or the OM filter wheel is moved to the closed position.
- The MIC response of bright area sources is needed to estimate the required avoidence angle more accurately.
- The baffle attenuation for small off-axis angles is needed to estimate the required avoidence angle more accurately.
- The shape and size of the straylight image in the focal plane is not known. More information is needed to improve the accuracy of the avoidence cone estimates.