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Zodiacal Light contribution for the UV ETC background

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ABSTRACT

One of the major contributors to the total HST sky background is the Zodiacal light. The Exposure Time Calculator (ETC) uses an estimate of the Zodiacal light at different helio-ecliptic angles in order to estimate its contribution for different sky positions and epochs. A recent discrepancy between the limit in the sun angles allowed by the ETC and those from the Astronomer Proposal Tool (APT) set into motion a reevaluation of these limits and of the data itself. This memo provides an update to its contribution with angle in the sky for wavlengths below 5 μm. It also describes how the Zodiacal light information is used by the ETC

Introduction

Zodiacal light is one of the major contributors to the sky background and should be taken into account for planning observations with HST. The Zodiacal light is the result of the absorption and scattering of the sun light by dust grains. At wavelengths between 1300 Å and 3000 Å the contribution is due to scattered radiation; which is about 10% of the incident Sun light. At infrared wavelengths, mainly between 5 μm and 100 μm the contribution is due to the thermal emission of dust grains heated by absorption of the remaining 90% of the solar radiation [1]. In this report, we will provide updates to the Zodiacal contribution for the UV and NIR region of the spectra.

Both, the APT and the Exposure Time Calculators take into account its contribution in order to plan observations. In the case of the APT, the contribution is not numeric but rather via the Sun angle; which defines a region of solar avoidance beyond which observations cannot be made. The ETC poses a similar limit by not allowing calculations for sources that are within the solar avoidance angle; however in this case the level of contribution of the Zodiacal light is important to accurately estimate the background.

Zodi light at UV wavelengths

The brightness of the Zodiacal light depends on the scattering angle, the line of sight of the observer, the size, the composition and structure of the dust particles. In the ecliptic plane it can be as bright as 1.5×10^{-6} $ergs\ s^{-1}\ cm^{-2}\ sr^{-1}\ Å^{-1}$; while at heliocentric longitudes between 130-170 degrees away from the Sun it is at is faintest due to the larger scattering angles and lower densities of interplanetary dust.

Since scattering strength is only weakly dependent on wavelength, the spectrum of the Zodiacal light follows that of the sun between 0.2 and 10 µm. It is generally smooth, showing up to 10% variation with season at high and medium ecliptic latitudes. Therefore, brightness of the Zodiacal light for each line of sight can be accurately modeled by the average of interplanetary dust particles of different size, structure and composition as well seasonal variations[2].

Table Table 1 gives the Zodiacal light brightness, in units of $mag\ arcsec^{-2}$, measured from the Earth and for different positions in the sky. The brightness is for wavelengths near 0.55µm for different ecliptic latitudes and helioecliptic longitudes ($\lambda - \lambda_{\odot}$). These values have been corrected by inclination of the symmetry plane and for the Earth's orbit eccentricity [1]. The same values are presented as a contour plot in Figure 1.

The original values from Landolt & Bornstein (2009) are in units of 10^{-8} $W\ m^{-2}\ str^{-1}\ \mu m^{-1}$ and have to be converted to ETC units; i.e. $mag\ arcsec^{-2}$. For this, the original values are first converted to F_ν units using the relation

$$F_\lambda d\lambda = F_\nu d\nu$$

Since $d\nu/d\lambda = c/\lambda^2$, with λ in cm, this becomes:

$$\beta_\lambda{}^2 F_\lambda = F_\nu$$

where $\beta = 3.3357 \times 10^{-15}$ if F_λ is given in units of erg s^{-1} cm^{-2} μm^{-1} and F_ν is given in units of $erg\ s^{-1}\ cm^{-2}\ Hz^{-1}$. For $\lambda = 0.56\ \mu m$ this equation becomes:

$$1.04607 \times 10^{-12}\ F_\lambda\ (W\ m^{-2}\ \mu m^{-1}) = F_\nu\ (erg\ s^{-1}\ cm^{-2}\ Hz^{-1})$$

where the erg/s was replaced by W using the relation $1\ W = 10^7\ erg/s$, and cm by m. Using this value of F_ν and the following equation to convert to V mag surface brightness

$$m_\nu\ (mag\ arcsec^{-2}) = -2.5\ log(F_\nu\ (erg\ cm^{-2}\ s^{-1}\ Hz^{-1}\ str^{-1})) - 22.02$$

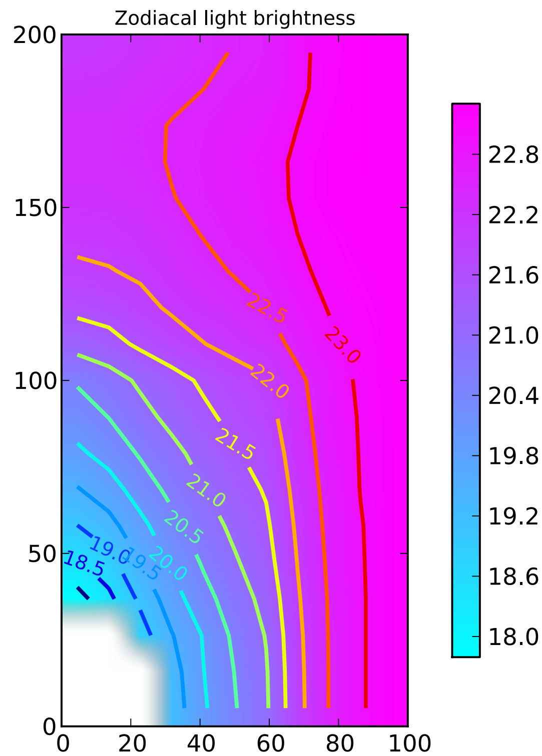

Figure 1: Contour plot with the zodiacal light brightness at 0.55μm in units of *mag arcsec*$^{-2}$. Values have been corrected by inclination of the symmetry plane and for the Earth's orbit eccentricity [1].

the values given in Table 1 were derived.

When user request to calculate the contribution of the Zodiacal light with position, the ETC uses these values. For this, first the Equatorial coordinates given by the user are converted to Ecliptic coordinates and corrected by the Sun angle given by the user or derived from the chosen date. Appendix A provide with the transformation between Ecliptic and Equatorial coordinates and how to introduce the correction with he Sun angle.

Once the Helioeclipic coordinates are calculated, the ETC performs a bilinear interpolation using the values in Table 1 in order to derive the Johnson V magnitude for the Zodiacal contribution. The result is then fed to the pysynphot task renorm to renormalize the Zodiacal light spectrum model (currently *zodiacal_model_001.fits*) to the derived V magnitude.

HST Observation

Most of he HST observations are made at roughly 90° from the sun (nominal roll). However, scheduling constrains (e.g., specific orientation is required at a specific date or the same orientation is required for observations made at different times) can force the observations to other sun angles. Off-nominal rolls are restricted to approximately 5° when the sun angle is between 50° and 90°, < 30° when the sun angle is between 90° and 178°, and is unlimited at anti-sun pointing of 178^{o} to 180^{o}. These restrictions affect, in particular, some of the Solar System objects like Venus which is always within the 50^{o} degree Solar pointing exclusion. There are exceptions to these rules for HST pointing in certain cases; but even on these cases the onboard safety features, like the aperture door closing automatically whenever HST is pointed within 20^{o} of the Sun, prevent direct sunlight from reaching the optics and focal plane (HST Cycle 20 Primer Section 2.4).

Table 1: Zodiacal light background (V mag/arcsec^2) in ecliptic latitude (β) and helio-ecliptic longitude ($\lambda - \lambda_{\odot}$[1]). The nan values correspond to the exclusion zone.

β $\lambda - \lambda_0$	**0 ^{o}**	**5 ^{o}**	**10 ^{o}**	**15 ^{o}**	**20 ^{o}**	**25 ^{o}**	**30 ^{o}**	**45 ^{o}**	**60 ^{o}**	**75 ^{o}**	**90 ^{o}**
180 ^{o}	22.0418	22.1315	22.2236	22.3243	22.4216	22.5210	22.6304	22.8998	23.1473	23.3037	23.2298
165 ^{o}	22.2180	22.2407	22.3181	22.4014	22.4989	22.5743	33.6554	22.9104	23.1607	23.3037	23.2298
150 ^{o}	22.3181	22.3243	22.4014	22.5210	22.6060	22.6896	22.7801	22.9990	23.2016	23.3037	23.2298
135 ^{o}	22.3181	22.3243	22.3948	22.5284	22.6304	22.7339	22.8483	23.0707	22.2298	23.2885	23.2298
120 ^{o}	22.2639	22.2757	22.3305	22.4844	22.5980	22.7071	22.8186	23.0707	23.2298	23.2736	23.2298
105 ^{o}	22.1315	22.1419	22.2124	22.3686	22.5136	22.6387	22.7614	22.9990	23.1607	22.2298	23.2298
90 ^{o}	21.9155	21.9768	22.0660	22.2350	22.3948	22.5284	22.6470	22.9104	23.1212	23.2016	23.2298
75 ^{o}	21.6258	21.6965	21.8737	22.0611	22.2180	22.3621	22.4989	22.7801	23.0024	23.1607	23.2298
60 ^{o}	21.1844	21.3356	21.5842	21.7872	21.9859	22.1525	22.2937	22.6304	22.9104	23.1212	23.2298
45 ^{o}	20.5523	20.7885	21.0810	21.3356	21.5717	21.7872	21.9545	22.3948	22.7801	23.0707	23.2298
40 ^{o}	20.2614	20.5107	20.8426	21.1315	21.4026	21.6258	21.8257	22.3181	22.7522	23.0343	23.2298
35 ^{o}	19.9014	20.1896	20.5523	20.8667	21.1736	21.4514	21.6861	22.2350	22.7071	23.0224	23.2298
30 ^{o}	19.4634	19.7698	20.2339	20.6342	20.9775	21.2750	21.5441	22.1578	22.6554	23.0107	23.2298
25 ^{o}	18.9881	19.3218	19.8557	20.3483	20.7661	21.1110	21.4186	22.0808	22.6141	22.9762	23.2298
20 ^{o}	18.4335	18.8208	19.4950	20.0743	20.5523	20.9422	21.3061	22.0135	22.5743	22.9649	23.2298
15 ^{o}	17.7944	18.3699	19.1064	19.7757	20.3284	20.7515	21.1523	21.9501	22.5360	22.9538	23.2298
10 ^{o}	nan	nan	18.7609	19.4678	20.0284	20.6083	21.0233	21.8944	22.52.10	22.9538	23.2298
5 ^{o}	nan	nan	nan	19.2759	19.9844	20.5107	20.9597	21.8656	22.5136	22.9538	23.2298
0 ^{o}	nan	nan	nan	19.2070	19.9284	20.4649	20.9335	21.8494	22.5136	22.9538	23.2298

Knowing the allowed scheduling windows is important; however, this is only part of the considerations when planning observations. The Zodiacal light varies depending on location of the sky and date. For most observations, which are not background constrained, an approximation to the level of this contribution is adequate. For others, having a more accurate prediction is important. In order to cover all these possibilities the ETC offers different options for estimating the Zodiacal light contribution to the observed background. These options are:

1. Users can use standard Zodiacal light normalizations with levels: Low, Average, High, and none.
2. Users can specify their own Johnson V magnitude normalization.
3. Users can scale its contribution by a given factor.
4. Users can provide a position in the sky and a specific date or helioecliptic latitude and find a more accurate normalization value.

Normalization

Normalization of the Zodiacal light is done using the template Zodiacal spectra shown in Figure 2. In the case where users specify the contribution of the Zodiacal light as Low, Average, or High, the ETC normalizes the template spectra to three Johnson V magnitudes: 23.3 for Low, 22.7 for Medium, and 21.1 for High level. The result of these normalizations are shown in Figure 3.

For the case when the coordinate of the object is given, the template spectra is used to determine the contribution of the Zodiacal light to the total observed background. The calculations are made internally within the ETC using the surface brightness given in Table 1. This table cover angles that are beyond the HST solar avoidance angles, so the ETC uses only those values that are between $\beta = 15^{o}$ and $(\lambda - \lambda_{\odot}) = 15^{o}$. These provide coverage for all possible observing regions; however, the final decision on restrictions and scheduling constrains for HST observations are left to the APT software.

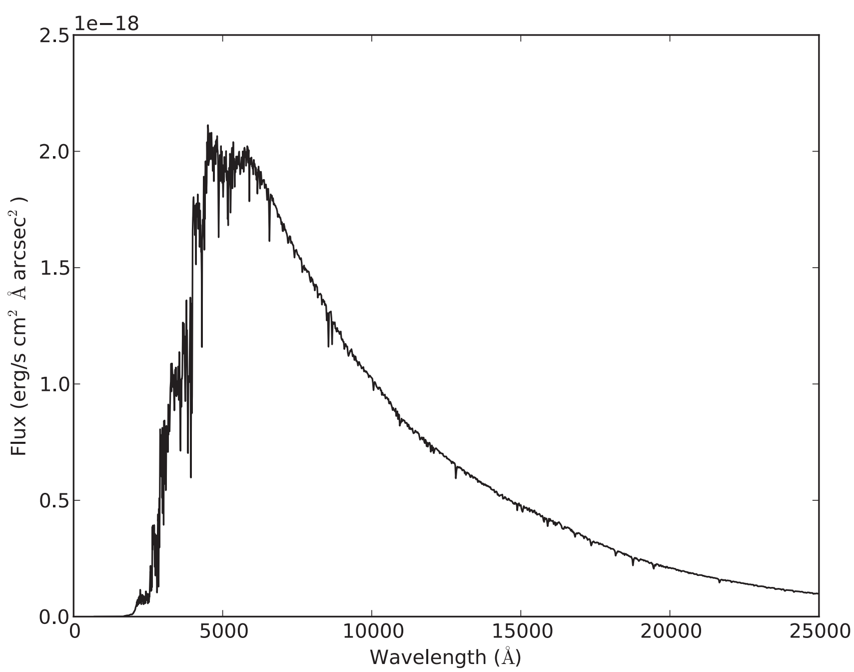

Figure 2: Zodiacal Light template spectra

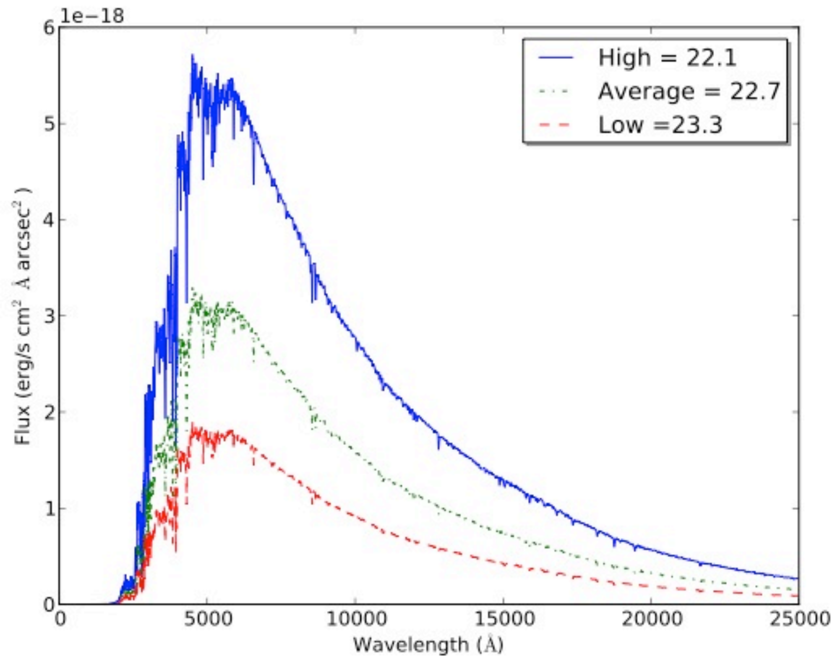

Figure 3: Contribution of the Zodiacal light normalized to its Low, Average, or High values.

References

1 Landolt, H. & Bornstein, R 2009, Landolt-Brnstein: Numerical Data and Functional Relationships in Science and Technology - New Series, eds: Martienssen, Werner, Springer

2 Linert, Ch., Bowyer, S. Haikala, L.K, Hanner, M.S., Hauser, M.G, Levasseur-Regourd, A.-Ch., Mnn, I. Mattila, K., Reach, W.T., chlosser, W., Staude, H.J., Toller, G.N., Weiland, J.L. Weinberg, JL., & Witt, A.N. 1998, A&A, 127, 1

Appendix A: Coordinates Transformation

The Zodiacal light is given in ecliptic coordinates β (ecliptic latitude) and $\lambda - \lambda_{\odot}$ (helio-ecliptic longitude or elongation). For a given equatorial coordinate, its contribution can be determined by finding the corresponding ecliptical coordinates and Table 1. The relation between these set of coordinates is:

$$
\begin{aligned}
\sin\beta &= \sin\delta \cos\varepsilon - \cos\delta \sin\varepsilon \sin\alpha \\
\cos\lambda &= \cos\alpha \cos\delta / \cos\beta \\
\sin\lambda &= [\sin\delta \sin\varepsilon + \cos\delta \cos\varepsilon \sin\alpha] / \cos\beta
\end{aligned}
\tag{5}
$$

or from (λ, β) to (α, δ)

$$
\begin{aligned}
\sin\delta &= \sin\beta \cos\varepsilon + \cos\beta \sin\varepsilon \sin\lambda \\
\cos\alpha &= \cos\lambda \cos\beta / \cos\delta \\
\sin\alpha &= [-\sin\beta \sin\varepsilon + \cos\beta \cos\varepsilon \sin\lambda] / \cos\delta
\end{aligned}
\tag{6}
$$

where ε is the obliquity of the ecliptic with values $\varepsilon = 23.489^{o}$ for equinox 2000 and $\varepsilon = 23.446^{o}$ for equinox 1950.

To determine the brightness along the line of sight the ETC uses the following equation to calculate the helio-ecliptic logitude or elongation (angle between sun-earth and earth particle):

$$\lambda - \lambda_{\odot} = \lambda - \lambda_{\oplus} - 180 \tag{7}$$

where $\lambda_{\oplus}$ is the equatorial longitude of the earth and is derived as follows:

$$\lambda_{\oplus} = 360 * \Delta / 365.25 \tag{8}$$

Δ is the numer of days from the Vernal Equinox of the selected year (March 20).