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Modeling of the GSO background

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This document describes a modeling method of the GSO background. Among the Suzaku SWG team, this model is referred to as "bgd_d" .

The HXD-PIN background (BGD) depends mainly on the geomagnetic cut-off-rigidity (COR). Similarly, the GSO BGD depends on the COR in energies below 100 keV, but the dependence becomes weaker toward higher energies. Instead, the GSO BGD exhibits much stronger variations as a result of activation induced during the SAA passages. These variations are strongly energy-dependent, because many activated nuclei emit various gamma-ray lines together with the continuum. Therefore, in constructing "bgd_d", we directly fit the GSO BGD light curves with an empirical model, and determine its parameters. Then, the model is used to predict the BGD count rate at any given time.

Due to the activated nuclei with long decay-time constants, the GSO background gradually increases. As a result, simply constructing a single and universal BGD database would not be sufficient, unlike the case of PIN. Therefore, we accumulate the GSO data for about a month (details to be described later), under the following conditions. The target elevation angle should be $< -5°$ (namely, during the Earth occultation); the data rate should not be low; the in-orbit HXD data transfer should not be saturated; and the COR should be > 6 GV. We then divide the accumulated GSO events into 32 energy bands, and derive 200-sec bin light curves in each energy band. Boundaries of the 32 energy bands are logarithmically spaced from 53 keV to 1024 keV, with each band having a typical BGD rate of 0.5–1 c/s. Note that this modeling can be applied to the PIN BGD as well; in fact, a part of the public PIN BGD model is based on this modeling, in which the PIN light curve is analyzed in a single 11–70 keV energy band since the count rate is not so high and the BGD is less dependent on the energy.

After the 32 light curves are prepared, we fit them individually, with an empirical model to be constructed in the following manner. Like in the PIN BGD modeling, the COR dependence is represented by a term which is a second-order polynomial function of the PINUD counts summed over the 64 PIN diodes. Likewise, the activation component is represented by another term with PINUD build-up counts, namely a convolution of the PINUD counts in the SAA with several exponential decay functions with different time constants τ_k. The convolution integral is calculated up to $30\tau_k$, in order to save the calculation time.

Various studies indicate that we need at least 3 to 4 time constants, τ_k, to represent the build-up effects in each energy band. In order to find them, we performed a preliminary analysis. That is, we fitted a light curve consisting of the entire Earth occultation data acquired in the period from 2005 September 2 to 2006 February 28. with a model consisting of the second-order polynomial function of the PINUD counts and the PINUD build-up term with two time constants. Then, we produced confidence contours for the two time constants by scanning them independently. First, we scanned the two time constants in a range shorter than one day, and determined them. After fixing these two short time constants, we newly added two build-up time constants longer than one day, and repeated the search. One time constant was scanned at grid values of 0.5, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.0, 10.0, 13.0, 15.0, 18.0, 22.0, 30.0, 45.0, 60.0, 80.0, and 100 ksec, wile the other over 0.15, 0.25, 0.35, 0.45, 0.55, 0.8 1.0, 2.0, 3.0, 5.0, 6.5, 8.0, 10.0, 20.0, and 30.0 Msec. Thus, we have obtained 4 time constants that describe the PINUD build-up effects in each energy band. The obtained four time constants are typically 1–2 ksec, 10-20 ksec, a few days, and several tens days, depending on the energy band.

While the activation effects have thus been described approximately by PINUD counts integrated with four time constants, we have found that the activation BGD also depends on the angle $\theta_{\rm B}$ between the geomagnetic field and the HXD field of view; when $\theta_{\rm B}$ is small, the SAA particles directly enter the tight HXD shield "Wells", and increase the GSO background level even for the same PINUD build-up count (5–10% higher when the angle is around 0°). Although a direct inclusion of this angle dependence somewhat improves the background reproducibility, we have found that the effect is efficiently represented more simply by the 450–700 keV GSO count rate, $GSOHCNT(t)$, where celestial signals are less than 0.2% even during the Crab observation.

From the above consideration, the empirical model describing the GSO light curve in the i-th energy band is expressed as

$$
\begin{aligned}
BGD_i(t) = \quad & a_i + \sum_{k=0}^{3} b_{k,i} \int \left\{ 1 + c_{k,i} \frac{90^\circ - \theta_{\rm B}(t')}{90^\circ} \right\} \cdot PINUD(t') \cdot \exp\left(-\frac{t - t'}{\tau_k} \right) dt' \\
& + d_i \cdot PINUD(t) + e_i \cdot PINUD^2(t) + f_i \cdot GSOHCNT(t) \cdot \left[1 + g_i \exp\left(-\frac{t - t_{\rm SAA}}{\tau_g} \right) \right] \\
& + h_i(t) \quad ,
\end{aligned}
$$

where the coefficients a_i, $b_{k,i}$, $c_{k,i}$, d_i, e_i, f_i, and g_i are model parameters to be adjusted, and $t_{\rm SAA}$ is the elapsed time from the end of the latest SAA, while τ_g is set to 10000 sec and τ_k are fixed to the values as described above. The last term in this model, h_i, is a correction bias to be explained later, introduced in order to reduce the current uncertainty as much as possible. The input data for modeling the background are $PINUD(t)$, $\theta_{\rm B}(t)$, and t.

A set of monthly model parameters are determined by fitting the light curve of the Earth occultation data from each month, together with those before and after 10 days of that month. Each fit does not cross any occasion when the HXD operation mode (such as high-voltages and lower discriminator levels) was changed. After once performing the fit, we exclude data points with large deviations by $> 5\sigma$ (with σ the root-mean-square), and perform the fit again to obtain the final parameters. In the fitting, we fix the correction bias f_i to 0. Afterwards, we calculate the residual between the background and the model in every 150 ksec, and employ the residual as the correction bias h_i; $h_i(t)$ varies every 150 ksec, while the other model parameters are constant in each month. Presently, h_i is at most 0–2% of the total background. In figure 1, we show an example of the light curve fitting and the correction bias.

After the BGD model parameter sets are thus determined for the 32 energy bands, we create the background light curve in each energy band at each HK time. Finally, fake BGD events in each band are created, with their pulse heights determined by a Monte-Carlo method referring to the model-predicted counts in each HK frame. As shown in figure 2, the pulse height is uniformly and randomly distributed within each energy band . Therefore, users are advised to use exactly the same energy boundaries as the present model, when binning the GSO spectra.

For reference, pulse heights of fake events in the PIN model background follow probability distributions referring to the actual pulse-height spectral database, accumulated under various values in the COR and T_SAA_HXD; the database is sorted at boundaries of 6, 7, 8, 9, 10, 11, 12 GV in the COR, and 2000, 4000, 10000 sec with respect to T_SAA_HXD. The database is created from the earth occultation data using intervals of 2005 August 17 – 2005 September 01, 2005 September 2 – 2006 February 28, 2006 March 29 – 2006 May 12, 2006 Jun 1 –2006 September 30, and 2006 October 06 –2006 November 30, so that the observational set-up of the HXD is the same within each period.

Currently, the number of parameters and the model form of the GSO background may not be necessarily optimized. Therefore, the mode parameters could exhibit discontinuities from a month to the next.

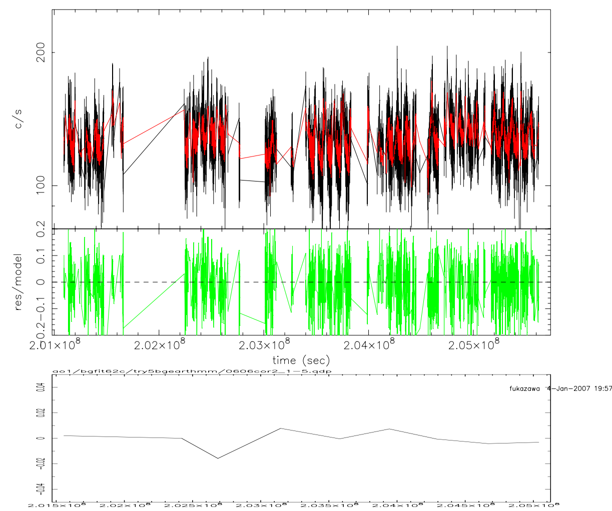

Figure 1: (Top) An example of the empirical model fitting to the GSO BGD light curve in 70–80 keV, for a particular case of 2006 June. Time bin is 200 sec. Black and red are the data and the best fit model, respectively. (Middle) Fractional residual of the fit. (Bottom) The corresponding correction bias $f_i(t)$.

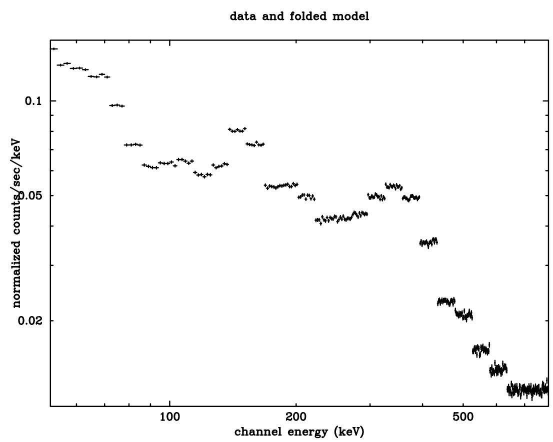

Figure 2: An example of the GSO background model spectrum.