Multicomponent modelling of the gamma-ray background

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INTRODUCTION

The accurate background estimation is a key element for weak transient detections in the gamma-ray sky. Well handled signal backgrounds are essential for any useful science even in the presence of small glitches (e.g. Gruber & Fermi/GBM Collaboration (2012)) for weak, long and slow transients which will not trigger the onboard algorithm. The detection of a very weak and short signals near the instrument’s energy boundaries (i.e. the very soft or very hard transients) could also be improved by the right background model.

It is hard to model the gamma-ray background observed by all sky spaceborne detectors due to its complex nature. These detectors usually cover the whole sky, therefore both transient and point source contributions to the observed counts. Here we investigate the Fermi Gamma-ray Burst Monitor (GBM). For the GBM the satellite’s specific motion further complicated the signal as the spacecraft continuously sweeps over the sky.

The Fermi GBM detector system consists of 12 NaI(Tl) and two BGO Germanium (BGO) detectors, observed by photomultipliers (Meegan et al. 2009). The NaI(Tl) detectors cover the low-energy (9 keV to 1 M eV) spectrum while the BGO detectors are sensitive in the energy range of 20 keV to 40 MeV. Since November 2012, the GBM CTTE (continuous-time-tagged event) data is stored for each photon for each detector and energy channel, with a time resolution of 2 ns.

The photomultipliers’ signals are analyzed with a pulse height analysis and the height of a given impulse will be stored into one of the 128 channels. The function between the incoming photon energy and the channels are linear, described by the DRM detector response matrix. This matrix depends on the geometry (angular dependence of the efficiency, point source and dispersion, atmospheric and spacecraft scattering).

The background problem is further complicated by the fact that the events are correlated between the detectors and channels implicitly. The field of views of the detectors facing similar directions.

The background estimation problem is to find the best approximation of this correlated, quite sparse multivariate-multipletime series in a time interval (i.e. during the transient), with data from the pre- and post-interval only. This complex job has several solutions, some methods were developed especially for the Fermi Gamma-ray Burst Monitor.

BACKGROUND ESTIMATION WITH ORBIT STACKING

The typical GBM event is short, usually below 1000 s, while the usual variation timescale of the background is about one ten times longer. Therefore the simple polynomial fitting is usually not suitable. The GBM/DL5 DRMs are 4th order polynomials estimated for each channel for each day and then stacked on top of each other.

Similarly the Fermi’s TRFL package also uses this generic method. For a given search interval two regions should be selected, usually one before and one after the transient. The exact selection depends on the user (the manual user must decide "Do not reject too much background to choose events down to energy X", and it can take very rapidly varying background, but hard to automate. The software approximates the background for every detector channel for every channel (both in a month either for 120 FFA range) with some low order polynomial.

As an example we show the background estimations for the GBM091030 event (Fig. 1), where after the trigger the satellite rotated.

BACKGROUND ESTIMATION WITH THE DIRECTION DEPENDENT BACKGROUND FITTING

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Neither the DDBF nor the Background Components Modelling could be the final method for GBM background modelling since the method or new background component should be automatically included in the process. The method is not really suitable for space-like transients. The usage of the physical components (or components derived from the observed photos events) is also crucial. It’s clear that all data of all available detectors and energy channels should be used for the estimation.

In Bagoly et al. (2016) we developed the Automated Detector Weight Optimization (ADWO) or for a non-triggered, short-duration transient searches. ADWO combines the data of all available detectors and energy bands, identifying those with the strongest signal. With optimized weights different energy channels and detectors the Signal-to-Noise’s Peak to Background Ratio was maximized in the transient interval.

The finest GBM resolution is 14 detectors with 128 channels: i.e. we leave the 4 lowest and the 2 highest channels (out of 112 observables) to 128 channels (14 = 122 + 6 (108 channels)). The GBM photon data event for each detector and for each channel is quite sparse: usually several or even less than one events per minute. Clearly this data cannot be handled by the traditional approaches or by the energy channel. It should be somehow binned and spread over the whole detector in its energy channel. This filtering will not enhance the signal-to-noise ratio with correlation. Without filtering, there will be practically no photon counts.

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GAMMA-BACKGROUND ESTIMATION WITH MATRIX FACTORIZATION

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We here propose to use the matrix factorization with non-negativity constraints to factor the C matrices into two components:

\[ C = X \times L \times X^T \]

where \( X \) is a \( n \times l \times a \times n \)-dimensional matrix. The \( L \) will give the best possible approximation of the number of the real physical components (seen by the detector with a limited spatial and energy resolution, according to the DRMs).

The factorization method is well known in many areas (e.g. Pascual-Montano et al. (2008), Frigyesi & Heldinger (2008) and has the advantage being online. The l-dimensional components are non-negative, just like the real radiation intensity, while the C-matrix contains the aggregated count information about the photons’ energy.

We imply further constrains for \( L \): all rows (component lightcurves) should be fitted with a second order polynomial. Clearly, high order polynomials will provoke negative region, where we want to estimate the orbit background with. Setting these parts to zero will not help as the approximation breaks down exactly the interpolating region. Rapid changes in the background will require higher order values as we’re looking to background estimation with time normalization overfitting, which will enhance the sensitivity, while we also normalize the sum of the columns to 1.

The algorithms for a matrix factorization with non-negativity constraints are not available for almost every component language. Here we use the classic algorithm in Matlab (e.g. Pascual-Montano et al. (2006), with trivial modifications for the second order constrains)

We show the GBM091030 background estimation on Fig. 9.