A Robust Filter for the BeppoSAX Gamma Ray Burst Monitor Triggers

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Abstract. The BeppoSAX Gamma Ray Burst Monitor (GRBM) is triggered any time a statistically significant counting excess is simultaneously revealed by at least two of its four independent detectors. Several spurious effects, including highly ionizing particles crossing two detectors, are recorded as onboard triggers. In fact, a large number of false triggers is detected, in the order of 10/day. A software code, based on an heuristic algorithm, was written to discriminate between real and false triggers. We present the results of the analysis on an homogeneous sample of GRBM triggers, thus providing an estimate of the efficiency of the GRB detection system consisting of the GRBM and the software.

THE GAMMA RAY BURST MONITOR

The GRBM \([1,3,2,4]\) is a gamma-ray detection system onboard the BeppoSAX satellite. It is the secondary function of the anticoincidence shields of the PDS experiment. It is composed of four \(\sim 1100\) cm\(^2\) slabs of CsI(Na) scintillators operating in the 40-700 keV range. Each detector provides time series of the detected counts in the above energy range, with 1 s resolution as a continuous housekeeping and with better than 8 ms resolution upon trigger. An onboard trigger is active whenever a statistically significant counting excess is simultaneously detected in at least two of the four detectors.

AIMS, METHOD AND LIMITS

Besides of being gamma-ray detection devices, the scintillating crystals composing the GRBM are sensitive to highly ionizing particles that, leaving a large amount of energy (\(\sim\)GeV) in just one shot, result in a phosphorescence phenomenon, with a consequent detection by the electronics of a large number of counts in few tens of ms, i.e. a spike in the counting rate. When the same particle subsequently crosses two
detectors, it causes the onboard logic to trigger on the event, that is electronically undistinguishable from a cosmic gamma-ray transient (no particle anticoincidence is available to the GRBM). The number of spikes that trigger the onboard electronics (originating false triggers) is of the order of 9-10/day. Therefore, the aim of this work is to provide a software filter that allows to make a ‘safe’ first-order discrimination of the ‘instrumental’ triggers from the ‘cosmic-origin’ triggers. This will allow the reduction of the huge number of onboard triggers recorded so far (of the order of 10,000 in the first three years of BeppoSAX operations), and to apply a more refined program to the generated sample of triggers. A first drawback of the ‘roughness’ of our filter is that it does not include criteria to separate gamma ray bursts from solar flares and from soft gamma repeaters events. This task will be carried out by the ‘second order’ filter.

Our software filter is based on the automatic on-ground analysis of the high resolution time series, according to criteria established on the basis of the known detector/electronics behaviour and an extended study of the GRBM time series. Usually, an eye inspection of a GRBM light curve is sufficient to discriminate cosmic gamma-ray events from spurious events. However, when an archival search for real GRB is carried out this becomes not viable anymore, and an automatic filter is needed. We therefore set-up an IDL-based software code that implements a number of discrimination criteria to the GRBM light curves. This is a first approach to the problem and we did not make use of all the information that the GRBM provides for each onboard trigger. In fact, also 1-s resolution data are available in two energy ranges (40-700 and >700 keV) and time-averaged energy spectra but they are not used in the analysis presented here.

The criteria implemented in the program are based on the knowledge of the instrument operational principles and on experience on the observed light curves. It is likely that particular cases exist that were not taken into account in our code. At this time, the following parameters of the individual events are computed for each of the four GRBM detection units: duration, rise time, simultaneity, shape, full width at half maximum. The basic criterion of the code is to assign a ‘score’ to each of these parameters, based on their comparison between pairs of detectors, with the goal of having the smallest score to the most-likely-cosmic events. The individual scores for the different parameters then combine together to give a total score accounting for all the measured event characteristics. For the final score, the higher is the value the smaller is the probability of being a cosmic event.

**CALIBRATION OF THE FILTER**

In order to test and calibrate the efficiency of our software filter, we set-up a sample of selected events whose origin was known by different methods (typically BATSE or IPN events). To these a number of eye-screened false triggers were added. In Figure 1 we present the results of the analysis carried out with our filter on such a sample of events. The x-axis reports the score given to each event by the
Table 1. Score calibration for the software filter

| Score | Burst      | Spike      | Doubt     |
|-------|------------|------------|-----------|
| Score < 2 | (83.3 ± 5.8)% | (9.6 ± 4.5)% | (7.1 ± 4.0)% |
| 2 ≤ Score < 4 | <4.5% (conf. lev. 68%) | (16.0 ± 7.3)% | (84.0 ± 7.3)% |
| Score ≥ 4 | (1.7 ± 1.0)% | (94.0 ± 1.8)% | (4.2 ± 1.6)% |

Figure 1. Efficiency diagram of the software filter: probability of true cosmic events is inversely proportional to the score value on x-axis

The software filter. The texture classifies the events, based on the comparison with data from other satellites (BATSE, Ulysses, etc.). The sample includes several short GRBs in order to test the ability of the software to distinguish between them and spikes, but many long GRBs are also included. Thus, we can define 3 score classes (Burst, Spike, Doubt), with the confidences given in Table 1 (the sum of every row is 100%), computed assuming multinomial distribution. The software works on single peaks even during the evolution within a multiple-peaked event. Therefore, the results reported in the Table should be intended as applicable to individual peaks in each light curve. Examples of events belonging to these three categories are presented in Figure 2.

There are 3 additional special classes in the plot: No-End, No-Class, No-Trig. No-End: the signal does not return to noise level before the end of the light curve (GRBM high time resolution data have a maximum coverage of 106 s). This can be due to long bursts, or to a variable background (see an example in [2]). No-Class: the signal has not been analyzed. This can happen for weak events if the software
is not able to estimate the duration of the signal. No-Trig: the software is unable to find other than noise in the light curve, possibly due to very weak signals.

**APPLICATION TO THE GRBM DATABASE**

The software filter has been applied to a fraction of the BeppoSAX GRBM data archive, covering more than 3 years of elapsed time, but consisting of about 603 days of satellite observing time. The goal was to test our software on an homogenous sample of onboard triggers. A noticeable by-product of this operation is an estimate of the GRB detection efficiency. As stated above, the filter operates on individual peaks. The result of the analysis gives: 440 peaks from cosmic events, 510 doubt cases, 4648 spikes, 58 No End, 86 No Class. If we apply the filter efficiency that was defined in the previous section, then the number of cosmic peaks become (367±26). They belong to about 340 individual events, of which only ∼180 have been post-facto verified to be real cosmic events.

**SUMMARY AND CONCLUSIONS**

The results of the analysis on an unselected portion (∼40%) of the BeppoSAX/GRBM data archive presented in this paper allow to draw the following conclusions:
- A number of ∼180 cosmic events detected by the BeppoSAX/GRBM were identified (including a small number of Solar Flares and events from Soft Gamma Repeaters), over a net exposure time of ∼545 days, leading to an estimation of the GRBM efficiency on triggering cosmic events of ∼0.33/day (additional events are detected, but without an onboard trigger).
- The automatic filter has a ∼50% efficiency on selecting real events out of false triggers (i.e., any event selected by the program has a ∼50% probability of being of cosmic origin). This reduced efficiency is likely due to the incompleteness of the sample on which the code was calibrated.
- The automatic filter has a >90% efficiency on discarding false triggers (i.e., any event not selected by the program has a less than 10% probability of being a real event, based on the software calibration). So, the filter allows to reduce the number of light curves to be analyzed to about 10% of the total, with an expected efficiency of more than 90%.

**REFERENCES**

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FIGURE 2. 8-ms resolution light curves in the four GRBM detectors, for a real short gamma ray burst (Top 4 panels), a spike (Middle 4 panels) and a dubious event (Bottom 4 panels). X-axis is time in seconds, Y-axis gives the counts/bin.