Setting the Triggering Thresholds on Swift

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Abstract. The Burst Alert Telescope (BAT) on Swift has two main types of "rate" triggers: short and long. Short trigger time scales range from 4ms to 64ms, while long triggers are 64ms to ≈ 16 seconds. While both short and long trigger have criteria with one background sample (traditional "one-sided" triggers), the long triggers can also have criteria with two background samples ("bracketed" triggers) which remove trends in the background. Both long and short triggers can select energy ranges of 15-25, 15-50, 25-100 and 50-350 KeV. There are more than 180 short triggering criteria and approximately 500 long triggering criteria used to detect gamma ray bursts. To fully utilize these criteria, the thresholds must be set correctly. The optimum thresholds are determined by a tradeoff between avoiding false triggers and capturing as many bursts as possible. We use realistic simulated orbital variations, which are the prime cause of false triggers.

INTRODUCTION

Swift is a rapidly slewing satellite, that can quickly point the field of views (FOVs) of the X-Ray telescope (XRT) and the ultraviolet-optical telescope (UVOT) at the gamma-ray bursts (GRBs). In order to begin this process, the Burst Alert Telescope (BAT) must detect that a burst has occurred and locate its position. Swift's behavior in responding to GRBs depends crucially on BAT triggering, which means that it is vital to optimally set the thresholds for the various trigger criteria. The main drive behind the thresholds is one of balancing sensitivity against false triggers. This paper presents the procedure we used to select the thresholds for Swift's various trigger criteria.

BAT uses about 800 different criteria to detect GRBs, each defined by a large number of commandable parameters. Usually the critical parameter is the time scale of the sample being analyzed for a statistically significant increase. There are three triggering systems. One is called the "short triggers" and covers times ranging from 4ms to 64 ms. The short triggers have a fixed background sample duration of about 1 sec. The second system is the "long triggers" and covers time scales range from 64ms to as large as we dare command without trends in the background producing too many false triggers(≈ 16 sec currently). There is a third trigger system (which we will not discuss) that searches for new point sources in images that are reconstructed periodically (typically every 32 sec, 320 sec, and $\tilde{1}000$ sec) from the detector plane observations. (See [1] for details on the imaging.)

Both short and long triggers can target the 15-25, 15-50, 25-100 and 50-350 KeV energy ranges. A criterion can also target a quadrant (or any combinations of quadrants)

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of the detector plane, primarily to be more sensitive to bursts at the edge of the FOV. Swift has the most comprehensive set of triggering criteria ever attempted.

We trigger on a burst when there is a statistically significant increase in the counts for any particular criteria. See [2] for more information on how the trigger is evaluated. Once the BAT has a rate trigger, it then images the detector plane to find any new point sources. If no new sources are found, the trigger is rejected as false. Thus, we can tolerate false triggers in orbit and be more sensitive to bursts.

To create a high fidelity simulation of BAT in its orbital conditions we simulate the steady, diffuse x-ray/gamma-ray sources, GRBs, and particle variations throughout orbit. Two software packages are used to accomplish this. The GRMCFLIGHT program simulates the gamma-ray transport through BAT. GRMCFLIGHT produces the photon energy, location, and time of incidence on the detector plane. GENERATE1355 is a program which simulates the BAT electronics, and produces the data stream which is fed to the flight code. The combination of GRMCFLIGHT and GENERATE1355 allows us to trace each photon from its origin (an astronomical source or the background) all the way through the BAT flight software.

The ability to inject BATSE burst profiles into GRMCFLIGHT allows us to go even further and test the high-level scientific features of the BAT flight software: namely triggering and imaging. This can then be used for system-wide BAT tests, such as slewing to a GRB location. The result of these tests tells us how many bursts we will trigger on, image, and slew to (see [3]).

To set the thresholds, we run simulations with no injected bursts under various background conditions. We typically run between 10 and 20 hours of background, and try to set the threshold such that there would be no false triggers over this period of time. All simulations have a diffuse x-ray background component of about 8 KHz plus an additional 4 kHz background due to particles. We add various bumps in the background to mimic the orbital variations of the particle background. These bumps were typically Gaussian in shape with a full width at half maximum of about 24 minutes. We studied, in particular, bumps that added 20 kHz and 4 MHz. The 4 MHz bump is what we expect in the SAA.

SETTING THE SHORT TRIGGER THRESHOLDS

We ran each of the 180 short trigger criteria separately through the three different background variations: flat 12 KHz, flat 12 KHz plus a 20 KHz bump, and flat 12 KHz plus a 4 MHz bump. Since the background for the short triggers is within 1 sec of the foreground sample, we find that the thresholds are approximately the same for all three background variations. In order to allow for statistical variations, we ran each short trigger (i. e., 180 criteria) through about 10 orbits (each with a 4 MHz SAA bump) to determine the maximum score. The short criteria tended to require about the same threshold for various permutations of areas of the detector plane and energy ranges. We set the thresholds for the short criteria to only depend on the time scale (i.e., 4, 8, 16, 32, and 64 msec). In Figure 1, the short criteria are denoted by filled squares and have thresholds of about 6σ to 7σ.

SETTING THE LONG ONE-SIDED TRIGGER THRESHOLDS

Swift uses two types of triggers in the > 64ms range: *one-sided* and *bracketed* triggers. One-sided triggers have only one background sample which is before the foreground sample, and they have been used in all past missions, such as BATSE. For the one-sided triggers, since they do not remove trends in the data, we set them to withstand orbital variations of about 20kHz, a rather large bump for Swift in a quiet, non-SAA orbits.

We have diagnostic reports to the telemetry of the maximum score for each criterion, each orbit. We plan to use this diagnostic output to set the thresholds on orbit once we have a few days of background data. To set the long thresholds on the ground prior to launch we simulate 14 orbits (about 20 hrs) of background with 20kHz bumps in each orbit. The telemetry provides a maximum score for each criteria in each orbit. Let $S_{\rm max,i}$ be the overall maximum score for the i-th criteria seen over the 14 orbits. Let σ_i be the RMS of the 14 maximum scores from each orbit. We set T_i, the threshold for the i-th criteria, to be

$$T_i = S_{\rm max,i} + 2\sigma_i \quad . \tag{1}$$

The open squares in Fig.1 show the thresholds for the one-sided long triggers. The one-sided criteria have foreground durations of 0.128, 0.256, 0.512, and 1.024 sec. The one-sided criteria are very susceptible to trends in the background. A one percent trend over one second will produce a one sigma increase in the count rate. For that reason, we could not make one-sided criteria use foregrounds much longer than one second.

For each foreground duration, there can be 36 different criteria. There are four different energy ranges (15-25, 15-50, 25-100, 50-350 KeV) and nine combinations of subareas of the detector plane (the four quadrants, four halves, and the full detector plane). We do not necessarily use a set of criteria that include all 36 permutations.

SETTING LONG BRACKETED TRIGGER THRESHOLDS

Bracketed triggers have a background sample before and after the foreground sample, allowing a fit to trends in the background rate. To date these have only been used in the HETE flight trigger algorithm. The bracketed triggers efficiently remove background trends so we could set the thresholds to be much lower than the one-sided triggers and use much longer foreground time samples. They are occasionally sensitive to the *peak* of a bump in the background. We initially simulated bumps ranging from 200Hz to 2 MHz in steps of a factor of ten.

The opened circles in Fig. 1 give the thresholds for various permutations of energy and detector plane regions for foreground durations between 0.128 and 16 sec. We used 14 orbits of background with a flat background of 20 KHz. No bumps were used because the two-sided criteria removes trends and the size of the bump had little effect on the thresholds. Equation 1 was applied to the maximum scores reported by the diagnostic software to obtain the thresholds. By using a flat background, we were able to get scores in the range of 3σ to 5σ.

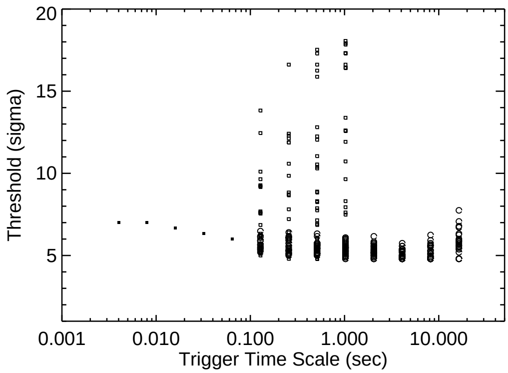

FIGURE 1. Thresholds for the BAT rate trigger criteria as a function of the foreground duration. The solid squares are for the short rate triggers. The open squares are for one-sided long criteria and the open circles are for two-sided long criteria. In contrast, the equivalent threshold for BATSE was 11 sigma and foreground time durations were only 64, 256, and 1024 ms.

CONCLUSION

Our strategy is to have the trigger thresholds as low as possible and allow approximately 2 to 3 false triggers per hour. The flight software will form an image at the time of the trigger and those false triggers will be rejected because there will not be a new point source in the image. Sources in a coded aperture image will usually have a smaller signal-to-noise than the signal-to-noise in the trigger. As a result, valid triggers near the threshold will not have significant new point sources in the image. Thus although Fig. 1 shows the thresholds required for a trigger, a successful image requires a stronger signal.

There is often the concern that the two-sided criteria introduce a delay in recognizing that a burst is occurring. This is true. Our strategy is that we will use one-sided criteria with durations as long as we can (which is ≈ 1 sec) and with threshold that avoid excessive false triggers. Those thresholds, unfortunately, can be as large as ≈ 15. The two-sided criteria indeed take longer, but they are only used when the one-sided were unable to detect the burst. It is better to get the burst later than not at all.

REFERENCES

1. Palmer, D., et al. these proceedings (2004).
2. Fenimore, E. E., et al., in *Gamma-ray Burst and Afterglow Astronomy 2001* edited by G.R. Ricker & R. K. Vanderspek, AIP 662, pp. 491-493 (2003).
3. Fenimore, E. E., et al., Baltic Astron. in press (2004).