

A Gamma-Ray Burst Trigger Toolkit

David L. Band

GLAST SSC, Code 661, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

`dband@lheapop.gsfc.nasa.gov`

ABSTRACT

The detection rate of a gamma-ray burst detector can be increased by using a count rate trigger with many accumulation times Δt and energy bands ΔE . Because a burst's peak flux varies when averaged over different Δt and ΔE , the nominal sensitivity (the numerical value of the peak flux) of a trigger system is less important than how much fainter a burst could be at the detection threshold as Δt and ΔE are changed. The relative sensitivity of different triggers can be quantified by referencing the detection threshold back to the peak flux for a fiducial value of Δt and ΔE . This mapping between peak flux values for different sets of Δt and ΔE varies from burst to burst. Quantitative estimates of the burst detection rate for a given detector and trigger system can be based on the observed rate at a measured peak flux value in this fiducial trigger. Predictions of a proposed trigger's burst detection rate depend on the assumed burst population, and these predictions can be wildly in error for triggers that differ significantly from previous missions. I base the fiducial rate on the BATSE observations: 550 bursts per sky above a peak flux of $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$ averaged over $\Delta t=1.024 \text{ s}$ and $\Delta E=50\text{--}300 \text{ keV}$. Using a sample of 100 burst lightcurves I find that triggering on any value of Δt that is a multiple of 0.064 s decreases the average threshold peak flux on the 1.024 s timescale by a factor of 0.6 . Extending ΔE to lower energies includes the large flux of the X-ray background, increasing the background count rate. Consequently a low energy ΔE is advantageous only for very soft bursts. Whether a large fraction of the population of bright bursts is soft is disputed; the new population of X-ray Flashes is soft but relatively faint.

Subject headings: gamma-rays: bursts

1. Introduction

The goal of the next generation of gamma-ray burst missions such as *Swift* and *EXIST* is to detect and localize the largest number of bursts possible. This will be accomplished both by increasing the detector's effective area or decreasing its background, and by increasing the sensitivity of the trigger system. Increasing the sensitivity through hardware can be expensive,

often requiring a larger and heavier detector. However, increasing the sensitivity through a more sophisticated trigger is relatively inexpensive, particularly with the availability of more powerful flight-qualified CPUs. But different triggers respond to different burst properties, and the relevant question which I address is how much fainter are the bursts at threshold for the more sophisticated triggers relative to the previous generation of triggers. I reference different triggers to a fiducial trigger; normalizing the detection rate for this fiducial trigger permits estimates of the detection rate for proposed detector and triggers systems. However, the actual detection rate will depend on the burst population, which will be unknown in unexplored regions of parameter space; consequently an estimate of a proposed detector's capabilities should state the assumed burst population.

In a count rate trigger, the detector triggers if the number of counts accumulated over a given energy band ΔE and time scale Δt increases by a statistically significant amount over the expected number of background counts. The expected number of background counts is calculated by accumulating counts over non-burst time intervals. Current triggers (e.g., for *HETE-II* and *Swift*) estimate trends in the background, which improves the accuracy of the background determination, but does not increase the sensitivity. The trigger threshold can be converted into the burst's peak flux (photons $\text{s}^{-1} \text{cm}^{-1}$) using the Instrument Response Function (IRF) and a typical burst spectrum. A more sophisticated trigger may result in a nominally much greater sensitivity—numerically smaller peak flux at the trigger threshold—than a simpler trigger. However, the peak flux values measured by the different triggers will be over different energy bands and will be averaged over different timescales; since bursts have temporal and spectral structure, they have very different peak fluxes when averaged over these energy and time bins. Consequently, greater quantitative sensitivity does not mean that proportionately fainter bursts are detected. The relevant question is how much fainter are bursts at threshold for one trigger relative to another trigger.

Here I consider only single-stage count rate trigger systems where an increase in a single count rate time series suffices. Thus, I do not consider the sensitivity of triggers where the count rate trigger must be corroborated by a point source in an imaging system (as for *Swift*); the second stage decreases the overall sensitivity since the imaging system will reject events that triggered the count rate trigger system. Nor do I consider the sensitivity for triggers based on multiple detectors (e.g., the WFC and GRBM on *BeppoSAX*—Frontera et al. 2000).

The sensitivity of different trigger systems can be compared by reference to a fiducial system. Furthermore, normalizing the rate for the fiducial trigger permits the estimate of a mission's detection rate, which is required both to forecast the achievable scientific results and to plan mission operations (e.g., telemetry or onboard memory requirements). I use the results of the Burst And Transient Source Experiment (BATSE) on the *Compton Gamma-Ray Observatory (CGRO)*, which provided a very large burst sample accumulated with a well-understood trigger system

I first present in §2 a fiducial trigger system normalized by the BATSE results. Next, in §3 I formulate a methodology for evaluating the sensitivity of different triggers relative to the fiducial trigger, which I then apply to triggers with different time (§4) and energy (§5) bins. A significant

issue is the population of soft bursts (or X-ray flashes) that a detector sensitive at low energy might detect (§6). The results are summarized in §7.

2. BATSE Fiducial

BATSE consisted of 8 modules, each with two different detectors (Fishman et al. 1989): a large (2025 cm^2), flat Large Area Detector (LAD); and a smaller (127 cm^2), thicker Spectroscopy Detector (SD). The detectors relevant to burst detection, the LADs were oriented on the faces of a regular octahedron. BATSE as a whole triggered when two or more LADs triggered. The standard LAD trigger required at least a 5.5σ increase in the counts in the 50–300 keV band accumulated on timescales of 0.064, 0.256 or 1.024 s. Note that this trigger criteria had to be met by the second most brightly illuminated detector, which was considered by the BATSE team in calculating their instrument's sensitivity.

The revised 4B catalog (Paciesas et al. 1999) found that BATSE was 0.5 and ~ 0.82 complete for peak fluxes of 0.25 and $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$, respectively, accumulated in 1.024 s time bins over the 50–300 keV band; I use $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$ as BATSE's threshold. Note that the conversion from the observed peak count rate to the peak flux assumes a spectral shape. The peak flux may have occurred during a gap in the burst lightcurve, and consequently bursts with such gaps cannot be used for studies of the peak flux distribution. Thus the distributions the BATSE team published after they improved the sky exposure calculation (e.g., Paciesas et al.) used only bursts without data gaps. However, such bursts occurred, and must be included in normalizing the burst rate. In the 4B catalog there are ~ 750 bursts without data gaps above $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$. The sky exposure for the 4B catalog while BATSE triggered on the 50–300 keV band was 1.73 sky-years. W. Paciesas (2002, personal communication) estimates that $\sim 20\%$ of the bursts have data gaps. Consequently there are ~ 550 bursts per year per sky above the threshold of $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$. This is consistent with the estimate of ~ 666 bursts per year per sky above BATSE's threshold (Paciesas et al. 1999) after accounting for the bursts BATSE triggered on with a peak flux below $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$ (Paciesas, 2002, personal communication). At this threshold peak flux, the BATSE cumulative intensity distribution is approximately a power law with an index of -0.8.

Was BATSE's threshold indeed at a peak flux of $0.3 \text{ ph cm}^{-2} \text{ s}^{-1}$? BATSE's sensitivity can be estimated analytically. I attribute most of the background below 300 keV to the X-ray Background (using the formulation of Gruber 1992), and use the BATSE LAD effective area curve (Fishman et al. 1989) to estimate the counts from the burst. I find in the 50–300 keV band a 5.5σ threshold of $\sim 0.17\text{--}0.18 \text{ ph cm}^{-2} \text{ s}^{-1}$ on axis. The least sensitive case is when the burst is along the normal to one detector and thus $\cos \theta = 1/3$ for the second most brightly illuminated detector; the resulting threshold flux is $0.525 \text{ ph cm}^{-2} \text{ s}^{-1}$. The most sensitive case is when the burst falls directly between the normal to 2 detectors, for which $\cos \theta = 0.8165$, giving a peak flux of $0.21 \text{ ph cm}^{-2} \text{ s}^{-1}$. Based on the symmetry of the octahedron, there is more solid angle near the most sensitive case than near the least sensitive case. Additional complications that are not modelled include the splash off

the Earth's atmosphere and off of the rest of *CGRO*, both of which increased the signal for a given burst flux. Thus the BATSE team's threshold distribution curve is reasonable.

3. Trigger Sensitivity

Assume the number of background counts accumulated on a time scale Δt over an energy range ΔE is $B(\Delta t, \Delta E)$. Here I consider triggers that only use contiguous accumulation times. The burst signal—the increase in the count rate resulting from the burst—is $S(\Delta t, \Delta E)$. Both B and S are the counts the detector assigns to the range of energy channels labelled ΔE , i.e., B and S result from folding the burst's spectrum through the detector's response. Thus the nominal ΔE will correspond to somewhat different actual energy ranges for different detectors based on the detectors' energy response. I do not consider the apparent increase in B that can occur when burst flux is included in the estimate of B if the burst rises slowly before the peak flux. The significance of S is

$$\sigma(\Delta t, \Delta E) = S(\Delta t, \Delta E) / \sqrt{B(\Delta t, \Delta E)} . \quad (1)$$

Since $B(\Delta t, \Delta E)$ is determined primarily by the design of the detector (although there may also be a dependency on time variable particle fluxes, internal activation, etc.), specifying the threshold value of σ , σ_0 , sets the minimum value $S_0(\Delta t, \Delta E)$ that triggers the detector. This value of S_0 is used as a measure of the detector's sensitivity.

However, $S(\Delta t, \Delta E)$ is a function of Δt and ΔE for a given burst, and thus the threshold bursts for triggers using different sets of Δt and ΔE are not fainter in proportion to the threshold values S_0 for the different sets. Therefore, I compare the significance for a given set of Δt and ΔE to the significance for a fiducial set Δt_f and ΔE_f for a given burst,

$$R(\Delta t, \Delta E; \Delta t_f, \Delta E_f) = \frac{\sigma(\Delta t, \Delta E)}{\sigma(\Delta t_f, \Delta E_f)} = \frac{S(\Delta t, \Delta E)}{S(\Delta t_f, \Delta E_f)} \sqrt{\frac{B(\Delta t_f, \Delta E_f)}{B(\Delta t, \Delta E)}} . \quad (2)$$

R is the factor by which a given burst could have been fainter and still be detected by a trigger with Δt and ΔE relative to a trigger with the fiducial set Δt_f and ΔE_f . Clearly, a more sensitive detector and trigger system has a greater value of R , and for a fixed threshold σ_0 , $S_0 \propto 1/R$. Since $S(\Delta t, \Delta E)$ varies from burst to burst, R will vary from burst to burst, resulting in a distribution of R values for the burst ensemble.

Therefore, to estimate the detection rate for a detector with a prescribed trigger system the properties of the burst ensemble must be known or assumed. Conversely, assumptions about the prevalence of bursts with spectral or temporal properties to which previous trigger systems were relatively insensitive (e.g., the burst rate for bursts with $E_p = 10$ keV to which BATSE's 50–300 keV trigger was insensitive) will have a large effect on the estimated burst rate for trigger systems with very different sensitivities. Consequently the assumptions about the burst population must accompany any estimate of a detector's burst detection rate.

4. Sensitivity to Temporal Structure

Here I am concerned only with the dependence on the accumulation time Δt , and therefore I drop the explicit dependence on ΔE . Note that the dependencies on Δt and ΔE are not separable since burst light curves differ by energy band. Next, I assume that the background does not vary significantly over the burst, and therefore $B \propto \Delta t$ (B and S are the number of background and source counts accumulated over Δt). Consequently $\sqrt{B(\Delta t_f)/B(\Delta t)} = (\Delta t/\Delta t_f)^{-1/2}$. The burst counts S are characterized by two extremes. The burst may be a pulse much shorter than both Δt and Δt_f and therefore $S(\Delta t)/S(\Delta t_f) \simeq 1$. Alternatively, the burst may be flat-topped with a peak count rate that is constant over a time greater than both Δt and Δt_f , and consequently $S(\Delta t)/S(\Delta t_f) = \Delta t/\Delta t_f$. Thus $R(\Delta t; \Delta t_f)$ is bracketed by $(\Delta t/\Delta t_f)^{\pm 1/2}$. A trigger with a different Δt can be either more or less sensitive than the fiducial trigger!

One can use a very large number of accumulation times, not just BATSE's $\Delta t = 0.064, 0.256$ and 1.024 s. Note that BATSE used consecutive non-overlapping time accumulation bins, and thus the registration of the burst with respect to these time bins determined whether a weak burst triggered the detector; the peak with the maximum count rate may have fallen into either one or two accumulation bins. The "ultimate" trigger would use accumulations over all possible overlapping accumulation times. The maximum sensitivity from this "ultimate" trigger is the maximum value of R with respect to Δt .

To determine the distribution of R for realistic burst light curves, I use the BATSE 0.064 s resolution light curves for channels 2+3 (~ 50 – 300 keV) from all the LADs that triggered; these light curves are available at ftp://cossc.gsfc.nasa.gov/compton/data/batse/ascii_data/64ms/. The burst sample consists of the 100 BATSE bursts for which the data are available with the largest values of $P_{0.064}$, the peak flux on the 0.064 s time scale. The bursts in this sample are far above BATSE's detection threshold; they are chosen to represent fiducial light curves. Of course, systematic differences between the brightest and dimmest bursts are ignored. I fit a linear background to these light curves, and then compute σ for all possible values of Δt that are multiples of 0.064 s. Figure 1 shows the distribution of maximum R using the most sensitive BATSE trigger (i.e., I maximize R by varying Δt for each of the 3 BATSE accumulation times, and then use the minimum of these 3 values). Figure 2 shows the distribution of R for $\Delta t_f = 1.024$ s. As can be seen, on average the "ultimate" trigger does not increase the significance by large factors over BATSE. Figure 3 shows the distribution of the accumulation times Δt that maximize R . This study uses trigger times with a resolution of 0.064 s; trigger times with a much greater resolution, e.g., 0.01 s, will greatly increase the sensitivity to very short bursts, and will increase the sensitivity to all bursts slightly since the accumulation time can be better tailored to actual light curves. However, note that there are few bursts in my study for which the sensitivity is greatest at the smallest possible accumulation time of 0.064 s. Thus a much smaller trigger time of 0.01 s may not detect a significantly larger number of bursts.

5. Sensitivity to Energy Band

Next I consider the energy band dependence, and hold the accumulation time constant. Consequently, I drop the explicit dependence on Δt . Thus

$$R(\Delta E; \Delta E_f) = \frac{S(\Delta E)}{S(\Delta E_f)} \sqrt{\frac{B(\Delta E_f)}{B(\Delta E)}}. \quad (3)$$

The background is usually dominated by the X-ray background below ~ 200 keV. The sensitivity involves a competition between the burst spectrum and the diffuse background. Since the spectrum changes from burst to burst, the trigger energy range ΔE that maximizes R varies.

As an example, I calculate R for all possible energy bands with edges at 10, 20, 30, 40, 50, 100, 200, 300 and 500 keV, i.e., 10–20 keV, 10–30 keV, 20–30 keV, etc. The fiducial energy band is 50–300 keV, which was BATSE’s usual trigger band. For the background I use the X-ray background and an approximate internal background that dominates above ~ 250 keV. I parameterize the burst spectrum with the traditional four parameter GRB spectrum (Band et al. 1993). I assume the detector’s efficiency is constant as a function of energy. R is a function of the three parameters which determine the shape of the GRB function—two spectral indices and a break energy. Figure 4 shows the dependence of R on E_p (the energy at which $E^2 N(E) \propto \nu F_\nu$ peaks) for four sets of the power law indices. As can be seen, only for low values of E_p is the maximum R significantly larger than for the fiducial energy band. The sensitivity also increases for high values of E_p because the detector efficiency is assumed to remain high at high energy, which is usually not the case (e.g., for Cadmium-Zinc-Telluride, the detector material for *Swift* and *EXIST*). A more negative value of the high energy spectral index β (i.e., softer high energy spectrum) results in a greater sensitivity to low values of E_p when ΔE extends to low energy because there are relatively few photons in the fiducial band.

6. Low Values of E_p

The efficacy of lowering the low energy end of ΔE depends on the distribution of E_p for the bursts’ peak flux. The spectral evolution studies (e.g., Ford et al. 1995) found that E_p is greatest when the count rate peaks early in the burst, the part of the light curve that triggers detectors. Preece et al. (2000) fit 5500 time-resolved spectra from 156 bursts with various spectral models, including the GRB model (Band et al. 1993). The E_p distribution in this study peaks between 200 and 250 keV with very few values below 100 keV. This study used LAD spectra starting at 25 keV, and thus should have been able to fit E_p values lower than were observed. The Preece et al. sample fit spectra from different parts of the burst, not just the peak, and the spectra from the peak often were accumulated over long periods (so that the spectra had a sufficient number of counts). Thus the Preece et al. distribution underestimates the E_p of the peak flux. As an aside, the distributions of the low and high energy spectral indices peak at $\alpha \sim -0.8$ and at $\beta \sim -2.3$,

respectively. Similarly, Mallozzi et al. (1995) fit the spectra accumulated over the entire burst for ~ 400 bursts; the E_p for these spectra are lower than the E_p of peak flux. Dimmer bursts have lower E_p ; nonetheless, the average for the dimmest 1/5 of the bursts is $\langle E_p \rangle \sim 175$, and only $\sim 15\%$ of the bursts in this dimmest group had $E_p < 80$ keV.

On the other hand *Ginga* observed burst spectra that were significantly softer than those found by BATSE; 13 out of 22 bursts analyzed by Strohmayer et al. (1998) had $E_p < 80$ keV. The discrepancy between the BATSE and *Ginga* results has never been explained. Both *Ginga* and BATSE triggered on the same energy range, and thus should have selected the same burst population. Since the *Ginga* detectors were much smaller than BATSE's LADs, the bursts *Ginga* studied were drawn from the bright end of BATSE's burst distribution. *Ginga* had a proportional counter sensitive to ~ 2 keV, whereas BATSE's spectra extended down only to ~ 18 keV; thus *Ginga* would have been able to detect low energy rollovers to which BATSE would have been insensitive. However, if many bursts are as soft as *Ginga* observed, BATSE would have seen many steep power law spectra, but did not. In addition, BATSE consisted of 8 detectors of two different types while *Ginga* had only one low energy detector. The burst direction relative to BATSE was known, while the burst direction was generally unknown for *Ginga*.

Preece et al. (1996) calibrated the DISCSP, the lowest energy discriminator channel for BATSE's SD detectors, and performed joint fits between DISCSP (with energies in the 5–20 keV range, depending on the burst) and the SHERB spectra, the SD spectra resulting from pulse height analysis. They also compared the observed DISCSP count rate in this discriminator channel to the prediction from fits to the SHERB spectrum. While both data types resulted from the same detector, they used different electronics. In 12 out of 86 bursts the observed DISCSP count rate was $> 5\sigma$ higher than the prediction; the difference between the observed and predicted count rate was attributed to a low energy excess, and not a softer spectrum. The higher energy SHERB spectra were well-fit by the "GRB" function (Band et al. 1993) with $E_p > 100$ keV. It should be noted that this excess resulted from the comparison of two different data types, which is always difficult, and from integrations over the entire burst. Observing this excess in the same data type would confirm its reality.

Frontera et al. (2000) performed spectral fits to the WFC (2–26 keV) and GRBM (40–700 keV) data for 8 bursts observed by *BeppoSAX*. Each burst was broken into a number of time segments. In 7 out of the 8 bursts the fit to the time segment with the peak flux in the GRBM band provided only a lower limit to E_p which was greater than 170 keV; in four cases $E_p > 700$ keV. Only GRB980425 had $E_p = 68 \pm 40$ keV at the peak. The bursts in this sample had to have significant flux in both the WFC and GRBM detectors, which introduces complicated selection effects. Nonetheless, this sample does not suggest a large population of bright soft gamma-ray bursts.

The newly-identified X-ray Flashes (XRFs—Heise et al. 2001) are a population of soft transients which may or may not be related to the classical gamma-ray bursts (Kippen et al. 2002). These XRFs are detected in *BeppoSAX*'s WFC but not the GRBM; Kippen et al. found that 9

of the 10 XRFs which could have been observed by BATSE had detectable flux in the untriggered BATSE data. As noted above, dimmer bursts are softer (Mallozzi et al. 1995), but as a group, the XRFs have smaller E_p values than predicted by the E_p -peak flux correlation. Of course, the XRFs are X-ray selected (by the WFC), and a bias towards X-ray richness is expected. The physical question is whether the XRFs have the same origin as the classical bursts; the operational question is the number of bursts or XRFs a sensitive detector with a low energy trigger band ΔE would detect.

In conclusion, the BATSE and *BeppoSAX* observations are inconsistent with the fraction of bright soft bursts observed by *Ginga*. The BATSE SD low energy discriminator suggests that there is an additional soft component. The *BeppoSAX* detections of XRFs indicate there is a population of faint soft transients. Therefore sensitive low energy detectors may detect large numbers of XRFs.

7. Summary

More sophisticated triggers can increase the sensitivity of a detector system. Here I consider count rate triggers, where a statistically significant increase in the count rate triggers the detector. The proposed triggers use a variety of accumulation times Δt , energy bands ΔE , and background rate estimation methods.

Traditionally (e.g., for BATSE) the background was assumed to be constant and equal to the average over a period of time. More sophisticated triggers (e.g., for *Swift*) attempt to estimate trends in the background by considering the background over various blocks of time. These more complicated background calculations should increase the accuracy of the background estimates, but not the nominal sensitivity of the trigger.

Here I analyze triggers that use contiguous accumulation times and energy bands. Greater sensitivity might be gained by excluding the energies of prominent background lines, or by using the peaks of the highly variable burst lightcurves (e.g., using Bayesian blocks to isolate high flux periods); however, I do not consider such triggers. The most sensitive triggers I consider use all possible values of Δt and ΔE .

A detector's threshold peak flux will differ for different sets of Δt and ΔE . These peak flux values will be the averages over these Δt and ΔE . Because bursts have highly variable lightcurves, and evolving spectra, a burst's peak flux for one set of Δt and ΔE will not be equal to that for another set. As a concrete example, a trigger's threshold peak flux is generally proportional to $\Delta t^{-1/2}$; thus the threshold peak flux for $\Delta t = 4$ s will be 1/2 that for $\Delta t = 1$ s. However, if the burst is less than 1 s long, then the $\Delta t = 4$ s trigger will average the burst over 4 s and will consider the burst to have a peak flux 1/4 that of the peak flux averaged over $\Delta t = 1$ s. Thus the $\Delta t = 4$ s trigger will have a nominal sensitivity twice as good as the $\Delta t = 1$ s trigger, but will trigger on short bursts only half as faint as the $\Delta t = 1$ s trigger!

To quantify the relative sensitivities of different sets of Δt and ΔE , I reference these sensitivities to the fiducial $\Delta t=1.024$ s and $\Delta E=50\text{--}300$ keV. Estimates of the detection rate of a detector and trigger system can be estimated from these relative sensitivities and the BATSE-observed burst rate of ~ 550 bursts per sky-year at a peak flux of $0.3\text{ photons cm}^{-2}\text{ s}^{-1}$ in this fiducial trigger band. Using the lightcurves of the 100 brightest BATSE bursts shows that using a trigger time which is any multiple of 0.064 s would have permitted BATSE to detect bursts a factor of 1.3 fainter. While the burst photon flux increases as the low end of ΔE is pushed down to 10 keV, the photon flux of the diffuse background increases even more rapidly, and thus only bursts with very soft spectra with a paucity of photons in the higher energy trigger band will benefit from the lowering the low end of ΔE . XRFs are a population of faint soft X-ray transients that sensitive low energy detectors should detect.

Finally, the predicted burst detection rate of a new detector and trigger system depends on the assumed burst population, and estimates justifying a proposed detector should specify the burst population used to model the detection rate. An actual detection rate significantly lower than the prediction should not be regarded as a failure of the mission, but as a discovery about the burst population.

I would like to thank M. Briggs, E. Fenimore, N. Gehrels, J. Norris, W. Paciesas, and R. Preece for discussions and comments upon this work.

REFERENCES

- Band, D. L., et al. 1993, *ApJ*, 413, 281
- Fishman, G. J., et al. 1989, in *Proceedings of the Gamma Ray Observatory Science Workshop*, 2-39
- Ford, L., et al. 1995, *ApJ*, 439, 307
- Frontera, F., et al. 2000, *ApJS*, 127, 59
- Gruber, D. E. 1992, in *The X-ray Background. Collected Papers and Reviews from a Workshop held in Laredo, Spain, September, 1990*, eds. X. Barcons & A. C. Fabian, (Cambridge: Cambridge University Press), p. 44
- Kippen, R. M., Woods, P. M., Heise, J., in't Zand, J. J. M., Briggs, M. S., & Preece, R. D. 2002, in *Gamma-Ray Burst and Afterglow Astronomy 2001: A Workshop Celebrating the First Year of the HETE Mission*, eds. R. Vanderspek and G. Ricker, in press (astro-ph/0203114)
- Mallozzi, R., et al. 1995, *ApJ*, 454, 597
- Paciesas, W. S., et al. 1999, *ApJS*, 122, 465

Preece, R., et al. 1996, ApJ, 473, 310

Preece, R., et al. 2000, ApJS, 126, 19

Strohmayer, T., Fenimore, E., Murakami, T., & Yoshida, A. 1998, ApJ, 500, 873

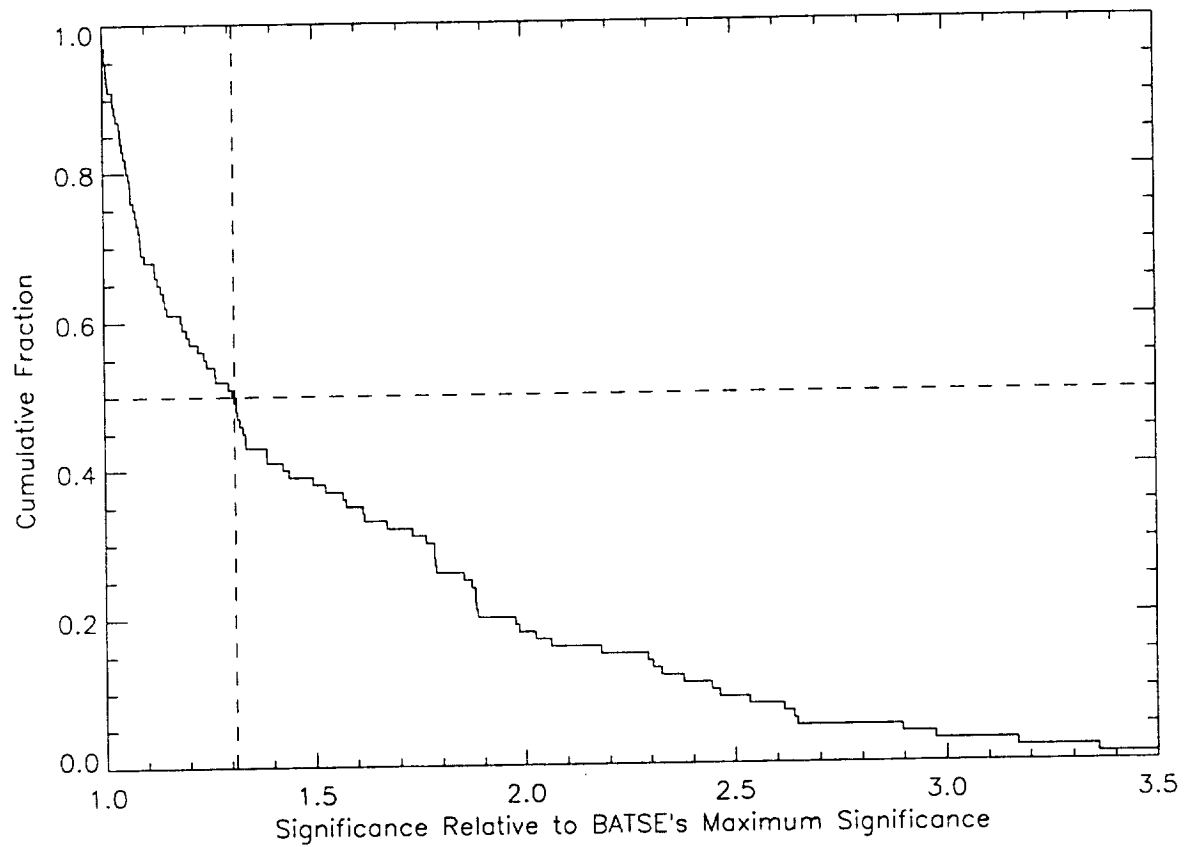


Fig. 1.— Cumulative distribution of the maximum significance relative to BATSE's maximum significance.

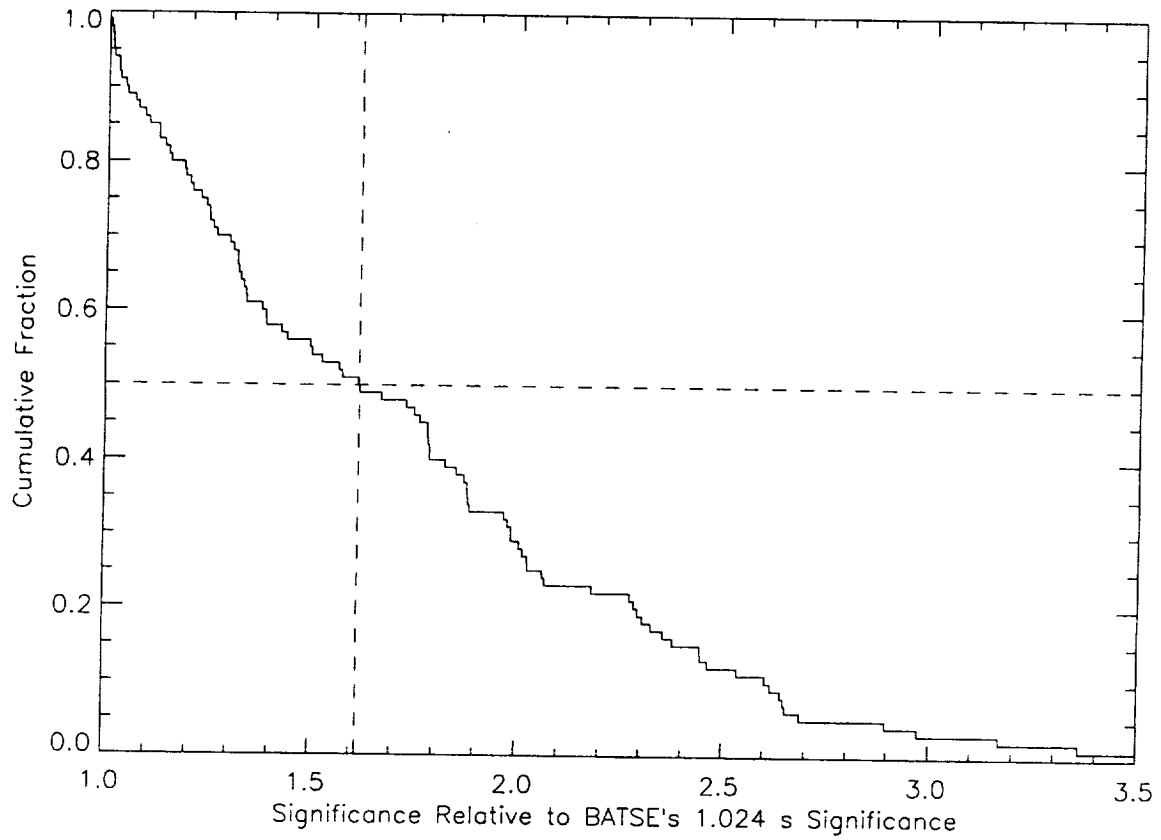


Fig. 2.— Cumulative distribution of the maximum significance relative to BATSE's significance on the 1.024 s timescale.

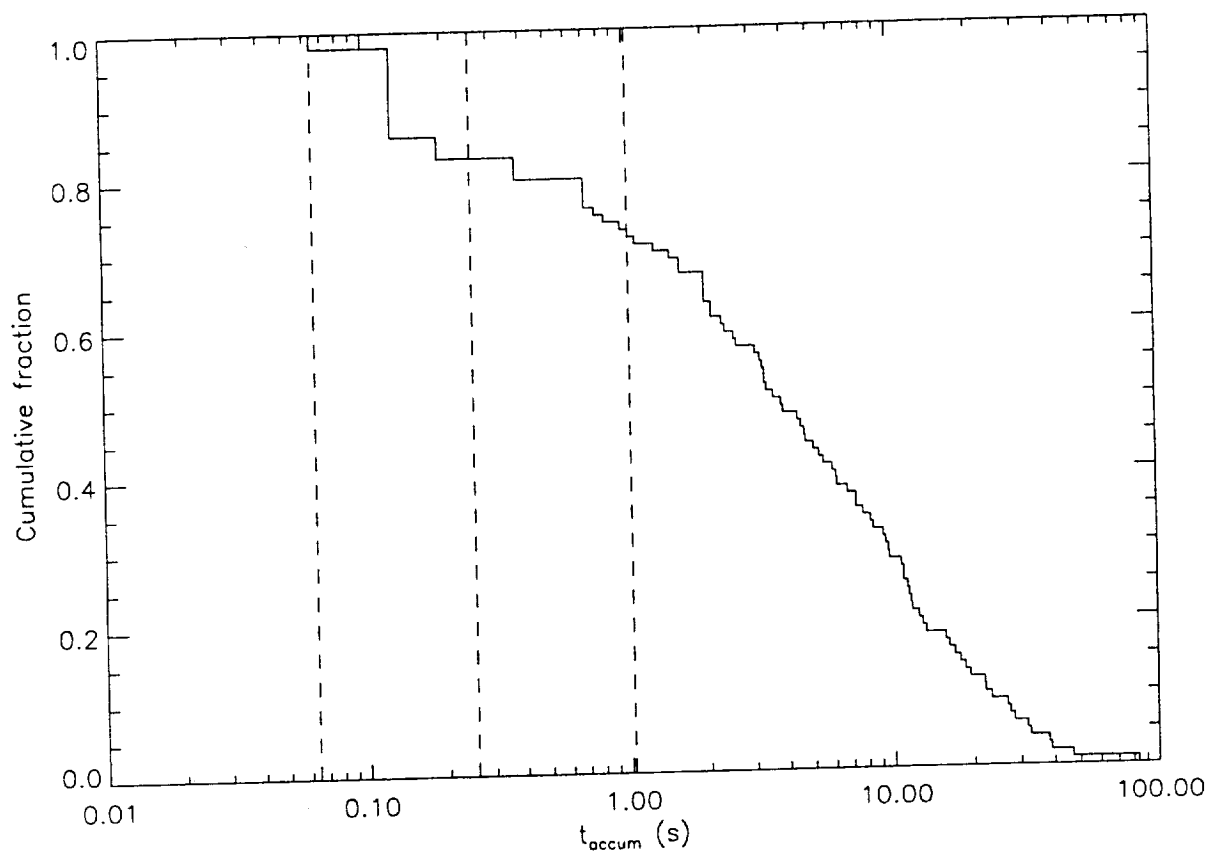


Fig. 3.— Cumulative distribution of the accumulation time of the maximum significance.

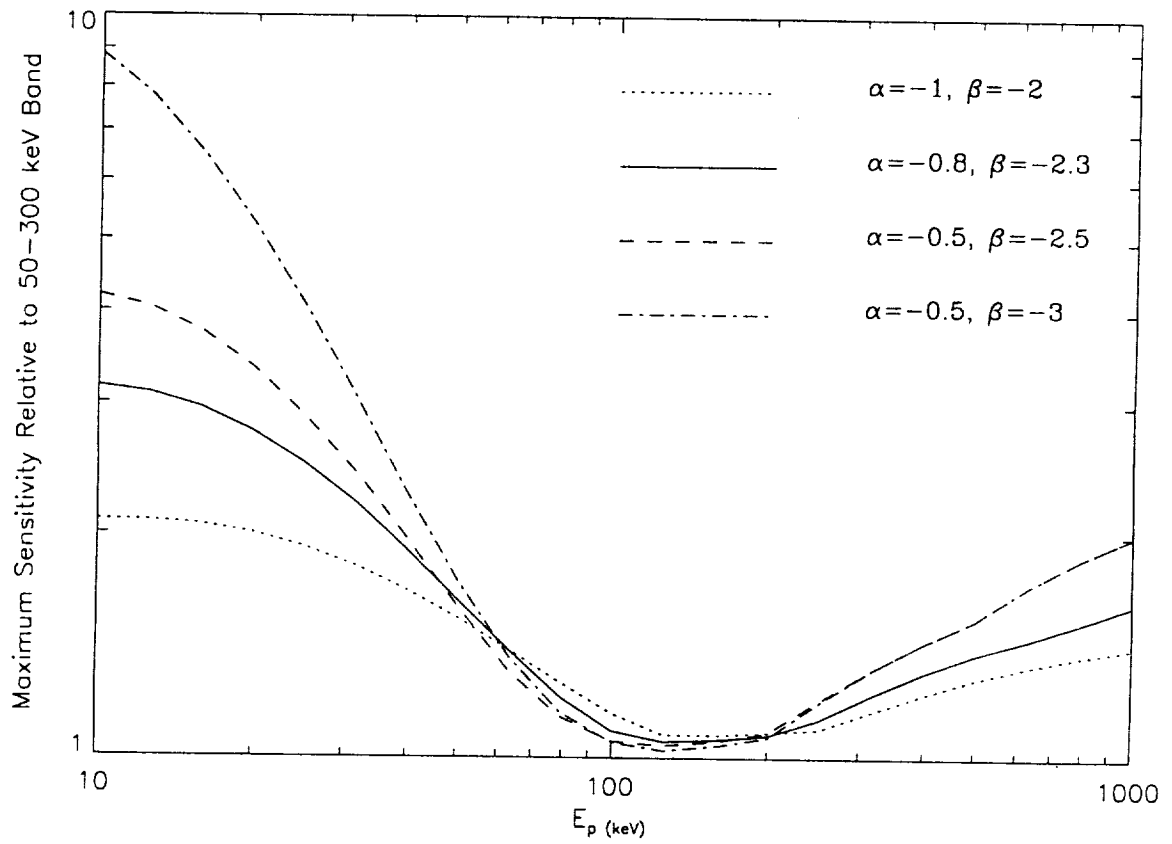


Fig. 4.— Sensitivity for the optimum energy band relative to the 50-300 keV band as a function of E_p .