Are Durations of Weak Gamma-Ray Bursts Reliable?

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Summary. — Simulations in the GUSBAD Catalog of gamma-ray bursts suggest that the apparent duration of a burst decreases as its amplitude is decreased. We see no evidence for this effect in the BATSE catalog. We show that for a burst at the detection limit, the typical signal-to-noise ratio at the edges of the $T_{90}$ duration is around 1.5, suggesting that $T_{90}$ must be quite uncertain. The situation for $T_{50}$ is less unfavorable. Simulations using the exact procedure to derive the durations listed in the BATSE catalog would be useful in quantifying the effect.

PACS 95.85.Pw – gamma-ray.
PACS 98.70.Rz – gamma-ray bursts.

1. – Introduction

Astronomers are generally familiar with the fact that the observation of spectra of astronomical objects requires many more photons than a mere detection. For that reason, spectra are usually available for the brighter objects in a catalog only. A similar consideration of durations of gamma-ray bursts (GRB) would suggest that these are only given for the brighter objects in a catalog: it takes more photons to define the time profile needed to derive the duration than to just detect the burst. Actually, the BATSE catalog lists durations $T_{50}$ and $T_{90}$ for GRBs regardless of peak flux. Bias in the durations of weak GRBs has been a concern [1,2]. In this paper we discuss simulations that illustrate the situation in deriving durations for weak bursts.

2. – Simulations Based on the GUSBAD Catalog

Our own experience is based on the GUSBAD catalog [3,4], which is based on BATSE DISCLA data at a time resolution of 1024 ms. The catalog covers the full CGRO mission from April 19, 1991 till May 26, 2000. The detection algorithm required an excess of at least 5σ in at least two detectors in the energy range 50 – 300 keV. The search was limited to times when incomplete or contaminated data were not interfering in the detection process. As a consequence, for each of the 2204 GRBs in the catalog all derived
Fig. 1. – Durations $T_{\text{det}}$ derived from the GUSBAD catalog plotted against the BATSE duration $T_{90}$.

properties are given. There are 589 GRBs in the GUSBAD catalog that are not listed in the BATSE catalogs.

Among the properties given in the GUSBAD catalog are the time bin of first detection (trigger) and the last time bin when the flux exceeded the detection flux limit. We do not give durations in the catalog but one can use these two time bins to define a detection duration $T_{\text{det}}$ which is the total time span over which the GRB was detectable. In the derivation of the Euclidean value of $V/V_{\text{max}}$ a simulation was carried out in which the (unknown) distance of the GRB was increased until it did not trigger the software trigger anymore. We noticed in this process that as the amplitude of the burst declined, $T_{\text{det}}$ became smaller and smaller and would end up at one time bin (1024 ms) at the detection limit. Clearly $T_{\text{det}}$ for weak GRBs is not a physically meaningful duration, which is the reason why we did not list it in the GUSBAD catalog.

One may ask whether the detection time $T_{\text{det}}$ is a valid measure of duration for strong GRBs. Figure 1 compares GUSBAD $T_{\text{det}}$ and BATSE $T_{90}$ durations for objects common to the two catalogs. For strong GRBs there appears to be a good correlation between the two, with a small number of outliers. For weak GRBs the correlation between $T_{\text{det}}$ and $T_{90}$ breaks down. For these sources, the $T_{90}$ durations range from a fraction of a second to several hundred seconds.

We illustrate the derivation of duration for weak bursts by a simulation on the strong BATSE GRB 940217 = GUSBAD 940217.960. We show in Figure 2 the sum of the counts in the two brightest illuminated detectors, reduced by a factor of 20. At the top of the figure, we plot the simulated counts at the detection limit (corresponding to the BATSE trigger of an excess of 5.5σ over background in the second detector). These counts are the sum of the reduced burst signal and a stretch of background preceding
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3. Discussion

The early work of Norris [1] and our simulations involving $T_{\text{det}}$ in the GUSBAD catalog suggest that there is likely to be a duration bias for weak GRBs in the sense that their durations are underestimated. We show in Figure 3 a histogram of $T_{50}$ durations in the BATSE catalog, observed while the on-board trigger was in standard mode, i.e., requiring a $5.5\sigma$ excess in at least two detectors in the energy range $50 - 300$ keV. Such a histogram was used by Kouveliotou et al. [5] to show that the $T_{50}$ distribution is bimodal. The figure shows separate histograms for bursts with values of $C_{\text{max}}/C_{\text{min}}(64\text{ms})$ larger and smaller than the median value 2.08. If the duration bias existed in the BATSE catalog, the weaker bursts should show a larger fraction of short bursts than the stronger bursts. We do not see the effect in Figure 3; in fact there is marginal evidence for the opposite effect.

This agrees qualitatively with the data in Figure 1: the bursts that have a $T_{\text{det}}$ of $1 - 2$ s, almost all of which are weak, have a wide range of $T_{90}$, up to hundreds of seconds. A
Fig. 3. – Histogram of durations $T_{50}$ for 665 GRBs in the BATSE catalog, for strong and weak bursts separately.

A remarkable example is the second burst in the BATSE catalog 4B 910423, a weak burst with $C_{\text{max}}/C_{\text{min}}(1024\text{ms}) = 1.11$ with a listed duration of $T_{90} = 208.6 \pm 1.1$ s. Given the results from the simulations illustrated in Figure 2 and the S/N ratios quoted there, it is hard to understand how this can be realistic.

The situation for $T_{50}$ is less clear. It is not possible to convert the S/N ratios around $3-4$ found in the simulations into a quantitative estimate of the uncertainty in $T_{50}$. Since $T_{50}$ is the basis for the duration bimodality of GRBs, it would be particularly useful if the experience (including the use of analytical interpolations of the background) that went into the derivation of durations for the BATSE catalog could be applied to the results of simulations such as we have described above. In this fashion one might hope to gain quantitative information about the statistical and systematic errors in $T_{50}$ and $T_{90}$ as a function of peak flux.

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