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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.

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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 (Gamma-ray bursts Uniformly Selected from BATSE Archival Data) catalog [3,4], which is based on archival BATSE DISCLA (DISCriminator Large Area) 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

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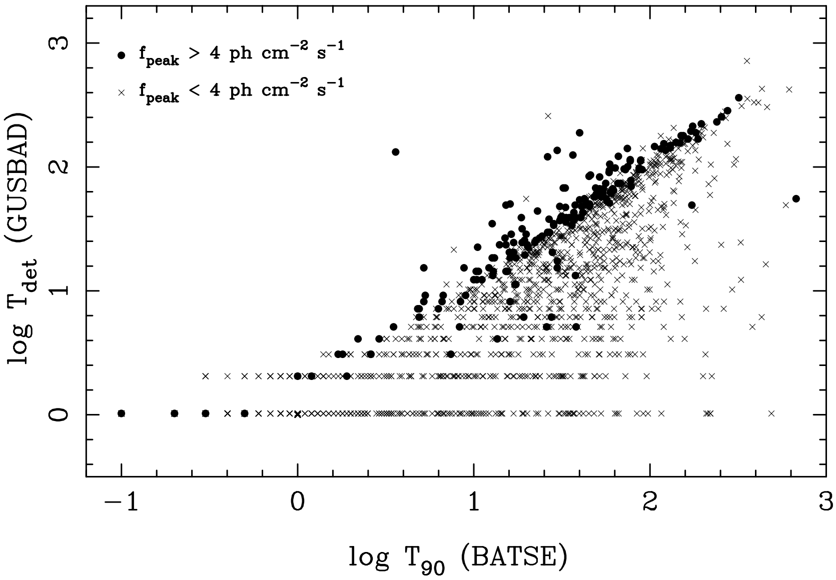

Fig. 1. – Durations $T_{\rm det}$ derived from the GUSBAD catalog plotted against the BATSE duration T_{90}.

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 2207 GRBs in the catalog all derived 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* $T_{\rm det}$ which is the total time span over which the GRB was detectable. For each burst the Euclidean value of $V/V_{\rm max}$ is derived, where V is the volume of a sphere centered on the observer with a radius that equals the (unknown) distance of the GRB and $V_{\rm max}$ is the volume out to the maximum distance $r_{\rm max}$ to which the GRB can be detected above the catalog flux limit. This derivation involved a simulation in which the 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, $T_{\rm det}$ became smaller and smaller and would end up at one time bin (1024 ms) at the detection limit. Clearly $T_{\rm det}$ 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 $T_{\rm det}$ is a valid measure of duration for strong GRBs. Figure 1 compares GUSBAD $T_{\rm det}$ 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 $T_{\rm det}$ 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 fig. 2 the sum of the counts in the two brightest illuminated detectors, reduced by a factor of 20. At the top of the

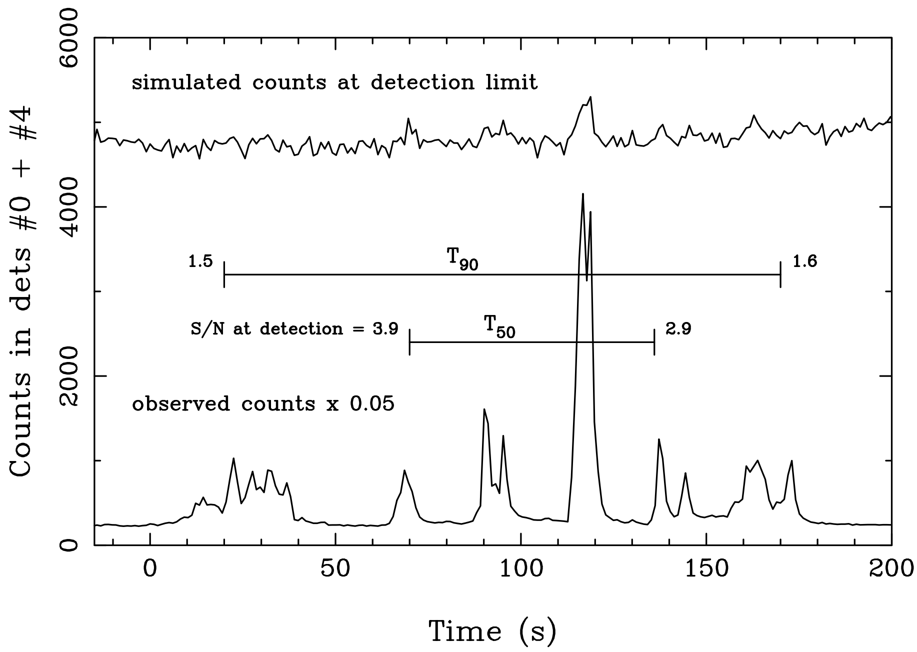

Fig. 2. – Results of a simulation showing how the strong burst GRB 940217 would be seen if its amplitude is decreased to be at the BATSE limit of detection. The observed time profile of the burst is also shown, together with the T_{90} and T_{50} windows according to the BATSE catalog.

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 the burst. Also shown are the time windows corresponding to the two durations given in the BATSE catalog as well as the S/N ratios at either end of the windows. These S/N ratios are actually averaged over 24 GRBs common to the BATSE and GUSBAD catalogs with a peak count $C_{\max} > 5000$ and $T_{\rm det} > 100$ s. The average S/N ratio of the peak is 8.3. The edges of the T_{90} window have S/N ratios around 1.5, suggesting that the reliability of T_{90} is problematic at best. The edges of the T_{50} window in the simulation have an average S/N ratio around 3–4 at the detection limit.

3. – Discussion

The early work of Norris [1] and our simulations involving $T_{\rm det}$ 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 fig. 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 5.5σ 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 the ratio of peak count over minimum detectable count $C_{\max}/C_{\min}(64\,\text{ms})$ 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 fig. 3; in fact there is marginal evidence for the opposite effect.

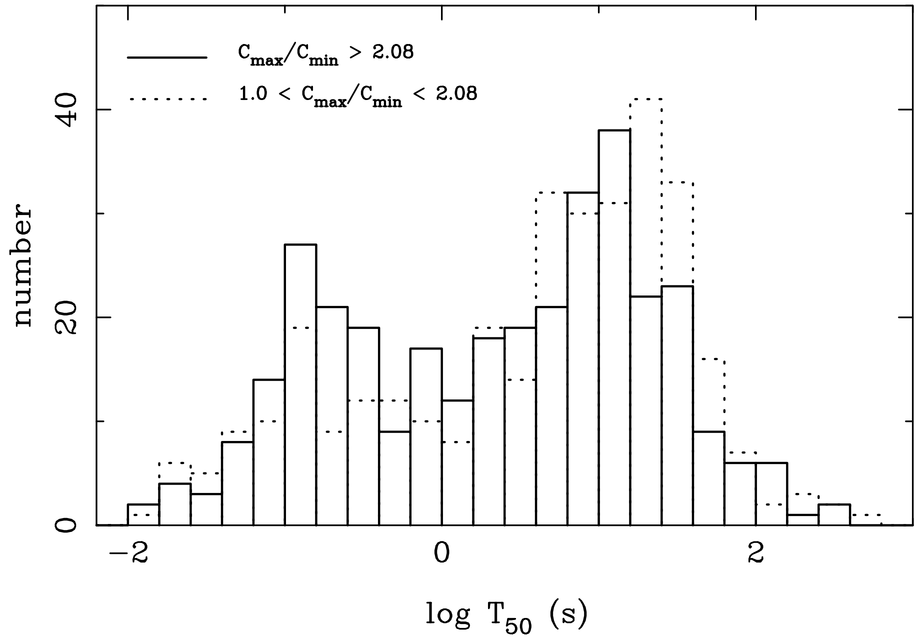

Fig. 3. – Histogram of durations T_{50} for 665 GRBs in the BATSE catalog, for strong and weak bursts separately.

This agrees qualitatively with the data in fig. 1: the bursts that have a T_{det} of 1–2 s, almost all of which are weak, have a wide range of T_{90}, up to hundreds of seconds. A remarkable example is the second burst in the BATSE catalog 4B 910423, a weak burst with $C_{\max}/C_{\min}(1024\,\mathrm{ms}) = 1.11$ and a listed duration of $T_{90} = 208.6 \pm 1.1\,\mathrm{s}$. Given the results from the simulations illustrated in fig. 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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