Low Peak Energies in Dim GRBs and the BATSE Fluence Distributions

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We find that it is possible to reproduce the long gamma–ray burst (GRB) distribution of fluences under the assumptions that the GRB redshift distribution follows the star formation rate and that the recently proposed correlations between GRB energetics and peak energies hold for all bright (BATSE) GRBs. If the observed distribution of peak energies is extended toward lower values with respect to those characterizing bright events, the fluence distribution for all BATSE long GRBs (bright and dim) can be also accounted for.

1. INTRODUCTION

The recent findings of correlations between the energetics of the prompt emission and the spectral properties of GRBs could have an important role in constraining the mechanism(s) producing the prompt emission and the fireball dynamics, and would have a strong impact in the cosmological use of GRBs. Correlations have been proposed by several authors. [1] have examined the correlation between observed peak energies and peak fluxes searching for evidence of redshift effects; [2] suggested the existence of a strong correlation between peak energies and the total fluence, claiming its consistence with the internal shock model. More recent findings include the correlation between intrinsic peak energy E_{peak} (in $\nu f(\nu)$) and peak luminosity ([3]), and the correlation between E_{peak} and the total isotropic energy ($E_{\rm iso} \propto E_{\rm peak}^{0.5}$), both based on a study of a handful of GRBs with measured redshifts ([4]). Finally, [5] found an even tighter relation between the E_{peak} and the prompt energy corrected for the jet opening angle (as estimated from the achromatic break in afterglow light curves (see e.g. [6]), $E_\gamma \propto E_{\rm peak}^{0.7}$. As these results have been found from a rather limited number of GRBs (with available redshift and afterglow measurements) it is crucial to establish whether they represent a robust property of all GRBs.

To this aim we ([8]) focused on testing whether the relations found by [4] and [5] [hereafter A02 and G04] are consistent with the observed statistical properties (fluence distributions) of the bulk of the BATSE long GRBs, under the assumption that the GRBt redshift distribution follows the cosmological star formation rate.

2. METHOD

We initially considered a sample of 156 bursts (selected for either high peak flux or high fluence) for which [7] reported the results of their time resolved spectral analysis. The distribution (time-averaged) of the corresponding peak energies is shown in Fig. 2. We simulated - via Monte Carlo method - the fluence distribution for this population of ('bright') GRBs, as follows:

- within the plausible scenarios for the origin of long GRBs involving the death of massive stars, we assumed that the GRB population follows the star formation rate distribution in redshift (as estimated by [9]);
- we randomly assigned a redshift and a characteristic $E_{\rm peak}$ to each event;
- we adopted the A02 correlation to estimate the corresponding energetics - note that when applying the empirical relations we introduced the scatter around their best fit lines, as a simple Gaussian spread in logarithmic energy (with width σ=0.17 for the A02);
- by applying the cosmological corrections [1], we estimated the corresponding fluence in the 50-300 keV energy range (a typical Band spectral ([10]) representation with $\alpha = -1$ and $\beta = -2.25$ has been adopted, see[7]);
- we compared the resulting fluence distribution with that of bright BATSE GRBs[2].

The analogous procedure applying the G04 relation, i.e. using the collimation-corrected energies instead of the isotropic ones, requires the information on the jet opening angle distribution for the whole sample. G04 considered the sample of 22 GRBs with known jet break time from which the collimation angle θ could be derived. Based on these few estimates, we assumed that the jet opening angles follow a lognormal distribution.

Furthermore, we applied this method to a larger sample of BATSE bursts ($\sim$ 1500 events), to test

[1]Throughout this work we adopt a 'concordance' cosmology
[2]http://cossc.gsfc.nasa.gov/batse/BATSE_Ctlg/flux.html

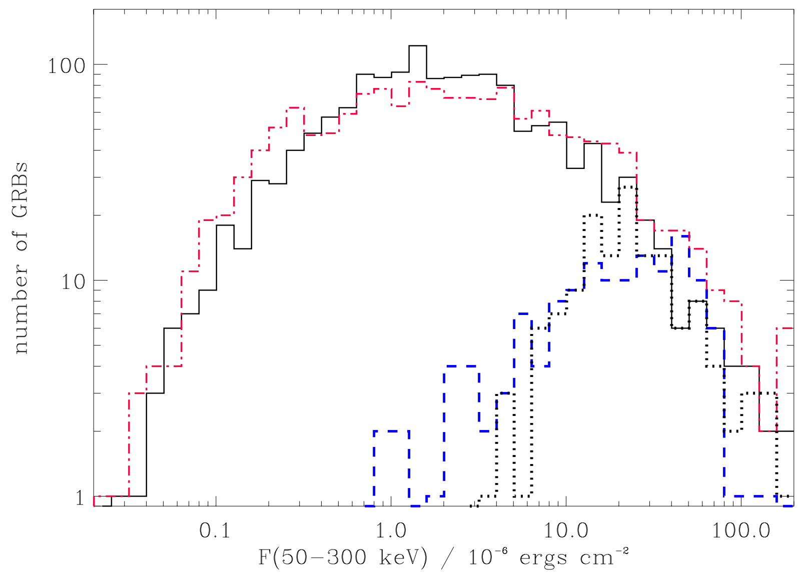

Figure 1: Fluence distributions for the whole BATSE long population (solid line) and 'bright' GRBs analyzed by [7](dotted line). Dashed and dot-dashed lines show the fluence distributions resulting from the simulations assuming the A02 relation.

whether the above correlations between energetics and spectral properties are independent of selection effects.

We quantified our results via statistical tests. We adopted as the relevant parameter the maximum difference D between the cumulative (observed and simulated) distributions as in the Kolmogorov-Smirnov statistics. Although the probability that the two distributions stem from the same parent one is only P_{KS} = 0.002 for the limiting value of D accepted in our analysis (D> 0.07), we adopted this value as a quantitative condition for the consistency of the model and experimental distributions.

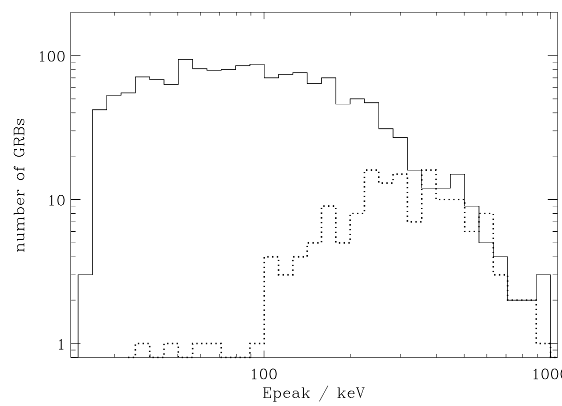

Figure 2: Distribution of the peak energies. Dotted line: the time-averaged results reported by [7]; solid line: the assumed lognormal distribution of peak energies accounting for the observed fluences of all long GRBs.

3. RESULTS AND DISCUSSION

We find that a cosmological GRB distribution following the star formation rate satisfying the correlation between the intrinsic peak energy and the total energy radiated during the prompt phase can indeed account for the fluence distributions as observed by BATSE.

For the sample of bright bursts with known spectral properties the agreement with the simulated events corresponds to a K-S probability of P_{KS}=0.06 (Fig. 1).

To test for the validity of the correlations at lower fluences one needs to extrapolate the observed peak energy distribution toward lower values, as the intrinsic correlations between spectral properties and energetics dominate over the cosmological effects. To this effect we assumed a lognormal distribution for the peak energies. We stress the fact that the required statistical agreement for the fluence distributions (see Fig. 1) strongly constrains the E_{peak} distribution, to that reported in Fig. 2, where the majority of GRBs has $E_{peak} \sim 80$ keV. Note that this would correspond to the E_{peak} distribution for (only) BATSE GRBs.

In an analogous way we tested the G04 relation. As mentioned we assumed a distribution of the jet collimation angles following the experimental one. However, in order to account also for the large sample comprising dim GRBs, larger angles have to be con-

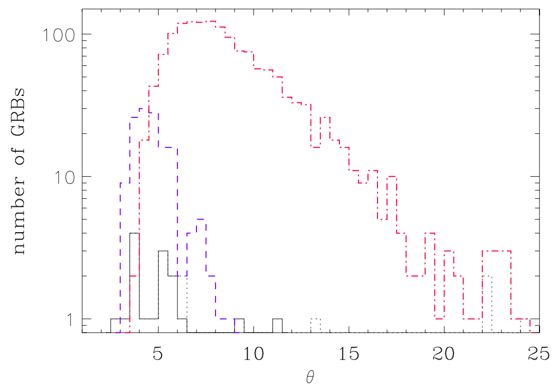

Figure 3: Jet opening angle distribution. Solid and dotted lines represent estimated and limits on the opening angles (from G04), respectively. Dashed (dot-dashed) line represents the assumed lognormal distribution for the sample of 156 bright GRBs (for the large BATSE sample).

sidered (see e.g. [11], [12]): the corresponding distribution peaks around $\sim$6-8^o and extends to 20-25^o (Fig. 3).

The general conclusion (see [8] for details) is that the intrinsic energetics of GRBs dominate over the cosmological distance distribution in accounting for the observed range of fluences: the distributions of peak energies and jet opening angles measured so far for the 'bright' events cannnot account for the whole observed fluence distribution (including dim GRBs). This result supports the possibility that the proposed spectral-energetics correlations (A02 and G04) might be indeed representing a general property of long GRBs.

The extension of the E_{peak} distribution toward the range of definition of X-ray rich GRBs corresponds to a rising number of events at lower E_{peak} with respect to that of bright GRBs. This finding has been a posteriori supported by its consistency with the properties of the GRB sample analyzed by [3] (with fluences lower than those of the [7] GRBs). The larger sample of bursts with known redshifts, lower E_{peak} and possibly opening angles that will be provided by HETE and Swift will be decisive in confirming/discarding the above empirical correlations.

Acknowledgments

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