A Crazy Question: Can Apparently Brighter Gamma-ray Bursts Be Farther Away?

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Abstract

The cosmological relationships between observed and emitted quantities are determined for gamma-ray bursts (GRBs). The relationship shows that apparently fainter bursts need not, in general, lie at larger redshifts.This is possible when the luminosities (or emitted energies) in a sample of bursts increase faster than the dimming of the observed values with redshift. Four different samples of long bursts suggest that this is what really happens.

Keywords: cosmology-miscellaneous, gamma-ray bursts.

1 Introduction

The Burst and Transient Source Experiment (BATSE) instrument at the Compton Gamma Ray Observatory detected around 2700 GRBs[1], but only a few of these have directly measured redshifts from the optical afterglow (OA) observations [1, 2]. During the last couple of years the situation has improved, mainly due to the observations made by the Swift satellite[2]. There are already dozens of directly determined redshifts [3]. However, this sample is only a small fraction of the thousands of detected bursts.

Beside direct determination of redshifts from OAs, there are several indirect methods which utilize gamma-ray data alone. In these mainly statistical studies, a key role is played by the assumption that — on average — apparently fainter bursts should lie in smaller redshifts.

The purpose of this paper is to show that this is not always the case. The paper is in essence a shortened version of [4].

2 Theoretical considerations

Let the observed peak-flux or fluence $P(z)$ of a GRB be given. This value is given by [5, 6]

$$P(z) = \frac{(1+z)^N \tilde{L}(z)}{4\pi d_l(z)^2},$$

where it can be $N = 0; 1; 2$, and where z is the redshift, $d_l(z)$ is the luminosity distance, and $\tilde{L}(z)$ is either the isotropic peak-luminosity or the isotropic emitted energy.

There are four possibilities [5, 6]:

- $P(z)$ – fluence is in "photons/cm^2" units; $N = 2$; $\tilde{L}(z)$ is in "photons" units,
- $P(z)$ – fluence is in "erg/cm^2" units; $N = 1$; $\tilde{L}(z)$ is in "erg" units,
- $P(z)$ – peak-flux is in "photons/cm^{2}s" units; $N = 1$; $\tilde{L}(z)$ is in "photons/s" units,
- $P(z)$ – peak-flux is in "erg/cm^{2}s" units; $N = 0$; $\tilde{L}(z)$ is in "erg/s" units.

In GRB, topic $P(z)$ is usually measured in an energy interval of photons $E_1 < E < E_2$. In addition, it is a good approximation that all arriving photons from this interval are detected, but none from outside. Then $\tilde{L}(z)$ is from the energy-interval $E_1(1+z) < E < E_2(1+z)$.

It is a standard cosmological behaviour that for small z's ($z \ll 0.1$) $d_l(z) \propto z$, and for large redshifts

$$\lim_{z\to\infty} \frac{d_l(z)}{1+z} = \textit{finite positive number}$$

for any H_o, Ω_M, Ω_Λ [7]. Hence, $\tilde{L}(z)$ is a monotonically increasing function of the redshift along with $(1+z)^{2-N}$ for fixed $P(z) = P_0$ and for the given value of $N \leq 1$. This means that $z_1 < z_2$ implies $\tilde{L}(z_1) < \tilde{L}(z_2)$. Expressing this result in other words: more distant and brighter sources may give the same observed value of P_0. Now, if a source at z_2 has $\tilde{L} > \tilde{L}(z_2)$, its observed value P'_{obs} will have $P'_{obs} > P_0$, i.e. it becomes apparently brighter despite its greater redshift than that of the source at z_1. The probability of the occurrence of this kind of *inversion* depends on $f(\tilde{L}|z)$, on the conditional probability density of $\tilde{L}$ assuming z is given, and on the spatial density of the objects.

Assume now specially that

$$\tilde{L}(z) \propto (1+z)^q; \quad N + q > 2; \quad \text{for} \quad z \to \infty.$$

Then

$$\frac{dP(z)}{dz} > 0; \quad \text{for} \quad z \to \infty.$$

[1] http://www.batse.msfc.nasa.gov/batse/grb/catalog/

[2] http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html

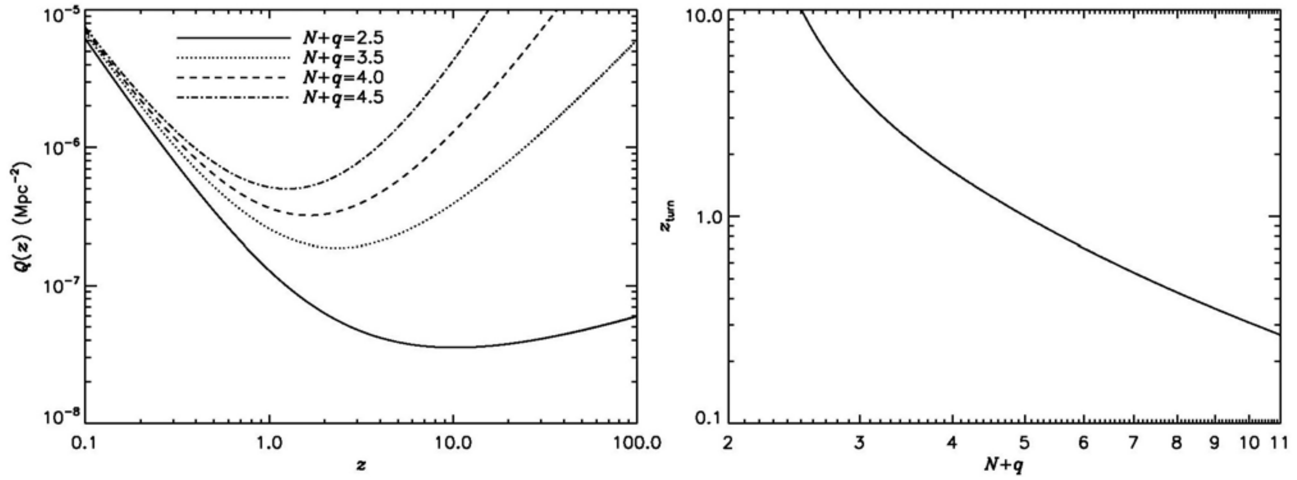

Fig. 1: *Left panel*: Function $Q(z)$ for $\Omega_\mathrm{M} = 0.27$ and $\Omega_\Lambda = 0.73$. *Right panel*: Dependence of z_turn on q for $\Omega_\mathrm{M} = 0.27$ and $\Omega_\Lambda = 0.73$

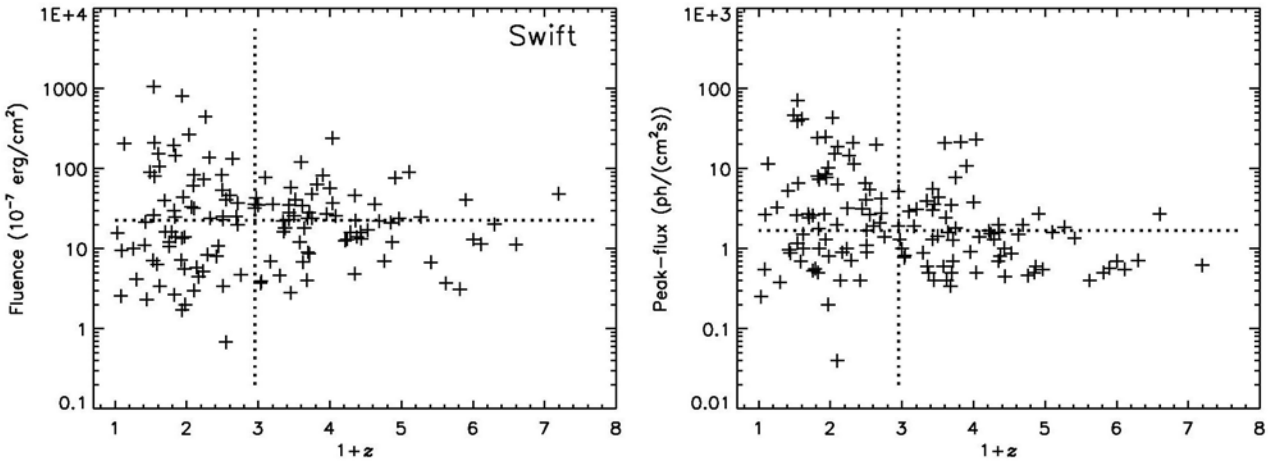

Fig. 2: Distribution of the fluences (left panel) and peak-fluxes (right panel) of Swift GRBs with known redshifts. The medians separate the area into four quadrants. The objects in the upper right quadrant are brighter and have larger redshifts than those of the GRBs in the lower left quadrant

Hence, if $\tilde{L}(z)$ increases fast enough ($(N + q) > 2$), then it is possible that on average $dP(z)/dz > 0$ can happen. This means that for small z's $P(z)$ always decreases as z^{-2}, but if $\tilde{L}(z) \propto (1 + z)^q$, $(N + q) > 2$ at higher redshifts, then $P(z)$ increases as z^{N+p-2} for big z's; again always.

If this is the case, then the question naturally arises: Where is z_turn, where $dP(z)/dz = 0$? Mathematically this means that one has to search for the minimum of function $Q(z) = (1 + z)^{N+q}/d_\mathrm{l}(z)^2$; i.e., when $dQ(z)/dz = 0$ holds. The results of numerical solutions for z_turn are shown in Figure 1.

3 The samples

The expectation that more distant GRBs are on average apparently brighter for the observer can be verified on samples for which there are well-defined redshifts, as well as measured peak-fluxes and/or fluences. We discuss four samples here: BATSE GRBs with known redshifts (8 long GRBs), BATSE GRBs with pseudo-redshifts (13 long GRBs), the Swift sample (134 long GRBs) and the Fermi sample (6 long GRBs).

For the Swift sample, the effect of inversion can easily be seen by the scatter plots of the [log fluence; z] and [log peak-flux; z] planes; Figure 2. To demonstrate the effect of inversion we marked the medians of the fluence and peak-flux with horizontal lines and the medians of the redshift with vertical dashed lines. The medians split the plotting area into four quadrants. The GRBs in the upper right quadrants are apparently brighter than those in the lower left quadrants, although their redshifts are larger. It is worth mentioning that the GRB with the greatest redshift in the sample has higher fluence than 50 % of all the items in the sample.

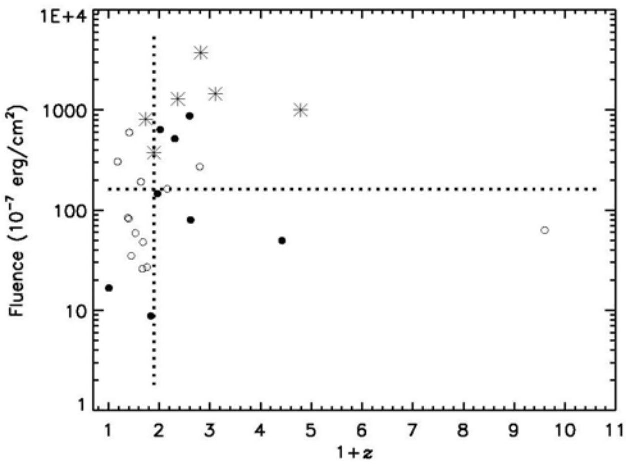

Fig. 3: Distribution of the fluences (left panel) and peak-fluxes (right panel) of GRBs with known redshifts, where Fermi GRBs are denoted by asterisks, and BATSE GRBs with determined redshifts (pseudo-redshifts) are denoted by dots (circles). The medians separate the area into four quadrants. The objects in the upper right quadrant are brighter and have larger redshifts than those of the GRBs in the lower left quadrant

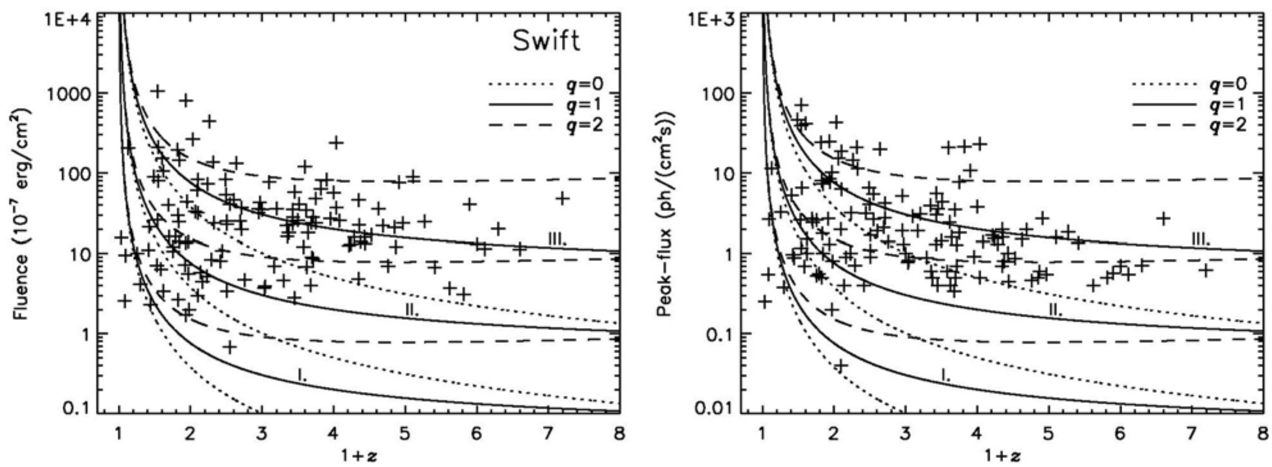

Fig. 4: Distribution of the fluences (left panel) and peak-fluxes (right panel) of Swift GRBs with known redshifts. On the left panel the curves denote the values of fluences for $\tilde{E}_{\rm iso} = \tilde{E}_o(1+z)^q$ (the three constant $\tilde{E}_o$ are in units 10^{51} erg: I. 0.1; II. 1.0; III. 10.0). In the panel on the right the curves denote the values of the peak-fluxes for $\tilde{L}_{\rm iso} = \tilde{L}_o(1+z)^q$ (the three constant $\tilde{L}_o$ are in units 10^{58} ph/s: I. 0.01; II. 0.1; III. 1.0)

The fluence (peak-flux) vs. redshift relationship of the Fermi and of the two BATSE samples are summarized in Figure 3. To demonstrate the inversion effect — similarly to the case of the Swift sample — the medians are also marked with dashed lines. Here it is quite evident that some of the distant bursts exceed in their observed fluence and peak-fluxes the values of those with smaller redshifts. Here again the GRBs in the upper right quadrants are apparently brighter than those in the lower left quadrant, although their redshifts are larger. Note that the upper right quadrants are even more populated than the lower right quadrants. In other words, the trend of increasing peak-flux (fluence) with redshift is really evident here.

Using the special assumption $\tilde{L}(z) \propto (1+z)^q$, the effect of inversion may also be illustrated distinctly in the Swift sample, as follows. In Figure 4 the fluences and peak-fluxes are typified against the redshifts. Let the luminosity distances be calculated for $H_0 = 71\,\mathrm{km/(s\,Mpc)}$, $\Omega_{\rm M} = 0.27$ and $\Omega_\Lambda = 0.73$. Then the total emitted energy $\tilde{E}_{\rm iso}$ and the peak-luminosity $\tilde{L}_{\rm iso}$ can be calculated with $N = 1$. In the figure, the curves of the fluences and peak-fluxes are shown after substituting $\tilde{L}_{\rm iso} = \tilde{L}_o(1+z)^q$ and $\tilde{E}_{\rm iso} = \tilde{E}_o(1+z)^q$ where $\tilde{L}_o$ and $\tilde{E}_o$ are constants, and $q = 0; 1, 2$. The inverse behaviour is quite obvious for $q > 1$ and roughly for $z > 2$.

4 Conclusions

In all samples, both for the fluences and for the peak-fluxes, the "inverse" behaviour can happen. The apparently faintest GRBs need not also be the most distant. The question of the title can really be answered by a clear "Yes, they can.".

It should be noted that no assumptions have been made in this paper about the models of the long GRB. In addition, no cosmological parameters needed to be specified.

The results of this paper can be summarized as follows:

1. A theoretical study of the z-dependence of the observed fluences and peak-fluxes of GRBs have shown that fainter bursts could well have smaller redshifts.

2. This is really fulfilled for the four different samples of long GRBs.

3. These results do not depend on the cosmological parameters and on the GRB models.

4. All this suggests that the estimations (see, for example, [8]), leading to a large fraction of BATSE bursts at $z > 5$, need not be correct.

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