Mem. S.A.It. Suppl. Vol. 21, 198

Memorie della
Supplementi

Apparently fainter gamma-ray bursts at smaller redshifts: an absurdity or a reality?

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Abstract. Naturally, it is expected that the apparently fainter objects should, on average, lie at larger redshifts. It is shown - by theoretical and observational studies of different satellite data samples - that this need not be the case for the long gamma-ray bursts (GRBs). Therefore, bursts at redshifts larger than 5 should be really rare due to this inverse behaviour. The apparently fainter objects can, on average, be at smaller redshifts indeed.

Key words. gamma-rays: bursts – Cosmology: miscellaneous

1. Introduction

Several claims (Paczyński 1992; Mészáros & Mészáros 1995, 1996; Horváth et al. 1996; Reichart & Mészáros 1997) have been put forward that an essential fraction of long-duration BATSE gamma-ray bursts should lie at redshifts larger than 5. In addition, Lin et al. (2004) claims that even the majority of bursts should be at these high redshifts. This point-of-view follows from the natural assumption that *fainter objects should, on average, lie at larger redshifts.* However, redshifts larger than 5 are rare for bursts observed by Swift (Bagoly et al. 2006), seemingly contradicting the BATSE estimates.

The controversy can be explained by the remarkable and curious fact that apparently fainter bursts need not, in general, lie at large redshifts. In such a case $dP(z)/dz > 0$ can hold in statistical sense, where $P(z)$ is either the peak-flux or the fluence, and z is the redshift. Hence, the bursts at high redshifts need not form a large fraction.

Four different samples are studied to show that this can happen: 8 BATSE bursts with redshifts, 13 bursts with derived pseudo-redshifts, 134 Swift bursts with redshifts, and 6 Fermi bursts with redshifts. The analysis is independent on the assumed cosmology, on the observational biases, as well as on any gamma-ray burst model. For the details of these considerations see Mészáros et al. (2011).

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2. Formulas

For the observed peak-flux or fluence $P(z)$ of a GRB it holds (Mészáros & Mészáros 1995):

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

In this formula $N = 0;\ 1;\ 2$ can be, z is the redshift, $d_l(z)$ is the luminosity distance and $\tilde{L}(z)$ means either isotropic peak-luminosity (if $P(z)$ is the peak-flux) or emitted energy (if $P(z)$ is the fluence).

Four possibilities can happen:

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

$P(z)$ is given by photons with energies $E_1 \leq E \leq E_2$, where $E_{1,2}$ is the detector range. Then $\tilde{L}(z)$ is from energy range $E_1(1+z) \leq E \leq E_2(1+z)$.

It is a standard cosmology that for small z's ($z \ll 0.1$) $d_l(z) \propto z$, but for large redshifts $\lim_{z\to\infty} d_l(z)/(1+z) = finite\ positive\ number$ for any H_o, Ω_M, Ω_Λ.

Assume now that $\tilde{L}(z) \propto (1+z)^q;\ N + q > 2\ for\ z \to \infty$. Then one obtains

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

Hence, if $\tilde{L}(z)$ increases faster with z than $\propto (1+z)^{2-N}$ for high redshifts, then an inverse behaviour can happen, and the apparently brighter GRBs can be at higher redshifts: $dP(z)/dz > 0$ can occur.

Where is z_{turn}, where $dP(z)/dz = 0$? This question is equivalent to the mathematical problem, which searches for the minimum of $Q(z) = (1+z)^{N+q}/d_l(z)^2$, i.e. one has to find where $dQ(z)/dz = 0$ holds.

The values of z_{turn} can be seen on Fig. 1.

3. Inverse behaviour of the long GRBs

On Fig. 2 the 134 long GRBs - detected by Swift- are shown. The objects at the right upper quandrant are not less populated than that of the objects at the right bottom quadrant. Simply, there is no decrease of the number of GRBs with high redshifts.

On Fig. 3 the 134 long GRBs - detected by Swift - are shown again. On the left panel the curves denote the values of fluences for $\tilde{E}_{\text{iso}} = \tilde{E}_o(1+z)^q$ (the three constant $\tilde{E}_o$ are in units 10^{51} erg: I. 0.1; II. 1.0; III. 10.0). On the right panel the curves denote the values of peak-fluxes for $\tilde{L}_{\text{iso}} = \tilde{L}_o(1+z)^q$ (the three constant $\tilde{L}_o$ are in units 10^{58} ph/s: I. 0.01; II. 0.1; III. 1.0). Because here $N = 1$, the value $q = 1$ is the limiting case.

On Fig. 4 the situation is opposite: $\tilde{E}_{\text{iso}}$ and $\tilde{L}_{\text{iso}}$ are shown for constant fluences and peak-fluxes. *Left panel*: $\tilde{E}_{\text{iso}}$ vs. $(1+z)$ (dots). Dashed contours denote constant fluences (in units 10^{-7} erg/cm^2): I. the maximal fluence, i.e. 1050; II. 105; III. 10.5; IV. the minimal fluence, i.e. 0.68; *right panel*: $\tilde{L}_{\text{iso}}$ vs. $(1+z)$ (dots); dashed contours denote constant peak-fluxes (in units ph cm^{-2}s^{-1}): I. the maximal peak-flux, i.e. 71; II. 7.1; III. 0.71; IV. the minimal peak-flux, i.e. 0.04. The objects below a curve at smaller redshifts together with those at higher redshifts and above the curve illustrate the inverse behaviour.

On Fig. 5 the distribution of the fluences (left panel) and peak-fluxes (right panel) of the GRBs from other satellites with known redshifts are shown: 6 Fermi GRBs are denoted by asterisk, BATSE GRBs with determined redshifts [9 GRBs] (pseudo-redshifts [13 GRBs]) 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 the that of GRBs in the lower left quadrant.

Both the Swift sample and also the objects from other satellites support the occurence of the inverse behaviour.

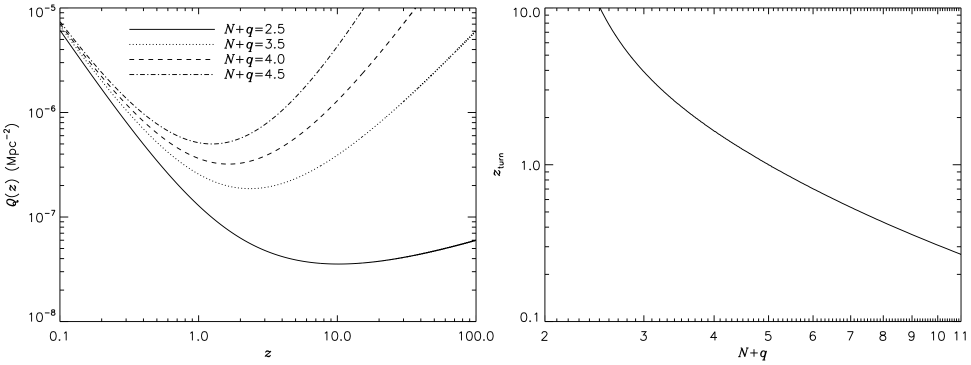

Fig. 1. *Left panel*: Function $Q(z)$ for $\Omega_M = 0.27$ and $\Omega_\Lambda = 0.73$. *Right panel*: Dependence of z_{turn} on $N + q$ for $\Omega_M = 0.27$ and $\Omega_\Lambda = 0.73$.

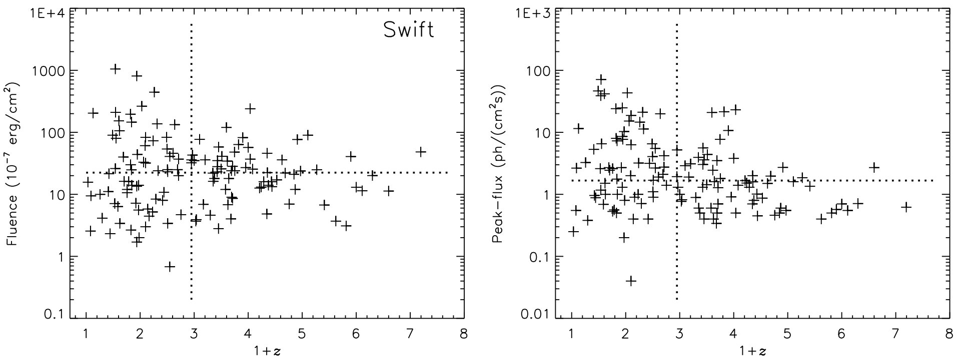

Fig. 2. 134 long Swift GRBs with know redshifts are shown. Distribution of the fluences (left panel) and peak-fluxes (right panel) of these Swift GRBs are shown on the figure. The medians separate the area into four quadrants. The objects in the upper right quadrant are brighter and have larger redshifts than that of GRBs in the lower left quadrant.

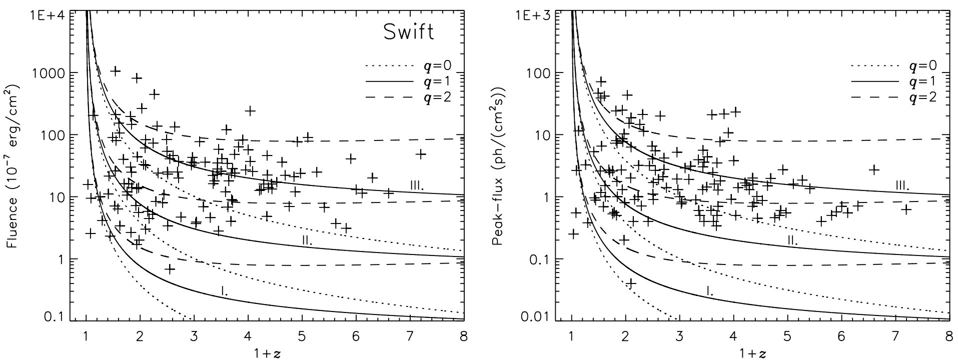

Fig. 3. 134 long Swift GRBs are shown again, but here the constant $\tilde{E}_{iso}$ and $\tilde{L}_o$ are shown, too. For more explanation see the text.

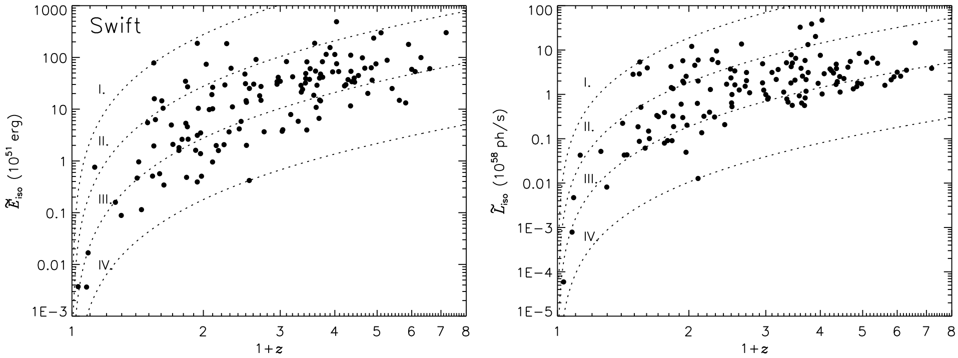

Fig. 4. 134 long Swift GRBs are shown again, but here the calculated $\tilde{E}_{\rm iso}$ and $\tilde{L_o}$ are shown with constant fluences and peak-fluxes - see also the text for more details.

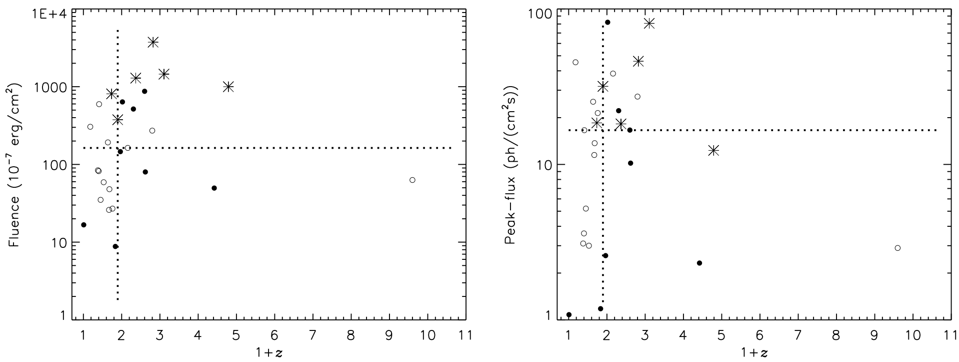

Fig. 5. GRBs from other satellites with known redshifts - for more details see the text.

4. Conclusions

The results of this study may be summarized as follows:

- The theoretical study of the z-dependence of the observed fluences and peak-fluxes of GRBs shows that fainter bursts could well have smaller redshifts.
- This is fulfilled for different samples of long GRBs.
- These results do not depend on the cosmological parameters and on the GRB models.

Acknowledgements. This study was supported by the OTKA grant K77795, by the Grant Agency of the Czech Republic grants No. P209/10/0734, by the Research Program MSM0021620860 of the Ministry of Education of the Czech Republic, and by the Swedish National Space Agency.

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