IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10094-4

A comparison of the X-ray light curve of GRB afterglows with known redshift(*)

B. Gendre([1]) and M. Boër([2])

([1]) *IASF - via Fosso del Cavaliere 100, 00133 Rome, Italy*
([2]) *Observatoire de Haute provence - 04870 St. Michel l'Observatoire, France*

(ricevuto il 23 Maggio 2005; pubblicato online il 3 Ottobre 2005)

Summary. — We have made a comparison of the X-ray light curve of a sample of GRB afterglows with a known redshift. We have applied to this sample corrections factor in order to take into account cosmological effects on the light curves of the bursts. We observe a clustering of data around two groups in the flux vs time diagram of this sample. We study the properties of these two groups and discuss this result, in the light of the GRB fireball model.

PACS `95.85.Nv` – X-ray.
PACS `98.70.Rz` – γ-ray sources, γ-ray bursts.
PACS `01.30.Cc` – Conference proceedings.

1. – Introduction

To date, only long Gamma-Ray Burst (GRB) afterglows were observed. This allowed the emergence of the fireball model [23, 15, 17]. In this model an isotropic blast wave propagates into a surrounding uniform InterStellar Medium (ISM). Two refinements were made later. First, the isotropic assumption was relaxed. This model without the isotropy assumption was called the "jet model" [24]. Second, observations showed that long GRBs may be linked with the explosion of a massive star (hypernova [16]). In such a case, the surrounding medium should not be uniform [2], due to the wind from the progenitor of the GRB. This model is referred as the "wind model" [4, 17, 2].

We discovered that GRB X-ray afterglows with known redshifts have a bimodal luminosity evolution: the faintest GRB afterglows appear to decay more slowly than the brighter ones [1]. Bright and faint X-ray afterglows are separated by one order of magnitude in flux one day after the burst. In this paper we re-examine our work, using a larger sample of X-ray afterglows. The data are presented in sect. **2**, together with the

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.

TABLE I. – *Data for the GRB sources we used in the present work. We indicate the observed flux one day after the burst. We indicate bursts from group I (see text for definitions) at the top of the table and bursts from group II at the bottom of the table.*

Source name	Redshift	Decay index	Spectral index	X-ray flux at 1 day (10^{-12} erg $\cdot$ cm$^{-2}\cdot$ s^{-1})	Reference
GRB 971214	3.42	1.6 ± 0.1	1.2 ± 0.4	0.23 ± 0.05	[3, 5]
GRB 990123	1.60	1.44 ± 0.11	1.00 ± 0.05	1.8 ± 0.4	[9]
GRB 990510	1.619	1.4 ± 0.1	1.2 ± 0.2	1.2 ± 0.2	[13, 25]
GRB 991216	1.02	1.6 ± 0.1	0.8 ± 0.5	5.6 ± 0.3	[22, 12, 7]
GRB 000926	2.066	1.7 ± 0.5	0.7 ± 0.2	—	[18]
GRB 010222	1.477	1.33 ± 0.04	1.01 ± 0.06	2.7 ± 0.6	[18]
GRB 970228	0.695	1.3 ± 0.2	0.8 ± 0.3	0.9 ± 0.4	[3, 8]
GRB 970508	0.835	1.1 ± 0.1	1.1 ± 0.3	1.0 ± 0.4	[3, 19, 21]
GRB 980613	1.096	1.1 ± 0.2	—	0.27 ± 0.07	[3, 6]
GRB 980703	0.966	0.9 ± 0.2	1.8 ± 0.4	0.48 ± 0.07	[27]
GRB 000210	0.846	1.38 ± 0.03	0.9 ± 0.2	0.21 ± 0.06	[11]
GRB 000214	0.37-0.47	0.7 ± 0.3	1.2 ± 0.5	0.6 ± 0.2	[18]
GRB 011121	0.36	4^{+3}_{-2}	2.4 ± 0.4	0.6 ± 0.2	[18]
GRB 011211	2.14	1.3 ± 0.1	1.2 ± 0.1	0.03 ± 0.01	[11]
GRB 030226	1.98	2.7 ± 1.6	0.9 ± 0.2	—	[11]
GRB 030329	0.168	0.9 ± 0.3	0.9 ± 0.2	14.3 ± 2.9	[11, 26]
GRB 980425	0.0085	0.16 ± 0.04	1.0 ± 0.3	0.47 ± 0.07	[20]

N.B: The observations of GRB 000926 and GRB 030226 did not allow a meaningful extrapolation of the light curves. We thus cannot estimate the X-ray flux one day after the burst for these two events. The flux of GRB 000926 was $1.2 \times 10^{-13} \pm 0.1 \times 10^{-13}$ erg $\cdot$ s$^{-1}\cdot$ cm^{-2} 2.78 days after the burst and that of GRB 030226 was $3.5 \times 10^{-14} \pm 0.2 \times 10^{-14}$ erg $\cdot$ s$^{-1}\cdot$ cm^{-2} 1.77 days after the burst. The spectral index of GRB 980613 has never been reported, we assumed a value of 1.

normalization applied to the GRB afterglow light curves. The results are given in sect. **3** and discussed in sect. **4**, before the conclusions.

2. – The data

Our sample is listed in table I. We used only GRBs with known redshifts that exhibit an X-ray afterglow observed either by BeppoSAX, XMM-Newton or Chandra (ACIS imaging mode only). The detail of data analysis is presented in [11].

We have corrected the fluxes for distance, time dilation, and energy losses due to the cosmological energy shift. To compute these corrections, we used a flat universe model, with an Ω_m value of 0.3. We normalized the flux to a common distance of $z = 1$ rather than using the luminosity. We corrected the cosmological energy shift as in [14]. In order to reduce uncertainties, we did not correct for the time dilation effect by interpolating the flux as in [14]; instead, we computed the time of the measurement in the burst rest-frame. Finally, we restricted the light curves to the 2.0–10.0 keV X-ray band, where the absorption is negligible. This allowed us to get rid of any other corrections for absorption by the ISM. These corrections do not take into account any beaming due to a possible jet.

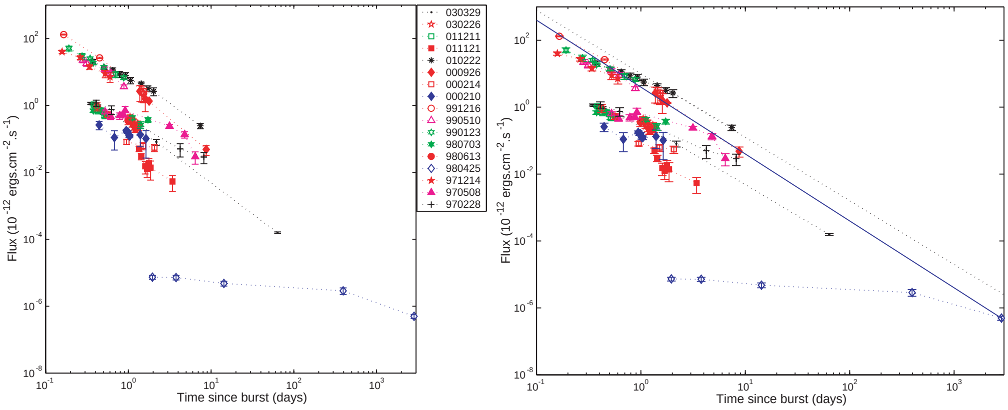

Fig. 1. – Left: X-ray light curves of the GRB afterglows rescaled at a common redshift of $z = 1$. See the electronic version for a color version. Right: X-ray light curve of the sample of GRB rescaled to a common distance corresponding to a redshift of $z = 1$. We plotted the limiting fluxes computed as the mean of the bursts from *group I* (solid line) or as the mean power law corresponding to the brightest burst (dashed line).

3. – Results

The two groups reported in [1] are still present (see fig. 1). All but one burst lie in one of the two groups. The only exception is GRB 980425; however the overall properties of this burst are very peculiar compared to other GRBs [10]. In the following we call *group I* the set of 6 GRB afterglows with the brightest luminosity, and *group II* the 10 dimmer ones. The probability that a uniform luminosity distribution causes the observed distribution is 1.64×10^{-8}. Using a power law luminosity distribution, letting the index be a free parameter, we obtain a maximum probability of 1.10×10^{-4} (index value: -1). We conclude that the observed clustering in two groups is significant to at least the 4 σ level.

We computed the mean decay index of the groups. We find $\delta = 1.6 \pm 0.2$ for *group I*. If we take into account all bursts of *group II*, we find $\delta = 1.5 \pm 0.9$. However, if we take into account only the bursts with a good decay constraint (hence ignoring GRB 011121 and GRB 030226), we get $\delta = 1.1 \pm 0.2$. Using a Kolmogorov-Smirnov test to check if this repartition is due to a single population of GRBs, we obtain a probability of 0.13: this distribution of decay indices may be due to only one population.

4. – Discussion

We used the mean decay index of *group I* to interpolate the flux of GRB 971214 at large times (see fig. 1). This interpolation seems to define a limit, where there is no data point belonging to *group II*, and some afterglow light curves of *group II* which should cross this line display a steepening. One may argue that this limit is not valid: some bursts of *group I* lie above the limit. We computed a new limit, using the parameters from the brightest burst (see fig. 1), but we cannot draw any firm conclusion about the steepening.

As we noted in [11], the nature of these two groups cannot be explained by adiabatic/radiative cooling of the fireball, a difference in the microphysic parameters, and a jet effect. Whatever the nature of these groups, we expect each model parameter to vary within a certain range. Hence the flux should vary within two extrema, while we observe clustering around two groups. This may be an indication that GRB physical parameters and their environmental parameters should lie within a very narrow range, and might even be identical from burst to burst.

5. – Conclusions

We analyzed the X-ray afterglow data of seventeen GRBs with known redshift values. GRB X-ray afterglows can be segregated by their decay index and brightness. The interpretation of this clustering within the framework of the standard fireball model remains unclear. We report evidence for a flux limit, *i.e.* all burst display a flux below $9 \times 10^{-12} \cdot \mathrm{erg} \cdot\ \mathrm{s}^{-1}\ \mathrm{cm}^{-2}$ one day after the burst. Long-lasting (1 month or more), and continuous X-ray observations of GRB are needed to confirm the validity of the above-reported limit after ten days.

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We thank L. Piro, M. DePasquale and A. Galli for useful discussions, comments, and for allowing us to use unpublished data. We acknowledge the use of the web page of J. Greiner (`http://www.mpe.mpg.de/~ jcg/grbgen.html`). This work was supported by the EU FP5 RTN "Gamma ray bursts: an enigma and a tool".

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