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The Early X-ray Afterglows of Optically Bright and Dark Gamma-Ray Bursts *

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Abstract A systematic study on the early X-ray afterglows of both optically bright and dark gamma-ray bursts (B-GRBs and D-GRBs) observed by *Swift* is presented. Our sample includes 25 GRBs of which 13 are B-GRBs and 12 are D-GRBs. Our results show that the distributions of the X-ray afterglow fluxes ($F_{\rm X}$), the gamma-ray fluxes (S_γ), and the ratio ($R_{\gamma,{\rm X}}$) are similar for the two kinds of GRBs, that any observed differences should be simply statistical fluctuation. These results indicate that the progenitors of the two kinds of GRBs are of the same population with comparable total energies of explosion. The suppression of optical emission in the D-GRBs should result from circumburst but not from their central engine.

Key words: gamma rays: bursts

1 INTRODUCTION

Over the past 8 years since Gamma-ray Burst (GRB) afterglow was discovered, more than 100 of bursts have been localized and their counterparts in the X-ray, optical/IR, and radio bands detected. About 90% of these well-localized bursts have detected afterglows in X-ray, while about half of them have no optical transient (OT) detection, and these are the so-called optically dark gamma-ray bursts (D-GRBs; e.g., Groot et al. 1998; Fynbo et al. 2001; Reichart & Yost 2001). Before the *Swift* era, when early afterglow observations were still lacking, it was thought that the dark bursts might be a bias due to the observations being too late and shallow. However, very tight limits at very early phases made by the *Swift* UV-optical telescope (UVOT) have shown that about 50% of *Swift* GRBs are indeed remarkably dark (Roming et al. 2005). The nature of the D-GRBs has become quite a controversial issue and several interpretations have been proposed. Extinction by dust and gas of the host galaxy (e.g., Taylor et al. 1998; Djorgovski et al. 2001; Piro et al. 2002) and/or circumburst absorption (Lazzati, Covino & Ghisellini 2002; Fynbo et al. 2002) are intuitive explanations. However, the faintness and relatively rapid decay of the afterglow of the bright GRB 020124, combined with the low inferred extinction, indicate that some dark bursts are intrinsically dim rather than dust obscured (Berger et al. 2002). Ly-α blanketing and absorption effect due to high redshift have also been proposed (Fynbo et al. 2002; Groot et al. 1998). However, the redshifts of two typical dark bursts, GRB 970828 and GRB 000210, are normal and no different from the bright GRBs (B-GRBs). Recently, Roming et al. (2005) argued that the D-GRBs may be intrinsically faint and/or high-efficiency gamma-ray emitters, with their cooling frequency closed to the X-ray band (Pedersen et al. 2005) and faint at optical wavelengths (e.g. Lazzati, Covino & Ghisellini 2002; Fynbo et al. 2002).

X-ray afterglow is the main parameter that distinguishes the bright and dark GRBs. De Pasquale et al. (2003) systematically compared the X-ray fluxes by extrapolating the X-ray flux to 10 hours after GRB trigger and found that dark GRBs tend to have lower X-ray fluxes. Jakobsson et al. (2004) used a joint

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optical-to-X-ray spectral index to discriminate the dark and bright GRBs by the X-ray and optical afterglows at 11 hours after the GRB trigger. Rol et al. (2005) tried to quantify the degree of the optical darkness by comparing optical upper limits and the inferred optical fluxes from X-ray fluxes based on standard afterglow model. However, two significant biases are involved in the late X-ray afterglow data used by previous authors. The first one is a sampling bias. Due to the lack of early and deep optical observation, some previously-thought dark GRBs might in fact be bright GRBs. The optical afterglow observations of previous GRBs were made at significantly different epochs. This also results in an inhomogenous effect in the sample selection. Secondly, XRT observations have revealed that the early X-ray afterglows of GRBs are enormously different from the late ones. In this work we systematically analyze the early X-ray afterglows observed by the *Swift*/XRT for bright and dark GRBs. We collect the *Swift* GRB data up to June, 2005. There are 25 bursts in our sample. We present our sample in Section 2. The results are presented in Sections 3, 4 and 5. Conclusions and discussion are presented in Section 6.

2 SAMPLES

For the sake of homogeneity and reliability, we include only *Swift* GRBs in our sample. A total of 25 GRBs are included. We identify as dark GRBs those GRBs without OT detection by *Swift*/UVOT or by the ground-based telescopes. In our sample 12 bursts are dark GRBs.

The X-ray afterglows of the bursts in our sample were observed by *Swift*/XRT from $\sim 10^2$ s up to 10^5 s after the GRB trigger. For our purpose we require the X-ray fluxes measured at a time that is early enough and we require the X-ray fluxes at this time should be reliably measured from the XRT light curves of most of the bursts. We take this time to be 1 hour (1440 s) after the GRB trigger. Our general considerations are as follows. First, most of the XRT light curves have a bright and steep tail in the early phase lasting from $\sim 10^2$ s up to $\sim 10^3$ s and these tails are believed to be from prompt emissions. To reduce contamination from the tail emissions, we should select a time that is later than 10^3 s. Secondly, more than half of the XRT light curves have a gap around 1500–3000 s lacking observations, so we should also skip this period. We notice that around 1 hour after the GRB trigger most of the XRT light curves begin to evolve into a power law with a normal index (~ -1). At this time the fluxes are also not affect by the jet effect. [1] We were thus led to the choice of 1 hour after the GRB trigger.

For the objects in our sample, their X-ray afterglow fluxes ($F_{\rm X}$) at 1 hour after the GRB trigger are read off or extrapolated/interpolated from their X-ray light curves observed by *Swift* X-ray telescope (XRT). Their gamma-ray fluences (S_γ) and the durations (T_{90}) in 15–350 keV are also collected from the literature. They are listed in Table 1. The successive headings are: GRB, gamma-ray fluence (S_γ) in 15–350 keV band (in units of 10^{-6} erg cm^{-2}), GRB duration (T_{90}) in 15–350 keV, X-ray afterglow flux ($F_{\rm X}$) in 0.3–10 keV band at 1 hour since the GRB trigger, and references.

3 EARLY X-RAY FLUX AS A FUNCTION OF GAMMA-RAY FLUENCES

With the data shown in Table 1 we present, in Figure 1, the gamma-ray fluence versus X-ray flux plot and the two marginal distributions. The two quantities can be seen to be correlated for both the B-GRBs and the D-GRBs (panel a), with Spearman correlation coefficient $r = 0.79 \pm 0.40$ (chance probability $p < 0.0001$) for B-GRBs and $r = 0.60 \pm 0.58$ ($p = 0.01$) for the D-GRBs. The best fitting lines are also shown in panel (a), showing that the D-GRBs tend to have a larger ratio of $S_\gamma/F_{\rm X}$ than the B-GRBs. The dispersion of the correlation for the D-GRBs is significantly larger than that for the B-GRBs.

From Figure 1 one can observe that the D-GRBs and B-GRBs span about the same ranges in both S_γ and $F_{\rm X}$. The S_γ range of the D-GRBs tends to be slightly larger than that of the B-GRBs, and the $F_{\rm X}$ range of the D-GRBs tends to be slightly smaller than that of the B-GRBs.

4 RATIO OF EARLY X-RAY AFTERGLOW FLUX TO AVERAGE GAMMA-RAY FLUX

GRBs are from cosmological distances so the observables on them must be affected by cosmological effects. Since most of the bursts in our sample have no redshift measurement, we can not make the cosmological correction. Now, the hardness ratio between two observed energy bands is independent of the cosmological effect, so we study the hardness ratios of the two kinds of GRBs. We define the hardness ratio between

[1] The jet break is usually longer than half a day.

Table 1 Observational Data of Our GRB Sample

GRB	S_γ 10^{-6} erg cm^{-2}	T_{90} s	$\log(F_{\rm X})$ erg cm^{-2} s^{-1}	Ref[a]
		Dark GRBs		
GRB 050124	2.10	4.1	–10.88	1; 1; 1
GRB 050126	1.10	30	–11.47	3; 2; -
GRB 050128	4.50	13.8	–10.49	4; 3; 5
GRB 050215b	0.23	10	–11.35	7; 7
GRB 050219a	9.40	23	–11.42	7; 6; 7
GRB 050219b	24.90	27	–10.26	7; 8; 7
GRB 050223	0.92	23	–12.84	7; 9; 7
GRB 050326	18.60	29.5	–10.46	7; 10; 7
GRB 050410	6.63	43	–11.77	7; 11; 7
GRB 050421	0.18	10.3	–12.62	7; 12; 7
GRB 050422	1.20	59.2	–12.00	7; 16; 7
GRB 050509a	0.46	13	–11.08	7; 17; 7
		Bright GRBs		
GRB 041223	38.50	130	–9.74	23; 24
GRB 050315	4.20	96	–11.12	3; 3; 7
GRB 050318	1.97	32	–10.34	7; 3; 7
GRB 050319	0.80	15	–10.79	7; 3; 7
GRB 050401	14.00	33	–10.04	3; 25; 14
GRB 050406	0.09	5	–12.21	7; 26; 7
GRB 050412	2.10	26	–11.59	7; 27; 7
GRB 050416a	0.38	2.4	–11.33	7; 3; 7
GRB 050502b	0.80	7	–11.61	7; 28; 7
GRB 050505	4.10	60	–10.21	3; 3; 7
GRB 050525a	20.00	8.8	–10.19	3; 3; 7
GRB 050603	13.00	10	–10.07	7; 29; 7
GRB 050607	0.89	26.5	–11.51	13; 3; 15

Notes: [a] In order of: S_γ ; T_{90} ; $F_{\rm X}$ **References:** (1) Cummings et al. 2005a; (2) Sato et al. 2005; (3) Nousek et al. 2005; (4) Cumming et al. 2005b; (5) Antonelli et al. 2005; (6) Hullinger et al. 2005a; (7) Roming et al. 2005; (8) Cumming et al. 2005c; (9) Mitani et al. 2005; (10) Cumming et al. 2005d; (11) Fenimore et al. 2005a; (12) Sakamoto et al. 2005a; (13) Retter et al. 2005; (14) De pasquale et al. 2005; (15) Burrows et al. 2005; (16) Suzuki et al. 2005; (17) Hurkett et al. 2005; (23) Markwardt et al. 2005; (24) Tueller et al. 2005; (25) Sakamoto et al. 2005b; (26) Krimm et al. 2005; (27) Fox et al. 2005; (28) Falcone et al. 2005; (29) Fenimore et al. 2005.

gamma-ray and X-ray fluxes as $R_{\gamma,\rm X} = \overline{F_\gamma}/F_{\rm X}$, where $\overline{F_\gamma}$ is the average gamma-ray flux in 15–350 keV band over one T_{90}. The two-dimensional flux distribution is shown in panel (a) of Figure 2 with different symbols for the two kinds of GRBs The figure shows that the two kinds are well mixed. Panel (b) of Figure 2 shows that the $R_{\gamma,\rm X}$ distributions for the two kinds of GRBs are similar, with the D-GRBs tending to have slightly larger values of $R_{\gamma,\rm X}$. We carried out a K-S test to see whether or not the two distributions are from the same parent population. The significant level for the null hypothesis that two data sets are from the same distribution is $P_{\rm KS} = 0.098$. The null hypothesis is marginally accepted.

5 BOOTSTRAP TEST

De Pasquale et al. (2003) found that the extrapolated X-ray afterglow fluxes at 11 hours since GRB trigger of the D-GRBs tend to be weaker by a factor ~ 6 than those of the B-GRBs . For our sample, we found $\overline{\log F_{\rm X}} = -11.39 \pm 0.82$ for the D-GRBs, and -10.66 ± 0.85 for the B-GRBs, corresponding to a factor of ~ 5 between the fluxes. However, this difference is not significant considering the large errors involved: a K-S test indicates that the $F_{\rm X}$ distributions for both D-GRBs and B-GRBs are drawn from the same parent population. We use a bootstrap method to examine if the slight difference between them is due to statistical fluctuation. We bootstrap 10^3 pair samples of D-GRBs and B-GRBs, and then calculate the $P_{\rm KS}$

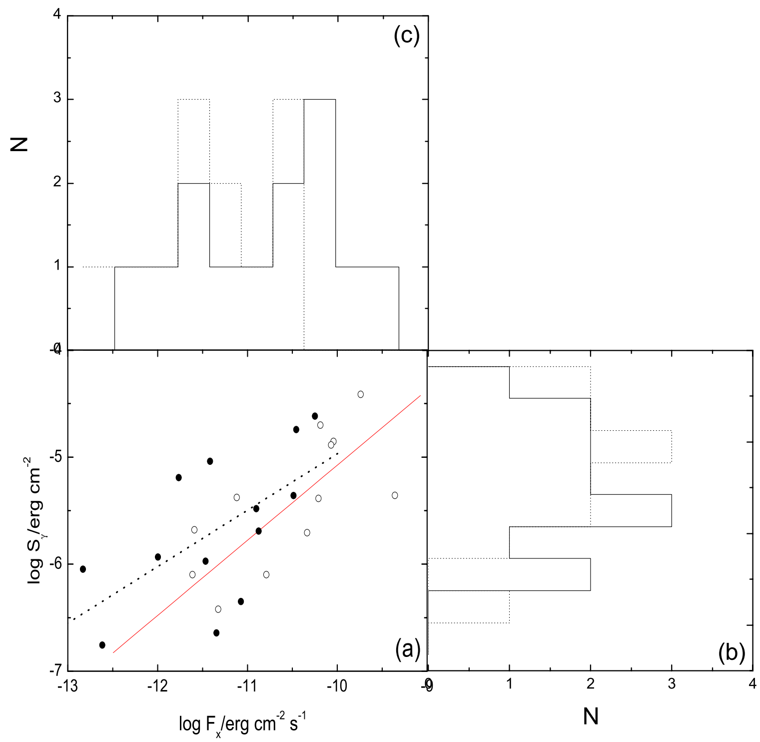

Fig. 1 Two-dimensional distributions of the gamma-ray fluences and the X-ray fluxes for the optically bright GRBs (open circles in panel (a) and solid lines in panels (b) and (c)) and the optically dark GRBs (filled circles in panel (a) and dotted lines in panels (b) and (c)). The solid and dotted lines in the panel (a) are the best fit results for the bright and dark GRBs, respectively.

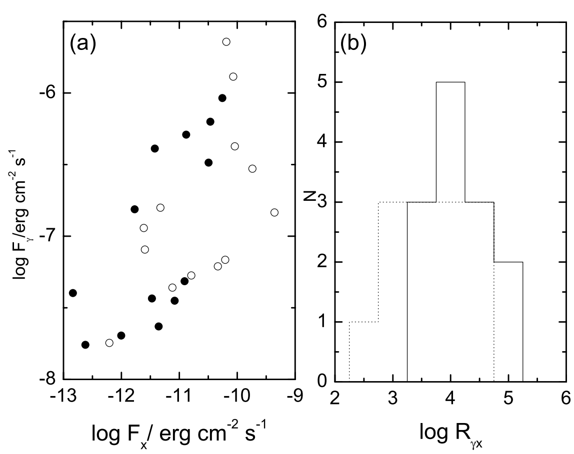

Fig. 2 (a) Two-dimensional flux-distributions (average gamma-ray flux versus X-ray flux) for the B-GRBs (open circles) and the D-GRBs (solid circles) (b) The hardness ratio histograms for the B-GRBs (solid) and the D-GRBs (dotted).

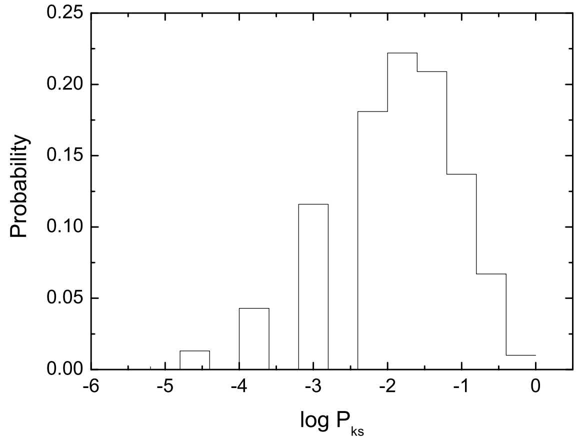

Fig. 3 $P_{\rm KS}$ distribution for 10^3 pair bootstrap samples.

for each pair sample. The distribution of the $P_{\rm KS}$ is shown in Figure 3, indicating the hypothesis that the pair samples are drawn from the same parent is accepted at a significance level of $\sim 3\sigma$. We also combine each pair samples as an assembled sample and then apply KMM algorithm (Ashman et al. 1994) to check if the assembled sample can be classified as two unique groups. It is found that the null hypothesis, that the assembled sample is classifiable into two unique groups, is ruled out at a significance level of $\sim 3\sigma$.

6 CONCLUSIONS AND DISCUSSION

With a homogenous sample detected by *Swift* we have shown that the distributions of $F_{\rm X}$, S_γ and $R_{\gamma,{\rm X}}$ for the D-GRBs and B-GRBs are from the same parent populations. These results indicate that the progenitors of the two kinds of GRBs are the same, and their total energies of explosion should be comparable. The suppression of optical emission in D-GRBs should be resulted from circumburst.

As suggested by Roming et al. (2005), there might be diverse mechanisms of suppressing optical emission in the D-GRBs. The diversity may be a reflection of the variety of the circumburst. Extinction is the most popular mechanism to explain the D-GRBs. However, the dust in the host galaxy may be destroyed by the early radiation from γ-ray burst and their afterglows (Waxman & Draine 2000; Fruchter et al. 2001). It is found that the optical extinction is 10$\sim$100 times smaller than is expected from the X-ray absorption (Galama et al. 2001). We examined the X-ray absorptions in our GRB sample and did not find systematically difference of excess nH between the D-GRBs and B-GRBs. Extinction effect alone is hard to explain the darkness of the GRBs. The darkness should involve more physical mechanisms. Most recently, Liang & Zhang (2005) found an intriguing result that within the optically bright GRBs there exist two distinct classes of the late optical afterglow: in their sample a minority of GRBs was found to have a luminosity dimmer than the typical ones by a factor $\sim$ 30. If this is true the nature of the dim group may cast some light on the D-GRBs.

Here we give a possible explanation that the optical dark bursts may be caused by synchrotron self-absorption (SSA) (Granot, Piran & Sari 1999). If the SSA frequency is a little greater than the observed optical frequency, which might be caused by the larger circum-density (Sari & Piran 1999) or more loading baryons, then the optical afterglow will be darker than that in the case of no SSA.

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