Evidence for intrinsic absorption in the Swift X–ray afterglows

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Abstract. Gamma-ray burst (GRB) progenitors are observationally linked to the death of massive stars. X–ray studies of the GRB afterglows can deepen our knowledge of the ionization status and metal abundances of the matter in the GRB environment. Moreover, the presence of local matter can be inferred through its fingerprints in the X–ray spectrum, i.e. the presence of absorption higher than the Galactic value. A few studies based on BeppoSAX and XMM-Newton found evidence of higher than Galactic values for the column density in a number of GRB afterglows. Here we report on a systematic analysis of 17 GRBs observed by Swift up to April 15, 2005. We observed a large number of GRBs with an excess of column density. Our sample, together with previous determinations of the intrinsic column densities for GRBs with known redshift, provides evidence for a distribution of absorption consistent with that predicted for randomly occurring GRB within molecular clouds.

INTRODUCTION

Evidence has been accumulating in recent years that at least a subclass of Gamma–ray bursts (GRBs), the ones with a long ($\gtrsim 2$ s) burst event, are associated with deaths of massive stars (e.g. Woosley 1993; Paczyński 1998; MacFadyen & Woosley 1999). This evidence was initially based on the relatively small offset of the GRB location with respect to the center of the host galaxy (Bloom, Kulkarni & Djorgovski 2002). Moreover, decisive supernova features have been observed in the afterglow of a few nearby GRBs (Galama et al. 1998, Della Valle et al. 2003; Stanek et al. 2003; Malesani et al. 2004), directly linking long GRBs to massive stars. This also provides strong observational evidence for the connection of GRBs to star formation (Djorgovski et al. 1998; Fruchter et al. 1999; Prochaska et al. 2004). A study on the GRB host galaxies by Le Floc'h et al. (2003) found that these hosts have very blue colours, comparable to those of the faint blue star-forming sources at high redshift. The association of long GRBs with star forming regions supports the idea that a large fraction of the optically-dark GRBs (i.e. GRBs without an optical afterglow), as well, are due to high (dust) absorption (Lazzati, Covino & Ghisellini 2002; Rol et al. 2005; Filliatre et al. 2005).

Together with optical studies, which probe the dust content of the GRB environment, X–ray studies of the GRB afterglows can give insight on the ionization status and metal abundances of the matter in the GRB environment. This can be done by using either emission or absorption features (e.g., Böttcher et al. 1999; Ghisellini et al. 2002). Although emission features are more apparent, the cumulative effect of low-energy cutoff is easier to detect in the relatively low signal to noise spectra of X–ray afterglows. Moreover, if the absorbing material is located close to the GRB site ($\sim 0.1 - 10$ pc), it is expected that GRB photons may lead to a progressive photoionization of the gas, gradually reducing the effect of low energy absorption (Lazzati & Perna 2002).

X–ray absorption in excess of the Galactic value has been reported for a handful of GRB afterglows (Owens et al. 1998; Galama & Wijers 2001; Stratta et al. 2004; De Luca et al. 2005; Gendre, Corsi & Piro 2005). Evidence for a decrease of the intrinsic column density with time in the X–ray prompt emission of some GRBs has also been found (GRB980506, Connors & Hueter 1998; GRB980329, Frontera et al. 2000; GRB011211, Frontera et al. 2004). Lazzati & Perna (2002) interpreted them as evidence for GRBs occurring within overdense regions in molecular clouds similar to star formation globules in our Galaxy.

Stratta et al. (2004) presented a systematic analysis of a sample of 13 bright afterglows observed with BeppoSAX narrow field instruments. They found a significant detection of additional intervening material in only two cases (namely, GRB990123 and GRB010222), but, owing to the limited photon statistics, they could not exclude that intrinsic X–ray absorption is also present in the other bursts. Chandra observations of GRB afterglows have yielded a few detections and constraints of the presence of intrinsic X–ray absorption (Gendre et al. 2005). XMM-Newton observed 9 GRB afterglows (for a review see De Luca et al. 2005 and Gendre et al. 2005). These are mainly INTEGRAL GRBs, the large majority of which has been discovered close to the Galactic plane (i.e. are characterized by a relatively high Galactic column density). From XMM-Newton data one can gather evidence that at least several GRBs occur in high density regions within their host galaxies (e.g, De Luca et al. 2005).

Here we investigate the presence of intrinsic absorption in the complete set of all the 17 GRBs promptly observed by Swift up to April 15, 2005, for more details (especially on the data) see Campana et al. (2006) and Table 1.

TABLE 1. Results of the spectral analysis.

GRB	N_H Gal.* 10^{20} cm^{-2}	N_H obs.† 10^{20} cm^{-2}	$\chi^2_{\rm red}$ (dof)
041223	10.9 (9.9) [5.6]	$16.8^{+5.2}_{-4.2}$	0.8 (26)
050124	5.2 (2.6) [1.7]	$6.2^{+3.9}_{-2.5}$	1.3 (35)
050126	5.3 (3.2) [2.6]	$4.1^{+2.7}_{-2.6}$	0.9 (10)
050128	4.8 (4.9) [3.8]	$12.5^{+1.4}_{-1.3}$	1.3 (105)
050215b	2.1 (2.0) [0.9]	< 3.4	1.0 (4)
050219a	8.5 (10.1) [8.1]	$30.1^{+6.5}_{-5.9}$	1.0 (57)
050219b	3.8 (3.0) [1.7]	$23.8^{+4.0}_{-3.7}$	1.0 (98)
050223	7.1 (6.6) [4.4]	$9.5^{+23.8}_{-7.3}$	1.2 (3)
050306	3.1 (2.9) [3.5]	$46.1^{+35.6}_{-28.8}$	1.0 (3)
050315	4.3 (3.3) [2.5]	$14.9^{+3.9}_{-2.2}$	1.3 (42)
050318	2.8 (1.8) [0.9]	$4.2^{+1.9}_{-1.5}$	0.8 (39)
050319	1.1 (1.2) [0.5]	$3.0^{+0.9}_{-0.8}$	1.3 (29)
050326	4.5 (3.8) [1.8]	$18.9^{+7.1}_{-6.0}$	1.0 (25)
050401	4.8 (4.4) [3.3]	$21.1^{+2.2}_{-1.8}$	1.0 (297)
050406	2.8 (1.7) [1.1]	< 6.6	1.2 (10)
050408	1.7 (1.5) [1.3]	$30.7^{+5.5}_{-4.9}$	0.9 (45)
050412	2.2 (1.7) [1.0]	$26.4^{+14.9}_{-12.4}$	1.4 (11)

* Column density values are from Dickey & Lockman (1990). Values between parentheses are from Kalberla et al. (2005) and in square parentheses from Schlegel, Finkbeiner & Davis (1998), using the usual conversion $N_H = 5.9 \times 10^{21}\, E(B-V)$ cm^{-2}.

† The values of the column density have been computed at $z = 0$ since we do not have any knowledge of the GRB redshift for most of them (but see Table 2).

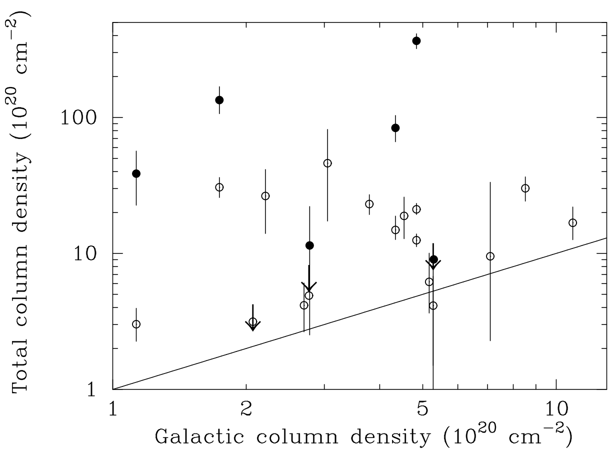

FIGURE 1. Galactic column density versus column density obtained from spectral fit of the X–ray afterglow. Open circles are values obtained without any redshift information. Filled circles indicate values for the six GRBs with known redshift at the redshift of the host galaxy. Upper limits are also indicated with filled and open circles, as above. The line represents the prints of equal values between the Galactic and the total column density (i.e. no intrinsic absorption).

TABLE 2. Results of the spectral analysis of GRB with known redshift. Refs.: 1) Berger, Cenko, Kulkarni 2005; 2) Kelson & Berger 2005; 3) Berger & Mulchaey 2005; 4) Fynbo et al. 2005; 5) Fynbo et al. 2005; 6) Berger, Gladders & Oemler 2005. Values in the second part of the table are from Stratta et al. (2004), De Luca et al. (2005) and Gendre et al. (2005).

GRB	Redshift (ref.)	N_H Gal. 10^{20} cm^{-2}	N_H obs.* 10^{20} cm^{-2}	$\chi^2_{\rm red}$ (dof)	N_H DLA (90%) 10^{20} cm^{-2}
050126	1.29 (1)	5.3	< 9.4	1.0 (10)	0.8 (6.4)
050315	1.95 (2)	4.3	$83.7^{+19.7}_{-17.4}$	1.4 (43)	1.4 (5.7)
050318	1.44 (3)	2.8	$11.3^{+10.7}_{-8.9}$	0.6 (39)	0.9 (12.9)
050319	3.24 (4)	1.1	$38.6^{+18.0}_{-16.0}$	1.4 (29)	3.6 (447)
050401	2.90 (5)	4.8	366^{+47}_{-46}	1.1 (294)	3.0 (272)
050408	1.24 (6)	1.7	134^{+34}_{-28}	1.0 (45)	0.8 (4.7)
980703	0.97	5.8	290^{+71}_{-27}		0.6 (1.7)
990123	1.60	2.1	30^{+70}_{-20}		1.1 (23.1)
990510	1.63	9.4	160^{+19}_{-13}		1.1(25.1)
000210	0.85	2.5	50^{+10}_{-10}		0.0 (0.0)
000214	0.47	5.8	< 2.7		0.0 (0.0)
000926	2.07	2.7	40^{+35}_{-25}		1.6 (73.9)
010222	1.48	1.6	120^{+70}_{-60}		1.0 (15.1)
001025a	1.48	6.1	66^{+30}_{-30}		1.0 (15.1)
020322	1.80	4.6	130^{+20}_{-20}		1.3 (40.7)
020405	0.70	4.3	47^{+37}_{-37}		0.0 (0.0)
020813	1.25	7.5	< 36.5		0.8 (5.0)
021004	2.33	4.3	< 34		2.0 (118)
030226	1.98	1.6	68^{+41}_{-33}		1.5 (60.8)
030227	3.90	22	680^{+18}_{-38}		5.2 (649)
030328	1.52	4.3	< 44.3		1.0 (17.3)

* Column density values have been computed at the GRB redshift.

DISCUSSION

The evidence that a large fraction of GRBs is characterized by an absorbing column density larger than the Galactic one clearly points to a high density interstellar medium (ISM) in the proximity of the GRB (in fact with X–rays we directly probe the GRB line of sight, whereas in the optical the observations might be contaminated by the host galaxy contribution). Dense environments in the host galaxy, possibly associated with star forming regions, provide a further clear signature in favour of the association of long GRBs to the death of massive stars. Moreover, the effect of an intrinsic column density can be hidden either by a large Galactic absorber (as often occurs for INTEGRAL GRBs) or by a large redshift shifting the energy scale by $(1+z)$ and the column density effective value by $\sim (1+z)^{2.6}$.

We combine our sample of GRBs with known redshift with other intrinsic column densities available in the literature (Stratta et al. 2004; De Luca et al. 2005; Gendre et al. 2005), obtaining a sample of 21 GRBs (see Table 2). In principle the absorption excess found in most GRBs might not be local to the host galaxy but may come from a line-of-sight interlooper. This often occurs in optical studies of quasar with dumped Lyman absorber (DLA). Based on quasar studies (Wolfe, Gawiser & Prochaska 2005; Péroux et al. 2003) we simulated for each of our bursts a distribution of line-of-sights (10000 trials), evaluating a mean absorption (weighted as $(1+z)^{2.6}$) and 90% confidence value. These values are reported in column six of Table 2. The influence of DLA systems is marginal in our sample even if there are a few GRBs in which the observed absorption excess may come from intervening DLAs. Indeed, such systems have recently been found in few Swift GRBs (e.g. GRB050730 with $\log(N_H) = 22.3$, Starling et al. 2005, Chen et al. 2005, and GRB 050401, Watson et al. 2005, $\log(N_H) = 22.5$). However, they are due to the ISM in the GRB host. One of these GRBs is part of our sample, GRB 050401, and indeed we obtained a high value of the instrinsic column density.

In order to understand the origin of the absorption excess, we compared the distribution of measured intrinsic column densities with the distribution expected for bursts occurring in Galactic-like molecular clouds (Reichart & Price 2002) and with the one expected for bursts occurring following a host galaxy mass distribution using the Milky Way as a model (Vergani et al. 2004). For each of these two column density distributions we simulated 10000 GRBs and compared, by means of a Kolmogorov-Smirnov (KS) test, their instrinsic absorption distribution to the observed distribution. We found that the observed distribution is inconsistent with the galaxy column density distribution (Vergani et al. 2004), with a KS null hypothesis probability of 10^{-11}, but it is consistent with GRBs distributed randomly in molecular clouds (KS null hypothesis probability of 0.61). These results would support an origin of long GRBs within high density regions such as molecular clouds. We stress that our sample also contains upper limits and that we are sensitive to low values of column density, which however are found only in a small fraction of the total sample.

SUMMARY AND CONCLUSIONS

The main goal of the present paper is to investigate the presence of intrinsic absorption in the X–ray spectra of GRB afterglows. We analyzed a complete set of 17 afterglows observed by Swift XRT before April 15, 2005. In 10 of them we found clear signs of intrinsic absorption, i.e. with a column density higher than the Galactic value estimated from the maps by Dickey & Lockman (1990) at $> 90\%$ confidence level (and with low probability of contamination from intervening DLA systems). For the remaining 7 cases, the statistics are not good enough to draw firm conclusions. This clearly suggests that long GRBs are associated with high density regions of the ISM, supporting the idea that they are related to the deaths of massive stars.

For the 6 GRBs with known redshift, together with 15 already known, we can have an unbiased view of the intrinsic absorption in the host galaxy rest frame. We found a range of $(1-35)\times 10^{21}$ cm^{-2} for all GRBs. This range of values is consistent with the hypothesis that GRBs occur within giant molecular clouds, spanning a range of column density depending on their exact location (Reichart & Price 2002). In our rest frame this column density is then reduced by a factor $\sim (1+z)^{2.6}$, making it more difficult to determine the intrinsic column density, especially for distant GRBs or for GRBs occurring at large Galactic column densities.

Finally, we compared the distribution of GRB column densities with known redshift with theoretical predictions available in the literature finding good agreement with the expectation (Reichart & Price 2002) for bursts occurring in molecular clouds.

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