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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.

Key words. gamma rays: bursts – X-rays: general

1. 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 et al. 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 et al. 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 GRBsite (∼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; Perna & Lazzati 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 et al. 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 (GRB 980506, Connors & Hueter 1998; GRB 980329, Frontera et al. 2000; GRB 011211, 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, GRB 990123 and GRB 010222), 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. The paper is organized as follows. In Sect. 2 we present the data collected by Swift and the analysis procedure. In Sect. 3, we derive values and/or upper limits on the column density in excess of the Galactic value (based on the maps by Dickey & Lockman 1990). For 6 GRBs a redshift has also been determined through spectroscopic observations. For these we investigate the intrinsic excess of absorption. In Sect. 4 we discuss our results. Section 5 is dedicated to our conclusions.

Table 1. Observation log.

GRB	Start time (s)*	Mode	Region$	Exp. time (s)
041223	16661	PC	0, 20	4018
050124	11113	WT	40 × 20	7351
		PC	0, 20	11 066
050126	131	PC	2, 20	278
		PC	0, 13	8720
050128	108	PC	5, 20	2878
		PC	0, 15	14 316
050215b	2100	PC	0, 10	35 563
050219a	92	WT	40 × 20	5003
		PC	0, 20	2570
050219b	3130	WT	40 × 20	15 051
		PC	0, 20	5724
050223	2875	PC	0, 10	2337
050306	127390	PC	0, 10	12 284
050315	83	WT	40 × 20	748
		PC	7, 40	690
		PC	0, 20	9642
050318	3277	PC	2, 20	395
		PC	0, 20	3938
050319	87	PC	3, 40	1495
		PC	0, 40	2511
050326	3258	PC	1, 16	60
		PC	0, 15	40 723
050401	131	WT	40 × 20	2292
		PC	3, 20	276
		PC	0, 15	2079
050406	92	WT	40 × 20	109
		PC	2, 30	70
		PC	0, 10	49 050
050408	4653	PC	0, 11	1041
		PC	0, 5	57 532
050412	89	WT	40 × 20	168
		PC	2, 30	145

* Time from the BAT trigger time.
$ Extraction region. In PC mode it is a circular/annular region with inner and outer radii reported in the column. In the case of WT mode the region is always a 40 × 20 region along the column centered on source.

2. Swift data

The X-Ray Telescope (XRT, Burrows et al. 2005a) on board Swift (Gehrels et al. 2004) is a focusing X-ray telescope with a 110 cm^2 effective area at 1.5 keV, 23 arcmin field of view, 18 arcsec resolution (half-power diameter) and 0.2−10 keV energy range. The first GRB followed by XRT was GRB 041223 (Burrows et al. 2005b). Since then 22 other GRBs were observed by Swift up to April 15, 2005, together with one discovered by HETE II. Of these 24 GRBs, 19 were observed by XRT and only two of them (GRB 050410 and GRB 050117a; see also Hill et al. 2005) were not detected or have too few photons to perform a meaningful spectral analysis. For eight of them Swift was able to repoint within a few hundred seconds, whereas the remaining nine were observed at later times (>30 min). In Table 1 we present a log of the XRT observations used in the present work.

GRBs are observed by XRT with different observing modes and source count rates. These modes were designed to minimize photon pile-up when observing the highly variable flux of GRB afterglows. The change between observing modes should occur automatically when the XRT is in the so-called Auto State (for a thorough description of XRT observing modes see Hill et al. 2004). Many of these early bursts were observed in Manual State instead, with the observing mode fixed, during the calibration phase (before April 5, 2005). For these GRBs observations were often carried out in Photon Counting (PC, the usual mode providing 2D images) and for some bright bursts the initial data are piled-up. This effect can be corrected by extracting light curves and spectra from an annular region around the source center (rather than a simple circular region), with a hole size that depends on the source brightness. As the afterglows decays the pile-up effect becomes negligible and extraction from a circular region is feasible. For bursts observed in Auto State observations started in Window Timing (WT) mode (providing just 1D imaging). Cross-calibration between modes assures that the two modes, PC and WT, provide the same rate (within a few percent) on steady sources.

Here we analyzed the dataset shown in Table 1. All data were processed with the standard XRT pipeline within FTOOLS 6.0 (`xrtpipeline` v. 0.8.8) in order to produce screened event files. WT data were extracted in the 0.5−10 keV energy range, PC data in the 0.2−10 keV range. Standard grade filtering was adopted (0−2 for WT and 0−12 for PC, according to XRT nomenclature, see Burrows et al. 2005a). From these we extracted spectra using regions selected to avoid pile up and to maximize the signal to noise (see Table 1). In WT mode we adopted the standard extraction region of 40 × 20 pixels along the WT line. In PC we used an annular region when the inner core of the Point Spread Function (PSF) was piled-up and circular regions otherwise. The size of the extraction region depends on the source strength and background level. Appropriate ancillary response files were generated with the task `xrtmkarf`, accounting for PSF corrections. The latest response matrices (v.007) were used. The data were rebinned to have 20 counts per energy bin (in some cases with few photons energy bins with as low as 10 counts per bin were used).

The data were fitted with a simple absorbed power law model. We have adopted the usual photoelectric absorption using Wisconsin (Morrison & McCammon 1983) cross-sections (`wabs` model within XSPEC). Normalizations were left free to vary. Power law photon index and absorbing column densities were first tied across the different observations and observing modes, but if the fit was not satisfactory the photon index was allowed to vary between observations (indicating a spectral evolution). We searched for variations of the column density with time by allowing the column density to vary across different observations. For GRBs with known redshift we also fitted an absorbed power law model with a fixed Galactic column density component plus a free column density at the redshift of the GRB. Results are shown in Tables 2 and 3 and in Fig. 1, where GRB total column densities are plotted against the Galactic column densities.

3. Discussion

We have analyzed the X-ray spectra of 17 GRB afterglows observed with Swift up to April 15, 2005. In at least 10 of them we find significant evidence that the observed column density is higher than the Galactic value. In contrast to previous investigations (De Luca et al. 2005; Stratta et al. 2004; Gendre et al. 2005) based on BeppoSAX, INTEGRAL and HETE II, the Swift sample has GRBs at low Galactic extinction (all below $\lesssim 10^{21}$ cm^{-2}), therefore more effectively probing the presence of absorption due to the GRB environment or host galaxy.

Table 2. Results of the spectral analysis.

GRB	N_H Gal.[a] 10^{20} cm^{-2}	N_H obs.[b] 10^{20} cm^{-2}	χ^2_{red} (d.o.f.)
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)

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

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 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. For GRBs characterized by a low number of counts no firm conclusions can be drawn. 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 et al. 2005; Péroux et al. 2003) we simulated for each of our bursts a distribution of line-of-sights (10 000 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.

Table 3. Results of the spectral analysis of GRB with known redshift.

GRB	Redshift (ref.)	$N_{\rm H}$ Gal. 10^{20} cm^{-2}	$N_{\rm H}$ obs.* 10^{20} cm^{-2}	$\chi^2_{\rm red}$ (d.o.f.)	$N_{\rm H}$ 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.

References: (1) Berger et al. (2005a); (2) Kelson & Berger (2005); (3) Berger & Mulchaey (2005); (4) Fynbo et al. (2005a); (5) Fynbo et al. (2005b); (6) Berger et al. (2005b). Values in the second part of the table are from Stratta et al. (2004), De Luca et al. (2005) and Gendre et al. (2005).

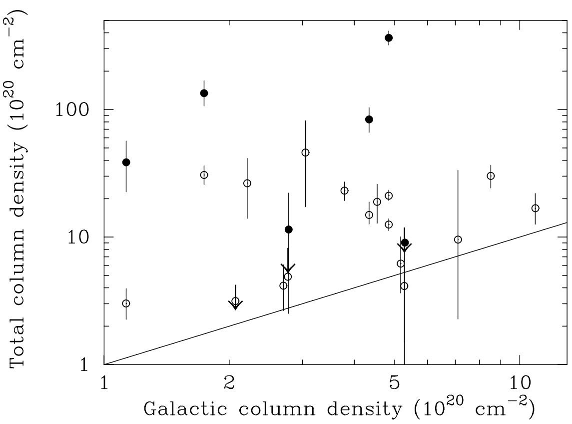

Fig. 1. Galactic column density versus column density obtained from spectral fit of the X-ray afterglow. Open circles are values obtained without any redshift information. Filled circles indicate values for the six GRBs with known redshift at the redshift of the host galaxy. Upper limits are also indicated 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).

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. GRB 050730 with $\log(N_{\rm H}) = 22.3$, Starling et al. 2005, Chen et al. 2005; and GRB 050401, Watson et al. 2005, $\log(N_{\rm H}) = 22.5$). However, they are due to the interstellar medium 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 10 000 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). The simulated distribution in the case of bursts occurring in Galactic-like molecular clouds and the observed one are plotted in Fig. 2. This 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.

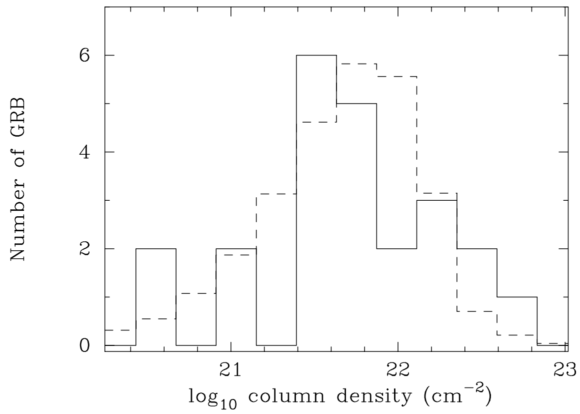

Fig. 2. Distribution (solid histogram) of intrinsic column density in a sample of 18 GRBs observed by Swift and other satellites (Stratta et al. 2004; De Luca et al. 2005). This is compared with the expected distribution of column density for GRB that occur in Galactic-like molecular clouds (dashed histogram, from Reichart & Price 2002).

4. 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 interstellar medium, 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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References

Berger, E., & Mulchaey, J. 2005, GCN 3122
Berger, E., Cenko, S. B., & Kulkarni, S. R. 2005a, GCN 3088
Berger, E., Gladders, M., & Oemler, G. 2005b, GCN 3201
Bloom, J. S., Kulkarni, S. R., & Djorgovski, S. G. 2002, AJ, 123, 1111
Böttcher, M., Dermer, C. D., Crider, A. W., & Liang, E. P. 1999, A&A, 343, 111
Burrows, D. N., Hill, J. E., Chincarini, G., et al. 2005a, ApJ, 622, L85
Burrows, D. N., Hill, J. E., Nousek, J. A., et al. 2005b, SSR, 120, 165
Chen, H.-W., Prochaska, J. X., Bloom, J. S., & Thomson, I. B. 2005, ApJ, 634, L25
Connors, A., & Hueter, G. J. 1998, ApJ, 501, 307
Della Valle, M., Malesani, D., Benetti, S., et al. 2003, A&A, 406, L33
De Luca, A., Melandri, A., Caraveo, P. A., et al. 2005, A&A, 440, 85
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Djorgovski, S. G., Kulkarni, S. R., Bloom, J. S., et al. 1998, ApJ, 508, L17
Filliatre, P., D'Avanzo, P., Covino, S., et al. 2005, A&A, 438, 793
Frontera, F., Amati, L., Costa, E., et al. 2000, ApJS, 127, 59
Frontera, F., Amati, L., in't Zand, J. J. M., et al. 2004, ApJ, 616, 1078
Fruchter, A. S., Thorsett, S. E., Metzger, M. R., et al. 1999, ApJ, 519, L13
Fynbo, J. P. U., Hjorth, J., Jensen, B. L., et al. 2005a, GCN 3136
Fynbo, J. P. U., Jensen, B. L., Hjorth, J., et al. 2005b, GCN 3176
Galama, T. J., Vreeswijk, P. M., van Paradijs, J., et al. 1998, Nature, 395, 670
Galama, T. J., & Wijers, R. A. M. J. 2001, ApJ, 549, L209
Gehrels, N., Chincarini, G., Giommi, P., et al. 2004, ApJ, 611, 1005
Gendre, B., Corsi, A., & Piro, L. 2005, A&A, submitted [arXiv:astro-ph/0507710]
Ghisellini, G., Lazzati, D., Rossi, E., & Rees, M. J. 2002, A&A, 389, L33
Hill, J. E., Burrows, D. N., Nousek, J. A., et al. 2004, SPIE, 5165, 217
Hill, J. E., Morris, D. C., Sakamoto, T., et al. 2005, ApJ, submitted [arXiv:astro-ph/0510008]
Kalberla, P. M. W., Burton, W. B., Hartmann, D., et al. 2005, A&A, 440, 775
Kelson, D., & Berger, E. 2005, GCN 3101
Lazzati, D., & Perna, R. 2002, MNRAS, 330, 383
Lazzati, D., Covino, S., & Ghisellini, G. 2002, MNRAS, 330, 583
Le Floc'h, E., Duc, P.-A., Mirabel, I. F., et al. 2003, A&A, 400, 499
MacFadyen, A. I., & Woosley, S. E. 1999, ApJ, 524, 262
Malesani, D., Tagliaferri, G., Chincarini, G., et al. 2004, ApJ, 609, L5
Morrison, R., & McCammon, D. 1983, 1983, ApJ, 270, 119
Owens, A., Denby, M., Wells, A., et al. 1997, ApJ, 476, 924
Paczyński, B. 1998, ApJ, 494, L45
Perna, R., & Lazzati, D. 2002, ApJ, 580, 261
Péroux, C., et al. 2003, MNRAS, 345, 480
Prochaska, J. X., Bloom, J. S., Chen, H.-W., et al. 2004, ApJ, 611, 200
Reichart, D. E., & Price, P. A. 2002, ApJ, 565, 174
Rol, E., Wijers, R. A. M. J., Kouveliotou, C., et al. 2005, ApJ, 624, 868
Schlegel, D., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Stanek, K. Z., Matheson, T., Garnavich, P. M., et al. 2003, ApJ, 591, L17
Starling, R. L. C., Vreeswijk, P. M., Ellison, S. L., et al. 2005, A&A, 442, L21
Stratta, G., Fiore, F., Antonelli, L. A., Piro, L., & De Pasquale, M. 2004, ApJ, 608, 846
Vergani, S. D., Molinari, E., Zerbi, F. M., & Chincarini, G. 2004, A&A, 415, 171
Watson, D., Fynbo, J. P. U., Ledoux, C., et al. 2005, ApJ, submitted [arXiv:astro-ph/0510368]
Wolfe, A. M., Gawiser, E., & Prochaska, J. A. 2005, ARA&A, 43, 861
Woosley, S. E. 1993, ApJ, 405, 273