The Astrophysical Journal, 635:L133–L136, 2005 December 20

DISCOVERY OF AN AFTERGLOW EXTENSION OF THE PROMPT PHASE OF TWO GAMMA-RAY BURSTS OBSERVED BY *SWIFT*

S. D. Barthelmy,[1] J. K. Cannizzo,[1,2] N. Gehrels,[1] G. Cusumano,[3] V. Mangano,[3] P. T. O'Brien,[4] S. Vaughan,[4] B. Zhang,[5] D. N. Burrows,[6] S. Campana,[7] G. Chincarini,[7,8] M. R. Goad,[4] C. Kouveliotou,[9] P. Kumar,[10] P. Mészáros,[6] J. A. Nousek,[6] J. P. Osborne,[4] A. Panaitescu,[11] J. N. Reeves,[1,12,13] T. Sakamoto,[1,14] G. Tagliaferri,[7] and R. A. M. J. Wijers[15]

Received 2005 September 12; accepted 2005 November 8; published 2005 December 8

ABSTRACT

BAT and XRT observations of two recent well-covered GRBs observed by *Swift*, GRB 050315 and GRB 050319, clearly show a prompt component joining the onset of the afterglow emission. By fitting a power-law form to the γ-ray spectrum, we extrapolate the time-dependent fluxes measured by BAT, in the energy band 15–350 keV, into the spectral regime observed by XRT, 0.2–10 keV, and examine the functional form of the rate of decay of the two light curves. We find that the BAT and XRT light curves merge to form a unified curve. There is a period of steep decay up to ∼300 s, followed by a flatter decay. The duration of the steep decay, ∼100 s in the source frame after correcting for cosmological time dilation, agrees roughly with a theoretical estimate for the deceleration time of the relativistic ejecta as it interacts with circumstellar material. For GRB 050315, the steep decay can be characterized by an exponential form, where the *e*-folding decay time $\tau_e \simeq 24 \pm 2$ s (BAT), and $\tau_e \simeq 35 \pm 2$ s (XRT). For GRB 050319, a power-law decay $-d \ln f/d \ln t = n$, where $n \simeq 3$ provides a reasonable fit. The early-time X-ray fluxes are consistent with representing the lower energy tail of the prompt emission and provide our first quantitative measure of the decay of the prompt γ-ray emission over a large dynamic range in flux. The initial steep decay is expected, due to the delayed high-latitude photons from a curved shell of relativistic plasma illuminated only for a short interval. The overall conclusion is that the prompt phase of GRBs remains observable for hundreds of seconds longer than previously thought.

Subject headings: gamma rays: bursts — X-rays: individual (GRB 050315, GRB 050319)

1. BACKGROUND

Gamma-ray bursts (GRBs) are among the most energetic phenomena in the universe and are believed to contain gas with the highest bulk-flow Lorentz factors. GRBs belonging to the "long" class—with duration >2 s (Kouveliotou et al. 1993)—are thought to herald the death of a massive star possessing high angular momentum, with the additional constraint that our line of sight coincides almost exactly with the rotational axis of the progenitor star. The apparent isotropic equivalent energies of $\sim 3 \times 10^{53}$ ergs decrease to $\sim 5 \times 10^{50}$ ergs when one corrects for beaming (Frail et al. 2001; see also Panaitescu & Kumar 2001). The prompt emission from GRBs is thought to come from a relativistically expanding fireball (Rees & Mészáros 1992, 1994), likely ejected during the collapse of massive stars (MacFadyen & Woosley 1999). Because of the traditionally long delay between the observations of the GRB prompt emission and the start of the afterglow observations, the exact site of the prompt emission has remained largely unknown. It has been argued that it could come either from the internal shocks (Rees & Mészáros 1994) or from the external shocks (see, e.g., Zhang & Mészáros 2004 and references therein). If the prompt emission were due to external shocks, one would see a continuous variation in flux between the prompt and afterglow light curves, with the decay slopes being equal. If it were caused by internal shocks, one should expect distinct components for the γ-ray light curves and the late afterglow. Looking for the bridge between the early, γ-ray light curve (<100 s) and the later, X-ray light curve (>100 s) is therefore essential in clarifying the emission site for the early flux. The unique capability of *Swift* makes this possible. In particular, early-time X-ray Telescope (XRT) data reveal that early X-ray afterglow shows a distinct, steeply decaying component followed by a shallower, more standard decaying component (Tagliaferri et al. 2005; Nousek et al. 2005).

The finite γ-ray background of large field-of-view (FOV) detectors such as the Burst and Transient Source Experiment (BATSE) limits the available dynamic range in flux to about 2 orders of magnitude, except for unusually bright GRBs. For instance, Giblin et al. (1999) examined the BATSE decay light curve of GRB 980923 and fitted a decay law of the form $A(t - t_0)^{-n}$, where $n = 1.8 \pm 0.02$. Other workers have carried

[1] NASA Goddard Space Flight Center, Exploration of the Universe Division, Greenbelt, MD 20771.
[2] Joint Center for Astrophysics, University of Maryland, Baltimore County, Baltimore, MD 21250.
[3] INAF–Istituto di Astrofisica Spaziale e Cosmica, Via Ugo La Malfa 153, I-90146 Palermo, Italy.
[4] Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK.
[5] Department of Physics, University of Nevada, Las Vegas, NV 89154-4002.
[6] Department of Astronomy and Astrophysics, Department of Physics, Pennsylvania State University, University Park, PA 16802.
[7] INAF–Osservatorio Astronomico di Brera, Via Bianchi 46, I-23807 Merate, Italy.
[8] Universitá degli studi di Milano-Bicocca, Dipartimento di Fisica, Piazza delle Scienze 3, I-20126 Milan, Italy.
[9] NASA Marshall Space Flight Center, NSSTC, XD-12, 320 Sparkman Drive, Huntsville, AL 35805.
[10] Department of Astronomy, University of Texas, Austin, TX 78712.
[11] Space Science and Applications, Los Alamos National Laboratory, MS D466, Los Alamos, NM 87545.
[12] Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218.
[13] Universities Space Research Association, 10211 Wincopin Circle, Suite 500, Columbia, MD 21044-3432.
[14] National Research Council, 2101 Constitution Avenue, NW, Washington, DC 20418.
[15] Astronomical Institute "Anton Pannekoek," University of Amsterdam, Amsterdam, Netherlands.

TABLE 1
SUMMARY

Parameter	Value	Reference
GRB 050315		
T_{50} (BAT) (s)	25 ± 5	1
T_{90} (BAT) (s)	96 ± 10	1
Fluence (BAT)	3.4 ± 0.3	1
Γ (1 s peak) (BAT) (10^{-6} ergs cm^{-2})	2.3 ± 0.2	1
Γ (T_{50}) (BAT)	2.02 ± 0.07	2
Redshift z	1.949	3
$E_{isotropic}$ (ergs)	3.2×10^{52}	
Γ (80–300 s) (XRT)	2.5 ± 0.4	2
Γ (300–10^4 s) (XRT)	1.7 ± 0.1	2
GRB 050319		
T_{50} (BAT) (s)	124.1 ± 0.4	
T_{90} (BAT) (s)	141.2 ± 0.8	
Fluence (BAT)	1.6 ± 0.2	4
Γ (BAT) (10^{-6} ergs cm^{-2})	2.1 ± 0.2	4
Redshift z	3.24	5
$E_{isotropic}$ (ergs)	3.7×10^{52}	
Γ (90–300 s) (XRT)	2.6 ± 0.2	4
Γ (300–10^4 s) (XRT)	1.7 ± 0.1	4

NOTE.—Fluence is in the range 15–150 keV; Γ = photon index; and $E_{isotropic}$ is the isotropic equivalent γ-ray energy.

REFERENCES.—(1) Krimm et al. 2005; (2) V05; (3) Kelson & Berger 2005; (4) C05; (5) Fynbo et al. 2005.

out similar studies and placed constraints on the decay index: $n = 0.69 \pm 0.17$ (GRB 920723; Burenin et al. 1999), $n = 0.7$ (GRB 910402) and $n = 0.6$ (GRB 920723) (Tkachenko et al. 2000), and $n = 3.7$ (GRB 990510; Pian et al. 2001). Also, in 't Zand et al. (2001) found a steep falloff of the 2–10 keV emission of GRB 010222 after 100 s.

Connaughton (2002) co-added the background-subtracted BATSE light curves for 400 long GRBs and found $n \simeq 0.6$ for the ensemble decay. It is not clear how physically meaningful this averaged value is, given the potential variety of decays for different bursts, and the systematics of the background subtraction for individual bursts. A related issue is how to "line up" different GRBs, i.e., the choice of t_0. For instance, if each distinct spike within a multispike GRB results from a δ-function injection of energy into a relativistic plasma, the relevant t_0 for times well past the end of the GRB would be the starting time for the last spike. The use of a physically inappropriate t_0 would smear out the results of an ensemble average. There may also be a dependence of the results on the energy range being used.

Swift was launched into a low-Earth orbit on 2004 November 20 (Gehrels et al. 2004). It contains three instruments: the Burst Alert Telescope (BAT; Barthelmy et al. 2005) with an energy range of 15–350 keV, XRT (Burrows et al. 2005b) with an energy range of 0.3–10 keV, and the UV/Optical Telescope (UVOT; Roming et al. 2005) with a wavelength range of 170–650 nm. The BAT initially detects the GRB and transmits a 1′–3′ position to the ground within ∼12–45 s. The spacecraft then autonomously slews to the GRB location within 20–75 s, at which time observations with the two narrow-field instruments XRT and UVOT begin.

For this study we consider two of the best cases with known redshifts: GRB 050315 and GRB 050319. These are also the longer of the long bursts and so potentially allow us to test the relation between BAT and XRT fluxes during the near-overlap time of useful data with the two instruments.

2. DATA ANALYSIS

The BAT data analysis is performed using the *Swift* software package (HEAsoft 6.0). From the known GRB position determined from the initial trigger, the shadow mask weighting pattern for this position is calculated for the coded aperture. The background is subtracted using the modulations of the coded aperture. In this technique, photons with energy greater than 150 keV become transparent to the coded mask and are treated as a background. The effective BAT energy range is from 15 to 150 keV in this mask-weighted technique.

The BAT spectrum and the detector response matrix (DRM) are created using the HEAsoft 6.0 software packages and the *Swift* calibration database (CALDB 20050327). We also apply an energy-dependent systematic error vector to the spectral files before doing spectral fitting.[16] The background-subtracted (mask-weighted) spectral data are used in the analysis. The XSPEC version 11.3.1 software package is used for fitting the data to the model spectrum.

Swift was slewing during GRB 050319, and the BAT trigger is disabled during this interval. The actual GRB began ∼135 s before the originally reported trigger time t_0, which is now known to represent the onset of the last of the four spikes composing the GRB. Nevertheless, in this study we use the original t_0 value and restrict our attention only to the last spike. Each individual spike would have a decay in X-rays associated with it, and in any given train of spikes constituting the entire GRB, only the most recent would be of relevance, since the earlier ones would largely have decayed by the later time. This convention for GRB 050319 concerning t_0 is different from that adopted by Cusumano et al. (2005, hereafter C05), who took the trigger time for the first spike in the GRB 050319 complex.

2.1. *Methodology*

We calculate the decay of the prompt emission as follows. We first extract the BAT light curve in the energy range 15–350 keV, fit a power law to the spectrum over the central 50% of the fluence, i.e., T_{50}, and then extrapolate this emission into the 0.2–10 keV energy range. The conversion factor for each GRB is calculated using the flux calculator tool PIMMS. The power-law index inferred from the γ-ray spectrum, with its associated 1 σ error, is propagated through as error bars that add in quadrature to the Poisson flux errors. In addition to the formal systematic errors, one also has extrinsic errors of uncertain magnitude stemming from the assumption of one continuous power law over a broad spectral range.

For times close to t_0 that are of interest in this study, the exact value of t_0 determines the logarithmic decay slope. In this work we take the same $t_0(\mathrm{XRT}) = t_0(\mathrm{BAT}) = t_0(\mathrm{trigger})$, the GRB trigger time. A summary of the BAT and XRT derived measurements is given in Table 1.

GRB 050315.—A detailed description of the XRT data reduction is given in Vaughan et al. (2005, hereafter V05). The XRT count rate of GRB 050315 at the start of the pointed observation was in excess of 100 counts s^{-1} (∼3×10^{-9} ergs s^{-1} cm^{-2}), resulting in heavy pileup in the PC-mode data. Ordinarily, the XRT camera would have switched to a different mode (e.g., WT or Photodiode modes) in order to accommodate such a high rate, but the XRT was in manual state at the time of the trigger and remained in PC mode during the early observations.

The most obvious effect of pileup is an apparent loss of counts from the center of the image, compared to the expected point-spread function (PSF). This effect was used to determine at what count rate pileup can no longer be ignored, by fitting the image radial profile with a PSF model and successively ignoring the inner regions until the model gave a good fit. The

[16] See http://legacy.gsfc.nasa.gov/docs/swift/analysis/bat_digest.html.

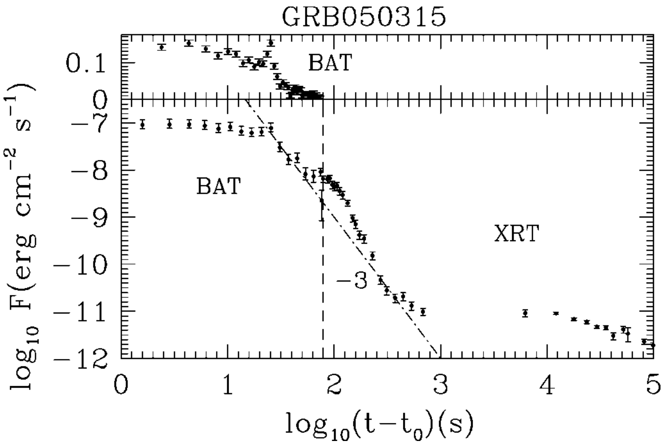

FIG. 1.—Combined BAT/XRT 0.2–10 keV light curve of GRB 050315. The small panel on top shows the BAT data on a loglinear scale, in units of background-subtracted 15–350 keV flux per fully illuminated detector. The main, large panel shows the combined BAT and XRT data. The vertical dashed line shows the approximate time of the start of XRT observations, and the dot-dashed line indicates a logarithmic decay slope of −3.

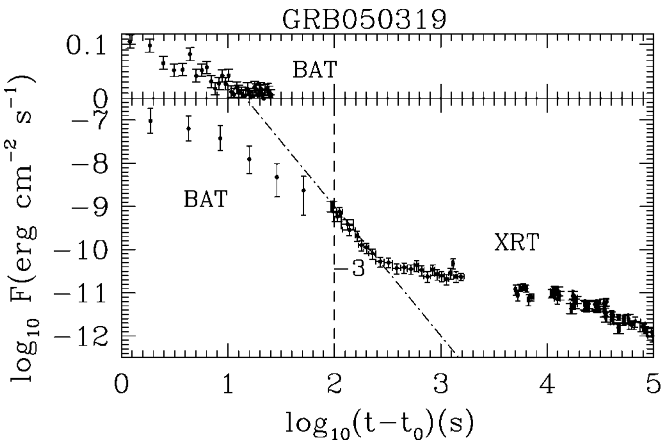

FIG. 2.—Combined BAT/XRT 0.2–10 keV light curve of GRB 050319. The conventions are the same as in Fig. 1.

region over which the PSF model gave a good fit is the region over which pileup may be ignored. In the present analysis the central 8 pixels (radius) were ignored for (observed) count rates between 1 and 5 counts s^{-1}, and the central 14 pixels (radius) were ignored for higher count rates. (Note that one pixel corresponds to 2″.36.) After excluding the center of the image, the fluxes were corrected simply by calculating the fraction of the integrated PSF used in the extraction. (These results were obtained using only monopixel events, i.e., grade = 0, which should be least affected by pileup.) A light curve was extracted over the 0.2–10 keV band, binned such that there were 25 source events per bin, and a background was subtracted using a large annulus concentric with the source extraction region. Error bars were calculated assuming counting statistics.

GRB 050319.—A detailed description of the XRT data reduction is given in C05. The XRT count rate values were obtained extracting events (0–12 grade; 0.2–10 keV) in a circular region. Pileup in the first part of the observation was then corrected by excluding the central pixels, fitting a PSF model to the wings of the emission, and rescaling the central portions using the instrumental PSF to recover the lost counts. Events were binned in order to have a constant signal-to-noise ratio of 5. The light curve was then fitted with a broken power law with two temporal breaks. The conversion factor from count rate to flux was obtained by performing the spectral analysis of the whole XRT spectrum and by comparing the unabsorbed flux in the 0.2–10 keV band with the average count rate in the same energy band. This correction factor was then applied to both the XRT light curve and the best-fit model.

Figures 1 and 2 show the composite light-curve decays for the 0.2–10 keV fluxes, extrapolated from the BAT and measured by the XRT. The dot-dashed line in each plot, indicating a logarithmic slope of −3, is not a fit to the data, but rather intended to be illustrative. Up to ∼250 s after burst onset, one sees a steep decay in the light curve. After this time the slope flattens abruptly, demarcating the time at which the prompt emission gives way to the early afterglow. For GRB 050315, exponential decays give a better characterization than a single power-law decay for the BAT and XRT light curves for $t - t_0 < 300$ s. The *e*-folding decay times are $\tau \simeq 24 \pm 2$ s (BAT) and $\tau \simeq 35 \pm 2$ s (XRT); after taking into account the cosmological $(1+z)$ time dilation, these transform to $\tau \simeq 8 \pm 1$ s (BAT) and $\tau \simeq 12 \pm 1$ s (XRT) at $z = 1.95$ (V05). This slight difference between BAT and XRT is consistent with modest hard-soft evolution. As discussed in detail in V05, the $t - t_0 < 10^3$ s XRT light curve for GRB 050315 evolves through flat → steep → flat phases (followed by a second steepening seen in later orbits). This first part of the light curve, until the end of the steep descent at ∼300 s, can be modeled using either a broken power law or an exponential decay. (The second break and additional flat power law accounts for the true afterglow emission.) A single power law for the steep decay is not acceptable. The two solutions are (1) a break in the power law from $n = 2$ to 5 at $t - t_0 \sim 120$ s (V05; see their Table 2) or (2) an exponential decay. Both models give excellent fits; formally, the exponential model gives a worse χ^2 fit, but has two fewer free parameters. It may be more appealing due to its simplicity than an arbitrary power-law break. Exponential decays also avoid the problem of the choice of t_0, which has a strong influence on the derived decay slope n.

3. DISCUSSION

We have presented convincing evidence that for two GRBs observed by *Swift*, the prompt emission can be seen in X-rays up to about 300 s after the GRB trigger. In addition, the light curves from the BAT and XRT connect continuously, without there being a significant offset. For completeness, we note that not all such GRBs for which complete early-time XRT observations exist share this property. For instance, Tagliaferri et al. (2005) presented data for two other GRBs, GRB 050126 and GRB 050219a, for which the early-time XRT light curve lies significantly above an extension of the BAT 0.2–10 keV (extrapolated) light curve. It is possible that strong spectral evolution and/or non–power-law spectral shape may invalidate the simple prescription we and others have adopted for extrapolating the BAT flux into the XRT bandpass. Another possibility is that a flare occurred in the X-ray bandpass (Burrows et al. 2005a), with the maximum located before the XRT observation began (i.e., at $t < t_0 + 100$ s). All five of the GRBs studied by Tagliaferri et al. show XRT light curves in which the initial steep decay gives way at later times to a more shallow decay, thereby supporting the idea of the initial X-ray flux as representing a continuation of the prompt emission. Campana et al. (2005) presented an XRT light curve for GRB 050128 that shows evidence for flat decay at $t < 300$ s, followed by a steeper decay out to $t > 10^5$ s. It is difficult to form a general hypothesis of the early X-ray behavior based on so few examples (e.g., Nousek et al. 2005), but it may be that for most GRBs the intrinsic tendency is for the prompt decay up to ∼300 s to be steep, as in GRB 050315 and GRB 050319, whereas for others a variety of systematic effects, such as viewing geometry, rapid cooling of the ejecta, and evolutionary effects such as the shifting of the synchrotron cooling frequency ν_c out of the observational (XRT) bandpass conspire to distort and hence obscure this simple, underlying behavior.

Within the theoretical framework of the expanding, relativistic blast wave model in which synchrotron emission from relativistic electrons dominates, the power-law decay index for the decaying light curve depends only on the index of the power-law distribution of electrons with energy, the density stratification of the medium into which the burst propagates, and the location of the frequency of the observing bandpass relative to ν_c. The most straightforward interpretation of the steep initial decay for GRB 050315 and GRB 050319 may be the "curvature effect" associated with the time delay from high-latitude emission within the relativistic ejecta. This effect is due to the fact that, when the internal shocks stop radiating, an observer viewing the emission close to the primary velocity vector of the ejecta sees emission from larger and larger viewing angles due to the Doppler delay effect (Kumar & Panaitescu 2000, hereafter KP00; see Dermer [2004] for a more complete derivation).

As noted in § 2.1, for GRB 050315 an exponential decay fits better than a power-law decay, indicating that at least one of the underlying assumptions entering into the power-law derivation is not fulfilled. An exponential decay from the large-angle GRB emission would be obtained if the comoving-frame energy band, which is Doppler-shifted to the observer's 0.2–10 keV band, were above the cooling frequency only if the outflow were tightly collimated and we could see its boundary. If the GRB emission stopped at t_0, then at $t - t_0 \sim 100$ s, we see the emission from an angle $(100\ \mathrm{s}/t_0)^{1/2}\gamma^{-1}$ ($<2\gamma^{-1}$) because the arrival time for the large-angle emission increases as the square of the angle from which that emission arises. Hence, the large-angle GRB emission would exhibit an exponential decay (above the cooling frequency) only if the jet is narrower than 1°. On the other hand, if the break in the XRT light curve at $t - t_0 \simeq 2 \times 10^5$ s represents the jet break, the observed $E_{\rm iso}$ value for GRB 050315 implies a jet opening angle $\theta_0 \simeq 5°$ (V05), which would be inconsistent with this explanation. One possible remedy may involve some aspect of alternative models that advocate a much smaller beaming angle (<1°) and a larger Lorentz factor ($>10^3$) for the GRB jet (Dar & Rújula 2004).

The transition at $t \simeq 250$–300 s in our reference frame to a much flatter decay law in GRB 050315 and GRB 050319 may provide a clue to the timescale for the relativistic shell to decelerate as it moves into the interstellar medium (ISM) gas. KP00 give the shell deceleration time, measured in the local rest frame at a given z, as 100 s $E_{52}^{1/3}(1-\eta)^{1/3}(\eta n_0 \gamma_2^8)^{-1/3}$, where E_{52} is the isotropic equivalent γ-ray energy in units of 10^{52} ergs, η is the efficiency factor for converting internal energy of the explosion into γ-ray energy, $\gamma_2 = \gamma_0/10^2$ is the initial Lorentz factor of the ejecta, scaled to 100, and n_0 is the number density of the ISM. (The deceleration time measured in the comoving ejecta frame is larger by a factor $\sim 2\gamma^2 \simeq 10^4$.) The times at which the initial steep XRT decays abruptly give way to much shallower decays are ∼100 s in the frame of an observer at a cosmological redshift $z = 1.95$ for GRB 050315 (∼300 s in our reference frame), and ∼60 s at $z = 3.2$ for GRB 050319 (∼250 s in our frame). The fact that the time of our flattening is consistent with the theoretical deceleration time adds strength to the standard model of relativistic ejection and prompt emission, followed by deceleration and afterglow emission. As a potential caveat to this interpretation, Zhang et al. (2005) carried out detailed numerical calculations of the curvature effect and found that the observed transition time between steep and shallow decay may only be an upper limit to the deceleration time. The fireball could well be decelerated earlier, but the deceleration signature (marked by a rising phase followed by a $n \simeq -1$ decay) could be buried beneath the steep-decay component. Zhang et al. (2005) used the observed transition times for GRB 050315 and GRB 050319 to set lower limits on the initial fireball Lorentz factors.

4. CONCLUSION

We present combined BAT/XRT data from two GRBs observed by *Swift* for XRT observations that began within 100 s of the BAT trigger. The data presented here give a clear indication that the prompt emission and late afterglow emission are two distinct components. The early X-ray afterglow is the tail of the prompt γ-ray emission, and the late X-ray afterglow is the normal forward shock afterglow. This lends support to the prevailing notion that prompt emission is from internal shocks rather than external shocks.

REFERENCES

Barthelmy, S. D., et al. 2005, Space Sci. Rev., in press
Burenin, R. A., et al. 1999, A&A, 344, L53
Burrows, D. N., et al. 2005a, Science, 309, 1833
———. 2005b, Space Sci. Rev., in press
Campana, S., et al. 2005, ApJ, 625, L23
Connaughton, V. 2002, ApJ, 567, 1028
Cusumano, G., et al. 2005, ApJL, in press (C05)
Dar, A., & De Rújula, A. 2004, Phys. Rep., 405, 203
Dermer, C. D. 2004, ApJ, 614, 284
Frail, D. A., et al. 2001, ApJ, 562, L55
Fynbo, J. P. U., et al. 2005, GCN Circ. 3136, http://gcn.gsfc.nasa.gov/gcn/gcn3/3136.gcn3
Gehrels, N., et al. 2004, ApJ, 611, 1005
Giblin, T. W., et al. 1999, ApJ, 524, L47
in 't Zand, J., et al. 2001, ApJ, 559, 710
Kelson, D., & Berger, E. 2005, GCN Circ. 3101, http://gcn.gsfc.nasa.gov/gcn/gcn3/3101.gcn3
Kouveliotou, C., Meegan, C. A., Fishman, G. J., Bhat, N. P., Briggs, M. S., Koshut, T. M., Paciesas, W. S., & Pendleton, G. N. 1993, ApJ, 413, L101
Krimm, H., et al. 2005, GCN Circ. 3105, http://gcn.gsfc.nasa.gov/gcn/gcn3/3105.gcn3
Kumar, P., & Panaitescu, A. 2000, ApJ, 541, L51
MacFadyen, A. I., & Woosley, S. E. 1999, ApJ, 524, 262
Nousek, J. A., et al. 2005, ApJ, submitted (astro-ph/0508332)
Panaitescu, A., & Kumar, P. 2001, ApJ, 560, L49
Pian, E., et al. 2001, A&A, 372, 456
Rees, M. J., & Mészáros, P. 1992, MNRAS, 258, P41
———. 1994, ApJ, 430, L93
Roming, P. W. A., et al. 2005, Space Sci. Rev., in press
Tagliaferri, G., et al. 2005, Nature, 436, 985
Tkachenko, A., et al. 2000, A&A, 358, L41
Vaughan, S., et al. 2005, ApJ, in press (astro-ph/0510677) (V05)
Zhang, B., Fan, Y. Z., Dyks, J., Kobayashi, S., Mészáros, P., Burrows, D. N., Nousek, J. A., & Gehrels, N. 2005, submitted (astro-ph/0508321)
Zhang, B., & Mészáros, P. 2004, Int. J. Mod. Phys. A, 19, 2385