Swift Observations of GRB 100728A

J. K. Cannizzo (NASA/UMBC), H. A. Krimm (GSFC/USRA),
M. Stamatikos (OSU), P. A. Evans (U. Leicester),
S. R. Oates (MSSL-UCL), for the Swift Team

1 Introduction

BAT triggered on a long burst, GRB 100728A, at T = 02:18:24 UT(trigger=430151). (Cannizzo, et al., *GCN Circ.* 11004). *Swift* slewed immediately to the burst. The BAT on-board calculated location is RA, Dec = (88.743, −15.262) deg, which is {05h 54m 58s; −15d 15' 42"} (J2000) with $\sigma = 3$ arcmin (radius, 90% containment, including systematic uncertainty). The BAT light curve showed a multi-peaked structure with a duration of $\gtrsim$ 200 s, although the burst was already in progress when the spacecraft slewed to the original position. The peak count rate was $\sim 11,000$ c s^{-1} $(15-350$ keV), at $\sim T+25$ s.

The XRT began observing the field at 02:19:41.0 UT (T+76.7 s). XRT found a bright, uncatalogued X-ray source located at RA, Dec = (88.7610, −15.2561) deg, which is {05h 55m 02.63s; −15d 15' 21.9"} (J2000) with $\sigma = 5.8$ arcsec(radius, 90% containment). This location is 64 arcsec from the BAT onboard position. The initial flux in the 0.1 s image was 2.01×10^{-8} erg cm^{-2} s^{-1} $(0.2-10$ keV).

UVOT took a finding chart exposure of 150 s with the White filter starting at $T+86$ s. No credible afterglow candidate has been found in the initial data products. The 2.7'×2.7' sub-image covers 100% of the XRT error circle. The typical 3σ U.L. has been about 19.6 mag. The 8'×8' region for the list of sources generated on-board covers 100% of the XRT error circle. The list of sources is typically complete to about 18 mag. No correction has been made for the expected extinction corresponding to $E(B-V)$ of 0.18.

The burst was also seen by *Fermi* GBM (T = 02:17:30.61 UT; von Kienlin et al. GCN Circ. 11006), *INTEGRAL* SPI/ACS (T = 02:18:24 UT[1]), *Konus-Wind* (T = 02:18:20.008 UT; Golenetskii et al. GCN Circ. 11021), and *Suzaku* WAM (T = 02:17:32.68 UT; Tsai et al. GCN Circ. 11037). The GBM light curve shows a multi-peaked structure with a duration ($T90$) of $\sim 162.9 \pm 0.9$ s $(50-300$ keV). The time-averaged spectrum from $T-8.192$ s to $T+191.491$ s is well fit by a power law function with an exponential high energy cutoff. The power law index is -0.76 ± 0.01 and the cutoff energy, parameterized as $E_{\rm peak}$, is 353.7 ± 6.7 keV (Castor C-STAT 3540 for 727 d.o.f.) . The event fluence $(8-1000$ keV) in this time interval is $(1.291 \pm 0.008) \times 10^{-4}$ erg cm^{-2}. The 1.024−s peak photon flux measured starting from $T+80.2$ s in the $8-1000$ keV band is 10.8 ± 0.2 ph cm^{-2} s^{-1}.

The *Konus-Wind* burst light curve shows a complex structure with a total duration of $\sim$ 200 s. There is a hint of a weaker emission lasting at least to $T+290$ s. The emission is seen up to several MeV. The fluence was $1.95(\pm 0.35) \times 10^{-4}$ erg cm^{-2}, and the 256−ms peak flux, measured from $T+27.392$ s, of $4.2(\pm 0.7) \times 10^{-6}$ erg cm^{-2} s^{-1} (both in the $0.020-10$ MeV energy range).

The *Suzaku* WAM light curve shows a multi-peaked structure starting at $T-5$ s, ending at $T+198$ s, with $T_{90} \simeq 162$ s. The fluence in $100-1000$ keV was $9.09(-1.55, +0.07) \times 10^{-5}$ ergs cm^{-2}. The 1−s peak flux measured from $T+80$s was $4.66(-0.78, +0.03)$ ph cm^{-2} s^{-1} in the same energy range.

[1] `http://www.mpe.mpg.de/gamma/instruments/integral/spi/acs/grb/trigger/2010-07-28T02-18-24/index.html`

NIR observations with GROND between $T + 7$ hr and $T + 8$ hr identified a faint point source within the enhanced XRT error circle (Olivares et al. GCN Circ. 11020). Mainly upper limits were derived, with one detection $H = 21.2 \pm 0.3$. The detection and upper limits imply very red colors of the afterglow, $J - H > 0.8$ and $r - H > 2.7$, suggestive of a highly extinguished optical/NIR afterglow.

2 BAT Observation and Analysis

Using the data set from $T - 130$ to $T + 963$ s, further analysis was performed (Ukwatta et al. GCN Circ. 11018). The BAT ground-calculated position is RA, Dec = (88.753, −15.259) deg which is {05h 55m 00.7s −15d 15' 33.0"} (J2000) with an uncertainty of 1.0 arcmin, (radius, sys+stat, 90% containment). The partial coding was 81%.

The BAT light curve is quite complex with a long series of peaks and flares extending from $\sim T-100$ s to $T + 750$ s. Detected emission began around $T - 100$ s, rising to a first peak at $T - 40$ s. The burst continued as a series of at least ten overlapping peaks with the strongest peak centered at $T + 30$ s. There was a strong set of BAT peaks centered at T+120 sec, corresponding with the second flare detected by the XRT (Evans & Cannizzo, GCN Circ 11014). This was followed by a series of weaker flares out to $T + 750$ s, at times which appear to correspond to flares detected by the XRT. The burst triggered just after the spacecraft settled following a slew to a pre-planned target, so it is possible that there was some very early emission (before $T - 120$ s) which was not detected. T90 ($15 - 350$ keV) is 198.5(±12.7)s (estimated error including systematics).

The time-averaged spectrum from $T - 84.3$ to $T + 334.0$ s is best fit by a simple power-law model. The power law index of the time-averaged spectrum is 1.18 ± 0.02. The fluence in the $15 - 150$ keV band is $3.8(\pm 0.0) \times 10^{-5}$ erg cm^{-2}. The 1−s peak photon flux measured from $T + 28.26$ s in the $15 - 150$ keV band is 5.1(±0.2) ph cm^{-2} s^{-1}. All the quoted errors are at the 90% confidence level.

3 XRT Observation and Analysis

Using 5085 s of XRT Photon Counting mode data and 8 UVOT images (Beardmore et al. GCN Circ. 11005), an astrometrically corrected X-ray position is found (using the XRT-UVOT alignment and matching UVOT field sources to the USNO-B1 catalogue): RA, Dec = (88.75839, −15.25531) which is {05h 55m 2.01s; −15d 15' 19.1"} (J2000) with $\sigma = 1.4$ arcsec (radius, 90% confidence).

Analysis of 10 ks of XRT data (Evans & Cannizzo GCN Circ. 11014), from $T + 66$ s to $T + 23.4$ ks was carried out. The data comprise 1.3 ks in Windowed Timing (WT) mode (the first 9 s were taken while *Swift* was slewing) with the remainder in Photon Counting (PC) mode. The enhanced XRT position for this burst was given by Beardmore et al. (GCN. Circ 11005).

The light curve can be modeled with a broken power-law decay, with a series of flares superimposed during the first ks. The underlying decay begins with a decay index of 1.6 ± 0.1, breaking at $T+410$ s to a decay index of $1.07(+0.03, -0.04)$. The decay then breaks again at $T + 11600$ s to a final decay of 1.82 ± 0.2. Nine discrete flares can clearly be identified, with peak times of $T + 88$, 111, 189, 252, 296, 383, 445, 516, 659 s (all in WT mode).

A spectrum formed from the WT mode data can be fitted with an absorbed power-law with a photon spectral index of 2.022 ± 0.022. The best-fitting absorption column is $3.69(+0.09, -0.08) \times 10^{21}$

cm^{-2}, in excess of the Galactic value of 1.0×10^{21} cm^{-2} (Kalberla et al. 2005). The PC mode spectrum has a photon index of 2.05 ± 0.09 and a best-fitting absorption column of $3.7(\pm 0.3) \times 10^{21}$ cm^{-2}. The counts to observed (unabsorbed) $0.3 - 10$ keV flux conversion factor deduced from this spectrum is 4.5×10^{-11} (7.6×10^{-11}) erg cm^{-2} c^{-1}.

4 UVOT Observation and Analysis

The *Swift*/UVOT began settled observations of the field of GRB 100728A at $T + 86$ s (Oates & Cannizzo, GCN 11016). A new source is not detected at the enhanced Swift XRT position (Evans et al. GCN 11005).

The preliminary 3σ upper limits for the finding chart exposures (FC) and summed images are:

Filter	T_start	T_stop	Exp(s)	Mag (3-sigma UL)
white (FC)	86	236	147	>20.54
white	578	7432	657	>21.16
u (FC)	299	548	246	>19.82
u	702	7021	490	>20.04
v	628	11695	1218	>20.06
b	554	7226	510	>20.37
uvw1	677	13337	1228	>20.62
uvm2	1255	12600	1337	>20.69
uvw2	604	7554	447	>20.19

The quoted upper limits have not been corrected for the expected Galactic extinction corresponding to a reddening along the line of sight of $E(B - V) = 0.18$ mag. All photometry is on the UVOT photometric system described in Poole et al. (2008, MNRAS, 383, 627).

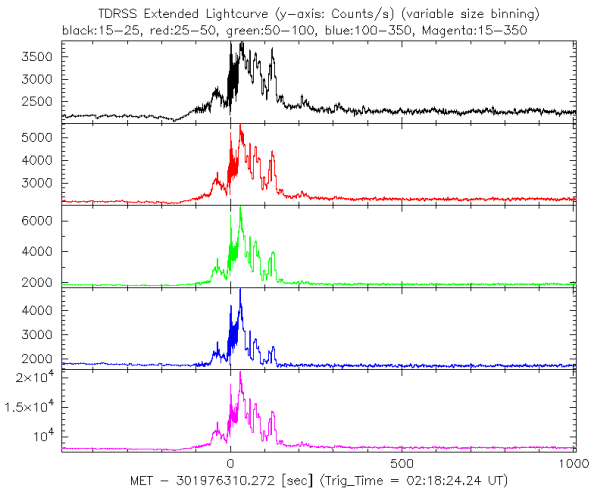

Figure 1: BAT Lightcurve. The light curve in the 4 individual plus total energy bands ($15-25$ keV, $25-50$, $50-100$, $100-350$, and $15-350$).

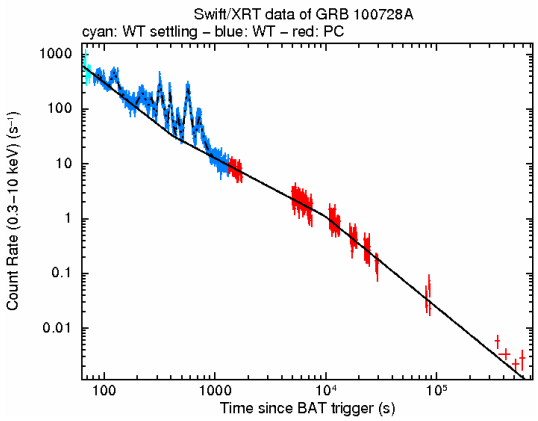

Figure 2: XRT Lightcurve. A broken powerlaw fit gives: $\alpha_1 = 1.57 \pm 0.09$, $t_{\rm break,\ 1} \simeq 420$ s, $\alpha_2 = 1.07 \pm 0.03$, $t_{\rm break,\ 2} \simeq 10$ ks, a $\alpha_3 = 1.65 \pm 0.07$.

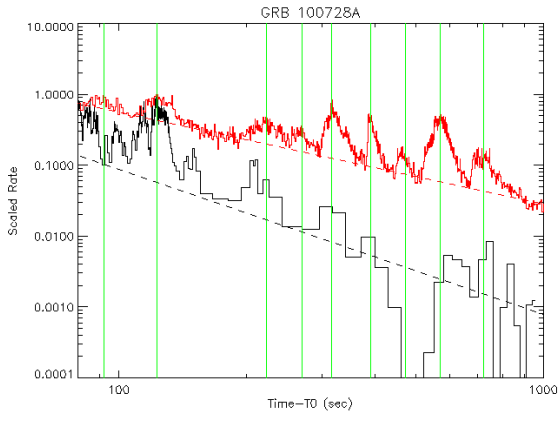

Figure 3: Correspondence between nine flares in XRT (red) and BAT (black).