Swift Observations of GRB 100316D


1 Introduction

At $T_0 = 12:44:50$ UT, on March 16, 2010, the BAT triggered on GRB 100316D (trigger #416135) (Stamatikos et al., GCN Circ. 10496). Swift slewed immediately allowing for XRT and UVOT follow-up observations at $T+137.7$ and $T+148$ sec, respectively, which resulted in the detection of an afterglow candidate in the former and upper limits in the latter. The best Swift localization, based upon 1967 sec of XRT Photon Counting mode data and 1 U-band UVOT image, is an astrometrically corrected X-ray position\(^1\) (using the XRT-UVOT alignment and matching UVOT field sources to the USNO-B1 catalogue): RA, Dec (J2000) = 107.62763° (7h 10m 30.63s), -56.25547° (-56d 15' 19.7''), with an uncertainty of 3.7 arcsec (radius, 90% confidence). A redshift of $z=0.059$ (Vergani et al., GCN Circ. 10512, 10513) and associated SN2010bh connection (Wiersema et al., GCN Circ. 10525, Chornock et al., GCN Circ. 10541, Bufano et al., GCN Circ. 10543 and Rau et al., GCN Circ. 10547) were confirmed by ground-based afterglow observations. Additional analysis may be found in Starling et al. 2010 (http://adsabs.harvard.edu/abs/2010arXiv1004.2919S).

2 BAT Observations and Analysis

Using the data set from T-239 to T+963 sec from the telemetry downlink, further analysis\(^2\) of BAT GRB 100316D was performed. The BAT ground-calculated position is RA, Dec (J2000) = 107.619° (7h 10m 28.6s), -56.277° (-56d 16' 37.6''), with an uncertainty of 2.8 arcmin, (radius, sys+stat, 90% containment). The partial coding was 85%.

The mask-weighted light curve (Figure 1) is very non-typical for a GRB and the spectrum is soft. The unusual characteristics of GRB 100316D lead to additional pre-burst analysis (Sakamoto et al., GCN Circ. 10524). Using the batsurvey script on BAT hard X-ray survey (Detector Plane Histogram) data, pre- and post-trigger period fluxes were extracted at the location of the GRB. While Swift was pointing at GRB 100316C (Stamatikos et al., GCN Circ. 10491) from T-2650 sec to T-80 sec, the location of GRB 100316D was in the BAT’s FOV. At 12:43 UT, Swift slewed to a pre-planned target (1E 1048.1-5937), and subsequently triggered on GRB 100316D. After re-pointing to the location of GRB 100316D, Swift slewed away at T+750 sec due to an observational constraint. However, GRB 100316D came back into the FOV of BAT at T+5050 sec due to a pre-planned observation of 1E 1048.1-5937.

The light curves\(^3\) produced by overlaying the BAT event-by-event and survey data are given in Figures 2 and 3. There is a probable early low-level emission starting from T-1500 sec. The emission then rises at T-500 sec, peaks at T-100 sec, and decays with an exponential decay constant of $\sim 750$ sec. The emission continues through the slew at T+750 sec, but is no longer detected by BAT after T+5050 sec.

The time-averaged spectrum from T-159.0 to T+794.8 sec is best fit by a simple power-law model. The power law index of the time-averaged spectrum is $\beta = 2.39 \pm 0.16$. The fluence in the 15-150 keV


\(^2\)The results of the batgrbpass product analysis are available at http://gcn.gsfc.nasa.gov/notices/416135/BA/.

\(^3\)The 14-195 keV band light curve from T-6000 sec to T+6000 sec (Figure 2) and (zoomed-in) from T-2000 sec to T+1000 sec (Figure 3) are available online at http://gcn.gsfc.nasa.gov/other/GRB100316D_bat_lc.gif and http://gcn.gsfc.nasa.gov/other/GRB100316D_bat_lc_zoomin.gif, respectively.
band is \((3.4 \pm 0.3) \times 10^{-6}\) erg/cm\(^2\). The 1-sec peak photon flux measured from T-104.04 sec in the 15-150 keV band is \(0.4 \pm 0.2\) ph/cm\(^2\)/sec. All the quoted errors are at the 90% confidence level.

As pointed out in Sakamoto et al., GCN Circ. 10511, the BAT light curve profile of GRB 100316D is very similar both in the temporal and spectral properties to GRB 060218-SN2006aj (Camapana, et al.; Nature, v224, p 1008). The BAT light curve of GRB 060218 shows a rise at T-300 sec, a peak at T+450 sec, and an exponential decay constant of \(\sim 500\) sec, with a duration of \(\sim 2000\) sec. GRB 100316D was detected in Swift-BAT from \(T - 500\) sec to at least \(T + 800\) sec, hence the lower limit on the duration of GRB 100316D is \(\sim 1300\) sec. The fluence in the 15-150 keV band measured with the available 955 sec of event data corresponds to an isotropic equivalent energy \((E_{\text{iso}})\) of \(3.1 \times 10^{49}\) ergs in the 15.88 keV - 158.85 keV band at the GRB rest frame assuming a redshift \(z=0.059\) of a potential source and a galaxy inside the XRT error circle (Vergani et al., GCN Circ. 10512, 10513). This unusually long duration in concert with a soft spectrum and a low \(E_{\text{iso}}\) (\(E_{\text{iso}}\) of GRB 060218 was \(6.2 \times 10^{49}\) ergs) strengthens the similarity between GRBs 100316D and 060218.

3 XRT Observations and Analysis

The XRT began observing the field at 12:47:08.1 UT, 137.7 sec after the BAT trigger and found a bright, uncatalogued X-ray source. Data taking began with 10 sec of Windowed Timing (WT) settling mode data, followed by 594 sec of WT pointed data, and continued with 49.8 ksec of Photon Counting (PC) mode data taken between \(T + 3 \times 10^4\) and \(T + 5 \times 10^5\) sec. The UVOT-enhanced XRT position is reported in Starling et al., GCN Circ. 10519.

The XRT light curve (Figure 4) initially decays very slowly and can be modeled with a power law of decay index \(\alpha_1 = 0.13 \pm 0.03\). The data after \(1 \times 10^4\) sec, all in PC mode, can be modeled with a power law of decay index \(\alpha_2 = 1.35 \pm 0.30\). The final upper limit contains 6 ksec of data.

We fit the time-averaged WT spectrum with an absorbed power law model, finding a photon spectral index of \(\Gamma = 1.42 \pm 0.04\). The best-fitting absorption column is \((5.9 \pm 0.3) \times 10^{21}\) cm\(^{-2}\), in excess of the Galactic value of \(7.0 \times 10^{20}\) cm\(^{-2}\) (Kalberla et al. 2005). The counts to observed (unabsorbed) 0.3–10 keV flux conversion factor deduced from this spectrum is \(6.6 \times 10^{-11}\) \((8.7 \times 10^{-11})\) erg/cm\(^2\)/count.

We also fit the time-averaged PC spectrum with an absorbed power law model, fixing the intrinsic absorption using the value from the WT fit, resulting in a power law photon index of \(\Gamma = 3.5 \pm 1.0\). The counts to observed (unabsorbed) 0.3-10 keV flux conversion deduced from this spectrum is \(2.9^{-11} (1.9 \times 10^{-10})\) erg/cm\(^2\)/count. In Figure 4 count rates have been converted to flux making use of both the WT and the PC conversion factors.

Motivated by the high count rate (around 30 counts/sec, but far from the pile up limit) and by the constant spectral shape an estimate of the GRB redshift was made from the X-ray data (Campana et al., GCN Circ. 10517), which constrained\(^4\) the value to lie within the 90% confidence level \((\Delta \chi^2 = 4.61)\) of 0.014 < \(z\) < 0.28, thus consistent with observations (Vergani et al., GCN Circ. 10512, 10513).

4 UVOT Observations and Analysis

The Swift/UVOT began settled observations of the field of GRB 100316D 148 sec after the BAT trigger. No source was detect within the original Swift XRT error circle (Stamatikos et al., GCN Circ. 10496). However, coincident with the refined Swift XRT error circle (Starling et al., GCN Circ. 10519), the DSS galaxy, which hosts the Objects A and B reported by Vergani et al., GCN Circ. 10512,10513, was detected but was unable to be resolved. Our photometry, performed on 3 ksec of data in the 7 UVOT

\(^4\)The contour plot is available at http://www.brera.inaf.it/utenti/campana/100316d.gif.
filters, shows no change larger than 1σ in the flux of the DSS galaxy (Oates et al., GCN Circ. 10520). The 3σ upper limits for the finding chart exposures (FC) and summed images determined at the XRT position are given in Starling et al. 2010 (http://adsabs.harvard.edu/abs/2010arXiv1004.2919S).

**Figure 1:** The BAT light curve for GRB 100316D. The mask-weighted light curve in the 4 individual plus total energy bands. The time of each bin is in the middle of the bin. The units are counts/sec/illuminated-detector and $T_0$ is 12:44:50 UT.
Figure 2: The BAT mask-weighted light curve for GRB 100316D using survey (black) and event (red) data in the 14-195 keV energy band. Significant pre-burst activity begins at T-500 sec. The gap from $T + 750 \leq t \leq T + 5050$ sec is due to a slew accommodating Swift’s observational constraints.

Hence, the duration of GRB 100316D is at least $\sim 1300$ sec, which is comparable to GRB 060218.

Figure 4: XRT light curve of GRB 100316D, in the 0.3 – 10 keV energy band, for Windowed Timing (WT) settling (cyan), Windowed Timing (blue) and Photon Counting (PC, pink) modes. The counts to observed (0.3-10 keV) flux conversion factor deduced from this time averaged spectrum are $6.6 \times 10^{-11}$ and $2.9 \times 10^{-11}$ erg/cm$^2$/count, for WT and PC modes, respectively. Times are with respect to BAT trigger time ($T_0 = 12:44:50$ UT). The final upper limit contains 6 ksec of data.