Swift Observations of GRB 100316D

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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 ∼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 2.39 ± 0.16. The fluence in the 15-150 keV

[1]The latest position can be viewed at `http://www.swift.ac.uk/xrt_positions`. Position enhancement is described by Goad et al. (2007, A&A, 476, 1401) and Evans et al. (2009, MNRAS, 397, 1177).

[2]The results of the batgrbproduct analysis are available at `http://gcn.gsfc.nasa.gov/notices_s/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 ± 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 ~ 500 sec, with a duration of ~ 2000 sec. GRB 100316D was detected in Swift-BAT from $\sim T-500$ sec to at least $\sim T+800$ sec, hence the lower limit on the duration of GRB 100316D is ~ 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_{iso}) of 3.1×10^{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 Eiso (Eiso of GRB 060218 was 6.2×10^{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 1×10^4 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 ± 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 7.0×10^{20} cm^{-2} (Kalberla et al. 2005). The counts to observed (unabsorbed) $0.3-10$ keV flux conversion factor deduced from this spectrum is 6.6×10^{-11} (8.7×10^{-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 ± 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`).

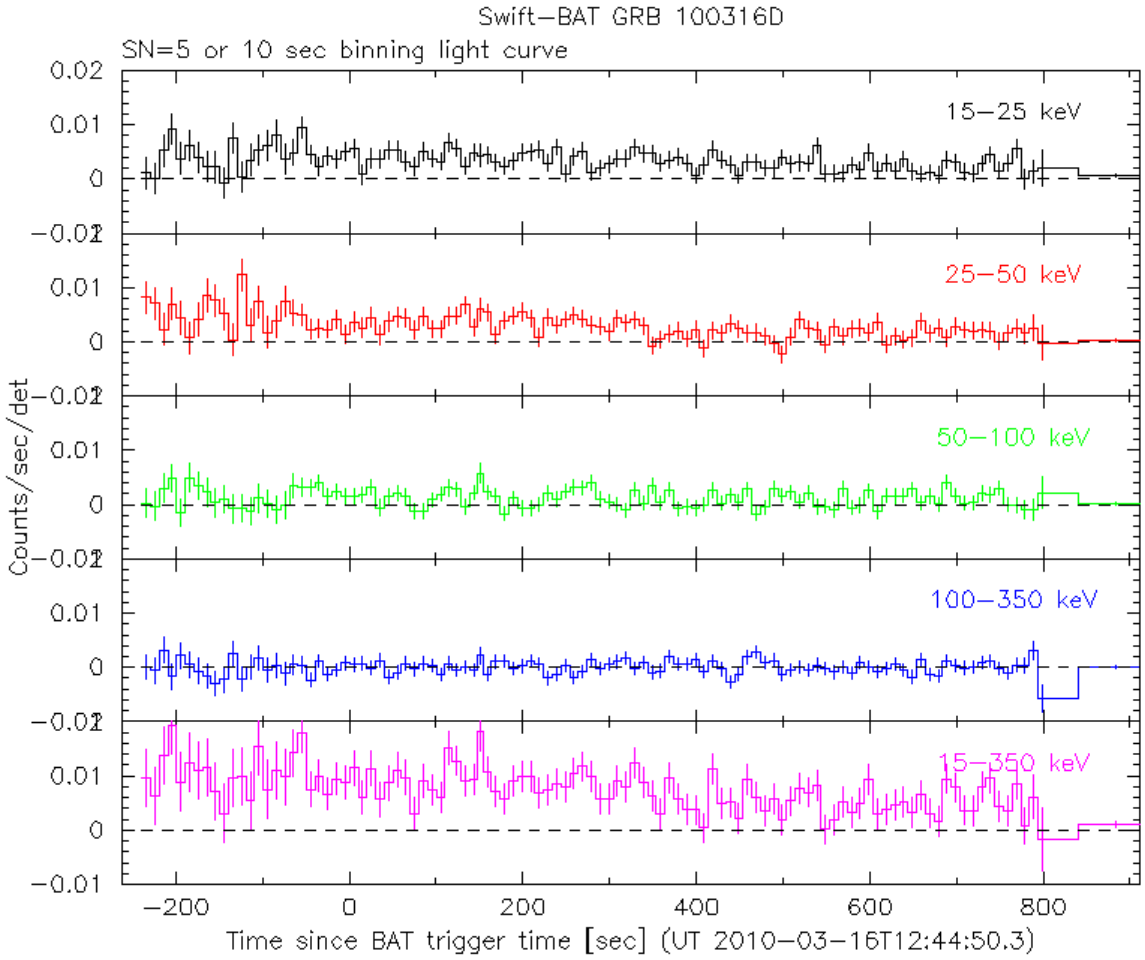

Figure 1: The BAT light curve for GRB 100316D. The mask-weighted light curve in the 4 individual plus total energy bands. The time of each bin is in the middle of the bin. The units are counts/sec/illuminated-detector and T_0 is 12:44:50 UT.

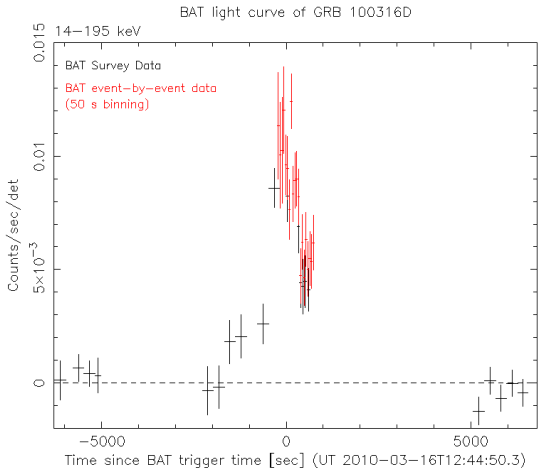

Figure 2: The BAT mask-weighted light curve for GRB 100316D using survey (black) and event (red) data in the 14-195 keV energy band. Significant pre-burst activity begins at T-500 sec. The gap from $T + 750 \leq t \leq T + 5050$ sec is due to a slew accommodating Swift's observational constraints.

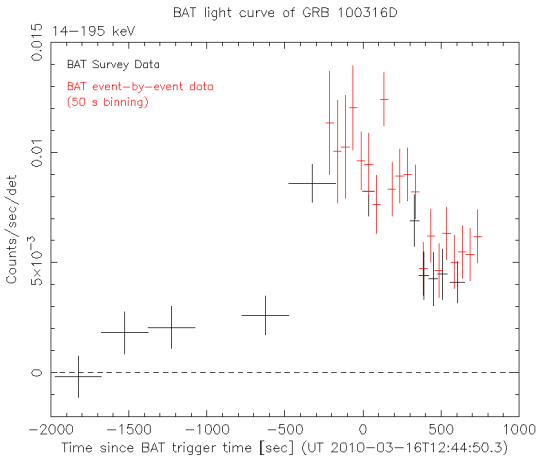

Figure 3: The BAT mask-weighted light curve for GRB 100316D using survey (black) and event (red) data in the 14-195 keV energy band. Emission continues beyond the end of data at ∼T+800 sec. Hence, the duration of GRB 100316D is at least ∼ 1300 sec, which is comparable to GRB 060218.

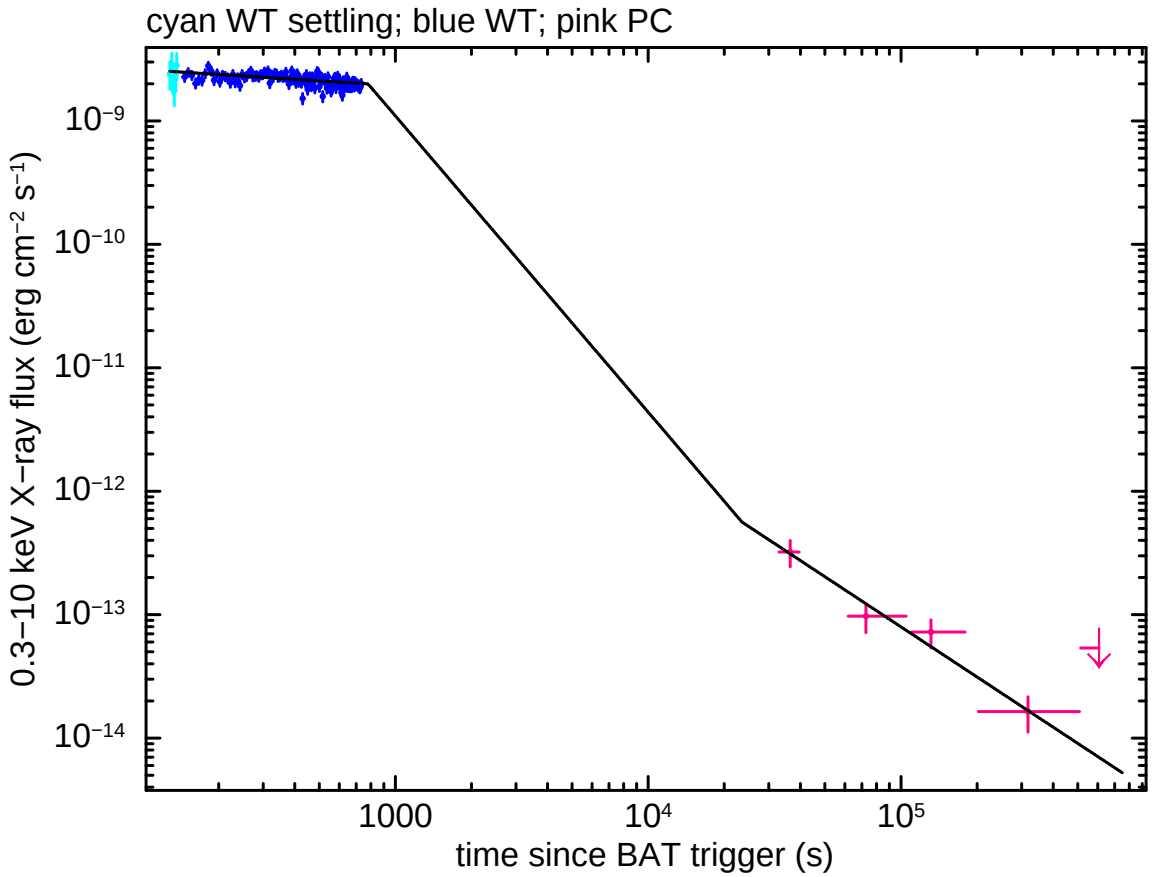

Figure 4: XRT light curve of GRB 100316D, in the $0.3 - 10$ keV energy band, for Windowed Timing (WT) settling (cyan), Windowed Timing (blue) and Photon Counting (PC, pink) modes. The counts to observed (0.3-10 keV) flux conversion factor deduced from this time averaged spectrum are 6.6×10^{-11} and 2.9×10^{-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.