Swift Observations of GRB 070110

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0 Revisions

This version includes updated XRT and UVOT light curves and updates to the fits to the decay curves in the XRT and the V, B and U bands of UVOT.

Version 26.2 includes updated XRT and UVOT light curves showing further unusual behavior in the X-rays and continued detection in the V, B and U filters. The XRT and UVOT sections have been updated to include this new information.

1 Introduction

BAT triggered on GRB 070110 at 07:22:41.6 UT (Trigger 255445) (Krimm, *et al.*, *GCN Circ.* 6005). This was a 3.072 sec rate trigger on a long length burst with $T_{90} = 85 \pm 5$ sec. Swift slewed to this burst immediately and XRT began follow-up observations at T+93 sec, and UVOT at T+104 sec. Our best position is the UVOT location RA (J2000) = 0.9133° = (00h 03m 39.20s), Dec (J2000) = −52.9740° = (-52°58′26″.3) with an estimated uncertainty of 1 arcsec. Observations with the ESO VLT (Jaunsen *et al.*, *GCN Circ.* 6010) starting on 2007 Jan 11.04 UT (17.6 hr after the GRB) show several absorption lines leading to an inferred redshift of $z = 2.352 \pm 0.001$.

2 BAT Observation and Analysis

Using the data set from T-239 to T+963 sec, the BAT ground-calculated position is RA (J2000) = 0.934° = (00h 03m 44.2s), Dec (J2000) = −52.978° = (-52°58′39″.8) with an uncertainty of 1.1 arcmin, (radius, sys+stat, 90% containment). The burst was 20.91° from the boresight with a partial coding of 97%.

The mask-tagged light curve (Figure 1) shows a very broad peak beginning at T-3 sec and peaking at T+0 sec. Then there is a slow exponential decline in the light curve out to T+135 s, with two or three additional peaks superimposed.

The time-averaged spectrum from T-2.7 to T+100.6 is best fit by a simple power-law model. The power law index of the time-averaged spectrum is 1.57 ± 0.12. The fluence in the 15-150 keV band is $1.6 \pm 0.1 \times 10^{-6}$ erg/cm^2. The 1-sec peak photon flux measured from T-0.16 sec in the 15-150 keV band is 0.6 ± 0.1 ph/cm^2/sec. All the quoted errors are at the 90% confidence level.

3 XRT Observations and Analysis

We have analyzed the first orbits of XRT data of GRB07011, consisting of 171 s of exposure in Windowed Timing (WT) mode and 16.9 ks of exposure in Photon Counting (PC) mode. The XRT location is RA (J2000) = 0.9143° = (00h 03m 39.43s), Dec (J2000) = −52.9741° = (-52°58′26″.7) with an uncertainty of 3.6 arcsec (radius, sys + stat, 90% confidence, including boresight uncertainties). This is 45.3 arcsec from the refined BAT position, 3.0 arcsec from the preliminary XRT position and 1.9 arcsec from the UVOT position.

The 0.3-10 keV light curve (Figure) shows an initial steep decay with slope -2.53 ± 0.07 followed by a flat decay phase with slope -0.05 ± 0.04 that starts 580 ± 43 s after the trigger. A small flare is detected starting at about T+380 s. After a further break at 20.3 ± 0.8 ks from the trigger the light curve steepened abruptly, with a slope -7.9 ± 0.9. Then at T+35 ks the source began to rise, reaching a rate of 3.2 $\times 10^{-2}$ counts/s. Then between T+45 ksec and T+75 ksec, the light curve again turned over, dropping to 6×10^{-3} counts/sec at 100 ksec, before flattening again. On average, the late time X-ray light curve is decaying very slowly and in fact the three latest data points in Figure 2 suggest a slight upward trend. Fitting the data after the steep drop in flux (from T+35 ks to T+800 ks), but excluding the big rise at around T+6 ksec, the best fit decay index is -0.6 +/- 0.1.

Although flares have been observed in other bursts at times > 10 ksec, such behavior (a steep drop followed by a slow rise) has not before been observed in a Swift burst (see for example P. O'Brien et al (2006), ApJ 647, 1213). There is no corresponding increase in the hardness ratio at the time of the initial break (Figure 3) which argues against a change in absorption causing the feature in the light curve.

The WT and PC spectra are well fit by an absorbed power law with photon index 2.00 ± 0.08. The absorption is at the level of 3×10^{20} cm^{-2}, consistent with the Galactic absorpion along the line of sight (1.8×10^{20} cm^{-2}). The average unabsorbed fluxes of the WT and PC spectra are 7.0×10^{-10} and 1.7×10^{-11} erg cm^{-2} s^{-1}, respectively.

All quoted errors are the 90% confidence level.

4 UVOT Observation and Analysis

UVOT took a finding chart exposure of 100 seconds with the White (160-650 nm) filter starting 104 seconds after the BAT trigger. The afterglow location: RA (J2000) = 0.9133° = (00h 03m 39.20s), Dec (J2000) = −52.9740° = (-52°58′26″.3) (with an estimated uncertainty of 1 arcsec) is 4.6 arcsec from the XRT position. The $2.7' \times 2.7'$ sub-image covers 100% of the XRT error circle. No correction has been made for the expected extinction corresponding to E(B-V) of 0.014.

The UVOT light curve is quite extraordinary. The early photometry results are given for the 7 UVOT filters in Table 1 and the five channel light curve is shown in Figure 4. The afterglow was originally detected at V=20 at T+104 sec and continued to be detectable to T+200 ks in the V and B filters with a common power law decay index of -0.50 ± 0.05 in both filters. At T+203 ksec, the afterglow is seen at V=21.6. U band observations show continued detection to T+ ∼500 ks, at U=23.5. The U band decay slope is -0.70 ± 0.05. Converting to magnitudes using the zero points for the filters yields the following fits to the UVOT light curves:

$V_{mag} = 21.2 + 1.25 * \log(t)$

$B_{mag} = 21.9 + 1.25 * \log(t)$

$U_{mag} = 21.8 + 1.75 * \log(t)$.

where the time, t, is measured in days from the trigger.

Thus the optical light curves do not show any of the extreme variability seen in the X-rays. It is very rare that a burst which was first detected at V=20 is still detectable at T > 200 ksec. The afterglow was not detected in the UVW1 filter, with a 3σ limiting magnitude of 22.26 for a 4071-sec exposure beginning at T+75 ks. This non-detection is consistent with the redshift z=2.352 reported for the burst.

Filter	Tstart	Tstop	Exp	Mag	Error	Significance
White	104	5882	590	20.0	0.14	9.1
V	210	23205	2065	20.3	0.20	5.7
B	4046	29593	1568	20.9	0.17	7.1
U	5274	35376	3166	20.4	0.10	11.6
UVW1	5069	34757	3758	20.8		(3σ UL)
UVM2	4864	33850	2739	21.1		(3σ UL)
UVW2	4456	39315	1853	20.9		(3σ UL)

Table 1: Magnitudes from UVOT observations

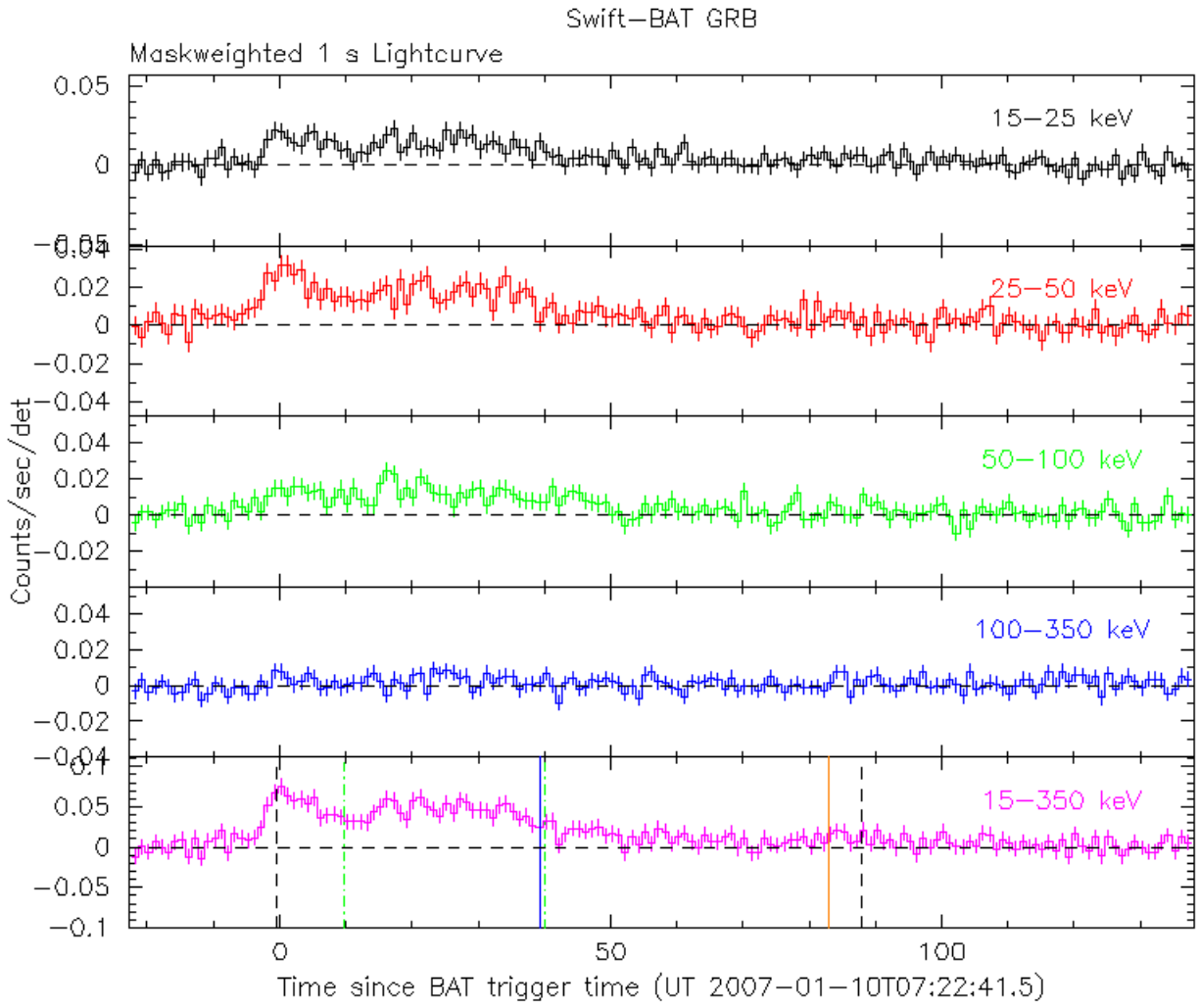

Figure 1: BAT Light curve for GRB 070110. The mask-weighted light curve in the 4 individual plus total energy bands. The green and black dotted lines bracket the T_{50} and T_{90} intervals. The blue and yellow solid lines are the start and end, respectively, of the slew to the burst. The units are counts/sec/illuminated-detector and T_0 is 07:22:41.5 UT.

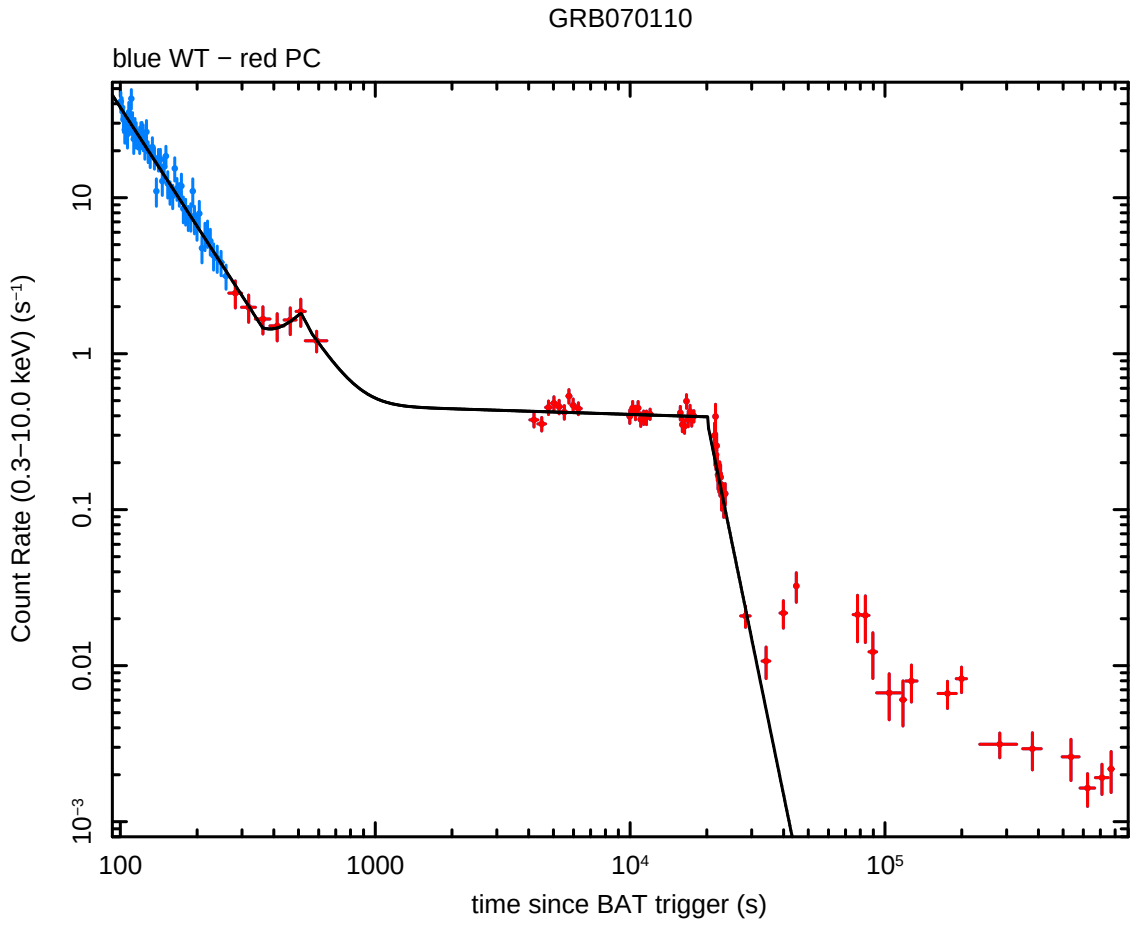

Figure 2: XRT Lightcurve. Counts/sec in the 0.3-10.0 keV band: Window Timing mode (blue), Photon Counting mode (red). The approximate conversion is 1 count/sec = $\sim 4.7 \times 10^{-11}$ $ergs/cm^2/sec$.

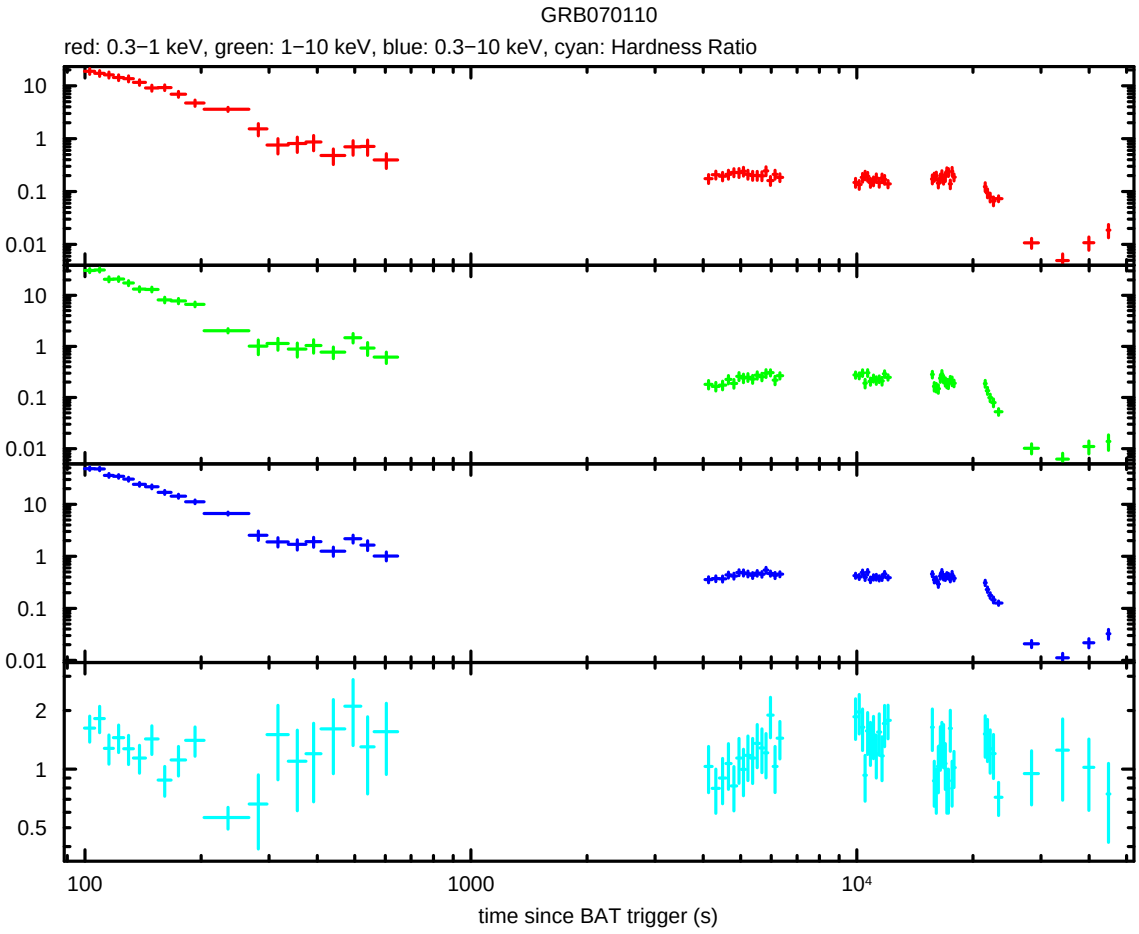

Figure 3: XRT Hardness Ratio and Light curve in three energy bands. The hardness ratio is the counts ratio: C(1-10 keV)/C(0.3-1 keV). Note that the time scale does not continue as far as that in Figure 2.

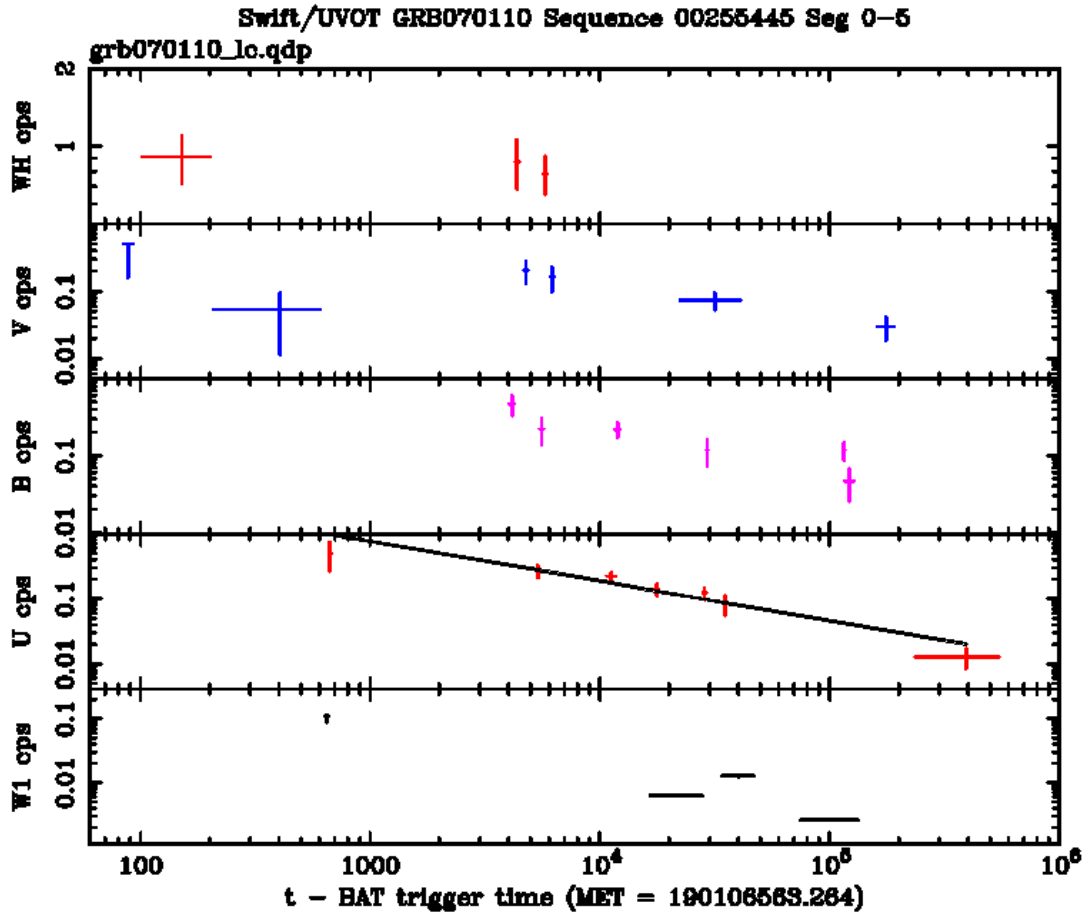

Figure 4: UVOT light curve in five filters. Here "WH" is a white filter and "W1" is UVW1. The straight line on U band light curve is a fit to the data shown