Swift Observations of GRB 080330

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1 Introduction

BAT triggered on GRB 080330 at 03:41:16 UT (Trigger 308041) (Mao *et al.*, *GCN Circ.* 7537). This was a 1.024-s rate-trigger on a long burst. XRT observations began at $T + 77$ s and discovered a bright and fading uncatalogued X-ray source. UVOT began observing at $T + 63$ s and found the optical counterpart of 18.8 ± 0.5 mag. A number of robotic ground based telescopes promptly detected it: e.g., TAROT (Klotz *et al.*, *GCN Circ.* 7536); ROTSE–III (Schaefer & Guver, *GCN Circ.* 7538); Liverpool Telescope (Gomboc *et al.*, *GCN Circ.* 7539); GROND (Clemens *et al.*, *GCN Circ.* 7545). Our best position was obtained from the UVOT field match to the USNO-B1 catalogue: RA(J2000)= 169.26881 deg ($11^h17^m04.515^s$), Dec(J2000)= +30.62319 deg ($+30^d37'23.47''$), with an estimated uncertainty of 0.3 arcsec (radius, 1σ).

Shortly after arriving on-target, the spacecraft began slowly drifting because the star tracker did not lock properly on the star field (Burrows, *GCN Circ.* 7541) and this led to a prompt X-ray position (Mao *et al.*, *GCN Circ.* 7537) inconsistent with the optical afterglow. The correct X-ray position was finally derived and distributed (Mao & Guidorzi, *GCN Circ.* 7583).

Spectroscopic observations performed with NOT by Malesani *et al.* (*GCN Circ.* 7544) provided a measure of the redshift, $z = 1.51$, later confirmed by Cucchiara & Fox (*GCN Circ.* 7547) with the Hobby-Eberly Telescope.

2 BAT Observation and Analysis

Using the data set from $T - 240$ to $T + 963$ s, the BAT ground-calculated position is RA(J2000) = 169.278 deg ($11^h17^m06.7^s$), Dec(J2000)= +30.607 deg ($+30^d36'24.1''$) with an uncertainty of 1.8 arcmin (radius, sys+stat, 90% containment). The partial coding was 53%.

The mask-weighted light curve (Fig. 1) shows an initial set of 3 overlapping peaks (the brightest first) starting at $\sim T + 0$, and the third ending at $\sim T + 15$ s, then it returns to baseline. A fourth peak starts at roughly $T + 50$ s and ends at roughly $T + 70$ s. T_{90} (15–350 keV) is 61 ± 9 s (estimated error including systematics).

The time-averaged spectrum from $T - 0.5$ to $T + 71.9$ s is best fit by a simple power-law model. The power law index of the time-averaged spectrum is 2.53 ± 0.45. The fluence in the 15–150 keV band is $(3.4 \pm 0.8) \times 10^{-7}$ erg cm^{-2}. The 1–s peak photon flux measured from $T + 0.44$ s in the 15–150 keV band is 0.9 ± 0.2 ph cm^{-2} s^{-1}. All the quoted errors are at the 90% confidence level.

The results of the batgrbproduct analysis are available at
`http://gcn.gsfc.nasa.gov/notices_s/308041/BA/`.

We note that the fluence ratio in a simple power-law fit between the 25–50 keV band and the 50–100 keV band is 1.44. This fluence ratio is larger than 1.32 which can be achieved in the Band function of $\alpha = -1.0$, $\beta = -2.5$, and $E_{\rm p} = 30$ keV. Thus, preliminary analysis shows that $E_{\rm p}$ of the burst is very likely around or below 30 keV. Therefore the burst can be classified as an X–ray flash (e.g. Sakamoto et al. ApJ in press, arXiv:0801.4319).

3 XRT Observations and Analysis

The XRT began observing GRB 080330 in Windowed Timing mode at $T + 77$ s and switched to Photon Counting mode at $T + 134$ s. Using the first orbit PC data we extracted the following refined position from 134 to 311 s, when the star tracker drifting seems to have little impact: RA(J2000)= 169.26950 deg ($11^{\rm h}17^{\rm m}04.68^{\rm s}$), Dec(J2000)= +30.62355 deg ($+30^{\rm d}37'24.78''$), with an uncertainty of 4.0 arcsec (radius, 90% confidence). This is consistent with the optical ground-based position (2.7 arcsec away from the PAIRITEL position reported by Bloom & Starr, *GCN Circ.* 7542; Mao & Guidorzi, *GCN Circ.* 7583).

The light curve (Fig. 2) can be modelled with a broken power law with the following best-fitting parameters: $\alpha_{x1} = 4.8 \pm 0.4$, $t_{\rm b} = 163^{+9}_{-10}$ s, $\alpha_{x2} = 0.26 \pm 0.10$ (χ^2/dof = 66/70). The late 3-σ upper limit requires a further break. Figure 2 shows the case of a second break occurring right after the end of the first orbit and compatible with the upper limit. This turns into a lower limit on the final index, $\alpha_{x3} > 1.3$.

The WT mode spectrum spanning from $T + 77$ to $T + 134$ s can be fit by a simple power-law model, with a photon index of $2.06^{+0.10}_{-0.09}$ and a column density fixed to the Galactic value in this direction of 1.23×10^{20} cm^{-2}. By leaving the rest-frame column density free to vary, we derive an upper limit of 1.4×10^{21} cm^{-2}. The spectrum formed from the PC data can be modelled with a power law of photon index 1.9 ± 0.1 and a rest-frame absorbing column of $(2.4 \pm 1.4) \times 10^{21}$ cm^{-2} (in excess with respect to the Galactic one). The corresponding observed (unabsorbed) 0.3–10 keV flux is 2.4×10^{-11} (2.7×10^{-11}) erg cm^{-2} s^{-1}. All the quoted errors are given at 90% confidence.

Detailed light curves in both count rate and flux units are available in both graphical and ASCII formats at `http://www.swift.ac.uk/xrt_curves/`.

4 UVOT Observation and Analysis

The UVOT began observing GRB 080330 with a settling exposure in the UVOT v–filter at $T + 63$ s, and a finding chart exposure in the white filter starting at $T + 83$ s. During the subsequent exposures the spacecraft drifted. In the 400-s V image, a clear trail is visible for all the stars in the field. Using an aperture that encompassed the whole track, initial estimates of the brightness of the GRB were reported (Kuin & Mao, *GCN Circ.* 7552).

The position was determined from the UVOT field match to the USNO–B1 catalogue is the following: RA(J2000)= 169.26881 deg ($11^{\rm h}17^{\rm m}04.515^{\rm s}$), Dec(J2000)= +30.62319 deg ($+30^{\rm d}37'23.47''$), with an estimated uncertainty of 0.3 arcsec (radius, 1σ). This is consistent with the position provided by ground telescopes (e.g., PAIRITEL, Bloom & Starr, *GCN Circ.* 7542).

The drift rate of the spacecraft, as determined using the UVOT event data, varies from less than 1 to about 7 arcsec per minute. The initial event data were split up in periods long enough, that the drift was small enough within the time bins to do aperture photometry. In some time bins the track is just bound within the aperture. Using larger and smaller apertures for a $12^{\rm th}$ and a $15^{\rm th}$ magnitude star in the field shows that the effect of movement of the source within the aperture is at most 0.04 mag.

Kuin & Mao (*GCN Circ.* 7552) had included a large error appropriate to the less sophisticated method of measurement employed. The data reported in Table 1 are much more accurate and have been calibrated also using late observations of nearby stars, where necessary. Observations were taken with apertures of 3, 5, 6, or 6.5 arcsec, in order to optimise the observation, and aperture corrected using a nearby $15^{\rm th}$-mag star as reference (see Poole et al. 2008, for the methodology used).

Figure 3 shows the multi-filter light curves.

The values quoted above are not corrected for the expected Galactic extinction corresponding to a

Filter	$T_{\rm mid}$ (s)	Exposure (s)	Mag
v	68	10	> 17.38
white	103.2	40	20.06 ± 0.397
white	128.2	10	18.55 ± 0.20
white	138.2	10	18.36 ± 0.44
white	148.2	10	18.28 ± 0.39
white	158.2	10	18.39 ± 0.43
white	168.2	10	18.22 ± 0.38
white	178.2	10	18.05 ± 0.32
v	214	50	17.74 ± 0.19
v	264	50	17.72 ± 0.22
v	314	50	17.75 ± 0.26
v	364	50	17.52 ± 0.23
v	414	50	17.37 ± 0.17
v	464	50	17.79 ± 0.24
v	514	50	17.44 ± 0.18
v	557	36	17.37 ± 0.20
uvw1	629	20	> 18.02
u	654	20	17.14 ± 0.16
b	673	10	17.81 ± 0.23
white	688	10	17.76 ± 0.14
v	733	20	17.74 ± 0.34
uvw1	782	20	> 18.04
uvw2	788	172	> 18.77
u	807	20	16.66 ± 0.17
b	827	10	17.66 ± 0.22
white	838	10	17.55 ± 0.12
white	848	10.4	17.91 ± 0.15
uvm2	992	796	> 18.55
v	1010	50	17.37 ± 0.17
v	1060	50	17.37 ± 0.17
v	1110	50	17.41 ± 0.17
v	1160	50	17.72 ± 0.21
v	1210	50	17.36 ± 0.21
v	1260	50	17.75 ± 0.26
v	1310	50	18.11 ± 0.29
v	1360	51	17.77 ± 0.22
uvw1	1426	10	17.67 ± 0.29
b	1475	20	18.14 ± 0.22
v	72100	5887	> 20.10
b	307644	47917	> 21.49
v	307940	47715	> 20.53
u	307583	47956	> 21.15
uvw1	307483	48074	> 21.58
white	391039	40970	> 23.32

Table 1: Magnitudes from UVOT observations. Upper limits are 3 σ.

reddening of $E_{B-V} = 0.02$ mag in the direction of the burst (Schlegel et al. 1998).

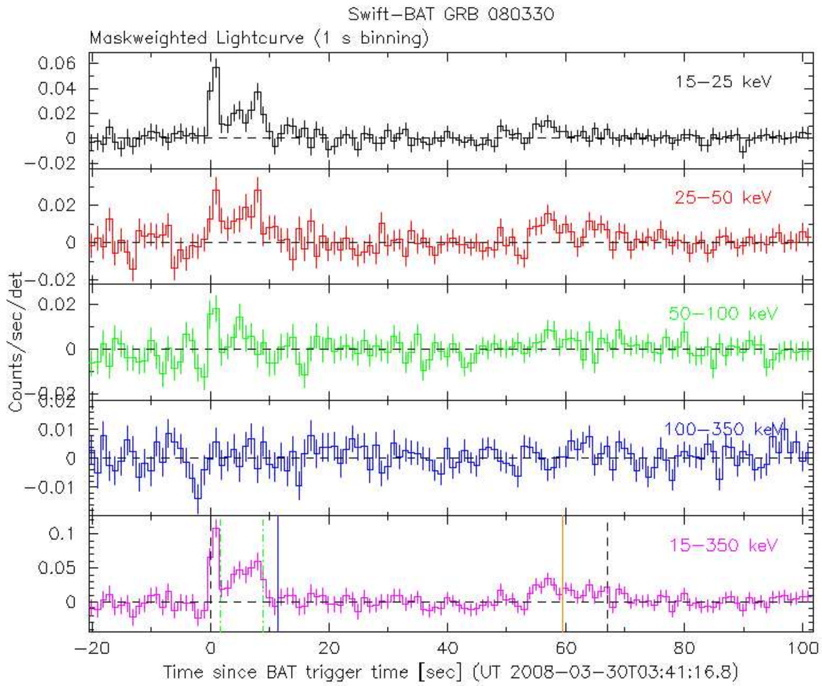

Figure 1: BAT Light curve. The mask-weighted light curve in the 4 individual plus total energy bands. The units are counts/s/illuminated-detector (note illum-det = 0.16 cm^2) and T_0 is 03:41:16 UT.

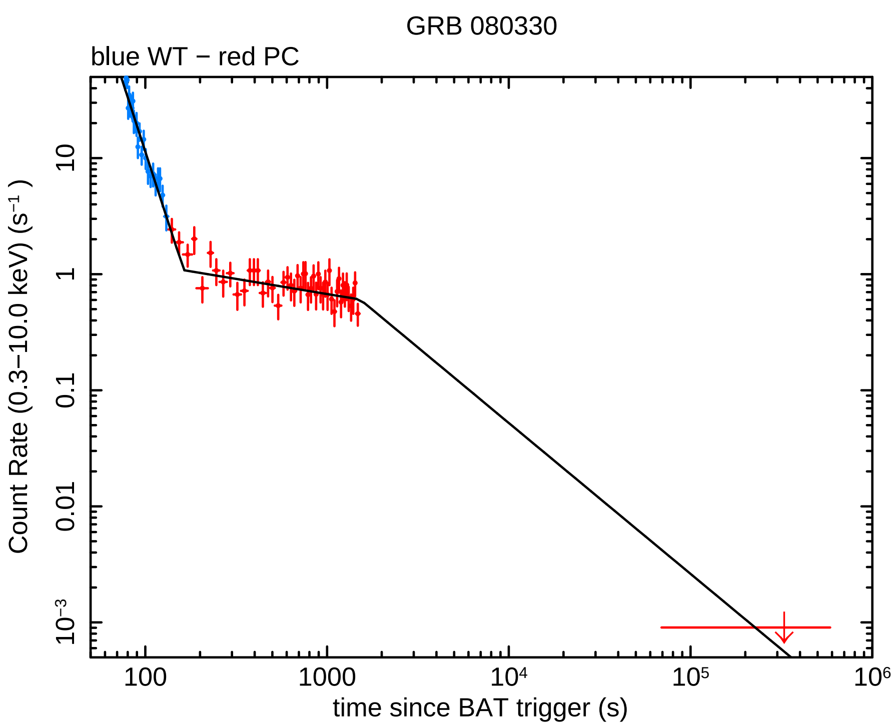

Figure 2: XRT Lightcurve. Flux in the 0.3-10 keV band: Windowed Timing (blue) and Photon Counting (red) mode data. The upper limit is at 3 σ. The approximate conversion is 1 count/s $\sim 4.4 \times 10^{-11}$ erg cm^{-2} s^{-1}.

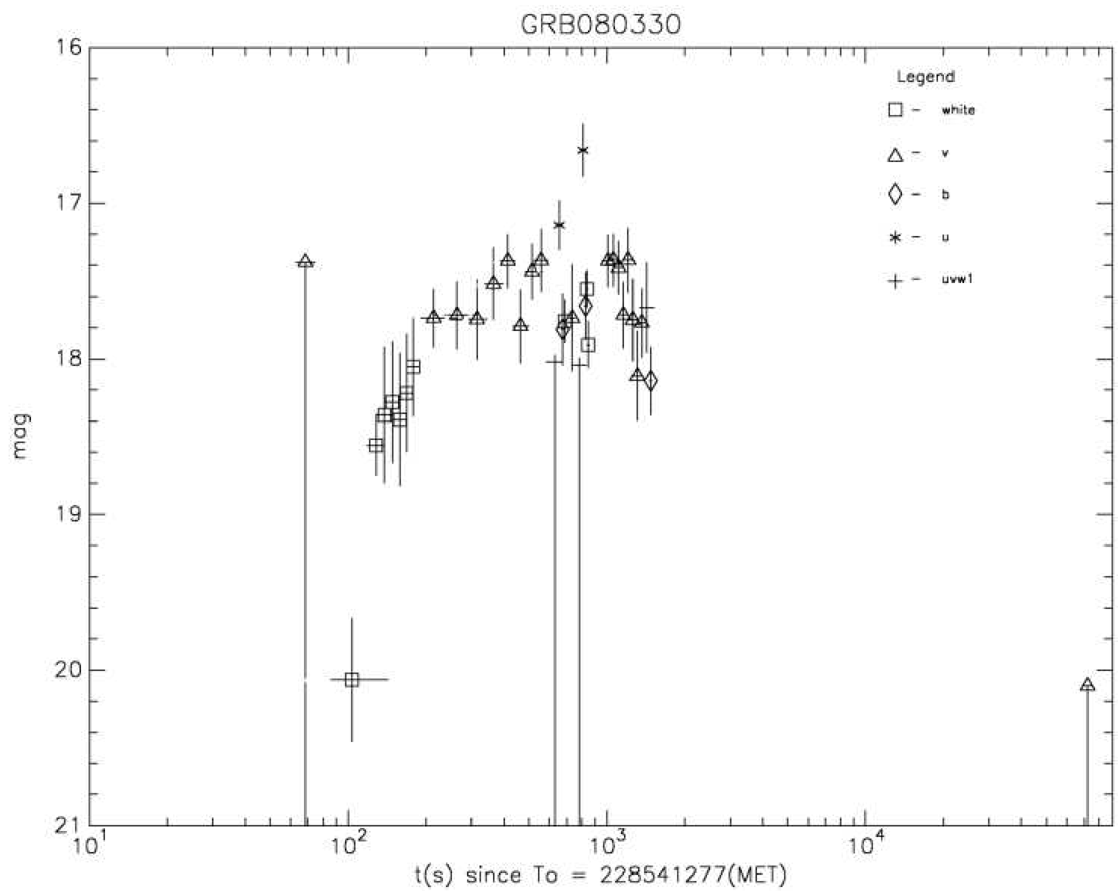

Figure 3: UVOT Lightcurve.