# Swift Observation of GRB 061004

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## 0 Revisions

The BAT off-axis angle is corrected. The latest XRT lightcurve, modified refined and astrometrically-corrected XRT positions are added. Two possible redshifts suggested by ground follow-up and their consequence for the nearby optical source as host galaxy is discussed. A typo in the explanation of the XRT spectrum is corrected.

## 1 Introduction

BAT triggered on GRB 061004 at 19:50:30.5 UT (Trigger 232339) (Ziaeepour, *et al.*, *GCN Circ.* 5691). This was a 1.024 sec rate-trigger on an intermediate length burst with $T_{90} = 6.2$ *sec*. Swift slewed to this burst immediately and XRT began follow-up observations at $T + 60$ *sec*, and UVOT at $T + 69$ *sec*. Our best position, extracted from the XRT full data (Racusin *et al.*, *GCN Circ.* 5774), is location RA($J2000$) = $97.7956deg$ ($06h31m10.94s$), Dec($J2000$) = $-45.9065deg$ ($-45d54'23.3$") with an estimated uncertainty of 2.0 arcsec (radius, 90% containment). This position is at 5.9 arcsec from candidate optical counterpart detected by VLT (Jakobsson *et al.*, *GCN Circ.* 5698). The lack of variability, estimated redshift of $z \sim 3.3$ or $z \sim 0.3$ (Jakobsson *et al.*, *GCN Circ.* 5782), and relatively large distance between this source and the XRT position, make it unlikely to be the afterglow or the host galaxy of this burst. The VLT limiting magnitude for the follow-up observation (0.542 days post-burst) is $R > 25.1$ (2 sigma)(Jakobsson *et al.*, *GCN Circ.* 5782), and therefore this is one of the darkest bursts ever observed.

## 2 BAT Observation and Analysis

Using the data set from $T - 239$ to $T + 596$ *sec*, further analysis of BAT GRB 061004 has been performed by Swift team (Krimm, *et al.*, *GCN Circ.* 5694). The BAT ground-calculated position is RA($J2000$) = $97.795deg$ ($06h31m10.8s$), Dec($J2000$) = $-45.903deg$ ($-45d54'09.8''$) $\pm$ 0.8 $arcmin$, (radius, systematic and statistical, 90% containment). The partial coding was 98% (the off-axis angle was 16.6 $deg$).

The masked-weighted light curves (Fig.1) starts at trigger time $T$ with a single mildly rapid rise, and returns to background at about $T + 8$ *sec*. $T_{90}(15 - 350keV)$ is $6.2 \pm 0.3$ (estimated error including systematics).

The time-averaged spectrum from $T + 0.2$ to $T + 8.1$ *sec* is best fitted by a simple power law model. This fit gives a photon index of $1.81 \pm 0.10$, ($\chi^2 = 36.5$ for 57 d.o.f.). For this model the total fluence in the $15-150$ $keV$ band is $(5.7 \pm 0.3) \times 10^{-7} ergs/cm^2$ and the 1-sec peak flux measured from $T+2.67$ *sec* in the $15 - 150$ $keV$ band is $2.5 \pm 0.2$ $ph/cm^2/sec$. All the quoted errors are at the 90% confidence level.

## 3 XRT Observations and Analysis

Using the full XRT data set of GRB 061004, 61 ksec between October 4 and October 10, 2006 in Photon Counting mode, and applying the new XRT boresight definition (Burrows *et al.*, *GCN Circ.*

5750), the refined boresight-corrected position is (Racusin *et al.*, *GCN Circ.* 5774): RA(J2000): 06h 31m 10.68s, Dec(J2000): -45d 54' 22.7", with an estimated uncertainty of 3.6 arcsec (radius, 90% containment). This position is 6 *arcsec* from the faint VLT optical source reported by Jakobsson *et al.*, *GCN Circ.* 5698.

To further improve the accuracy of this position, the data from the XRT observations of GRB 061004 when the satellite position was stable (54 *ksec* in Photon Counting mode) is used, and additional correction of astrometry is obtained by matching serendipitous X-ray sources in the XRT field of view with their optical counterpart from USNO-B1 catalog. This procedure leads to an astrometrically-corrected XRT position (Racusin *et al.*, *GCN Circ.* 5774):
RA($J2000$) = $97.7956deg$ ($06h31m10.94s$),
Dec($J2000$) = $-45.9065deg$ ($-45d54'23.3$")
with an estimated uncertainty of 2.0 arcsec (radius, 90% containment). This position is 5.0 arcsec from the original refined XRT position given in Page *et al.GCN Circ.* 5695, 2.8 arcsec from the boresight corrected XRT position, and 5.9 arcsec from the optical source (Jakobsson *et al.GCN Circ.* 5698).

The $0.3-10$ $keV$ light curve (Fig.2) shows an initial steep decline with a slope of $1.62^{+0.22}_{-0.14}$, following by a shallow slope of $0.28\pm0.42$, beginning at $T+442\pm116$ *sec*. At $(2.6^{+4.3}_{-0.9})\times10^3$ *sec* the light curve breaks with a slope of $1.17\pm0.11$.

The spectrum of three segments of the X-ray lightcurve can be modeled with an absorbed power-law with spectral indices of $1.43\pm0.16$, $1.96\pm0.13$, and $1.79\pm0.40$, respectively. The NH column density is the same as galactic column density, $5.7\times10^{20}cm^{-2}$. The average observed (unabsorbed) flux over $0.3-10$ $keV$ for this spectrum (spanning a time of 68-86 seconds after the trigger) is $2.83\times10^{-10}$ ($3.07\times10^{-10}$) $ergs/cm^2/sec$.

## 4 UVOT Observation and Analysis

The UVOT began observing the field of GRB 061004 at 19:51:14 UT, 51 sec after the initial BAT trigger (Ziaeepour *et al.*, *GCN Circ.* 5691). No new source was detected within the XRT error circle in the white (100 *sec*) and V (400 *sec*) finding exposures, or in the co-added images in any filter down to 3-sigma magnitude. Upper limits are summarized in Table 1. These upper limits are not corrected for Galactic extinction E(B-V) = 0.062.

| Filter | Start | Stop | Exposure | 3-Sigma UL |
|---|---|---|---|---|
| WHITE (finding) | 68 | 168 | 100 | 18.4 |
| V (finding) | 174 | 574 | 400 | 20.0 |
| V | 704 | 24752 | 1477 | 18.9 |
| B | 652 | 13187 | 928 | 19.9 |
| U | 625 | 18969 | 1225 | 20.5 |
| UVW1 | 604 | 18895 | 2121 | 21.2 |
| UVM2 | 580 | 17988 | 1357 | 20.4 |
| UVW2 | 680 | 24092 | 1337 | 20.5 |
| WHITE | 665 | 6706 | 520 | 20.3 |

Table 1: Magnitude limits from UVOT observations

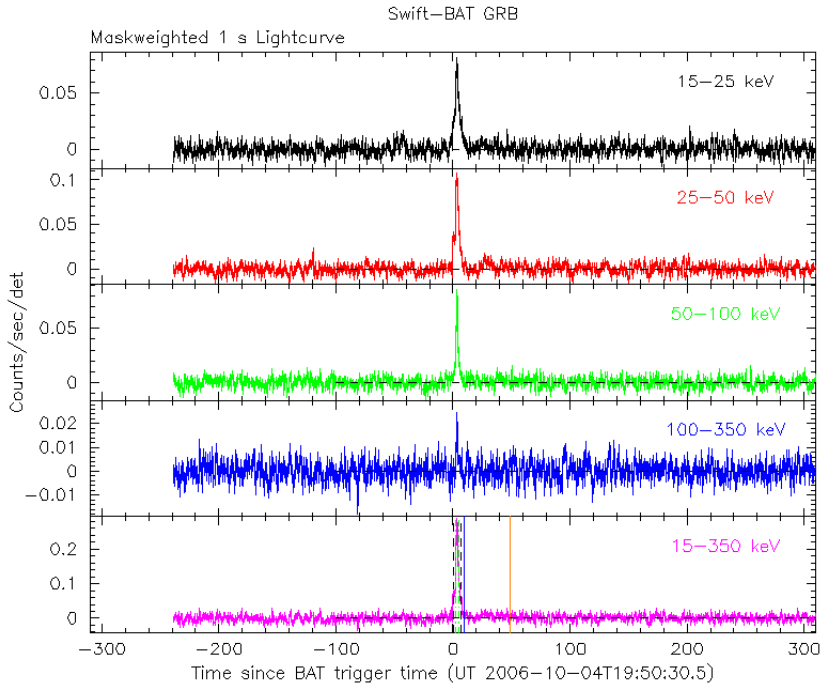


Figure 1: BAT Light curve. The mask-weighted light curve in the 4 individual plus total energy bands. The units are counts/sec/illuminated-detector (note illum-det = $0.16cm^2$) and $T_0$ is 19:50:30.5 UT.

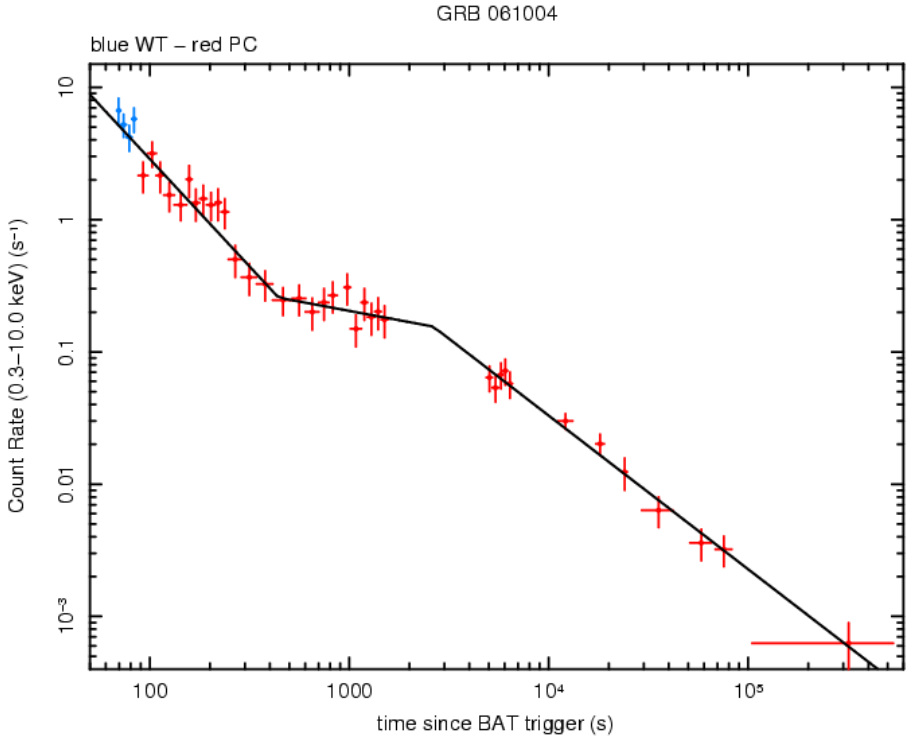


Figure 2: XRT Lightcurve. Counts/sec in the 0.3-10 keV band: Window Timing mode (blue), Photon Counting mode (red). The approximate conversion is 1 count/sec = $\sim 5. \times 10^{-11}$ $ergs/cm^2/sec$.