# Swift Observations of GRB 070616

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## 1 Revisions

XRT count to flux conversion corrected.

## 2 Introduction

BAT triggered on GRB 070616 at 16:29:33 UT (Trigger 282445) (Starling, *et al.*, *GCN Circ.* 6542). This was an image-trigger on a long burst with $T_{90} = 402 \pm 10$ sec. Swift slewed to this burst immediately and XRT began follow-up observations at $T + 131$ sec, and UVOT at $T + 142$ sec. Our best position is the astrometrically refined XRT location RA(J2000) = 02h 08m 36.59s, Dec(J2000) = +56 d56′ 43.8″ with an error of 2.4 arcsec (90% confidence). An optical transient is found inside the XRT error circle in UVOT V and U band images.

## 3 BAT Observations and Analysis

Using the data set from $T - 239$ to $T + 497$ sec, further analyses of BAT GRB 070616 have been performed (Stamatikos, *et al.*, *GCN Circ.* 6543; Sato, *et al.*, *GCN Circ.* 6551). The BAT ground-calculated refined position is
RA(J2000) = 32.1458 deg (02h 08m 35.0s), Dec(J2000) = +56.9445 deg (+56d 56′ 40″) ± 37 arcsec, (radius, 90% containment). The partial coding was 60%.

The time-averaged spectrum from $T - 2.6$ to $T + 602.2$ sec is best fit by a simple power-law model. The power law index of the time-averaged spectrum is 1.61 ± 0.04. The fluence in the 15-150 keV band is $1.92 \pm 0.03 \times 10^{-5}$ erg cm$^{-2}$. The 1-sec peak photon flux measured from $T + 139.74$ sec in the 15-150 keV band is 1.9 ± 0.1 ph/cm2/sec. All the quoted errors are at the 90% confidence level.

The mask-weighted light curve (Fig.1) shows many peaks. The burst started with a low-level smooth emission at $\sim T - 55$ sec continuing smoothly and increasing slowly until $\sim T + 100$ sec when the main emission started. The main peak is at $T + 120$ sec. Smaller overlapping peaks continue out past $T + 550$ sec. In particular, there is a small peak from $T + 730$ to $T + 850$ sec which is coincident with a peak (flare) in the XRT lightcurve (Fig.2). $T_{90}$ (15-350 keV) is 402 ± 10 sec (estimated error including systematics).

## 4 XRT Observations and Analysis

We have analysed all the Swift XRT data collected for GRB 070616, totalling 144.5 ks of data out to $T_0 + 3.7 \times 10^5$ sec.

Using 899 s of overlapping XRT Photon Counting mode and UVOT V-band data, we find an astrometrically corrected X-ray position (using the XRT-UVOT alignment and matching UVOT field sources to the USNO-B1 catalogue) of RA, Dec = 32.15248, 56.94549 deg corresponding to

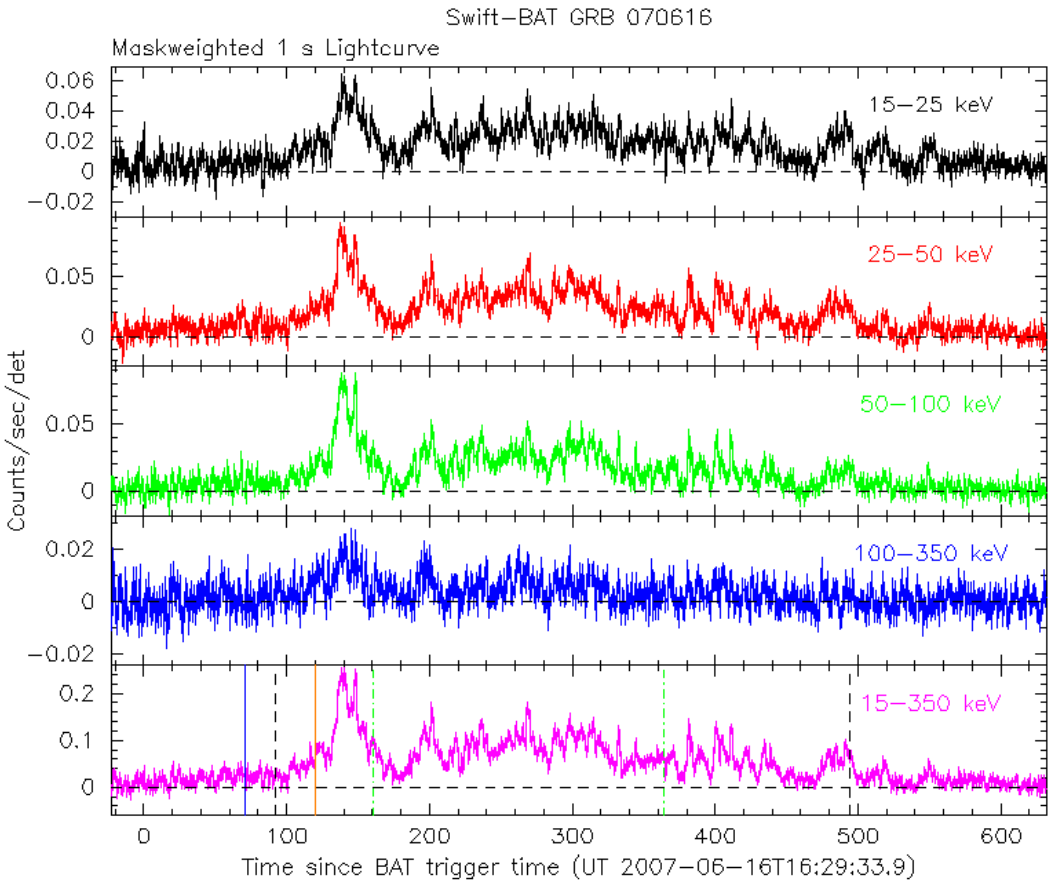


Figure 1: BAT Light curve. The mask-weighted light curve in the 4 individual plus total energy bands. The units are counts/sec/illuminated-detector and $T_0$ is 16:29:33 UT.

RA(J2000) = 02h 08m 36.59s
Dec(J2000)= +56d 56′ 43.8″

with an error of 2.4 arcsec (radius, 90% containment). This is 2.7 arcsec from the initially reported XRT position (Starling, *et al.*, *GCN Circ.* 6542) and 13.6 arcsec from the refined BAT position, and contains a bright star listed in the USNO-B1.0 catalogue.

The lightcurve (Fig.2) began with a constant flux up to $T_0 + 536$ sec, and then decayed with $\alpha \sim -4.6$ until about $T_0 + 1000$ sec. A steep decay follows this, though there are not enough data to accurately measure its slope. After approximately $T_0 + 2000$ sec the decay continues with a shallower slope of $\alpha = -(1.57 \pm 0.04)$ fitting a single power law. However, the final data point lies below the fit of a single power law, so we also fitted a broken power law and find $\alpha_1 = -(1.26^{+0.01}_{-0.09})$, $E_{\rm bk} = 50^{+19}_{-17}$ ks and $\alpha_2 = -(2.4^{+0.5}_{-0.3})$ which improves the fit from $\chi^2$/dof (single power law) = 101/46 to $\chi^2$/dof = 51/45. Given the very few data points after the possible break time, we find it is not possible to confirm any break in the lightcurve from these data. Several small flares appear on top of the continuum emission up to $T_0 + 1000$ sec, some of which are simultaneous with peaks in the BAT lightcurve.

The spectrum evolves from hard to soft during the first 1000 sec. The PC mode spectrum from the second orbit onwards is well fit with a power law of photon index $\Gamma = 2.4^{+0.2}_{-0.1}$ (90%) absorbed only by the large Galactic column of $3.4{\times}10^{21}$ cm$^{-2}$ (Dickey & Lockman 1990). The 0.3-10 keV observed (unabsorbed) flux is $2.2{\times}10^{-12}$ ($4.0{\times}10^{-12}$) erg cm$^{-2}$ s$^{-1}$, corresponding to a count rate of $4.9{\times}10^{-2}$

count $s^{-1}$.

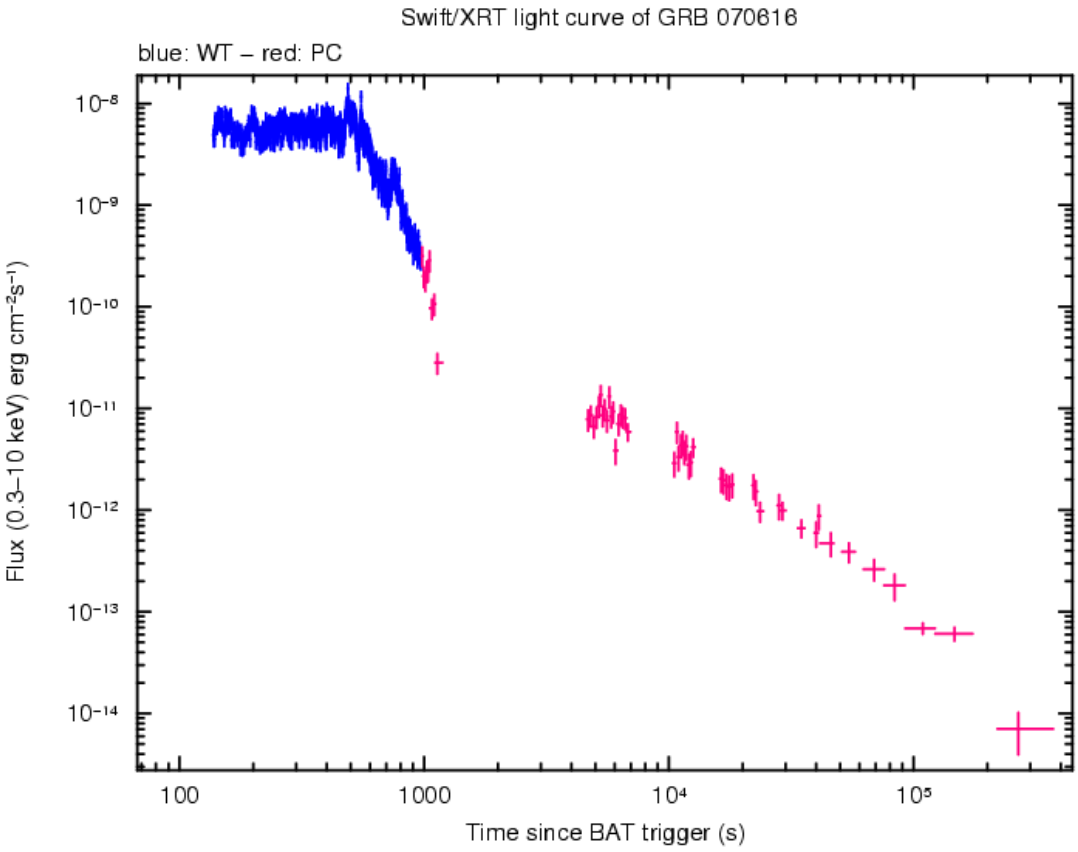


Figure 2: XRT fluxed lightcurve in the 0.3-10 keV band. Power law fits are described in the text. The approximate count rate to flux conversion is 1 count $s^{-1}$ = $4.5 \times 10^{-11}$ erg $cm^{-2}$ $s^{-1}$, based on the spectrum from orbit 2 onwards.

## 5 UVOT Observations and Analysis

The Swift UVOT telescope began its White filter finding chart exposure of GRB 070616 144 sec after the trigger. After a detailed investigation of the refined XRT error circle, which contains the bright (V = 14.4) star USNO-B1.0 1469-0076513, we find good evidence to suggest that the optical afterglow is detected in the early Swift/UVOT observations.

The count rates in V and U band exposures between 250 and 1050 sec after the trigger show a significant excess (at the $10\sigma$ level in the V band combined image and at the $5\sigma$ level in the U band combined image) with respect to late observations ($T > 1$ day). This excess corresponds to an optical source of magnitude V = 16.5 and U = 16.9. The source appears to have disappeared in exposures taken later than 1100 sec, thus indicating a drop in the optical flux suggestive of a GRB afterglow behaviour. We obtain a $3\sigma$ upper limit of V>17.9 at $T = 6$ ks after the trigger.

The blended image of the star plus the afterglow is extended compared to other stars in the image. Fitting it with two point sources indicates that the afterglow is about $1.8''$ west and $0.9''$ north of the USNO-B1.0 star with a statistical uncertainty of $\sim 0.3''$ in each axis (90% confidence). Detection of the afterglow in the U band indicates a redshift less than $\sim 3$.

Analysis of another star in the same field of view reveals no change of flux throughout the observations, thus ruling out instrumental effects. While we cannot completely exclude that the star in the XRT

error circle might have varied mimicking a GRB afterglow, observations carried out for the further 2 days suggest a constant source. Furthermore, the UV magnitudes of the star in the XRT error circle do not show any significant variation corresponding to those seen in the optical filters, thus supporting the afterglow hypothesis.

No correction has been made in the magnitudes given for the high Galactic reddening of $E(B-V) = 0.4$ (Schlegel et al. 1998). We note that this value should be taken with caution, the burst having occurred at low Galactic latitude.