Rapid Identification of GRB Afterglows with Swift/UVOT

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Abstract. As part of the automated response to a new GRB, the UVOT instrument on Swift starts a 200-second exposure with the V filter within ~ 100 seconds of the BAT burst trigger. The instrument searches for sources in a $8' \times 8'$ region, and sends the list of sources and a 160" × 160" sub-image centered on the burst position to the ground via TDRSS. These raw products and additional products calculated on the ground are then distributed through the GCN within a few minutes of the trigger. We describe the sensitivity of these data for detecting afterglows, summarize current results, and outline plans for rapidly distributing future detections.

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INTRODUCTION

A major goal of the Swift mission is to enable ground-based observations of the afterglows of gamma-ray bursts (GRBs) by rapidly providing accurate positions to the community. In this paper we discuss the relevant capabilities of the Ultraviolet and Optical Telescope (UVOT), one of the three instruments of the Swift Observatory. UVOT is a 30-cm. telescope that is sensitive to photons in the wavelength range of 170 to 600 nm (Roming et al. [1]). Spectral information is available using a filter wheel which includes UV and optical grisms and 6 broad band filters.

Swift typically responds to a new GRB in the following fashion. After BAT determines the position of the GRB, the spacecraft maneuvers to point the co-aligned X-Ray Telescope (XRT) and UVOT at the GRB. After the maneuver ends (typically 1 to 2 minutes after the BAT trigger), UVOT takes a "finding chart" exposure lasting 200 seconds using the V filter. The response of UVOT can be configured. On October 3, 2005, the exposure was increased from 100 seconds to the current 200 seconds to increase the sensitivity. Early in 2006 the response will be changed again so that multiple finding chart exposures will be taken. The data from the finding chart exposure are then processed by the instrument and the results rapidly sent to the ground using NASA's Tracking and Data Relay Satellite System (TDRSS). The results and the additional processing on the ground are described in the following sections. The complete data from the initial exposure including event-by-event data from the full $17' \times 17'$ UVOT field-of-view are eventually sent to the ground using the Malindi Ground Station, but these data are not the subject of this paper.

UVOT DATA PRODUCTS

The on-board processing is designed to reduce the volume of telemetry so that it will fit into the limited available bandwidth while still providing the most important information about an afterglow. UVOT sends down two major products. The first is a list of detected sources with counts from a few surrounding pixels (the Source List data). The second is an image that is a subset of the full image.

The Source List data are produced by searching the $8' \times 8'$ image from the finding chart exposure for sources. For each of a maximum of 190 sources the location and counts of the central pixel and the counts in each of a small number of surrounding pixels is sent to the ground. The total number of pixels for a source can be either 1, 5, or 21. If a small number of sources is detected, then information is available for all the sources and for 21 pixels for each source. If a large number of sources is detected, not all of them will be sent to the ground and fewer pixels will be reported for some of the sources. The on-board algorithm is designed to send the brighter sources and to use more pixels for the brighter sources.

The Source List telemetry are processed automatically when received at GSFC to produce four files in standard formats. One (uvot_raw_srclist.fits) converts the data into FITS format with little additional processing. Another (uvot_sky_srclist.fits) maps the detector positions for the sources onto the sky to produce (a very sparse) sky image. A postscript file (uvot_field_image.ps) is also produced. It plots the source positions on a Digital Sky Survey (DSS) image. Fig. 1 shows an example of this file. The final file (uvot_catalog_srclist.fits) is of primary interest for this paper. An improved aspect solution is attempted by comparing the list of sources to the USNO-B.1 catalog of optical sources (Monet et al. [2]). Typically the improved aspect solution is offset by $\sim 2''$ from the original solution. If the attempt is not successful, then this file is not produced. When produced, the file contains the list of sources, their corrected sky positions, a flag indicating whether the source has been matched with a object in the ground catalog, the identification of the matched object, and an estimate of the V magnitude of the source based on the counts in the nearby Source List pixels. The list of sources is sorted by distance from the position of the afterglow determined with XRT if available; otherwise, it is sorted by distance from the GRB position determined with BAT. All these files are distributed to the community as soon as they are produced.

There are a few problems with the Source List data that need to be accommodated in their analysis. The most important is that spurious sources are found by the on-board source detection algorithm near bright ($V < 12.0$) sources. Tens of such spurious sources can be produced for very bright sources ($V < 8.0$). These sources are not flagged in the distributed data files.

The estimation of the magnitude for the sources is hampered by the limited number of pixels available. Even when 21 pixels are available, only part of the source image is available. Consequently it is necessary to correct for the "missing" counts before converting the source count rate to V magnitude. The correction factor was determined by comparing the counts reported in Source List data to the actual source counts determined after examining the complete finding chart image. Fig. 2 shows the results of this comparison for several finding chart images. The best-fit linear relationship between Source List counts and total counts has been used to compute the V magnitude. This slightly

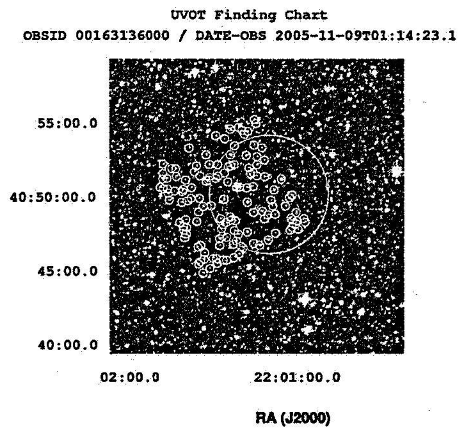

FIGURE 1. Source List positions (small circles) overlaid on the Digital Sky Survey image of the region near GRB 051109A. The distribution of the positions indicate the projection of the 8'x8' finding chart image on the sky. The large circle shows the initial BAT error circle.

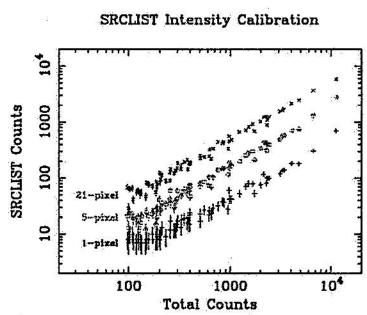

FIGURE 2. Source List counts vs. total counts for the 3 types of data.

overestimates the brightness when the total counts are less than ~ 150 (~ 18.1 V magnitude for a 200 second exposure).

The position given for an entry in the Source List is simply taken as the position of the pixel with the most counts. Consequently the accuracy of the Source List positions is significantly worse than the accuracy of positions obtained after the complete finding chart data are available on the ground. Fig. 3 shows the distribution of position errors for a Source List entries in a typical finding chart. 90% of the positions are within 1.3" of the correct position.

In addition to the Source List data, a small sub-image is created for each finding chart exposure and sent to the ground. The image is binned 2×2 (producing 1" $\times$ 1" pixels) and covers 160" $\times$ 160". Nominally the image is centered on the XRT position for the afterglow if it is available; otherwise the image is centered on the BAT position. The image is large enough to easily cover all of of a typical XRT error circle, but only covers $\sim 25\%$ of a typical BAT error circle.

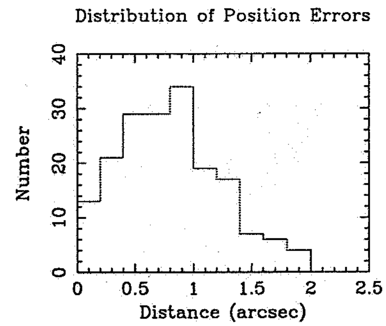

FIGURE 3. Observed distribution of position errors for Source List sources for a typical finding chart image.

Ground processing for the sub-image is similar to that for the Source List data except that a source detection algorithm is run on the ground instead of on the instrument. The same type of files are created with "image" replacing "srclist" in the names of the files. The sensitivity and positional accuracy that can be obtained is very similar to that for standard UVOT images.

RESULTS AND FUTURE PROSPECTS

Source List data products have been produced for most of the GRBs detected with Swift. Afterglows can be detected if they are brighter than $\sim$ 18.0 magnitude in V. Magnitudes can be determined to $\sim$ 0.5 (1σ), and positions determined to $\sim$ 1.3". Through November, 2005, GRB afterglows are seen in Source List data for 7 GRBs (GRB050525A, GRB050712, GRB050726, GRB050730, GRB050802, GRB050922C, and GRB051109A). The optical afterglow for GRB050730 was discovered in the sub-image data (Holland et al. [3]).

The automated UVOT response will soon be changed to produce two finding charts using both the V and B filters. Changes are also being made to increase the fraction of the time that the sub-image covers the XRT error circle. Finally ground software is being improved so that afterglows can be detected automatically and reported to the community within $\sim$ 10 minutes of the burst trigger.

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