Discovery and Observations of the Optical Afterglow of GRB 071010B

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Abstract On 2007 October 10 at 20:45:48 UT, the Swift satellite detected the bright, long-soft gamma-ray burst GRB 071010B in the constellation Ursa Major. Coordinates were automatically distributed via the Gamma-ray Burst Coordinate Network (GCN), and observations were begun by A. Oksanen at the Hankasalmi Observatory in Hankasalmi, Finland, within fifteen minutes of the burst. A previously uncatalogued optical source was detected at R.A. 10^h 02^m 09.26^s, Dec. +45° 43' 50.3" (J2000) at an unfiltered (*R*-band calibrated) magnitude of approximately 17.5. Imaging over the following six hours showed that the source faded, indicating that it was likely the optical afterglow of GRB 071010B. The discovery was published via the *GCN Circulars*, and the coordinates were subsequently used by other major telescope facilities to conduct follow-up photometry and spectroscopy.

The discovery of the optical afterglow by A. Oksanen is the first discovery of a GRB afterglow by an amateur astronomer since the discovery of GRB 030725 by L. A. G. Monard in 2003 (Monard 2003). The early detection of this afterglow and subsequent dissemination of coordinates via the GCN has proved very valuable from a scientific standpoint. These data are the earliest available photometry for this burst, enabling the study of the early stages of the GRB optical light. They were also the first localization, and these coordinates were subsequently used by other major optical facilities for their follow-up observations. This burst clearly shows that individual observers still have a role to play in GRB observations even in the era of automated, robotic telescopes, and that the amateur community is an important partner of the professional community in the observation of GRB afterglows.

1. Introduction

The Swift satellite (Gehrels *et al.* 2004) has been a prolific source of GRB localizations over the past three years of its operation; over 150 bursts have been detected and localized in gamma-rays, X-rays, and/or optically by the satellite itself, and the high-energy localizations provided in real-time by Swift have enabled ground-based follow-ups of many of these GRBs. The AAVSO International High Energy Network (AAVSO HEN) grew from the AAVSO International GRB Network, formed in April 2000 as a link between the amateur observer community and the wider gamma-ray burst research community. It has since grown into an organized observing program within the AAVSO that provides GRB localizations from Swift and other satellites, along with a mechanism for sharing information among network members and publishing observations via the *GCN Circular*. The rapid distribution of satellite localizations has been key to amateur participation in GRB observations, just as it has been in professional GRB research.

In principle, GRB fields can be imaged within seconds of detection of the gamma- rays, so long as the observer is in darkness, and can view the field from their location; GCN localizations are used by all ground-based rapid follow-up projects, including robotic facilities (e.g. ROTSE-III) that can slew to target within seconds of receipt. Human-discovered afterglows with 0.5-meter aperture telescopes and smaller have become very rare, given the near-instantaneous response of robotic systems that respond directly to GCN coordinates in real-time. However, robotic systems still have limitations; they may be in daylight or experiencing poor weather, or the coordinates may be inaccessible from the site. Thus human observers—particularly amateur GRB enthusiasts—still have an important role to play.

In this paper, we describe the discovery, observation, and subsequent analysis of GRB 071010B—the first GRB optical afterglow discovered by an amateur-astronomer since 2003. In Section 2, we describe the discovery and observations made by A. Oksanen along with the photometric reductions. In Section 3, we present our analysis of the light curve and compare these results to other published optical studies of GRB 071010B.

2. Observations

One of us (A. Oksanen) received the Swift gamma-ray localization for GRB 071010B (Markwardt *et al.* 2007) via the GCN, and within fifteen minutes began observations with the Hankasalmi Observatory RC Optical Systems 0.4-meter Richey-Chretien telescope. This telescope is mounted on a Paramount ME, and uses an SBIG STL-1001E CCD Camera with standard *BV RcIc* photometric filters. The majority of observations were made unfiltered, including the initial detection of the GRB. Sets of 10 × 60-second exposures were made in *V* and *Ic* following the initial detection, and were combined to obtain calibrated photometry of the source; the remainder of the time-series observations were conducted unfiltered for the first night. The field was revisited again 2.2 days after the gamma-ray burst, and 40 × 120-second, unfiltered exposures were acquired.

The early observations beginning within fifteen minutes of the GRB detection are the only early-light optical data known to exist for GRB 071010B and provide an important photometric record of this burst. Although the source was below the pole and below the horizon of most observatories, the observer's high northern latitude enabled the prompt acquisition of the source. These circumstances were particularly fortunate for this burst, given that the Swift satellite had not yet been restored to full functionality following the 2007 August 11 gyroscope failure (see Gehrels 2007a, b), and thus the spacecraft did not autonomously slew to observe the field with UVOT.

The afterglow of GRB 071010B was clearly detected on the first night, and approximately six hours of unfiltered time-series data were obtained. The afterglow faded from an unfiltered (CR) magnitude of approximately 17.5 down to 19.0 over the course of six hours. The burst was again detected two days later, although it had faded to CR ~ 20.3 ± 0.1 and was too faint for time-series observations; the acquired frames were therefore averaged together. The results of the first night's observations were subsequently published in Oksanen (2007) and in Templeton *et al.* (2007).

For this paper, all images acquired by A. Oksanen were reanalyzed by A. Henden using point-spread function (PSF) fitting in IRAF. Calibration of the field was performed by A. Henden with the Sonoita Research Observatory 0.35-meter telescope in Arizona (Henden 2007). The early unfiltered images were photometered individually; the *V* and *Ic* images and later unfiltered images were stacked to improve the signal-to-noise. One image stack centered on JD 2454384.4882 was discarded due to severe interference from cosmic rays. The single data point obtained 2.2 days post burst was measured from a stack of images with total exposure time of 4,800 seconds. Table 1 gives the resulting photometry following reanalysis.

3. Analysis

We computed a best-fit power-law decay slope of the afterglow optical flux, $F \propto t^{\alpha}$:

$$\log F = \text{const} + \alpha \log (t - t_0), \qquad (1)$$

where t_0 = JD 2454384.3651 (the time of the Swift detection of the GRB) and the constant is the flux predicted at $\log(t - t_0) = 0$ (or t_0 + 1 day). We fit three separate polynomials to these data: one to the earliest unfiltered data, taken within 0.05 day of the burst, and two to the later data. The two later-time fits were made to data that did and did not include the single observation made two days later. The three fits are given in Table 2, and are shown along with the light curve in Figure 1.

These decay rates are different from the value of $\alpha = -0.482$ given in Templeton *et al.* (2007), primarily because the two epochs of unfiltered data were combined to compute a single power law for that paper. It is apparent from the current analysis that the data follow a broken power law. Both the early and late decay rates are significantly different from one another, indicating that there were significant physical changes occurring during each epoch of the decay. We note that there is some evidence for a flare around $t-t_0=0.02$ day, but this is based on a single data point and thus not confirmed. The slope we obtain for our late-time unfiltered observations (about $\alpha=-0.53$ for both the short and longer data sets) is similar to $\alpha=-0.56$ derived by Kann *et al.* (2007b) using a combined data set from the Hankasalmi (Oksanen 2007), Mount Lemmon (Im *et al.* 2007) and TLS Tautenburg 1.34-meter (Kann *et al.* 2007a) telescopes. The Kann *et al*. (2007b) fit includes more late-time data, and is thus consistent with the fit to the “late (long)” data being slightly steeper; the physical properties of the light source may have been evolving through this later stage even up to the second break. An analysis of all available photometry is currently in progress (Kann *et al.* 2008, in preparation).

4. Discussion

The localization and light curve of GRB 071010B obtained with the Hankasalmi telescope provided the wider GRB community with important data on this GRB, and facilitated the study of this burst by other major telescopes, including spectroscopic observations by Gemini North (Cenko *et al.* 2007) and Keck (Prochaska *et al.* 2007; Stern *et al.* 2007) that have established a redshift of $z \sim 0.947$ for the burst and host galaxy. Although GRB 071010B likely would have been localized by any of several other telescopes that subsequently made optical observations, the data presented in this paper are the earliest photometry available for this burst from any facility, and they provide unique information on the early evolution of the optical afterglow that will be important in future physical studies of this bright GRB.

Manually-controlled amateur and smaller professional telescopes continue to provide important data and upper limits to several GRBs per year, both through AAVSO HEN and independently via the *GCN Circular*s. Robotic telescopes devoted solely to GRB followups clearly have an advantage over human beings in the early detection of GRB afterglows, but even in this task they are not guaranteed to detect every burst on the sky. The number of robotic facilities is growing, but they do not have sufficient global coverage to guarantee a clear view of the entire sky at all times. There is an element of serendipity in amateur detections of GRB afterglows, but as this work makes clear, there is still the possibility for unique and important amateur contributions to the field of GRB research.

5. Acknowledgement

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Table 1. Photometry of GRB 071010B obtained with the Hankasalmi Observatory 0.4-meter telescope. Observations by A. Oksanen; photometry by A. Henden.

HJD	*magnitude*	*err(mag.)*	*filter*	n_{comp}	n_{stack}
2454384.3744	17.468	0.044	CR	10	1 × 60s
2454384.3757	17.510	0.054	CR	10	1 × 60s
2454384.3769	17.536	0.048	CR	10	1 × 60s
2454384.3781	17.607	0.052	CR	10	1 × 60s
2454384.3793	17.673	0.069	CR	10	1 × 60s
2454384.3806	17.649	0.057	CR	10	1 × 60s
2454384.3818	17.800	0.075	CR	10	1 × 60s
2454384.3831	17.785	0.069	CR	10	1 × 60s
2454384.3844	17.638	0.069	CR	10	1 × 60s
2454384.3876	17.537	0.093	I	10	5 × 60s
2454384.3954	17.781	0.109	I	10	5 × 60s
2454384.4028	18.296	0.083	V	10	5 × 60s
2454384.4091	18.324	0.061	V	9	5 × 60s
2454384.4191	18.154	0.030	CR	8	3 × 120s
2454384.4262	18.248	0.037	CR	9	3 × 120s
2454384.4322	18.239	0.025	CR	8	3 × 120s
2454384.4382	18.320	0.033	CR	9	3 × 120s
2454384.4443	18.383	0.028	CR	9	3 × 120s
2454384.4504	18.383	0.030	CR	9	3 × 120s
2454384.4580	18.413	0.027	CR	9	5 × 120s
2454384.4683	18.461	0.028	CR	9	5 × 120s
2454384.4782	18.506	0.037	CR	9	5 × 120s
2454384.4998	18.630	0.025	CR	8	7 × 120s
2454384.5139	18.681	0.027	CR	9	7 × 120s
2454384.5279	18.748	0.026	CR	9	7 × 120s
2454384.5421	18.797	0.033	CR	9	7 × 120s
2454384.5584	18.800	0.035	CR	9	10 × 120s
2454384.5784	18.928	0.027	CR	9	10 × 120s
2454384.5988	18.984	0.026	CR	9	10 × 120s
2454384.6189	19.028	0.038	CR	9	10 × 120s
2454386.5660	20.458	0.082	CR	9	40 × 120s

Table 2. Flux decay rate of GRB 071010B as a function of time. The notation "late (long/short)" indicates the lightcurve (does/does not) include data taken two days post-burst. The flux constants have been converted back to their corresponding CR magnitudes predicted at $t = t_0 + 1$ day.

time	$m_{CR}(t_0 + 1d)$	α	*reduced* χ^2
early	19.30 ± 5	–0.36 ± 1	0.88
late (short)	19.767 ± 5	–0.516 ± 1	0.90
late (long)	19.810 ± 5	–0.534 ± 1	1.28

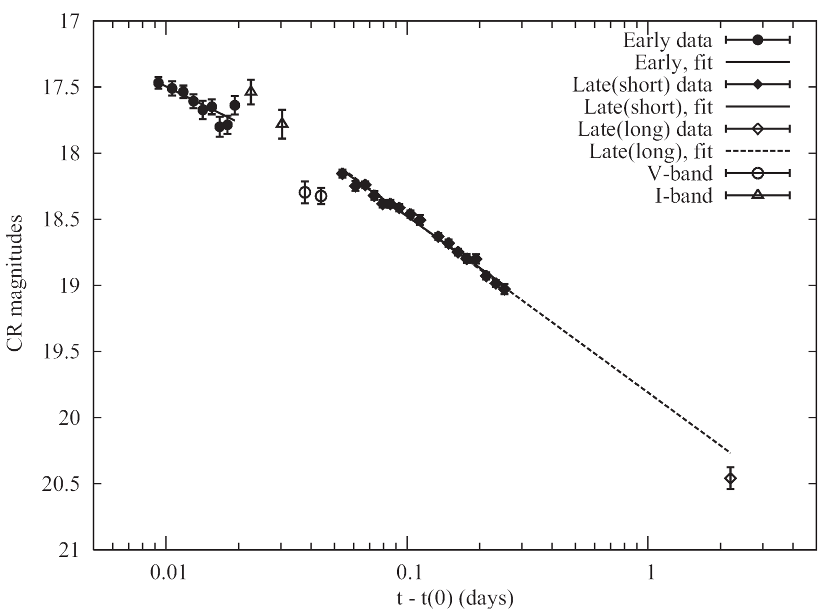

Figure 1. Light curve of GRB 071010B obtained at Hankasalmi Observatory. The majority of data are unfiltered (CR) magnitudes, with two *V* and *Ic* observations. The fits given in Table 2 are shown by the solid and dotted lines.