GRB follow-up with BOOTES Optical: Chapter 5: The *Swift* Era

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Abstract

BOOTES is a robotic observatory system, whose primary aim is to observe gamma-ray burst prompt emission. Since 1998 BOOTES has provided follow-up observations for more than 70 GRBs; the most important results obtained so far are the detection of an OT in the GRB 000313 error box and the non detection of optical emission simultaneous to the high energy emission for several GRBs (both long/soft and short/hard events). During the time of operation we have got triggers from CGRO/BATSE, Beppo SAX, HETE-2, INTEGRAL, and Swift.

Here we present our early detections of GRB optical emission using the 30cm Bootes-1B telescope in the R,V and I-band since the launch of Swift.

An stereoscopic robotic observatory

BOOTES-1, the main BOOTES site, is located in Mazagón (Huelva), a very dark sky area in southern Spain, and is hosted by the Estación de Sondeos Atmosfericos (ESAt) in INTA (Instituto Nacional de Tecnica Aerospacial) in its *Centro de Experimentación de El Arenosillo*[1,2]. It has two domes: BOOTES-1A and BOOTES-1B that hold three Schmidt-Cassegrain telescopes and several wide-field cameras. Following complementing schemes, the instruments carry out systematic exploration of the night sky, responding to GRB alerts at any time via GCN socket connection.

The second observatory (BOOTES-2) is in operation since 2002. It is located at *La Mayora* (Málaga), a research center under the auspices of the CSIC (Consejo Superior de Investigaciones Científicas), 240 km from BOOTES-1. This way, GRB may be observed simultaneously from different locations, discriminating near earth objects easily.

Figure 1: BOOTES-1B: the triple mount with one 30 cm and two 20 cm telescopes.

Mount and Dome control

Over years we have developed BOOTES hardware considerably. The first were Meade LX200 mounts equipped with CCD cameras. In the present time we have Paramount with one 30 cm and two 20 cm telescopes (see Fig. 1 and Fig. 2).

All our domes are independent, but controllable over internet. Both stations have weather stations, to provide information necessary for autonomous opening and closing in case of unusable weather conditions. GSM/SMS based control system is used as a back-up for the case the Internet fails.

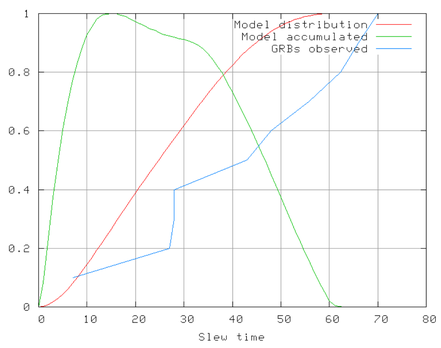

Figure 2: BOOTES-1B: the triple mount theoretical and practical slew time.

Software

RTS2 is designed as a networked system for driving of robotic telescopes[3]. It is composed of several device servers, central server and various observational clients cooperating over a TCP network. For the communication, there is a private protocol, ensuring speed and reliability. It is intended to be independent on used astronomical equipments, with access points for controlling of different types of mounts, domes and CCDs. Observation entries, requests and results are kept in database. Positions of GRBs are received from the Internet, and observed either in prompt mode, or added to list of observation targets, depending on weather and other conditions influencing the observation. During the idle time, when there is not any request for GRB observations, the telescope spends monitoring various active galaxies. The database lookup entry point is accessible at http://lascaux.asu.cas.cz/bartdb.

Afterglow detections of *Swift* GRBs by BOOTES

Figure 3 – 6 show early follow-ups by BOOTES-1B. Figure 7 shows all the early lightcurves.

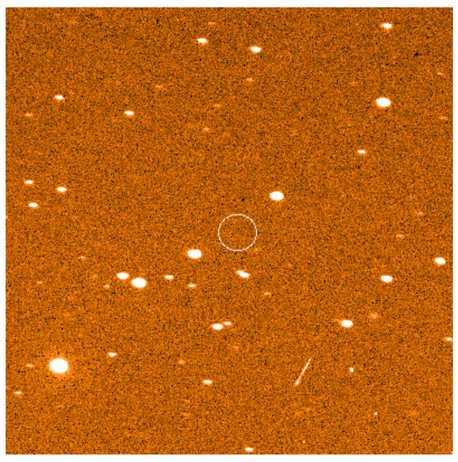

Figure 3: The GRB 050904 - R-band image obtained 124s after the burst. The Gunn-Petterson effect prevented the detection of optical emmision.

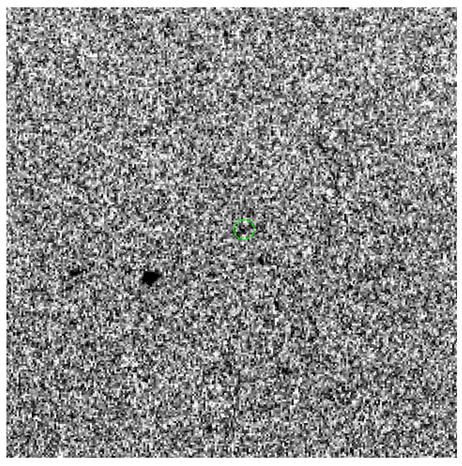

Figure 4: The GRB 050922C - early afterglow in the R-band.

Rapid GRB observations by BOOTES

During past year, BOOTES has followed many GRB alerts, in four cases it has observed an optical transient. In some other cases even the magnitude limits were very interesting. In one case, we have detected the OT simultaneously in two colors. Table 1 displays constraining the results of the follow-up observing.

GRB	Δt_{GRB}	Δt_{GCN}	exposure	magnitude	comment
050505	609s	70s	?	V>15,I>14	GCN 3434
050509B	62s	48s	10s,4min	V>11.5,12.5	Short burst, poor conditions
050525A	383s	28s	25s	V∼15.5	V-band data only
050528	71s	28s	60s	V>13.8,I>13.0	light twillight, GCN 3500
050730	233s	172s	300s	R>18.0	during SW update: longer delay
050805A	136s	66s	5x300s	R>18.0	
050805B	62s	7.2s	10s	R>16.0	
050824	636s	55.8s	600s	R=18.2	2 co-added images
050904	124s	43s	10s	R>16.6	GCN 3929, GRB @ z=6.3
050922C	228s	62.3s	2x10 s	R∼14.5	clouds, three usable windows
051109A	54.8s	27s	10s	R=16.2	GCN 4227, R+I simultaneously

Table 1: GRB observations by BOOTES-1B. Only real-time reactions are shown. Δt_{GRB} stands for time between GRB trigger and start of first image, Δt_{GCN} is the time between reception of the GCN coordinates and first image (most of the time is due to telescope slew).

Image analysis

Has been developed an astrometry package for BOOTES image analysis, based on JIBARO[4]. This way we can set-up mapping between image (x,y) and sky (α,δ) coordinates (WCS) with plate solution precission typically better than 1/10 of a pixel. This approach further simplifies automatization of photometry, object detection and other possible tasks needed in real-time pipeline.

All images obtained and stored in database have proper WCS keywords in their FITS header and are roughly photometrically calibrated (in terms of a limiting magnitude against catalog) and in some cases the relative photometry is performed. Automated transient detection is being actively tested and expected to be routinely used soon.

RTS2 is designed to cooperate with the astrometry package, calls and maintains the pipeline and depending on result, it stores the image in the archive.

Figure 5: The GRB050824 - early afterglow in the R-band.

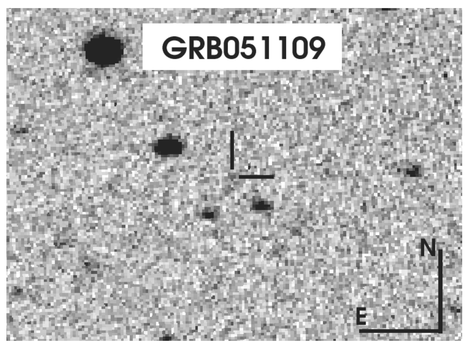

Figure 6: The GRB 051109A - BOOTES R&I-band detection of the early afterglow.

References

(1) A. J. Castro-Tirado et al., The Burst Observer and Optical Transient Exploring System (BOOTES), Astron. Astrophys. Suppl. Ser. 138, 583585 (1999)

(2) A. J. Castro-Tirado et al. Simultaneous and optical follow-up observations by BOOTES, Nuovo Cimiento 28, 715 (2005)

(3) P. Kubánek et al., RTS2 – Remote Telescope System, 2nd Version, AIP Conference Proceedings, Vol. 727

(4) A. de Ugarte Postigo et al., JIBARO: Un conjunto de utilidades para la reducción y análisis automatizado de imagenes, Astrofísica Robotica en España, Madrid, 35–50, 2005

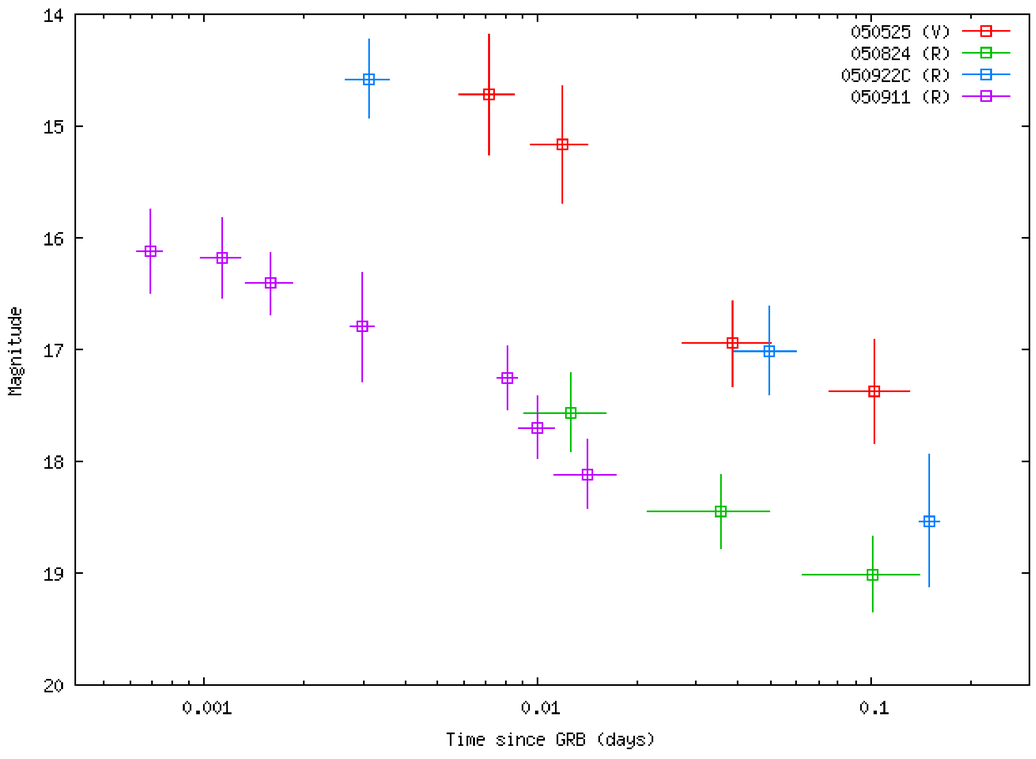

Figure 7: GRBs observed by BOOTES-1B.

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Conclusions

BOOTES-1B has finally proven it can successfully follow GRB notices. Although we have been on watch for many years, Swift gave us the possibility to follow tens of GRB alerts per year, thus allowing the telescope to show it's full power. This work has returned in four OT detections and several interesting limits which have been obtained using this instrumentation. BOOTES has, however, several intrinsic limitations. Mount speed, telescope diameter and wavelength limitation are being overcome in our project BOOTES-IR.