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

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Abstract. BOOTES is a robotic 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 short/hard GRB 000313 error box, the detection of several optical after-glow for long/soft GRBs 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*, *BeppoSAX*, *HETE-2*, *INTEGRAL* and *Swift*.

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

Keywords: black hole formation, starburts galaxies, gamma ray bursts
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A STEREOSCOPIC ROBOTIC OBSERVATORY

BOOTES-1, the main BOOTES observing station, is located in Mazagón (Huelva), a very dark sky area in southern Spain. It is hosted by the Estación de Sondeos Atmosféricos (ESAt) in INTA (Instituto Nacional de Tecnica Aerospacial) in the 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, instruments carry out systematic exploration of the night sky, responding to GRB alerts at any time via GCN socket connection (See Fig. 1).

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 away from BOOTES-1. On this way, GRB may be observed simultaneously from different locations, discriminating the near earth objects easily.

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,

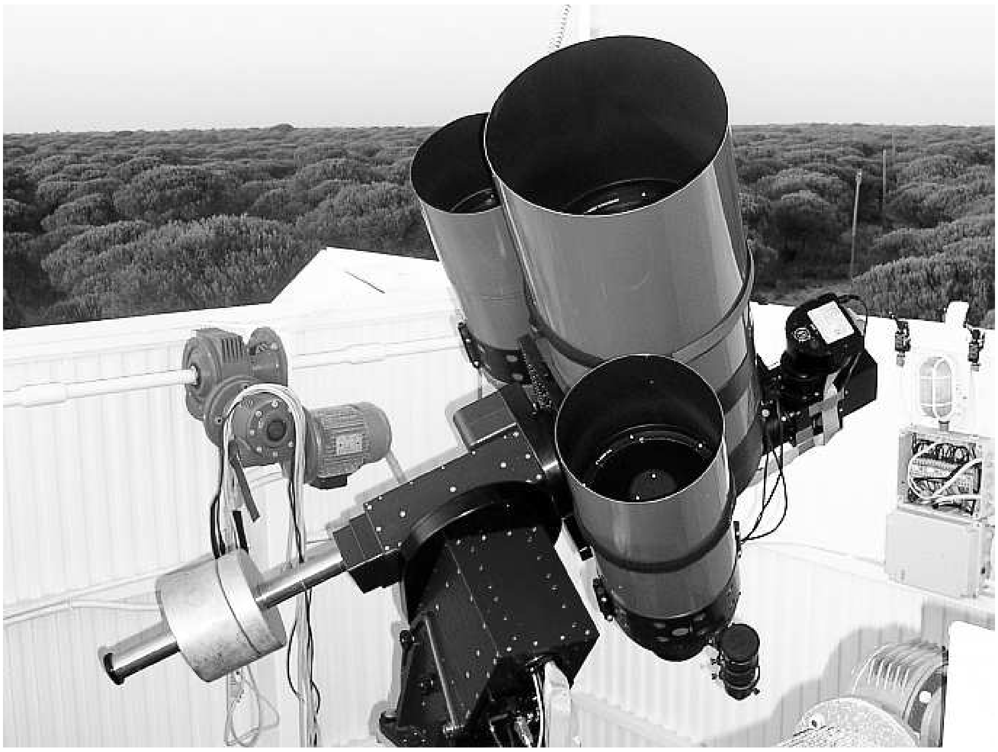


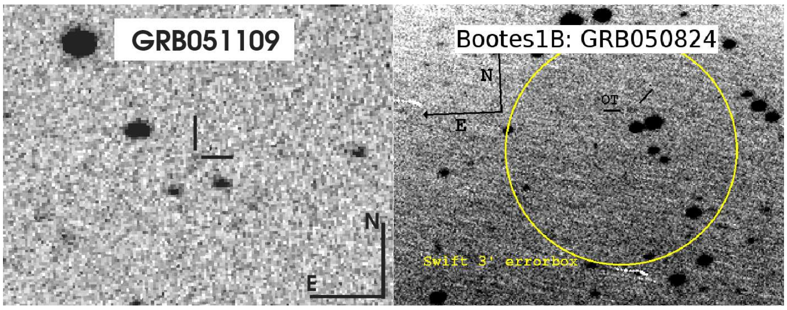
FIGURE 1. The BOOTES-1 telescopes at the Estación de Estudios Atmosféricos (Esat)/INTA in Huelva.

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.

IMAGE ANALYSIS

An astrometric package for BOOTES image analysis, based on JIBARO [4] has been developed. 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 astronomical catalogues) and in some cases the relative photometry is performed. Automated transient detection is being actively tested and expected to be routinely used



Source: BOOTES

FIGURE 2. Afterglow detections of *Swift* GRBs by BOOTES.

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.

MOUNT AND DOME CONTROL

Over the 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.

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.

RAPID GRB OBSERVATIONS BY BOOTES

During 2005, BOOTES has followed many GRB alerts in four cases it has observed an optical transient (See Fig. 2). In some other cases even the magnitude limits were important for constraining early decay rates and so on [5]. In one case, we have detected the OT simultaneously in two colors. Table 1 displays the results of the follow-up observations performed in 2005.

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 its full power. This work has provided in four OT detections and several upper 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 [6].

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).

GRB	Δt_{GRB}	Δt_{GCN}	exposure	magnitude	comment
050505	609s	70s	300s	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

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