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Simultaneous and optical follow-up GRB observations by BOOTES(*)

A. J. Castro-Tirado(1), M. Jelínek(1), T. J. Mateo Sanguino(2)
A. de Ugarte Postigo(1), P. Kubánek(3)(7), R. Hudec(3), S. Vitek(4)
P. Páta(4), M. Bernas(4), J. M. Castro Cerón(5), J. Gorosabel(1)
J. Á. Berná Galiano(6), J. Soldán(7), T. Soria(8), R. Fernández(8)
B. de la Morena Carretero(9) and J. Torres Riera(10)

(1) *IAA (CSIC) - Apartado de Correos, 3.004, E-18.080 Granada, Spain*
(2) *Univ. de Huelva (EPS La Rábida) - E-21.819 Palos de la Frontera (Huelva), Spain*
(3) *Astr. Inst. (AV CR), Ondřejov - Fricova 298, 25165 Ondrejov, Czech Republic*
(4) *FEL, Czech Tech. Univ. - Technická 2, 166 27 Praha, Czech Republic*
(5) *INB, Kø benhavns Universitet - Juliana Maries Vej, 30, DK-2.100 Kø benhavn, Denmark*
(6) *DFISTS, EPS, Univ. de Alicante - Apartado de Correos, 99, E-03.080 Alicante, Spain*
(7) *INTEGRAL Scientific Data Center - Versoix, Switzerland*
(8) *EELM (CSIC) - E-29.750 Algarrobo Costa (Málaga), Spain*
(9) *ESAt (INTA) - Carretera A-494, Km. 33, E-21.130 Mazagón (Huelva), Spain*
(10) *DCEyTE (INTA) - Carretera de Ajalvir, Km. 4, E-28.850 Torrejón de Ardoz (Madrid), Spain*

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Summary. — 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).

PACS 95.55.Cs – Ground-based ultraviolet, optical and infrared telescopes.
PACS 95.75.De – Photography and photometry (including microlensing techniques).
PACS 95.75.Fg – Spectroscopy and spectrophotometry.
PACS 98.70.Rz – γ-ray sources; γ-ray bursts.
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1. – A stereoscopic system

BOOTES, the *B*urst *O*bserver and *O*ptical *T*ransient *E*xploring *S*ystem, is mostly a Spanish-Czech international collaboration that works to fill the paucity of studies on rapid variable astronomical objects. It is specially aimed at the detection and study

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Fig. 1. – The BOOTES-1B set of telescopes and cameras at INTA-CEDEA, South Spain.

of the optical transients (OT) that are generated in conjunction with the elusive GRBs (Gamma Ray Bursts). First light was in 1998 [1]. It is a pioneer robotic observatory for OT follow-ups [2] and it is also part of the ground segment for *INTEGRAL* (see also [3,4]).

BOOTES-1, the main BOOTES observatory, is located in Mazagón (Huelva), a very dark sky area in southern Spain, and it is hosted by the INTA (Instituto Nacional de Técnica Aeroespacial) in its "Centro de Experimentación del Arenosillo". It has two domes (BOOTES-1A and BOOTES-1B) that shelter three Schmidt-Cassegrain telescopes and several wide field cameras (fig. 1). Following complementing schemes, all instruments carry out systematic explorations of the sky each night [5, 6] responding to GRB alerts at any time by means of a RTS-2 control system under Linux [7].

A second observatory (BOOTES-2) is in operation since 2002. It is located at at "La Mayora" (Málaga), a research centre under the auspices of the CSIC (Consejo Superior de Investigaciones Científicas), 240 km away from each other. This allows to simultaneously observe the same field of the sky from both locations. Thus, using parallax, it can discriminate against near Earth detected sources up to a distance of 10^6 km. An existing radiolink allows to access remotely the images. The instrumentation is reported on table I([1]).

Although it was first thought as a tool to perform rapid searches of GRB optical counterparts, BOOTES has also participated in the study of meteor storms. Additionally, it has accumulated an enormous database of sky images to study objects which exhibit short-lived variations.

([1]) See `http://laeff.inta.es/BOOTES/ for additional information.`

TABLE I. – *BOOTES current instrumentation (as of 2005).*

	Device	Field of view	Limiting magnitude
BOOTES-1A WF3	tele 400 mm f/3.3	5°	$R_{lim} = 16.0$ (600 s)
BOOTES-1B NF4	SC200 mm Øf/6.3	20′	$V_{lim} = 16.5$ (300 s)
BOOTES-1B NF5	SC200 mm Øf/6.3	20′	$I_{lim} = 15.4$ (300 s)
BOOTES-1B WF6Spec	SC300 mm Øf/6.3	20′	$V_{lim} = 13.0$ (300 s)
BOOTES-1A AS7	16 mm f/2.8	150°	$R_{lim} = 10.0$ (30 s)
BOOTES-2 NF8	SC300 mm Øf/3.3	30′	$I_{lim} = 16.2$ (300 s)
BOOTES-2 WF9	50 mm f/2.0	16°	$I_{lim} = 12.5$ (300 s)
BOOTES-2 AS10	16 mm f/2.8	150°	$R_{lim} = 10.0$ (30 s)

2. – Scientific results

Since 1998 BOOTES has responded to more than 60 GRB triggers with different results [8, 9]. The majority of the follow-ups has provided upper limits to the GRB optical emission despite the prompt response, thus ratifying the elusiveness of these phenomena. Here we present the most significant results.

2·1. *Long-duration GRBs*

2·1.1. Simultaneous observations. GRB 010220: it was the first time that a long/soft GRB error box was imaged by a CCD camera prior to the beginning of the burst, during the entire burst and after it. The first image began 52 seconds before the γ-ray event registered on 20th February 2001 and covered the first 8 seconds of it. The second one covered from 68 to 128 seconds after the trigger. No OT was detected in any of these images. This can be attributed to the high extinction ($A_V = 3.3$ magnitudes) in this direction, at only 1.38° from the galactic plane [10]. Upper limits of $R = 10$ and 11.5 were derived for GRB 030115 [11] and GRB 030226, respectively [12]. In the latter case, an optical afterglow was discovered few hours after the event and it was possible to constraint the reverse shock emission [13]. Further upper limits were reported for GRB 041016 [14], GRB 041219, GRB 041214 and GRB 041226 [15].

2·1.2. Follow-up observations. The only positive detection so far is SN2003dh/GRB 030329, that was detected ~ 30 h after the event at the BOOTES-1B station, at $V \sim 16.4$. Additional upper limits were reported for GRB 000126, GRB 040913 and GRB 041008.

2·2. *Short-duration GRBs*

2·2.1. Simultaneous observations. Excluding GRB 020531 (imaged under poor meteorological conditions [16]), GRB 021201 was the first case for which a short/hard GRB error box was imaged by a CCD camera prior to the beginning of the burst, during the entire burst and after it. The limiting magnitude was $R = 10$ [17].

2·2.2. Follow-up observations. Besides a follow-up observation to the short/hard burst GRB 000607 [18, 19], on 13th March 2000 BOOTES responded to a GCN alert and started exposing at the given coordinates, 4 minutes after the GRB trigger by BATSE (Burst and Transient Source Experiment). The image was in the I band, 5 minutes long and going down to 13th magnitude.

A 9th magnitude source, not present in the Digital Sky Survey, was found in the said image. After this first image, and because of the big error box given by BATSE, BOOTES started a mosaic around this field, so no other image was taken at the original position until 49 minutes had elapsed since the trigger. By then further imaging revealed that the source had faded away. The results are discussed in [20].

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