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Building the BOOTES world-wide Network of Robotic telescopes

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Abstract. We show the status of the BOOTES Network, which is expanding worlwide with four autonomous robotic observatories already deployed in Spain, New Zealand and China. We briefly discuss the technical as well as the sciencific aspects we have already achieved and the goals we are aiming at.

Keywords : gamma-ray bursts, supernovae, multiwavelength astronomy

1. Introduction

Here we describe the (B)urst (O)bserver and (O)ptical (T)ransient (E)xploring (S)ystem (BOOTES), a set of instruments that was conceived in 1995 and has contributed significantly to the understanding of astrophysical transients and other high-energy phenomena in the Universe.

The first observing station (named BOOTES-1) is located at El Arenosillo (Huelva), a dark-sky site in Spain owned by the Instituto Nacional de Técnica Aerospacial (INTA), and the first light was achieved in 1998. The second Spanish station was placed at the Estación Experimental de La Mayora (Málaga), 240 kms apart. The latter is run by the Consejo Superior de Investigaciones Científicas (CSIC). First light was achieved in 2001. The third station (first one abroad) was placed at Vintage Lane Observatory in Blenheim (New Zealand) in collaboration with University of Auckland. First light was achieved in 2009. The fourth station was placed at Lijiang Astronomical Observatory (depending from Kumming Astronomical Observatory, China). First light was achieved in 2012. All the units are placed under a special enclosure, opens automatically according to weather conditions and are designed by our team in collaboration with a Spanish company.

2. Technical details

The four subsystems comprising each BOOTES station are:

2.1 The enclosure and related weather/imaging sensors

The enclosure design has been evolved since the first design of the BOOTES-1 enclosure in 1998. Nowadays, at 2.5m above the ground level, the enclosure has a 3.3m x 3.3m plant, 2m height, which holds the two dome halves, which are especially designed to be completely open thus allowing to access any part of the sky minimizing the dome seeing as well. The design is slightly different depending on the given location. Thus, a hydraulic system is preferred at the BOOTES-2 station (45 m a.s.l.) and a electrical 4-motors system is preferred at the BOOTES-4 station (3250 m a.s.l.).

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Weather sensors (a meteorological camera, a precipitation sensor and a cloud sensor) and surveillance cameras (inside and outside the dome) are working in real time so the domes are opened/closed in less than 30-s according to the measured parameters, under the control of programmable relay control unit.

2.2 The CASANDRA cameras

Each BOOTES station is equipped with a CASANDRA camera. CASANDRA stands for (C)ompact (A)ll-(S)ky (A)utomated (N)etwork (D)eveloped for (R)esearch in (A)stronomy. Images are obtained every minute showing the sky conditions and detecting all stars brighter than 8th magnitude close to the horizon and reaching 10th magnitude at zenith (See Fig. 1). The CASANDRA database goes back to 2002 (Castro-Tirado et al. 2008) and images are normally stored at a pace of 1 every minute. The design for the CASANDRA devices is based on features the and technical details given in Table 1.

2.3 The telescope and narrow field camera

Each one of the BOOTES telescope have 600 mm aperture featuring a Ritchey-Chretien design at f/8 beam. The ultralight optics allow to accommodate them on

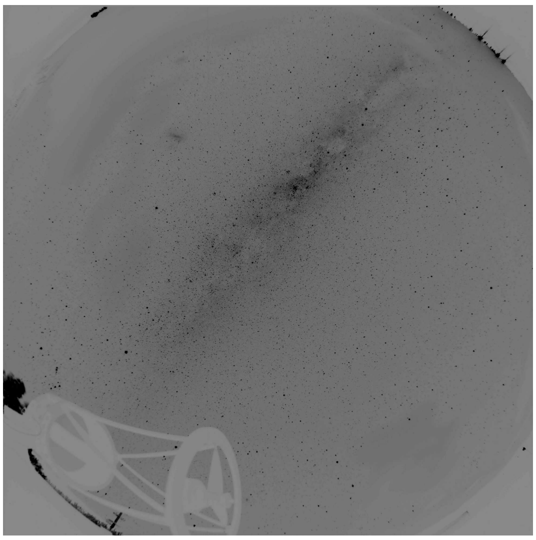

Figure 1. A CASSANDRA-3 image of the Southern sky obtained in 2009 at the BOOTES-3 station in Blenheim (New Zealand), showing the silhouette of the 60cm diameter Yock-Allen telescope against the starry sky crossed by the Milky Way.

Table 1. Features of the Bootes Cassandra cameras.

Lens	16 mm @ f/2.8
CCD	4096 x 4096 pixels
field of view	180° (diagonal)
angular resolution	2.2’
limiting magnitude (30-s)	R ~ 8-10 (from horizon to the zenith)

Table 2. Features of the BOOTES Telescopes (TELMA at BOO-2; YA at BOO-3; MET) at BOO-4 and the corresponding NF Cameras.

Mirror	600 mm diameter primary mirror (RC) @ f/8
CCD	1024 x 1024 pixels
field of view	10’ x 10’
angular resolution	0.59”
limiting magnitude (30-s)	r’ ~ 18

a carbon-fiber truss structure so the overall weight (about 70 kg) can be used on a fast slewing mounts to achieve high slewing speeds (up to 100 deg/s) and accelerations (up to 10 deg/s^2) so any part of the sky is accessible in less than 8s (see Fig. 2).

All CCD cameras at the telescope foci are identical, i.e. EMCCDs 1024 x 1024 pixels, covering a 10’ FOV. A set of 6 para-focal filters are used at each station: clear, Sloan g’r’i’ and WFCAM/VISTA Z and Y.

Table 2 displays the main characteristics of the BOOTES telescopes.

Figure 2. The TELMA telescope at the BOOTES-2 astronomical station in Spain, also showing the fully-opened enclosure.

2.4 The observatory manager rts2

Each astronomical BOOTES station is running under RTS2, the (R)obotic (T)elescope (S)ystem version 2, an open source project aimed at developing a software environment for control of a fully robotic observatory. RTS2 consists of various components which communicate via an ASCII based protocol. The protocol has benefited from an initial design as it was from the beginning intended for an astronomical observatory control system. Thus it provides some unique features which are hard to find in the other communication systems (see the description in Kubánek (2010)).

3. Brief overview of scientific results

3.1 Meteors and Fireballs

CASSANDRA scientific applications are the search for simultaneous optical emission associated to gamma-ray bursts, study of meteor showers, and determination of possible areas for meteorite recovery from the reconstruction of fireball trajectories. This last application requires at least two such devices for simultaneously recording the sky at distance of the order of ∼ 100 km.

Bright fireballs have also been recorded (e.g. Trigo-Rodrguez et al. (2003)), allowing the determination of trajectories, as in the case of the fireball of 30 July 2005. This device is a very promising instrument for continuous recording of the night sky with moderate angular resolution and limiting magnitude (up to $R \sim 10$ mag).

3.2 Gamma-Ray Bursts

GRBs are indeed one of the main scientific goals of BOOTES. We know that GRBs arise at cosmological distances (with mean redshift $z \sim 2.5$ and redshifts in the range ∼0.01 to ∼ 10), with huge isotropic equivalent radiated energy, and small timescales (in the range few ms to 10^2 s), thus implying a small emitting regions (< ct). The spectrum is non-thermal and relativistic outflows ($\Gamma > 100$) are involved. A frequent assumption is that short and long GRBs (with the short ones representing 1/3 of the overall GRB population) are due to different progenitors leading to the same succession of events: formation of a compact object and ejection of a relativistic outflow which produces the (long-lasting) afterglow at other wavelengths. The standard models were developed by Meszaros & Rees (1997) and also by Paczynski & Rhoads (1993) to understand the prompt and afterglow emissions.

3.2.1 *Prompt optical emission*

Following the first event (GRB 990123), detected by ROTSE (Akerlof et al. 1999), the main observational results obtained so far by robotic telescopes are: i) GRB 080319B reaching 5.6 peak magnitude; ii) Bright in the optical even at high redshifts; iii) Correlation/non correlation behavior with gamma-rays (on a case by case basis).

More than 20 gamma-ray burst (GRB) error boxes (most containing long/soft events but 2 including short/hard GRBs) have been imaged simultaneously to the gamma-ray emission, but no optical emission has been detected, thus setting up some constrains on the prompt phase at optical wavelengths (Castro-Tirado et al. 2008).

3.2.2 *Reverse shock*

The reverse shock is due to the interaction with the surrounding medium, a reverse shock propagates within the ejecta. It is usually believed to contribute to the prompt emission (optical flash) and/or the early afterglow. For an uniform shell, the reverse shock is short-lived. An important assumption is that the reverse shock micro-physics parameters are equivalent to the internal shock micro-physics parameters and different (in both cases) to the forward shock ones. If the outflow is variable, the reverse shock can be much more complicated than this simple picture and can even be long-lived Thus, the strength of the reverse shock depends on magnetization content of the ejecta (see Zhang, Kobayashi & Meszaros (2003) and Gomboc A. et al. (2009)).

The BOOTES observations have also helped to constrain a few of these cases.

3.2.3 *Forward shock*

The afterglow is usually interpreted as the signature of the deceleration of the relativistic outflow (the forward shock) by the external medium. with several aspects being discussed previously: i) Dynamics (Blandford & McKee 1982) and McKee 1982); ii) Micro-physics (ϵ_e, p, ϵ_B); iii) Synchrotron radiation (Sari, Piran & Narayan 1998); iv) the effect of a stellar wind (Chevalier & Li 2000); and v) Spherical outflows and jets (Rhoads 1997).

BOOTES-1 follow-ups have been partially summarize by Jelinek M. et al. (2011). Recently, BOOTES has continued discovering optical afterglows. For instance, GRB 080330, GRB 080603B, GRB 080605, GRB 080606 (Jelinek M. et al. 2011) and GRB 101112A (de Ugarte Postigo et al. 2010). BOOTES-2 and BOOTES-3, with larger diameter telescopes, have also contributed to some detailed studies on the forward shock evolution, as in the case of GRB 080603B, GRB 080605 and GRB 080606

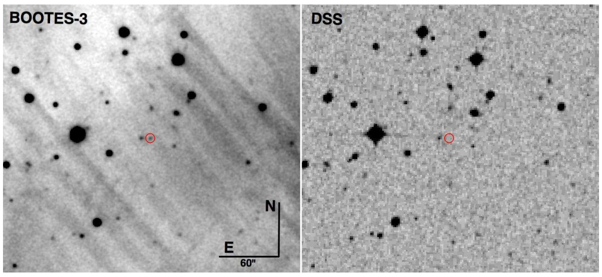

Figure 3. The BOOTES-3 discovery image of the GRB 091029 optical afterglow. Figure taken from de Ugarte Postigo et al. (2010).

(Jelinek 2013) including the discovery of the optical afterglows to GRB 091029 (Fig.3) and GRB 091208B.

On the aggregate, BOOTES-1 have followed ~ 40 events, detecting 10 afterglow, BOOTES-2/TELMA have followed up 9 events, detecting 3 afterglows, whereas BOOTES-3/YA have followed up 17 events, detecting 5 afterglows.

The data gathered so far by robotic instruments (including BOOTES) coupled to larger diameter telescope data, have shown that after the initial *Swift* results, the picture has turned out to be more complicated: the canonical *Swift* X-ray afterglow lightcurve presents five distinct regions (Nousek et al. 2006): i) a steep decline; ii) a shallow slope; iii) the classical afterglow; iv) a jet break/late plateau; and v) flares (mostly in X-rays). But this is not usually seen at optical wavelengths, being especially noticeable the fact that the break times in these two wavelengths use to differ in many cases.

3.3 Miscellanea

The BOOTES network is also regularly monitoring several kind of objects, ranging from minor planets, micro-lensing events and variable stars in our Galaxy to extragalactic supernovae and distant blazars.

4. Conclusions

We have shown the advances in establishing the worldwide network of BOOTES telescopes in different locations of the globe. BOOTES has played a significant role in the gamma-ray burst field over the last decade. Multiwavelength observations (photometry, spectroscopy, polarimetry) are ideal to better understand the GRB diversity and the contamination by other astrophysical objects (Castro-Tirado et al. 2008, 2013). Technological developments are also required, at both ground-based facilities (instruments, robotic and rapid reacting systems) and space (forthcoming space-borned missions). A synergy between network of robotic observatories like BOOTES and space-borned instruments is most essential to better understand the zoo of transient sources in the Universe.

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