Detection of an optical transient following the 13 March 2000 short/hard gamma-ray burst *

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Abstract. We imaged the error box of a gamma-ray burst of the short (0.5 s), hard type (GRB 000313), with the BOOTES-1 experiment in southern Spain, starting 4 min after the $\gamma$-ray event, in the $I$-band. A bright optical transient (OT 000313) with $I = 9.4 \pm 0.1$ was found in the BOOTES-1 image, close to the error box (3$\sigma$) provided by BATSE. Late time $VRJK$-band deep observations failed to reveal an underlying host galaxy. If the OT 000313 is related to the short, hard GRB 000313, this would be the first optical counterpart ever found for this kind of events (all counterparts to date have been found for bursts of the long, soft type). The fact that only prompt optical emission has been detected (but no afterglow emission at all, as supported by theoretical models) might explain why no optical counterparts have ever been found for short, hard GRBs. This fact suggests that most short bursts might occur in a low-density medium and favours the models that relate them to binary mergers in very low-density environments.

Key words. gamma rays: bursts – optical transients – techniques: photometric – cosmology: observations

1. Introduction

Gamma Ray Bursts (GRBs hereafter) are flashes of cosmic high energy photons, and they remained for 25 years one of the most elusive mysteries for high energy astrophysicists, the main problem being the lack of knowledge about the distance scale. The detection of counterparts at other wavelengths for the long duration, soft GRBs, revealing their cosmological origin (see van Paradijs et al. 2000 for a recent review). Thus, counterparts to about 30 bursts have been discovered so far with about 25 redshifts measured, but all of them belong to the so called long duration ($\sim 20$ s), soft bursts class that comprises about 75% of all GRBs (Mazets et al. 1981). There are evidences that the two classes of bursts are different: whereas long bursts have softer spectra, short bursts have harder spectra (Dezalay et al. 1996). The latter ones comprise about 25% of all GRBs (Kouvelioutou et al. 1993) and their origin still remain a puzzle. No counterparts at longer wavelengths have

* Based in part on observations made with the BOOTES instruments in South Spain.
been found yet in spite of intense efforts in order to detect the optical, infrared and radio counterparts to several short, hard bursts (Kehoe et al. 2001, Hurley et al. 2002, Gorosabel et al. 2002). Therefore, one of the remaining GRB mysteries is whether the origin of the two populations are substantially different from one another.

Here we present the results of a follow-up observation for one of these short/hard events. GRB 000313 was detected on 13 March 2000, UT 21 h 13 min 04 s by the Burst and Transient Source Experiment (BATSE) instrument aboard the Compton Gamma-ray Observatory (trigger number 8035). The single–peaked gamma–ray burst lasted 0.768 ± 0.458 s, showed substructure and was possibly detected below 50 keV. It reached a peak flux (50-300 keV) of ~1.2 (± 0.1) \times 10^{-7} \text{ erg cm}^{-2} \text{ s}^{-1} and a fluence (≥ 25 keV) of ~2.6 (± 1.7) \times 10^{-7} \text{ erg cm}^{-2}. The gamma-rays properties as well as the duration of the burst make from GRB 000313 a clear short/hard gamma-ray burst. The original BATSE position reported through the GCN/BACODINE Network (Barthelmy et al. 1998) was R.A.(2000) = 13h 31m, Dec(2000) = +27° 10’ which was later on refined to R.A.(2000) = 13h 11m, Dec(2000) = +10° 14’.

2. Observations

We obtained I-band and unfiltered images with the wide field CCD cameras of the Burst Observer and Optical Transient Exploring System (BOOTES-1) (Castro-Tirado et al. 1999a) beginning 4 min after the event (13 Mar, UT 21 h 17 min). The image taken with the ultrawide field CCD camera (a 1,524 x 1,024 pixel CCD attached to a 18-mm f/2.8 lens yielding 1′.64/pixel) covered the original BATSE error box whereas a mosaic of 9 images was performed with the wide field CCD camera (a 1,524 x 1,024 pixel CCD attached to a 50-mm f/2.0 lens yielding 0′.64/pixel) in order to cover the full error box. The narrow field CCD camera at the Cassegrain focus of the 0.3-m BOOTES-1 telescope (yielding 2′/pixel) imaged part of the field starting on 14 March, 00 h 05 min (4.8 hr later), once the OA was confirmed by the BOOTES team. Further observations were made the same night with the CCD camera at the 1.0-m Jacobus Kapteyn Telescope (JKT) at La Palma under very poor seeing conditions and with the 1.55-m Telescope at the U.S. Naval Observatory (USNO) in Flagstaff. Late time observations were obtained with the MAGIC NIR camera on the 1.23-m telescope at Calar Alto (CAHA) and with the ALFOSC instrument on the Nordic Optical Telescope (NOT) at La Palma. Table 1 report the list of observations. All frames were de-biased and flat-fielded using standard procedures.

3. Results

A comparison of the frames acquired by the BOOTES-1 wide field CCD on Mar 13, 21 h 17 min UT and Mar 13, 22 h 09 min UT revealed an optical transient (OT) (see Figure 1) at R.A.(2000) = 13h 50m 07.9s, Dec(2000) = +31° 16’ 49″ (± 3″) (Castro-Tirado et al. 2000). The object is not detected in the rest of BOOTES-1 images covering the OT position that were taken during the night, starting at 22 h 09 min UT. Using aperture photometry software, we could determine the magnitude of the optical transient in the image as $I = 9.4 \pm 0.1$, by com-
comparison with secondary standards in the field (Henden 2000). The object is not present in the simultaneous ultrawide field CCD frame taken with the 18mm lens at 21 h 17 min UT, but only an upper limit of \( R > 9.1 \) can be derived, which explains the non-detection. Late-time observations, carried out between 40 days and \( \sim 2 \) year later, have failed to reveal any quiescent source within the OT error circle down to \( V \sim 23.5, R \sim 24.5, I \sim 23.5 \) and \( K^\prime \sim 18.0 \) (Figure 2).

### 4. Discussion

#### 4.1. The reality of the object

The OT is point-like, with the same point-spread-function (PSF) as other field stars. The PSF of the OT image (and also of comparison stars in the field) was fitted with a two dimensional Gaussian function, making use of the nonlinear least-squares Marquardt-Levenberg algorithm. From the fitted profiles it follows that the OT it a real star-like object. We can also exclude a glint of a satellite (for example a Molniya satellite, i.e. with an inclination larger than 60°) because the image is not trailed in spite of being exposed for 300 s, as seen is many of the BOOTES database images. Moreover, a search on satellite databases has given negative results. During this time frame, within 0.5 degrees of this position, there was only one satellite, namely NORAD no. 14,473, this is a small piece of debris of a rocket launch with a radar cross section of \( 0.05 \) m\(^2\). It appears on a track that remains at 0.5° away from the measured position of the OT and the track it follows in the sky never gets closer than 0.5 degrees. More importantly, this satellite is tiny, and is at a range of \( \geq 3,000 \) km. Even under full sun conditions, magnitude 10 is difficult to believe for this object. In reality, the orbit is deeply into the Earth’s shadow, almost \( 1,000 \) km. Under such conditions, only moon-light could reflect off of it, which renders it at least 13 magnitudes fainter, and definitely fainter than mag 18. So, under no conditions can the optical transient be this satellite. There are no other known candidate satellites to explain it. In addition, the tiny angular extent of the observed optical signal (0.03°), tells that for this to be a satellite, it would have to have been an optical glint or flash of very short duration (< 0.25 s). An airplane flash is ruled out as no other such event is detected in the full 16° x 11° field of view. We can also exclude a cosmic-ray (CR) mimicking an OT as the mean rate of CR in the BOOTES ST-8 CCD cameras is 0.1 min\(^{-1}\) cm\(^{-2}\), i.e. 0.06 in a 300-s typical exposure. The probability of having a CR with a PSF similar to that of a star in the field is \( \leq 10^{-2} \), thus this possibility can be significantly reduced (\( P \leq 6 \times 10^{-4} \)). A head-on meteor cannot be completely ruled out, although is extremely improbable, of order of \( < 10^{-6} \) (Hudec 1993, Varady and Hudec 1992). Moreover, the PSF analyses indicate no detectable trailing for the image.

#### 4.2. A relationship to GRB 000313?

The OT 000313 is \( 23^\circ \) from the center of the refined BATSE error box (the so-called Huntsville position). The statistical-only error radius is \( 7.6^\circ \), and the total error is best described by a two-component model, sum of two Gaussians, Briggs et al. (1999). Thus, the OT lies at \( 3.0\sigma \) from the center of the refined GRB 000313. The fact that this event was not detected by any other satellite resulted in the lack of a more accurate position from the high-energy data itself. The temporal coincidence between the burst and the OT strength a relationship.

In the GRB fireball model the prompt optical flash seen in GRBs is thought to arise when a reverse shock moves into the ejecta (Sari and Piran 1999), whereas the afterglow emission that starts few minutes after the event is thought to be due to the relativistic matter undergoing external shocks with the interstellar medium that surrounds the central engine (Mészáros and Rees 1997). If the OT 000313 is related to the GRB 000313 and we assume a power-law decay with the flux \( F \propto t^{-\alpha} \) then, the derived power-law decay index is \( \alpha \geq 2.2 \), only comparable to the steepest GRB optical afterglows (Castro-Tirado et al. 2001). Figure 3 shows the light curve of the OT 000313 superimposed to the light curve of the GRB 990123 event for which a prompt optical flash was detected (Akerlof et al. 1999). The OT 000313 data are consistent with a fast decay similar to that of GRB 990123 (\( \alpha = 2.1 \), Akerlof et al. 1999) but with the absence of the optical afterglow (that started at about 0.01 day after the occurrence of GRB 990123). We can interpret this observational fact considering that only prompt optical emission has been detected in the OT 000313 but no optical afterglow emission at all. No radio afterglow emission was detected either (Berger et al. 2000, Frail 2000), just like none has ever been found in other short, hard GRBs (Gorosabel et al. 2002, Hurley et al. 2002).

Although the origin of the long duration, soft GRBs seems to be widely accepted as the collapse of massive stars (Bodenheimer and Woosley 1983, Woosley 1993), the origin of the short duration, hard GRBs is still an open question. It has been proposed that the extremely brief bursts (< 100 ms) might be due to primordial black hole (BH) evaporation
Fig. 3. The light curve of the OT 000313 (I-band, star, upper limits and solid line) superimposed to the light curve of the long-duration GRB 990123 (R-band, empty circles and dashed line), the only burst for which a prompt optical flash has been detected. The OT 000313 data are consistent with a prompt optical flash fast decay ($\alpha \geq 2.2$) comparable to that of the GRB 990123 ($\alpha = 2.1$) but with the absence of an optical afterglow (that started at about $T_0 + 0.01$ day in the GRB 990123). The GRB 990123 data are taken from Akerlof et al. (1999), Castro-Tirado et al. (1999b) and references therein.

(Hawkin 1974, Cline et al. 1999) although most of the short, hard burst population is thought to be due to binary mergers (Narayan et al. 1992). Lifetimes of neutron star–neutron star (NS) systems are of the order of $\sim 10^5$ yr, and large escape velocities are usual, putting them far away from the regions where their progenitors were born. Therefore, the GRB progenitors in the binary merger model context would be located in very low density regions, where no afterglow emission is expected. The likely result is a Kerr black hole and the energy released during the merging process is $\sim 10^{54}$ erg, provided that the disk is sufficiently small and the accretion is driven by neutrino cooling (Narayan et al. 2001). In that case, the expected duration of the relativistic wind (i.e. the GRB) is $\sim 1$ s. A similar “output” would be expected from a NS–BH merger (Paczynski 1991).

Theoretical models have recently claimed that short GRBs only could exhibit very faint optical afterglow emission ($R > 23$, a few hours after the gamma-ray event, Panaitescu et al. 2001), therefore consistent with our upper limits. The fact that no host galaxy is found within the error circle down to the above mentioned upper limits is not unusual, due to the fact that most host galaxies are fainter than $R = 24$ ($R = 24.8$ is the median apparent magnitude, Djorgovski et al. 2001). If the OT 000313 is related to the short GRB 000313 then, the fact that only prompt optical emission has been observed (and no optical afterglow emission) might explain the fact that no other optical counterpart for the short GRB class has been detected. These observational facts might indicate that short GRBs occur in a low-density medium, favouring the models that relate them to binary mergers in galactic haloes or in the intragalactic medium.

5. Conclusions

If the OT 000313 is indeed related to the short GRB 000313 then, the fact that only prompt optical emission has been observed (and no optical afterglow emission) might explain the fact that no other optical counterparts for the short GRB class has been detected. These observational facts might indicate that short GRBs occur in a low-density medium, favouring the models that relate them to binary mergers in galactic haloes or in the intragalactic medium.

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