Observational constraints on the afterglow of GRB 020531

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Abstract. We present the data acquired by the TAROT automated observatory on the afterglow of GRB 020531. Up to now, no convincing afterglow emission has been reported for this short/hard GRB at any wavelength, including X-ray and optical. The combination of our early limits, with other published data allows us to put severe constraints on the afterglow magnitude and light curve. The limiting magnitude is 18.5 in R band, 88 minutes after the GRB, and the decay slope power law index could be larger than 2.2.

Key words. gamma-ray : bursts

1. Introduction

Since their first detection by van Paradijs et al. 1997, gamma-ray burst (GRB) optical afterglows have been detected in about 40% of the sources displaying an X-ray afterglow. The fireball model (Rees and Meszaros 1992, Mészaros and Rees 1997, Panaitescu et al. 1998) has been established as a standard tool to interpret these observations. In this framework the afterglow emission is described as synchrotron and inverse Compton emission of high energy electrons accelerated during the shock of an ultra-relativistic shell with the external medium, while the prompt emission is due to the internal shocks produced by shells of different Lorentz factors within the relativistic blast wave (see Piran 1999 for a review). Both the prompt emission and early afterglow phases provide critical information to establish the physical processes at work during the burst itself, as well as the physical conditions of the surrounding environment (Kumar and Panaitescu 2000, Kumar and Piran 2000). There is a general consensus that the fireball plasma is constituted by $e^- e^+$ pairs and $\gamma$-ray photons, however the ultimate energy reservoir and the detailed radiation mechanisms are still a challenge to theoretical models.

The situation of 60% of the GRB afterglows which are not observed at optical wavelengths (called dark GRBs) is not clear. As it has been shown in Boër and Gendre (2000), the optical flux is not correlated with the intensity of the X-ray afterglow, nor with the distance. Generally speaking the absence of an optical transient associated with a GRB can be attributed to four, non exclusive, reasons, namely 1) the distance of the source, though this is obviously not the general case, 2) the absorption of the visible light by a dense medium (i.e. dust), 3) the rapid decay of the optical afterglow, and 4) the intrinsic faintness of the source at long wavelengths (i.e. optical, NIR...). However, a few reports of near IR and optical non-detection of GRB afterglows show, that hypothesis 2 is not the main reason (see e.g. GRB 010214, Piro 2001 and subsequent GCN circular available at the URL http://gcn.gsfc.nasa.gov/gcn/other/010214.gcn ). In the absence of rapid simultaneous X-ray and optical measurements, hypotheses 3 and 4 are difficult to evaluate.

It should be noted that for the sub-class of GRBs that exhibit a short duration and a hard spectrum, usually called short/hard GRB (Dezalay et al. 1996, Kouveliotou et al. 1993), no optical counterpart has been detected yet (Hurley et al. 2002, Gorosabel et al. 2002). This is largely due to the scarcity of the observations. If this appears a “general” law, it can be the indication of a different geometry (as viewed from the observer) or of another mechanism for the emission of the afterglow (e.g. Shanthi et al. 1999). Hence, it is important to get rapid and deep measures (or upper limits) on the afterglow emission for GRB sources of all classes, and particularly for the short GRBs.

In this letter we report on the early observations of GRB 020531 performed with the automatic TAROT observatory (Boër et al. 1999). Our data, combined with the data from other telescopes strongly constrain both the magnitude and the decay slope index of the optical counterpart, if any.
2. Observations

2.1. Detection and follow up of the burst

The High Energy Transient Explorer satellite (HETE, Ricker et al. 2000) detected GRB 020531 with the FREGATE and WXM instruments on May 31, 2002 at 0h26min18.73 UTC (Ricker et al. 2002). This event is a short/hard GRB: \( t_{90} = 0.94\text{s} \), \( t_{50} = 0.45\text{s} \), and fluence is \( 8 \times 10^{-7} \text{erg cm}^{-2} \) in the FREGATE 50-300 keV band. The absolute localization was not performed by the flight software and the preliminary coordinates were computed by a ground analysis. The GRB Coordinates Network (GCN - Barthelmy 1997) broadcasted the position at 1h54min22s UT. Twenty-five GCN circulars (GCNC) were published on this event between May 31 and July 25, 2002. In the first very early reports, it appears that no unambiguous optical counterpart was recorded. Five days after the GRB, only four faint sources were detected by the Chandra satellite ACIS-I array (Butler et al. 2002) in the final error box given by the Inter Planetary Network (IPN) published on the July 10th 2002 (Hurley et al. 2002b). The connection of one of these X-ray sources with the gamma-ray transient remains to be confirmed. Complementary informations about the GRB localization can be found in Lamb et al. 2002.

Up to now, none of the suggested optical counterparts of GRB 020531 has been confirmed. In this study we present the data acquired with the TAROT observatory. Our limits are compared with the limiting magnitudes obtained by other observers at different times after the GRB. Given that our data were obtained only 88 minutes after the burst itself, we can infer strong limits both on the optical counterpart magnitude and decay slope.

2.2. Tarot observations

TAROT is a fully autonomous 25 cm aperture telescope installed at the Calern observatory (Observatoire de la Cote d’Azur - France). Its 2° field of view ensures the total coverage of HETE error boxes. This telescope is devoted to very early observations of GRB optical counterparts. A technical description of TAROT can be read in Boër et al. 1999 and in Bringer et al. 2001. The CCD camera is based on a THX7899 Thomson chip. It is placed at the newtonian focus. The focal length is 0.81 meter and the pixel size is 14 microns. The spatial sampling is 3.5 arcsec/pixel. The readout noise is 13 electrons rms and the actual gain is 3.6 photo-electrons/adu. The main feature of this camera is its very short readout time: 2 seconds to read the entire 2048x2048 matrix with no binning.

The first image was taken by TAROT less than 6 seconds after the position of GRB 020531 was provided by the GCN. A series of 11 unfiltered images of 30 seconds was then taken. An automatic preprocessing software gave...
scientific images in the following minutes. We compared them to the Digital Sky Survey (DSS) images. We concluded quickly that no bright new source was present. The limiting magnitude of the individual images, in the Cousin R band, is about 16.7.

Then we coadded the 11 images to improve the signal to noise ratio (see figure 1). A limiting magnitude of 18.5 (compared to the R cousin band) is reached. This limiting magnitude is estimated from comparison with a set of synthetic images computed from the BVRcIC USNOFS all-sky photometry of field (Henden 2002). On figure 2, only stars brighter than Rc=18.5 are plotted.

Three TAROT sources, afterglow candidates, were published in the GCN circulars: sources A and B (Boer et al. 2002) and C (Klotz et al. 2002).

Table 1. Log of the published values of the limiting magnitudes, presented in the chronological order. The first column is the date from GRB (in days). The second is the limiting R magnitude of the image. The third is the GCN circular index of the publication.

| Date   | R lim | GCNC | Instrument         |
|--------|-------|------|--------------------|
| 0.0654 | 18.5  | 1408 | TAROT (D=0.25 m)   |
| 0.0997 | 17.7  | 1406 | D. West (D=0.20 m) |
| 0.1512 | 17.5  | 1404 | Super-LOTIS (D=0.60 m) |
| 0.1831 | 18    | 1400 | NEAT (D=1.2 m)     |
| 0.1859 | 18    | 1401 | SDSS (D=0.5 m)     |
| 0.1873 | 20.5  | 1405 | KAIT (D=0.8 m)     |
| 0.3790 | 18    | 1401 | SDSS (D=0.5 m)     |
| 0.9017 | 24.7  | 1433 | INT (D=2.5 m)      |
| 1.1417 | 23.6  | 1434 | Baade (D=6.5 m)    |
| 1.2352 | 20.5  | 1405 | KAIT (D=0.8 m)     |
| 2.9717 | 25.2  | 1433 | INT (D=2.5 m)      |
| 5.4317 | 25.5  | 1434 | Subaru (D=8.2 m)   |
| 10.1117| 24.0  | 1434 | Baade (D=6.5 m)    |

Source A, RA=15h14min51s DEC=-19°25'06" (J2000.0), R=17.4, cannot be the asteroid number 2 mentioned by Li et al. 2002 in the GCNC 1405, as it was supposed by Boer et al. 2002 in the GCNC 1408. The reason is that it lies in the opposite side of the apparent motion published by Li et al. 2002 in the GCNC 1408. Source B, RA=15h14min57s DEC=-19°28'12" (J2000.0), R=17.1, is a known star visible in DSS and various other images. Anyway, A and B sources lie outside the IPN error box. Source C, RA=15h15min12s DEC=-19°24'24" (J2000.0), R>18.5, is considered as the best TAROT image candidate in the IPN error box. We reproduced the raw images using the calibration frames taken both before and after the night of May 30-31, 2002, and we obtained a fainter source on the new refined co-added images. This meant that source C could be a group of "hot pixel" badly corrected by the automatic preprocessing which uses only the calibration frame taken during the preceding day, to produce synthetic calibration data.

Other fuzzy patches are also seen in the image of TAROT presented in figure 1. All of these patches can be related to known stars fainter than Rc=18.5. However, as the TAROT image is unfiltered, it is not surprising to find these stars (color effects).

2.3. Other Observations

The data reported in various GCN circulars are summarized on table 1. The first column is the delay, in fraction of day, between the burst and the beginning of the observation, the second column gives the limiting magnitude, the third column indicates the GCN circular in which the data was reported, and the last one the instrument used as well as its aperture. For early observations (< 1 day after GRB), only small aperture telescopes (i.e. < 2 meters) scanned the field. During this delay, the better limiting magnitude is 20.5 from the Katzman Automatic Imaging Telescope (KAIT, Li et al. 2002). From later observations...
 (> 1 day), the better limiting magnitude is 25.5 obtained by the Isaac Newton Telescope at La Palma (Salamanca et al. 2002). The limiting magnitudes, summarized in table 1, are displayed on figure 3.

3. Discussion

Up to now, no afterglow of a short/hard GRB was detected. However, it is possible to get some constraints on the optical light curve. The best limits to constrain the light curve for the afterglow of GRB 020531 comes from TAROT, KAIT, and INT data. If GRB 020531 was followed by an optical afterglow, its light curve must lie in the left part of figure 3, below the dashed line.

Before GRB 020531, the earliest optical observations of a short/hard GRB were obtained on GRB 010119 (Gorosabel et al. 2002).

The decay slope index $\alpha$ for an afterglow of a short/hard GRB (assuming flux proportional to $t^{-\alpha}$) is now constrained by GRB 020531 observations. Typical long GRBs afterglow decays are between 0.7 and 1.8, marginally higher than 2 (i.e. GRB 980519, Vrba et al. 2000). Concerning GRB 020531, if the flux of the afterglow was about the limiting magnitude of TAROT ($R = 18.5$ at 1.47 hour after the burst), then its decay slope $\alpha$ must be $> 2.2$. If the afterglow was fainter at this date, the decay slope should have a lower value.

Comparing to the dimmest long GRBs, e.g. GRB 020124 (Berger et al. 2002, see figure 3), it implies that the afterglow of GRB 020531 must be fainter. TAROT upper limit is the first measurement obtained at such early stage for a short/hard GRB. It constrains the afterglow to be very dim. This result is correlated to the 50-300 keV fluence which is one decade fainter than typical those of long GRBs.

If the afterglow exists and decays with a $t^{-\alpha}$ law, and if the source flux was about the limiting magnitude of late observations, one can calculate $R = 22.0$ at 1.47 hour after the GRB (TAROT observations) assuming $\alpha = 1.2$ (the typical case). Obviously, the afterglow can be even fainter if it is dimer than the limiting magnitude of late observations. As a consequence, plans for future searches of afterglows of short/hard GRBs can be addressed: large aperture telescopes, equipped by wide field cameras, should observe early stages (until 1 hour after GRB). Small aperture telescopes could also contribute if they shoot until 15 min after GRB with a limiting magnitude $R > 18$.

4. Conclusion

The afterglow of GRB 020531, if it exists, is very dim, compared to the observed optical counterparts of long GRBs. If the optical counterpart of GRB 020531 is typical of short/hard GRBs, it means that these kind of GRBs are associated to very dim afterglows or no afterglow at all. The observations suggest that the decay slope $\alpha$ could be larger than 2.

It must be mentioned that dim afterglows can be localized only by early optical observations (case of GRB 020124 afterglow, found at 1.67 hour after the GRB).

Of course the possibility that GRB 020531 had no afterglow cannot be excluded. This proves the need to get more sensitive observations of the afterglow, as early as possible after the main event. The TAROT observatory demonstrated that this is possible, provided that the alert is sent quickly by the instrument. The increase in the HETE performances, the recent successful launch of the Currie-INTEGRAL satellite, as well as the perspective of the SWIFT GRB dedicated satellite gives hope that rapid observations of GRB optical counterparts will be soon possible, as it was the case with BATSE (Akerlof et al. 1999, Boër et al. 2001, Park et al. 1999).

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