A&A 454, L119–L122 (2006)
DOI: 10.1051/0004-6361:20065092
© ESO 2006

Astronomy
&
Astrophysics

Letter to the Editor

The bright optical flash from GRB 060117*

M. Jelínek[1], M. Prouza[2,6], P. Kubánek[3,4], R. Hudec[3], M. Nekola[3], J. Řídký[2,6], J. Grygar[2,6], M. Boháčová[2,6], A. J. Castro-Tirado[1], J. Gorosabel[1], M. Hrabovský[2,6], D. Mandát[2,6], D. Nosek[5,6], L. Nožka[2,6], M. Palatka[2,6], S. B. Pandey[1], M. Pech[2,6], P. Schovánek[2,6], R. Šmída[2,6], P. Trávníček[2,6], A. de Ugarte Postigo[1], and S. Vítek[1]

[1] Instituto de Astrofísica de Andalucía (IAA-CSIC), Apartado de Correos, 3.004, 18080 Granada, Spain
e-mail: `mates@iaa.es`
[2] Fyzikální ústav AV ČR, Na Slovance 2, 182 21 Praha 8, Czech Republic
[3] Astronomický ústav AV ČR, Fričova 298, 251 65 Ondřejov, Czech Republic
[4] *INTEGRAL* Science Data Centre, Ch. d'Ecogia 16, 1290 Versoix, Switzerland
[5] Ústav částicové a jaderné fyziky, MFF UK Praha, V Holešovičkách 2, 180 00 Praha 8, Czech Republic
[6] For the Pierre Auger Collaboration

Received 26 February 2006 / Accepted 30 May 2006

ABSTRACT

We present a discovery and observation of an extraordinarily bright prompt optical emission of the GRB 060117 obtained by a wide-field camera atop the robotic telescope FRAM of the Pierre Auger Observatory from 2 to 10 min after the GRB. We found rapid average temporal flux decay of $\alpha = -1.7 \pm 0.1$ and a peak brightness $R = 10.1$ mag. Later observations by other instruments set a strong limit on the optical and radio transient fluxes, unveiling an unexpectedly rapid further decay. We present an interpretation featuring a relatively steep electron-distribution parameter $p \simeq 3.0$ and providing a straightforward solution for the overall fast decay of this optical transient as a transition between reverse and forward shock.

Key words. gamma-rays: bursts

1. Introduction

After the establishment of the GRB Coordinates Network (GCN) (Barthelmy et al. 1995) in 1995, the technical advances have enabled a fast and reliable dissemination of satellite gamma-ray burst (GRB) data to ground-based observers. Subsequently, wide use of the sophisticated robotic follow-up systems has led to the first insight into the very early phases (less than 5 min after trigger) of the optical transients (OTs) accompanying some GRBs. However, despite the extended efforts, optical data at the very early stages are still sparse, so the whole picture remains unclear.

The definition of the prompt optical emission was given by Piran (1999) as the optical emission arising during the γ-emission period. This early emission is usually explained in terms of either a reverse or an internal shock (Sari & Piran 1999). With a certain delay after the GRB, the afterglow – emission due to the forward shocks – starts to dominate the steeply decaying prompt emission. This transition flattens the lightcurve. The original rapid decay of the prompt emission slows down to a more modest decay due to the afterglow. It is generally accepted that the physical mechanisms of the prompt emission and the afterglow are distinct. The distinction is probably not absolute, some observations suggest (cf. Chincarini et al. 2005) that at least the X-ray intensity of the early emission phases can be extrapolated from the GRB emission itself.

In this letter we present the observation of a very bright optical transient associated with GRB 060117 observed by the robotic telescope FRAM.

2. Observations

A bright long-soft GRB 060117 was detected by *Swift* satellite on January 17, 2006, at 6:50:01.6 UT. It showed a multi-peak structure with $T_{90} = 16 \pm 1$ s with maximum peak flux 48.9 ± 1.6 ph cm^{-2} s^{-1}. Coordinates computed by *Swift* were available within 19 s and immediately distributed by GCN (Cummings et al. 2006).

FRAM received the notice at 06:50:20.8 UT, 19.2 s after the trigger and immediately started the slew. The first exposure started at 06:52:05.4, 123.8 s after the GRB. Eight images with different exposures were taken before the observation was terminated. A bright, rapidly decaying object was found, and its presence was reported by Kubánek et al. (2006) and Jelínek et al. (2006) soon after the discovery. The point-spread function of the object is similar to the stars in the image, and the object did not move more than 2″ over the course of our observation, ruling out a near-Earth object crossing the field of view. The weather conditions during the observation were very good, but the Moon was nearly full (93%) and the GRB location was only slightly more than 5° above the horizon. Consequently, the magnitude limits of our observation were ~2.5 mag worse than the technical limit of the FRAM instrument in the optimal conditions. Table 1 displays the log of our observations (see also Fig. 1), where the magnitude errors do not include systematic error of the USNO-B1.0 R1 magnitude, which should be <0.1 mag.

---

[*] Based on observations of robotic telescope FRAM, operated by the Pierre Auger collaboration at Los Leones site, Malargüe, Argentina.

Article published by EDP Sciences and available at http://www.edpsciences.org/aa or http://dx.doi.org/10.1051/0004-6361:20065092

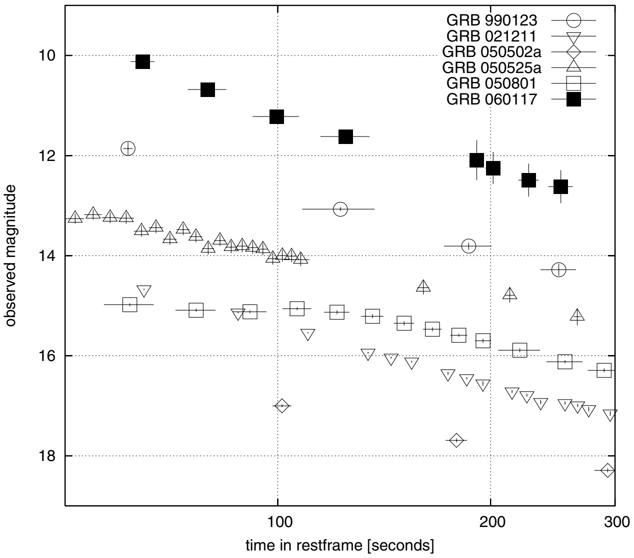

Fig. 1. The optical light curve of GRB 060117 in comparison with other well-covered early GRB optical emissions: GRB 990123 (Akerlof et al. 1999), GRB 021211 (Li et al. 2003), GRB 050502a (Guidorzi et al. 2005), GRB 050525a (Blustin et al. 2006), and GRB 050801 (Rykoff et al. 2006). In this figure we use $z \approx 1.0$ for GRB 060117. Observed R-band magnitudes are shown, except for GRB 050525a, where the V-band values are plotted.

Table 1. Optical R-band photometric observations of the optical flash GRB 060117. The magnitudes are not corrected for Galactic extinction ($A_R \sim 0.01$ mag). $T - T_0$ is mean exposure time since the GRB.

UT Date of exp. start	$T - T_0$[s]	$T_{\rm exp}$[s]	R	δR
2006 Jan. 17.786169	128.8	10	10.12	0.13
2006 Jan. 17.786833	159.1	20	10.68	0.12
2006 Jan. 17.786343	199.3	30	11.22	0.14
2006 Jan. 17.787583	249.7	40	11.62	0.18
2006 Jan. 17.789109	382.4	10	12.09	0.45
2006 Jan. 17.789410	403.4	20	12.25	0.36
2006 Jan. 17.789815	452.9	30	12.49	0.37
2006 Jan. 17.790336	502.9	40	12.62	0.37

An optical counterpart to GRB 060117 was found 128.8 s after the burst at

$$\alpha = 21^{\rm h}51^{\rm m}36\overset{\rm s}{.}23 \quad \delta = -59°58'39\overset{''}{.}3 \quad \pm 1\overset{''}{.}5 \quad ({\rm J2000}).$$

The error amounts to a 1-σ uncertainty including systematic errors.

3. Follow-up

Swift itself could not observe the GRB with its X-ray and optical instruments, because of the Sun observing constraint (Campana et al. 2006). One month later on Feb. 14 and 15, 2006, *Swift* XRT (Burrows et al. 2005) pointed to the burst position and did not detect any source at the corresponding position with a 3-σ limit of 1.0×10^{-3} counts s^{-1}, corresponding to an unabsorbed 0.2–10 keV flux upper limit of 2.3×10^{-14} erg cm^{-2} s^{-1}. The burst was also detected by Konus-Wind (Golenetskii et al. 2006) and by Suzaku WAM (Terada et al. 2006).

Unfortunately, the later optical follow-up was unsuccessful due to cloudy weather in both New Zealand and South Africa. The limits reported by PROMPT (Nysewander et al. 2006) (observations beginning 18.0 h after the burst), however, suggest a surprisingly rapid decay. The search for a radio afterglow was also unsuccessful (Schmidt et al. 2006).

The lag-luminosity pseudo-redshift estimation from *Swift* data yields $z \simeq 1.3 \pm 0.3$ (Cummings et al. 2006). The redshift estimate based on the γ-ray data from Konus-Wind gives $z \simeq 0.45 \pm 0.2$ (Pelangeon & Atteia 2006).

4. Data acquisition and reduction

FRAM is part of the Pierre Auger cosmic-ray observatory (Pierre Auger Collaboration 2005), and its main purpose is to immediately monitor the atmospheric transmission. FRAM works as an independent, RTS2-driven (Kubánek et al. 2004), fully robotic system, and it performs a photometric calibration of the sky on various UV-to-optical wavelengths using a 0.2 m telescope and a photoelectric photomultiplier. As a primary objective, FRAM observes a set of chosen standard stars and a terrestrial light source. From these observations it obtains instant extinction coefficients and the extinction wavelength dependence. Additionally, FRAM is able to follow GCN alerts, using its wide-field camera with a fixed R-band filter.

The wide-field camera consists of a Carl Zeiss Sonnar 200 mm $f/2.8$ telephoto lens, SBIG ST7 imager, and Bessel R-band filter. The ST7 camera has a 768×512 Kodak KAF-0402E CCD that covers a field of view of $120' \times 80'$ with a scale of $9\overset{''}{.}6$/pixel. The effective diameter of the lens is 57 mm and the 3σ limiting magnitude under optimum conditions reaches $R \sim 15.0$ for a 30 s exposure.

The raw images were dark-frame subtracted using a median of several dark-frame exposures. Given the significant dark current of the camera, the darks were treated separately for each exposure time. The flat-field correction was then applied using the median of 40 normalized 1s exposures obtained while mosaicing through the twilight sky. The aperture photometry was done using the `phot` routine in IRAF[1] with the aperture diameter of 2 pixels. To get a precise astrometric position of the source, we used the four most significant images and computed the average position.

The images were astrometrically and photometrically calibrated on the fly using the `past` program in the context of JIBARO (de Ugarte Postigo et al. 2005), using all sources with more than 10-σ significance from the image compared to USNO-B1.0 (Monet et al. 1998) positions and *R1* magnitudes. `Past` employs a sigma-clipped third-degree polynomial surface fit. For the astrometry, an error-weighted mean of the zero point is used. Systematic errors of USNO-B1.0 should be less than $0\overset{''}{.}2$ in the astrometry and less than 0.1 mag for the photometry. Since the Galactic extinction, taken from the maps published by Schlegel et al. (1998) is very low ($E_{B-V} = 0.038$), we neglect this value in the following discussion.

5. Discussion

In the search for the interpretation of the lightcurve, we assume a uniform ISM, and that the influence of the internal shock emission on the lightcurve is negligible because our observation starts ~100 s after the end of the gamma-ray burst.

In the simplest case, the lightcurve can be fitted and a single power law with a temporal flux-decay index $\alpha = -1.73 \pm 0.12$. The χ^2/d.o.f. for this fit is 1.296. If we assume this decay to be a signature of a pure forward shock, we get the value of the

---

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under co-operative agreement with the National Science Foundation.

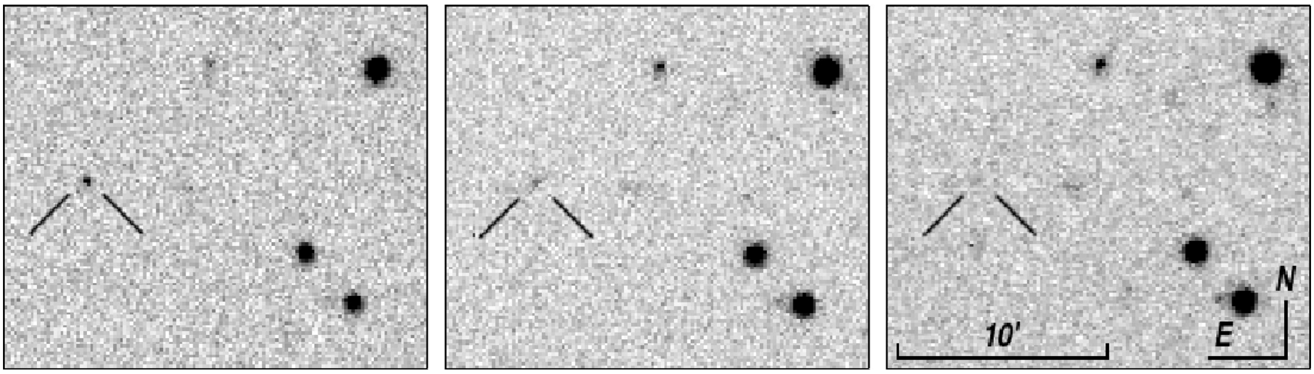

Fig. 2. Details of the surroundings of the optical flash of GRB 060117 as observed by FRAM. Images taken 129, 249, and 480 s after the trigger.

electron energy distribution power-law index $p = 3.3 \pm 0.1$. This value is very high in comparison with other known optical transients, but it is consistent with $p = 3.82^{+1.0}_{-0.5}$ as computed from the Konus-Wind spectra of the GRB (Golenetskii et al. 2006) (cf. Shen et al. 2005). In contrast, if the linear decay is a signature of a pure reverse shock, we get $p = 2.0 \pm 0.1$ – close to the typical value for the optical transients observed so far. We should note that such a reverse shock emission should be accompanied by a forward shock with $\alpha_{\rm F} \simeq -0.7$.

Another possibility (after Shao & Dai 2005) is to interpret the data as a type I lightcurve (as given by Zhang et al. 2003), which depicts a transition between the reverse and the forward shock with the passage of the typical frequency break ν_m through the observed passband at time $t_{m,f}$. We assume the lightcurve is initially dominated by a rapidly falling reverse-shock emission with $F_{\nu,r} \sim t_d^{-(27p+7)/35}$, followed by a forward-shock emission that rises as $F_{\nu,r} \sim t_d^{+1/2}$ before $t_{m,f}$ and then decays with $F_{\nu,f} \sim t_d^{-(3p-3)/4}$. Using a χ^2 minimization fit to this scenario, we obtain $p = 2.96 \pm 0.06$, a magnitude of forward shock maxima $m_{m,f} = 11.82 \pm 0.04$, a time of the maxima $t_{m,f} = 301 \pm 4$ s (after trigger), and a magnitude of the reverse shock at $t = t_{m,f}$ $m_{m,r} = 12.43 \pm 0.05$ (χ^2/d.o.f. for this fit is 0.015). Corresponding decay indices are $\alpha_{\rm R} = 2.49 \pm 0.05$ and $\alpha_{\rm F} = 1.47 \pm 0.03$ (see Fig. 3). If the crossing time $t_\times$ (Zhang et al. 2003) coincides with the end of the GRB (i.e. ~20 s), then we can estimate the peak magnitude of this OT as $R \sim 5$ mag by backward extrapolation.

Note, that this is only one of the plausible interpretations. There may be other possible explanations for this behaviour including density jump in the media (Lazzati et al. 2002) or energy injection (Björnsson et al. 2004). Without a multiwavelength observation it is impossible to distinguish which of these possibilities actually took place.

The position of the burst and its distance from the Sun made the object difficult to observe. PROMPT (Nysewander et al. 2006) shows that the bright OT decayed very fast, and 20 hours after the burst its magnitude was already $I > 21.2$. Using the procedure of Šimon et al. (2001) we transform this limit to the filter of our observation: $R \gtrsim 21.5$ From this limit we then get the estimate of an average late decay as $\alpha_{\rm late} < -1.62$. Among the three interpretations we have shown, only the pure forward shock scenario is compatible with this limit without introducing an unusually early jet break, which is required to explain the other two scenarios.

Soon after the *Swift* trigger, a suspicion of an extremely low-redshift GRB was raised (Tanvir 2006) due to the presence of a nearby galaxy PGC 128172 with $z = 0.04$ in the *Swift* errorbox. However, this discovered transient lies $3'.1$ from this galaxy, accordingly the projected distance – 160 kpc – is approximately four times larger than the visible major diameter of this galaxy. Furthermore, the position angle of the transient with respect to the PGC 128172, which we observe practically edge-on, is 97°. The association of the OT with this galaxy is, therefore, quite unlikely.

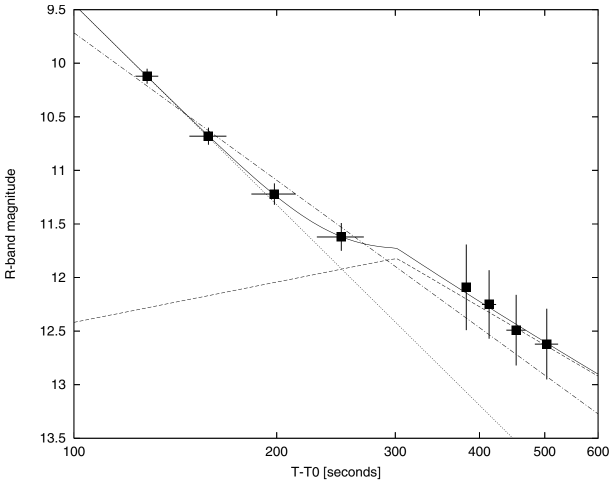

Fig. 3. The *R*-band afterglow lightcurve of GRB 060117. The lightcurve is fitted as a superposition of reverse shock (dotted line) and forward shock (dashed line). The linear fit is plotted by a dot-and-dash line.

6. Conclusions

The GRB 060117 is the most intense (in terms of peak flux) GRB detected so far by Swift. With the maximum brightness of $R = 10.1$ mag, FRAM has discovered one of the optically brightest prompt optical emissions ever detected. The initial optical decay was found to be one of the steepest of an early GRB optical afterglow observed.

We have presented 3 scenarios for explaining the lightcurve. The apparent change in its slope is neglected in two simple scenarios, where we suppose the observed lightcurve to only be the trace of a forward, resp. reverse, shock. In the third (preferred) scenario, the shape of the lightcurve is explained as a transition between reverse and forward shock emission. The forward-shock-only interpretation is flawless regarding the PROMPT limit, but shows rather spurious value of p. The other two scenarios (i.e. those involving reverse shock) result in a relatively slowly decaying forward shock, and later limits require an early jet break $t_{\rm j} \sim 0.2$ d. The detailed analysis of this problem is beyond the scope of this letter.

Progress in further study of the particular case of GRB 060117 depends on the measurement of its distance.

Therefore the follow-up and identification of host galaxy with a large telescope is of high importance.

A larger sample of GRB rapid follow-ups is needed to decide whether this kind of transition, already suggested for other bursts, is common.

Acknowledgements. The telescope FRAM was built and is operated under the support of the Czech Ministry of Education, Youth, and Sports through its grant programs LA134 and LC527.

M.J. would like to thank to the Spanish Ministry of Education and Science for the support via grants AP2003-1407, ESP2002-04124-C03-01, and AYA2004-01515 (+ FEDER funds), M.P. was supported by the Grant Agency of the Academy of Sciences of the Czech Republic grant B300100502. The currently used FRAM wide-field camera was obtained with support from ESA PECS Project 98023.

We would also like to thank Primo Vitale for care for the telescope, Rene Goerlich for his help with Gemini GOTO and Petr Heinzel, the director of the Astronomical Institute of the Academy of Sciences of the Czech Republic, for his generous support during the telescope testing at the site of the Astronomical Institute in Ondřejov.

References

Akerlof, C., Balsano, R., Barthelmy, S., et al. 1999, Nature, 398, 400
Barthelmy, S. D., Butterworth, P., Cline, T. L., et al. 1995, Ap&SS, 231, 235
Björnsson, G., Gudmundsson, E. H., & Jóhannesson, G. 2004, ApJ, 615, L77
Blustin, A., Band, D., Barthelmy, S., et al. 2006, ApJ, 637, 901
Burrows, D. N., Hill, J. E., Nousek, J. A., et al. 2005, Space Sci. Rev., 120, 165
Campana, S., Barthelmy, S., Gehrels, N., et al. 2006, GCN, 4533
Chincarini, G., Moretti, A., Romano, P., et al. 2005 [`arXiv:astro-ph/0506453`], 1
Cummings, J., Barbier, L., Barthelmy, S., et al. 2006, GCN, 4538
de Ugarte Postigo, A., Jelínek, M., Gorosabel, J., et al. 2005, in Astrofísica Robótica en España, ed. A. Castro-Tirado, B. de la Morena, & J. Torres, Madrid, 35
Golenetskii, S., Aptekar, R., Mazets, E., et al. 2006, GCN, 4542
Guidorzi, C., Monfardini, A., Gomboc, A., et al. 2005, ApJ, 630, L121
Jelínek, M., Kubánek, P., Prouza, M., Nekola, M., & Hudec, R. 2006, GCN, 4536
Kubánek, P., Jelínek, M., Nekola, M., et al. 2004, in AIP Conf. Proc., 727, Gamma-Ray Bursts: 30 Years of Discovery
Kubánek, P., Jelínek, M., Prouza, M., Nekola, M., & Hudec, R. 2006, GCN, 4535
Lazzati, D., Rossi, E., Covino, S., Ghisellini, G., & Malesani, D. 2002, A&A, 396, L5
Li, W., Filippenko, A. V., Chornock, R., & Jha, S. 2003, ApJ, 586, L9
Monet, D. B. A., Canzian, B., Dahn, C., et al. 1998, VizieR Online Data Catalog, 1252, 0
Nysewander, M., LaCluyze, A., Reichart, D., et al. 2006, GCN, 4548
Pelangeon, A., & Atteia, J. L. 2006, GCN, 4544
Pierre Auger Collaboration 2005, in Proceedings of the 29th International Cosmic Ray Conference, Pune, India, also the FERMILAB `preprint FERMILAB-PUB-05-469-A-TD`
Piran, T. 1999, Phys. Rep., 314, 575
Rykoff, E., Mangano, V., Yost, S., et al. 2006, ApJ, 638, L5
Sari, R., & Piran, T. 1999, ApJ, 520, 641
Schlegel, D., Finkbeiner, D., & Davis, M. 1998, ApJ, 500, 525
Schmidt, B., Wieringa, M., Frail, D. A., & Soderberg, A. 2006, GCN, 4546
Shao, L., & Dai, Z. G. 2005, ApJ, 633, 1027
Shen, R., Kumar, P., & Robinson, E. 2005 [`arXiv:astro-ph/0512489`]
Šimon, V., Hudec, R., Masetti, N., & Pizzichini, G. 2001, in ESA SP-459: Exploring the Gamma-Ray Universe, 441
Tanvir, N. 2006, GCN, 4534
Terada, Y., Yamaoka, K., Sugita, S., et al. 2006, GCN, 4573
Zhang, B., Kobayashi, S., & Mészáros, P. 2003, ApJ, 595, 950