GRB 030227: The first multiwavelength afterglow of an INTEGRAL GRB


Published in:
Astronomy & Astrophysics

DOI:
10.1051/0004-6361:20031393

Citation for published version (APA):
GRB 030227: The first multiwavelength afterglow of an INTEGRAL GRB


1 Instituto de Astrofísica de Andalucía (IAA-CSIC), Apartado de Correos, 3004, 18080 Granada, Spain
2 Space Telescope Science Institute, 3700 San Martin Drive, Baltimore MD 21218, USA
3 Department of Physical Sciences, University of Hertfordshire, College Lane, Hatfield, Herts AL10 9AB, UK
4 Istituto di Astrofisica Spaziale e Fisica Cosmica, Sez. di Milano “G. Occhialini” – CNR v. Bassini 15, 20133 Milano, Italy
5 Joint Astronomy Centre, 660 N, A’ohoku Place, Hilo, HI 96720, USA
6 State Observatory, Manora Peak, Nainital 263129, Uttaranchal, India
7 Istituto di Astrofisica Spaziale e Fisica Cosmica – Sezione di Bologna, via Gobetti 101, 40129 Bologna, Italy
8 Istituto di Radioastronomia, sezione di Firenze, CNR, Largo E. Fermi 5, 50125, Firenze, Italy
9 Lund Observatory, Sölvegatan 27, PO Box 43, 221 00 Lund, Sweden
10 Astronomical Observatory, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark
11 University Observatory Munich, Scheinerstr. 1, 81679 Munich, Germany
12 Special Astrophysical Observatory of RAS, Karachai-Cherkessia, 369167, Nizhny Arkhyz, Russia
13 Danish Space Research Institute, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark.
14 Grupo de Astrofísica y Ciencias del Espacio, Universidad de Valencia, Apdo. 2085, 46071 Burjassot (Valencia), Spain
15 European Space Agency, Research Science Division, Noorwijk, The Netherlands
16 Thüringer Landessternwarte Tautenburg, 07778 Tautenburg, Germany
17 Max Planck Institut für extraterrestrische Physik, Giessenbachstr., PF 1312, 85741 Garching, Germany
18 University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands
19 Astronomical Observatory of Tiaret, via Tiepolo 11, 34131 Trieste, Italy
20 Astrophysikalisches Institut, An der Sternwarte 16, 14482 Potsdam, Germany
21 Department of Physics and Astronomy, Aarhus University, Ny Munkegade, 8000 Aarhus C, Denmark
22 NASA/MSFC, NSSTC, SD-50, 320 Sparkman Drive, Huntsville, AL 35805, USA
23 European Southern Observatory, Alonso de Córdova 3107, Casilla 19001, Santiago 19, Chile

Received 14 July 2003 / Accepted 10 September 2003

Abstract. We present multiwavelength observations of a gamma-ray burst detected by INTEGRAL (GRB 030227) between 5.3 hours and ∼1.7 days after the event. Here we report the discovery of a dim optical afterglow (OA) that would not have been detected by many previous searches due to its faintness (R ∼ 23). This OA was seen to decline following a power law decay with index \( \alpha_R = -0.95 \pm 0.16 \). The spectral index \( \beta_{\text{opt/NIR}} \) yielded \( -1.25 \pm 0.14 \). These values may be explained by a relativistic expansion of a fireball (with \( p = 2.0 \)) in the cooling regime. We also find evidence for inverse Compton scattering in X-rays.

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

1. Introduction

Gamma Ray Bursts (GRBs) are flashes of high energy (∼1 keV–10 GeV) photons (Fishman & Meegan 1995), occurring at cosmological distances. Since their discovery in 1967, ∼3000 GRBs have been detected in γ rays but only ∼50 have been pinpointed at optical wavelengths in the last six years (Greiner 2003), with redshifts ranging from \( z = 0.0085 \) (Galama et al. 1998) to \( z = 4.50 \) (Andersen et al. 2000).
Fig. 1. INTEGRAL image of GRB030227 in the Crab field during the calibration phase. The image has been obtained in the 15–200 keV range with the IBIS/ISGRI instrument and deconvolved using the IBAS software. The distance between the Crab and the GRB is ∼10°. North is up, East to the left.

ESA’s INTEGRAL satellite offers unique capabilities for the detection of GRBs thanks to its high sensitivity and imaging capabilities at γ-ray energies and X-ray/optical. GRB 030227 was discovered in the INTEGRAL IBIS data by the automatic IBAS software (Mereghetti et al. 2003a) on 27 February 2003 (see Fig. 1). The burst started at 08:42:03 UT and lasted for ≈18 s, putting it in the “long-duration” class of GRBs. It had a peak flux of 1.1 photons cm$^{-2}$ s$^{-1}$ and a fluence of 7.5 × 10$^{-7}$ erg cm$^{-2}$ in the 20–200 keV range (Mereghetti et al. 2003b). The prompt dissemination (50 min) of the GRB position (Götz et al. 2003a,b) enabled triggering of a target of opportunity (ToO) observation with ESA’s XMM-Newton satellite, starting ∼8 hr after the event. This observation revealed a fading X-ray source consistent with the IBIS error circle which was identified as the X-ray afterglow of GRB 030227 (Loiseau et al. 2003; González-Riestra et al. 2003). The INTEGRAL data analysis indicates a soft gamma-ray spectrum for GRB 030227, possibly placing it in the “X-ray rich” class, with the brightest X-ray afterglow detected by XMM-Newton so far (Mereghetti et al. 2003b). Here we report the discovery of the optical afterglow of the GRB, and present further multiwavelength observations.

2. Observations

ToO observations were triggered starting 5.3 hr after the event at the 1.0 m State Observatory telescope (1.0SO) in Nainital (India). Subsequently, observations were made at the Wendelstein 0.8 m telescope (0.8Wend) close to Munich (Germany), at the 2.5 m Isaac Newton Telescope (2.5INT), at the 2.56 m Nordic Optical Telescope (2.56NOT) and the 3.58 m Telescopio Nazionale Galileo (3.58TNG), at La Palma (Spain), and at the 3.6 m telescope (3.6ESO) at the European Southern Observatory, at La Silla (Chile). Near-IR observations were obtained at the 3.8 m United Kingdom Infrared Telescope (UKIRT) on Mauna Kea (Hawaii). Table 1 displays the observing log. We performed aperture photometry using the PHOT routine under IRAF$^1$. The optical field was calibrated using the secondary standard stars provided by Henden (2003). The near-IR images were calibrated using the standard FS114. The RATAN-600 radio telescope in Karachai-Cherkessia (Russia), observed the field at 3.9 GHz during the period Mar. 6–9, 2003.

3. Results and discussion

The deep optical observations taken at the 2.5INT (simultaneously with the XMM-Newton follow-up) revealed a point source within the 6″ radius XMM-Newton error circle, which was proposed as the optical afterglow (OA) to GRB 030227 (Castro-Tirado et al. 2003; see Fig. 2). This identification was confirmed by further optical imaging (Soderberg et al. 2003; Berger et al. 2003; Gorosabel et al. 2003), which showed the source to be fading. An astrometric solution based on 10 USNO A2-0 reference stars in the 2.5INT image taken on 27 Mar. 2003 yields for the OA $\alpha_{2000} = 4^h57^m33.05^s$, $\delta_{2000} = +20^\circ29'05.0''$. The internal error of the position is 0.55″, which has to be added to the 1σ systematic error of the USNO catalogue ($\approx0.25''$ according to Assafin et al. 2001). The final astrometric error corresponds to 0.60″. No radio afterglow was detected with RATAN-600 at the position of the OA down to a flux density limit (3σ) of 2 mJy (at 3.9 GHz).

3.1. The lightcurve of the GRB 030227 OA

Our R band lightcurve (Fig. 3) shows that the source was declining in brightness. Most GRB optical counterparts appear to

---

$^1$ IRAF is distributed by the NRAO, which are operated by USRA, under cooperative agreement with the US NSF.
Table 1. Journal of optical and near-infrared (NIR) observations of the GRB 030227 field.

<table>
<thead>
<tr>
<th>Date of 2003 UT</th>
<th>Telescope</th>
<th>Filter</th>
<th>Exposure time (seconds)</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb. 27, 13:45–14:00</td>
<td>1.0SO (CCD)</td>
<td>R</td>
<td>300 + 600</td>
<td>22.0 ± 0.3</td>
</tr>
<tr>
<td>Feb. 27, 18:08–18:40</td>
<td>0.8Wend (MONICA)</td>
<td>R</td>
<td>1320</td>
<td>&gt;21.5</td>
</tr>
<tr>
<td>Feb. 27, 20:40–20:50</td>
<td>2.5INT (WFC)</td>
<td>R</td>
<td>600</td>
<td>23.10 ± 0.16</td>
</tr>
<tr>
<td>Feb. 27, 20:51–21:01</td>
<td>2.5INT (WFC)</td>
<td>B</td>
<td>600</td>
<td>24.5 ± 0.3</td>
</tr>
<tr>
<td>Feb. 27, 23:17–23:30</td>
<td>2.5INT (WFC)</td>
<td>R</td>
<td>800</td>
<td>23.19 ± 0.18</td>
</tr>
<tr>
<td>Feb. 27, 23:32–23:45</td>
<td>2.5INT (WFC)</td>
<td>B</td>
<td>800</td>
<td>&gt;23.0</td>
</tr>
<tr>
<td>Feb. 28, 05:00–05:40</td>
<td>3.8UKIRT (UFTI)</td>
<td>K</td>
<td>1800</td>
<td>19.2 ± 0.1</td>
</tr>
<tr>
<td>Feb. 28, 05:40–06:30</td>
<td>3.8UKIRT (UFTI)</td>
<td>H</td>
<td>1800</td>
<td>20.2 ± 0.1</td>
</tr>
<tr>
<td>Feb. 28, 20:00–20:47</td>
<td>2.56NOT (ALFOSC)</td>
<td>R</td>
<td>3 × 600</td>
<td>24.1 ± 0.2</td>
</tr>
<tr>
<td>Feb. 28, 20:10–21:00</td>
<td>3.5TNG (DOLORES)</td>
<td>B</td>
<td>3 × 900</td>
<td>25.4 ± 0.2</td>
</tr>
<tr>
<td>Feb. 28, 22:25–23:15</td>
<td>2.5INT (WFC)</td>
<td>R</td>
<td>3 × 600</td>
<td>&gt;23.9</td>
</tr>
<tr>
<td>Feb. 28, 23:15–Mar. 1, 00:37</td>
<td>3.6ESO (EFOSC2)</td>
<td>R</td>
<td>6 × 600</td>
<td>24.75 ± 0.25</td>
</tr>
</tbody>
</table>

Fig. 3. The R band lightcurve of the GRB 030227 OA. Circles represent measured magnitudes and triangles represent upper limits. The dashed line is the best fit to the data (excluding the 3.6ESO point), a power-law decline with $\alpha_R = -0.95 ± 0.16$. In addition to upper limits reported in this paper we also include the earlier ones derived by Urata et al. (2003), Pavlenko et al. (2003) and Torii et al. (2003).

An upper limit to the redshift of $z \leq 3.5$ can be estimated from the absence of the onset of the Lyman forest blanketing in the optical data, consistent with the estimates from the X-ray spectra ($z \sim 3–4$, Mereghetti et al. 2003b; $z \sim 1.6$, Watson et al. 2003).

3.2. The spectral shape of the afterglow: Evidence for inverse Compton scattering

We have determined the spectral flux distribution of the GRB 030227 OA on 28.24 UT Feb 2003 (mean epoch of the HK band images) by means of our $BRHK$ broad band photometric measurements obtained with the different telescopes. We interpolated the $B$ and $R$ band magnitudes to that epoch, and fitted the observed flux distribution with a power law $F_\nu \propto \nu^{\beta}$, where $F_\nu$ is the flux density at frequency $\nu$, and $\beta$ is the spectral index. The optical flux densities at the wavelengths of $BRHK$ bands have been derived without subtracting the contribution of any host galaxy, assuming a reddening $E(B-V) = 0.46$ from the DIRBE/IRAS dust maps (Schlegel et al. 1998). In converting the magnitude into flux, the effective wavelengths and normalisations given in Fukugita et al. (1995) were used. The flux densities are 2.4, 2.7, 10.2 and 15.0 $\mu$Jy at the $BRHK$ bands, corrected for Galactic reddening (but not for possible intrinsic absorption in the host galaxy). The fit to the NIR/optical data $F_\nu \propto \nu^{\beta}$ gives $\beta_{\text{opt/NIR}} = -1.25 ± 0.14 (\chi^2/d.o.f. = 0.08)$. Figure 4 shows the broadband spectrum (from near-IR/optical photometry to X-rays) for the GRB 030227 afterglow. The NIR/optical spectral index ($\beta_{\text{opt/NIR}} = -1.25 ± 0.14$) is consistent with the spectral index for the unabsorbed X-ray spectrum ($\beta_X = -0.94 ± 0.05$, Mereghetti et al. 2003b) but they do not match each other’s extrapolations, similarly to GRB 000926 (Harrison et al. 2001) and GRB 010222 (in’t Zand et al. 2001). We have investigated whether considerable extinction in the host galaxy (considering different extinction laws) could produce such effect, in order to reproduce an optical-IR spectrum as an extrapolation of the X-ray spectrum, but found this not feasible. This results in no spectral break between the NIR/optical and X-ray bands, which will be...
also consistent with the similar decay indexes in both bands ($\alpha_E = -0.95$ and $\alpha_X = -1.0$). Thus, we suggest that in contrast to the NIR/optical band, where synchrotron processes dominate, there is an important contribution of inverse Compton scattering to the X-ray spectrum besides line emission (Watson et al. 2003), as it has been proposed for GRB 000926 (Harrison et al. 2001). This implies a lower limit on the density of the external medium, $n \geq 10 \text{ cm}^{-3}$ (see Panaitescu & Kumar 2000).

3.3. Adiabatic expansion or cooling regime?

Many afterglows exhibit a single power law decay index. Generally this index is $\alpha \sim -1.3$, a reasonable value for the spherical expansion of a relativistic blast wave in a constant density interstellar medium, according to the standard fireball model (Meszaros & Rees 1997). In fact, the value of $\alpha$ for GRB 030227 falls within the boundaries defined by the observations made to date, from $-0.67 \pm 0.1$ in the GRB 020331 (Dullighan et al. 2002) to $-1.73 \pm 0.04$ in the GRB 980519 (Jaunsen et al. 2001). $\beta$ only depends on $p$ (the exponent of the power-law distribution of the Lorentz factor for the relativistic electrons) and it does not depend on the geometry of the expansion. Hereafter we will assume $\alpha = -1.0$ and $\beta = -1.0$ for the NIR/optical/X-ray bands. Several models have been explored in order to reproduce the observed values of $\alpha$ and $\beta$.

For an adiabatic expansion ($\nu_m < \nu < \nu_c$) in a constant density interstellar medium (ISM), $\beta = (1 - p)/2$ and $\alpha = -3(p - 1)/4$, where $\nu$ is the observing frequency, $\nu_c$ is the cooling break frequency and $\nu_m$ is the synchrotron peak frequency (Sari et al. 1998). For a spherical adiabatic expansion with the density $n \propto r^{-s}$ with $s = 2$ (inhomogeneous medium due to a stellar wind, Chevalier & Li 2000), $\beta = (1 - p)/2$ and $\alpha = -(3p - 1)/4$. In both cases, we have considered values of $p$ in the range 1.8 to 3, as observed in most afterglows detected to date (van Paradijs et al. 2000), but we cannot reproduce the observed values of $\alpha$ and $\beta$.

For the cooling regime ($\nu_c < \nu$) in both the ISM ($s = 0$) and wind ($s = 2$) cases, the evolution is similar at NIR/optical and X-ray wavelengths, with $\beta = -p/2$ and $\alpha = -(3p - 2)/4$. The best results are obtained for $p = 2.0$, from which we derive $\alpha \approx -1.0$ and $\beta \approx -1.0$, consistent with our measurements.

In light of the previous arguments, we propose that both the observed slow decay in the NIR/opt/X-ray lightcurves and the intrinsic spectrum, are consistent with a fireball in the cooling regime with $p = 2.0$, but we cannot distinguish between the $s = 0$ and $s = 2$ cases. Only a detection in radio ($\nu < \nu_c$ at $t_0 + 0.87$ days) would have allowed us to discriminate both models.

4. Conclusions

We presented multiwavelength observations of the afterglow associated with the possibly X-ray rich GRB 030227. This would be one of the few OAs detected to date to an X-ray rich GRB. The decay index in the $R$-band lightcurve is $\alpha_R = -0.95 \pm 0.16$, with a possible break detection at $t_0 + \sim 1.5$ days. The optical-NIR spectrum at $t_0 + 0.87$ days allowed us to determine a spectral index $\beta_{\text{opt/NIR}} = -1.25 \pm 0.14$. The multiwavelength spectrum can be modeled by the expansion of a fireball (with $p = 2.0$) in the cooling regime. We also found evidence for inverse Compton scattering in X-rays.
The GRB 030227 OA is only 0.5 mag brighter that the dimmest OAs found so far, like GRB980613 (Hjorth et al. 2002), GRB 000630 (Fynbo et al. 2001), GRB 020322 (Bloom et al. 2002) and GRB 021211 (Fox et al. 2003), once the galactic extinction is taken into account. For comparison purposes see the light curves of 18 afterglows shown in Fig. 3 of Gorosabel et al. (2002).

In combination with multiwavelength studies, it is expected that INTEGRAL will shed more light on the origin of GRBs.

Acknowledgements. We thank the Comité de Asignación de Tiempos del Observatorio del Roque de los Muchachos at Canary Islands (Spain) for generous allocation of the Spanish ToO programme. The data presented here have been taken in part using ALFOSC, which is owned by the IAA and operated at the NOT under agreement between IAA and the NBIAFG of the Astronomical Observatory of Copenhagen. Part of the observations presented in this paper were obtained under the ESO Programme 70.D-0227 (granted to the GRACE team). This work is also partially based on data taken with the UKIRT operated by the JAC on behalf PPARC. This research has been partially supported by the Ministerio de Ciencia y Tecnología de España under the programme AYA2002-0802 (including FEDER funds).

References
Fukugita, M., Shimisaku, K., & Ichikawa, T. 1995, PASP, 107, 945
Henden, A. 2003, GCN Circ., 1917
Pavlenko, E., Rumyantsev, V., & Pozanenko, A. 2003, GCN Circ., 1926
Urata, Y., Aoki, T., & Izumiura, H. 2003, GCN Circ., 1920