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GRB 030227: the first multiwavelength afterglow of an INTEGRAL GRB*

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Abstract. We present multiwavelength observations of a gamma-ray burst detected by INTEGRAL (GRB 030227) between 5.3 hours and $\sim$ 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 faintess (R$\sim$ 23). This OA was seen to decline following a power law decay with index $\alpha_R = -0.95 \pm 0.16$. The spectral index $\beta_{opt/NIR}$ yielded -1.25 ± 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 ($\sim$ 1 keV–10 GeV) photons (Fishman & Meegan 1995), occurring at cosmological distances. Since their discovery in 1967, $\sim$ 3 000 GRBs have been detected in γ rays but only $\sim$ 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).

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

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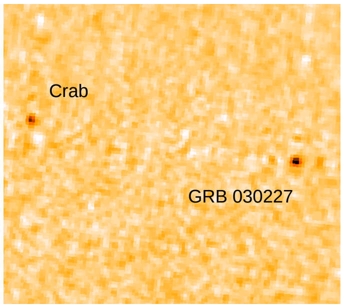

Fig. 1. INTEGRAL image of GRB030227 in the Crab field during the calibration phase. The image has been obtained in the 15-200 keV range with the IBIS/ISGRI instrument and deconvolved using the IBAS software. The distance between the Crab and the GRB is $\sim 10°$. North is up, East to the left.

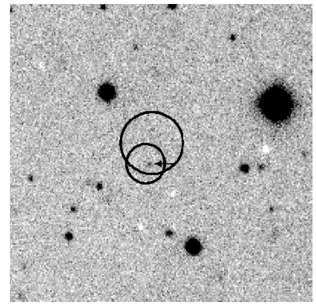

Fig. 2. The discovery R band image of the GRB 030227 field taken at the 2.5INT on 27 Feb 2003. The position of the OA is indicated by the arrow inside the preliminary (Loiseau et al. 2003) and final (Mereghetti et al. 2003b) XMM-Newton error boxes ($6''$ and $4''$ radii, respectively). The field is $1' \times 1'$ with North up and East to the left.

IBAS software (Mereghetti et al. 2003a) on 27 February 2003 (see Fig. 1). The burst started at 08:42:03 UT and lasted for $\approx$ 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 $\sim$8 hr after the event. This observation revealed a fading X-ray source consistent with the IBIS error box 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 3.8m 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.

[1] IRAF is distributed by the NRAO, which are operated by USRA, under cooperative agreement with the US NSF.

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 box, 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 $\alpha_{2000} = 4^{\rm h}57^{\rm m}33.05^{\rm s}$, $\delta_{2000} = +20°29'05.0''$. The internal error of the position is $0.55''$, which has to be added to the 1σ systematic error of the USNO catalogue ($\simeq 0.25''$ 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 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 be well characterised by a power law decay plus a constant flux component, $F(t) \propto (t - t_0)^{\alpha} + F_{\rm host}$ where, $F(t)$ is the total measured flux of the counterpart at time $(t - t_0)$ after the onset of the event at t_0, α is the temporal decay index and $F_{\rm host}$ is the flux of the underlying host galaxy. $F_{\rm host}$ is negligible in this case, as indicated by the lack of flattening of the optical light curve at the time of our last observations (we estimate $R_{\rm host} > 26$). From a least squares linear regression to the observed R band fluxes, a power law decline with $\alpha_R = -1.10 \pm 0.14$ (χ^2/dof = 1.53) provides an acceptable fit but it is ruled out by the early upper limits. However, if we exclude the 3.6ESO data point, a power law decline with $\alpha_R = -0.95 \pm 0.16$ (χ^2/dof = 0.64) provides a better fit, which is also just consistent with the earlier upper limits. This flux decay of the GRB 030227 agrees with the decay in X-rays $\alpha_X \simeq -1.0 \pm 0.1$ (Mereghetti et al. 2003b, Watson et al. 2003) and is comparable to the slow decline rates observed in other GRB OAs. There are OAs for which a break or a smooth, gradual transition does

Table 1. Journal of optical and near-infrared (NIR) observations of the GRB 030227 field.

Date of 2003 UT	Telescope	Filtre	Exposure Time (seconds)	Magnitude
Feb 27, 13:45–14:00	1.0SO (CCD)	R	300 + 600	22.0 ± 0.3
Feb 27, 18:08–18:40	0.8Wend (MONICA)	R	1 320	>21.5
Feb 27, 20:40–20:50	2.5INT (WFC)	R	600	23.10 ± 0.16
Feb 27, 20:51–21:01	2.5INT (WFC)	B	600	24.5 ± 0.3
Feb 27, 23:17–23:30	2.5INT (WFC)	R	800	23.19 ± 0.18
Feb 27, 23:32–23:45	2.5INT (WFC)	B	800	>23.0
Feb 28, 05:00–05:40	3.8UKIRT (UFTI)	K	1 800	19.2 ± 0.1
Feb 28, 05:40–06:30	3.8UKIRT (UFTI)	H	1 800	20.2 ± 0.1
Feb 28, 20:00–20:47	2.56NOT (ALFOSC)	R	3 × 600	24.1 ± 0.2
Feb 28, 20:10–21:00	3.5TNG (DOLORES)	B	3 × 900	25.4 ± 0.2
Feb 28, 22:25–23:15	2.5INT (WFC)	R	3 × 600	> 23.9
Feb 28, 23:15–Mar 1, 00:37	3.6ESO (EFOSC2)	R	6 × 600	24.75 ± 0.25

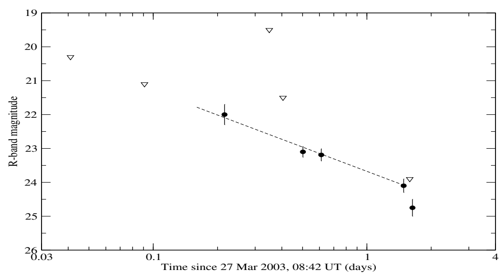

Fig. 3. The R band lightcurve of the GRB 030227 OA. Circles represent measured magnitudes and triangles represent upper limits. The dashed line is the best fit to the data (excluding the 3.6ESO point), a power-law decline with $\alpha_R = -0.95 \pm 0.16$. In addition to upper limits reported in this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

occur within 1-2 days of the burst. The 3.6ESO measurement might give indication of a break around $\sim$ 1.5 days but the lack of further data at later epochs precludes confirmation.

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 extrapolated the B & R band magnitudes to that epoch, and fitted the observed flux distribution with a power law $F_\nu \propto \nu^\beta$, where F_ν is the flux density at frequency ν, and β 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 μJy 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 $\beta_{opt/NIR} = -1.25 \pm 0.14$ (χ^2/dof = 0.08).

Fig. 4 shows the broadband spectrum (from near-IR/optical photometry to X-rays) for the GRB 030227 afterglow. The NIR/optical spectral index ($\beta_{opt/NIR} = -1.25 \pm 0.14$) is consistent with the spectral index for the unabsorbed X-ray spectrum ($\beta_X = -0.94 \pm 0.05$, 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 (considereing 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 (α_R = -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, $n \geq 10$ cm^{-3} (see Panaitescu and Kumar 2000).

3.3. A wind or an homogeneous circumstellar medium ?

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 (Mészáros & Rees 1997). In fact, the value of α for GRB 030227 falls within the boundaries defined by the observations made to date, from -0.67 ± 0.1 in the GRB 020331 (Dullighan et al. 2002) to -1.73 ± 0.04 in the GRB 980519

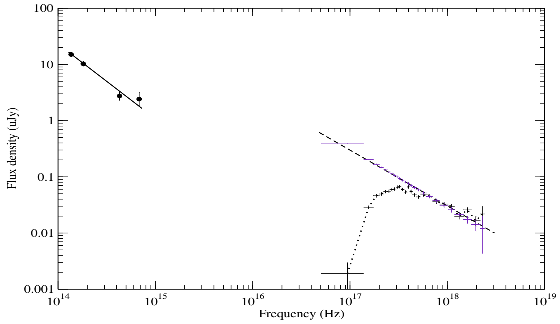

Fig. 4. The broadband spectrum for the GRB 030227 afterglow at t_0 + 0.87 days. The NIR/optical spectrum (solid line) has been dereddened assuming E(B-V) = 0.46 from the DIRBE/IRAS dust maps. A fit $F_\nu \propto \nu^\beta$ to the NIR/optical data gives $\beta_{opt/NIR} = -1.25 \pm 0.14$. The absorbed X-ray spectrum from XMM-Newton (dotted line) can be unabsorbed and represented by a power law (dashed line) with photon index Γ = 1.94 $\pm$ 0.05 (i.e. $\beta_X = -0.94 \pm 0.05$) , considering N_H = 6.8 $\times$ 10^{22} cm^{-2} at a redshift z $\sim$ 4, following Mereghetti et al. (2003b). This is equivalent to consider a value of N_H = 1.1 $\times$ 10^{22} cm^{-2} at z $\sim$ 1.6, as derived by and Watson et al.(2003).

(Jaunsen et al. 2001). β only depends on p (the exponent of the power-law distribution of the Lorentz factor for the relativistic electrons) and is independent of the geometry of the expansion. Hereafter we will assume $\alpha \simeq -1.0$ and $\beta \simeq -1.0$ for the NIR/optical/X-ray bands. Several models have been explored in order to reproduce the observed values of α and β.

For an adiabatic expansion ($\nu_m < \nu < \nu_c$) in a constant density insterstellar medium (ISM), β = (1 $-p$)/2 and α = $-3(p-1)/4$, where ν is the observing frequency, ν_c is the cooling break frequency and ν_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 and Li 2000), β = (1 $-p$)/2 and α = $-(3p-1)/4$. 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 α and β.

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 $p \simeq 2.0$, from which we derive $\alpha \simeq -1.0$ and $\beta \simeq -1.0$, 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 $\beta_{opt/NIR} = -1.25 \pm 0.14$. 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. 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.

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