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The optical afterglow of the not so dark GRB 021211

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Abstract. We determine Johnson B, V and Cousins R, I photometric CCD magnitudes for the afterglow of GRB 021211 during the first night after the GRB trigger. The afterglow was very faint and would have been probably missed if no prompt observations had been conducted. A fraction of the so-called "dark" GRBs may thus be just "optically dim" and require very deep imaging to be detected. The early-time optical light curve reported by other observers shows a prompt emission with properties similar to that of GRB 990123. Following this, the afterglow emission from ~11 min to ~35 days after the burst is characterized by an overall power-law decay with a slope 1.1 ± 0.01 in the R passband. We derive the value of spectral index in the optical to near-IR region to be 0.6 ± 0.2 during 0.13 to 0.8 day after the burst. The flux decay constant and the spectral slope indicate that during the first day after the burst, the optical band lies between the cooling frequency and the synchrotron maximum frequency of the afterglow.

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

1. Introduction

A long duration burst, GRB 021211 (≡ H2493), triggered at $11^{\rm h}18^{\rm m}34\overset{\rm s}{.}03$ UT on 11 December 2002 was detected by the High Energy Transient Explorer (HETE) FREGATE, WXM, and soft X-ray camera (SXC) instruments (Crew et al. 2003). It was also observed by ULYSSES and KONUS (Hurley et al. 2002). The burst had a duration of ~2.3 s at higher energies (85–400 keV) but a longer duration of about 8.5 s at lower energies (5–10 keV) band. It had a fluence of about 1 and 2 μerg/cm^2 in the energy bands of 7–30 keV and 30–400 keV respectively. This indicates that GRB 021211 is an "X-ray rich" burst (Crew et al. 2003). The SXC coordinates of the burst reported by Crew et al. (2003) are $\alpha = 08^{\rm h}09^{\rm m}00^{\rm s}$, $\delta = +06°44'20''$ (J2000). Within the error circle of SXC, an optical afterglow (OA) of the GRB 021211 was discovered by Fox & Price (2002) at $\alpha = 08^{\rm h}08^{\rm m}59\overset{\rm s}{.}883$, $\delta = +06°43'37\overset{''}{.}88$ (J2000). The source was subsequently also identified in a number of images taken at ~90, 108 and 143 s after the burst by robotic optical telescopes. Thus, GRB 021211 joins the group of GRB 990123 (Akerlof et al. 1999) and GRB 021004 (Fox et al. 2003b; Pandey et al. 2003) whose early optical emissions could be observed within few minutes of the trigger of the event. Spectroscopic observations by Della Valle et al. (2003) indicate a redshift value of $z = 1.004 \pm 0.002$ for the probable host galaxy of GRB 021211. Fox et al. (2003a) report optical and near-IR observations of the GRB afterglow and find that at optical wavelengths, the GRB 021211 afterglow is significantly fainter than most of the known afterglows at an epoch of ~1 day. The observed fluence in the 30–400 keV energy band by Crew et al. (2003) together with the measured redshift $z = 1.004 \pm 0.002$ (Della Valle et al. 2003) indicates an isotropic equivalent energy release $E_{{\rm iso},\gamma} \sim 6.1 \times 10^{51}$ erg for $H_0 = 65$ km s^{-1} Mpc^{-1} in a $\Omega_0 = 0.3$ and $\Lambda_0 = 0.7$ cosmological model. With a cosmological K-correction as in Bloom et al. (2001) the estimated isotropic-equivalent energy becomes $E_{{\rm iso},\gamma} \sim 1.02 \times 10^{52}$ erg, an order of magnitude lower than the corresponding estimate for GRB 990123 (Bloom et al. 2003).

In this paper we present optical observations obtained during the temporal gap of the light curves presented by Della Valle et al. (2003a), Fox et al. (2003a) and Li et al. (2003) using secure photometric calibrations.

2. Observations and data reduction

The broad band Johnson BV and Cousins RI photometric observations of the OA were carried out on 11 December 2002 using the 104-cm Sampurnanand telescope of the State Observatory, Nainital and 2-m Himalayan Chandra Telescope (HCT) of the Indian Astronomical Observatory (IAO), Hanle. At Nainital, one pixel of the 2048 × 2048 pixel^2 size CCD chip corresponds to a square of $0\overset{''}{.}38$ side, and the entire chip covers a field of ~13′ × 13′ on the sky. The gain and read out noise of the CCD camera are 10 e$^-$/ADU and 5.3 e$^-$ respectively.

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At Hanle, one pixel corresponds to a square of $0''.3$ side, and the entire chip covers a field of $\sim 10' \times 10'$ on the sky. It has a read out noise of 4.95 e^- and gain is 1.23 e^-/ADU. From Nainital, the CCD *BVRI* observations of the OA field along with Landolt (1992) standard SA 98 region were obtained on 26/27 December 2002 for photometric calibrations during good photometric sky conditions. During the observing run, several twilight flat field and bias frames were also obtained for the CCD calibrations.

ESO MIDAS, NOAO IRAF and DAOPHOT softwares were used to process the CCD frames in a standard way. The photometric calibrations derived using the six standards of the SA 98 region with color $0.61 < (V - I) < 2.14$ and brightness $13.1 < V < 16.3$ are: $b_{\rm CCD} = B - (0.036 \pm 0.01)(B - V) + (4.75 \pm 0.01)$

$v_{\rm CCD} = V - (0.027 \pm 0.01)(B - V) + (4.30 \pm 0.01)$

$r_{\rm CCD} = R - (0.004 \pm 0.01)(V - I) + (4.23 \pm 0.02)$

$i_{\rm CCD} = I - (0.064 \pm 0.01)(V - I) + (4.73 \pm 0.01)$

where *BVRI* are standard magnitudes and $b_{\rm CCD}, v_{\rm CCD}, r_{\rm CCD}$ and $i_{\rm CCD}$ represent the instrumental aperture magnitudes normalized for 1 s of exposure time and corrected for atmospheric extinction coefficients determined from the Nainital observations of SA 98 bright stars. The values are 0.27, 0.17, 0.11 and 0.10 mag at the zenith in B, V, R and I filters respectively on the night of 26/27 December 2002. The errors in the colour coefficients and zero points are obtained by fitting least square linear regressions to the data points. Using the above calibrations, *BVRI* photometric magnitudes of 10 secondary standard stars are determined in the GRB 021211 field and their average values are listed in Table 1. The (X, Y) CCD pixels are used to convert coordinates into equatorial coordinates $\alpha_{2000}, \delta_{2000}$ values using the astrometric positions given by Henden (2002). All the secondary stars have been observed seven times in a filter and have internal photometric accuracy better than 0.01 mag. A comparison of present magnitudes of the secondary stars with those given by Henden (2002) values yields zero-point differences of 0.04 ± 0.01, 0.01 ± 0.02, 0.01 ± 0.02 and 0.00 ± 0.02 mag in $V, (B - V), (V - R)$ and $(V - I)$ respectively. Zero point difference is thus significant in V, however these numbers can be accounted in terms of the errors present in the zero point determination of the two photometries. There is no colour dependence in the photometric differences. These demonstrate that the photometric calibrations used in the present work are secure.

Several short exposures up to a maximum of 30 min were generally given while imaging the OA (see Table 2). In order to improve the signal-to-noise ratio of the OA, the data have been binned in 2×2 pixel^2 and also several bias corrected and flat-fielded CCD images of OA field are co-added in the same filter, when found necessary. From these images, profile-fitting magnitudes are determined using DAOPHOT software due to the presence of bright star near the OT. The profile magnitudes have been converted to aperture (about 5 arcsec) magnitudes using aperture growth curve determined from well isolated secondary standards. They are differentially calibrated using the secondary standards listed in Table 1 and the values derived in this way are given in Table 2.

Table 1. The identification number (ID), (α, δ) for epoch 2000, standard V, $(B - V)$, $(V - R)$ and $(R - I)$ photometric magnitudes of the secondary standards in the GRB 021211 region.

ID	α_{2000} (h m s)	δ_{2000} (deg m s)	V (mag)	$(B - V)$ (mag)	$(V - R)$ (mag)	$(V - I)$ (mag)
1	08 08 56	06 42 53	16.81	1.21	0.73	1.29
2	08 08 57	06 43 35	17.01	0.65	0.40	0.71
3	08 09 00	06 43 52	15.43	0.43	0.30	0.55
4	08 09 00	06 43 03	14.25	0.90	0.53	0.96
5	08 09 01	06 48 26	14.99	0.39	0.26	0.48
6	08 09 00	06 47 47	15.61	0.87	0.50	0.86
7	08 09 03	06 47 26	13.90	1.28	0.69	1.27
8	08 09 04	06 46 40	16.60	0.53	0.35	0.65
9	08 08 57	06 46 03	14.70	0.72	0.44	0.75
10	08 09 05	06 45 45	15.34	1.05	0.67	1.21

Table 2. CCD BVRI broad band optical photometric observations of the GRB 021004 afterglow. At Hanle, 2-m HCT was used while at Nainital, 104-cm Sampurnanand optical telescope was used.

Date (UT) 2002 December	Magnitude (mag)	Exposure time (s)	Passband	Telescope
11.9347	22.7 ± 0.14	2×1200	B	104-cm
11.8264	22.3 ± 0.20	1800	V	104-cm
11.9632	>22.6	1800	V	104-cm
11.7549	21.9 ± 0.21	2×900	R	104-cm
11.7792	21.9 ± 0.16	2×900	R	104-cm
11.8640	22.1 ± 0.18	600	R	HCT
11.8730	22.1 ± 0.18	600	R	HCT
11.8822	22.1 ± 0.14	600	R	HCT
11.8914	22.4 ± 0.24	600	R	HCT
11.8993	22.5 ± 0.21	2×1800	R	104-cm
11.9318	22.2 ± 0.18	2×600	R	HCT
11.8028	>21.4	2×900	I	104-cm

3. Results

3.1. R band photometric light curve

In Fig. 1, we plot the temporal evolution of our R band GRB 021211 afterglow measurements along with those published by Della Valle et al. (2003a), Fox et al. (2003a), Fruchter et al. (2002), Levan et al. (2002), Li et al. (2003), McLeod et al. (2002), Park et al. (2002) and Wozniak et al. (2002) after correcting for the host galaxy contribution as described in the next paragraph. We also make use of the published photometric measurements which could be converted on the present photometric scales using secondary stars listed in Table 1. Figure 1 also shows the R band light curves of GRB 990123 and GRB 021004. Early time observations of GRB 990123 ($\Delta t <$ 7 min) and GRB 021211 ($\Delta t <$ 11min) can be well explained

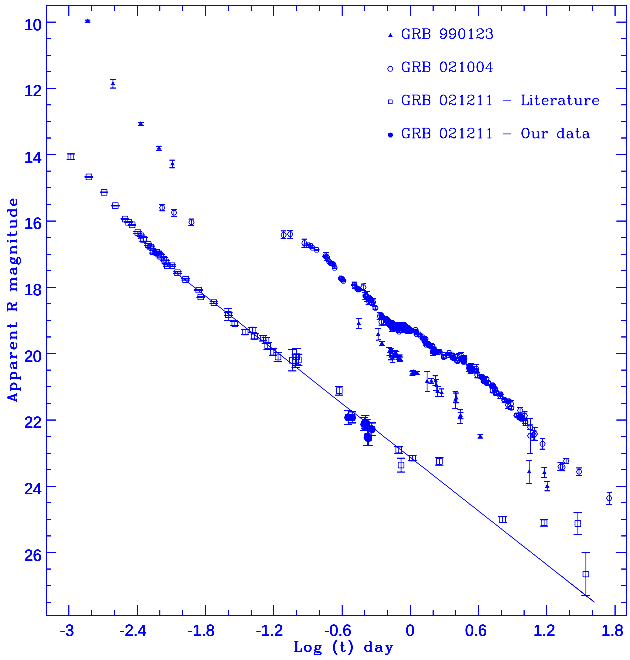

Fig. 1. Light curve of the GRB 021211 OA in *R* photometric passband. Filled circles denote the present data, whereas empty squares are data taken from the references given in the main text. The solid line represents a single power-law fit for the flux decay after subtracting 25.16 mag, the fitted host galaxy contribution. GRB 990123 (Akerlof et al. 1999 & Castro-Tirado et al. 1999) and GRB 021004 (Pandey et al. 2003) *R* band data are also plotted in the figure to show the relative faintness of GRB 021211 as these GRBs have the early time optical observations. Time *t* is measured from the GRB trigger.

in terms of reverse shock emission, taking into account that GRB 021211 ~4 mag fainter than GRB 990123 as noticed by Li et al. (2003) too. The GRB 021004 early time ($\Delta t < 19$ min) optical observations show unexpectedly shallower flux decay than that of GRB 990123 and GRB 021211 so reverse shock explanation can be ruled out either for homogeneous or for inhomogeneous environments (Chevalier & Li 2000; Fox et al. 2003b).

The flux decay of the GRB 021211 OA, at times >11 min after the burst can be well characterized by a single power law decay plus a constant flux $F_{\rm host}$, component for the underlying host galaxy and can be written as

$$F(t) = \text{const.} \times t^{-\alpha} + F_{\rm host} \qquad (1)$$

where $F(t)$ is total measured flux of the OT at time t after the burst and α is the temporal flux decay index. We fitted the above function using the least square regression method leaving $F_{\rm host}$ as a free parameter, including the late time VLT *R* band observations (Della Valle et al. 2003a) but excluding the HST points (Fruchter et al. 2002). This yields $\alpha = 1.11 \pm 0.01$, χ^2 per d.o.f. $= 3.73$ with host galaxy $R = 25.16 \pm 0.05$ mag, which is consistent with the value given by Della Valle et al. (2003a). The observations presented here follow the fitted light curve well and fill the existing temporal gap in the published data (see Fig. 1). The least square linear regression to the host galaxy contribution subtracted data including HST points yields $\alpha = 1.08 \pm 0.01$ with χ^2 per d.o.f. $= 5.48$. The larger values of χ^2 are mainly due to two deviant points (see Fig. 1) towards later epoch. As argued by Della Valle et al. (2003a), these deviations most probably arise due to the additional contribution from a supernova component, noticeable in their spectroscopic data.

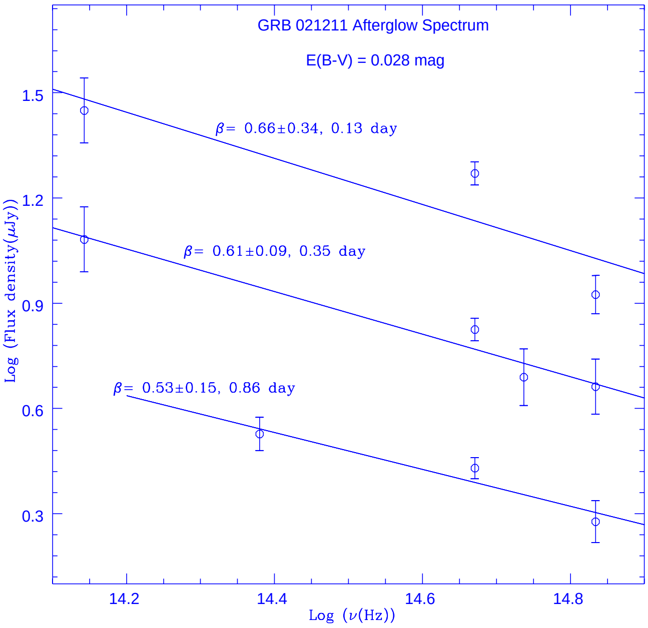

Fig. 2. Optical-near IR spectrum of the GRB 021211 OA corrected for $E(B-V) = 0.028$ mag at ~0.13, 0.35 and 0.86 days after the burst.

The value of flux decay α agrees fairly well with that determined by Fox et al. (2003a) and Li et al. (2003). The very fast flux decay, within a day after the burst, of the GRB 021211 OA can be compared with those of GRB 000630 (Fynbo et al. 2001), GRB 020124 (Berger et al. 2002) and GRB 020322 (Burud et al. 2002) afterglowsi, which had similar temporal flux decay slopes and were detected at ~23 mag in the *R* passband, one day after the burst.

3.2. Spectral energy distribution

Figure 2 shows the GRB 021211 afterglow optical to near-IR spectrum at three epochs: $\Delta t = 0.13$, 0.35 and 0.86 day using the present *BVR* optical data and the published $BRJK_s$ observations by Fox et al. (2003a) and Bersier et al. (2003). The epochs are selected according to the widest possible wavelength coverage. Where necessary, measurements are interpolated at a given wavelength. We used the reddening map provided by Schlegel et al. (1998) for estimating Galactic interstellar extinction towards the burst and found a small value of $E(B-V) = 0.028$ mag. We used the standard Galactic extinction reddening curve given by Mathis (1990) in converting apparent magnitudes into fluxes and used the effective wavelengths and normalizations by Fukugita et al. (1995) and Bessell & Brett (1988), for *BVR* and Epchtein et al. (1994) for *J* and K_s. We corrected the data for Galactic extinction only as the intrinsic extinction contribution from the host galaxy is unknown. We describe the spectrum by a single power law: $F_\nu \propto \nu^{-\beta}$, where F_ν is the flux at frequency ν and β is the spectral index. The values of β at 0.13, 0.35 and 0.86 days after the burst are 0.66 ± 0.34, 0.61 ± 0.09 and 0.53 ± 0.15 respectively. The corresponding values of $(B - R)$ are 1.2 ± 0.2, 0.8 ± 0.2 and 0.8 ± 0.2 mag respectively. Whereas the $(B - K_s)$ values are 3.4 ± 0.3 and 3.2 ± 0.3 at $\Delta t = 0.13$ and 0.35 day respectively. These values indicate that the spectral slope of GRB 021211 OA has not changed within a day after the burst and has a mean value of 0.6 ± 0.2.

4. Discussions and conclusions

BVRI optical observations of the GRB 021211 OA around 0.28 day after the burst are presented. The optical light curve of GRB 021211 OA (Fig. 1) at times >11 min after the burst can be well explained in terms of a single power law with the underlying host galaxy of $R = 25.16 \pm 0.05$ mag. GRB 011211 optical afterglow is intrinsically faint when compared with those of GRB 990123 and GRB 021004. It was detected only due to prompt, early follow up. Otherwise it would have been classified as a “dark GRB” as it was fainter than $R = 23$ mag, ~1 day after the burst and, in general, the usual follow-up observations do not go that deep. It thus appears that GRB 021211 is the first example of an “optically dim” burst for which early time (less than a few minutes after the burst) observations are available. It is thus likely that many optically “dark GRBs” could just be “optically dim” afterglows with the reason behind their non-detection being not only due to the high redshift and extinction due to host galaxy but also due to the OA being much fainter than those observed to date (Crew et al. 2003). So, GRB 021211 is an example to indicate that a fraction of the otherwise so-called “dark GRBs” are “not so dark”. Deeper and faster follow-up observations are required to detect them.

Our fitted R band values of temporal flux decay α and derived optical-near IR spectral slope β can be well understood in terms of simple spherical adiabatic case for the homogeneous medium (Sari et al. 1998) in which for $\nu < \nu_c$, $\alpha = 3\beta/2 = 3(p-1)/4$. The observed spectral slope $\beta = 0.6 \pm 0.2$ thus yields $\alpha = 0.9 \pm 0.3$, consistent with the observed value of $\alpha = 1.1 \pm 0.01$ and the electron energy distribution index $p = 2.2 \pm 0.4$. These values indicate that the cooling frequency ν_c lies above the optical band.

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References

Akerlof, C., Balsano, R., Barthelemy, S., et al. 1999, Nature, 398, 400
Berger, E., Kulkerni, S. R., Bloom, J. S., et al. 2002, ApJ, 581, 981
Bersier, D., Bloom, J., Challis, P., & Garnavich, P. 2002, GCNC, 1751
Bessell, M. S., & Brett, J. M. 1988, PASP, 100, 1134
Bloom, J. S., Frail, D. A., & Sari, R. 2001, AJ, 121, 2879
Bloom, J. S., Frail, D. A., & Kulkarni, S. R. 2003, ApJ, submitted [`astro-ph/0302210`]
Burud, I., Fruchter, A., Rhoads, J., & Levan, A. 2002, GCNC, 1536
Castro-Tirado, A. J., Zapatero-Osorio, M. R., Caon, N., et al. 1999, Science, 283, 2069
Chevalier, R. A., & Li, Z.-Y. 2000, ApJ, 536, 195
Crew, G., Lamb, D. Q., Ricker, G. R., et al. 2003, ApJ, submitted [`astro-ph/0303470`]
Della Valle, M., Benetti, S., Malesani, D., et al. 2003, GCNC, 1809
Della Valle, M., Malesani, D., Benetti, S., et al. 2003a, A&A, 406, L33
Epchtein, N., de Batz, B., Copet, E., et al. 1994, Ap&SS, 217, 3
Fox, D. W., & Price, P. A. 2002, GCNC, 1731
Fox, D. W., Price, P. A., Soderberg, A. M., et al. 2003a, ApJ, 586, L5
Fox, D. W., Yost, S., Kulkarni, S. R., et al. 2003b, Nature, 422, 284
Fruchter, A., Levan, A., Vreeswijk, P., Holland, S. T., & Kouveliotou, C. 2002, GCNC, 1781
Fukugita, M., Shimasaku, K., & Ichikawa, T. 1995, PASP, 107, 945
Fynbo, J. U., Jensen, B. L., Gorosabel, J., et al. 2001, A&A, 369, 373
Henden, A. 2002, GCNC, 1753
Hurley, K., Mazets, E., Golenetskii, S., & Cline, T. 2002, GCNC, 1755
Landolt, A. R. 1992, AJ, 104, 340
Levan, A., Fruchter, A., Welch, D., et al. 2002, GCNC, 1758
Li, W., Filippenko, A. V., Chornock, R., & Jha, S. 2003, ApJ, 586, L9
Mathis, J. S. 1990, ARA&A, 28, 37
McLeod, B., Caldwell, N., Grav, T., et al. 2002, GCNC, 1750
Pandey, S. B., Sahu, D. K., Resmi, L., et al. 2003, Bull. Astro. Soc. India, 31, 19
Park, H. S., Williams, G., & Barthelmy, S. 2002, GCNC, 1736
Sari, R., Piran, T., & Narayan, R. 1998, ApJ, 497, L41
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Wozniak, P., Vestrand, W. T., Starr, D., et al. 2002, GCNC, 1757