Optical photometry of the GRB 010222 afterglow

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Abstract. The optical afterglow of GRB 010222 was observed using the recently installed 2-m telescope at the Indian Astronomical Observatory, Hanle, and the telescopes at the Vainu Bappu Observatory, Kavalur, beginning ~ 0.6 day after the detection of the event. The results based on these photometric observations combined with others reported in the literature are presented in this paper. The R band light curve shows an initial decline of intensities proportional to $t^{-0.542}$ which steepens, after 10.3 hours, to $t^{-1.263}$. Following the model of collimated outflow, the early break in the light curve implies a very narrow beam angle (~ $2°-3°$). The two decay rates are consistent with the standard jet model in a uniform density ambient medium, but require a hard spectrum of electron power density with $p \sim 1.5$. The R band light between 14 and 17 hours since outburst departs from the power law fit by 0.1 mag and shows some evidence for fluctuations over timescales of an hour in the observer's frame. Such deviations are expected due to density inhomogeneities if the ambient medium is similar to the local interstellar medium. GRB 010222 is thus an example of a highly collimated outflow with a hard spectrum of electron energy distribution in normal interstellar environment.

1. Introduction

GRB 010222, one of the brightest bursts detected so far, was detected in both the Gamma-Ray Burst (GRB) Monitor and the Wide Field Camera-1 WFC aboard the BeppoSAX Satellite, on Feb 22.308 (Piro 2001). The refined position from WFC was centred at RA = $14^h52^m12.24^s$ and DEC = $+ 43°00'43.2''$ (J2000) with an error circle of radius 2.5 arcmin (Gandolfi 2001a). BeppoSax detected the X-ray afterglow in the 1.6–10 keV range about 9 hours after the GRB prompt event (Gandolfi 2001b). The X-ray afterglow was also observed by the Chandra Observatory about 15 hours after the burst on Feb 22.936 UT (Garmire et al. 2001) and again on March 3.54 UTC (Harrison, Yost & Kulkarni 2001). The Bepposax observations between 8 and 65 hours since the outburst are reported by in't Zand et al (2001).

Henden (2001a) reported the detection of the optical transient (OT) at about 18th magnitude in *V*, about 4.4 hours after the burst, located at RA = $14^h52^m12.0^s$, DEC = $+ 43°01'06''$ (J2000). Photometry of the OT has been reported in several GCN circulars and by Masetti et al. (2001), Lee et al (2001), Sagar et al. (2001) and Stanek et al (2001a). The optical spectrum of the OT showed several absorption line systems superimposed on a power-law continuum (Garnavich et al 2001; Jha et al 2001a,b; Masetti et al 2001). These absorption line systems consisted of red-shifted doublets of Fe II (2585, 2599 Å), Mg II (2796, 2803 Å) and a host of other lines which indicate basically three intervening absorbers located at $z \sim 0.927$, 1.155 and 1.475. The detection of Mg I line and the presence of strong absorption lines of Mg II with equivalent widths of $\sim$ 1–3 Å are generally interpreted as indicating that the GRB occurred in a galaxy at the highest redshift seen, viz. $z = 1.475$. The equivalent width of the Mg II doublet is particularly large especially in the system at $z = 1.475$ ($\sim$ 3 Å) which implies a column density of $n_H \sim 10^{21}$ atoms cm^{-2}, if the composition is taken to be universal.

We report here the optical observations made using the recently installed 2-m telescope at the Indian Astronomical Observatory, located in Hanle, Ladakh ($78°57'51''$ E; $32°46'46''$ N; altitude of 4500 m above msl). This set of observations forms one of the first data sets obtained from the telescope on scientific programmes even as the commissioning tests are underway. Also included in the paper are the observations made using the telescopes at the Vainu Bappu Observatory.

2. Observations and Analysis

2.1 Observations

The optical transient (OT) associated with GRB 010222 was observed for $\sim$ 8 days both from the Indian Astronomical Observatory (IAO) and the Vainu Bappu Observatory (VBO) beginning $\sim$ 0.6 day after the event.

2.1.1 IAO

R band CCD photometry from IAO was carried out using the optical CCD imager on the recently installed 2-m telescope. The telescope was installed in September 2000 and is undergoing commissioning tests. Details of the observatory and telescope may be obtained from *http://www.iiap.ernet.in/iao* and also Anupama (2000). The CCD imager is equipped with Johnson-Cousins *UBVRI* filters (see Bessell 1990) and a 1024 x 1024 SITe chip of 24μm square pixels covering a field of 4.7 x 4.7 arcmin at the f/9 Cassegrain focus. On Feb 22, four 600s exposures were obtained, while three 600s and two 300s exposures were obtained on Feb 26. The images recorded on Feb 22 are slightly trailed due to tracking and guiding errors, but are usable.

2.1.2 VBO

The OT was observed in the *R* band on Feb 22 and 23 using the 1-m Zeiss telescope equipped with a CCD imager similar to that in use at IAO. The total field covered at the f/13 Cassegrain focus is 6.5 x 6.5 arcmin.

Using a CCD imager similar to the other two systems, at the f/3.25 prime focus of the 2.3m VBT, the OT was observed in the R and I bands on Feb 24 and 25 and in the R band on Feb 28 and Mar 1 (Cowsik & Bhargavi 2001). The total field covered was 10.4 x 10.4 arcmin.

2.2 Analysis

We describe in the following, the analysis of the IAO and VBO 1-m data. The details of the VBT data analysis are presented in Bhargavi (2001).

All images were bias subtracted using the mean value of the nearest bias frames and flatfield corrected using a master flat generated by combining several twilight flats. Often a few processed frames were aligned and combined before extracting magnitudes in order to improve the S/N ratio. These frames are indicated in a single row of Table 1. It was not possible to perform a PSF fitting to the data obtained from IAO on Feb 22 as the stellar profiles were affected by the tracking and guiding errors. In order to have a uniform mode of magnitude estimation for all sets of data, magnitudes were obtained using aperture photometry and growth curve method (Howell 1989). Aperture photometry of the OT and several bright stars in the field was performed using concentric apertures ranging from 0.7 to 14 arcsec diameter centred on the object. Sky background was subtracted using a 1.5 arcsec annulus with an inner radius of 5–8 arcsec for the OT and 8–10 arcsec for the brighter stars. Based on a growth curve for the brighter stars, a 6–7 arcsec aperture was chosen for the photometric measurements to include most of the light from the source. The OT being faint, its magnitude was estimated from the 3–4 arcsec aperture. Corrections for the photons from the source outside this aperture were made using a correction factor estimated from the growth curve of the brighter stars (average of Henden 5, 16, 18, 27). The zero points were determined using star 'A' of Stanek et al. (2001b) whose magnitude was assumed to be $R = 17.175$ following Henden (2001b).

The magnitudes of other stars in the field were compared with Henden's photometry to ascertain that no systematic errors exist between the two data sets. A colour transformation equation was determined for residuals of the field stars with respects to Henden's photometry using Henden 5, 9, 11, 13, 16, 25, 33 (VBO) or 7, 11, 13, 16, 18, 20 (IAO). The bluest star Henden 18 was not used at VBO since it showed that the colour equation is nonlinear below $(V - R) = 0.3$. Since the OT had a colour of $(V - R) = 0.37 \pm 0.05$ (Masetti et al 2001), the nonlinearity does not affect the results. The zero-point correction to the field star photometry, together with the colour correction, resulted in a total correction ranging between 0.014 and 0.022 mag for different frames.

The details of observations and derived magnitudes are listed in Table 1 and plotted in Fig. 1.

2.3 R band light curve

The R band light curve of the OT of GRB 010222 is obtained using magnitudes from the following sources : (1) IAO and VBO magnitudes reported in this paper (VBO1 = 1-m telescope; VBT = 2.34-m telescope), (2) Sampurnanand Telescope (ST) observations reported by Sagar et al. (2001), (3) Telescopio Nazionale Galileo (TNG), Asiago, and Loraino Observatory measurements reported by Masetti et al. (2001), (4) F.L. Whipple Observatory (FLWO) and

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Table 1. GRB 010222 : CCD photometry.

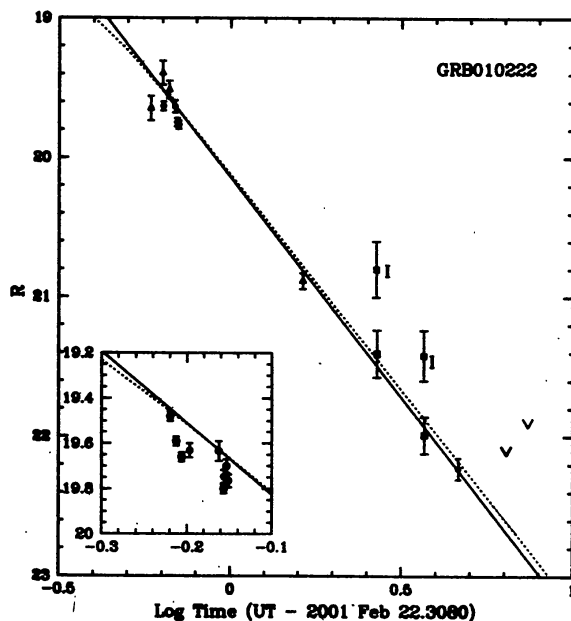| Date (UT)	Telescope	Exp Time(s)	Band	Magnitude
2001 Feb				
22.8931	VBO 1-m	180 + 300	R	19.646 ± 0.087
22.9413	VBO 1-m	1800	R	19.393 ± 0.086
22.9438	IAO 2-m	600	R	19.631 ± 0.031
22.9703	VBO 1-m	1800	R	19.512 ± 0.062
22.9958	IAO 2-m	600	R	19.634 ± 0.044
23.0056	IAO 2-m	600	R	19.747 ± 0.029
23.0139	IAO 2-m	600	R	19.765 ± 0.029
23.9375	VBO 1-m	2400 +1800+1200	R	20.870 ± 0.057
24.977	VBT	600	I	20.8 ± 0.2
24.9924	VBT	600	R	21.405 ± 0.17
25.9816	VBT	900	I	21.42 ± 0.18
25.9955	VBT	900	R	21.99 ± 0.13
25.9385	IAO 2-m	3 x 600 + 2 x 300	R	22.229 ± 0.077
28.9014	VBT	1200	R	> 22.1
28.9257	VBT	2400	R	> 22.1
2001 Mar				
1.9319	VBT	1800	R	> 21.9

Figure 1. Photometric observations reported in this paper. Magnitudes are in R band except where noted. Circles: IAO 2-m telescope; triangles: VBO 1-m telescope; open squares: VBT (R band); filled squares: VBT (I band). The R band upper limits obtained with VBT are also shown. The fits shown in Fig. 2 are also marked. The inset shows the region soon after the break magnified, with the IAO (filled circles) and ST (Sagar et al 2001; open circles) magnitudes.

Vatican Advanced Technology Telescope (VATT) measurements reported by Stanek et al. (2001a and kindly made available by K.Z. Stanek), and (5) Canada-France-Hawaii Telescope (CFHT) measurements reported by Veillet (2001a, b), (6) Subaru telescope measurements reported by Watanabe et al (2001) — though these estimates have large errors, they provide a point in the gap near the break. All these magnitudes are listed in Table 2.

Table 2. GRB 010222 : R magnitudes used.

Date (UT)	Telescope	Magnitude
2001 Feb		
22.4595	FLWO	18.40 ± 0.05
22.4610	FLWO	18.36 ± 0.03
22.4695	FLWO	18.40 ± 0.03
22.508	SUBARU	18.4 ± 0.1
22.5106	FLWO	18.55 ± 0.03
22.5349	FLWO	18.54 ± 0.05
22.5417	FLWO	18.63 ± 0.05
22.5480	FLWO	18.66 ± 0.05
22.5519	FLWO	18.67 ± 0.07
22.642	SUBARU	18.9 ± 0.1
22.8931	VBO1	19.65 ± 0.09
22.911	ST	19.48 ± 0.02
22.921	ST	19.59 ± 0.02
22.930	ST	19.66 ± 0.02
22.9413	VBO1	19.39 ± 0.09
22.9438	IAO	19.63 ± 0.03
22.9703	VBO1	19.51 ± 0.06
22.9958	IAO	19.63 ± 0.04
23.005	ST	19.80 ± 0.02
23.0056	IAO	19.75 ± 0.03
23.010	ST	19.70 ± 0.03
23.0139	IAO	19.77 ± 0.03
23.056	Masetti	19.75 ± 0.05
23.063	Masetti	19.79 ± 0.04
23.211	Masetti	20.00 ±0.01
23.219	Masetti	20.01 ± 0.01
23.3015	FLWO	20.12 ± 0.06
23.4076	FLWO	20.31 ± 0.09
23.4458	FLWO	20.40 ± 0.09
23.870	ST	20.77 ± 0.35
23.9375	VBO1	20.87 ± 0.06
24.127	Masetti	20.89 ± 0.09
24.236	Masetti	21.06 ± 0.03
24.239	Masetti	21.05 ± 0.02
24.9924	VBT	21.41 ± 0.17
25.253	Masetti	21.64 ± 0.03
25.4469	FLWO	21.73 ± 0.17
25.9955	VBT	21.99 ± 0.13
26.911	ST	22.20 ± 0.10
26.9385	IAO	22.23 ± 0.08
27.139	Masetti	22.11 ± 0.25
27.264	Masetti	22.38 ± 0.05
28.653	CFHT	22.73 ± 0.10
2001 Mar		
1.628	CFHT	22.96 ± 0.10
2.641	CFHT	23.10 ± 0.10
18.9	VATT	24.53 ± 0.25

3. Results and Discussion

3.1 Power-law fits

The R light curve shows a broken power-law behaviour with the first phase ending around 10 hours after which the decline became steeper. The curves before and after the break can be fit by power laws

$$I(R,t) = I_0(t/t_b)^{-\alpha},$$

where the time t is measured from the time of GRB detection, i.e. 2001 February 23.3080 (Piro 2001), and t_b is the time of break in the curve. The power law exponents for the two phase are denoted by α_1 ($t < t_b$) and α_2 ($t > t_b$).

Two linear χ^2-fits were obtained against $\log t$ using the magnitudes in Table 2. In order to obtain the asymptotic behaviour, the points close to the break between $t = 0.3 - 0.8$ d were excluded. The derived parameters are listed in Table 3 as Model 1. The quoted errors for I_0 and t_b are derived using $\pm 1\sigma$ errors on α_1, α_2, and the intercepts in magnitude. The degrees of freedom (ν) are also shown. The fits are shown in Fig. 2 by straight lines.

Table 3. Light curve fit parameters.

Parameters	Model 1	Model 2	Model 3
I_0	79^{+35}_{-21}	77.1 ± 0.4	77.6 ± 0.4
$t_b(d)$	0.427 ± 0.107	0.434 ± 0.003	0.431 ± 0.002
α_1	0.542 ± 0.071	0.594 ± 0.011	0.598 ± 0.008
α_2	1.263 ± 0.011	1.234 ± 0.005	1.241 ± 0.003
s	—	10	4.5
$X^2(\nu)$	4.5 (7), 21 (20)	39 (27)	126 (42)

The following smooth empirical function (cf. Beuermann et al. 1999) is often used to fit light curves of optical transients of GRBs.

$$I(t) = (2^{\frac{1}{s}} I_0)[(t/t_b)^{\alpha_1 s} + (t/tb)^{\alpha_2 s}]^{-\frac{1}{s}}$$

where $s > 1$ is a sharpness parameter and increases as the break becomes sharper. We find that such a curve does not describe the data in Table 2 well (see Model 3 in Table 3). We obtain a good fit if we exclude the region $t = 0.3 - 0.8$ d as shown in Model 2 of Table 3. The χ^2 reduces considerably as s increases until $s \sim 10$ and decreases very slowly thereafter. We have shown the fit for $s = 10$ by a dotted curve in Fig. 2. The constraint on smoothness also tends to increase the slope before the break and decrease it after the break. While the smooth fit provides smaller formal errors on the parameters, there is no specific reason to prefer the asymptotic values resulting from this fit to the values derived by linear fits away from the break. Figure 2 shows systematic deviation of the points away from the break which can be reduced only by increasing the value of s. On the other hand, a large value of s recovers the slopes fit by separate straight lines.
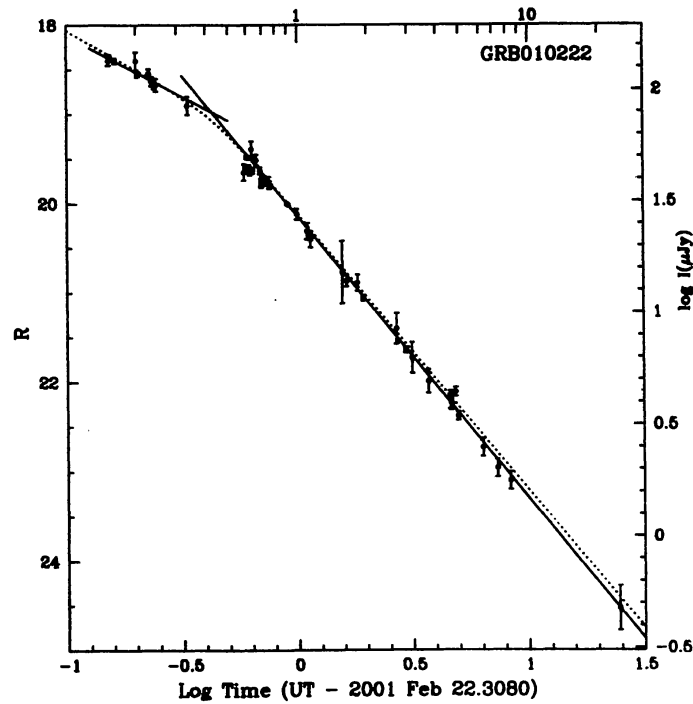
Figure 2. The broken power law fits to the early and late phases of the GRB 010222 optical transient in the *R* band corresponding to Model 1 of Table 3. A smooth fit corresponding to Model 2 of Table 3 is shown as a dotted curve.

The light curve parameters derived above may be compared with the values derived by Masetti et al. (2001): $\alpha_1 = 0.60 \pm 0.03$, $\alpha_2 = 1.31 \pm 0.03$, $t_b = 0.48 \pm 0.02$ d, and $s = 3.4 \pm 0.8$. Sagar et al (2001) derive a slightly steeper fit with $\alpha_1 = 0.76 \pm 0.03$, $\alpha_2 = 1.37 \pm 0.02$ with $s = 4$, and the break $t_b = 0.71 \pm 0.07$ considerably later than derived here, but in agreement with Stanek et al (2001a) : $\alpha_1 = 0.80 \pm 0.05$, $\alpha_2 = 1.30 \pm 0.05$, $t_b = 0.72 \pm 0.1$, though with a much sharper break ($s = 10$).

There appears a drop in the light curve with respect to both the fits (Models 1 and 2) around Feb 23.0. The observations of IAO and UPSO both agree in this behaviour (see inset in Fig. 1). The VBO 1-m magnitudes have large errors and the deviations are not apparent.

3.2 The jet model and physical conditions

The favoured model for GRB afterglows is synchrotron or inverse Compton scattering of electrons accelerated in a relativistic shock wave expanding in its surrounding medium (Mészáros & Rees 1997; Sari, Piran & Narayan 1998). The shock decelerates as it sweeps up ambient matter and the emission fades down. A steepening of the light curve has been observed in the optical transients of several GRB sources and has been generally explained either through expansion in a dense medium or in terms of collimated outflows (Rhoads 1999; Sari, Piran & Halpern 1999). The latter (jet) model is of special interest since it reduces the total energy requirement and increases the actual rate of occurrence of such events. According to this model, the hydrodynamics of the relativistic jet is not influenced by the finite angular size during the early evolution when the bulk Lorentz factor $\gamma > \theta_0^{-1}$ where θ_0 is the opening angle of the jet

in radians. In this case, the light curve behaves similar to the isotropic expansion. However, when $\gamma \sim \theta_0^{-1}$, the sideways expansion of the jet becomes significant and the light curve becomes steeper. The break in the light curve is expected at

$$t_j \sim 6.2 \ (E_{52}/n_1)^{\frac{1}{3}} \ (\theta_0/0.1)^{\frac{8}{3}} \ \text{hr},$$

where E_{52} is the isotropic energy of the ejecta in the units of 10^{52} ergs, n_1 is the ambient particle density in cm^{-3}, assumed to be homogeneous (Sari, Piran & Halpern 1999). With $t_b = (1 + z)t_j$ in the observer's frame, we derive

$$\theta_0 = 5°.7 \left[\frac{t_b}{6.2(1 + z)} \right]^{\frac{3}{8}} \left(\frac{n_1}{E_{52}} \right)^{\frac{1}{8}} .$$

For an isotropic energy of $E_{52} = 78$ (in't Zand et al 2001), the observed value of $t_b = 10.3 \pm 2.6$ h, implies a beam angle in the range of $2°.8 \pm 0°.3$ ($n_1 = 1$) and $16° \pm 1°.5$ ($n_1 = 10^6$). Note that the dependence on n_1 and E_{52} is rather weak.

The narrow beam angle ($3°$ for $n_1 = 1$) implies that such outbursts actually occur at a rate 1500 times higher than observed. This is not much higher than inferred for average GRBs with slightly wider beam angles, which has already triggerred an interest to look for their remnants in the local universe (Paczyński 2001).

The models of the evolution of the outflow also predict a spectral energy distribution (SED) with a peak either at the characteristic synchrotron frequency (v_m) or at the cooling frequency (v_c) depending on whether the cooling is slow or fast (Sari & Esin 2001). The spectrum would be self-absorbed below a frequency v_a which generally lies in the radio region. The shape of the spectrum and its time evolution can be determined by a single parameter p, the electron power law distribution index, assuming adiabatic expansion, or expansion of a jet in a homogeneous medium and neglecting the dust extinction. The shape and decay rate of the optical spectrum would then depend on its location with respect to v_c and v_m. We assume in the following that the spectrum is dominated by synchrotron rather than inverse Compton scattering and reached the slow cooling phase well before the break in the light curve.

Kulkarni et al. (2001) report a 350 GHz detection of the OT on Feb 22.54 at 4.2 ± 1.2 mJy. It was detected at 22 GHz a little later (Feb 22.62) with a flux of 0.70 ± 0.15 mJy (Berger & Frail 2001). The R band flux at these times based on our fit are: 0.110 mJy (Feb 22.54) and 0.093 mJy (Feb 22.62). The 220 GHz detections on Feb 23 and 24 (Kulkarni et al. 2001) are slightly lower than expected from these two points. Based on these observations, v_m is estimated to be in the sub-mm region just before the break. Further, the 350 GHz as well as 220 GHz flux remained nearly constant between Feb 22.54 and 24.68 (Kulkarni et al. 2001). Such a behaviour is expected when the peak frequency is passing through this spectral region. Kulkarni et al (2001) hypothesized that most of the sub-mm flux arises from the host galaxy, either from starburst regions, or due to reprocessing of GRB radiation. In such an event, the sub-mm flux of the OT will be lower and the peak could be placed at higher frequencies.

It has been suggested by Lee et al. (2001) that the break in R band decay may be caused by the passage of v_m through this spectral region. The JK magnitudes reported by Masetti et al. (2001) around 1–2 days after the outburst show little variation with time. If we suppose that v_m was passing through this region around day 1.0, considering that it drops as $t^{-3/2}$ in the adiabatic expansion phase, it could have passed through the optical region around the time of the break. However, the light curves of Masetti et al (2001) appear fairly achromatic despite limited data in the early phase and thus there is no strong indication of v_m passing through the optical region.

If we consider the possibility that $v_m < v_{opt} < v_c$, we expect $\alpha_1 = 3\ (p-1)\ /\ 4$ and $\alpha_2 = p$ (Sari, Piran & Halpern 1999). The observed slopes yield two estimates of $p = 1.72 \pm 0.09$ and 1.26 ± 0.01, considerably harder than the value of 2.4 obtained for several other GRBs. The optical spectrum is then predicted to vary as $v^{-\beta}$ with $\beta = (p - 1)/2$. The two estimates of β would be 0.36 ± 0.05 and 0.131 ± 0.005, considerably flatter than observed.

If we assume, on the other hand, that $v_m < v_c < v_{opt}$, we obtain $\alpha_1 = (3p - 2)/4$ and $\alpha_2 = p$. The derived values of p are 1.39 ± 0.09 and 1.26 ± 0.01 with the spectral index $\beta = p/2 = 0.70 \pm 0.05$ and 0.631 ± 0.005. These values are more consistent with each other and can be reconciled with the observed optical spectrum considering that extinction in the host galaxy would modify this spectral region (Lee et al 2001).

The 350 GHz flux decayed from 4.2 ± 1.3 mJy on Feb 24.68 (Kulkarni et al 2001) to 0.7 ± 0.15 mJy on March 2 (Ivison et al 2001). If all the flux is attributed to the GRB, the deduced decay index is $\alpha = 1.52$ which is numerically equal to p in the jet model. The 2–10 keV flux also decayed with $\alpha = 1.33$ beginning a couple of hours before the break to 2.4 days after the break (in't Zand et al. 2001).

The expressions for the decay rate exponents derived by Sari, Piran & Halpern (1999) assume an electron power law index of ~ 2.4. Bhattacharya (2001) has derived expressions for the case of $p = 1$–2 assuming that there is an upper cutoff in the electron energy spectrum at $\gamma_u \propto \Gamma^q$, where Γ is the bulk Lorentz factor of the blast wave, and a single power law between γ_m and γ_u. The decay rate exponents can then be derived in terms of p and q. Assuming that $v_c < v_{opt} < v_u$ where v_u is another critical frequency associated with γ_u, Eqs (26) and (28) of Bhattacharya (2001) imply $3\alpha_2 = 4\alpha_1 + 2$. Since α_2 has been determined well, we derive $\alpha_1 = 0.447$ using this relation, and derive a value of $q \sim 2$ for $p \sim 1.5$.

Dai & Cheng (2001), on the other hand, assumed a flat electron energy spectrum that gets steeper after the cooling break at $\gamma_c > \gamma_m$, and deduced that the light curve of the jet would decay as t^{-2} irrespective of the value of p as long as it is between 1–2. Observations are at variance with this model suggesting that either the jet model is not applicable, or the electron energy spectrum has a different shape.

It thus appears likely that the electron energy spectrum was considerably harder ($p \leq 1.5$) for GRB 010222 compared to typical GRBs ($p \sim 2.0 - 2.5$) exhibiting steeper decay in the optical. Sagar et al (2001) also reached a similar conclusion from the spectral slope assuming $v_c < v_{opt}$. A similar hard spectrum was suggested by Panaitescu (2001) for GRB 000301c whose spectrum around the light curve break shows a good resemblance with GRB 010222.

3.3 The light Curve soon after the break

The light curve of GRB 010222 is not well-observed between the time it set at the Pacific coast and later when it was recaptured from the Indian observatories. The early observations from IAO and ST suggest that the light curve had a significant dip with respect to the power law after the break. Similar deviations were also seen in the case of GRB 000301c and were attributed by Berger et al (2000) to the inhomogeneities in the ambient interstellar medium. These authors have argued that the flux above v_a would vary with ambient density as $n_1^{1/2}$. Thus the brightness would increase when the shock overtakes denser regions and dip when it reaches lower density regions.

Wang & Loeb (2000) and Ruffini et al. (2001) have considered the effects of inhomogeneities in the interstellar matter on the radiation from the afterglow in somewhat greater detail. They find that variations are expected over timescales of seconds or tens of seconds when the bulk Lorentz factor is high (> 100) and increase to days when the Lorentz factor reduces to ~ 3, if one assumes that the shock propagates through a medium similar to the local interstellar matter.

The observed R magnitudes of GRB 010222 between 14 and 17 hours since the outburst depart from the power law by 0.107 ± 0.066 mag including all the data in Table 2, and 0.111 ± 0.055 mag if we consider only the IAO and ST estimates which have an average error of 0.027 mag (see inset in Fig. 1). The 0.1 mag depression in the light curve can easily be caused by a 20% decrease in the ambient density. The rms fluctuation of 0.06 mag, though statistically not very significant, can be caused by density fluctuations of little over 10%. The IAO and ST observations have a mean interval of 0.6 hours. The bulk Lorentz factor has a value of about 20 at this epoch, at which time, density fluctuations of σ_n/n of 1–3 over 100 AU length scales and 0.1–0.2 over 1000 AU length scales can produce fluctuations of 0.05 mag amplitude over timescales of an hour. The values of density contrast are consistent with the inhomogeneities in the local interstellar medium (Lauroesch & Meyer 1999). The observed column densitites of $N_H \sim 10^{21}$ cm^{-2} imply a total path length of 300 pc for $n_1 \sim 1$, comparable to the thickness of disks of galaxies. We thus suspect that GRB 010222 occurred in a normal interstellar environment.

Fluctuations are not noticed in the light curves of most GRB afterglows suggesting that the ambient medium is considerably smooth around them. On the other hand, structure is evident over timescales of tens of seconds in the BATSE observations (see in't Zand et al in case of GRB 010222) which can be attributed to interstellar density fluctuations (Ruffini et al. 2001). Future GRB afterglows may be monitored more systematically with a view to probing the structure of the ambient medium.

4. Summary

The R band photometry of the OT of GRB 010222 performed with the telescopes at IAO, Hanle and VBO, Kavalur is presented here. These measurements together with the photometry reported in the literature show that the R band light curve of GRB 010222 had a sharp break at 10 hours from the outburst with decay rates 0.542 and 1.263 before and after the break. The light curve shows some evidence of fluctuations soon after the break. It is suggested that the variations are caused by the inhomogeneities in the ambient medium.

Following the standard models of collimated jet outflow, the early break in the light curve implies that the beam had a very narrow opening angle of ~ 3°. This is probably the narrowest observed for any GRB so far.

The decay rates imply a hard spectrum of electron energy distribution (p ~ 1.5), which is consistent with the a spectral index of β ~ 0.75 in the optical region.

It would thus appear that GRB 010222 is an example of a high-energy outburst with a narrow jet with a hard electron energy spectrum in a normal interstellar medium.

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